Impact of energy efficiency and renewable energy on electricity master planning and design parameters

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It all starts here ™

Preface

I am a director and professional engineer at a consulting engineering firm and liaise with clients on a continuous basis, while also guiding staff in the execution of projects to meet client needs. This research topic was selected based on the following considerations:

- the present working environment as a consulting electrical engineer;
- experience gained to date;
- a curiosity for the underlying interdependency of planning and design parameters including the assumptions we make when planning future networks;
- a changing environment brought about by an increased drive for energy efficiency and the implementation of renewable energy projects;
- a vision that the industry, especially the South African electricity distribution network sphere at municipal and Eskom distribution level, requires a pro-active approach to deal with this changing environment;
- my opinion that the industry may be tampering unknowingly with past assumptions without revisiting and revising those assumptions, especially in terms of future load forecasting and past designed and installed networks, while venturing into a new and unknown territory; and
- my opinion that we may have already done so through existing initiatives.

I delivered a paper at the AMEU convention in 2014 [1] during the early stages of this research and I plan to publish more papers on completion of the work.

Acknowledgements

I would like to thank my wife and children for their patience and understanding over the past three years. Without my wife's support, I would not have found the time to complete this study.

A special word of thanks to some of my clients and work colleagues for listening to my ideas.

I would like to acknowledge my study leader, Prof de Kock, for his guidance during the study.

Lastly, I would like to give thanks to God for the talents he bestowed upon us, without which this research would have been impossible.

Abstract

At the core of network planning and designs, *after diversity maximum demand* (ADMD) is routinely used to define network conditions at peak periods. This dissertation explores the impact of distributed generation and energy efficient measures on the parameters used in the planning and design of residential distribution networks through an appliance-based load profile simulation and load flow studies.

Traditionally, low voltage networks are operated radially in South Africa and the power flow direction is from the utility source to the customer load. Networks are designed for compliance with the lower end of the voltage regulation requirement (0.9 per unit) and to ensure that currents do not exceed transformer capacity, cable or line ratings. With distributed generation, especially when the load is low and generation is not restricted, voltage may rise and the power flow direction may be reversed so that it flows towards the utility source. Not all utilities have policies in place, and in many instances, distributed generation is implemented by households without knowledge of the utility.

Methods to determine ADMD when it is not directly calculated through measurement of the maximum demand, involves using a load factor and estimated energy consumption, or the application of coincidence factors to individual household maximum demand. Load factor, as seen by the utility, generally reduces when energy is generated during periods not coinciding with peak demand, for example when electricity is generated by photo voltaic panels in a predominantly evening-peak network. Off-peak generation will result in lower load factor and energy consumption. When the utility is unaware of the distribution generation embedded in the network and the ADMD is calculated using the load factor and energy consumption method and, the calculated ADMD will be lower than required for design purposes of similar areas. Similarly, too much distributed generation increases the coincidence factors. Increased coincidence factors indicate a lack of diversity, which may result in a reverse ADMD higher than the original ADMD for which the network was designed. This may lead to previously acceptable networks no longer complying with regulations.

Key terms

Distributed generation, after diversity maximum demand, ADMD, reverse power flow

Opsomming

Na-verskeidenheid maksimum-aanvraag (NVMA) vorm die kern van beplannings- en ontwerpberekeninge om die netwerktoestande tydens piektye te definieer. Hierdie verhandeling ondersoek die impak wat hernieubare energie en energie-effektiwiteitsmetodes het op die faktore en aannames wat gebruik word tydens beplanning en ontwerp van residensiële kragnetwerke deur middel van toestelgebaseerde lasprofielsimulasie en lasvloeistudies.

Laagspanningsnetwerke in Suid-Afrika word histories as radiale netwerke bedryf en die drywingsvloeirigting is vanaf die voorsieningsowerheidsbron na die verbruikerslas. Derhalwe word netwerke ontwerp om te voldoen aan die onderste grens van die spanningsregulasievereiste (0.9. per eenheid) en om te verseker dat stroomwaardes nie die transformator-, kabel- of lynvermoëns oorskry nie. Wanneer die las laag is en kragopwekking nie beperk word nie, kan die spanning styg en die drywingsvloeirigting omkeer sodat dit in die rigting van die voorsieningsowerheidsbron vloei. Nie alle voorsieningsowerhede het beleide in plek nie, en in baie gevalle implementeer huishoudings verspreide opwekking sonder die medewete van die voorsieningsowerheid.

Metodes om NVMA te bepaal wanneer dit nie direk bereken kan word deur middel van meting van die maksimum-aanvraag nie, behels die gebruik van lasfaktor en energieverbruik, of die toepassing van gelyktydigheidsfaktore en individuele maksimum aanvraag. In ’n netwerk met ’n dominerende aandpiek vind die kragopwekkingspiek vir sonkrag plaas wanneer die las laag is. In so ‘n netwerk verminder die lasfaktor en die energieverbruik, terwyl die gelyktydigheidsfaktore onder sommige omstandigehde kan verhoog as gevolg van ‘n gebrek aan diversiteit tussen generators. Die NVMA berekening deur middel van ‘n lasfaktor aanname en energieverbruiklesings lewer ’n laer waarde as wat dit werklik tydens die aandpiek is, omdat kragopwekking deur middel van die son nie noodwendig die aandpiek verminder nie. Waar daar geen beperking op kragopwekking geplaas word nie en meer krag word opgewek as wat die las benodig, vloei krag terug na die voorsieningsowerheid. Onder sekere omstandighede kan daar selfs meer krag terugvloei na die voorsieningsowerheid as waarvoor die netwerk ontwerp was, en die netwerk sal nie meer aan die regulasies voldoen nie.

Sleutelterme

Verspreide generasie, na-verskeidenheid maksimum-aanvraag, NVMA, terugwaartse drywingsvloei

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Abbreviations

ADMD	After diversity maximum demand
DG	Distributed Generation
EEDSM	Energy Efficiency and Demand Side Management
EHV	Extra High voltage
HV	High voltage
LV	Low voltage
MV	Medium voltage
RPP	Renewable Power Plants
SADC	South African Distribution Code
SAGC	South African Grid Code

Definitions

Embedded generator / Distributed generator

A grid-tied generator over which the system operator has no dispatching control because it is embedded in a customer's network, such as a solar roof-top photo voltaic system, or a diesel generator set.

Small-scale renewable energy

Energy generation through solar, wind, biomass or any other form of renewable energy smaller than or equal to 100 kW.

System operator

The party responsible for dispatching electricity from generators belonging to licensed generators, whether national or as independent power producers

Extra High voltage

A voltage (U_n) exceeding 220 kV[1]

High voltage

A voltage (U_n) exceeding 44 kV, but not exceeding 220 kV[2]

Medium voltage

A voltage (U_n) exceeding 1000 V, but not exceeding 44 kV[3]

Low voltage

A voltage (U_n) not exceeding 1000 V[4]

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[1] According to SANS 1019 of 2001 and the South African Grid Code.

[2] According to SANS 1019 of 2001 and the South African Grid Code. The South African Grid Code for RPPs indicate the lower limit as 33kV

[3] According to SANS 1019 of 2001 and the South African Grid Code. The South African Grid Code for RPPs indicate the upper limit as 33kV

[4] According to SANS 1019 of 2001

Chapter 1: Background

1.1 Introduction

Throughout the world there is a drive to improve energy efficiency, to reduce electricity demand and to encourage renewable energy generation. Various sources inform the public that this is good for the environment, will prolong generation and grid assets and natural resources such as fossil fuels and water. However, it may be possible that these initiatives change the performance of planned (future) and designed (existing) networks without engineers reconsidering past assumptions or traditional design methods.

In electricity distribution network master planning and designs, the planner or designer must make various assumptions while considering future loading and scenarios. The planning window is generally 20 years for master planning [2] and 15 years for electrification planning [3]. A few factors stand out in such planning exercises, namely diversity factors, load factors, load profiles, loss factors, growth rate and after diversity maximum demand (ADMD). Several assumptions are made in the selection of suitable parameters and combinations of parameters to predict future load and to plan and design infrastructure accordingly. If parameters are affected and the impact of a change is not considered, unexpected or even degraded performance of networks may result, while utilities and municipal electricity re-sellers may have to lay out unplanned capital to rectify or address the resulting problems.

1.2 Energy efficiency and demand side management

A recorded load profile for a 33 kV feeder in Ghana in 2011 (refer to Figure 1-1 below) revealed that the typical daily load profile has a load factor of approximately 80%. From a South African perspective, typical municipal load factors are approximately 50%. The Ghana feeder supplies predominantly residential customers with negligible commercial and industrial activity. Residential load factors in South Africa are lower than 50%. The high load factor and load profile shape raised questions about typical coincidence factors to be used for future load estimates while planning two new cities in Ghana.

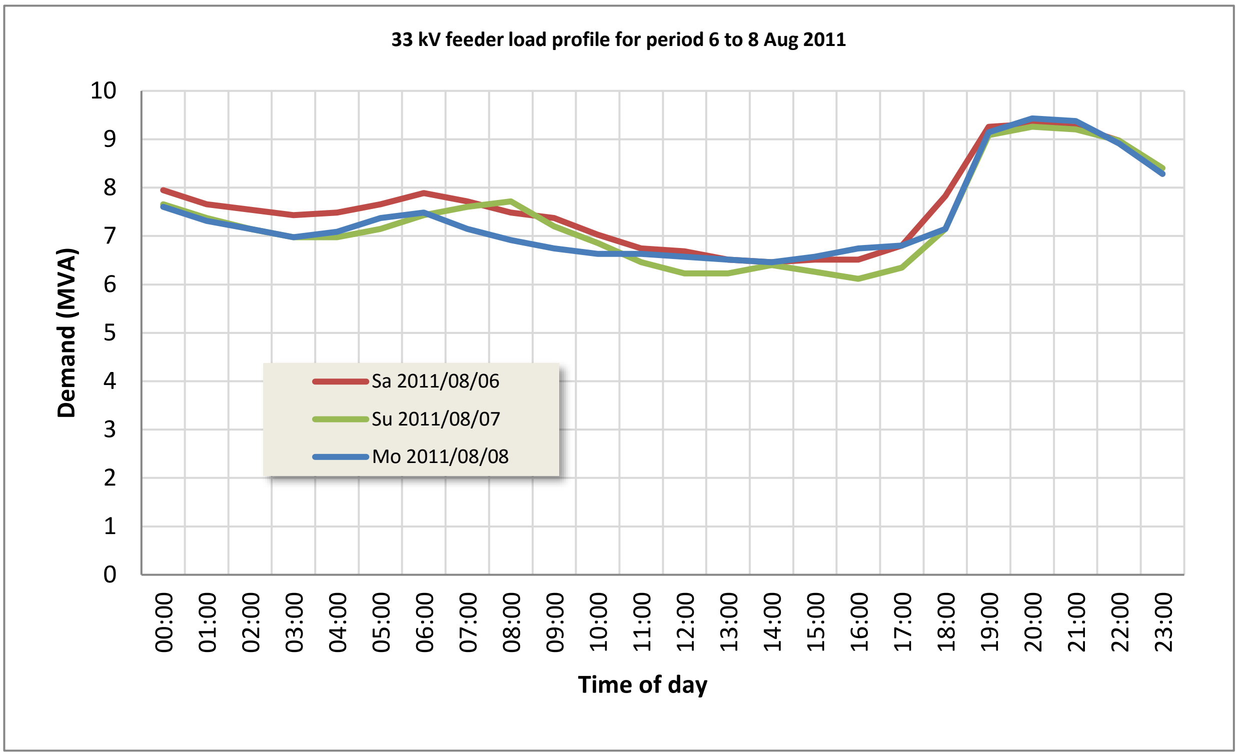


Figure 1-1:Typical daily load profile in Ghana for a typical 33 kV feeder over a randomly selected period of 3 days inclusive of a weekend

It was observed while visiting Ghana in 2011 and 2012 that electricity is neither used for water and space heating, nor for cooking. Standby loads are usually switched off after use (e.g. televisions and cell phone chargers) due to the high cost of electricity and limited supply. It therefore appears that climate and consumer behaviour will affect a load profile, which is reflected in the load factor. This poses a few questions, namely:

- Does a more efficient use of electricity, or a use influenced by behavioural change improve load factor?
- If it does, how does it change coincidence factors? In other words, is there a relationship between coincidence and load factor?

Another observation was that a ripple relay installation increases the maximum demand of a 45 MVA transformer from 42 MVA to 47 MVA. The new peak was due to the so-called “cold pick-up” load stage occurring when ripple relays switch hot water cylinders back on. The ADMD of the network increases and the load profile shape changes because the controlling algorithm is not properly configured to prevent such a scenario. Apart from the transformer, which is loaded in its emergency loading range for a short period every 24 hours, it is possible that network MV and LV feeders operate under stress or under overloaded conditions, while voltage drop limits could be exceeded. This is a good example of a DSM initiative that has changed a designed network and that would have rendered future load forecasts insufficient.

1.3 Renewable energy generation, embedded generation and distributed generation

Another consideration is the effect of single-phase consumers generating electricity through rooftop solar PV installations and consuming less electricity, while injecting surplus energy back into the network. The network could become unbalanced, or voltage rise could occur. As the unbalance increases, there can be a further voltage drop, which could exceed previously designed limits.

The distribution networks are generally designed for a power flow from the generation stations through the transmission, sub-transmission and distribution network to the end user, with inherent diversity between consumers in the network. The traditional flow of electricity can be illustrated as follows:

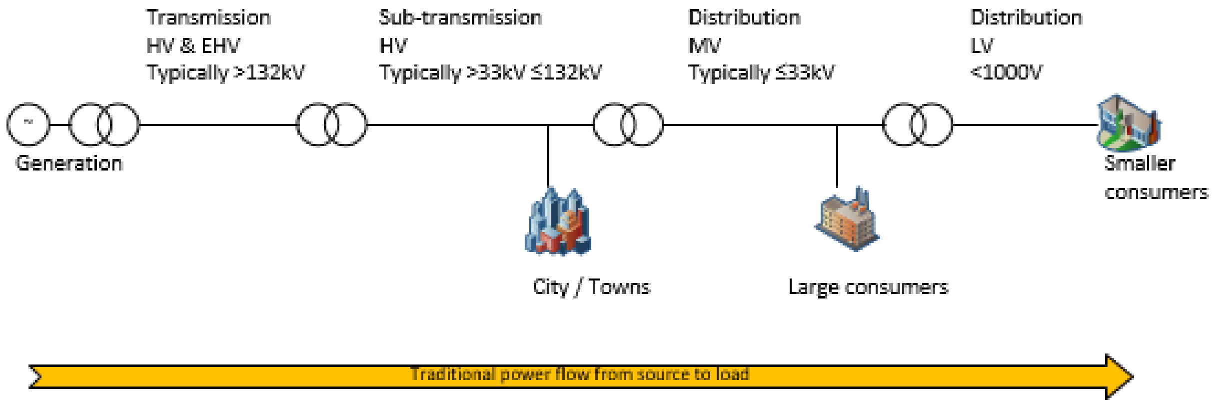


Figure 1-2: Traditional power flow

If several users inject energy back into the network, it is possible that some design assumptions, such as diversity or load factor, could be affected. Once planning and design assumptions are affected, questions arise about the adequacy of network components such as cables, switchgear and transformer capacities, as well as the performance of the network and compliance to regulatory requirements. Power flow in future networks can be illustrated as follows:

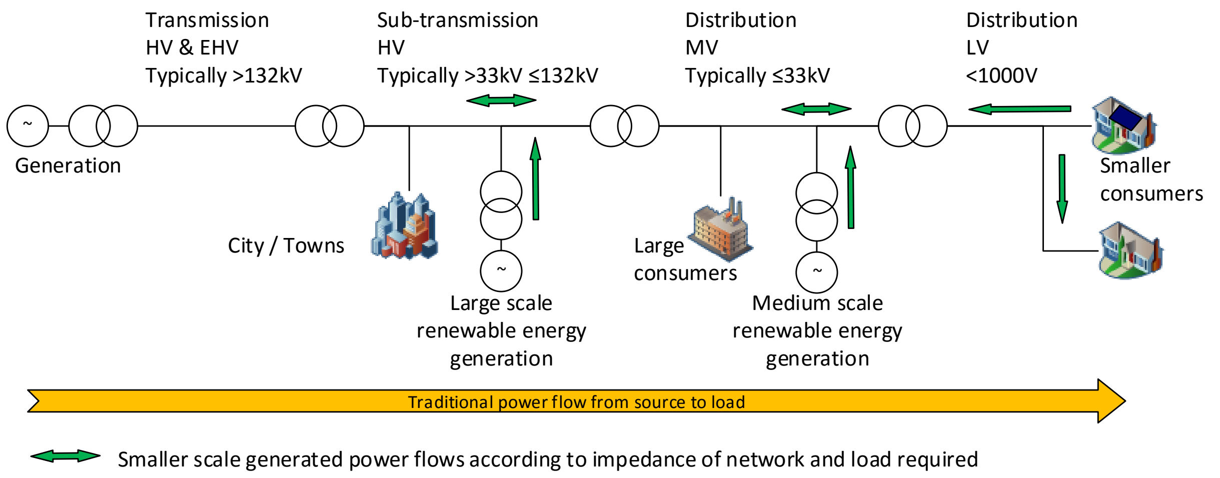


Figure 1-3: Power flow with smaller scale, distributed and embedded generation, with the possibility of reverse power flow indicated

When considering the South African peak demand, a decline in the annual demand since 2007 is observed:

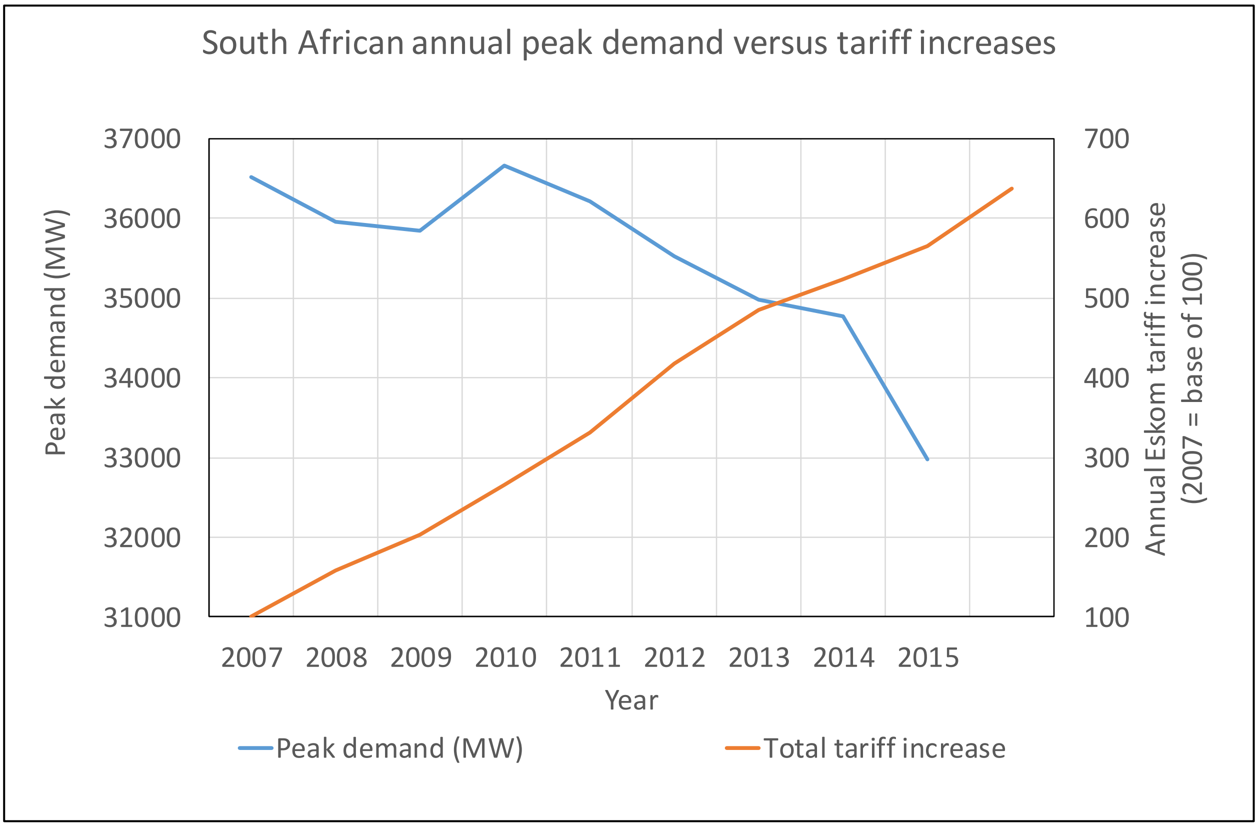


Figure 1-4: South African peak demand declines and Eskom tariff increases (derived from tabular data published in the NERSA System Adequacy Outlook report – table 1 [4], and the Eskom Tariff Book [5])

The decline may be attributed to a decline in economic activity, rising electricity costs and the rapid expansion of renewables. In 2008, load shedding took place, which resulted in an abnormal decline in peak demand. Electricity costs in South Africa have risen with 637% since 2007 (calculated from electricity increases published by Eskom [5]). The rapid expansion of renewables emphasizes the need to study the impact this technology will have on the South African networks.

1.4 **Research questions**

The questions that are investigated in this study, are:

(1) Which planning and design parameters are affected by EEDSM initiatives and small-scale renewable energy generation?

(2) How are these parameters affected?

(3) Is there an interdependency between these parameters, and if so, how sensitive would a change in one or more parameters be to other interdependent parameters?

Questions 2 and 3 above can be considered *in lieu* of the following questions:

(4) What is the relationship between coincidence or diversity and load factor?

(5) How does single-phase injection on the low voltage network affect the low voltage network's performance and integrity?

(6) How does generation from LV and MV embedded/distributed generation in general affect the network up- and downstream from the point of generation?

(7) How will ADMD factors be influenced by EEDSM and renewable energy generation at low voltage level / distributed generation?

(8) How are traditional diversity factors between LV feeders, transformers on medium voltage feeders, feeders at a substation and further upstream networks affected?

(9) How are system losses affected when load profiles are altered through EEDSM initiatives and reverse power flow due to renewable energy generation?

(10) How are fault-levels affected by renewable energy injection on the low voltage, medium voltage and high voltage networks respectively, and what is the impact on protection systems and equipment ratings?

The study excludes the following:

- impact on utility revenue streams,
- impact on health and safety, and
- impact on power quality.

1.5 **Research objective**

The objective is to investigate the impact, if any, on electricity network planning and design parameters and factors when energy efficiency, demand side management or renewable energy projects are implemented. In other words, are original planning and design assumptions still valid after implementation of EEDSM measures or renewable energy, or is there risk that "green measures" may affect the grid negatively?

1.6 **Hypothesis**

The following is postulated:

- Energy efficiency generally reduces the system peak and therefore ADMD. Technical losses will also be reduced.

- Load shifting techniques, when not properly controlled, can increase the ADMD, especially if the load is associated with thermal storage.

- Improving the load factor reduces the diversity of similar load class consumers.

- Reducing the diversity of consumers will impact designed and constructed networks by increasing the voltage drop experienced by consumers. However, the reduced energy consumption and demand could mean that the effect is cancelled out or reduced.

- Uncontrolled solar PV injection into the network may cause network unbalance, which will affect a voltage drop in designed and constructed networks. LV networks are designed for a diversified power flow in one direction. A reverse power flow in a high penetration solar PV network, producing excess energy during solar peak, will exceed the power a LV feeder can handle due to a lack of diversity during reverse power flow.

1.7 Research methodology and approach

The research entailed a literature review and simulations and calculations. A literature study was conducted to:

- review the basic regulatory requirements for planning compliance in South Africa and any prescribed parameters;
- review the planning standards applicable in South Africa;
- review theory;
- review historic and present methods for distribution network planning and design; and to
- review research conducted in the specific field.

On completion of the literature review, the research questions were further investigated by creating a load profile simulation and a load flow simulation model of a representative network. Parameters will be varied to determine impact, sensitivity as well as interdependency.

The methodology can be outlined as follows:

Table 1-1: Methodology to investigate respective research questions

ITEM	RESEARCH QUESTION	METHODOLOGY TO INVESTIGATE
RQ4	What is the relationship between diversity and load factor?	An analysis of the various formulae for the various parameters. This also involved an analysis of the summation of individual load profile curves per load class, with load factors per load class. The aim was to determine whether diversity is affected by changes in load profile. This was examined by considering e.g. ripple control demand side management altered profiles, subtracting solar PV renewable energy superimposed profiles and solar thermal water heating effects, gas cooking etc.
RQ5	How does single-phase injection on the low voltage network affect the low voltage network's performance and integrity?	Simulate by means of a network model for a typical designed network.
RQ6	How does generation from LV and MV embedded/distributed generation in general affect the network up- and downstream from the point of generation?	Simulate by means of a network model.
RQ7	How will ADMD factors be influenced by energy efficiency and renewable energy generation at low voltage level?	Perform calculations on load profiles, and supplement with load profiles from recently commissioned solar farms, NWU-measured data or simulated data.

ITEM	RESEARCH QUESTION	METHODOLOGY TO INVESTIGATE
RQ8	How are traditional diversity factors affected between LV feeders, transformers on MV feeders, between feeders at a substation and further upstream?	Detailed load data on 132 kV, 66 kV and 11 kV MV feeder level are available from a recent master plan study. This can be used to model diversity factors at various levels, compare with literature, international and South African "experience" values, where after profile changes can be applied.
RQ9	How are system losses affected by load profiles altered by energy efficiency and reverse power flow due to renewable energy generation?	Assess loss factor through its relationship to technical (I^2R) losses, its link to load factor and its link to diversity and changes to load profiles and these parameters.
RQ10	How are fault levels affected by renewable energy injection on the low voltage, medium voltage and high voltage networks respectively, and what is the impact on protection systems and equipment ratings?	Fault levels would generally increase at the point of power injection. The point at which it injects relative to previously existing critical elements and protection systems will be evaluated.

1.8 Dissertation structure

The dissertation is structured as follows:

- Preface
- Abstract
- Chapter 1: Introduction - In this chapter the reader is introduced to the problem, the research questions, the hypothesis and the proposed research methodology.

- Chapter 2: Literature Study - This chapter includes a review of local regulatory frameworks and standards as far as planning parameters are concerned, a review of theory and a review of review of research already conducted concerning the research questions.
- Chapter 3: Analyses and modelling - This chapter discusses the models generated, any data sets used and the analyses conducted.
- Chapter 4: Findings and results - This chapter documents the findings of all the simulations and analysis.
- Chapter 5: Conclusion
- Chapter 6: Recommendation for further studies / work - Should the research indicate that past assumptions are impacted and that design and planning methods or parameters have to change, this chapter offers recommendations for further investigation into new planning or design methods.
- Bibliography
- Appendices

Chapter 2 Literature study

2.1 Overview

A holistic understanding of the planning and design processes is crucial prior to investigating each aspect in more detail.

Eskom Distribution has provided a methodology for network master plans (NMPs) and network development plans (NDPs) under document number DGL 34-431 [2]. The NMP is the long-term plan with a 20-year horizon, while the NDP focuses on shorter horizons – typically five years. Shorter horizons (two to three years) are labelled as project planning.

Graphically, considering Figure 1-3, the master planning and design scope can be illustrated in Figure 2-1:

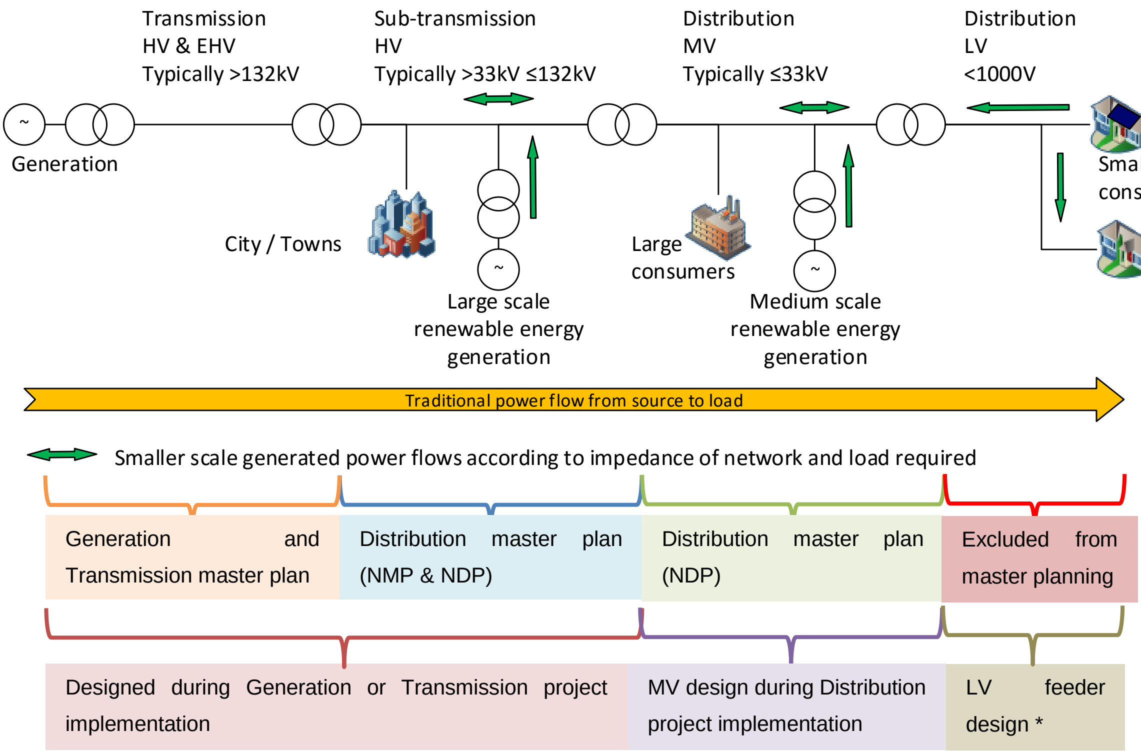


Figure 2-1: Master planning and design in context

Traditionally, municipalities in South Africa do not separate their master plans into multiple studies, but compile the short, medium and long-term plans as part of one master plan study.

Consulting engineers mostly execute these studies for municipalities and they lately follow the same methodology as Eskom.

H. Lee Willis explains the evaluation of alternatives for the master planning process in general [6], while Eskom [2] incorporated problem identification and goals with the evaluation of alternatives (see table 2-1):

Table 2-1: Master planning process – alternatives (Source: [2], [6])

Step	Activity	Notes
1	Identify the problem (includes gathering & analysing data)	Explicitly identify the range of application and its limits. Try to see the problem in terms of the goals and write it down.
2	Determine the goals	This tells you where you are aiming to go. What goals are to be achieved? Review the company's mission. What is to be minimised?
3	Identify the alternatives	What alternative solutions are available? This is a critical step. Never assume that one man can see all the alternatives. This should be a group session.
4	Evaluate the alternatives	Evaluate all the alternatives on a sound basis.
5	Select the best alternatives	Select the alternative that best satisfies the goals with respect to the problem

Willis also outlines a spatial approach to load forecasting [7] and Eskom has considered the international best practice outlined by Willis and refined it further for their needs [2]. Figure 2-2 illustrates the Eskom master planning process (which is generally accepted as best practice in South Africa):

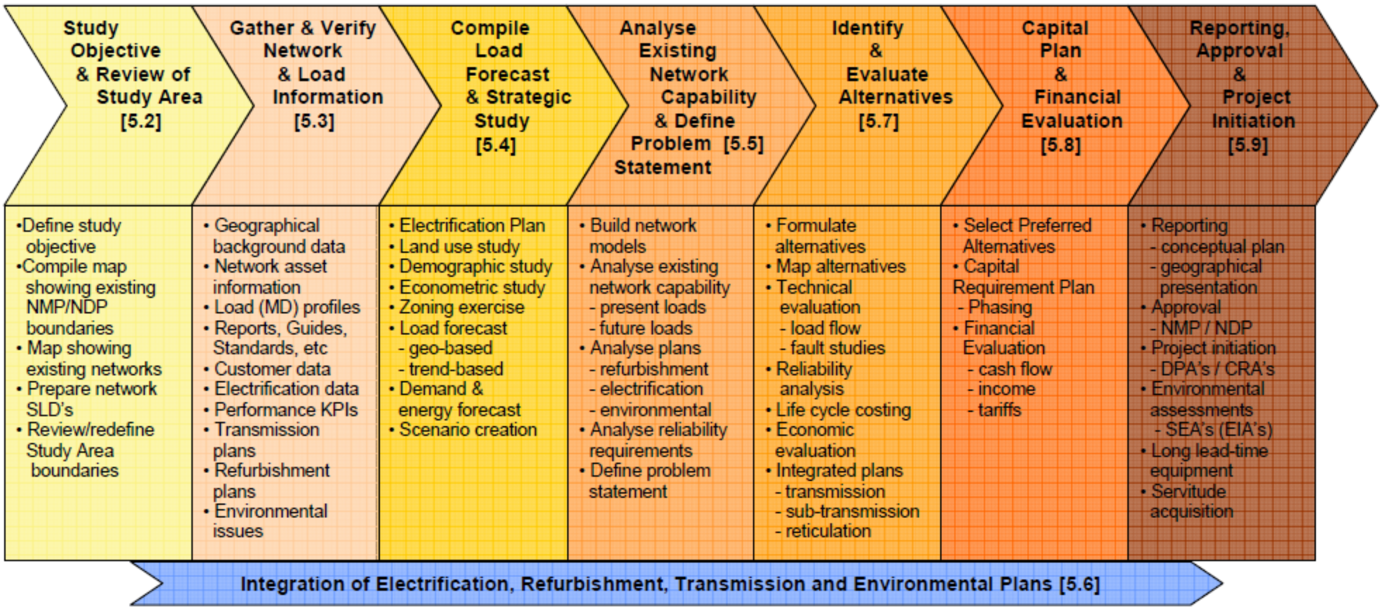


Figure 2-2: Eskom master planning methodology [2]

Using Figure 2-2 as a frame of reference, the master planning areas covered by this dissertation are:

- 5.3: Load (MD) profiles
- 5.4: Demand & Energy forecast (Load forecast in the diagram refers to the geographic location of the load and type of load)

The LV feeder design parameters are discussed in their entirety, as this is where most small scale distributed and embedded generation may have an impact. LV feeder, MV feeder and MV/LV transformer design involve the sizing of conductors to transfer the required load while maintaining the voltage within limits, sizing of transformers and other equipment, and protection and earthing arrangements. Earthing and protection arrangements are not discussed in this dissertation, except for fault level implications, or where power quality aspects caused by small scale distributed or embedded generation have an impact on energy and demand aspects.

2.2 Theory: planning parameters

2.2.1 Overview

Planning parameters refer to certain parameters required to do planning. Planning involves the sizing of equipment based on future loading requirements. Knowledge of planning parameters and how they relate to one another makes it possible to assess the impact new industry initiatives such as deploying DG or changing electrical geysers with solar geysers will have on past assumptions. It also provides guidance on how future thinking should change.

2.2.2 Load profile

The network's load profile is the sum of individual load class load profiles.

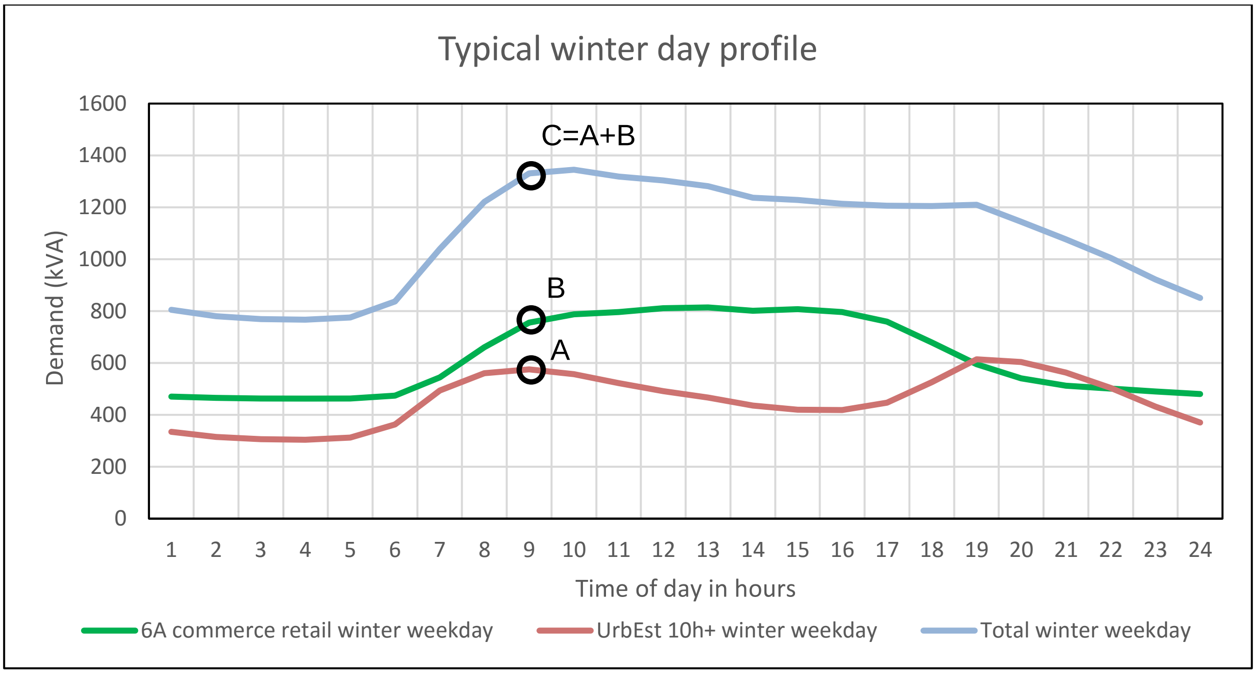


Figure 2-3: Typical load profiles, also illustrating the concept of composite load profiles

The residential and commercial load class load profiles in Figure 2-3 summate to produce the total load profile. The commercial load profile peaks around noon, while the residential profile peaks in the morning and the evening, but with the evening peak being the highest. When the two profiles are summated, the new peak is neither in the afternoon, nor in the evening, but rather in the morning.

Figure 2-3 shows the apparent demand in kVA. When the demand is shown in kW, the area under the line is the energy consumption. The load factor can be determined from the load profile if the maximum demand and the average demand are known, or if the maximum demand and the energy consumption are known.

2.2.3 Load factor

Load factor is the ratio of the average demand to the maximum demand, or alternatively expressed, the ratio of actual energy consumed to the sum of the total energy consumed and the energy that could still be consumed. The load factor can be determined when the load profile is studied. Graphically, the CSIR expresses load factor in their Human Settlements Planning Guideline [8] (so-called South African "Red Book") as per Figure 2-4 below:

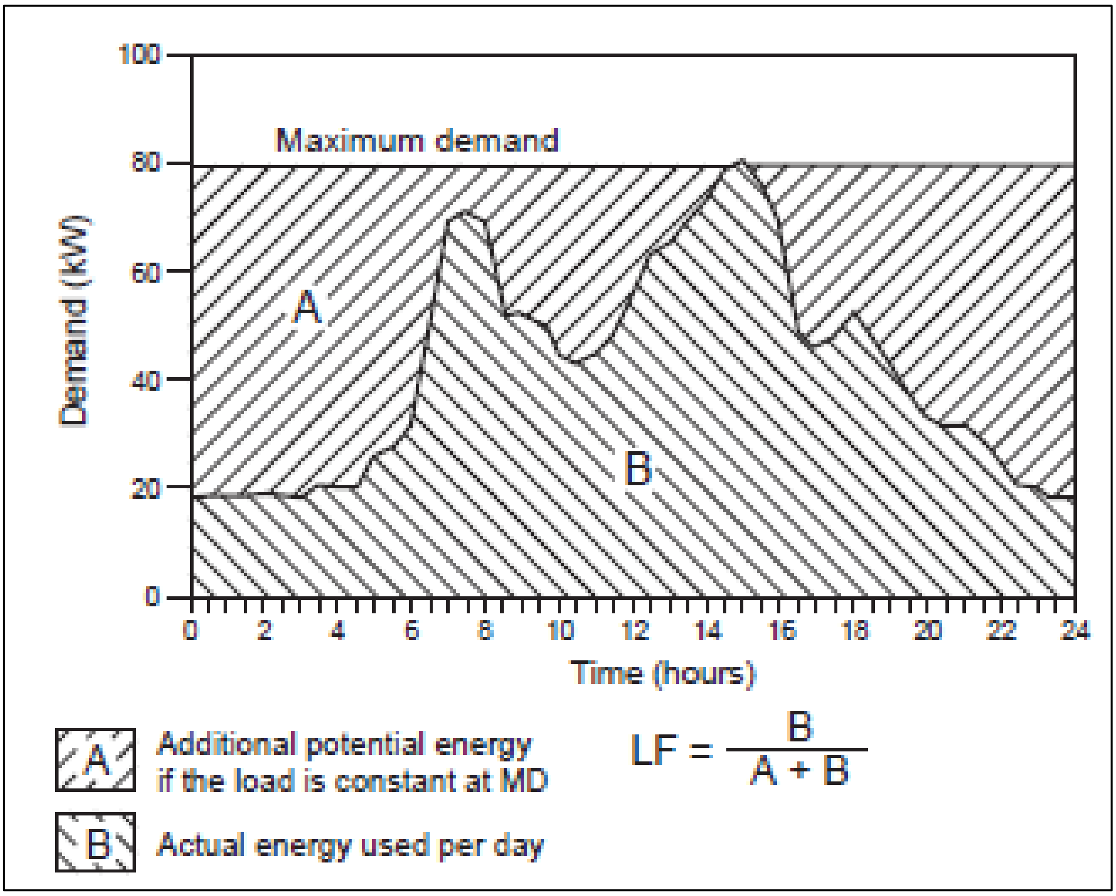


Figure 2-4: Load factor defined (Source: Guideline for Human Settlement Planning) [8]

In equation form, it can be expressed as:

$$LF = \frac{kWh}{h \times MD_{kVA} \times PF} \quad \text{... (1)}$$

Where

LF = annual load factor: a value between 0 and 1;

kWh = active energy consumed per annum. For ADMD calculations, it would be better to use the highest consuming month over the design lifespan of the load under consideration and to reduce the hours accordingly;

h = hours per month;

MD_{kVA} = Maximum demand in kVA;

PF = Power factor, a value between 0 and 1. For residential purposes this can be assumed to be > 0.95, provided that the load has not become too inductive. Residential load historically is assumed to be near unity power factor, but the use of compact fluorescent lamps, switch mode power supplies, heat pumps and air-conditioners will change residential load from resistive to inductive.

By assuming a load factor, the maximum demand can be calculated if the energy consumption is known, and the energy consumption can be calculated if the maximum demand is known. As this dissertation shows, the maximum demand is a very important design parameter and it is important to understand the factors that are used to calculate it or that have an effect on it.

The CSIR's Human Settlements Planning and Design Guideline [8] indicates that the load factor for high consumption load classes could be changed by demand side management techniques, such as ripple control to control hot water or other non-essential loads.

A study by Mistry and Roy [9] indicates that the load factor grows as load grows. This implies that energy consumption grows faster than maximum demand.

2.2.4 **ADMD**

The previous section mentioned the importance of the maximum demand. When the maximum demand of a network is related to the maximum demand per consumer, the after diversity maximum demand (ADMD) is calculated. This dissertation furthermore shows that the ADMD is one of the key parameters that is central to long-term load forecasting and network design.

The CSIR's Guidelines for Human Settlement Planning and Design [8] and Eskom [10] defined ADMD as the average maximum demand of a simultaneous group of consumers. Per definition, the equation for ADMD may be written as:

$$ADMD(n) = \frac{MD(n)}{n} \qquad \dots (2)$$

Where

ADMD(n) = ADMD for *n* customers

MD(n) = Maximum demand for *n* customers

n = Number of consumers

A study by McQueen et al [11] refers to the related formulae used in the electricity industry for determining the demand of a group of consumers as Prevalent Engineering Practice (PEP), and states the origins of these formulae as the work of JG Boggis, published in 1953. Boggis [12] states these PEP formulae in principle as follows:

$$MD = n \times DF \times ADMD \qquad \text{... (3)}$$

$$ADMD = \lim_{n \to \infty} \frac{1}{n} \sum_{i=0}^{n} MD_i \qquad \text{... (4)}$$

$$DF = 1 + \frac{k}{n} \qquad \text{... (5)}$$

Where

ADMD = After Diversity Maximum Demand

MD = Maximum demand, usually over a year

MD_i = Maximum demand of i^{th} consumer

n = Number of similar consumers

DF = Diversity factor

k = Coincidence factor

It is interesting to note the slight variance in the approach to the ADMD calculation when considering equations 2 and 4.

The literature studied contained variances in the number of consumers for which the ADMD stabilized. While McQueen [11] and Boggis [12] use the definition that the ADMD is accurate for a very large group (i.e. close to infinity), the Human Settlement Planning Guideline [8] and Eskom [10] generally accept that the ADMD for residential consumers is constant for a 1000 or more consumers. Boggis does state that 100 households are a large enough group. Prior to the work of Boggis, Bary [13] also indicated through studies conducted in the late 1930s and early 1940s that a group of 100 similar load-class consumers are sufficient, and even observed that groups as small as 30 to 50 consumers are sufficient to conclude an ADMD value that would not vary much when the number of consumers increases. Gaunt et al [14] observe that beyond approximately 150 consumers, the ADMD does not change.

In the author's experience, a group of 100 consumers is a conveniently sized group. One hundred consumers can still conveniently be connected to a 500 kVA transformer. One thousand consumers dictate that the ADMD applies to MV feeder or substation level, but should not differ much from the ADMD of a 100 or 150 consumers.

Generally, the ADMD increases as the number of consumers decreases due to a lack of diversity.

Apart from the formulae above, ADMD can otherwise be determined through direct measurement, the energy load factor method or through appliance modelling. A discussion of each method follows.

Direct measurement

Direct measurement is perhaps the best method, but the maturity of the network and any non-residential loads must be known, as the non-residential loads should be deducted to obtain the residential portion. The CSIR's Guidelines for Human Settlement Planning and Design [8] provides the formula for determining domestic maximum demand when non-domestic load is also present:

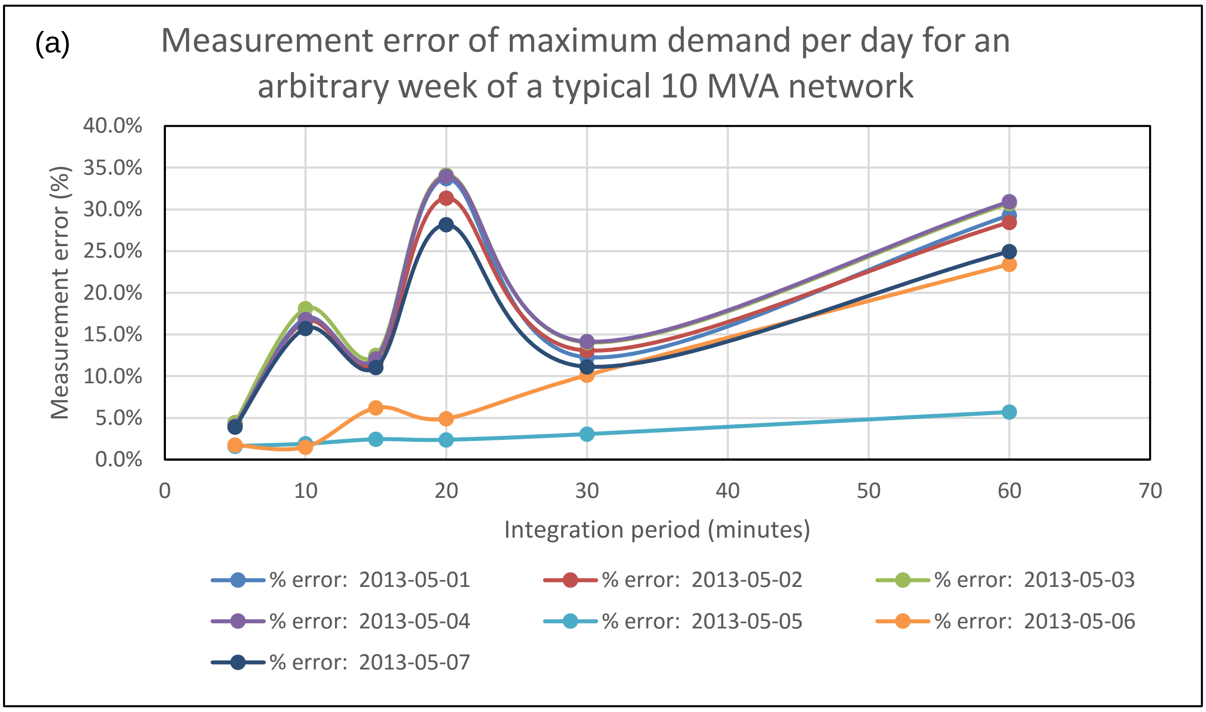
$$MD_{residential} = MD_{total} - MD_{non-residential} \qquad \ldots (6)$$

Where

MD = Maximum demand

This formula is flawed due to diversity between load classes (refer to figure 2-3). The formula is only valid if the domestic and non-domestic loads have coinciding maximum demands, meaning the maximum demands must take place at the same time. Vectorial subtraction should take place, meaning a 18:00 non-domestic load value must be subtracted from the 18:00 total demand value to yield a 18:00 non-domestic value.

Care should also be taken when measurements are used. The sampling period plays a major role. Own calculations from one-minute load profiles indicate that there is a margin of error as the sampling period of measurements is increased. This margin is even larger when load control is present.



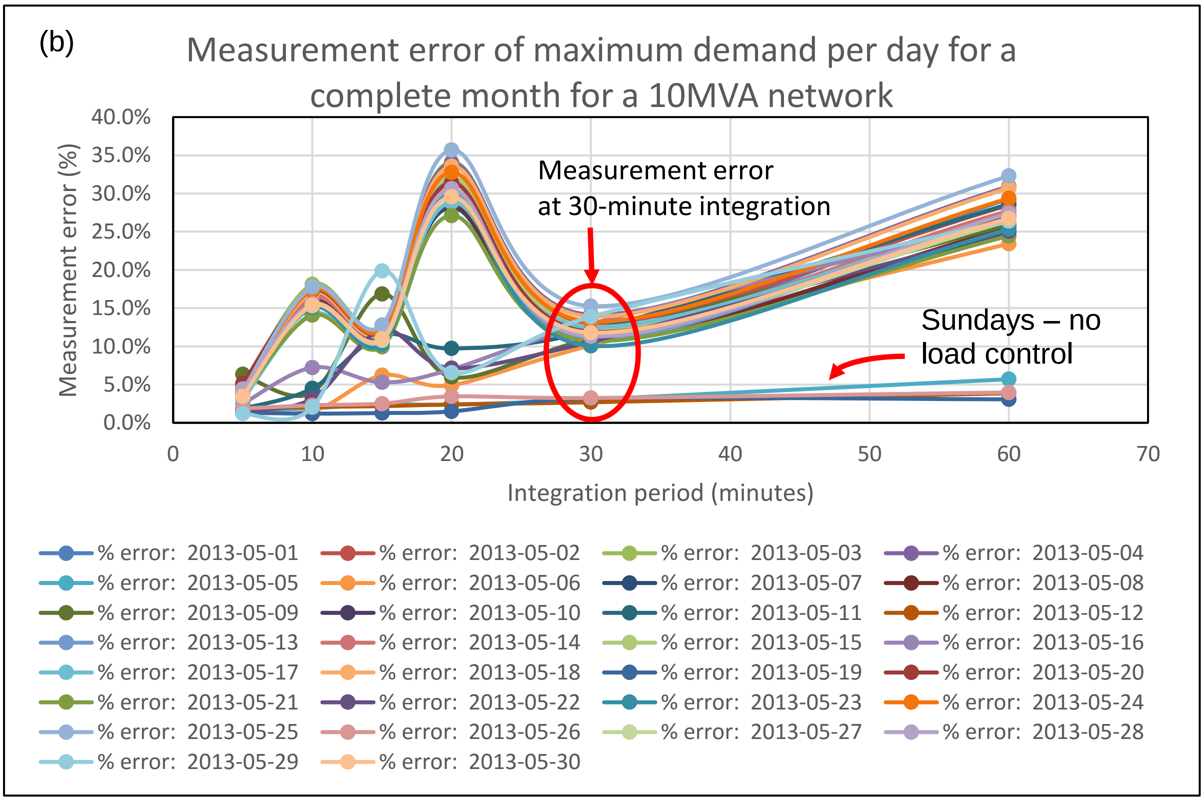


Figure 2-5: Measurement error of the maximum demand of a 10 MVA network, expressed as a percentage, as a result of integration over time compared to one-minute measurements for (a) seven consecutive days and (b) one month

The measurement error was calculated by comparing the average value during an integration period with the maximum integrated one-minute value recorded during the same integration period.

In Figure 2-5 (a), the 5th May 2013 was a Sunday. Load control was not implemented on the Sunday, and a smaller measurement error is observed. It is not clear why the Monday (6th May 2013) would calculate much lower errors at 5-minute, 10-minute, 15-minute and 20-minute integration intervals, as load control was implemented on the 6th May 2013 for the load profiles studied. When a full month's data were assessed (refer to Figure 2-5 (b), all the Sundays displayed the same result, while most days with load control present have increased percentage errors.

It is interesting to note that a 10% to 15% error is made on 30-minute integration with load control present. A 30-minute integration period is used for billing purposes in South Africa. When load control is not implemented, the measurement error will only be approximately 3%.

Therefore, when using measurement values, especially when load control is implemented, the ADMD will be calculated 10% to 15% lower than what it should be when it is based on 30-minute integration. In other words, if a network is designed according to the ADMD calculated from this set of measurement data, the cables and transformers will see a higher load than what the network will be designed for.

Alberts and De Kock [1] illustrated that load control increased the selected network's maximum demand by 11%. The calculation in Figure 2-5 is based on the same network's load profiles used by Alberts and De Kock to illustrate the effect of load control on the maximum demand (refer to Figure 2-13). The compounded effect of load control and the measurement error over a 30-minute integration period is in the range 21-25% (10 to 15% for measurement error plus 11% for load control impact on maximum demand). This example clearly illustrates the impact load control has on ADMD.

Energy load factor method

The energy load factor method uses measured or estimated kWh sales per month and an estimated load factor to calculate the ADMD. Rewriting Equation 1 for load factor to solve for the maximum demand, the formula becomes:

$$MD_{kVA} = \frac{kWh}{h \times LF \times PF} \qquad \dots (7)$$

Load factor per day, per month and per annum will differ due to the weekly cycle of load profiles and the seasonal changes during the year. In South Africa, the weekend domestic load profile is generally lower than the weekday profile. In Ghana, the weekend domestic load profile tends to be the same or slightly higher than weekday profiles on MV feeders with a predominant residential component (refer to Figure 1-1).

Appliance modelling

Appliance modelling is used to model the contribution of appliances during peak period, which would make up the maximum demand. However, the Human Settlement Planning guideline [8] warns that for high and very high-income groups, this method tends to underestimate the demand.

Appliance modelling techniques are most suitable to investigate the effects on load factor and ADMD when an appliance is changed, for example replacing electrical geysers with solar geysers.

2.2.5 **Demand factor, coincidence and diversity**

Beaty and Fink [15] in the Standard Handbook for Electrical Engineers define the demand factor, coincidence and diversity factor, and these definitions can be expressed in formula format as follows:

$$Demand\ factor = \frac{Maximum\ demand}{Total\ connected\ load} \qquad \dots (8)$$

$$Coincidence = \frac{Maximum\ demand}{\sum System\ component\ maximum\ demand} \qquad \dots (9)$$

$$Diversity = \frac{1}{Coincidence} \qquad \dots (10)$$

The demand factor is expressed as a percentage. It expresses the ratio of maximum demand to total connected load as a percentage. The value is between 0% and 100%. This value can never be more than 100% due to the diversity between loads.

Coincidence is expressed as a percentage and can never be more than 100%. Typically, the coincidence for a group of consumers would be the maximum demand as measured for such a group of consumers, divided by the sum of the individual consumer maximum demands. The maximum demand will generally be lower than the sum of the maximum demands, since it is unlikely that consumer maximum demands will coincide on day and time.

Beaty and Fink [15] provide the following table of diversity factors:

Table 2-2: Diversity factors as tabled by the Standard Handbook for Electrical Engineers, Table 18-26 [15]

Elements of system between which diversity factors are stated	Residential lighting	Commercial lighting	General power	Large users
Per level				
Between individual users	2.0	1.46	1.45	
Between transformers	1.3	1.3	1.35	1.05
Between feeders	1.15	1.15	1.15	1.05
Between substations	1.1	1.10	1.1	1.1
Between users and a particular point in the network				
From users to transformer	2.0	1.46	1.44	
From users to feeder	2.6	1.90	1.95	1.15
From users to substation	3.0	2.18	2.24	1.32
From users to generating station	3.29	2.40	2.46	1.45

The diversity factors (or its reciprocal, coincidence) between users and a particular point in the network from Table 2-2 can be plotted as follows:

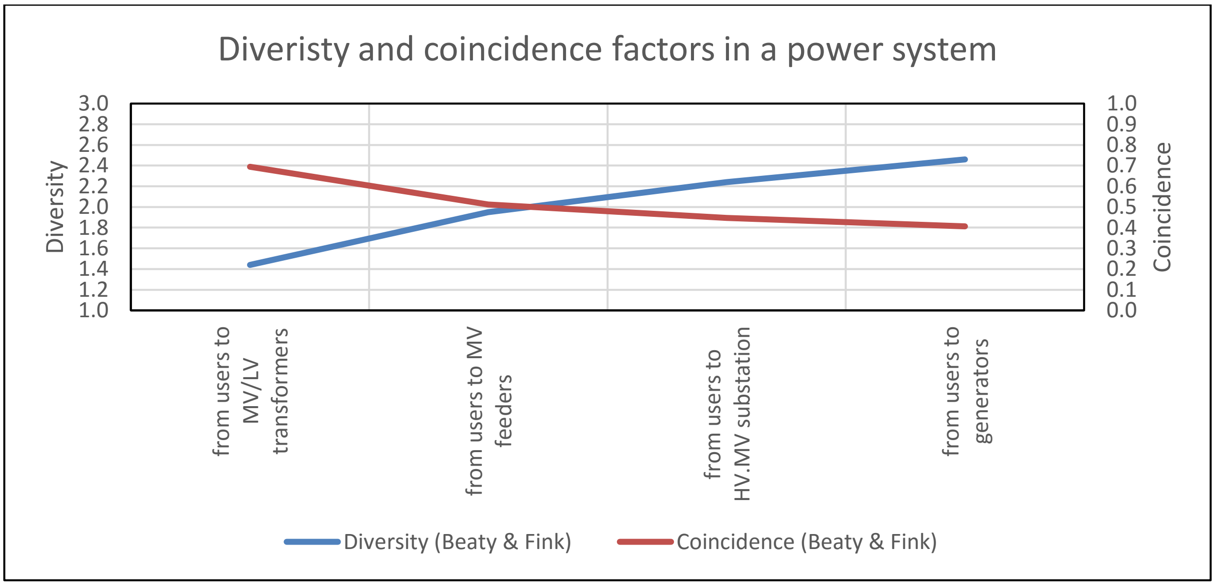


Figure 2-6: Diversity factors for a power system (derived from Table 2-2)

It is important to understand that consumer behaviour and the utilization of electricity would differ from country to country and are dependent on factors such as climate, pricing signals, consumer behaviour and EEDSM policies. Therefore, published factors should be considered against the background of the environment for which it has been published (in the case of the Standard Handbook for Electrical Engineers [15]: against conditions prevailing in the United States of America). They should be adjusted for instance where the climate is different, or where electricity is used for water heating if published figures excluded for argument sake water heating.

When considering losses, a load would not necessarily contribute its loss measured at maximum demand to the system peak, since the peaks do not necessarily coincide. This factor is referred to as the peak responsibility factor.

Eskom recommends the coincidence factors in Table 2-3 in electrification projects for non-residential load [10].

Table 2-3: Peak contribution of non-domestic loads (Source: Eskom [10], table in par 3.1b)

Type of load	Typical peak time coincidence factor
Clinic	0.05 to 0.15
School	0.05 to 0.10
Shop	0.50 to 1.00
Hospital	0.50 to 1.00

This means that a school would contribute 5% to 10% of its peak time load to the system evening peak. Of course, for a morning peak, this factor is different. A school typically peaks around mid-morning.

Already in the 1930s, Constantine Bary [13] did research on the coincidence factors applicable to groups of similar consumers and postulated that the relationship of coincidence to the number of consumers follows the path of a rectangular hyperbola. According to Gaunt et al [16], Rusck suggests a more refined formula. When comparing these two formulae, the difference in essence only lies in the treatment of the number of consumers: Bary used it as is, while Rusck uses the square of the number of consumers:

Bary: $$E_n = E_{n\infty} + \frac{1-E_{n\infty}}{N} \quad \ldots (11)$$

Rusck: $$k = k_\infty + \frac{1-E_{n\infty}}{\sqrt{N}} \quad \ldots (12)$$

In these formulae, E_n and k have the same meaning.

It is important to understand diversity as it allows the planner or engineer to compensate for coinciding maximum demands. Should an engineer or planner fail to understand the diversified nature of loads, it may result in under-designed or over-designed networks.

2.2.6 Unbalance and diversity correction factors

Historically, a few empirical formulae were also used to apply diversity and unbalance correction factors to voltage drop calculations on feeder designs, as summarized by Gaunt et al [16] and Eskom [17]. The table below contains the author's summary of these methods.

Table 2-4: Historical empirical diversity correction and unbalance correction factors used in South Africa, available with ReticMaster simulation software

Formula	Diversity correction	Unbalance correction
AMEU [17]	$DCF(N) = 1 + \frac{2}{N}$ ... (13)	$UCF(N) = 1 + \frac{2.8}{\sqrt{N}}$ ... (14)
DT [17] (Eskom)	$DCF(N) = 1 + \frac{8}{ADMD \times N}$ For ADMD ≤ 5 ... (15) $DCF(N) = 1 + \frac{12}{ADMD \times N}$ For ADMD > 5 ... (16)	$UCF(N) = 1 + \frac{2.8}{\sqrt{N}}$ ... (17)
British [16]	$F_1 \times F_2 = \left(1 + \frac{4.14}{\sqrt{N}}\right) \times \left(1 + \frac{k}{ADMD \times N}\right)$ ... (18) where k=8 or 12	
User defined [17]	$DCF(N) = 1 + m \cdot N^c$ ... (19) m,c = user defined variables	$UCF(N) = 1 + x \cdot N^y$ ... (20) x, y = user defined variables
Neutral	Not applicable	Vector sum
Where DCF(N) = Diversity correction function for N consumers UCF(N) = Unbalance correction function for N consumers		

Prior to the inclusion of the Herman-Beta voltage drop calculation method in NRS034, the preferred method by municipalities in South Africa was the AMEU method for diversity and unbalance correction. The DT formulae were not widely used and were experimental formulae developed by Eskom.

Voltage drop in empirical form in a balanced multi-phase system is calculated as:

$$\Delta V_{section} = I_{ADMD} \times n \times DCF(n) \times Z_{section} \qquad \dots (21)$$

Where

$\Delta V_{section}$ =	Volt drop of the line or cable section, in volts
I_{ADMD} =	ADMD current in ampere for a group of 1000 consumers
n=	Number of houses or consumers
$DCF(n)$ =	Diversity correction factor as per unbalance and diversity correction factors
$Z_{section}$ =	Impedance of the line or cable section, in ohms

In a single-phase system, the voltage drop will also be experienced over the neutral conductor and must be added.

The total voltage drop is the sum of the voltage drop of each of the sections along a feeder. A section is the section of a line or cable between distribution points. On a line, it would be between pole-top boxes and on a cable feeder between distribution or metering kiosks.

At present, the Herman-Beta method is used in load flow software such as Reticmaster. Reticmaster calculates unbalance through vectorial summation.

2.2.7 **Relationship between coincidence and load factor**

Bary [13] also related coincidence to load factor. His measurements were done prior to and during World War II in the United States of America during December (American winters) and he found that the relationship held true during the peace, defence (period leading up to the war) and war periods.

Bary [13] published his curves in the late 1930s and early to mid-1940s. Bary composed the following curves from measurements:

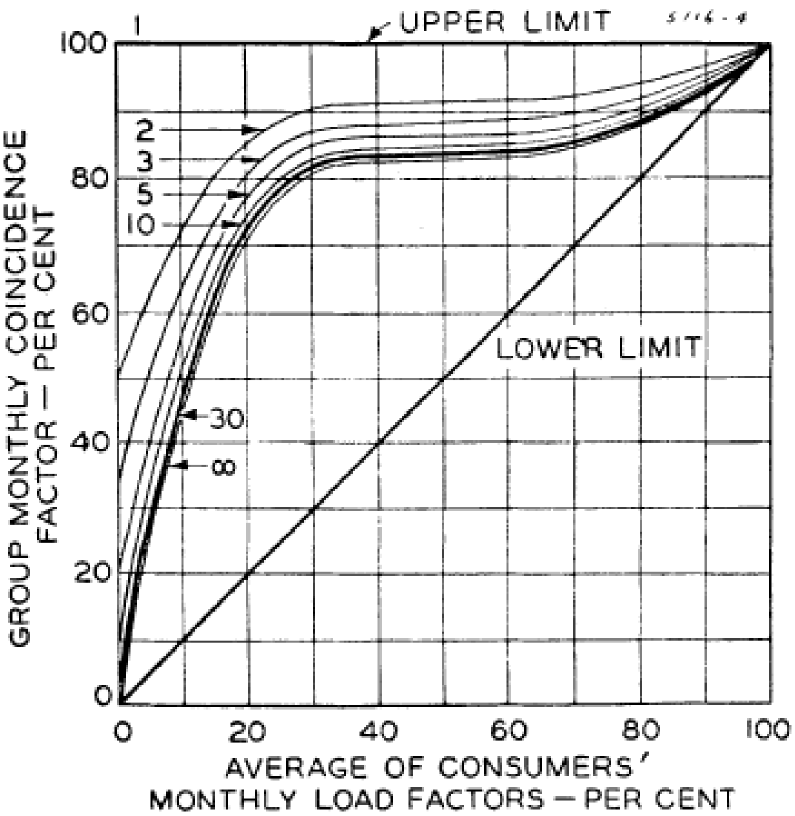


Figure 2-7: Bary's curve for various measurements of coincidence against load factor [13]

The Bary curve appeared in an unpublished version of NRS058 [18] as part of the South African electricity consumption tariff design methodology (unpublished as at date of compiling this dissertation).

The US Department of Defence [19] declassified a standard that contained a similar graph for use at its facilities. Although the document is labelled as “cancelled”, it still illustrates how widely Bary’s work has been adopted.

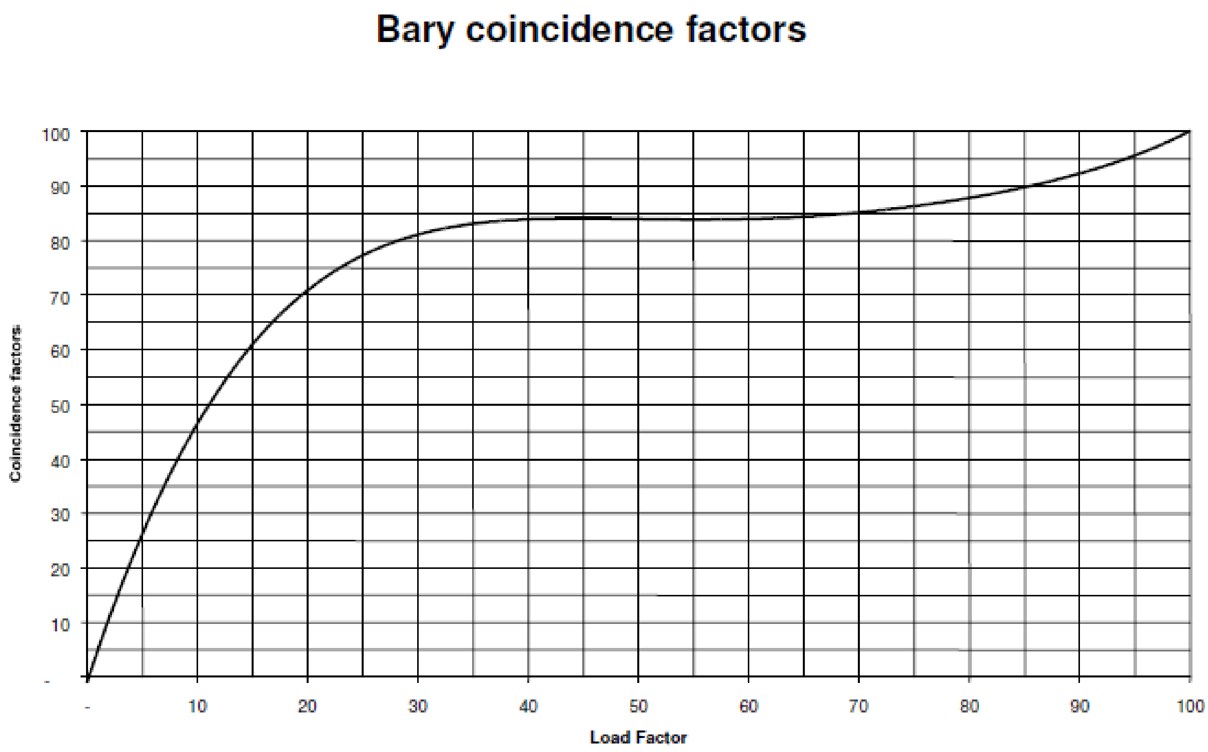


Figure 2-8: Bary coincidence factors related to load factor [18]

The Bary curve is applicable to the conditions that prevailed in the United States of America during the 1930s and 1940s, so the formulae may not necessarily hold true under different circumstances (i.e. different control and limiting strategies, appliance design, consumer behaviour, climate conditions etc.).

At a load factor of 80%, it does confirm the expectation that the coincidence in Ghana for similar residential consumers is high (±87%). However, the same also holds true for any load factor between 40% and 70%, which still yields a coincidence factor of 80%.

What is significant of Bary's work, is that a change in load factor will change the coincidence factors and vice versa, especially at low load factors (<40%). The Human Settlement Planning Guideline [8] and Eskom [10] indicate that load factors for domestic load is generally 40% and less.

A load shift or energy efficiency exercise will change the load profile and the load factor associated with it. This implies that a change in coincidence factors can be expected.

2.2.8 **Load loss factor**

Technical losses are inherent to any transmission or distribution system due to the energy lost as a result of the impedance of a network. Technical losses can be empirically calculated (I^2R, I^2Z, etc.), or it can be estimated using the load loss factor. The Standard Handbook for Electrical Engineers [15] defines the load loss factor as follows:

$$F_L = \frac{Average\ power\ loss\ over\ period\ of\ time}{Maximum\ power\ loss\ over\ period\ of\ time} \qquad \dots (22)$$

Where

F_L = Loss factor: a value between 0 and 1. It is also sometimes referred to as the load factor of losses. The symbol *LLF* is sometimes used instead of F_L

The loss factor only refers to technical losses and excludes non-technical losses. Non-technical losses include all losses not due to the impedance of the system, for example theft, billing errors, CT or VT ratio errors, faulty meters, faulty CTs, faulty VTs, meter reading errors, unmetered load etc. Beaty and Fink [15] provide the following formula relating the two factors based on studies of various load profiles:

$$F_L = 0.15LF + 0.85LF^2 \qquad \dots (23)$$

Where

LF = Annual load factor: a value between 0 and 1.

F_L = Loss factor: a value between 0 and 1.

Technical losses are usually estimated over a year, for example 8760 hours. The loss factor and the load factor can be related and the loss factor is usually less than the load factor. Mistry and Roy [9] report these values to be 0.2 and 0.8 instead of 0.15 and 0.85 respectively.

The cost of losses is determined as follows:

$$Cost\ of\ losses\ per\ kWh = \frac{F_S P}{8760\ F_L} + E \qquad \dots (24)$$

Where

F_S = Responsibility factor

F_L = Loss factor: a value between 0 and 1

E = Energy cost (R/kWh)

P = Annual cost of system capacity (R/kW-year)

Should the losses be incorrectly calculated, the life cycle costing would be incorrect. The cost of losses forms an important part of the evaluation of masterplan alternatives where full life cycle costs should rather be one of the key considerations as opposed to capital cost only.

2.2.9 **Load growth**

Load growth is modelled using S-curve behaviour. A typical S-curve formula used by Eskom is the Gompertz curve [20].

$$f(x) = \frac{1}{1+10C}\left[(2+10C)\left(A+\frac{(1-A)}{1+10Ce^{-7x/B}}\right)-1\right]. \qquad ..(25)$$

Where

f(x) = Unitized annual peak load estimate in year *x*, a value between 0 and 1. The value can be multiplied by the future estimated load to scale it to the correct future load in year *x*.

A = The base load expressed as a fraction of the future load, between 0 and 1.

B = The number of years until saturation, usually 20, but can be any positive value. The value is usually an integer.

C = A figure between 1 and 10 indicating the growth rate. 1 means fast initial growth, while 10 means slow initial growth.

x = The year of calculation.

An example of a growth forecast based on different growth rates is illustrated in Figure 2-9 for a 1000 residential units at a final ADMD of 1.3 kVA per residential unit, 20-year saturation and an initial load of 50 residential units at 0.7 kVA per unit:

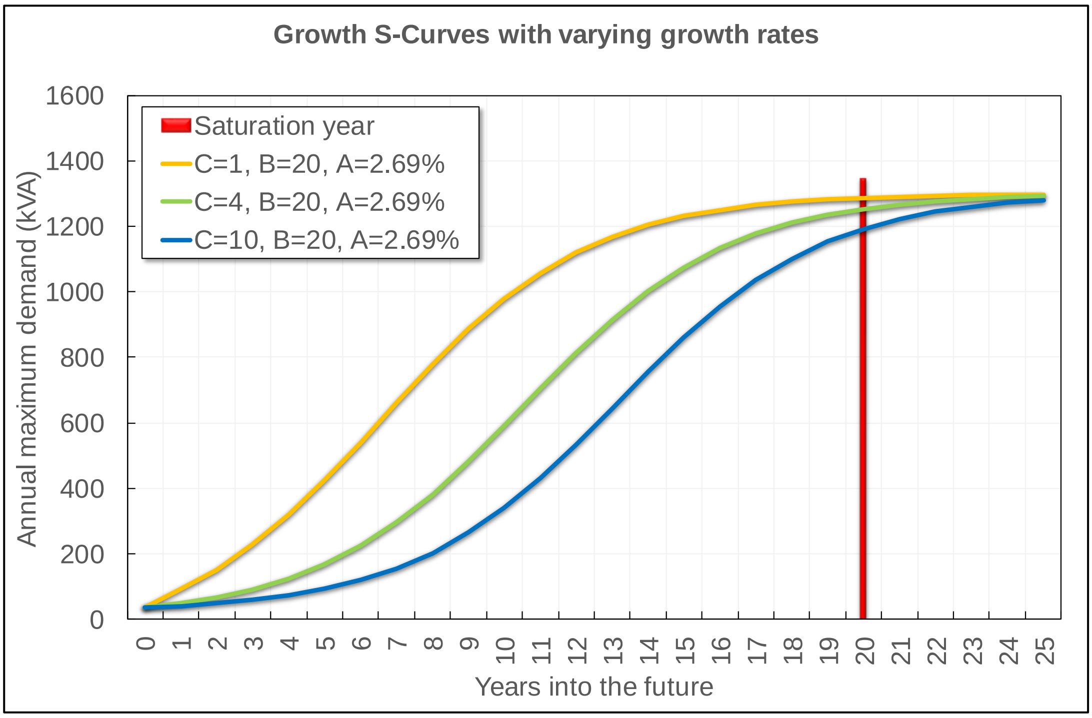


Figure 2-9: Growth S-curves illustrating variance in growth rate (calculated)

Changes in the ADMD will cause the growth to be either under- or overestimated. Underestimating the final demand may result in infrastructure projects starting too late or not having planned timeously for capital to execute the project, or a combination of these issues. Consider the growth forecast in the Figure 2-10.

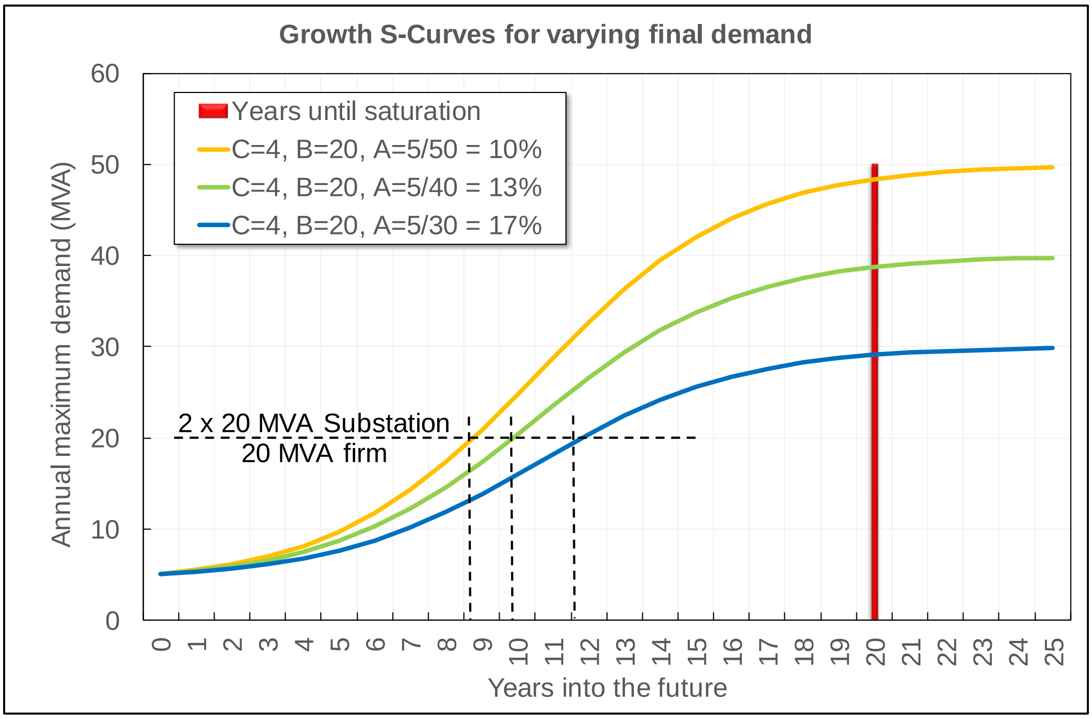


Figure 2-10: Example of growth curves with different future maximum demand

In Figure 2-10, a 2 x 20 MVA substation operated within firm capacity means that the substation load must not exceed 20 MVA. When the load exceeds 20 MVA, either a third transformer must be installed, the existing transformers replaced with larger transformers, or load must be shifted to another substation. Should a planner have forecasted the load incorrectly by using an inappropriate ADMD value, typical scenarios may play out as follows:

a) Underestimating the ADMD:
   i. Suppose the planner estimated the ADMD to be 3 kVA per residential unit for 10 000 residential units. The planner will reach an ADMD of 30 MVA and will propose that an upgrade or strengthening project must be completed by year 11.
   ii. Suppose, however, that the planner missed critical information and the ADMD should have been calculated as 5 kVA per unit. In such a case the strengthening project for the substation should have been implemented by year 9. The project may have started two years too late.
b) Overestimation of the ADMD:
   i. If, for instance, the correct future forecast was 30 MVA, but the planner initially predicted it to be 50 MVA, the two 20 MVA transformers would have been replaced by three 40 MVA transformers by year 9, but the future load of 30 MVA is less than a third of the newly installed capacity of 120 MVA (80 MVA firm).
   ii. The substation will consume no-load losses on two spare transformers and would have laid out unnecessary capital, which may be subjected to interest payments over a 20-year period for a loan.
   iii. Additional insurance costs for unnecessary equipment will also be paid.
   iv. Due to the long lead times on transformers, the decision to procure the transformers would have been taken up to 24 months earlier - too late to stop the process if it is later discovered to have been an error.

As is illustrated in the example above, it is important to understand load growth techniques, as it enables an engineer or planner to determine the future load of a network. Knowing the future load allows for the sizing of equipment. Again, maximum demand is the important factor calculated through this method. The base load (i.e. in year 0) affects the position along the S-curve for the present moment in time. If the base load is very low, the position is closer to the start of the S-curve. If a development is 75% developed, the position is closer to the saturation point.

2.2.10 LV feeder design methods

The sections above dealt with planning parameters for long-term load forecast. In order to size equipment such as cables and transformers correctly, a design must be done. LV feeder design is based on a model to describe the load. Deterministic methods were originally used, followed by probabilistic methods, such as the Herman-Beta method [3] in more recent years. In future, the application of stochastic models might become more widely used.

A study by McQueen et al [11] indicates that the ADMD method for demand estimation is a deterministic approach and does not lend itself to a risk-based perspective where statistical coherence is necessary. This study also observes that with a 30-minute metering integration period, also sometimes referred to as sampling period, the statistical confidence level is 99.994%, which is a cautious approach from a risk analysis perspective and does not provide any information on the time of day the demand occurs. Ferguson and Gaunt [21] indicate that Eskom traditionally used these two methods to model LV loads, namely deterministic and probabilistic methods. Deterministic methods use the average consumer demand to describe the load (e.g. the ADMD per residential unit), while probabilistic methods, such as the Herman-Beta method, consider a distribution of possible loads.

In a study completed in 2013, Li [22] observed that this deterministic approach can lead to uneconomical and unreliable solutions due to the worst case scenario followed. Li observed that electricity distribution is stochastic in nature as demand varies over time and depends on many variables. Temperature and consumer behaviour are some of these variables. Li further refers to several probabilistic methods recently developed, and indicates that the intermittent nature of renewable energy generation and risks associated with it requires a more probabilistic approach.

This dissertation explores only the deterministic and probabilistic approaches, as these methods are used in long-term load forecasting. Stochastic load modelling is more applicable to short-term load forecasting, for example next day forecasting required by a system operator to procure the correct energy mix from the correct energy sources.

2.3 Design and planning parameters informed by law, regulations, standards and guidelines in South Africa

2.3.1 Overview

Apart from the basic parameters, legislation, regulations, standards and guidelines may add additional parameters to consider when doing planning or design.

The following documents govern compliance with technical and supply quality performance requirements in South Africa in the electricity supply industry:

- South African Grid Code (consisting of multiple sub-codes);
- NRS specifications and SANS standards, and
- Guidelines for Human Settlement Planning [8].

These documents are briefly discussed in the following paragraphs:

2.3.2 **Grid code**

The South African Grid Code (SAGC) [23] is a collection of smaller codes. The Grid Code is the result of a legal requirement in the Electricity Regulation Act, Act 4 of 2006. This Act determines that the National Energy Regulator of South Africa (NERSA) should determine rules for compliance by licensees.

Table 2-5: South African Grid Code components

Grid Code document	**Basic contents / Scope**
Transmission system – Version 8, July 2010	
Grid Code Preamble	Sets out context of Grid code Definition of terms used in Grid Code
Governance Code	Provisions necessary for overall administration of the Grid Code
Network Code	Connection conditions for generators, distributors and end-use customers Standards for the transmission system
System Operation Code	Responsibilities and roles for operation, maintenance and outage planning
Metering Code	Transmission tariff and energy trading metering requirements Responsibility for metering installations
Transmission Tariff Code	Objectives of transmission service pricing
Information Exchange Code	Requirements for exchange of planning, operational and maintenance information
Renewable Power Plant, Version 2.8, November 2012	
Grid Connection Code for Renewable Power Plants	Minimum technical and design requirements for grid connection of renewable power plants
Distribution system, Version 6, July 2014	
Distribution Code Glossary and Definitions	Definitions applicable to Distribution Code
Distribution Code - Network Code	Set basic rules of connecting to the distribution system. Specify technical requirements to ensure safety and reliability
Distribution Code - System Operating Code	Sets out responsibilities and roles for operation of distribution system
Distribution Code - Tariff Code	Sets out objectives for pricing and tariff structures

Grid Code document	Basic contents / Scope
Distribution Code - Metering Code	Compliance requirements for tariff and energy trading metering, responsibilities for metering installations Appropriate procedures for maintenance, testing, collection, validation and verification of metering data
Distribution Code - Information Exchange Code	Requirements for exchange of planning, operational and maintenance information

The following criteria are extracted to emphasize the factors that can be altered through the application of distributed generation (DG) (e.g. voltages may rise above limits set by the Grid Code).

The Transmission Network Code [23] requires that load forecasts be done every year for the ten years ahead and that load forecasts of end-users and distributors be obtained. It states that diversity factors as measured or calculated may be applied to the data to provide sufficient planning information at higher levels. Therefore, it is important to ensure that selected diversity factors are not adversely influenced by for instance the roll-out of solar PV systems.

The Transmission Network Code further defines the minimum and maximum voltages to which systems must comply, the target voltages when performing planning actions, power factor, protection requirements, fault level management obligations, reliability and contingency planning requirements. The minimum and maximum voltages will perhaps always remain the main criteria for design compliance.

Power factor limits are stated and rules for engagement with stakeholders when fault level variations take place, are provided. Power quality and protection requirements are provided. These are all important aspects when considering the implementation of DG.

The Transmission Tariff Code [24] provides a section on loss charges through the application of loss factors. When loss factors change, the underlying basis of a tariff design may be influenced.

The South African Distribution Code (SADC) [25] is a part of the SAGC and applies to all distributors. As for the Transmission Network Code, the important parameters governed by the SADC Network Code is voltage and power factor and it states further that fault levels as agreed through contracts must not be exceeded. Adding DG has the potential to raise fault levels above contractual limits.

The Grid Connection Code for Renewable Power Plants [26] supplements the Transmission and Distribution Network Codes and provides the compliance requirements of Renewable Power Plants (RPPs). This section of the Grid Code provides criteria for operation and control of renewable power plants. These criteria are provided to protect the grid and to ensure proper quality of supply.

Unregistered solar PV systems are already installed and the present effects of excess energy injected into the grid are most likely negligible or overlooked due to the isolated occurrence thereof. However, as the tariff or pricing signals change and the risk of unavailable electricity to the general user increases, the occurrence of solar rooftop PV is expected to increase. These effects may cause unwanted performance of the grid as the system operators are unaware of it, and have not tested or simulated the effects of connection or disconnection.

2.3.3 **Standards and specifications overview**

The South African Bureau of Standards (SABS) regulates all the standards for compliance in the electricity supply industry. Most standards are IEC standards, which are adopted as SANS standards, while Rationalized User Specifications (NRS) guide further specific requirements. The most notable standards and specifications are:

- NRS 048: Quality of supply
- SANS 507 / NRS 034: Guidelines for the provision of electrical distribution networks in residential areas
- SANS 10142: The wiring code of premises

2.3.4 **NRS 048: Quality of supply**

NRS 048, especially Part 2, deals with the quality of supply voltage and frequency requirements for electricity networks in South Africa. NRS 048 is also referenced by the Grid Code and the criteria highlighted for the Grid Code are not repeated here again.

2.3.5 **SANS 507 / NRS 034**

NRS 034 [3] defines the network voltage drop calculation methodology in use at present in South Africa for low voltage installations through application of the Herman-Beta voltage drop method. This method uses a beta distribution curve with α and β parameters, an ADMD (kVA / household) and the limiting circuit breaker current rating (defined by the symbol c). ADMD can be related to the mean and standard deviation of a Beta distribution curve. The Beta distribution curve was found through research by Gaunt et al [27] to be representative of the distribution of currents along a feeder during network peak periods.

The equation set is as follows, based on the work by Gaunt, Herman et al [16], [3], to derive the *α* and *β* parameters from the ADMD and the circuit breaker size:

$$p(x) = \frac{x^{\alpha-1}(1-x)^{\beta-1}}{\int_0^1 x^{\alpha-1}(1-x)^{\beta-1}dx} \qquad \dots(26)$$

$$\alpha = \frac{\mu\left(c\mu-\mu^2-\sigma^2\right)}{c\sigma^2} \qquad \dots(27)$$

$$\beta = \frac{(C-\mu)\left(C\mu-\mu^2-\sigma^2\right)}{C\sigma^2} \qquad \dots(28)$$

$$\sigma^2 = c^2\frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)} \qquad \dots(29)$$

$$\mu = c\frac{\alpha}{\alpha+\beta} \qquad \dots(30)$$

Eskom describes ADMD in their Electrification Load Forecasting Planning Guideline [10] as follows:

$$ADMD = c\frac{\alpha}{\alpha+\beta}\times\frac{230}{1000} \qquad \dots(31)$$

Where:

p(x)= Beta probability distribution curve, with x between 0 and 1

c = Circuit breaker size, in ampere, provided as input

μ = Statistical mean (ADMD current) in ampere, provided as input. When multiplied with the nominal voltage per phase, i.e. 0.23 kV in the case of South Africa, it gives the ADMD in kVA.

σ^2 = Statistical variance (*σ* = standard deviation)

α, β = Beta distribution function parameters. If α < β, then load distribution along a feeder is left skewed. If α > β, then it is right skewed. Where α = β, a Gaussian distribution curve is obtained with the ADMD current equal to the mean, mode and median.

Substituting equation 30 into equation 31, the ADMD in kVA may be written as:

$$ADMD = 0.23\,\mu \qquad \dots(32)$$

A typical Beta distribution curve is as follows for c = 60 A. The curve indicates the probability that a consumer will draw a specific current. It can also be interpreted that at a given time, a probability plot of customers with the currents they draw, will represent the Beta distribution curve.

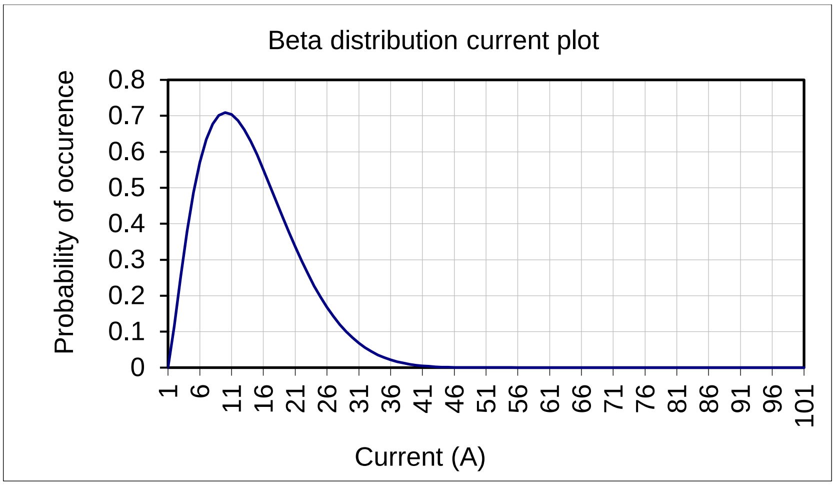


Figure 2-11: Example of a beta distribution curve that is left skewed

This curve can be applied to a group of consumers by multiplying the probability of occurrence with the number of consumers under consideration. This will provide the number of consumers drawing a specific current.

Ferguson [10] describes the shape of the dispersion at peak times as wealth-related. Poor consumers will have a high standard deviation $\sigma > 1$ per unit of mean (μ), while wealthy consumers approach 0.5 per unit of mean.

NRS 034 further provides a formula for determining the capacity required by a group of consumers based on the Central Limit Theorem [3], [28].

$$MD = 0.23 \times n \times \frac{c}{\alpha+\beta}\left[\alpha + 1.28\sqrt{\frac{\alpha \times \beta}{n(\alpha+\beta+1)}}\right] \quad \text{... (33)}$$

Where:

MD =	Maximum demand in kVA
n =	Number of consumers on heaviest loaded phase (see note in NRS 034)
α, β, c =	Beta probability curve parameters

Equation 33 includes a 10% risk (90% confidence level), represented by the value 1.28 for an infinite number of degrees of freedom, calculated using published tables for Student's[5] *t*-distribution [28]. For different values of confidence, a different value must be selected, e.g. a 95% confidence level will result in the 1.28 being replaced by 1.65.

Although this formula compensates for lack of diversity for a reduced number of consumers, NRS 034 cautions that this formula is generally not suitable for fewer than 10 consumers per phase.

NRS 034 [3] recommends the following values for the Herman-Beta voltage drop method:

Table 2-6: NRS 034-recommended Herman-Beta parameters for various income classes for residential load estimation – 15-year forecast values [3]

Consumer class	**Living Standard Measure**	**α**	**β**	**c (A)**	**ADMD (kVA)**
Rural settlement	LSM1	0.35	2.88	20	0.50
Rural village	LSM1&2	0.48	2.13	20	0.84
Informal settlement	LSM3&4	0.91	8.80	60	1.30
Township area	LSM5&6	1.22	5.86	60	2.37
Urban residential I	LSM7	1.25	3.55	60	3.59
Urban residential II	LSM7&8	1.42	4.10	80	4.72
Urban township complex	LSM8	1.42	4.13	80	4.70
Urban multi-storey estate	LSM 8	1.37	3.39	80	5.30

NRS 034 indicates that these parameters are for the interior of South Africa. Where cold wet winters are found, as in the case of the Western Cape, ADMDs are approximately 12% higher. For coastal areas similar to the climate of Durban, the ADMD can be 12% lower. With a different ADMD or circuit breaker size, the α and β values will be different.

[5] Student was the pseudonym for William Sealy Gosset (1876–1937)

2.3.6 **NRS 097**

NRS 097-2-1 [29] mainly focuses on small scale embedded generation within a utility and attempts to regulate the connection of small scale embedded generation to the distribution network. Small scale is defined as smaller than 100 kW and is connected at the LV level. The document does not have the status of a national standard. It mainly describes metering arrangements, earthing and synchronization requirements. It does not provide any further information applicable to this study.

NRS097-2-3 [30] sets simplified connection criteria for low voltage connected generators for households with a Living Standard Measure (LSM) larger than 7. These criteria attempt to limit the amount of PV that a utility should allow on feeders (refer to Figure 2-12).

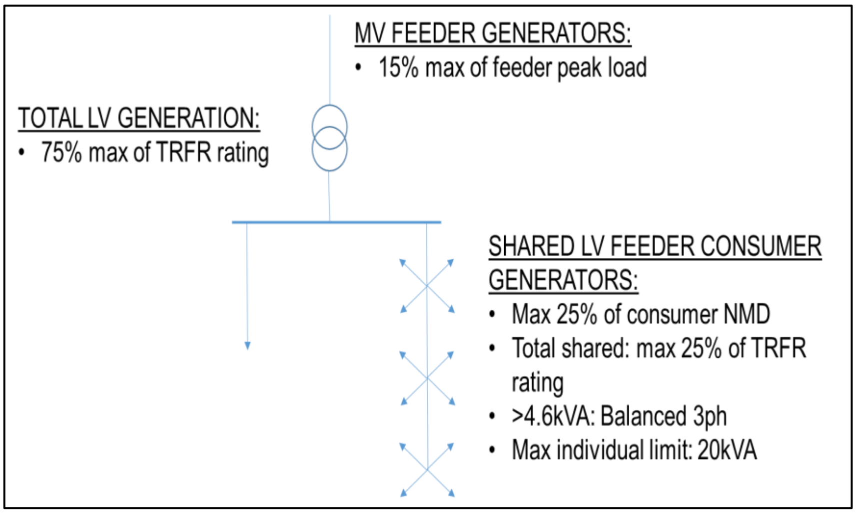


Figure 2-12: NRS097 proposed limits of embedded generation (based on values contained in [30])

General NRS 097 requirements are:

- Generally, generator sizes should be limited to less than 350 kVA.
- The LV fault level of the customer must be larger than 210 A.
- The total DG that is supplied by a MV feeder should be restricted to 15% of the feeder's peak load.
- The total DG connected to a MV/LV transformer should not exceed 75% of the transformer rating.

For shared LV feeders, the requirements are:

- The individual generator size should be limited to approximately 25% of a customer's NMD.
- The maximum generator size a customer can connect to a shared LV feeder, is 20 kVA. Larger than 20 kVA connections require a dedicated LV feeder.
- Any generator larger than 4.6 kVA must be a balanced three-phase system.
- The total limit of DG to be connected to shared LV feeders should be limited to 75%.
- Connections to DG that does not supply load will be on dedicated feeders.

The requirements as outlined above are summarized in Table 2-7.

Table 2-7: Allowable LV DG connections (individual limits) [29]**,** [30]

Phases	Circuit breaker size of service connection (Ampere)	NMD (kVA)	Maximum DG size that can be connected at unity power factor (kVA)
1	20	4.6	1.2
1	60	13.8	3.68
1	80	18.4	4.6
3	60 or 80	41.4	13.8 (4.6 per phase)

For dedicated LV feeders, the criteria are:

- DG connected to dedicated LV feeders from a transformer, is limited to 75% of the transformer's capacity.
- The dedicated LV feeder size should be limited so that voltage rise between the DG generator and the transformer LV busbars do not exceed 1%.

NRS097-2-3 [30] also states that larger connections can be allowed, but will be subject to further studies.

Considering the abovementioned limits imposed by NRS 097 if the limits are applied to each transformer zone on a MV feeder, the 15% limit for the MV feeder will be exceeded. Although NERSA requires utilities to maintain a database of all small-scale DG connected to the distribution network, consumers more than often simply install solar rooftop PV panels without consulting or informing the utility. This aspect was investigated by means of simulations to indicate what impact may be experienced, and is discussed in Chapters 3, 4 and 5.

2.3.7 **SANS 10142**

SANS 10142 consists of two parts: Part 1, covering the low voltage networks on premises, and Part 2, covering the medium voltage networks on premises. A Part 3 is envisaged, which will regulate DC distribution. DC distribution is used typically with solar PV plants between the PV panels and the inverters. At the time of preparing this dissertation, it had not been published.

SANS 10142-1 [31] defines mostly the requirements for the low voltage wiring of a premises. Diversity factors for groups of consumers on premises are provided over and above the technical requirements for design and wiring of electrical reticulation on premises, such as a block of flats or a cluster housing development (refer to Table 2-8).

Table 2-8: SANS 10142-1 Coincidence factors for residential units [31]

Units per phase	**Coincidence factor**	**Units per phase**	**Coincidence factor**
1	1.00	9	0.46
2	0.72	10	0.45
3	0.62	15	0.42
4	0.57	20	0.40
5	0.53	30	0.38
6	0.50	40	0.37
7	0.48	50	0.36
8	0.47	100	0.34

In SANS 10142, these factors are incorrectly referred to as diversity factors. Coincidence is smaller than 1, while diversity factors are larger than 1.

SANS 10142 also describes a method for neutral current unbalance calculation, and provides multiplication factors for use when calculating voltage drop. The formula for voltage drop published in SANS10142-1 is:

$$V_d = \frac{F_v \times I \times (R\cos\theta + X\sin\theta) x\ L}{1000} \qquad \text{... (34)}$$

Where

V_d = Voltage drop, in volts

F_v = Multiplication factor for unbalance correction (see table 2-9)

I	=	Current, in amperes
L	=	Length of conductor / cable, in metres
R	=	Resistance of conductor, in ohms per kilometre
X	=	Reactance of conductor, in ohms per kilometre
θ	=	The phase angle of the load (power factor = cos θ)

Table 2-9: Neutral unbalance multiplication factors for calculating volt drop (refer to [31] **Table E3)**

Type of supply and mode of connection	**Multiplication factor F_v**
Direct current load across two conductors	2
Single-phase load between phase and neutral	2
Single-phase load between two phases only	2
Balanced three-phase load on all three phases, neutral unconnected	1
Three identical single-phase loads, one between each phase and connected neutral	1
Unbalanced loads between all three phases and connected neutral:	
a) Unbalanced < 75%	1
b) Unbalanced > 75%	2
Unbalanced loads between all three phases and unconnected neutral:	
a) Unbalanced < 75%	1
b) Unbalanced > 75%	1.2

2.3.8 Planning Guidelines - overview

Distribution Network Planning in South Africa is guided by the following documents:

- Guideline for Human Settlement Planning, volume II [8]
- DGL 34-431 Eskom Methodology for Network Master Plans and Network Development Plans [2]
- DGL 34-1284 Geo-based Load Forecast Guideline [20]
- DGL 34-450 Network Planning Reliability Guideline [32]

Although the Reliability Planning Guideline contains critical information when compiling master plans, it does not contain planning parameters applicable to this study and will not be discussed further.

2.3.9 **Guideline for Human Settlement Planning**

The Guideline for Human Settlement Planning [8], or sometimes referred to as the “Red Book”, provides a section on Grid Planning and Off-grid planning. It uses certain definitions for consumer classes as defined in NRS034 and an ADMD discussion already touched on in earlier parts of this dissertation.

This guideline further provides two tables that relate consumer classes to annual consumption, load density, load factors and ADMD:

Table 2-10: Consumption classes (refer to [8] table 12.1.1)

Consumption Class	Approximate final loading and design ADMD (kVA)	Approximate annual load factor (%)	Approximate kWh per annum
Very High	>6	>42	>22 000
High	3 to 6	35-42	9 200 to 22 000
Medium	1.5 to 3	31-35	4 100 to 9 200
Low	0.5 to 1.5	29-31	1 200 to 4 100
Very low	≤ 0.5	28-29	< 1 300

The guideline states that for the very high consumption class listed above, load management may be implemented, which would influence the ADMD.

Eskom has published the same table [10], but with different values:

Table 2-11: Consumption classes (refer to [10] table 3)

Consumption Class	Approximate final loading and design ADMD (kVA)	Approximate annual load factor (%)	Approximate kWh per annum
Very High	6 to 9	30 to 45	>19 000
High	3 to 6	25 to 35	7 500 to 19 000
Medium	1.5 to 3	20 to 30	3 000 to 7 500
Low	0.5 to 1.5	15 to 25	1 200 to 3 000
Very low	≤ 0.5	10 to 20	< 1 200

A further useful planning table is provided in the Guideline for Human Settlement Planning, which considers load density. Eskom agrees with this table [10].

Table 2-12: Domestic density classification ([8] table 12.1.2, [10] table 4)

Domestic density classification	Stand size (m^2)	Average load density (kW / km^2)
Urban		0.5 ≤ ADMD ≤ 4.5
High density	< 1000	400 to 30 000
Medium density	1 000 to 4 000	300 to 5 000
Low density	4 000 to 20 000	100 to 1 500
Rural	> 20 000	0.5 to 250

2.3.10 **Parameters for non-domestic load**

SANS 204 [33] details energy efficiency requirements in non-domestic buildings and lists maximum demand and energy per annum. Below are average demand values (maximum per month summed over 12 months, divided by 12).

Table 2-13: Maximum energy demand per building classification for each climatic zone ([33] **table 1)**

Classification of occupancy of building	Description of building	Maximum energy demand[a] VA/m^2					
		Climatic zone[b]					
		1	2	3	4	5	6
A1	Entertainment and public assembly	85	80	90	80	80	85
A2	Theatrical and indoor sport	85	80	90	80	80	85
A3	Places of instruction	80	75	85	75	75	80
A4	Worship	80	75	85	75	75	80
F1	Large shop	90	85	95	85	85	90
G1	Offices	80	75	85	75	75	80
H1	Hotel	90	85	95	85	85	90

[a] The maximum demand shall be based on the sum of 12 consecutive monthly maximum demand values per area divided by 12/m^2 which refers to the net floor area.

[b] The climatic zones are given in annex A.

It must be noted that the maximum demand stated above is an annual average maximum demand, and not the maximum to be expected in the year.

SANS 204 also lists the target energy consumption per m^2 per year, as per the table below, with a footnote that any fossil-fuel non-electrical consumption should be converted to an electrical equivalent. This statement implies that any energy generated by another energy source will potentially distort the load factor calculation if not accounted for.

Table 2-14: Maximum annual consumption per building classification for each climatic zone in South Africa ([33] **Table 2**

Classification of occupancy of building	Description of building	Maximum energy consumption[ab] kWh/m^2					
		Climatic zone[c]					
		1	2	3	4	5	6
A1	Entertainment and public assembly	420	400	440	390	400	420
A2	Theatrical and indoor sport	420	400	440	390	400	420
A3	Places of instruction	420	400	440	390	400	420
A4	Worship	120	115	125	110	115	120
F1	Large shop	240	245	260	240	260	255
G1	Offices	200	190	210	185	190	200
H1	Hotel	650	600	585	600	620	630

[a] The annual consumption per square metre shall be based on the sum of the monthly consumption of 12 consecutive months.

[b] Non-electrical consumption, such as fossil fuels, shall be accounted for on a non-renewable primary energy thermal equivalence basis by converting mega joules to kilowatt hours.

[c] The climatic zones are given in annex A.

SANS 204 annual demand values are achievable with enough effort (and the client's budget) and incorporated into the design. However, the energy consumption targets are difficult to achieve.

2.3.11 **DGL 34-431 Eskom Methodology for Network Master Plans and Network Development Plans**

Following on the earlier introduction in Paragraph 2.1, the Eskom methodology for Network Master Plans and Network Development Plans [2] also describes the demand forecast and growth calculation processes.

The saturation demand forecast and the growth rate are key components of the Eskom planning process and define how much capacity will eventually be required. The saturation demand is derived by considering various load classes and their respective load profiles at a lower level. Since load growth is not uniform across a planning area, the load forecast is further derived through a geographic approach. The Geographic Load Forecasting (GLF) method employed by Eskom is discussed in the next section.

The process makes use of ADMD values and load profile shapes per load class at the lowest level chosen by the planner. Usually, the lowest planning level is selected as MV feeder level, as MV feeder load readings as a base are available, but it can be taken as low as erven level. An MV feeder is still made up of the composite load of various load classes. It is critical to understand that appropriate ADMD values must be applied to the load profile shapes. The ADMD of a residential area for instance is much lower at MV feeder level than at LV feeder or distribution transformer (MV/LV transformer) level. No diversity values are explicitly stated or used as input parameters by the GLF tool, as loads are mathematically and geographically summated using the base values provided from MV feeder level to substation level to HV feeder level to Main Transmission Substation (MTS) level, assuming that the MV feeder was the lowest level used. GLF makes provision for a scaling factor, which can be applied to adjust for diversity between hierarchy items (e.g. feeders, substations, load zones).

2.3.12 **DGL 34-1284 Geo-based Load Forecast Guideline**

Eskom has compiled a Geo-based Load Forecast Guideline [20] that explains the approach. The guideline states that geo-based load aggregation is much more accurate than using diversity or coincidence factors. While this is true, based on experience, geo-based load aggregation methods take long to populate, and quicker methods based on diversity or coincidence factors are still considered when a geo-based load aggregation study cannot be performed.

Various load forecast methods are listed in the Eskom guideline. Since the future saturation load value is not always known, a combination of these methods must be deployed to forecast the future load. Very often, only the base value (present load), the boundaries of the forecast area and the forecast method is required to estimate the future load. Some of these methods are:

- Land use-based forecast, which uses a saturation value per unit of land, for instance 40 kVA per hectare for residential load. Usually, an S-curve growth rate is applied to a base value, with a specified growth rate and saturation period. Land use for master planning purposes is obtained from spatial development frameworks compiled by municipalities and serves a long-term purpose. Therefore, basing the load forecast on proposed future land use is relatively safe as the envisaged land use and density will not vary. Master plans should be reviewed every five years, and should future land use requirements change, the master plan can be adapted. A change in land use will change the future saturation load.

- Customer-based forecast, which uses a kVA per customer basis. These ADMD values can be measured from existing data, or must be calculated. Usually, an S-curve growth rate is applied to a base value.

- Percentage growth - This is usually a fixed percentage per year, which provides an exponential growth pattern.

- Custom defined growth curve.

- Trending (curve fitting).
- Fixed increment - This adds a fixed demand value per year, and provides a straight-line growth approach. The value in kVA added every year to the previous year's load is the same for every year.

2.4 Impact of historic EEDSM initiatives

In a paper [1] investigating among other things the impact that ripple geyser control can have on ADMD, the ADMD increased by approximately 11% in the particular case that was studied. This increase may cause designed networks designed near the limit of operation to violate voltage regulation limits and cause conductors to be overloaded.

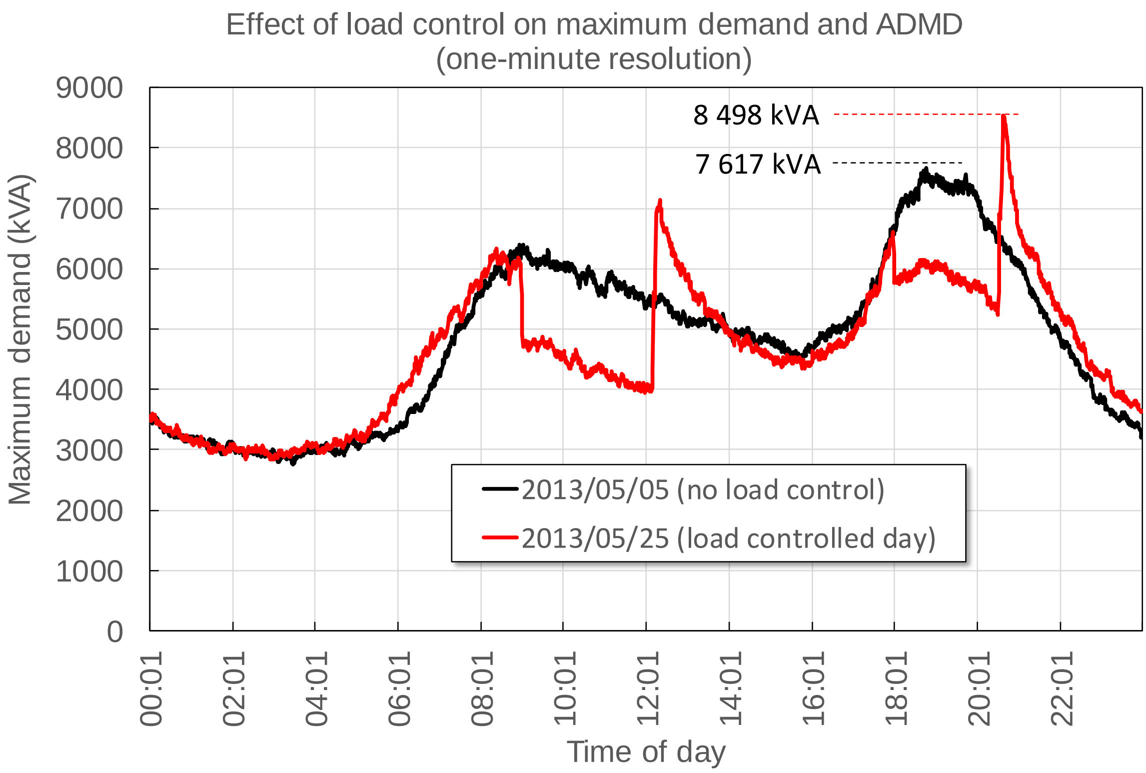


Figure 2-13: Effect of ripple control on maximum demand and ADMD [1]

Celli, Gaunt et al [16] reported that an Italian utility recommended an increase in 25% of the ADMD when planning networks that will have load control present.

Generally, cold-pickup load in demand-controlled networks with load of a thermal nature, such as hot water geysers, refrigerators, freezers etc., may cause the peak demand to increase drastically if control algorithms are not designed to restore load over a longer period, in other words to reduce the demand (see figure 2-13).

2.5 **Distributed generation**

2.5.1 **Overview**

Distributed generators can be connected at various grid locations. Figure 1-3 shows generators connected to the HV, MV and LV networks. Large scale solar and wind farms, for example 100 MW, will be connected to the HV network, while smaller systems such as 2 MW systems can be economically connected to the MV network. Small systems under 1MW are connected to LV networks.

A DG system typically has the following components:

- Energy generation (e.g. solar PV panels, wind turbine)
- DC to AC converter
- Optional storage, such as batteries
- Control system

Generators connected to the distribution network are referred to as distributed generation (DG), or embedded generation. The most common form of distributed generation is the solar photo voltaic (PV) panels mounted on rooftops. This type of system can be off-grid or grid-tied. Off-grid systems are typically found in areas where grid electricity is not available, such as deep rural villages. Where installations have access to grid electricity, grid-tie inverters are required to connect the solar PV to the local distribution system of a facility. Depending on how the inverter is configured, excess power may flow back into the grid.

The RPP Grid Code [26] requires that RPPs be equipped with control functions for categories A3, B and C. The Code stipulates the following:

- Unity power factor for categories A1 and A2.
- Voltage controlled mode (categories B and C). During voltage control, the reactive power is varied proportional to the voltage.
- Frequency control (category C only). The RPP must be able to respond to high and low frequencies according to rules outlined in the Grid Code.
- Q control (categories B and C). During Q control (also referred to as reactive power control), the reactive power is kept constant irrespective of the voltage or the active power.

- Power factor control (categories B and C). During this mode of control, the reactive power is controlled proportional to the active power so that a constant power factor is achieved at all values of active power.
- Production control modes:
    - Absolute production constraint (categories A3, B and C): This is used to limit the production output of the RPP.
    - Delta production constraint (category C): Production is limited proportional to the possible active power.
    - Power gradient control (categories A3, B and C): This form of control limits the rate of change of RPP production to changes in setpoint or available energy.

For categories A3, B and C, RPPs are required to control according to one or more of the modes discussed above.

This dissertation focusses on the LV domestic part of the network, and will therefore consider category A1.

2.5.2 **European case study**

A study conducted by DERlab [34] indicates the level of DG for various countries in terms of penetration and size. Consider the following extracts from this study:

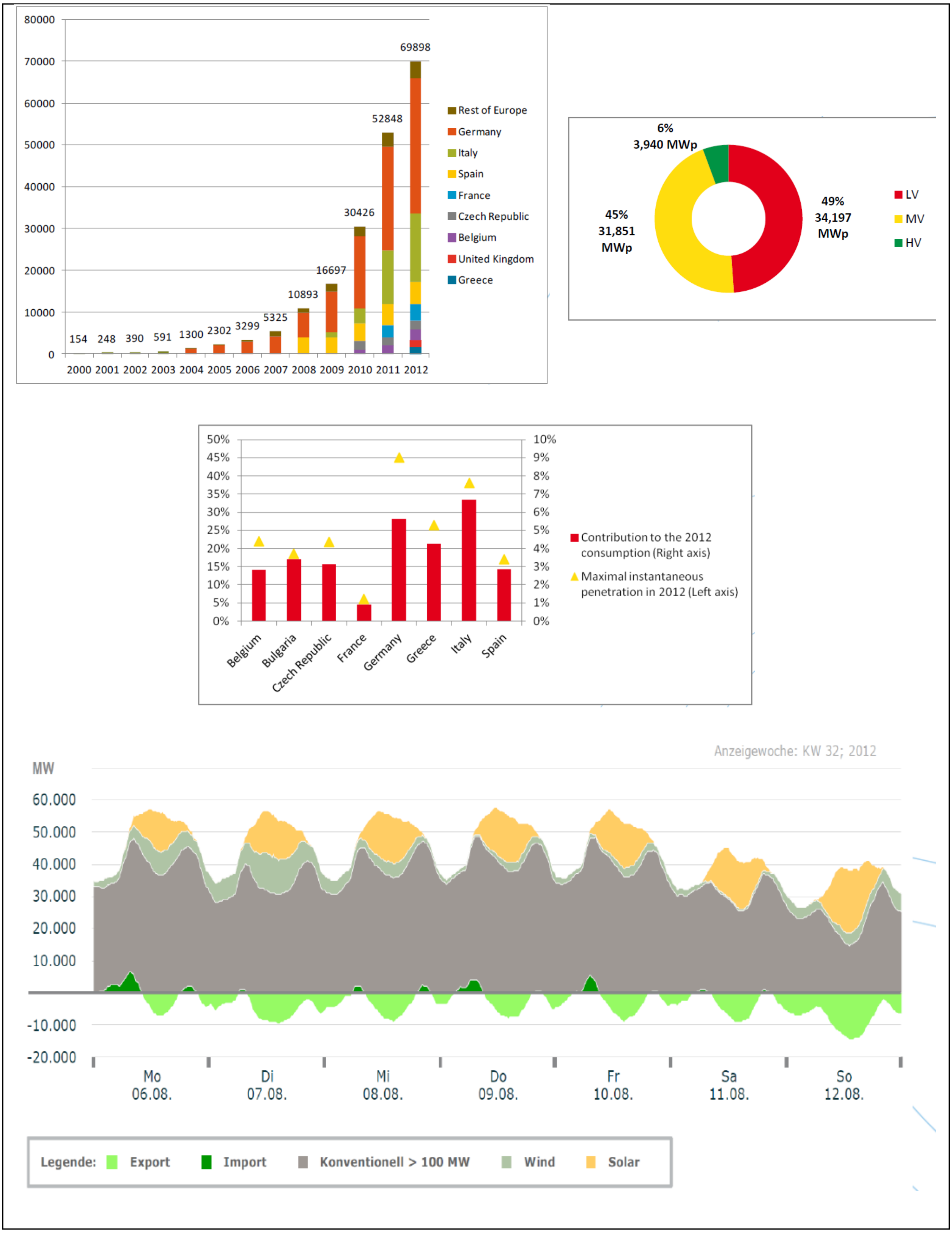


Figure 2-14: Figures 1,3, 4 and 6 of Derlab Study indicating solar PV expansion per year per EU country, network connectivity, penetration levels and German export scenario respectively [34]

Figure 2-14 illustrates the rapid growth experienced in the European Union. It is clear that Germany and Italy have the most installed PV capacity, of which approximately 49% is connected to the LV networks and 45% to the MV networks. Although PV only contributes 5% of the generated capacity, the penetration level reaches 40%. In the Bayern region in Germany, 10 GW of electricity is generated through PV. On 12 August 2012, Germany exported 40% of its base load generation to other countries, as it had an excess of base load once the PV and wind load was utilized at local levels. The Derlab study further referenced a grid study, compiled by Dena on the German grid, estimating that Germany in certain scenarios will have to invest approximately €42billion between 2012 and 2030 to reinforce its network to deal with reverse power flows.

The proportion of the networks in the European case study consisting of LV renewable energy generation illustrates that it is necessary to ensure that South African utilities catch up in time to ensure networks can cope with such levels of penetration.

2.5.3 **Benefits of introducing DG**

Consumers providing their own DG will reduce their utility bills and reduce the demand required by utilities to service their consumer loads. Balamurugan et al [35] proved through simulation that losses are reduced since less current will flow through the distribution network.

2.5.4 **Grid problems introduced by DG**

Studies by DERLab [34] and Balamurugan et al [35] found that the problems typically experienced by networks with DG connected are:

- Voltage rise
- Network feeder and transformer congestion
- Potential increased harmonics
- Increased fault level
- Increase in unbalance if single phase injection is done on LV feeders
- Power factor worsens

Apart from the issues listed above, there are more issues, namely safety concerns, billing and metering, as well as grid stability, but these issues are beyond the scope of this dissertation.

Voltage rise

Voltage rise occurs when the local connected load is less than the local generated capacity. The excess energy is supplied back into the grid (reverse power flow). When the feeders are long, the voltage rise can cause a violation of the upper voltage limit set by power quality standards

(NRS048 in the case of South Africa, EN50160 in the case of the EU). In South Africa, as with most EU countries, the LV voltage regulation is 90% < V_{nom} < 110%. Furthermore, MV/LV transformers have fixed taps and cannot adjust to compensate for voltage rise. On HV networks, the voltage regulation is 95% < V_{nom} < 105% and tap changers are available.

Suppose that a tap-changer for a HV/MV transformer has 17 taps with tap 5 being the nominal tap. There is a possibility that this tap-changer cannot reduce the voltage within voltage regulation limits when the voltage rises due to excess MV and LV grid-tied generators.

Congestion

Congestion occurs when the feeder or transformer is not rated for the current that flows through it. With high PV penetration and high PV sizes, there is no diversity in reverse power flows and feeders are generally designed with diversity in mind during peak periods. The level of reverse power flow combined with high penetration can cause a peak in the reverse direction in excess of the peak the network was designed for in the forward (traditionally normal) power flow direction.

Harmonics

Although harmonics is more of a power quality issue than an issue affecting maximum demand, this study investigates the contribution of harmonics to the maximum demand. If an increase in harmonics increases the maximum demand, it means that the ADMD has increased. An increased ADMD could mean that a system design no longer complies with its design conditions.

A study by Arghandeh et al [36] offer a few conclusions relating to harmonics, phase angle and phase balancing:

- Distortion caused by harmonic sources cause deviations in phase angle. The deviations in phase angle can either increase or decrease the harmonics in the network.
- Phase balancing can help reduce harmonic distortion. It follows that unbalance will increase harmonic distortion.
- Current harmonic distortion increases closer to the substation, while voltage harmonic distortion increases closer to the loads.

A guide developed by Leonardo Energy [37], an initiative managed by the European Copper Institute, indicates that electronics increase voltage harmonic levels at the point of connection even though electronics provide advanced system support capabilities.

Farhoodnea et al [38] indicate that harmonic distortion can increase the risk of parallel and series resonance and cause capacitor banks and transformers to overheat. It may also cause maloperation of protection devices. This study further shows that the severity of parallel resonance is increased with increased levels of penetration.

There is very little indication in the literature that harmonics contributes adversely to the maximum demand. The issues found in the literature are related to power quality issues.

Fault level

The fault level increases with the addition of generators connected to a network. This holds true for generators connected to the transmission system and the distribution system. The fault contribution of a typical diesel generator is generally accepted as three times the running current, while for a solar PV plant, the fault current is limited by the inverter power electronic components. Balamurugan et al [35] indicate that the short circuit current of a solar PV plant is not more than twice the rated current of the inverter.

In a distribution system with a connected PV array, current will be drawn from the PV array and the grid during a network fault. This reduces the fault current seen by protective devices on the upstream grid network. The possibility exists that fault currents are masked by DG plant and may not operate as supposed to. Grid-tied DG controllers and inverters are supposed to disconnect within a very short time (200ms) according to the Grid Code [26] to prevent them from unintentional islanding.

As a rule of thumb, the fault current must be more than twice a circuit breaker rating, or 1.6 times the fuse rating for the protective device to operate fast enough in the event of a fault. If the fault current is too low, it may be construed as load and could take a while to operate. It is often said in protection circles that more than three seconds becomes an eternity during which damage to equipment can occur.

It can also happen that the presence of DG causes previously coordinated protection devices (prior to the installation of DG) to lose coordination. Consider the scenario in the diagram below from a study by Sarabia [39] where a fault occurs on a MV feeder where a recloser is present, as well as a fuse on T-off section. Sarabia explains that during a fault near Load 3, the fault current flowing through the recloser is contributed to only by the substation. The fault current drawn from the DG source will not flow through the recloser. However, current from the substation and the DG system will flow through the fuse. In Sarabia’s opinion, this may cause the fuse to blow instead of the recloser to trip.

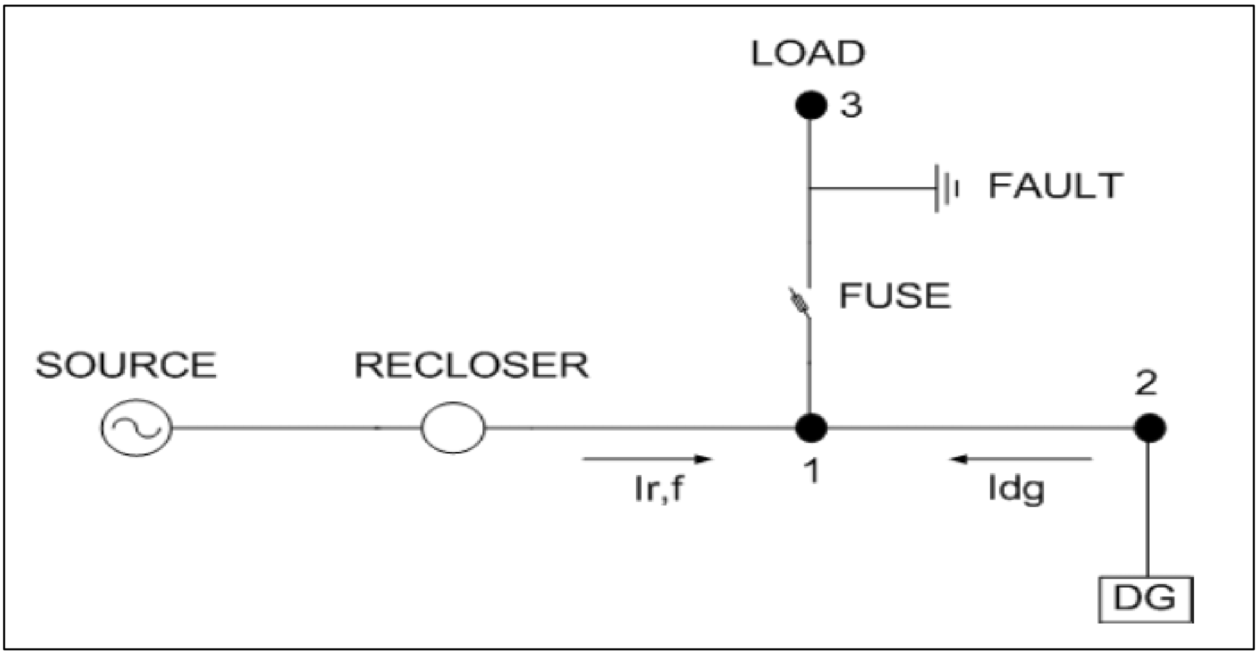


Figure 2-15: Fault currents during a fault with DG present [39]

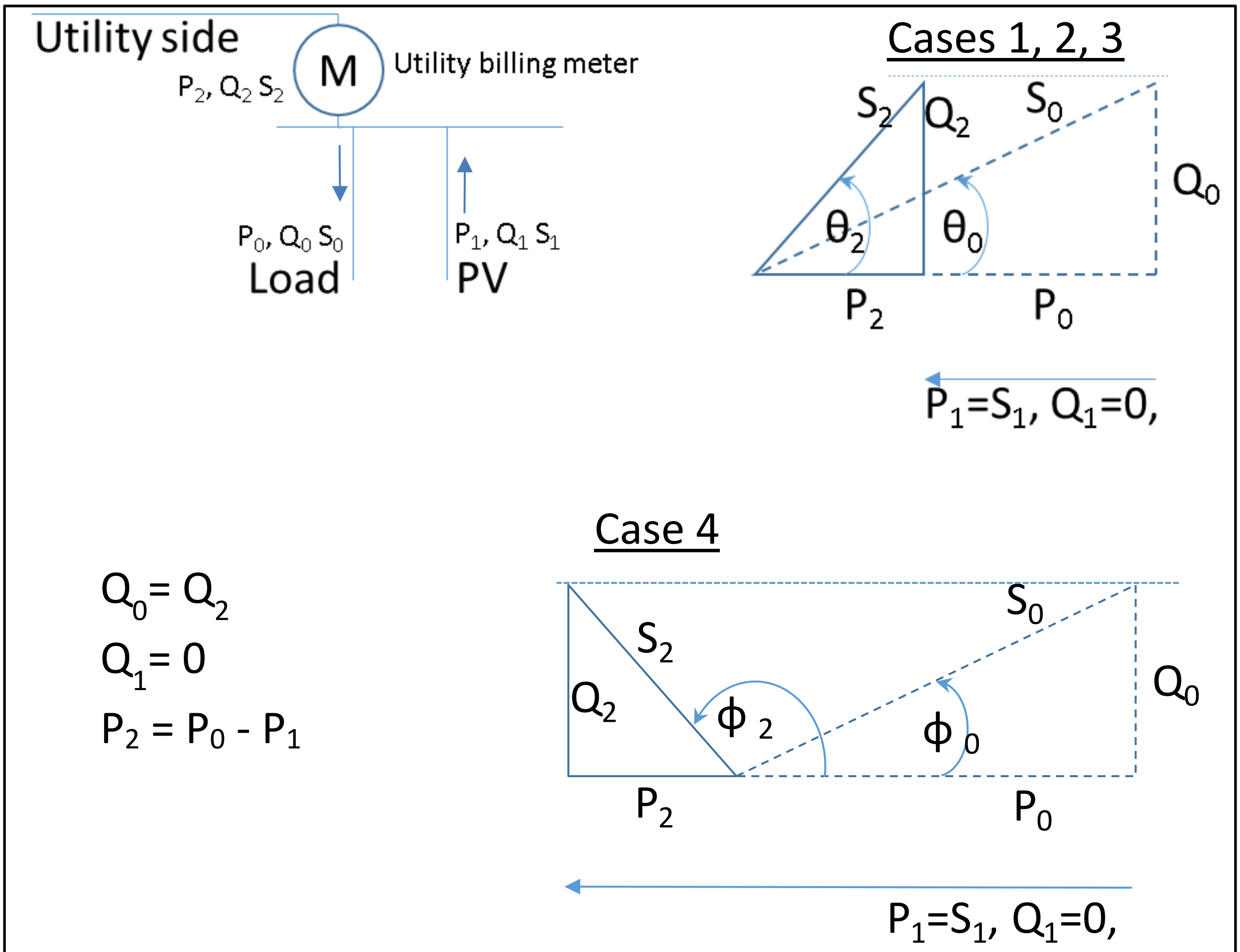
In the event that the recloser trips as it should and the DG does not disconnect from the grid, it may reclose onto a live system, since the DG may still be active. The DG system will most likely be damaged if synchronization does not take place.

Farhoodnea et al [38] indicate that unintended islanding of parts of the grid may occur at the time of a fault, during which time the DG may carry on feeding the faulted network.

Power factor

When DG is connected to the network at unity power factor, it reduces the active power provided by the utility, but the reactive power stays the same. This implies a worsening of the power factor. This is typical in the case of RPPs categorized as category A1 and A2 according to the South African Grid Code [26].

If for instance an installation can generate 100% of the real power it requires through PV and storage, the utility will be left with providing only the reactive power. In a domestic installation, this means that the utility earns no revenue through selling active power (kWh), but must still maintain networks and provide the reactive energy (kvarh) and resulting demand (refer to Figure 2-16).



Case No.	Case	Scenario	P (kW)	Q (kvar)	S (kVA)	Power factor
1	750 kW DG Commercial	Before DG	800	140	812	0.99
		After DG	50	140	149	0.34
2	9 kW DG Residential	Before DG	10.0	1.4	10.1	0.99
		After DG	1.0	1.4	1.7	0.57
3	3 kW DG Residential	Before DG	5.3	0.8	5.4	0.99
		After DG	2.3	0.8	2.4	0.95
4	9 kW DG Residential	Before DG	6.0	0.9	6.1	0.99
		After DG	-3.0	0.9	3.1	0.96

Figure 2-16: Effect on power factor through active power DG generation

Figure 2-16 shows an example with calculations for four cases. In each case, the DG system generates active power only. The reactive power must be provided by the utility. The power factor, as seen by the utility, is reduced in all instances.

Balamurugan et al [35] indicate that the inverters are normally set to operate at unity power factor. A study by Hung et al [40] shows that a proper dispatched system with control over active and reactive power control of optimally located PV can significantly reduce system losses and improve voltage stability, compared to DG at unity power factor.

The general problem with embedded DG is that it cannot be properly dispatched by a System Operator. A further problem, considering the requirements of the South African Grid Code, is that the Grid Code does not require categories A1 and A2 to have any reactive power generation, and it will be difficult to enforce this unless the Grid Code is amended. It may not be economically viable to deploy reactive power capable inverters for category A1 and A2.

2.5.5 **Impact of uncontrolled actions**

A study by Lacey et al [41] on electrical vehicle charging for the British environment found that uncontrolled charging of electrical vehicles may exceed thermal and voltage limits.

This dissertation draws a parallel to the work by Lacey by considering the uncontrolled penetration of DG. When DG is properly designed, its position and size can be influenced. However, a customer who simply connects his equipment to the grid without consultation with the utility does so in an uncontrolled manner, and may cause undesirable effects.

2.5.6 **Solutions proposed in the literature**

A study conducted by DERlab [34] listed and evaluated several solutions that may be deployed to cope with both MV and LV solar PV grid connected systems.

Effectiveness of solutions	Technical solution	CZ	DE	ES	IT
HIGH EFFECTIVENESS	Network Reinforcement	Green	Green	Green	Green
	Reactive power control by PV inverter Q(U) Q(P)	Red	Green	Red	Red
	Curtailment of power feed-in at PCC	Red	Red	Red	Red
	Active power control by PV inverter P(U)	Red	Red	Red	Red
	Network Reconfiguration	Green	Green	Green	Green
	SCADA + PV inverter control (Q and P)	Red	Red	Red	Red
	Advanced voltage control for HV/MV transformer	Green	Green	Green	Green
NORMAL EFFECTIVENESS	Static VAr Control	Green	Green	Green	Green
	SCADA + direct load control	Yellow	Yellow	Red	Red
	Self-consumption by tariff incentives	Green	Green	Yellow	Red
	Wide area voltage control	Yellow	Yellow	Green	Yellow
	DSO storage	Red	Red	Red	Yellow
	Prosumer storage	Red	Green	Red	Green
LOW EFFECTIVENESS	On Load Tap Changer for MV/LV transformer	Green	Green	Green	Green
	Booster Transformer	Green	Green	Green	Green
	Demand response by local price signals	Red	Red	Red	Red
	Demand response by market price signals	Yellow	Yellow	Yellow	Red
	Advanced Closed-Loop Operation	Grey	Green	Yellow	Grey

Table 10 - Effectiveness list of technical solutions for MV grids

Regulatory priority index - Legend
Adoption of solution requires regulatory development (Red)
Adoption of solution requires regulatory and technology developments (Yellow)
Technology is not mature (Grey)
Can be applied where problems occur (Green)

Figure 2-17: Proposed solutions by an European study [34], table 10

This guide points in the right direction, but does not give guidance on the impact on design and planning parameters.

2.6 Chapter summary

This chapter outlined the theory of planning and design parameters. A literature review on the impact of DG of MV and LV networks indicates that:

- Guidelines are provided to limit the impact on existing networks, e.g. NRS 097;
- There is no indication as to how planning and design methods should change, should the circumstances change; and
- Numerous papers have investigated some or other aspect of DG impact on distribution networks.

A study by Di Gangi et al [42] indicates that the “worries” of utilities about the impact of DG are exaggerated and that DG penetration levels will be limited by economic viability. However, the rising cost of electricity and a decreasing levelized cost of DG, will for the short to medium term not slow down. The difficulty in policing which devices customers connect to the grid inside their homes must be recognized and the impact of such actions should be considered.

Chapter 3 Analysis and modelling

3.1 Review of the findings from the literature study

Several references can be found in the literature, as examined in the previous chapter, speculating or predicting the effect some “green” measures may have on transmission and distribution systems. However, very little is known about the exact impact that energy efficiency and renewable energy has on our traditional planning and design methods. Literature indicates that voltage rise and fault levels increase at the point of renewable energy injection. It does not say how the design or planning in future should be approached. The question arises whether design and planning formulae should be adapted when DG is incorporated into the design. There is no indication in the literature that formulae should change.

In this chapter, a simulation approach is outlined to analyse the impact of “green” measures on design and planning parameters. This analysis can hopefully help to answer the research questions posted in Chapter 1. The term “green” measures are used collectively for energy efficiency, demand side management and renewable energy measures.

3.2 Review of research questions and basic approach

3.2.1 RQ4, 7, 8: Relationship between diversity and load factor, impact on ADMD and traditional diversity factors

Research questions 4, 7 and 8 are related to the load profile. The effects can be studied by evaluating many low voltage measurements at household level, or by simulating a load profile model based on appliance usage for a group of consumers. Due to the lack of sufficient low voltage measurements at household levels to generate profiles, it was decided to develop a simulation model and then vary the appliance profile or load parameters. Installing 500 data loggers was not deemed feasible. Downloading load profile data from smart metering installations covering each house on a large network (> 2000 houses) is not readily available either.

Appliance parameter variance may take on forms such as reducing the load for a more energy efficient approach, or omitting the appliance entirely when it is substituted with other forms of energy, for instance electric cooking versus cooking by gas. The effects can be studied by comparing a new resulting load profile to an original load profile and by calculating factors such as ADMD, load factor and diversity.

3.2.2 RQ5, 6, 9, 10: Solar PV impact on LV and MV network performance, system losses and fault levels

Research questions 5, 6, 9 and 10 can be evaluated by analyzing a network simulation or load flow model. A sample network was simulated in Digsilent Powerfactory. The effects can be studied by comparing a network simulation containing various penetration levels of embedded generation against a network containing none.

3.2.3 Approach summary

The basic approach for analysis is twofold, and this chapter deals with the design of the simulation for each of the following two approaches:

- Load profile simulation; and
- Load flow analysis.

3.3 Load profile simulation

3.3.1 General considerations

A load profile (e.g. 24-hour profile) for a MV feeder is the summation of MV/LV transformer profiles. A MV/LV transformer load profile is the summation of LV feeder profiles. An LV feeder profile is the summation of individual LV customer profiles.

Customer profiles, whether HV, MV or LV, consist of domestic and non-domestic profiles. A total load profile, as seen by a utility, is a composite profile consisting of the summation of domestic and non-domestic loads at the same time.

Individual domestic customer load profiles in turn are the summation of appliance loads associated per domestic household. This is a bottom-up approach, which allows for modification to appliances or their profiles to study the effect on the cumulative composite profile used when doing planning studies and designs.

An appliance load profile consists of load consumption over time. A typical 24-hour day load profile is considered. An hourly profile is considered too coarse for accurate modelling, and therefore 1-minute modelling is proposed. With a one-minute load profile, the nature of the use of appliances can be more accurately modelled, for example a kettle, which boils water for a few minutes. When viewed over an hour, the kWh value can only be related back to an average consumption over an hour, and does not give an indication exactly when during the hour the appliance was used in relation to other appliances.

Even if individual household LV load profiles were available, for example through smart metering technology, it is unlikely that one-minute profiles will be available due to the lack of storage space for such data.

A minute-based appliance model would consist of at least four dimensions, namely loads per appliance per household per 1440 one-minute timeslots (60 minutes x 24 hours). Such a four-dimensional array or matrix cannot be constructed in a spreadsheet since a spreadsheet can only represent a three-dimensional matrix (columns for time, rows for appliances and values for loads). It is therefore advisable to harness the multi-dimensional capabilities of Matlab.

A Matlab User Interface (UI) can display model input parameters, calculated parameters and graphs, as well as the adjustment of these parameters. The design of the user interface is not the objective of this study, and details of the user interface is attached in Appendix A. It is more important to focus on the algorithm, the validation of a base to compare with, and results obtained when varying the base profile with “green” measures such as replacing electric geysers with solar geysers.

3.3.2 **Load profile composition**

With a view of validation in mind, it is advisable to model both domestic and non-domestic load to obtain a composite load profile at utility scale or substation level. The shape of the profile will indicate whether the model provides a valid base to proceed. The shape of the calculated or simulated load must resemble a familiar shape obtained from metering data.

In essence, a typical 24-hour load profile on a one-minute basis consists of load per minute, which can be expressed as follows:

$$Total\ Load\ Profile_t = Domestic\ Load\ Profile_t + \ NonDomestic\ Load\ Profile_t \qquad \dots (35)$$

where

t =	timeslot per day (in minutes), represented by a value between 1 and 1440 for a 24-hour day
$Total\ Load\ Profile_t$ =	Composite load at time *t*,
$Domestic\ Load\ Profile_t$ =	Domestic load and time *t*

$NonDomestic\ Load\ Profile_t$ = Non-domestic load and time t

The concept of composite load profiles as the summation of individual load-class profiles is illustrated in Figure 2-3. The main focus though, is the domestic profile.

3.3.3 **Appliance load profile considerations**

When considering a large group of households, it is not possible to predict which household is using what appliance at any given time. There are simply too many parameters involved to predict it correctly. The average behaviour across a 24-hour day is similar and can be guessed for a large group of consumers

The probability that a certain household is using a certain appliance is somewhat random. However, it can most likely be assumed that a stove will not be used in the middle of the night when people are generally sleeping. Lights should not be burning during daytime. Some constraints or boundaries can therefore be set to limit the variables based on typical human behaviour, such as sleep and work patterns.

Even though it can be estimated when it is dinnertime for most households, it is still difficult to predict which household has an oven and/or stove switched on, or who has a refrigerator door open. The variation between households is still vested in random usage patterns between households. It is certain that a refrigerator door on a typical weekday will be opened when dinner is prepared. But exactly when, and exactly how many times, cannot be predicted. A household may be opening the refrigerator today at 17:37, and tomorrow at 17:45. Today the refrigerator door may be opened five times, and tomorrow seven times. There are similar uncertainties for each household. The uncertainties can be modelled using random numbers, such as selecting a random starting minute for an appliance within an hour.

3.3.4 **Algorithm to calculate a load profile based on appliances per household**

The algorithm to construct the household-appliance based model for a group of consumers of varying household sizes is as follows:

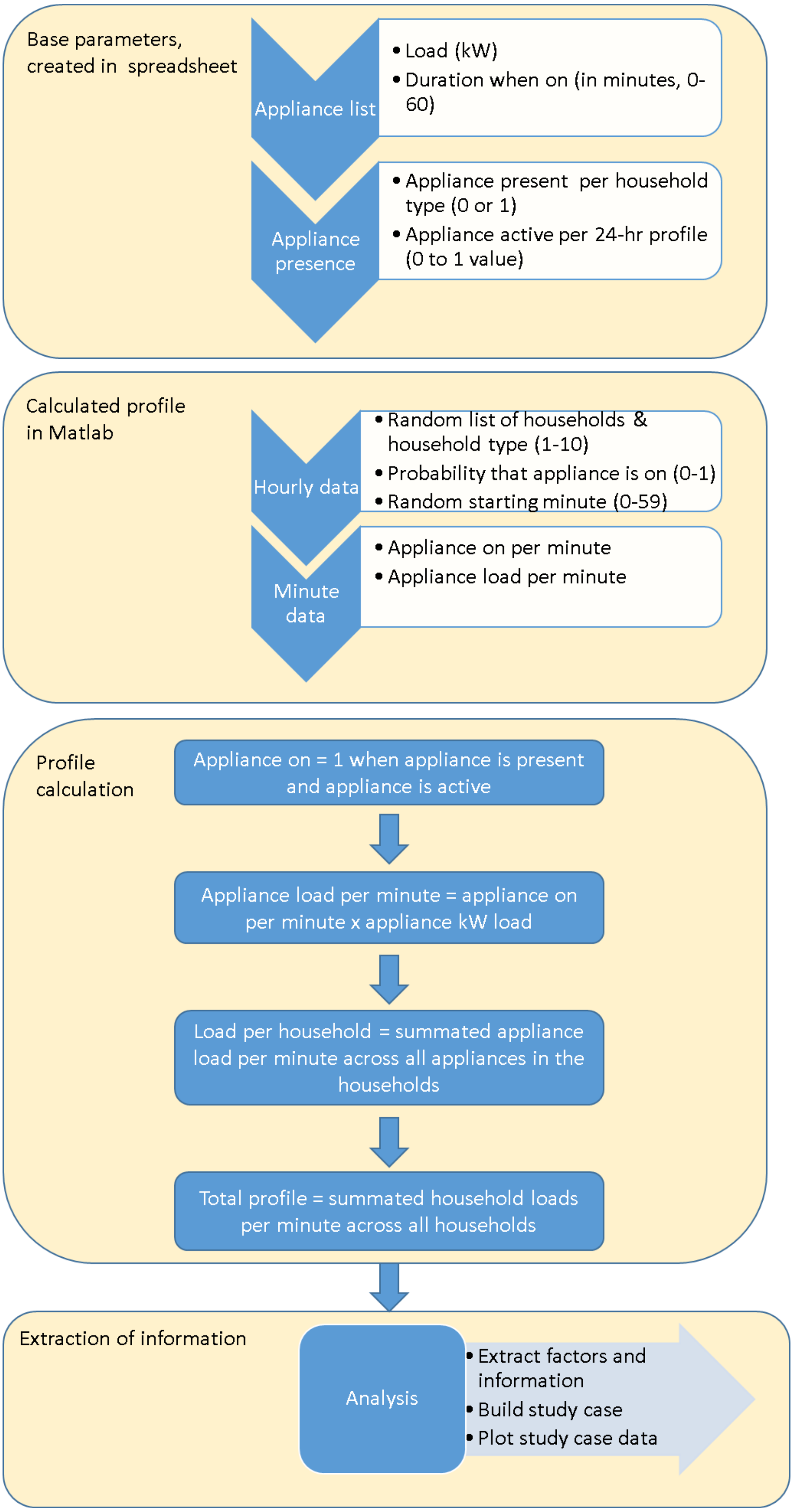


Figure 3-1: Load profile appliance-based model algorithm

3.3.5 Parameters that can be calculated from the constructed load profiles

It is possible to calculate ADMD, diversity (or its inverse – coincidence) and load factor from the load profiles of the individual households and the composite load profile.

The distribution of individual household currents as applicable at peak time can be demonstrated, which should reflect a beta distribution curve – the underlying load distribution model when using the Herman-Beta voltage drop method.

The relationship between various parameters can be demonstrated by plotting data from a case study database. A case study database is generated by calculating the load profile several times with the same set of parameters, where after the parameters are changed and the process repeated.

3.4 Matrices required to simulate the appliance model

The following key matrices have been defined to develop the load profile:

Table 3-1: Matrices / Vectors used in profile calculation

Description	Non-domestic load		Domestic load		Adjusted profile	
	Matrix / Vector name	Size	Matrix / Vector name	Size	Matrix / Vector name	Size
Base parameters						
List of appliances / Non-domestic load classes	NonDomestic_List	10 x 1	Appliance_List	35 x 1	-	-
kW value for each appliance or Non-domestic load	NonDomestic_Load	10 x 1	Appliance_Load	35 x 1	-	-
Duration of load in minutes, from 0 to 60. If the load duration is more than 60 minutes, 60 is selected	NonDomestic_Duration	10 x 1	Appliance_Duration	35 x 1	-	-
The season an appliance applies to, e.g. heaters are only used in winter.	NonDomestic_Season	10 x 1	Appliance_Season	35 x 1	-	-
Presence and activeness						
Presence of appliance per household type	NonDomestic_Present	10 x 10	Appliance_Present	35 x 10	-	-
Appliances active during specific hours of the day	NonDomestic_Active	10 x 24	Appliance_Active	35 x 24	-	-
Per household						
List of household types for each household in a group of households – random value	-	-	Households	N x 1	-	-
Probability that an appliance is switched on per household, random value	-	-	Appliance_Probability_On	35 x 24 x N	-	-
Starting minute of an appliance within an hour per household, random value	-	-	Appliance_Minute_Start	35 x 24 x N	-	-
Load per minute per appliance per household						
Conversion from hours to minutes for appliances being on or off at each minute of the day per household	NonDomestic_Minute_ On	10 x 1440	Appliance_Minute_On	35 x 1440 x N	-	-
kW value at each minute for each appliance per household	NonDomestic_Load_ Minute	10 x 1440	Appliance_Load_Minute	35 x 1440 x N	AdjustedProfile_ Minute	35 x 1440 x N
Total load						
Total load per household for each minute of the day	-	-	Appliance_Summated_ Profile_Minute	1 x 1440 x N	Adjusted_Appliance _Summated_Profile	1 x 1440 x N
Interim step required to summate per household	-	-	T (Transposed Summation)	N x 1440	T_Adjusted	N x 1440
Total summated load for whole group per minute	Non_Domestic_Profile	1 x 1440	Total_Domestic_Profile	1 x 1440	Adjusted_Total_ Domestic_Profile	1 x 1440

Notes:
N refers to NumHouseholds, a variable storing the number of households for a profile calculation.
1440 = 60 minutes per hour x 24 hours per day = total minutes per day

3.5 Application of matrices / vectors to develop the profile

3.5.1 Household type

Ten types of households are defined below. Each type is based on the number and age of occupants:

Table 3-2: Household type definition

Household type	Description
1	the bachelor
2	the young married couple (no children)
3	young couple with one baby
4	young couple with toddler (baby has grown up)
5	the young couple who has the toddler and now has a second child
6	the family of four with the children now both toddlers
7	the family of four with the children now both in primary school
8	the family of four with the children now both in secondary school
9	the family of four with the children now both students
10	the family of four now reduced to two pensioners as the children have left the house.

Each household type is characterized by the following parameters:

Table 3-3: Household type characteristics, indicating number of occupants, age of occupants, household size

Occupant / parameter	Units	Household type									
		1	2	3	4	5	6	7	8	9	10
Adult		1	2	2	2	2	2	2	2	2	
Baby				1		1					
Toddler					1	1	2				
Primary school child								2			
Teenager									2		
Student										2	

Occupant / parameter	Units	Household type									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Retired											2
House size minimum	m^2	80	80	120	140	140	140	140	140	150	120
House size maximum	m^2	120	200	200	200	200	250	300	350	400	400
House size average	m^2	100	140	160	170	170	185	220	245	275	260
Lighting	W/m^2	12	14	15	15	15	18	18	20	20	15

3.5.2 Households

The *Households* vector, with its size being the number of households in a study group, lists the household type for each household such a household belongs to. The household type is a random number from 1 to 10. For every calculation or study case, the household types are re-assigned to ensure that each study case is based on a different group of houses. The number of households is stored in a variable named *NumHouseholds*, which is used where dimensions of the various matrices are discussed. The number of households is varied to study the effects on parameters across a spectrum of households. Typically, the theory of ADMD stabilizing after a certain number of households can be tested.

3.5.3 Appliance list

The appliance list is a selection of 35 typical appliances found in households. The reader is referred to Table 3-4 in paragraph 3.5.4 for the list of appliances. There may be many more, but one of the appliances is listed as “other”. This provides the means to model all the “missing” appliances to simplify the modelling and incudes only minor appliances. Large appliances are modelled individually.

3.5.4 Appliances per household type

Different sizes households will contain different types and numbers of appliances. This is defined in the *Appliance_Present* matrix. The *Appliance_Present* matrix is a 35x10 matrix indicating whether each of the abovementioned 10 household types contains a certain appliance. This matrix is set only once. The bachelor will have one refrigerator, but as people grow older and the households become bigger, the old refrigerator is often kept and a second one added. The bachelor owns one television set, but as the family grows, each child ends up with a television set in an affluent home.

Appliance_Load is represented by a *35x1* vector, indicating the kW rating of an appliance. For simplicity, all appliance loads are expressed in kW, and power factor is a fixed value applicable to all households, for example 0.97 or 0.98. It would be inaccurate to assume unity power factor for all households, since inductive household load is being introduced such as heat pumps, fluorescent lighting, fans and air-conditioners. Electronic appliances with switch-mode power supplies tend to have poor power factors as well.

For simplicity, the *Appliance_Present* matrix and the *Appliance_Load* and *Appliance_Season* vectors are represented below in one table due to the interpretation of the lighting values (refer to the note at the bottom of the table below):

Table 3-4: Example of appliance presence, seasonality and appliance load rating

			Appliance present per household type 1=appliance present; 0=appliance not present									
Appliance	**Season**	**Load (kW)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Refrigerator 1	A	0.38	1	1	1	1	1	1	1	1	1	1
Refrigerator 2	A	0.55	0	0	0	0	0	0	1	1	1	0
Electrical Oven	A	2	1	1	1	1	1	1	1	1	1	1
Electrical Stove (4xplate)	A	2	1	1	1	1	1	1	1	1	1	1
Geyser 1	A	3	1	1	1	1	1	1	1	1	1	1
Geyser 2	A	3	0	0	0	0	0	0	1	1	1	0
Kettle	A	2.3	1	1	1	1	1	1	1	1	1	1
Toaster	A	0.95	1	1	1	1	1	1	1	1	1	1
Microwave	A	1.55	1	1	1	1	1	1	1	1	1	1
Dishwasher	A	1.9	0	0	0	0	0	0	0	1	1	1
Washing machine	A	0.38	1	1	1	1	1	1	1	1	1	1
Tumble dryer	A	2.9	0	0	0	0	0	0	0	1	1	1
Iron	A	2.2	1	1	1	1	1	1	1	1	1	1
Television 1	A	0.1	1	1	1	1	1	1	1	1	1	1
Television 2	A	0.12	0	0	0	0	0	0	1	1	1	0
Satellite TV decoder 1	A	0.05	1	1	1	1	1	1	1	1	1	1
Satellite TV decoder 2	A	0.05	0	0	0	0	0	0	1	1	1	0
DVD player	A	0.06	1	1	1	1	1	1	1	1	1	1
Amplifier	A	0.25	0	0	0	0	0	0	1	1	1	0
Game console 1	A	0.05	0	0	0	0	0	0	1	1	1	0
Game console 2	A	0.05	0	0	0	0	0	0	0	0	1	0
Heater 1	W	1.2	0	0	1	1	1	1	1	1	1	1
Heater 2	W	1.2	0	0	0	0	0	1	1	1	1	1
Air conditioner 1	S	1.5	0	0	0	0	0	0	1	1	1	0
Air conditioner 2	S	1.5	0	0	0	0	0	0	0	1	1	0
Computer 1	A	0.1	1	1	1	1	1	1	1	1	1	1

Appliance	Season	Load (kW)	Appliance present per household type 1=appliance present; 0=appliance not present									
			1	2	3	4	5	6	7	8	9	10
Computer 2	A	0.25	0	0	0	0	0	0	1	1	1	0
Router	A	0.05	1	1	1	1	1	1	1	1	1	1
Alarm system	A	0.05	1	1	1	1	1	1	1	1	1	1
Alarm clock 1	A	0.05	0	0	0	0	1	1	1	1	1	1
Cell phone charger 1	A	0.02	1	1	1	1	1	1	1	1	1	1
Cell phone charger 2	A	0.02	0	1	1	1	1	1	1	1	1	1
Instant water heater	A	1.4	0	0	0	0	0	0	1	1	1	0
Lights	A	1	1.2	1.96	2.4	2.55	2.55	3.33	3.96	4.9	5.5	3.9
Other	A	0.5	1	1	1	1	1	1	1	1	1	1

Notes:
Season: A = All year
S = Summer
W = Winter
Lighting load and lighting present is swapped around in the columns on purpose. Lighting is present for all houses, and since each house's lighting is different based on size, it has been calculated based on W/m^2 as set in the preceding table. The values in general are used as multipliers with the load kW rating, and the swapping around in the lighting row yields the correct answer.

For simplicity, all households had the same load rating for an appliance.

3.5.5 Appliances active per household

An appliance may be present, but is not necessarily always in use. An oven for instance is not used after 22:00 at night, while lights are not supposed to be burning during the day. Usage patterns are based on typical behaviour: when people wake up; when people go to work or school; when people come home from work or school; when meals are taken and when people settle down for the day.

Usage during a 24-hour day is defined by the *Appliance_Active* matrix. The *Appliance_Active* matrix is defined as a 35x24 matrix, indicating during which hours of the day an appliance may be used. The duration for which each appliance is typically switched on within active hours is a 35x1 vector, *Appliance_Duration*. This value is an integer between 0 and 60 minutes. The *Appliance_Active* matrix and the *Appliance_Duration* vector are common to all households.

Initially, the *Appliance_Active* matrix consisted only of 0 and 1 values, but it was adjusted to fractional values from 0 to 1 to improve the profile shape compensating for the load duration, intensity of usage and number of switching "on" times per hour. As an example, for intensity of usage, a stove may have four plates, but only one plate could be used for a short time, as opposed to cooking a large meal where two or three plates may be used for longer periods at a time.

Refer to Table 3-5 below.

Table 3-5: Example of the *Appliance_Active* matrix

Appliance Type	**Load duration (minutes)**	**Multiplier per hour, starting from the hour preceding up to the hour shown**																							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Refrigerator 1	20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Refrigerator 2	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Electrical Oven	30	0	0	0	0	0	0.025	0.025	0.025	0	0	0	0	0	0	0	0.05	0.25	0.4	0.4	0.1	0	0	0	0
Electrical Stove (4xplate)	60	0	0	0	0	0	0.2	0.3	0.15	0.05	0	0	0.05	0.05	0.05	0	0	0.3	0.5	0.5	0.3	0	0	0	0
Geyser 1	30	0.2	0.2	0.25	0.45	0.75	1	1	1	0.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.8	1	1	1	0.8	0.4	0.25	0.2
Geyser 2	30	0.2	0.2	0.25	0.45	0.75	1	1	1	0.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.8	1	1	1	0.8	0.4	0.25	0.2
Kettle	5	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Toaster	5	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Microwave	5	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
Dishwasher	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0
Washing machine	60	0	0	0	0	0.2	0.5	1	1	1	1	1	1	0.5	0.4	0.3	0.2	0.1	0	0	0	0	0	0	0
Tumble dryer	60	0	0	0	0	0	0	0	0.5	0.5	0.5	0.5	0.5	0	0	0	0	1	1	1	1	1	1	1	1
Iron	45	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0
TV 1	60	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
TV 2	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0
Satellite TV decoder 1	60	0.1	0.1	0.1	0.1	0.1	1	1	0.1	0.1	0.1	0.1	0.1	0.1	1	1	1	1	1	1	1	1	1	0.1	1
Satellite TV decoder 2	60	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	1	0.1	0.1	0.1	1
DVD player	60	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	1	1
Amplifier	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0
Game console 1	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
Game console 2	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appliance Type	Load duration (minutes)	Multiplier per hour, starting from the hour preceding up to the hour shown																							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Heater 1	60	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
Heater 2	60	1	1	1	1	1	1	1	0	0	0	0	0	0	0.5	1	1	1	1	1	1	1	1	1	1
Air-conditioner 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Air-conditioner 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Computer 1	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Computer 2	60	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0
Router	60	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Alarm system	60	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Alarm clock 1	60	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Cell phone charger 1	60	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
Cell phone charger 2	60	1	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Instant Water Heater	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lights	60	0.2	0.2	0.2	0.2	0.5	0.7	0.1	0	0	0	0	0	0	0	0	0	0	0.1	0.8	0.8	0.7	0.4	0.3	0.2
Other	60	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	2	2	2	1	1	1	1

3.5.6 **Appliance_Probability_On**

Even though a house may have an appliance, and the appliance may be active (i.e. it can be switched on), it is not to say that the appliance is in fact switched on. The status of the appliance (whether switched on or off) is selected at random for each appliance, for each hour of the day, for each household for every profile calculated. The *Appliance_Probability_On* matrix is a *35 x 24 x NumHouseholds* matrix where each value is generated between 0 and 100 at random, divided by 100 and then rounded to the nearest integer. This produces a value of 0 or 1, with sufficient randomness.

3.5.7 **Appliance_Minute_Start**

Even though a house may have an appliance that is within its active period, and it has the probability to be on, the appliance can still be switched on for example at 5 minutes into the hour or at 40 minutes into the hour. A random generated value between 0 and 60, representing the minute within the hour when an appliance is switched on, is generated at random per appliance, per hour, per household and stored in the *Appliance_Minute_Start* matrix with dimensions *35 x 24 x NumHouseholds*. The model is limited to one "switching on" scenario per hour. Multiple switching per hour can be modelled by adjusting the values in the *Appliance_Active* matrix.

3.5.8 **Appliance_Minute_On and Appliance_Load_Minute**

Using the values in *Appliance_Minute_Start* matrix and the *Appliance_Duration* vector, a value between 0 and 1 is calculated per minute for a 24-hour day per appliance per household, indicating whether an appliance is switched on or off, and stored in the *Appliance_Minute_On* matrix with dimensions of *35 x 1440 x NumHouseholds*. Checking is done to allow "on-minutes" to roll over to the next hour where the starting minute and the duration is more than 60.

The calculation for the *Appliance_Minute_On* matrix is effectively the multiplication of the *Appliance_Probability_On*, *Appliance_Active* and *Appliance_Present* matrices, using the checking rules, starting minute and duration as outlined above. The *Appliance_Active* matrix effectively scales the calculated load value between 0 and full load as outlined in Paragraph 3.5.5.

The *Appliance_Minute_On* matrix is multiplied with the *Appliance_Load* vector to obtain the *Appliance_Load_Minute* matrix – a matrix with dimensions *35 x 1440 x NumHouseholds,* storing the kW per minute per appliance per household. This operation forms the core of the algorithm.

The number of households in the group should be kept below 1500 unless calculations per study case above 10 minutes can be accepted, as this core calculation is done against each appliance per household per minute with rule checking.

3.5.9 **Appliance_Summated_Profile_Minute, T and Total_Domestic_Profile**

The *Appliance_Load_Minute* matrix can be summated for each minute to obtain a minute load profile per household, which is stored in the *Appliance_Summated_Profile_Minute* matrix with dimensions *1 x 1440 x NumHouseholds*. Summation is limited to 60A (13.8kW) only to ensure that the same limitation applies as in a normal household with a 60A single phase main circuit breaker.

The total group load profile is calculated by summating the load per minute of all households in the group. The result is stored after a transposition process using matrix *T* with dimensions *NumHouseholds x 1440* in the *Total_Domestic_Profile* matrix with dimensions *1 x 1440*.

It is now relatively easy to determine the maximum demand for each household and for the total group. All the important parameters (ADMD, diversity or coincidence, load factor as well as kWh per day, per month or per annum) can now be calculated and the relationship between parameters can now be studied.

3.5.10 **Typical "per-minute" appliance profiles generated**

A typical appliance model can be represented as:

TIME

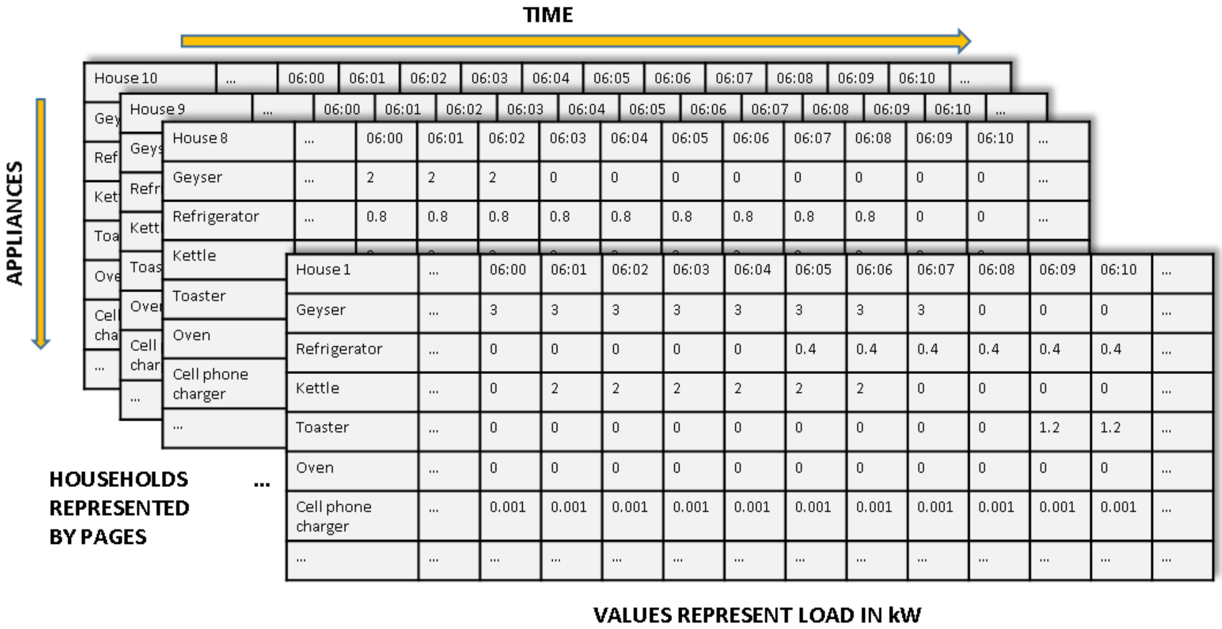
APPLIANCES

	...	06:00	06:01	06:02	06:03	06:04	06:05	06:06	06:07	06:08	06:09	06:10	...
Geyser	...	3	3	3	3	3	3	3	3	0	0	0	...
Refrigerator	...	0	0	0	0	0	0.4	0.4	0.4	0.4	0.4	0.4	...
Kettle	...	0	2	2	2	2	2	2	0	0	0	0	...
Toaster	...	0	0	0	0	0	0	0	0	0	1.2	1.2	...
Oven	...	0	0	0	0	0	0	0	0	0	0	0	...
Cell phone charger	...	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...

VALUES REPRESENT LOAD IN kW

Figure 3-2: Typical appliance model extract

When combining the above per household for a number of households, the household model can be expressed as:



House 8	...	06:00	06:01	06:02	06:03	06:04	06:05	06:06	06:07	06:08	06:09	06:10	...
Geyser	...	2	2	2	0	0	0	0	0	0	0	0	...
Refrigerator	...	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0	0	...
Kettle													
Toaster													
Oven													
Cell phone charger													
...													

House 1	...	06:00	06:01	06:02	06:03	06:04	06:05	06:06	06:07	06:08	06:09	06:10	...
Geyser	...	3	3	3	3	3	3	3	3	0	0	0	...
Refrigerator	...	0	0	0	0	0	0.4	0.4	0.4	0.4	0.4	0.4	...
Kettle	...	0	2	2	2	2	2	2	0	0	0	0	...
Toaster	...	0	0	0	0	0	0	0	0	0	1.2	1.2	...
Oven	...	0	0	0	0	0	0	0	0	0	0	0	...
Cell phone charger	...	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...

Figure 3-3: Extract of appliance model applied to multiple households

The combined load per minute can be determined easily by summating each minute column for each household, and by summating all households' total loads for the same minute.

3.5.11 **Total profile generated**

The total profile generated can be plotted against time to provide the simulated 24-hour day.

3.6 **Base model validation**

The model is simply validated against measured 24-hour residential load profile graphs, as well as the relationship of some of the parameters. As an example, the ADMD of a group of consumers exponentially decays as the group of consumers increase. This same phenomenon should also be observed in the coincidence calculation. The load profile shape and typical expected characteristics are well known from recorded load profiles. Load profile characteristics include the time of peaks and the expected time of steep load increases and decreases.

3.7 Introducing energy efficiency and renewable energy measures

The effect of various “green” measures can be studied by varying one or many appliances. The appliance-based energy efficiency measures that can be introduced and studied, are:

- Solar PV
- Replace electric stove with gas stove
- In addition, replace the electric oven with gas oven
- Geyser control (ripple control) – this has been illustrated already. A typical notch profile can be used from historic tests.
- Move loads to different time slots, e.g. swimming pool pump.

3.7.1 Solar PV curve

A solar PV curve resembles a parabola of the form $y = ax^2+bx+c$. The coefficients a, b and c can be determined by solving the roots of the parabola. A simplified form of the solar PV curve is when the sun rises at 06:00 and sets at 18:00 when PV output is 0, and is at peak at noon. Solving for the roots, the following parabolic formula coefficients are obtained.

Table 3-6: Simplified solar PV parabola coefficients

Coefficient	Minute basis	Hourly basis	Minute to hour conversion
a	$-1/360^2$	-1/36	3600
b	1/90	2/3	60
c	-3	-3	1

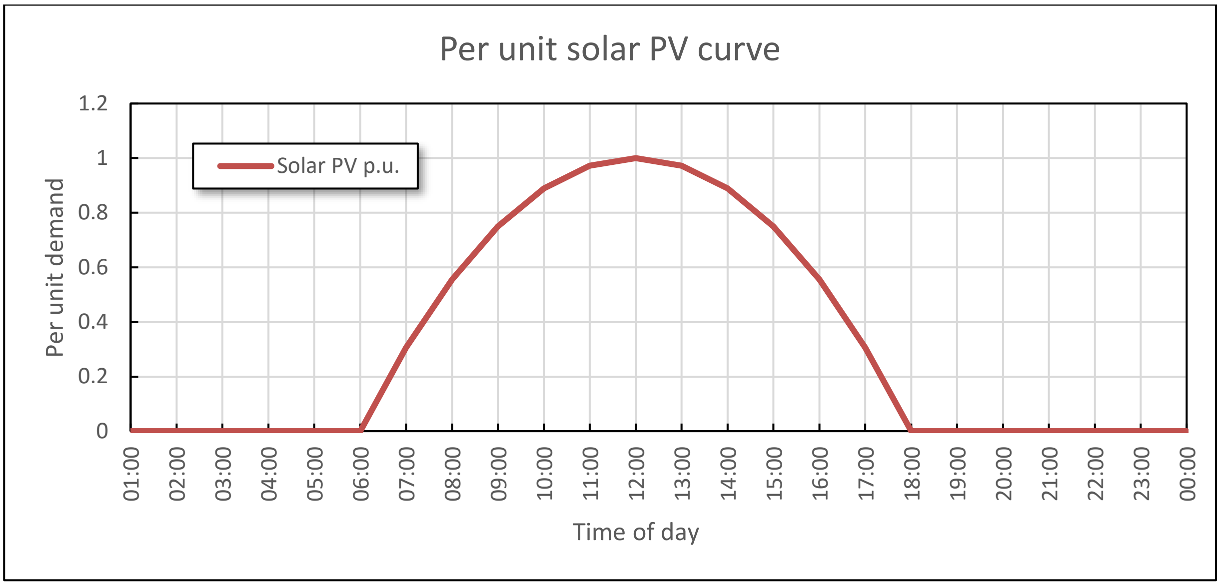


Figure 3-4: Solar PV per unit curve

The impact of solar PV was tested for various penetration levels and size combinations. For various sizes, the unity curve is simply scaled. Penetration levels were determined by specifying a percentage value.

Households were then selected at random, whether it has PV or not, by considering the penetration percentage value. As an example, consider the following: a 20% penetration has to be modelled. Generate a random number between 0 and 100, and then only assign PV to households where a number larger than 80 (=100-20) was generated, where 20 represents the 20% selected. If a 13% penetration level has to be simulated, then PV will be assigned to all households where a random number above 87 (=100-13) was assigned.

3.7.2 Gas-cooking – stove-top

With gas being used for cooking purposes for the stove-top, the stove top kW load is set to 0.

3.7.3 Gas-cooking - oven

With gas being used for cooking purposes for the oven, the oven kW load is set to 0.

3.7.4 **Load shifting**

Load shifting can be modelled by modifying the *Appliance_Active* matrix.

3.7.5 **Load reduction**

Load reduction can be modelled by modifying the *Appliance_Load* vector.

3.7.6 **Adjusted profile calculation**

The adjusted profile is calculated similarly to the original profile where the changes required are applied to the *Appliance_Load_Minute* matrix values. Changes are in the form of modified load values for each of the appliances where values are either reduced, higher or lower. If there is no change in the value, then no energy efficiency measure is applied. The adjusted appliance loads are stored in a vector *AppGreenLoad* with dimensions *35 x 1*. Adjusted appliances are marked in a vector *AppGreenSelected* with dimensions *35 x 1*, and values are either 0 or 1 (where 1 indicates that changes are applicable).

The *AppGreenSelected* vector is used as a multiplier with the *AppGreenLoad* vector:

$$\begin{aligned} AdjustedProfile\_Minute = {} & Appliance\_Load\_Minute \\ & - (Appliance\_Minute\_On \times AppGreenSelected \times Appliance\_Load) \\ & + (Appliance\_Minute\_On \times AppGreenSelected \times AppGreenLoad) \end{aligned} \quad \ldots(36)$$

The adjusted appliance load is then summated per household (limited to 13.8 kW per household at any given minute to correspond to a 60 A circuit breaker limit) and stored in the *Adjusted_Appliance_Summated_Profile_Minute* matrix with dimensions *1 x 1440 x NumHouseholds*. Similar to the load profile without any form of intervention, the transposition of the *Adjusted_Appliance_Summated_Profile_Minute* matrix is obtained and stored in matrix *T_Adjusted* with dimensions *NumHouseholds x 1440*.

The effect of solar PV is introduced only once the load per minute per household is summated by subtracting the PV profile per household from the transposed summated profile per household. The solar PV profile per household is stored in matrix *PVProfile* with dimensions *NumHouseholds x 1440*. At this stage, the model is simplified by assuming that all households with solar PV installed will have the same solar PV capacity.

Once the PV effect is applied, the adjusted transposed profile per household is summated to obtain the total adjusted load profile, stored in the *Adjusted_Total_Domestic_Profile* matrix – a matrix with dimensions *1 x 1440*.

Changes to the ADMD, load factor, diversity or coincidence, kWh per day, month and annum parameters can now be calculated and the results compared to draw conclusions about the effects of “green” intervention measures.

3.7.7 **Study case generation**

Study cases are generated by storing the results of each calculation. Each study case stores the following:

- the number of households per study case;
- parameters calculated from the profile without interventions and the profile after “green” interventions;
- the interventions which took place, the size and penetration level of PV applied;
- the calculated profiles *Total_Domestic_Profile* and *Adjusted_Total_Domestic_Profile*;
- the transposed interim matrices *T* and *T_Adjusted*; and
- the non-domestic profile and the total composite profile prior to interventions.

Storing the profiles in *.MAT* variable files requires relatively large storage space, which resulted in results being lost in some cases – especially where the number of households in the study group became relatively large (>1500). The creation of duplicate back-ups of the stored variable files at regular intervals were built into the program so that all results would not be lost. Study cases were set up to run unattended during the night when the computer was not required. However, storing the large matrices as outlined above is necessary to scroll through the various study cases to observe the effects of “green measures”.

Variable files were created for the following:

- Excel variables: the data originally populated in Excel and imported into Matlab
- Profile variables: the calculated profiles and parameters
- Study case, with parameters stored per case, except the matrices.
- Case data, storing the matrices per study case.

- Reference profile, storing the data for several reference profiles – one month's daily profiles of a selected measured one-minute load profile with maximum demand in the order of 9 MVA to be exact. The period selected was in May 2013 – the month during which the coldest temperature in 2013 occurred.

3.8 Load flow model

3.8.1 Load flow model requirements

A simple load flow model has to be constructed to allow adjustment of parameters and test the outcome.

Load flow studies are generally performed as balanced load flow in MV and HV studies, but for single-phase low voltage networks, unbalanced load flow studies must be performed. Domestic network coincidence is hardly used at higher voltage networks, but forms the underlying basis of the calculation at low voltage single-phase installations.

The load flow model should model low voltage networks where loads can be assigned to each phase along an LV feeder. Solar PV should be introduced at each house as well, and therefore the load flow model must be constructed to include the service cable or overhead conductor to the house. It will also be necessary to model the transformer and study the effects of possible voltage rise, fault level variation and reverse power flow at the transformer up to its MV terminals.

ReticMaster is used in South Africa for studies where unbalanced networks have to be modelled. ReticMaster does not model solar PV inverters through a built-in model. A model has to be constructed. A generator can be added, or a negative load can be used. ReticMaster further has a built-in Herman-Beta voltage drop calculation method, which has been verified through the author's own projects with the NRS034 test cases.

Digsilent Powerfactory on the other hand has proper built-in models for solar PV inverters, which allows different forms of control to be selected. It also allows for unbalanced network modelling on the low voltage networks. The Herman-Beta method is calculated using a built-in script issued with the software. The script did not work and has been referred back to the software suppliers in Germany. The built-in load-flow functionality for low-voltage analysis for unbalanced systems was used instead.

The Digsilent Powerfactory model was verified by comparing it with the ReticMaster model's results prior to introducing solar PV. Effects on voltage, reactive power and fault level can be studied. The modified parameters based on adjusted load profile simulation were introduced as well to compare effects on network performance.

3.8.2 **Load flow model design**

It was decided to select a LV feeder, designed up to its limits at an ADMD of 5.3 kVA / household. Each distribution kiosk along the feeder fed four feeders to ensure the voltage are unbalanced at each distribution point. The total number of households was a multiple of three so that the feeder phase connections are balanced. One distribution kiosk fed five households, and was placed at the end of the feeder. Additional feeders were simply modelled as bulk loads to ensure a sufficiently loaded transformer to introduce sufficient voltage drop over the transformer. A total of three feeders were modelled, and the total load as seen from the transformer was balanced based on the number of connections.

The same feeder configuration was used to assess two cable sizing scenarios: a tapered LV feeder size (Scenario A1) and one LV feeder size throughout (Scenario A2).

The same feeder design was used in a paper presented at the AMEU convention in 2014 [1]. The selected feeder design is as follows:

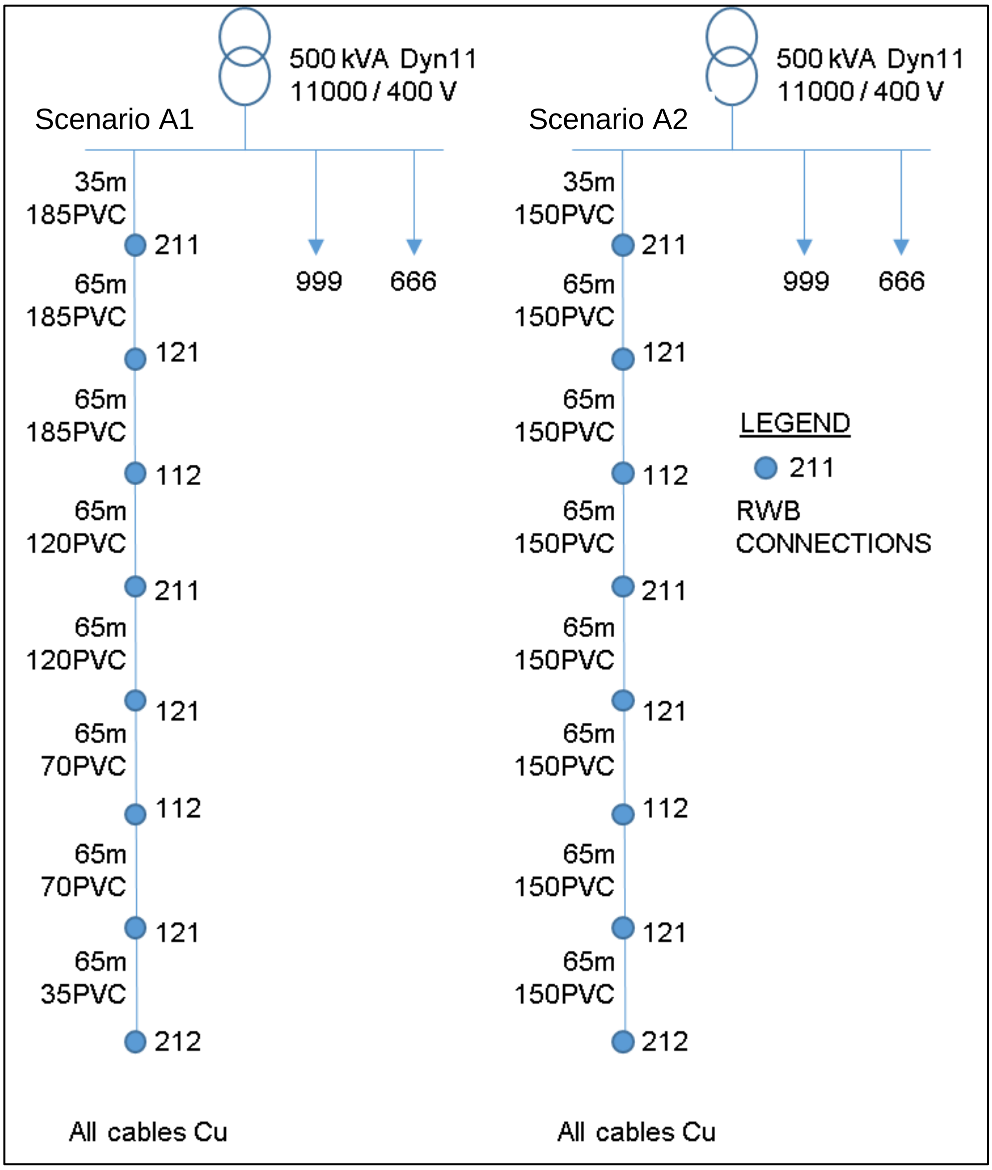


Figure 3-5: LV feeder configuration for load flow studies for tapered feeder (scenario A1) and one size feeder (Scenario A2) [1]

All primary LV cables are PVC/SWA/PVC 600/1000V 4-core Cu cables, with size in mm^2 as indicated, while secondary LV cables are 16 mm^2 2-core Cu cables.

The transformer supplies three feeders with 33, 27 and 18 houses each, and each phase as seen from the transformer per feeder, is balanced based on the number of connections per phase.

The ReticMaster and Digsilent Powerfactory models are illustrated in Figures 3-6 and 3-7 respectively:

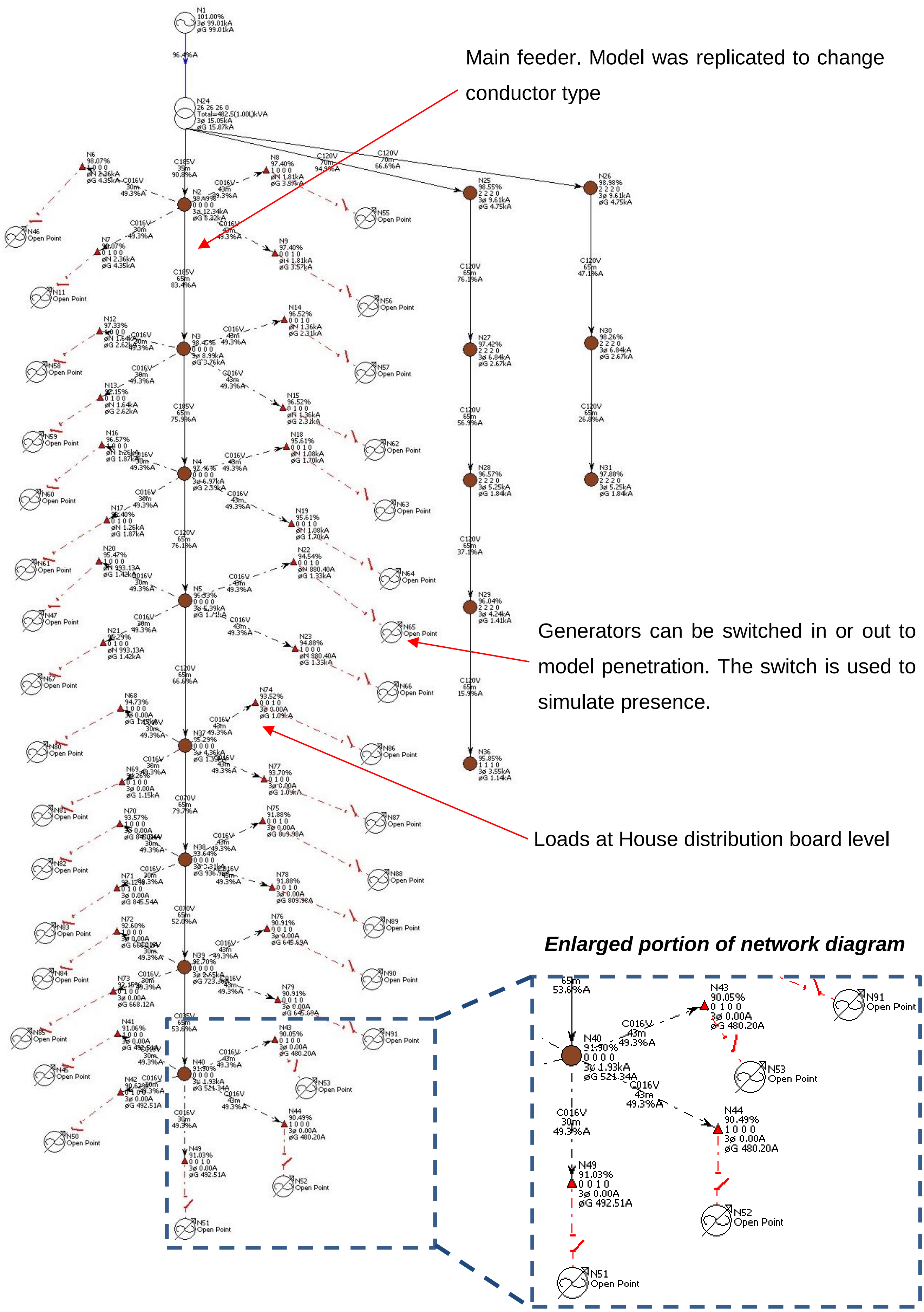


Figure 3-6: Reticmaster model for test LV feeder network

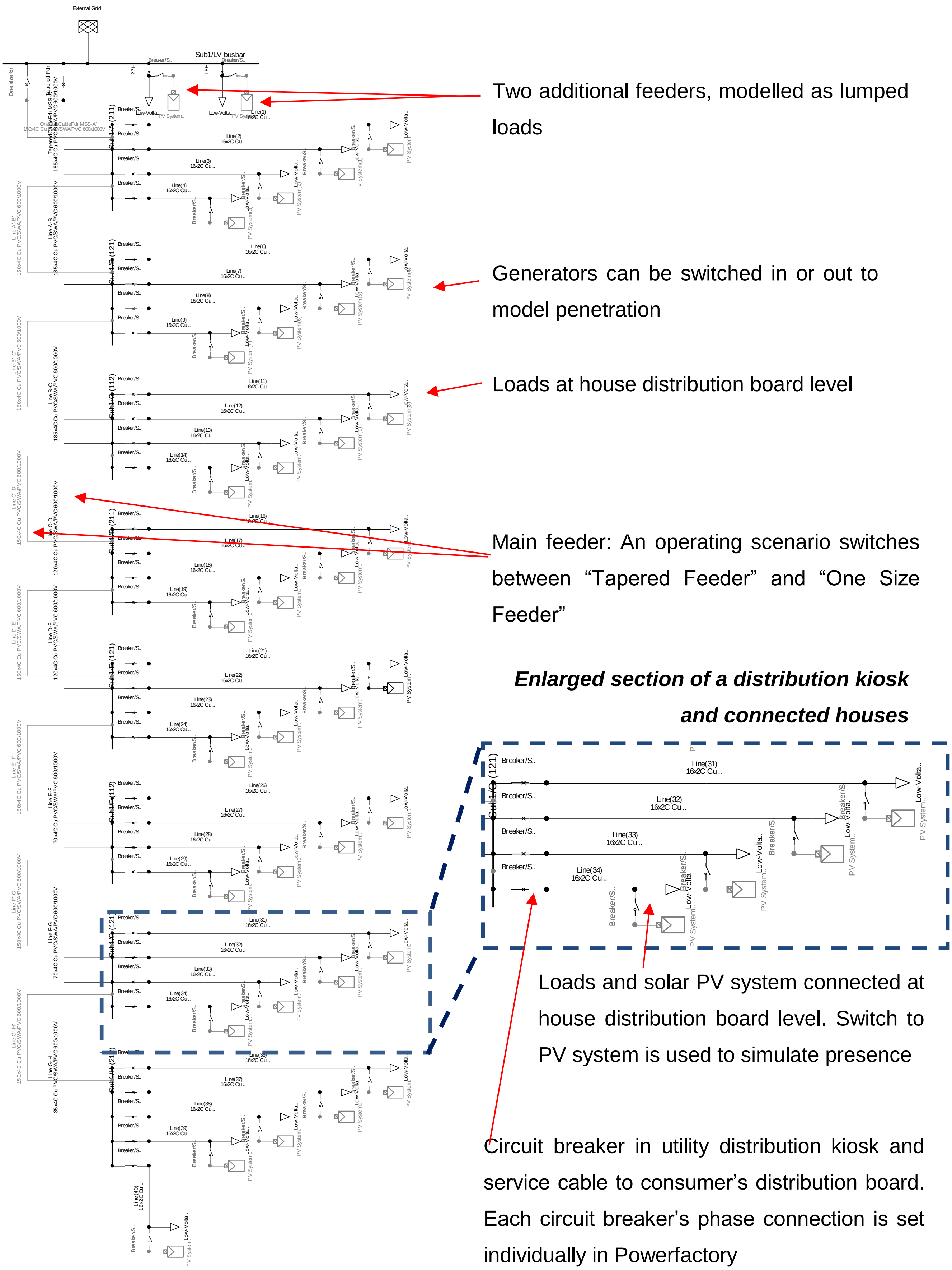


Figure 3-7: Digsilent Powerfactory model for test LV feeder network

3.8.3 **Load flow modelling scenarios**

LV feeders in residential areas mostly experience peak loading conditions during the evening. As such, a feeder at high load conditions will not experience an impact from solar PV on the Gauteng Highveld, but may very well experience some impact in the Western Cape where the sun sets later.

The baseline for comparison at high load conditions and low load conditions will be with no form of distributed or embedded generation present.

Suppose the test feeder is somewhere in the Gauteng province where solar PV will have no effect during high load conditions. A micro wind turbine may still have an effect during the evening peak and the effects of generating during high load conditions were investigated.

During a typical load condition, solar PV might be at its maximum output, and voltage rise is expected.

The Herman-Beta method may not necessarily apply during low load conditions, since the load distribution may be different. An empirical approach may be necessary where an average demand per household is determined equal to the load profile’s low load around the solar peak.

Simulating renewable power generation at the time of the feeder’s peak, however, will indicate for instance, what will happen if wind generation is deployed and sufficient wind is available to produce say 1.5 kW, or 3 kW, or even 9 kW at domestic level.

It was also assumed that utilities may not have control over what consumers do, and the restrictions as imposed by NRS097 [30] may not be adhered to. The assumption was made that consumers are ignorant and do not pay attention to NRS 097 and install any size system they prefer or can afford. Therefore, DG systems larger than 4.6 kW were not modelled as three-phase, but rather as a 9kW single phase system

The scenarios to be investigated are each of the two feeder configurations (Scenario A1 and Scenario A2), for both DG active during high demand and low demand scenarios. Generally, solar PV will be active during low demand periods, but a wind turbine may be generating electricity during the evening peak.

3.9 Chapter summary

In this chapter, a simulation tool was described that allows the ability to simulate changes in ADMD's after intervention of EEDSM and RPP type projects.

A load flow model was also described through which the impact on network performance can be quantified. The next chapter presents the findings and results.

Chapter 4 Findings and results

4.1 Introduction

In the previous chapter, the design of analysis and simulation tools were described in an effort to quantify the impact EEDSM and DG have on our grid networks.

4.2 Load profile validation and verification

4.2.1 General considerations

Validation in plain terms is defined as doing “the right thing”, while verification is defined in plain terms as doing “the thing right”.

When applying it to the process at hand, it means that validation focuses on the correlation of the calculated profile with actual profiles (to demonstrate that it is the right thing), and verification focuses on whether the calculations derived are done right (i.e. how it measures up to known theory and expected results). Aspects of validation and verification are summarized in the following table.

Table 4-1: Validation and verification methodology

Test aspect	**Validation** **Doing the right thing**	**Verification** **Doing it right**
Load profile shape	Is the reference load profile used for comparing purposes appropriate?	Does the simulated profile compare or correlate with the reference profile?
ADMD	Is it calculated using correct formula?	Does ADMD reduce as the number of consumers increase?
Diversity / Coincidence	Is it calculated using correct formula?	Does coincidence decrease or diversity increase as the number of consumers increase?
Load factor	Is it calculated using correct formula?	Is the load factor representative of expected loads, i.e. not too high, or not too low?

Test aspect	Validation **Doing the right thing**	Verification **Doing it right**
Applying green measures	Are the typical measures to be investigated representative of what one would expect to find on a domestic network?	Does the peak load reduce when geysers for instance are omitted (e.g. replaced with solar geysers without electrical back-up elements)?

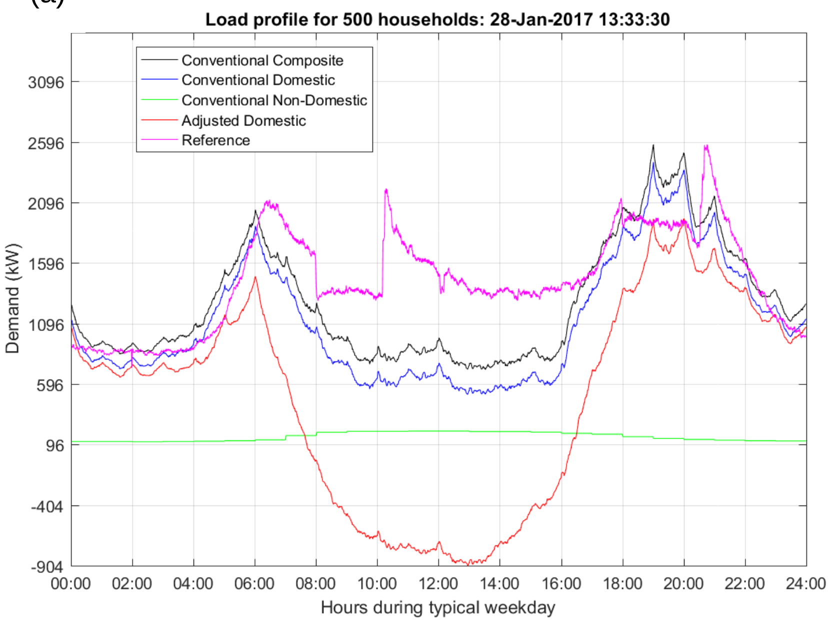
4.2.2 **Load profile shape**

A reference load profile was selected from available one-minute load profiles representing mostly domestic load. In any load measured at substation level for predominantly domestic load, there will always be non-domestic load such as street and area lighting, possibly traffic signals, a few small shops, schools and other community facilities such as churches, a police station etc.

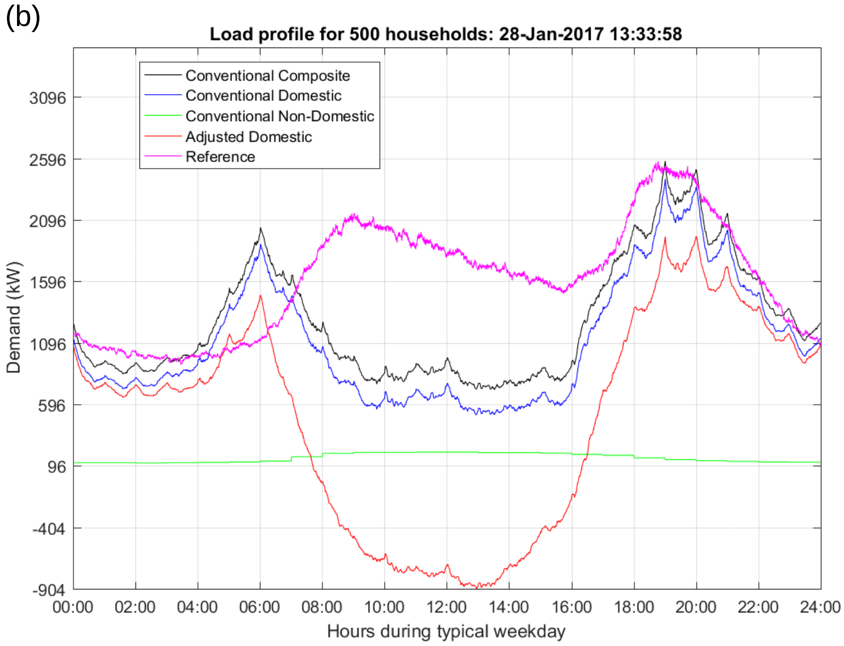
The network as measured in the reference curve, has ripple control present and the effects thereof is easily demonstrated comparing days when ripple control is active (e.g. weekdays) against days when the ripple control is inactive (e.g. typical Sunday). An inactive day was selected as reference curve, although any of the other days can also be selected by scrolling on the interface through the 31 imported daily profiles. May 2013 recorded the coldest day during 2013, or at least the maximum demand for many utilities. From experience, the coldest week of the year on the South African Highveld is experienced in July, and normally coincides with the annual Eskom maximum demand.

The calculated composite load profile, consisting of a domestic load component and a non-domestic load component, is compared to two reference profiles as follows:

(a)



(b)



Notes pertaining to figures on this page:

Number of households simulated = 500.
Reference curve for top graph (a) = weekday curve with ripple control active.
Reference curve for bottom graph (b) = Sunday curve with no load control.
Simulated curve = weekday curve.
In the top graph the morning profile rise and the evening load coincides with the reference curve.
For the bottom reference profile, the late rising of people on a Sunday as opposed to a normal weekday is observed. However, what is important here is the coincidence of the rise and drop of the evening peak. The high noon peak for the reference curve is due to home cooking on a Sunday, but for the weekday curve, it is not applicable.

Figure 4-1: Calculated load profile (black) compared to a reference curve (magenta) with load control (sub-figure a) and without load control (sub-figure b)

The selected reference profiles were scaled on the y-axis such that its maximum demand equals the simulated profile maximum demand (without interventions).

It is possible that the non-domestic load in the reference load profile is higher than anticipated. It was not verified. The “double hump” load profile constructed (black line) is considered satisfactory for further use. Only the domestic portion (blue line) is of interest in this study and the non-domestic load portion is not considered further. The reference curve is only used to verify that the calculated composite load profile (black line) is representative (i.e. as to where it calculates the peaks compared to an actual situation).

4.2.3 ADMD

It is expected that ADMD will decay as the number of households increase up to a point where after it does not decay substantially. From the simulated results, the following scatter plot is derived:

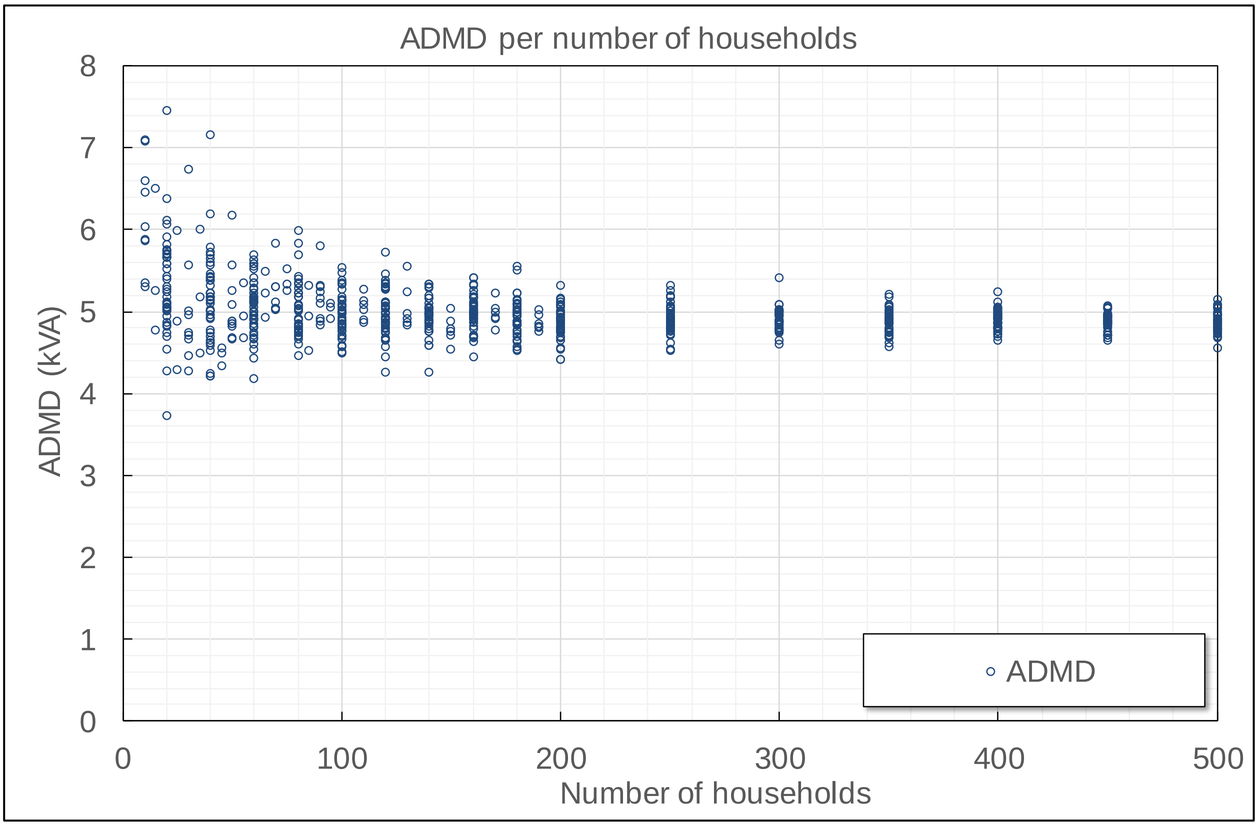


Figure 4-2: ADMD vs number of households (simulated)

The graph shows ADMD calculated results from 744 case study profiles ranging from 10 to 500 households. It is evident from the graph that the ADMD decays as the number of households increase and stabilizes for high household numbers. The number of low ADMDs for households below 50 is simply an indication that ADMD is in general not very accurate when based on small quantities due to lack of diversity. Even NRS034 [3] indicates an upward adjustment of ADMD (refer to Equation 33), to compensate for a lack of diversity.

It is concluded that the study cases and model provide useful ADMD values for comparison purposes.

The same case study data is used for all graphs following.

4.2.4 **Diversity / Coincidence**

It is expected that coincidence will decay as the number of households increase up to a point, where after it does not decay substantially. Figure 4-3 illustrates a coincidence scatter plot from the simulated results:

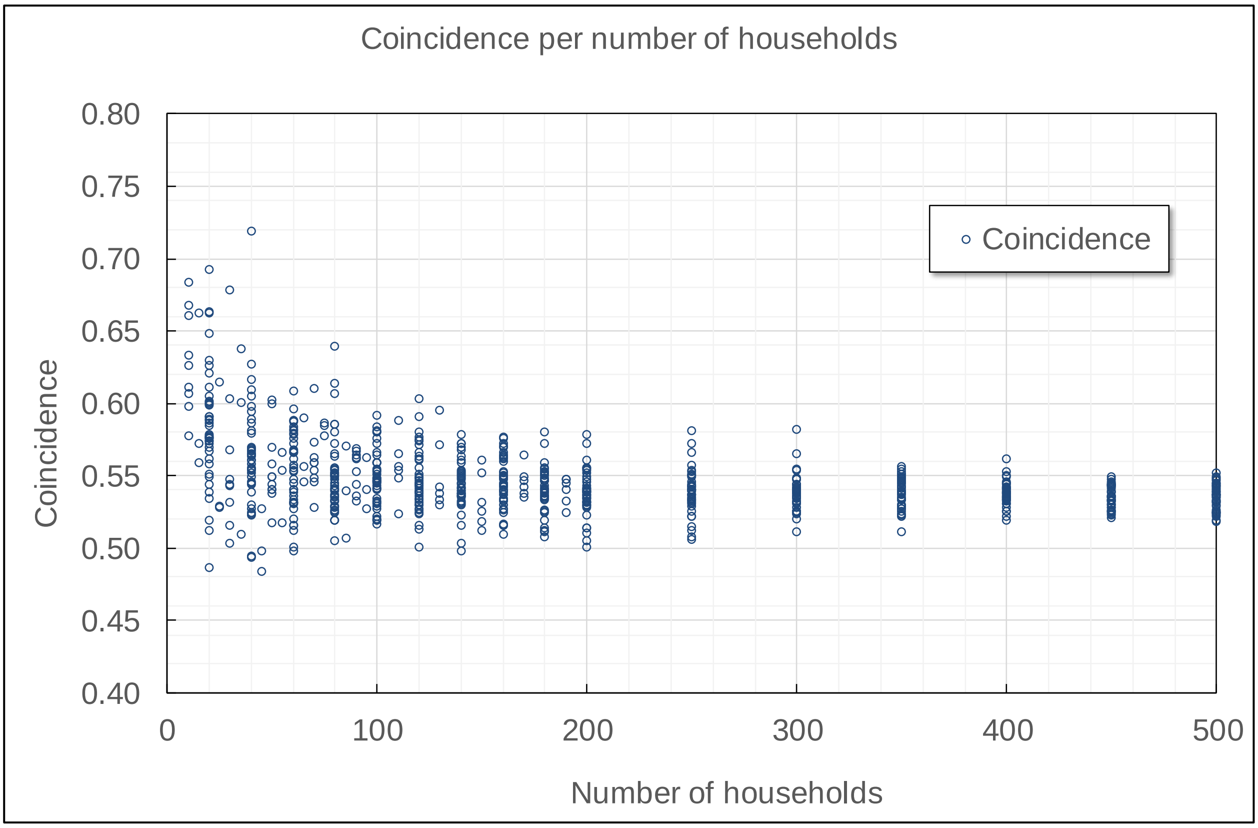


Figure 4-3: Coincidence vs number of households (simulated)

From the simulated results, it is evident that the coincidence indeed decays over time and reaches a stabilizing level. The simulation achieves slightly higher than anticipated results. It was expected to stabilize around 0.42, based on experience.

4.2.5 Load factor

Load factor (average demand divided by maximum demand) is a function of the maximum demand and it is expected that the load factor will follow the stabilizing pattern of the ADMD, which is also based on the maximum demand. The calculated results from the simulated profiles in the study case files are observed on the following scatter plot:

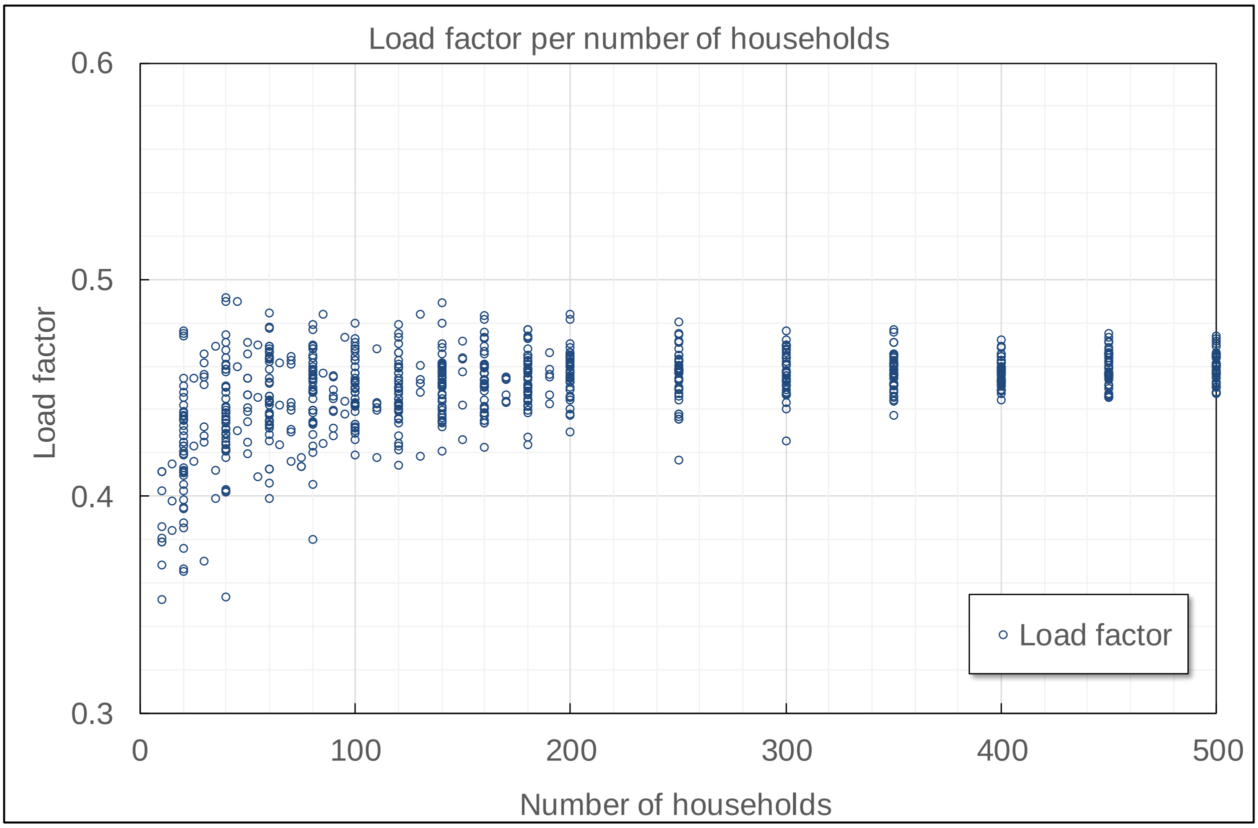


Figure 4-4: Load factor vs number of households (simulated)

The load factor is within acceptable limits for affluent residents.

4.2.6 Effect of "green" measures

Figure 4-1 in Paragraph 4.2.2 indicated a load curve in a red line after adjustment. In this instance, the following was applicable:

- 3 kW solar PV for 20% of the 500 households
- 100% electrical stoves replaced by gas stoves
- 100% replacement of all electrical geysers per household with solar geysers.

From the adjusted profile, it is evident that the profile reduces as electricity is generated by a solar PV system, especially during the middle of the day, and that the peaks are considerably lower, as will be expected when electrical geysers are replaced with solar geysers. The reduction technique applied therefore is acceptable for the purposes of modelling. Since the base profile was acceptable, it can be concluded that the calculation of an adjusted profile provides satisfactory results for comparison to conventional scenarios.

4.2.7 Validation and verification conclusion

It can be concluded that the simulation produces satisfactory results for studying the effects of renewable energy, energy efficiency and demand side management measures on planning parameters such as ADMD, coincidence and load factor.

4.3 Analysis of results obtained through appliance model simulation

4.3.1 Case studies

The following scenarios were investigated with the appliance model simulation tool.

Table 4-2: Study scenarios with appliance model simulation tool

Study scenario	PV penetration level	PV Size	Electric stoves replaced with gas stoves	Electric geysers replaced with solar geysers
A	10%	1.5 kW		X
B	10%	1.5 kW	X	
C	10%	1.5 kW	X	X

Study scenario	PV penetration level	PV Size	Electric stoves replaced with gas stoves	Electric geysers replaced with solar geysers
D	20%	1 kW	X	X
E	20%	3 kW	X	X
F	40%	3 kW	X	X
G	50%	5 kW	X	X

These scenarios were chosen as follows:

- A, B & C: study the effects of replacement of appliances with appliances reducing energy and demand such as replacement of electric stoves and geysers with gas appliances. The PV effect was kept the same.
- D & E: Keep PV penetration level the same, but vary the PV size.
- E & F: Keep PV size the same, but vary penetration level.
- G: Simulate high PV penetration with high PV size.

In Germany, the maximum solar PV penetration level reached on a macro scale is 45% [34], but on a localized scale, generation may exceed demand.

On the graphs that follow in Figures 4-5 to 4-13, the colours assigned to these scenarios are:

- Baseline = Grey circles
- A = Green
- B = Purple
- C = Cyan
- D = Red
- E = Orange
- F = Dark blue
- G = Maroon.

4.3.2 **Impact of green measures on ADMD**

The ADMD for the profile without intervention was illustrated in Figure 4-2. The same data in the graph below is represented by the grey circles. For each profile calculated, a “green” profile was also calculated.

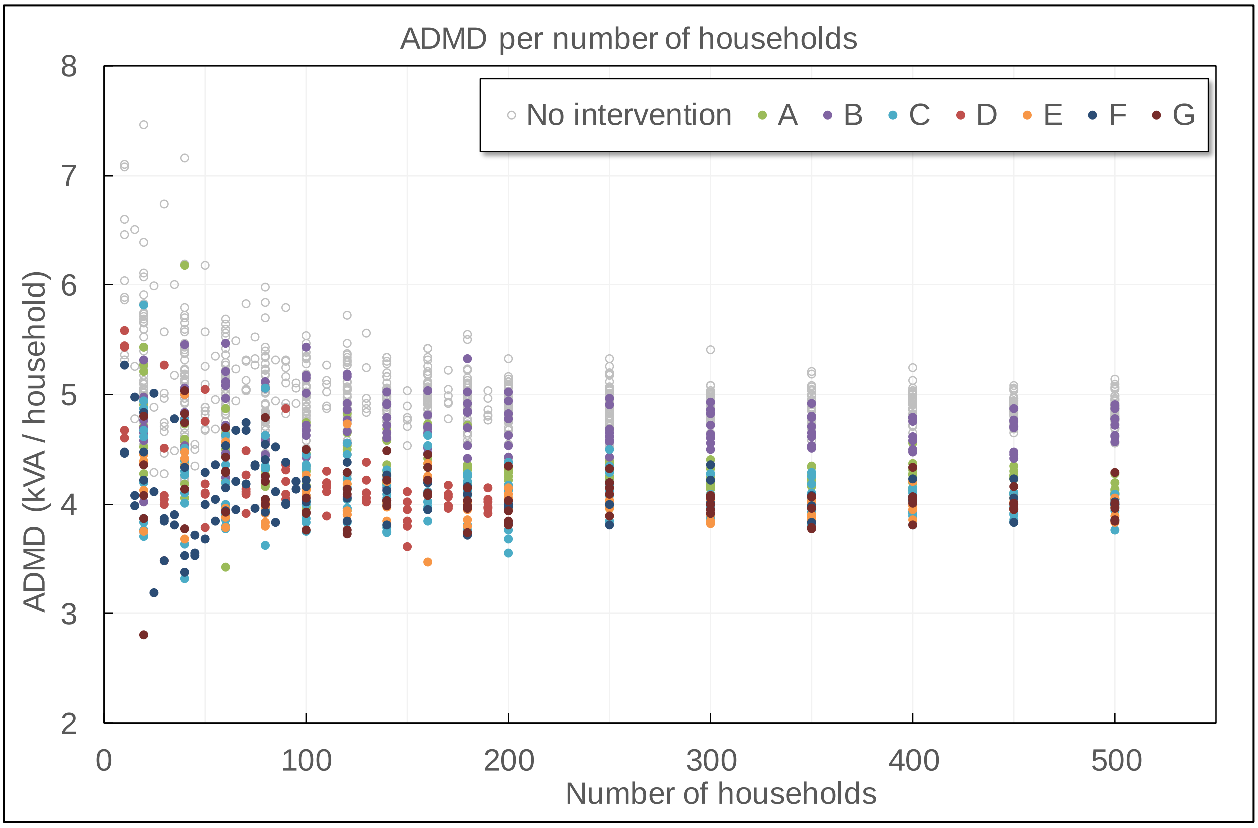


Figure 4-5: Effect of various green measures on ADMD, compared to a baseline without any interventions

The impact of various measures on ADMD is illustrated in figures 4-6 and 4-7.

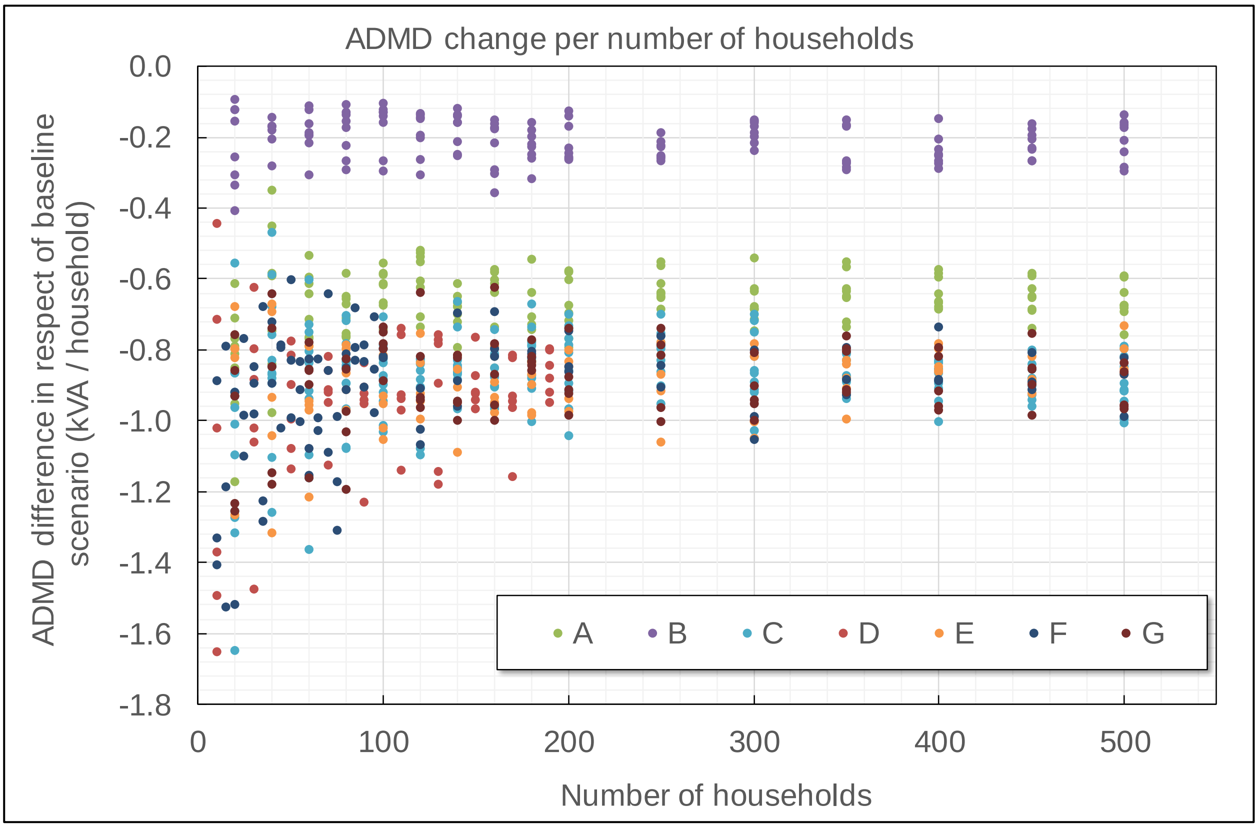


Figure 4-6: ADMD change in number of households for green interventions relative to a baseline without any form of intervention

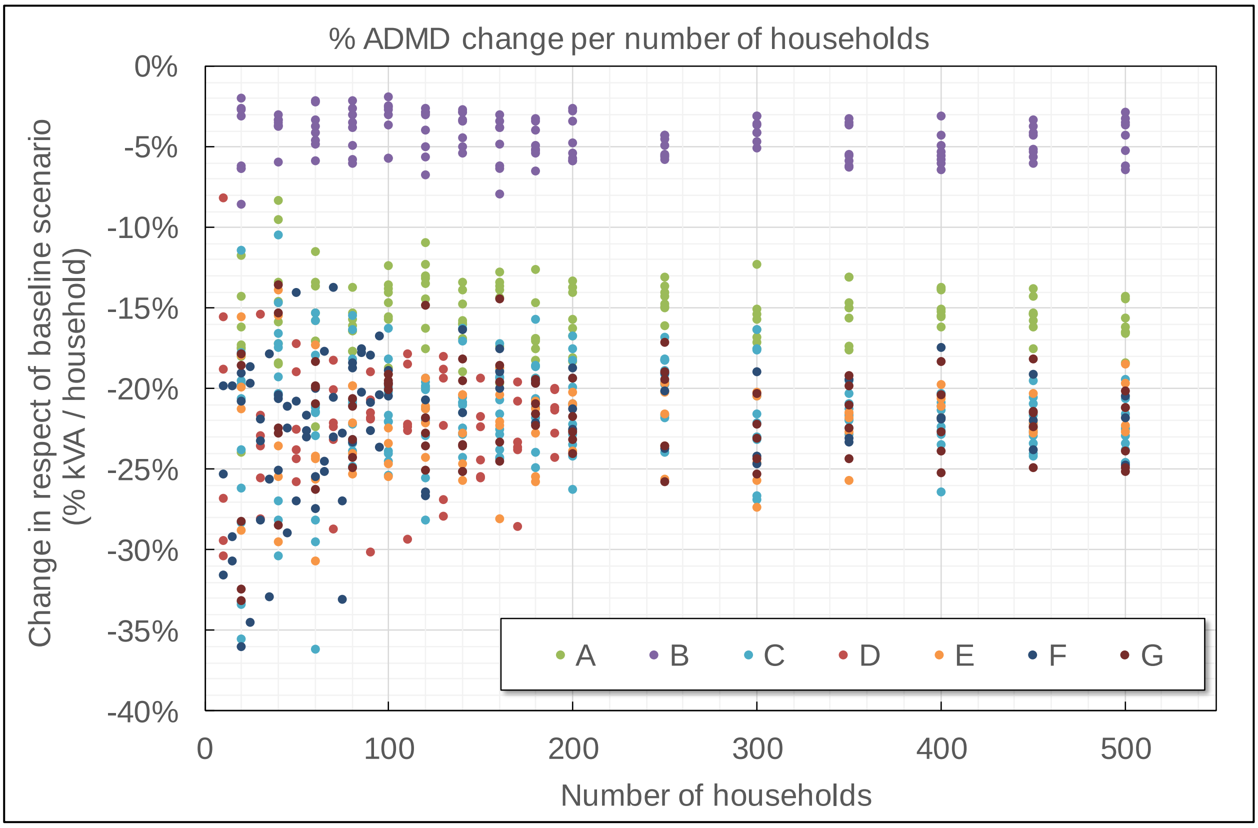


Figure 4-7: Percentage change in ADMD per number of households in the simulation group relative to a baseline without any form of intervention

4.3.3 Impact of green initiatives on coincidence

The impact on coincidence is expressed in Figures 4-8 and 4-9.

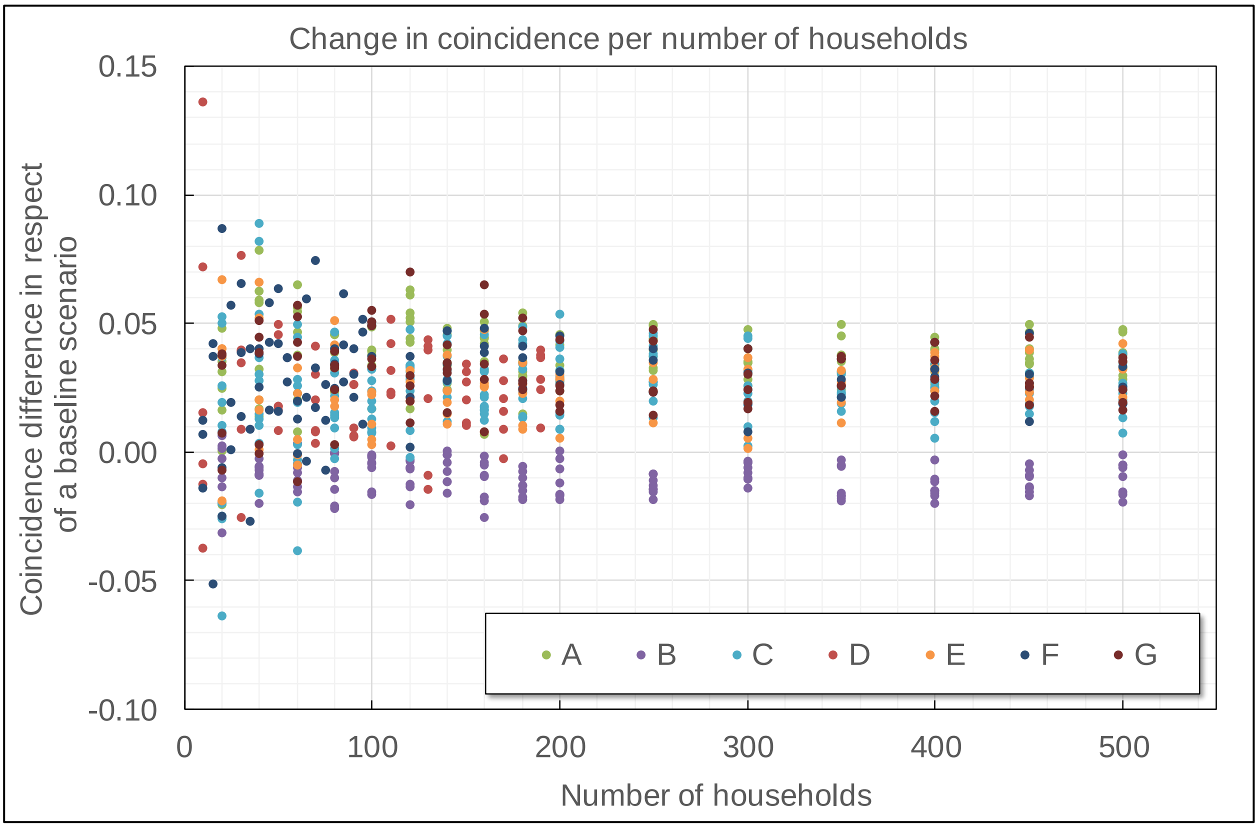


Figure 4-8: Impact on coincidence for green interventions relative to a baseline without any form of intervention

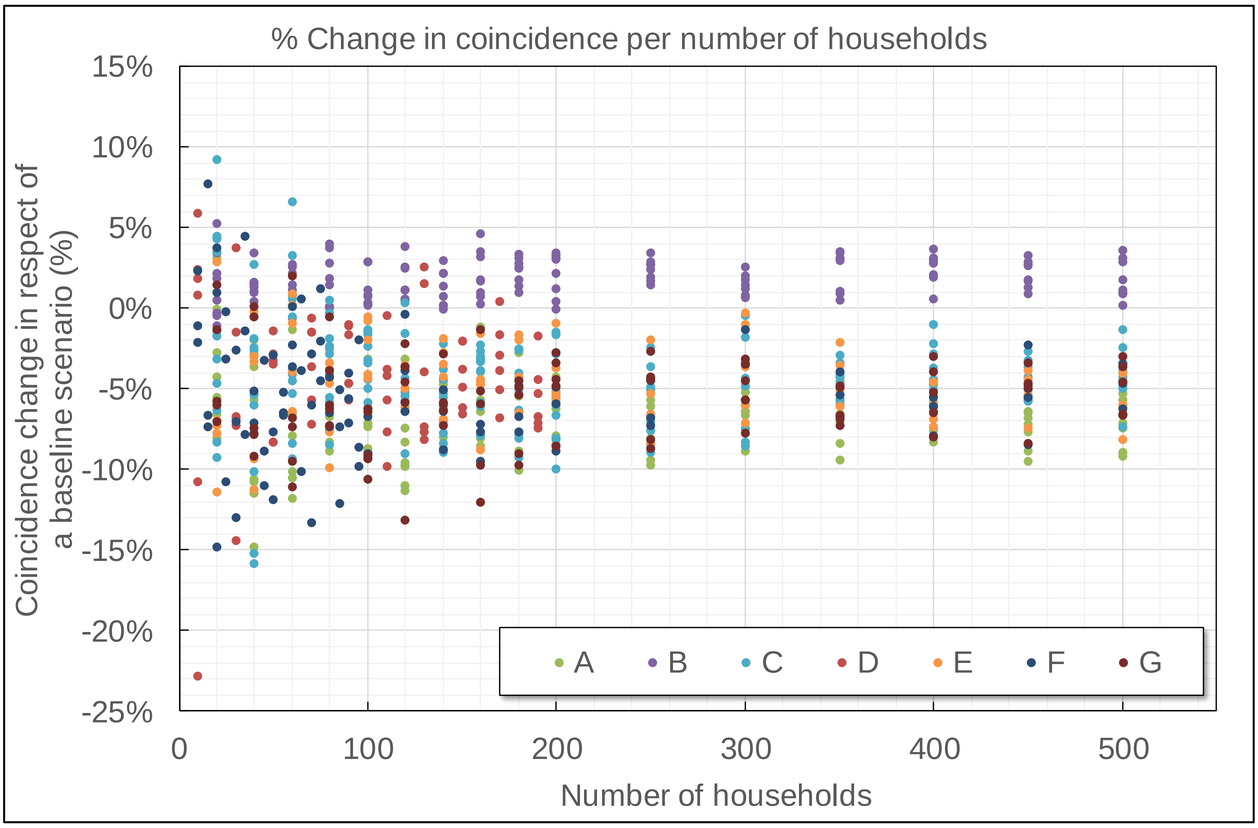


Figure 4-9: Percentage coincidence change for green interventions relative to a baseline without any form of intervention

4.3.4 Impact of green initiatives on load factor

The impact on load factor is observed in Figures 4-10 and 4-11.

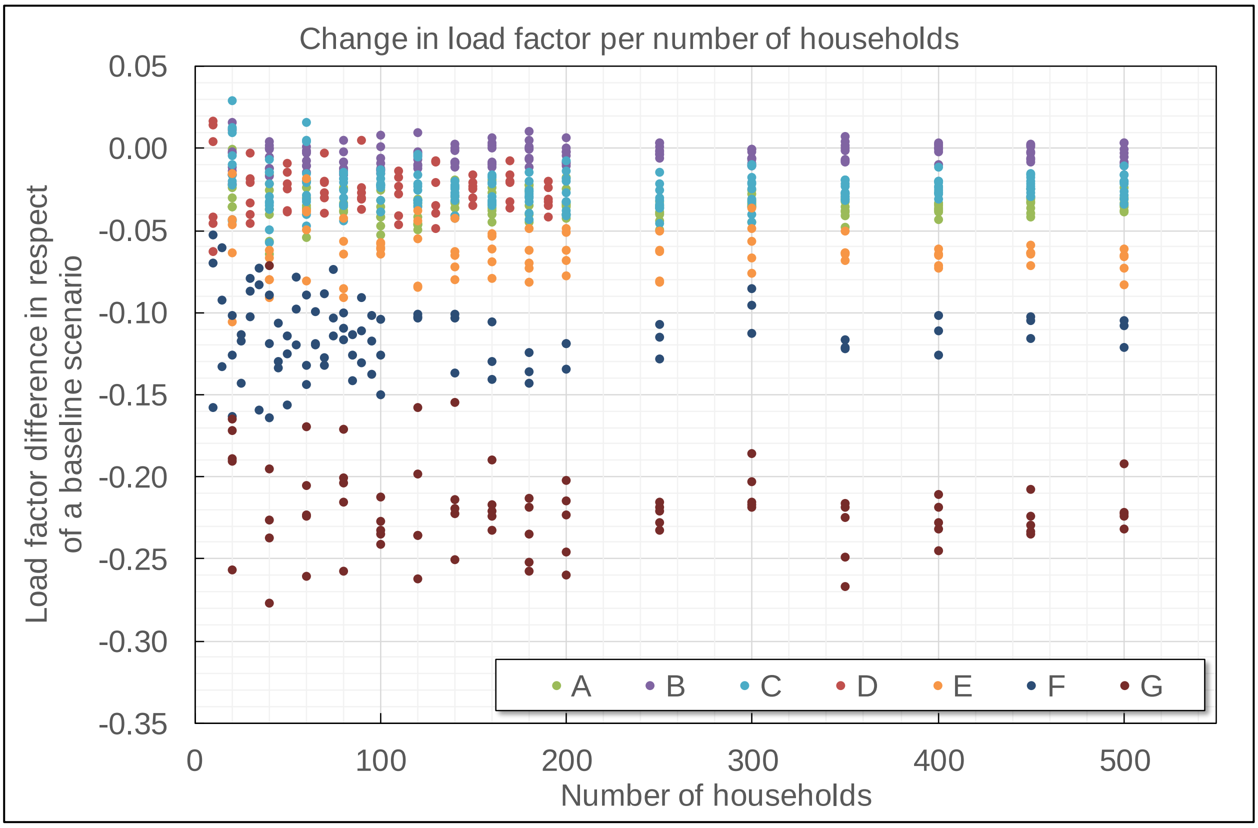


Figure 4-10: Impact on load factor for green interventions relative to a baseline without any form of intervention

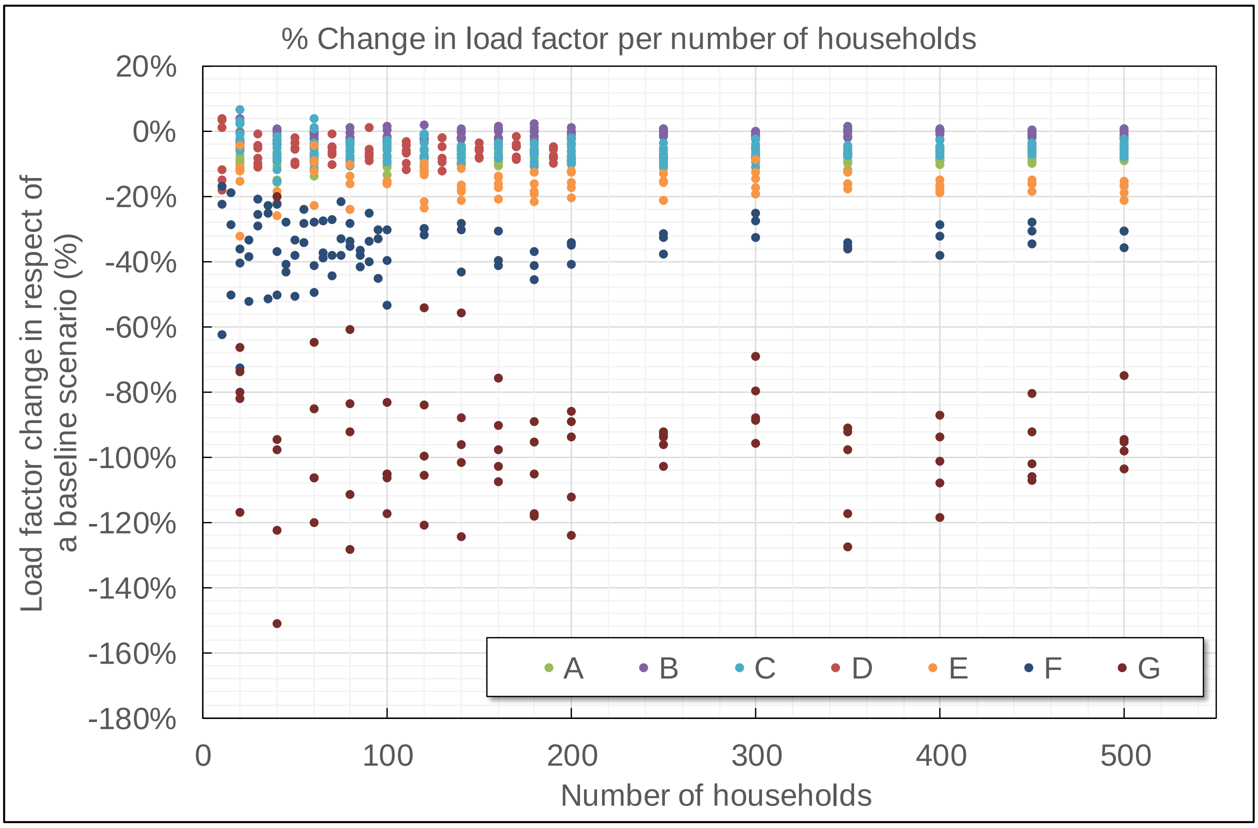


Figure 4-11: Percentage change in load factor for green interventions relative to a baseline without any form of intervention

4.3.5 Summary of initiatives and interdependent impact

The impact of the various green initiatives on ADMD, coincidence and load factor is summarized in Table 4-3.

Table 4-3: Impact on parameters for simulations of 100 households or more

Study scenario	**PV penetration level**	**PV Size kW**	**Gas stoves**	**Solar geysers**	**ADMD change kVA**	**ADMD change %**	**Coin-cidence change %**	**Load factor change %**
A-Green	10%	1.5		X	-0.52 to -0.85	-11 to -20	-1 to -11	-4 to -13
B-Purple	10%	1.5	X		-0.1 to -0.36	-2 to -8	0 to +5	-3.5 to +2.4
C-Cyan	10%	1.5	X	X	-0.66 to -1.09	-16 to -28	-1 to 0	-1 to -10

Study scenario	PV penetration level	PV Size kW	Gas stoves	Solar geysers	ADMD change kVA	ADMD change %	Coin-cidence change %	Load factor change %
D-Red	20%	1	X	X	-0.74 to -1.18	-18 to -29	-10 to +2.5	-2 to -12
E-Orange	20%	3	X	X	-0.73 to -1.09	-18 to -29	-9 to 0	-24 to -9
F-Dark blue	40%	3	X	X	-0.69 to -1.07	-16 to -27	-9 to 0	-25 to -53
G-Maroon	50%	5	X	X	-0.63 to -1.00	-14 to -26	-13 to -1	-54 to -127

Negative change indicates a reduction in value. This table is perhaps better illustrated graphically in Figure 4-12 (a)-(d):

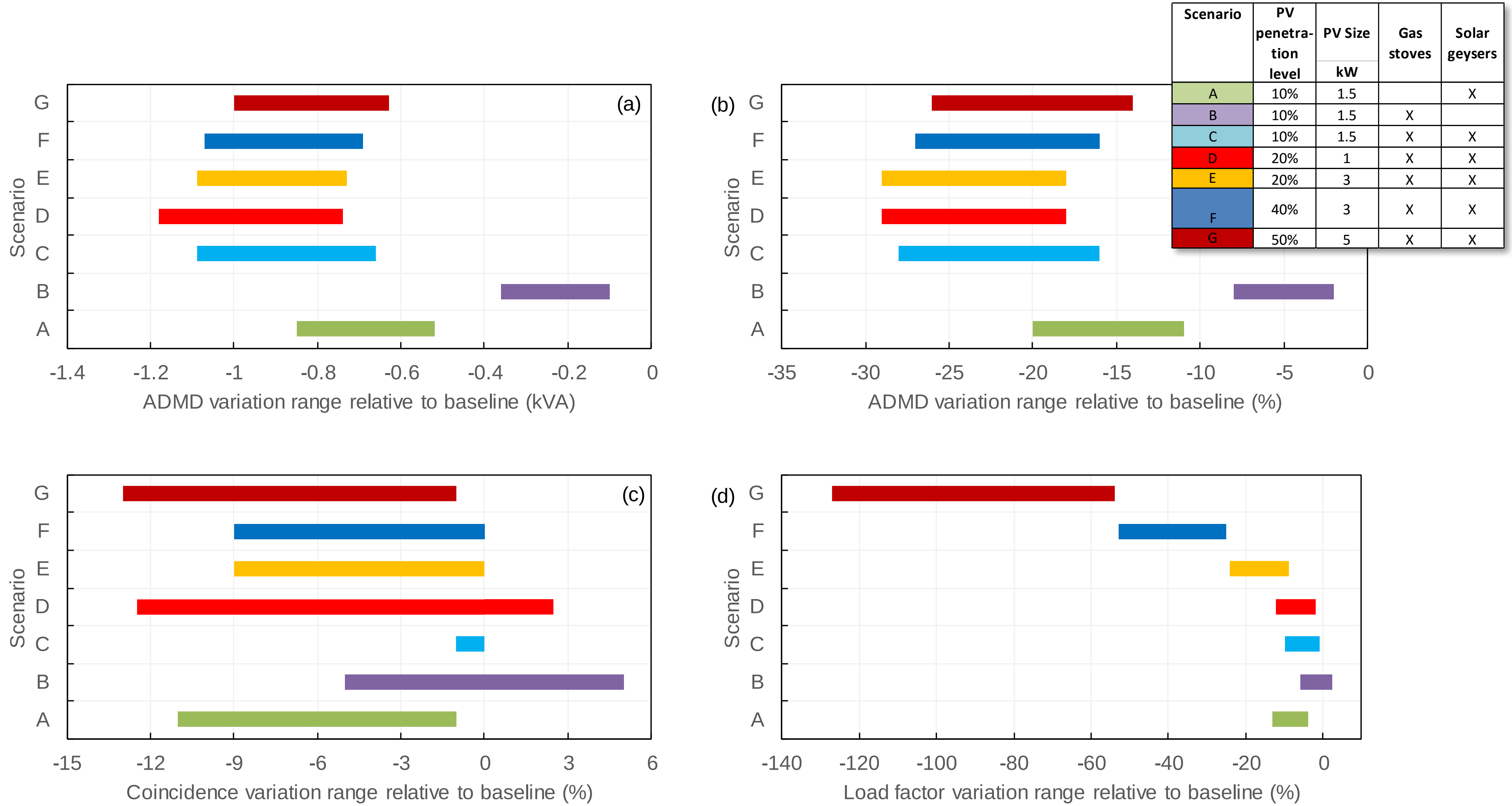
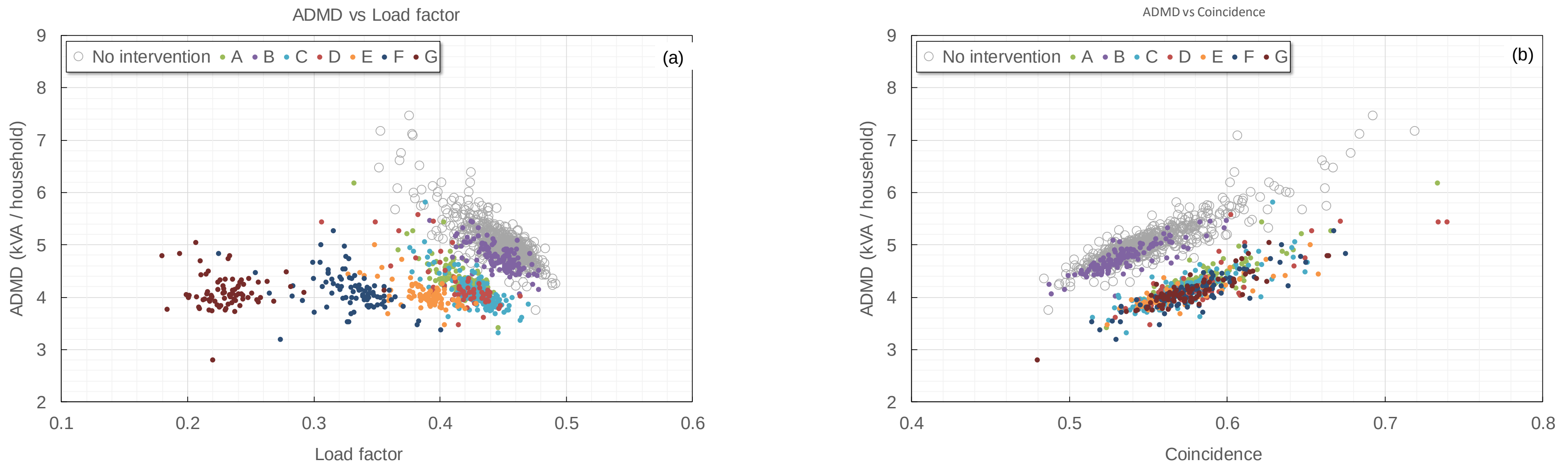
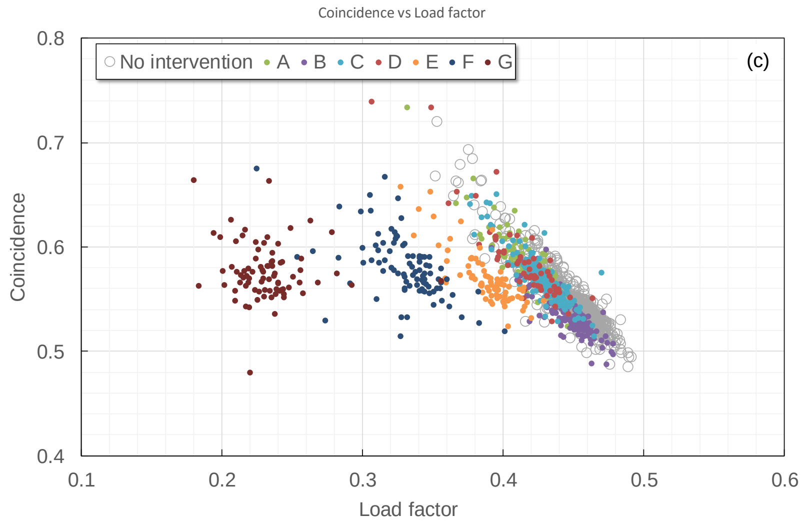


Figure 4-12: Impact of various green interventions: (a) ADMD change in kVA, (b) ADMD % change, (c) Coincidence % change and (d) Load factor percentage change

The load factor was further investigated in respect of coincidence. The graphs in Figure 4-12 illustrate the findings:





Key for scenarios of intervention combinations:

Scenario	PV penetration level	PV Size kW	Gas stoves	Solar geysers
A	10%	1.5		X
B	10%	1.5	X	
C	10%	1.5	X	X
D	20%	1	X	X
E	20%	3	X	X
F	40%	3	X	X
G	50%	5	X	X

Figure 4-13: Additional findings: (a) ADMD vs Load factor; (b) ADMD vs Coincidence; (c) Coincidence vs Load factor

In summary, the following conclusions can be drawn:

Table 4-4: Summary of impact to ADMD, coincidence and load factor due to implementation of various green initiatives

Variance in or application of green initiatives	Impact on ADMD, Coincidence and Load factor
Replacing electrical geysers with solar geysers	Largest reduction in ADMD through appliance replacement. Increase in coincidence, i.e. provide less diversity. Less coincidence is usually associated with higher ADMDs. Slight decrease in load factor due to lower energy usage.
Replacing electrical stoves with gas stoves	Reduces ADMD only slightly. Almost the same deviation from original coincidence in either direction. It is concluded that replacement of stoves with gas stoves does not significantly impact coincidence. Slight decrease in load factor due to lower energy usage.
Replacing electrical geysers with solar geysers and electrical stoves with gas stoves	Combined effect yields significant ADMD reduction. Combined effect causes little to no change in coincidence. Small change in load factor.
Increase solar PV penetration level	ADMD and coincidence levels do not change if reverse power flow does not cause ADMD to shift from evening peak to midday peak. Load factor reduces significantly due to reduction in energy consumption
Increase solar PV size	ADMD and coincidence levels do not change if reverse power flow does not cause ADMD to shift from evening peak to midday peak. Load factor reduces significantly due to reduction in energy consumption.

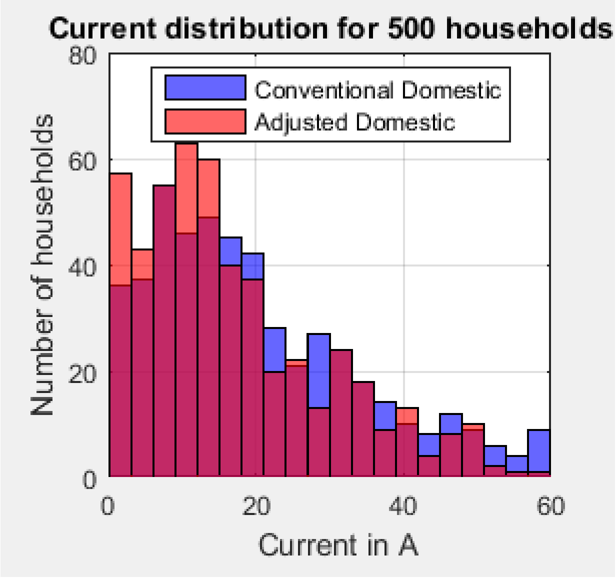
Variance in or application of green initiatives	Impact on ADMD, Coincidence and Load factor
Increase solar PV penetration level and size	ADMD and coincidence levels do not change if reverse power flow does not cause ADMD to shift from evening peak to midday peak. Load factor reduces significantly due to reduction in energy consumption

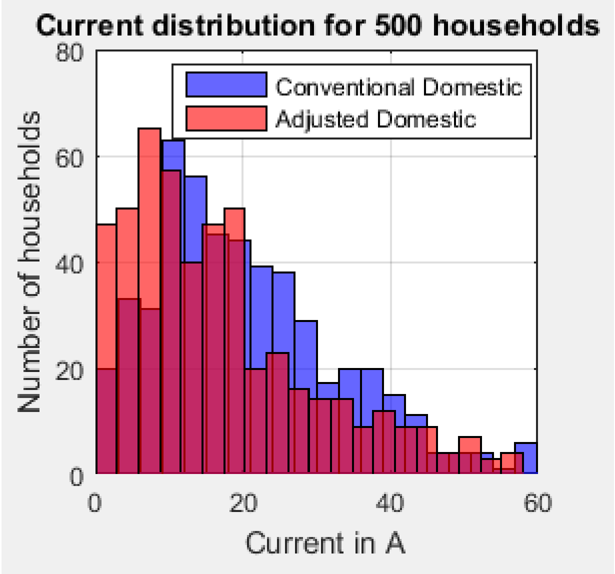
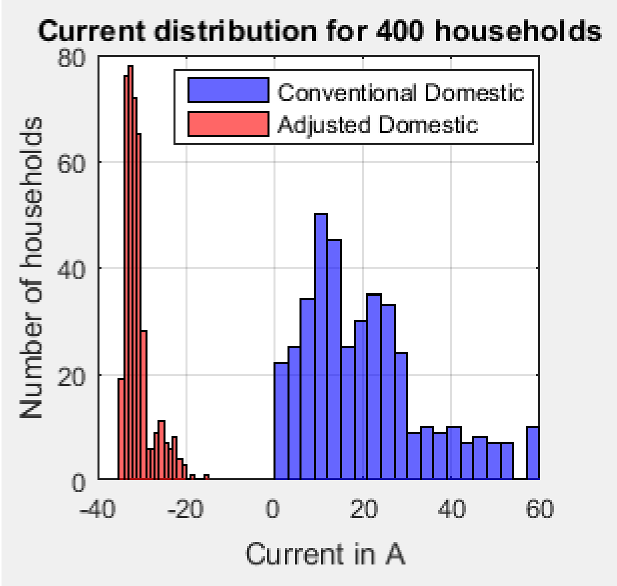
4.3.6 Analysis of the distribution of peak current

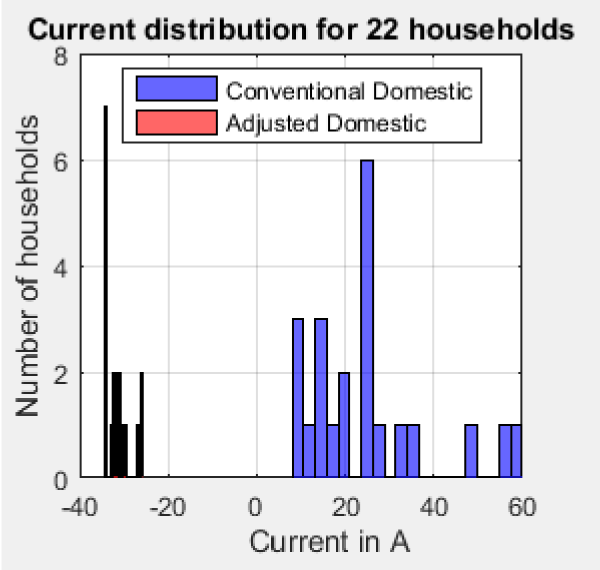
The model also allows for the analysis of the distribution of currents. The theory associated with the Herman-Beta voltage drop method states that the currents at peak time follows a Beta distribution curve. Using the *T* and *Adjusted_T* matrices, the current distribution at the time of coincident maximum demand can be observed. The current distribution is best viewed in the form of a histogram, where the frequency of occurrence of a current can be displayed against the current. The model assumes that the load has no dependency on voltage.

In the diagrams in Table 4-5, the peak current distribution is displayed in blue for a conventional case (no "green" measures), while the current distribution when adjustments through "green" measures are made, is displayed in red. Where the two scenarios overlap, it displays in maroon.

Table 4-5: Distribution of peak currents under various scenarios

Distribution of peak currents	Scenario summary
	Conventional ADMD: 4.7 kVA Adjusted ADMD: 3.97 kVA Conditions for adjusted curve: Solar PV 3 kW, 20% penetration Two geysers replaced with solar geysers. Stove replaced with gas stove. Conventional load factor: 0.47 Adjusted load factor: 0.39 Conventional coincidence: 0.51 Adjusted coincidence: 0.56

Distribution of peak currents	Scenario summary
	Conventional ADMD: 4.8 kVA Adjusted ADMD: 3.96 kVA Conditions for adjusted curve: Solar PV 5 kW, 50% penetration. Two geysers replaced with solar geysers. Stove replaced with gas stove. Conventional load factor: 0.46 Adjusted load factor: 0.24 Conventional coincidence: 0.53 Adjusted coincidence:0.57
	Conventional ADMD: 4.8 kVA Adjusted ADMD: -7.3 kVA Solar PV 7.5 kW 100% penetration Two geysers replaced with solar geysers. Stove replaced with gas stove. Conventional load factor: 0.46 Adjusted load factor: 0.13 Conventional coincidence: 0.54 Adjusted coincidence:1.0

Distribution of peak currents	Scenario summary
	Conventional ADMD: 5.9 kVA Adjusted ADMD: -7.45 kVA Solar PV 7.5 kW 100% penetration Two geysers replaced with solar geysers. Stove replaced with gas stove. Conventional load factor: 0.41 Adjusted load factor: 0.1 Conventional coincidence: 0.59 Adjusted coincidence: 0.94 Note: The narrow distribution cause the red bars to display the black boundaries close to one another and appears black.

From these results, the following observations are made:

- For the first and second graphs, there is a slight shift towards the left on the graph from the conventional scenario to the adjusted load profile scenario. The mean of a beta distribution represents the ADMD, and a mean shifting left is indicative of an ADMD reduction, which was confirmed through calculation.

- It is also observed that for the first and second graphs in the table, the load factor decreases, and the coincidence increases. An increase in coincidence is indicative of the reduction in diversity. With less geysers and stoves in the network, there is less variability in the load composition as seen from a supply transformer point of view.

- For the third and fourth graphs in the table above, there is a total lack of diversity when the peak currents flow in the reverse direction. The lack of diversity is observed through the lack of a wide distribution of currents. A larger number of the households draw the same current. The peak has shifted from 18:00 to 12:00 due to solar PV power in excess of own usage, and excess power is exported to the grid. Since this is the case in 100% of the households in the simulation, all the excess energy will flow back to MV/LV transformer and into the MV network. This may lead to LV feeder overloading in the reverse direction.

4.4 Load flow analysis

4.4.1 Analysis presented previously

The test feeder system in Chapter 3 was analysed in ReticMaster and presented in a paper at the AMEU convention in 2014, a paper delivered as part of this research [1]. The paper investigated the effects of increased ADMD as a result of ripple control and basic solar PV effects. In Reticmaster, the generated PV power was modelled as a pure active power generator without any reactive power capabilities. This is typical of an inverter with cos-phi control set at unity power factor where the current generated is in phase with the voltage.

However, Reticmaster does not have built-in inverter control functions, and Digsilent Powerfactory was used to investigate different forms of inverter control algorithms. This allowed for the investigation of inverters delivering reactive power, even for RPP categories A1 and A2

Digsilent Powerfactory allows for different forms of control, such as Q-control, Q-V control, Q-I control etc. The effects on voltage due to the deployment of different types of inverters or control algorithms were studied. The load flow studies also allow for the investigation of the research questions.

Table 4-6 below lists the scenarios investigated for two test feeders, a tapered cable feeder and a one size cable feeder, under high and low load conditions.

Table 4-6: Load flow scenarios

Scenario No.	**Scenario**	**High load** **Tapered feeder**	**High load** **One size feeder**	**Low load** **Tapered feeder**	**Low load** **One size feeder**
A1 & 2	No renewables (baseline)	HL-A1	HL-A2	LL-A1	LL-A2
E1	One DG unit close to transformer – 3 kW	HL-E1		LL-E1	
E3	One DG unit midway along feeder – 3 kW	HL-E3		LL-E3	
E2	One DG unit at the end of the feeder – 3 kW	HL-E2		LL-E2	

Scenario No.	Scenario	High load Tapered feeder	High load One size feeder	Low load Tapered feeder	Low load One size feeder
C, D	100% DG penetration – 3 kW	HL-D2,3,4,6,7	HL-C2,3,4,6,7	LL-D2,3,4,6,7	LL-C2,3,4,6,7
F, G	100% DG penetration – 9 kW	HL9-G2,3,4,6,7	HL9-F2,3,4,6,7	LL9-G2,3,4,6,7	LL9-F2,3,4,6,7

Control Algorithms 2, 3, 4, 6 and 7 for scenarios C, D, F and G in Table 4-6 are:

- 2: Voltage Q-droop: Reactive power is controlled proportionally to the voltage deviation from a set-point.
- 3: Voltage Iq-droop: Reactive current is controlled proportionally to the voltage deviation from a set-point.
- 4: Constant Q: The active and reactive power outputs are fixed according to user criteria specified.
- 6: Q(V) characteristic: Reactive power controller with a variable set-point. Within the set-point voltage limits, the reactive power output is maintained.
- 7: Cos phi (P) characteristic: Power factor controller.

Methods 1 and 5 in Digsilent Powerfactory were not investigated. Method 1 is for constant voltage control, where the voltage is controlled by varying the reactive power to maintain a setpoint voltage at the busbar. Method 5 is a Q(P) characteristic where the reactive power is varied according to the power output of the inverter.

Residential PV systems are generally controlled at unity power factor and the inverter will provide active power only to the network. Larger generation plant is required to be able to implement multiple control algorithms and the system operator may switch between these control functions.

4.4.2 **Baseline analysis**

To compare results, load flow studies under high and low load conditions were conducted for the two test feeders (tapered cable size feeder, and one cable size feeder) as per the scenarios listed in Table 4-6. Figures 4-14 and 4-15 illustrate the baseline voltage profiles along the two test feeders (tapered feeder and one-size feeder) under high and low load conditions respectively.

The analysis was done in Digsilent Powerfactory, using the unbalanced low voltage load flow settings. The coincidence factors required for high load conditions and low load conditions were calculated as follows:

- For high load conditions: ADMD = 13.8 kVA maximum demand x coincidence factor of 0.384058 = 5.3 kVA per house. 13.8 kVA is equivalent to a 60 A single-phase connection at 230 V at unity power factor. This represents the evening load.
- For low load conditions: Demand = 13.8 kVA maximum demand x coincidence factor of 0.17 = 2.346 kVA per house. This represents the midday load as baseline before adding solar PV to the network.

Of the two test feeder systems under high load conditions, the tapered cable feeder performed the worst although, both comply with legal limits (i.e. a voltage above 0.9 p.u. at the house).

A notable slight voltage rise in the blue phase is observed at the end of the feeder without any form of DG present. This was somewhat unexpected as one expects the voltage to drop continuously over the feeder length and this was noted in both Reticmaster and Digsilent Powerfactory. It can only be concluded that it is caused by a momentary unbalance at that particular point along the feeder.

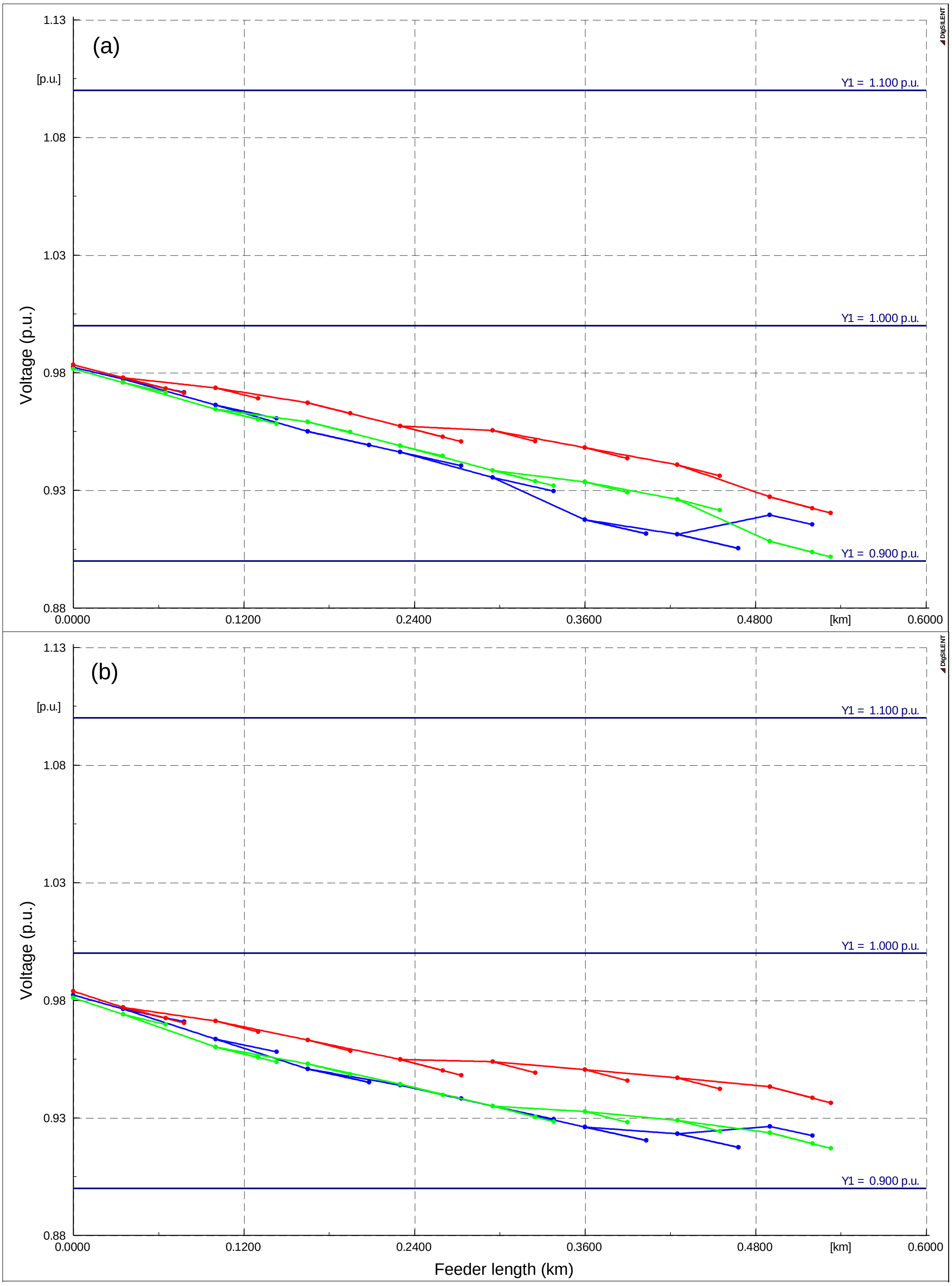


Figure 4-14: Baseline Digsilent Powerfactory voltage profile for the red, white and blue phases respectively along test feeder under high load conditions for a) tapered feeder, and b) one-size feeder

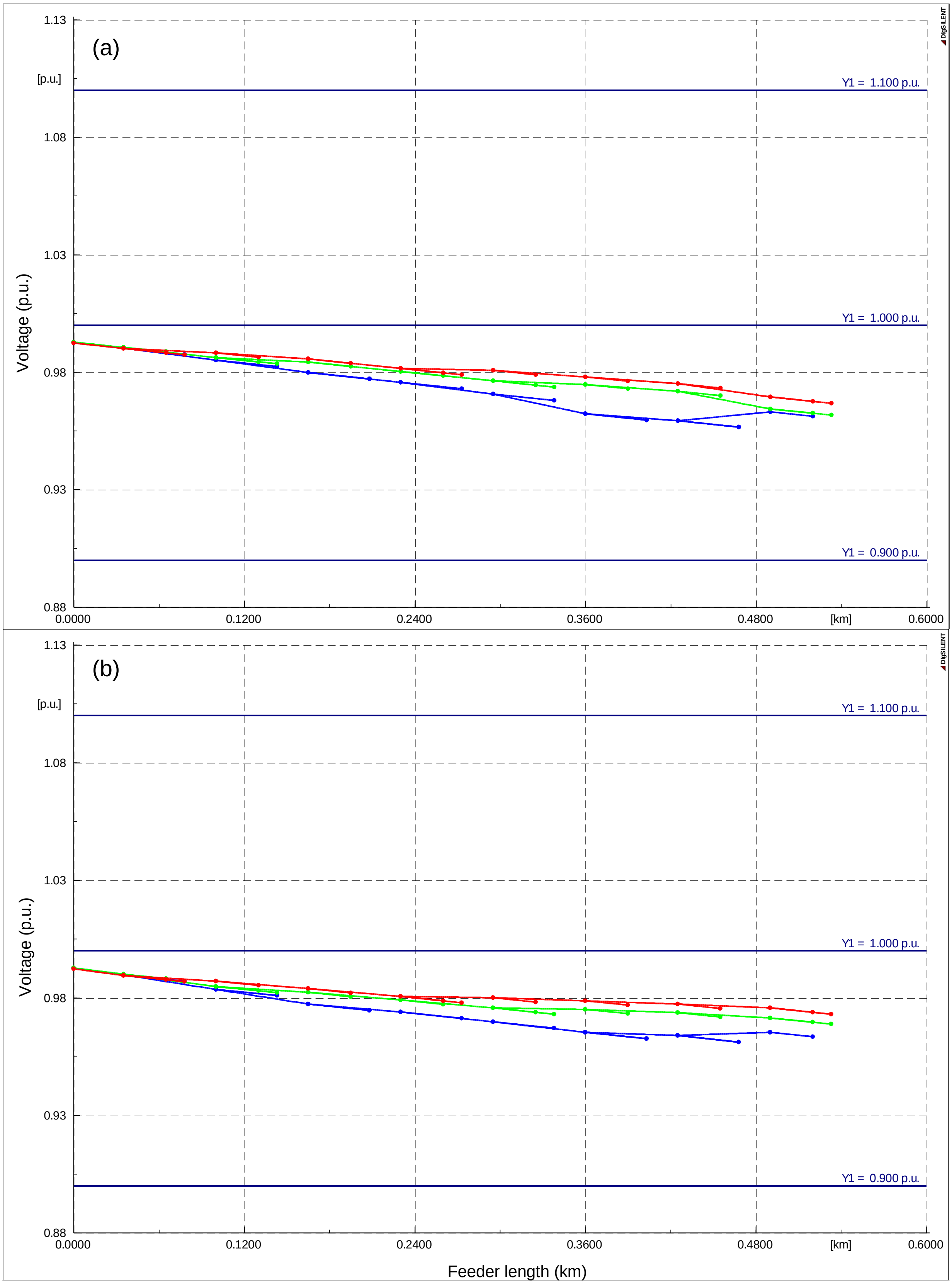
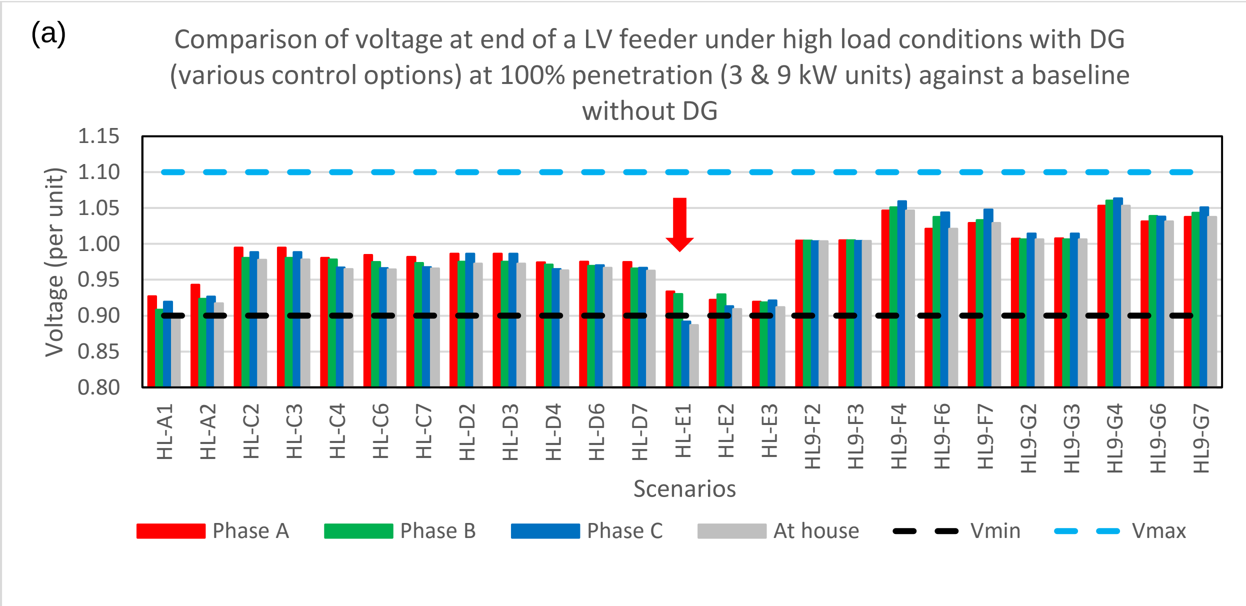


Figure 4-15: Baseline Digsilent Powerfactory voltage profile for the red, white and blue phases respectively along test feeder under low load conditions for a) tapered feeder, and b) one-size feeder

4.4.3 Comparison of results with different DG control algorithms: voltage

Even though solar PV will generate very little to nothing during the evening peak (high demand), other forms of DG may be present, such as micro wind turbines. The impact to voltage at the end of LV feeders for the two test feeder systems, when adding DG, were investigated considering various DG inverter control algorithms and penetration levels (refer to Table 4-6 for scenario descriptions). The results compared against the baselines are illustrated in Figure 4-16.



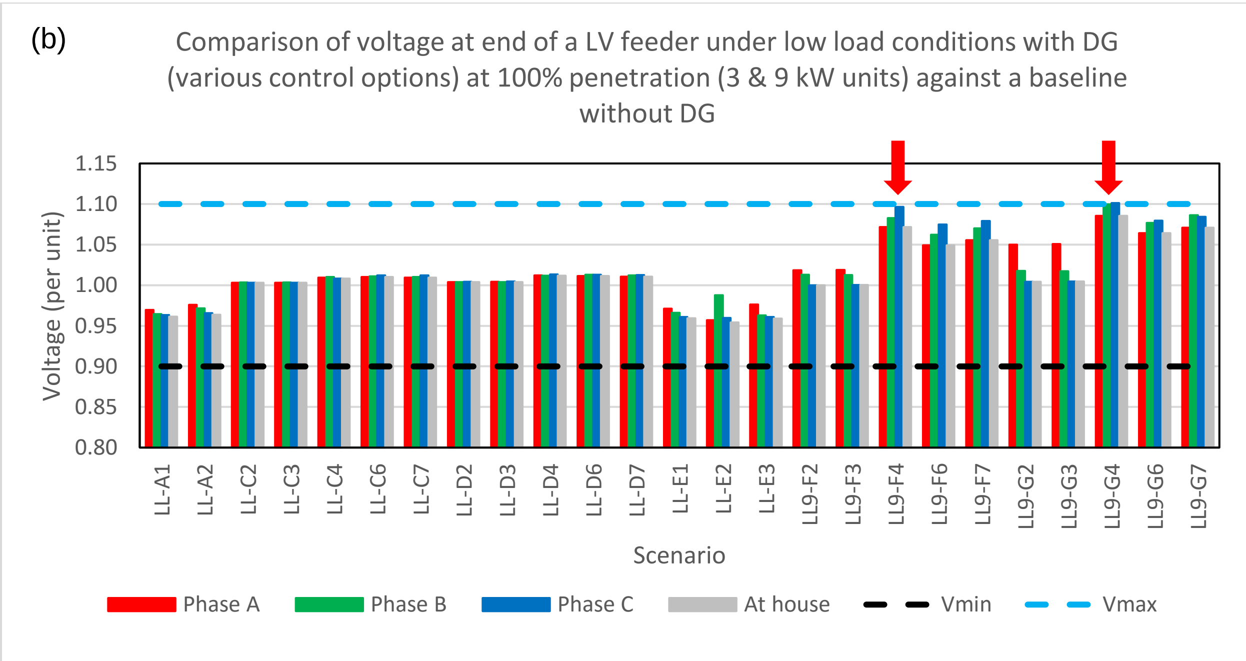


Figure 4-16: Comparison of various inverter control methods and sizes for a) high load conditions and b) low load conditions. Red arrows point to violation of voltage limits.

Scenarios A1 and A2 are the baseline scenarios for the tapered and one-cable-size feeders respectively. Under high load conditions, adding one 3 kW LV generator close to the transformer (scenario HL-E1), results in a voltage at the end of the feeder below 0.9 p.u. at the distribution kiosk and at the house on one of the phases.

Under low load conditions, the voltage at the end of the feeder rises once DG is introduced. As the size of DG increases, the voltage may rise to the point where the upper voltage limit is reached or exceeded (see scenarios LL9-F4 and LL9-G4).

4.4.4 Comparison of results with different DG control algorithms: current

The impact on the current carrying capacity of the cable for the test feeders for the various scenarios evaluated is graphically illustrated in Figures 4-17 and 4-18 for high load conditions, and Figures 4-19 and 4-20 for low load conditions.

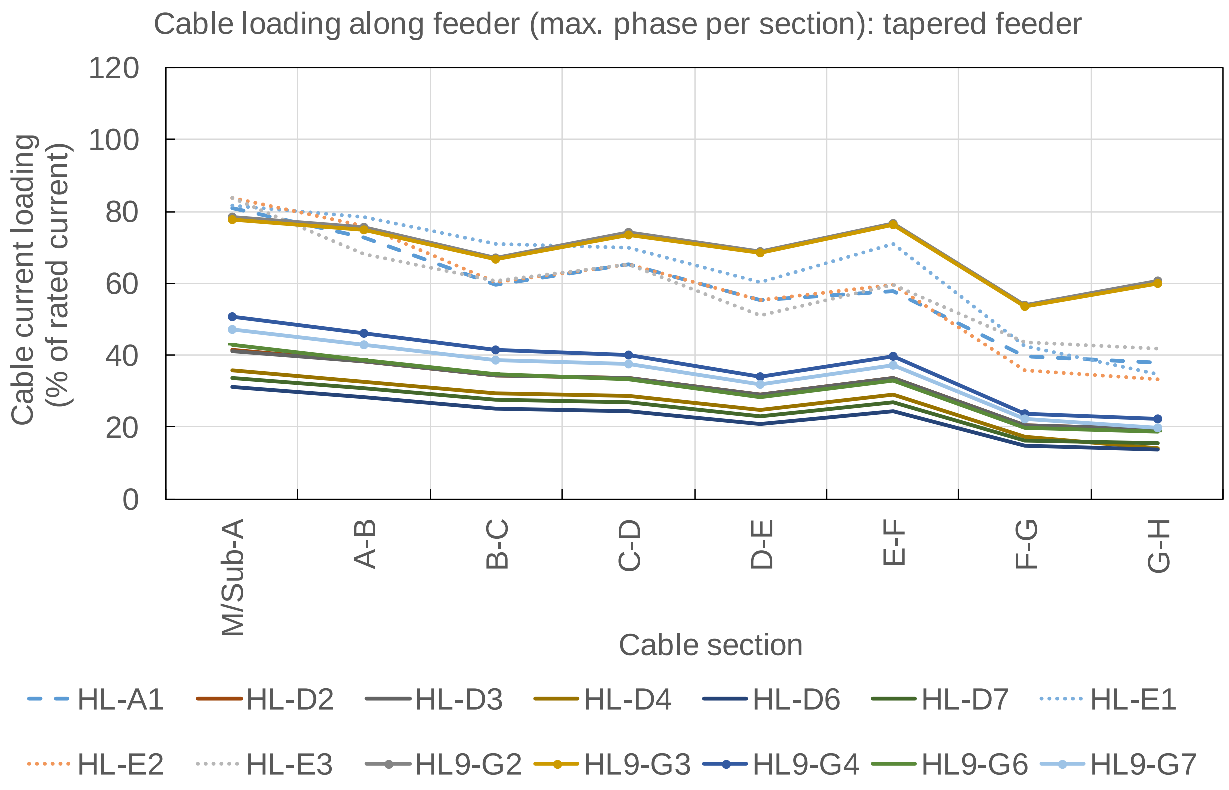


Figure 4-17: Cable loading (percentage of rated current for the highest loaded phase) along feeder for the tapered feeder under high load conditions

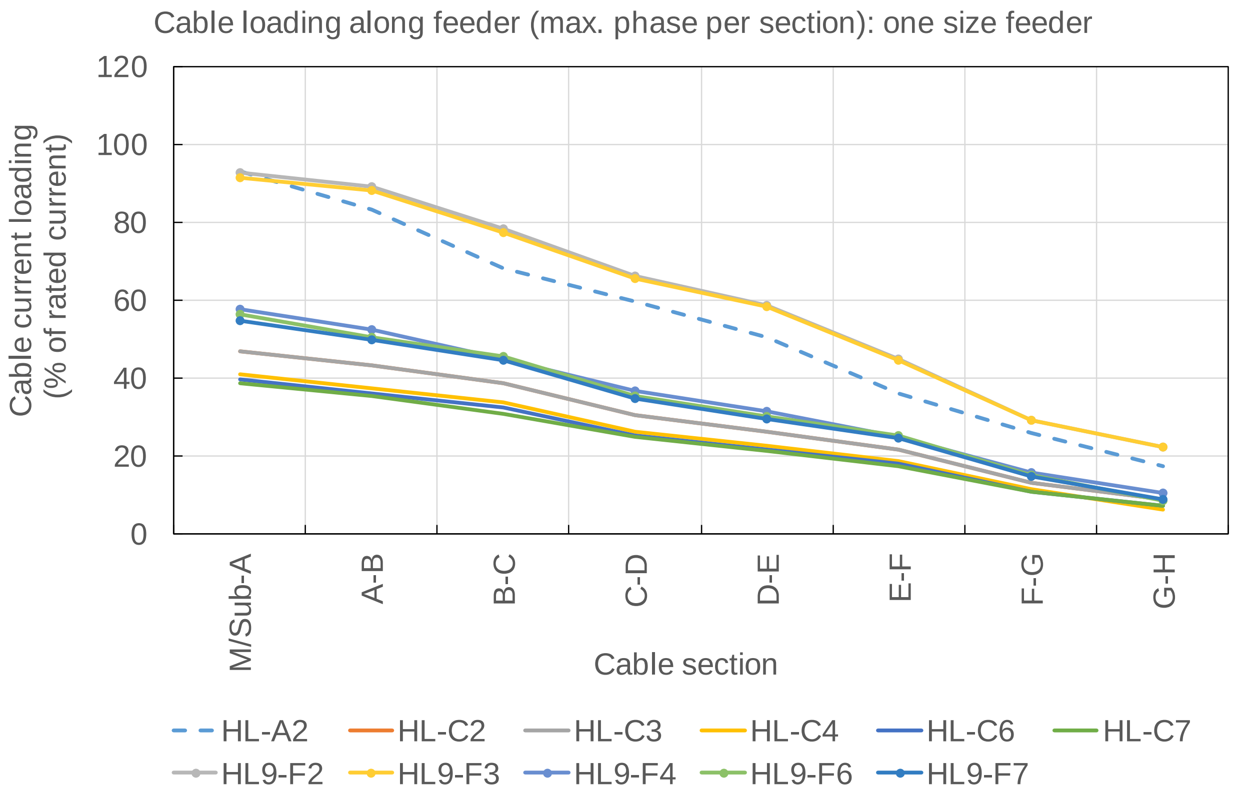


Figure 4-18: Cable loading (percentage of rated capacity for the highest loaded phase) for the one-size feeder under high load conditions

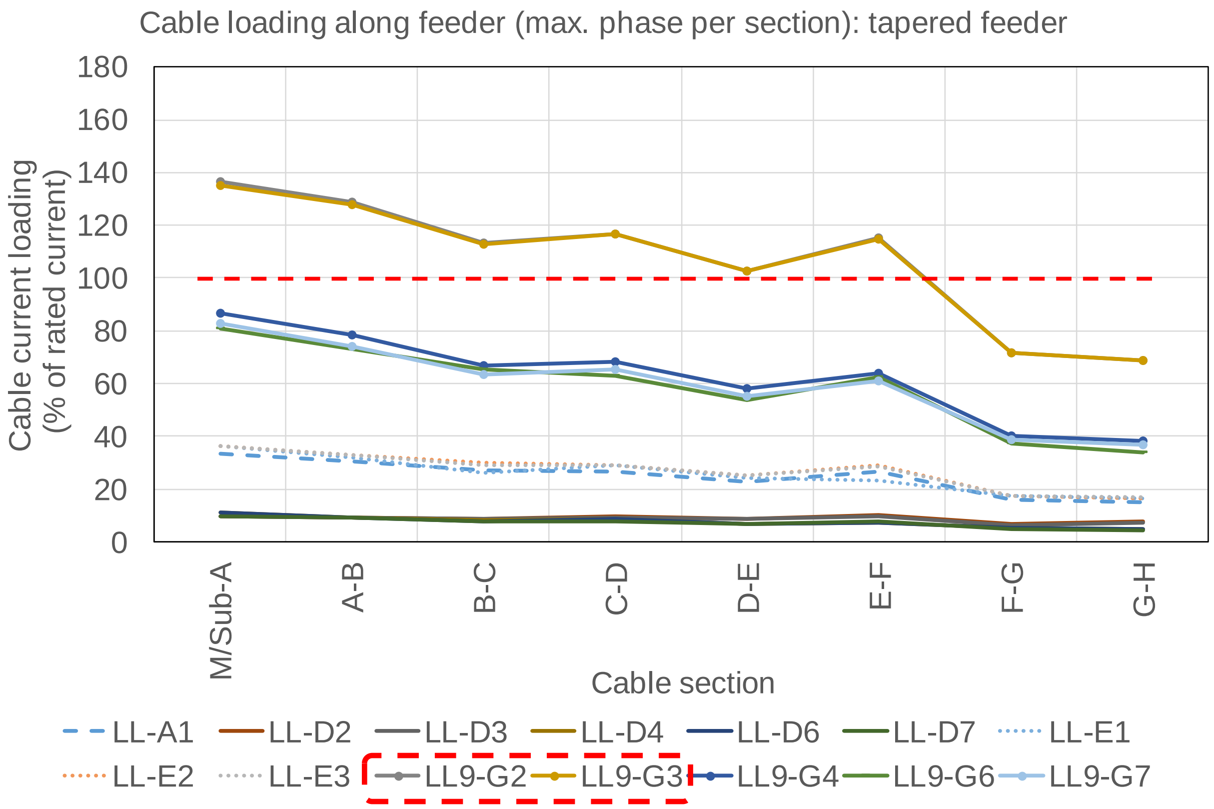


Figure 4-19: Cable loading (percentage of rated capacity for the highest loaded phase) along feeder for the tapered feeder under low load conditions. Scenarios marked with a red dashed box failed on cable overloading.

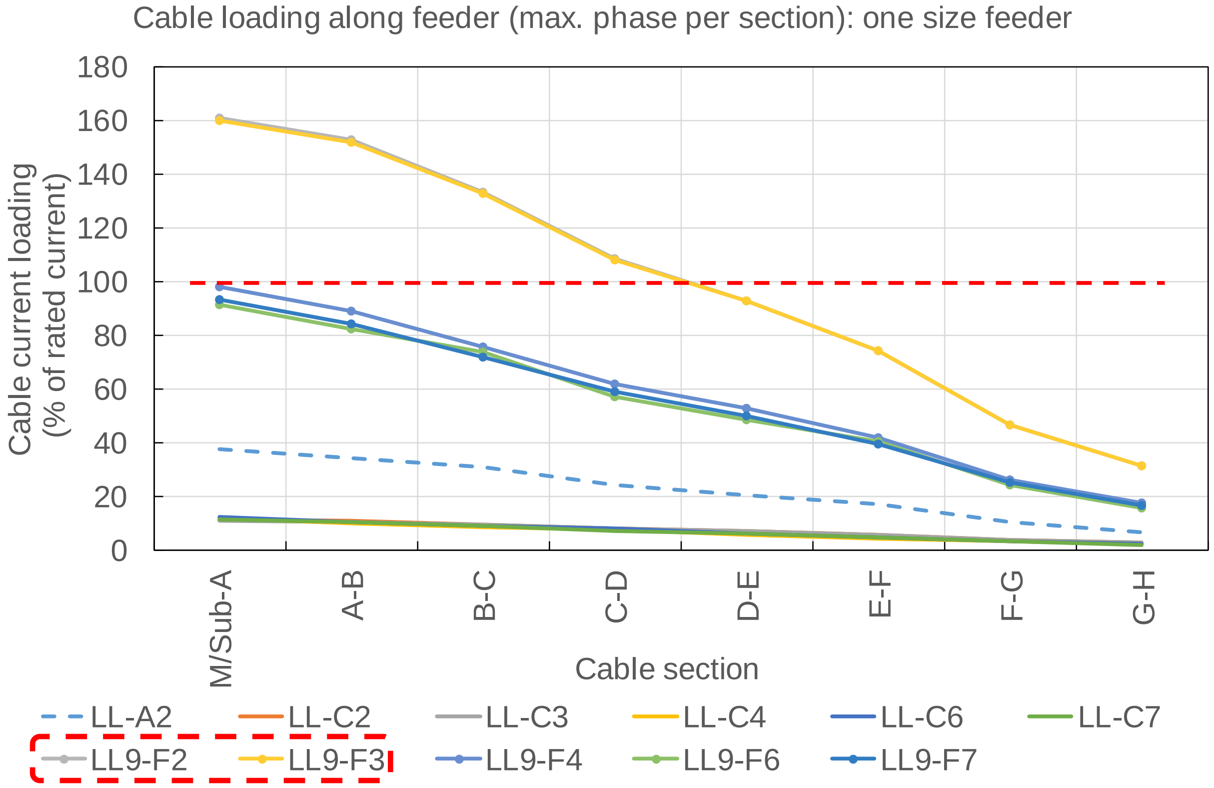


Figure 4-20: Cable loading (percentage of rated capacity for the highest loaded phase) for the one-size feeder under low load conditions. Scenarios marked with a red dashed box failed on cable overloading.

Under high load conditions, injecting large quantities of energy from the load's side does not adversely affect the cables in terms of their rating. Should DG larger than 9 kW be deployed, problems closer to the transformer may be experienced.

Under low load conditions the cable will be overloaded due to power flow in the reverse direction when deploying large DG systems, for example a 9 kW solar PV system at 100% penetration level, should inverters be capable of Voltage Q-droop and Voltage Iq-droop control algorithms be utilized. 100% penetration of 3 kW systems will typically not cause problems in a 5.3 kVA ADMD conventional network.

Similar than the tapered feeder, Voltage Q-droop and Voltage Iq-droop control algorithms for large DG systems deployed in residential systems, for example 100% penetration of 9 kW solar PV systems, also cause high cable loading due to reverse power flow.

Assuming that the utility was not consulted in the implementation of a large PV system implementation in a community, it is necessary to carefully consider past protection philosophies.

Considering the currents that can flow under overloaded cable conditions by studying Figure 4-21 below.

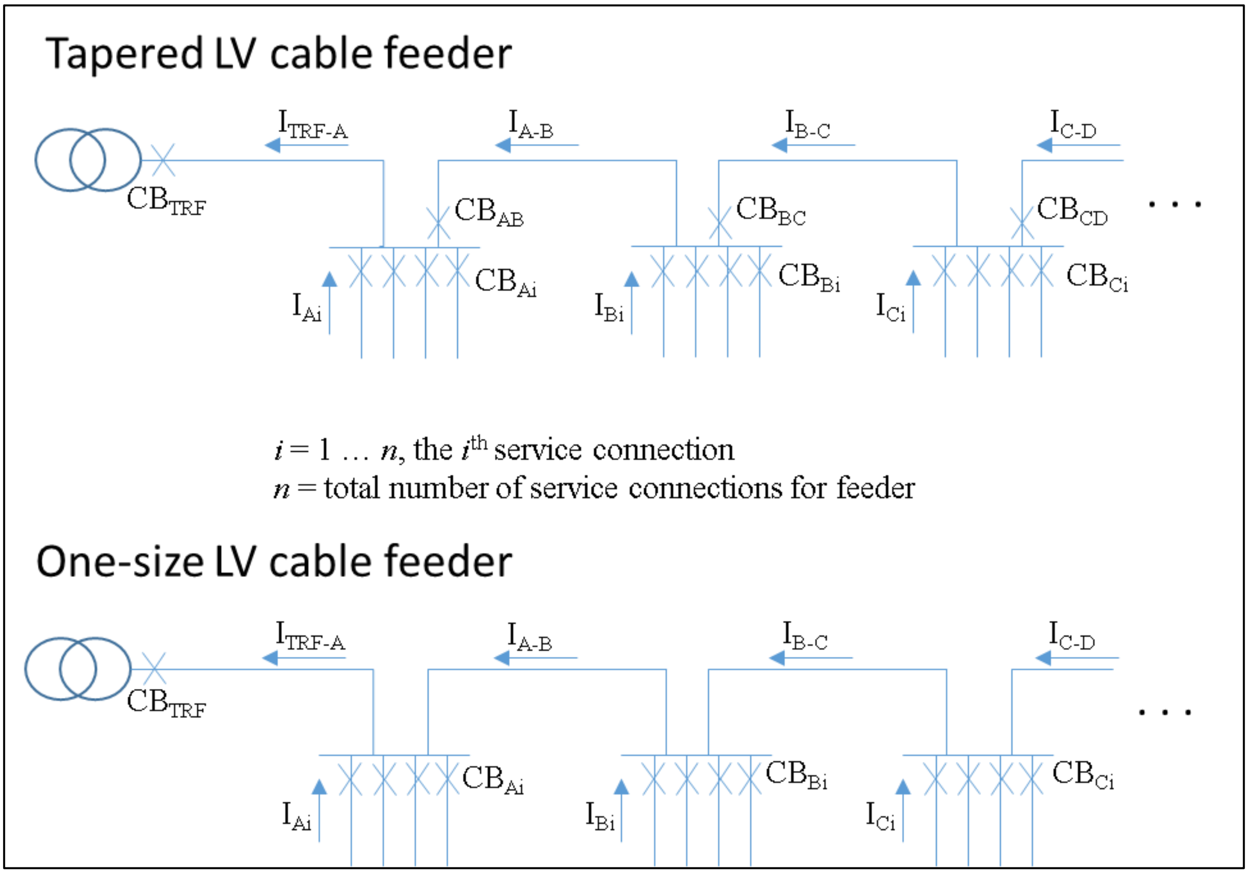


Figure 4-21: Protection device arrangement for a tapered and one-size LV cable feeder

The protection arrangement for both feeders are acceptable in the industry. A municipality in the North-West province of South Africa implements the one-size cable feeder philosophy with aluminium primary LV cables. The circuit breaker at the transformer protects the full cable. In a tapered cable feeder system, a circuit breaker is required each time the cable size is reduced.

For a 9 kW system, where the consumers have implemented single phase systems in contrast to the Grid Code requirement of a three-phase system, the original 60 A or 80 A circuit breakers are still adequately rated for current flowing into the grid.

The current direction for the primary cables is reversed, and the circuit breaker initially specified to protect the cable downstream from it is now located downstream from the cable it must protect. A circuit breaker in general will trip at 130% of its current rating (I_n). The cable will be subject to a higher current for a while. For the cable overload scenario in figure 4-20, the following question arises: if CB_{TRF} is a 250 A circuit breaker, does the cable burn off before the circuit breaker trips? If all feeders on the transformer exceed their limits by the same margin, the design current capacity of the transformer is exceeded. NRS097 attempts to prevent exactly this scenario by limiting LV current flowing to the MV network.

To determine the burn-off time of the cable, the following formula is generally used:

$$I_{SC} = \frac{K \times A}{\sqrt{t}} \qquad \dots (37)$$

Where

I_{SC} =	Short circuit current in ampere
t =	duration of short circuit in seconds
K =	a constant depending on the conductor material used. K = 115 for copper PVC / SWA / PVC cables and 76 for aluminium PVC /SWA /PVC cables.
A =	cable cross section in mm^2.

Replacing the short circuit current I_{SC} with the current that will flow under overload conditions (I), and rewriting Equation 37, the time in seconds the cable can withstand the current that will flow under such overload conditions becomes:

$$t = \left(\frac{K \times A}{I}\right)^2 \qquad \dots (38)$$

Using a current of 1.3 x 250 A for a 95 mm^2 cable, the cable will burn off in 18 minutes. For a 150 mm^2 cable, the burn-off time is 47 minutes. If the circuit breaker CB_{TRF} is rated at 250A, and the current that will flow through a 95 mm^2 copper cable is 160% of rated current, (refer to Figure 4-20), the cable burn-off time is 12 minutes, but the circuit breaker will trip in 2 minutes. A general check for cable burn-off against the circuit breaker tripping curve indicates that the risk of cable burn-off is low, when circuit breakers are selected according to the cables it should protect. This condition will hold true for tapered as well as one-size cable feeders.

In case of a fault, between distribution box A and B in Figure 4-1, in the case of the tapered feeder, circuit breakers CB_{AB} and CB_{BC} will trip. The circuit breakers feeding the houses (in the reverse power flow situation, the houses are feeding into the grid) should not trip, since the inverters must disconnect within approximately 200ms, if the inverters are complying with Grid Code requirements. In the case of the one-size feeder, CB_{TRF} will trip.

4.4.5 **Comparison of results with different DG control algorithms: total power flow**

The power flow that occurs because of the different DG control algorithms are illustrated in Figures 4-21 and 4-22 for the two test feeders under high load and low load conditions:

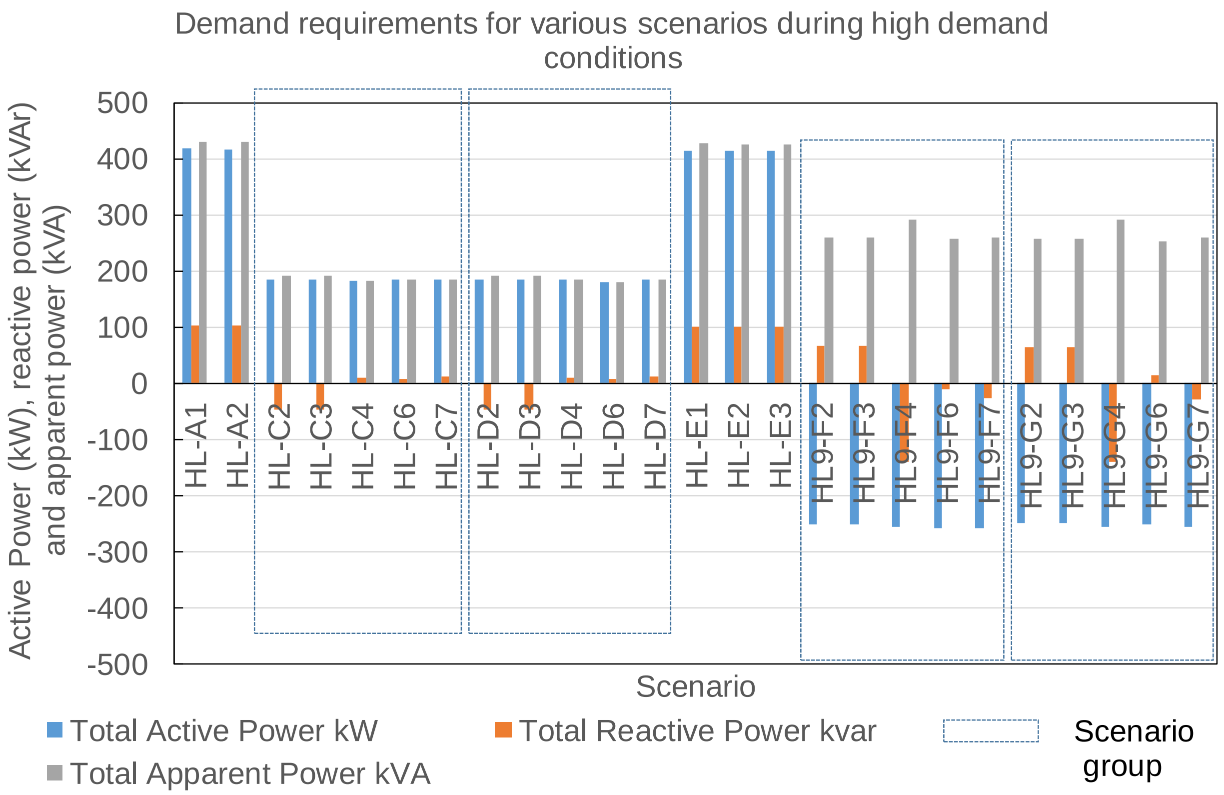


Figure 4-22: Power flow conditions through the transformer for various load flow scenarios

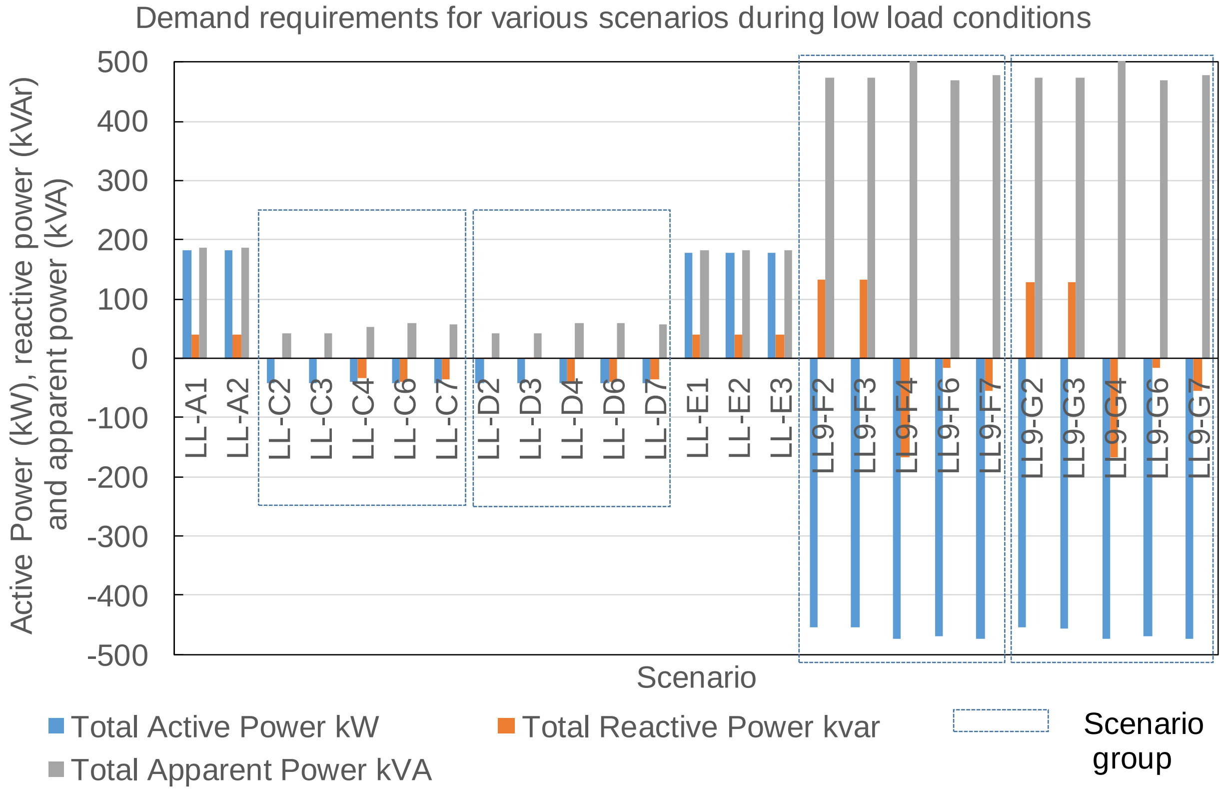


Figure 4-23: Power flow conditions through the transformer for various load flow scenarios

The negative power factor in the figure above should not be confused with leading power factor. It is simply an indication of direction of power flow. Either active power (P) or reactive power (Q) was negative when it was calculated.

For 3 kW DG at high load conditions, DG control algorithms 2 and 3 generate reactive power that is exported to the MV grid.

When the DG size is increased well above recommended NRS097 levels, P is exported to the MV grid. Q on the other hand is imported from the MV grid for algorithms 2 and 3, while for algorithms 4 and 7, P and Q is exported to the MV grid.

During low load conditions, for 3 kW DG, the situation is reversed. P is exported to the MV grid and Q imported for algorithms 2 and 3, while both P and Q are exported for algorithms 4, 6 and 7.

Under low load conditions, the power flows for 9 kW systems are amplified versions of the high demand scenarios.

High levels of exported power to the MV grid will be in violation with NRS097, which determines that only 15% of power should flow in the reverse direction for MV feeders.

4.5 Chapter summary

In this chapter, the findings from the load profile simulation indicate that changes to load profiles can be studied and ADMD's calculated when circumstances change. The changes to ADMD, load factor and coincidence were studied when energy efficiency and DG is implemented. This aids the understanding of how design assumptions change when circumstances change on the distribution networks for which it was not designed.

These assumptions can be reviewed by a utility in a controlled environment where consumers approach the utility before they add DG to the network.

The load flow analysis in this chapter demonstrates that utilities can expect degraded performance of their LV networks when consumers deploy DG in an uncontrolled manner. When consumers simply add DG without consultation with the utility, the risk exists that voltages may rise along LV feeders above 1.1 p.u. or cables may be overloaded.

Chapter 5 Conclusion

5.1 Load profile modelling conclusion

The research and simulations showed that the impact of appliance type and rating changes to a load profile can be demonstrated by an appliance-based modelling approach.

The load factor reduces when distributed generation takes place. Using the load factor and average energy consumption to calculate or estimate an ADMD may produce incorrect results if the designer or planner is not aware that DG is present in the system.

Diversity is severely impacted when DG is deployed, especially when high levels of penetration occurs. This may have an impact on diversity factors used to determine maximum demand or equipment ratings when considering historical knowledge of diversity factors present in a distribution system.

In general, energy consumption is reduced when DG is used, but when DG is not used during peak loading conditions, assumptions about ADMD reductions are not necessarily valid.

Although harmonics may increase, it will not impose a severe contribution to peak demand.

5.2 Load flow study conclusion

The load flow studies show that renewables, when used during high loading conditions, even when penetration levels are low and installed close to a transformer, may cause unbalance and consequently voltage drop below legal limits at the end of the LV feeder.

Renewables, when implemented during low load conditions at LV level at high penetration levels and sizes not limited by NRS097 or similar standards, may cause voltage rise at the transformer to exceed 1.1 p.u. If the deployment of DG is not managed well by a utility, systems may be deployed by residents that may adversely affect the LV networks feeding them. The deployment of DG during low demand scenarios may result in a reverse power flow condition. Increased DG sizes well above NRS097 recommended levels may impact the designed conditions of LV feeders. Voltage may rise and conductors may be overloaded, resulting in primary LV cable feeder circuit breakers tripping.

Under low load conditions, when reverse power flow occurs because of solar PV generated, the Herman-Beta voltage drop method cannot be used when the reverse power-flow ADMD is higher than the normal power flow direction ADMD. New parameters must be calculated because the ADMD has changed.

5.3 **Summarized conclusion**

3 kW solar PV systems are not a concern under low load conditions for a 5.3 kVA ADMD network. However, a high penetration of 9 kW solar PV systems in a 5.3 kVA ADMD network will cause problems. Limiting the PV system sizes to the NRS 097 limits of 4.6 kW in a 1.3 kVA ADMD network will also cause problems, indicating that limiting a solar PV system to 25% of the consumer's potential maximum demand will also not be sufficient. The consumer load profile, knowledge of the load at low load conditions under DG peak conditions, and designed network ADMD are important information to consider when adding DG to the network. The study can be concluded by formulating a formula to check whether problems may be encountered.

Generally, the network will perform satisfactorily if the following condition is met:

$$ADMD_{forward} \geq ADMD_{reverse} \qquad \dots (39)$$

The ADMD in the reverse power flow direction is a function of the DG size and the demand at the time. Equation 39 then becomes:

$$ADMD_{forward} \geq \left(\frac{PV\ size}{power\ factor} - Demand_{Solar\ max}\right) \qquad \dots (40)$$

Where

ADMD forward	=	Designed ADMD when no DG is present (normal power flow direction from utility source to load), in kVA.
ADMD reverse	=	Maximum demand in reverse power flow direction divided by the number of consumers, in kVA.
Demand solar max	=	Demand recorded at the time of solar maximum (generally at the time of relative low domestic load conditions), in kVA.
PV Size	=	Size of PV system installed (AC output), in kW.
Power factor	=	*Power factor of load.*

Solar PV is only one case of DG where residential systems experience a minimum load requirement during DG maximum output. Consider the following diagram:

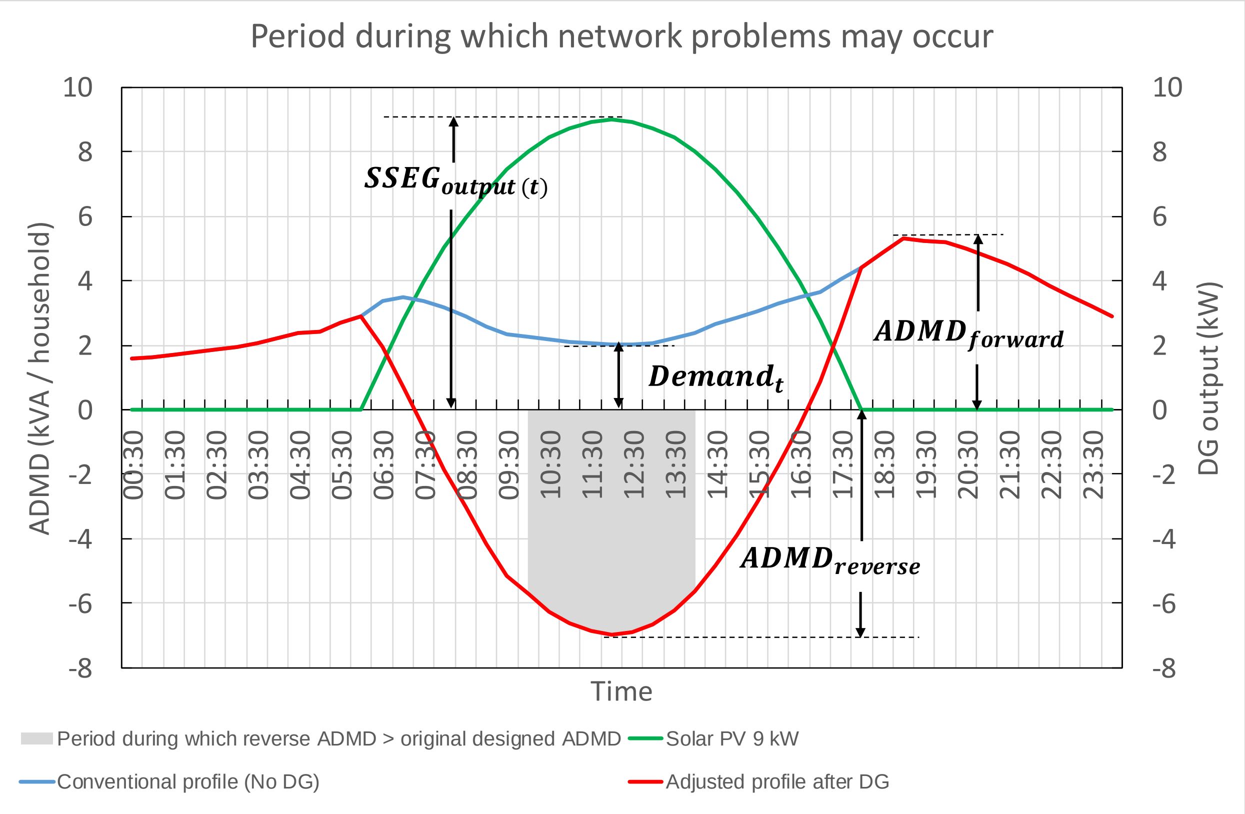


Figure 5-1: 24-hour load profile with reverse power flow as a result of DG

Equation 40 may be generalized further for any form of DG at any time during the day:

$$ADMD_{forward} \geq \left(\frac{DG_{output(t)}}{power\ factor} - Demand_t\right) \qquad \text{... (41)}$$

Where

Demand $_t$ = Average demand recorded at time *t* (total demand at time *t* divided by number of consumers), in kVA, prior to any DG connected.

DG $_{output\ (t)}$ = DG system output at time *t*, in kW

If Equation 39, or expanded as Equation 41, yields a true result, the network design will still comply in both the forward and reverse directions.

5.4 Review of research questions and associated findings

1) Research Question 4 (RQ4) - What is the relationship between diversity and load factor?

Finding - The Bary curve as indicated during the literature review stage, illustrates the relationship. The appliance modelling profile simulation study found a relationship that produced a line in the opposite direction than Bary found.

2) Research Question 5 (RQ5) - How does single-phase injection on the low voltage network affect the low voltage network's performance and integrity?

Finding - The effects of DG on unbalance during high load conditions have been demonstrated through the load flow analysis. DG closer to the transformer under high load conditions at low penetration may cause unbalance and a voltage drop towards the end of the feeder. During low load conditions, voltage rise and cable or line overload may be experienced at high penetration levels when the size of DG is not within NRS 097 recommended limits.

3) Research Question 6 (RQ6) - How does generation from LV and MV embedded/distributed generation in general affect the network up- and downstream from the point of generation?

Finding - Embedded generation reduce the real power required from the grid. However, with unity power factor DG, as is typical with category A1 & A2 inverters, the grid must still produce reactive power, and as a result, the utility's power factor will worsen drastically.

4) Research Question 7 (RQ7) - How will ADMD factors be influenced by energy efficiency and renewable energy generation at low voltage level?

Finding - Load shifting of thermal load can increase the ADMD. Generally, energy efficiency will reduce the ADMD. Under reverse power flow conditions, the network may be characterized by a new and higher ADMD at a different time of the day under high DG levels under low load conditions so that network failures may occur. This will occur only where the utility does not exercise control over the size of equipment being installed by consumers.

5) Research Question 8 (RQ8) - How are traditional diversity factors affected?

Finding - Diversity factors will decrease or coincidence factors will increase due to a lack of diversity between remaining type of loads when large loads such as geysers and stoves are replaced with alternative energy source appliances. The ADMD generally still reduces and the consumers' 60 A connections almost becomes an overkill.

6) Research Question 9 (RQ9) - How are system losses affected by load profiles altered by energy efficiency and reverse power flow due to renewable energy generation?

Finding - When the load factor decreases, the losses will decrease through the application of the load loss factor formula, which is only dependent on the load factor.

The load factor for most of the case studies decreased where large appliances have been removed, indicating that losses inherently reduced as well, since less current flows.

The load factor also decreased when DG is deployed at the load. The load loss factor will therefore also decrease, indicating that losses are reduced.

When DG is deployed elsewhere on the grid, the loads will require the same currents to flow and the same losses will still occur.

7) Research Question 10 - (RQ10) - How are fault levels affected by renewable energy injection, and what is the impact on protection systems and equipment ratings?
No adverse changes to fault levels were found during simulation. The inverter contribution to fault current on the primary LV grid is relative small.

However, protection coordination must be reviewed when adding DG to the network.

5.5 Review of findings against original hypothesis

The original expected findings compared with findings after completion of the research and analysis are summarized as follows:

Hypothesis - Energy efficiency generally reduces the system peak and therefore ADMD. Technical losses would also be reduced.

Finding - The expected finding was confirmed through load profile simulation.

Hypothesis - Load-shifting techniques, when not properly controlled, can increase the ADMD, especially if the load is associated with thermal storage.

Finding – The analysis conducted by the author for a paper [1] published during the early stages of the research and analysis confirmed the expected increases in ADMD.

Hypothesis - Improving the load factor reduces the diversity between similar load class consumers.

Finding - The coincidence versus load factor graph indicates that the coincidence factor remained the same or increased, but hardly decreased for a reduction in load factor. An increasing coincidence factor is indicative of a loss of diversity, which confirms the initial expected postulation.

Hypothesis - Reducing the diversity between consumers will impact designed and constructed networks by increasing the voltage drop experienced by consumers. However, the reduced energy consumption and demand could mean that the effect is cancelled out or reduced.

Findings:
For a high concentration of reverse power flow there is very little diversity between PV systems. Resulting excess DG capacity greater than the designed ADMD will cause cables to overload. Voltage drop is not the concern, but rather voltage rise and equipment loading.

A reduction in energy consumption combined with large PV systems during low load conditions may still cause overloading of conductors and voltage rise nearing upper limits.

A high penetration of PV is not likely, although localized cases may occur, such as a developer installing PV in a housing complex for all the residential units.

PV systems designed at NRS097 recommended upper limits may still cause problems where the ADMD is lower than the excess DG capacity. The key factor is to not only consider NRS 097 limits in isolation, but also the localized network ADMD and the customer profiles.

Hypothesis - Uncontrolled solar PV injection into the network may cause network unbalance, which will affect voltage drop of designed and constructed networks. LV networks is designed for a diversified power flow in one direction.

Finding - Network unbalance can occur with only one distributed generator connected close to the transformer. DG located closer to the transformer have a larger effect on unbalance and voltage drop at the end of the feeder, than DG located closer to the end of the feeder.

Hypothesis - A reverse power flow in a high penetration solar PV network producing excess energy during solar peak will exceed the power a LV feeder can handle due to a lack of diversity during reverse power flow.

Finding - The load flow studies for 9 kW solar PV systems illustrated that a network's performance may be adversely affected when DG sizes are not limited by a utility.

Chapter 6 Recommendation for further study / work

It is recommended that the following future work be considered:

6.1 Simulation model

Improvements to the Matlab model can be made as follows:

- Appliance modelling in this study assumed a fixed usage duration. The model may be improved by varying the usage duration.
- The list of appliances is fixed in the model. Make the list of appliances editable to allow appliances to be added or removed.
- Ten household types are predefined in the model. Make the list of household types editable. This can perhaps be combined with further classification using the Living Standard Measure (LSM).
- Expand the appliance model further by modelling duty cycle in more detail, e.g. refrigerators.
- The model does not group household nodes into transformer zones, MV feeder zones, substation zones or HV feeder zones. Amend the model to allow higher level network grouping of loads.
- The model indicated what is to be expected at higher penetration levels of DG. Networks with high penetration should be considered for detailed measurement and analysis to compare the modelled results with actual measurements.
- Appliance modelling can be further expanded to not only take active power into consideration with a fixed power factor, but to also allow for the reactive power consumption to be modelled.
- The model assumes the same size DG for all households where DG is randomly introduced. The model can be expanded by allowing variable DG size, as well as variable type (e.g. solar PV and micro wind turbines).
- NRS097 limits can be introduced in the model for further studies. The primary aim of this dissertation was to observe the impact of DG when no limitations were in place.

6.2 Reactive power and power factor

- The economic viability of domestic inverters with reactive power generation capability should be investigated. Voltage profiles in general may be improved by generation of reactive power by the consumer. This should also reduce losses on the utility's side.
- With power factor as viewed from a utility reducing considerably as larger quantities of DG is implemented, a case may be made for billing kVAh instead of kWh, or utilities will have to install meters capable of recording both kWh and kvarh consumed and generated.
- The contribution of reactive power to losses was not studied. This should be a study on its own.

6.3 Protection

- LV circuit breaker coordination for reverse feed conditions can be investigated.

6.4 Thermal cycling

- The Matlab model did not take thermal cycling of transformers, cables and overhead lines into consideration. With the variability of DG introduced into the distribution networks, it is proposed that the thermal cycling of network elements be studied further to obtain a better understanding of random behaviour of loads with a view on dynamic capacity ratings.

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Appendices

Appendix A: Appliance model load simulation tool: User Interface

7.1 Overview

7.1.1 User interface outline

The user interface consists of four main tabs, each with sub-tabs as follows:

- Profile
  - Main UI
  - Total Load Profiles
  - Graphs
  - Study cases
  - Sorted study case
- Hourly tables
  - Appliance Present
  - Appliance Active
  - Appliance load (kW)
  - Appliance “On” Duration (Minutes)
- Minute tables
  - Households
  - Appliance_Probability_On
  - Appliance_Minute_Start
  - Appliance_Minute_On
  - Appliance_Load_Minute
  - Profile per household (T)
- EE / DSM / Green measures
  - Appliance Modify

7.1.2 Application usage

The main focus of the application is to calculate load profiles from input parameters. Input parameters consist of the number of households, as well as a few tables that were originally generated in Excel and imported into Matlab and stored in a variable file.

For every 24-hour load profile calculated, the application also calculates an adjustment profile, which is based on parameters set on the EE / DSM / Green Measures main tab.

Every calculation's load profile, adjusted load profile and profile parameters are added to a study case database. It is also possible to set up a few calculations to run at a time to append the study case database faster. This is performed on the Study case sub-tab of the main Profile tab.

Histograms and scatter plots are provided to display the study case database data.

Table views are provided of the imported Excel vectors and matrices, which can be edited in Matlab, as well as the calculated matrices (which cannot be edited). The calculated matrices are mostly displayed for diagnostic purposes. The calculated matrices displayed are only for the last profile calculated. The displayed matrices are scrollable for all the households, allowing viewing each household's calculated profile, as well as how it was derived. The Excel imported vectors and matrices remain the same throughout, unless edited, while the calculated matrices are re-calculated for every calculation. This is mainly due to the random numbers generated for probability that an appliance is on, the household type a household belongs to as well as the starting minute within an hour for an appliance.

In study case mode, the detail tables are only stored for the last calculation executed. The case study variable file otherwise would have become very large. It has been observed that variable files in the order of 500MB generally can be handled, but larger files tend to become corrupt (in the order of 200 case studies depending on the number of households selected). The case study database was built up after many executions of the program and data copied to Excel where the main parameters were analyzed. 744 case studies were transferred to Excel for further analysis. Only the calculated parameters (ADMD, load factor, coincidence, diversity, kWh / day etc.) as well as the state of the appliances were transferred to Excel. The stored profiles are only available for the last 443 study cases (543 MB) since the previous corrupted case file.

The main UI and the various routines it calls send feedback messages to the Matlab command window. This was mainly built in for diagnostic purposes or to know what it is busy with during lengthy calculations. Selected messages are also displayed within the main UI.

7.1.3 **Application routines**

The following Matlab files form part of this application:

Table 7-1: Matlab application file list

No.	File name	Description
1.	**USER INTERFACE (UI)**	
1.1	LoadProfileSimUI.m	Main UI file
2.	**PROFILE AND STUDY CASE CALCULATIONS**	
2.1	Load_profile_calcuations.m	Calculates the load profile. Called from the main UI by either the *Calculate* or the *Generate study cases* buttons. Generates a study case each time it is executed and calls the *AdjustProfile* routine
2.2	ExtractParameters.m	Extracts the parameters for the study case and is called from the *Load_Profiles_Calculation* routine
2.3	CreateStudycase.m	Creates the study case and is called from the *Load_Profiles_Calculation* routine
2.4	AdjustProfile.m	This makes the adjustments to the load profile based on green measures selected. This is called by the *Load_Profile_Calculations* routine, but can also be called directly from the main UI through the *Adjust Load Profile* button on the *EE / DSM / Green measures* tab. When called from the UI, it does not add to the study cases.
2.5	GeneratePVprofile.m	This generates a solar PV "parabolic" simulated profile with no shade. This is called by the *AdjustProfile* routine. It can also be called from the main UI. When called from the main UI, it only calculates the PV curve and plots it.
3.	**GRAPH PLOTTING CUSTOMIZED ROUTINES**	
3.1	PlotTimeArray.m	This is a customized graph plotting function that can plot a time-based graph on either hourly or minute based X-axis and can scale the X and Y axis based on variable data

No.	File name	Description
3.2	PlotHistogram.m	This plots a customized histogram – at this stage it only plots the current distribution at peak time across the set of households.
3.3	PlotScatter.m	This plots a customized scatter plot of study case parameters, e.g. ADMD vs number of households
4. IMPORT AND EXPORT (FROM AND TO EXCEL)		
4.1	ReadDataFromExcel.m	This reads the *Bottom-up load profile modelling* Excel spreadsheet. It was only used once to create the *ExcelVariables.mat* file. Thereafter the parameters are edited in the main UI and stored in the *ExcelVariables.mat* file.
4.2	WriteData2Excel.m	Not really used, but can be used to export tables back to Excel. It creates a different file named *Test.xlsx* and does not overwrite data in the main Excel parameters file.
4.3	ReadReferenceProfilefromExcel.m	This reads 31 reference profile days from a load profile spreadsheet (already processed to isolate the 31 days' one-minute profiles). Creates the *ReferenceProfile.mat* variable set. The Reference Profile is used to compare against the calculated profile.
5. STORED VARIABLES		
5.1	ExcelVariables.mat	Stores the original few tables imported from Excel, and is updated when modified in the main UI. This update is not automatic.
5.2	ProfileVariables.mat	Stores the calculated profile variables. The application automatically generates a backup profile data set as well, appended by the number of study cases in it, so that a manual replacement of a corrupted profile variable set can be made.

No.	File name	Description
5.3	ReferenceProfile.mat	Creates the *ReferenceProfile.mat* variable set. The Reference Profile is used to compare against the calculated profile. Contains 31 reference profile days from a load profile spreadsheet downloaded from meters and processed to isolate the 31 days' 1-minute profiles.
5.4	CaseProfileVariables.mat	Stores the study case database as well as calculated profiles for each study case. The application automatically generates a backup profile data set as well, appended by the number of study cases in it, so that a manual replacement of a corrupted profile variable set can be made. Study case parameters can be manually copied from the main UI to Excel where further analysis can take place.

7.2 **Profile tab: The main user interface (UI) sub-tab**

7.2.1 **Main components**

The main user interface screen has the following components:

- Tabs and sub-tabs
- Graph screen displaying measurement reference and simulated load profile curves
- Buttons for various functions
- Parameter display
- Scroll bars to select different reference profile curves and stored case-file profile curves.
- Message display

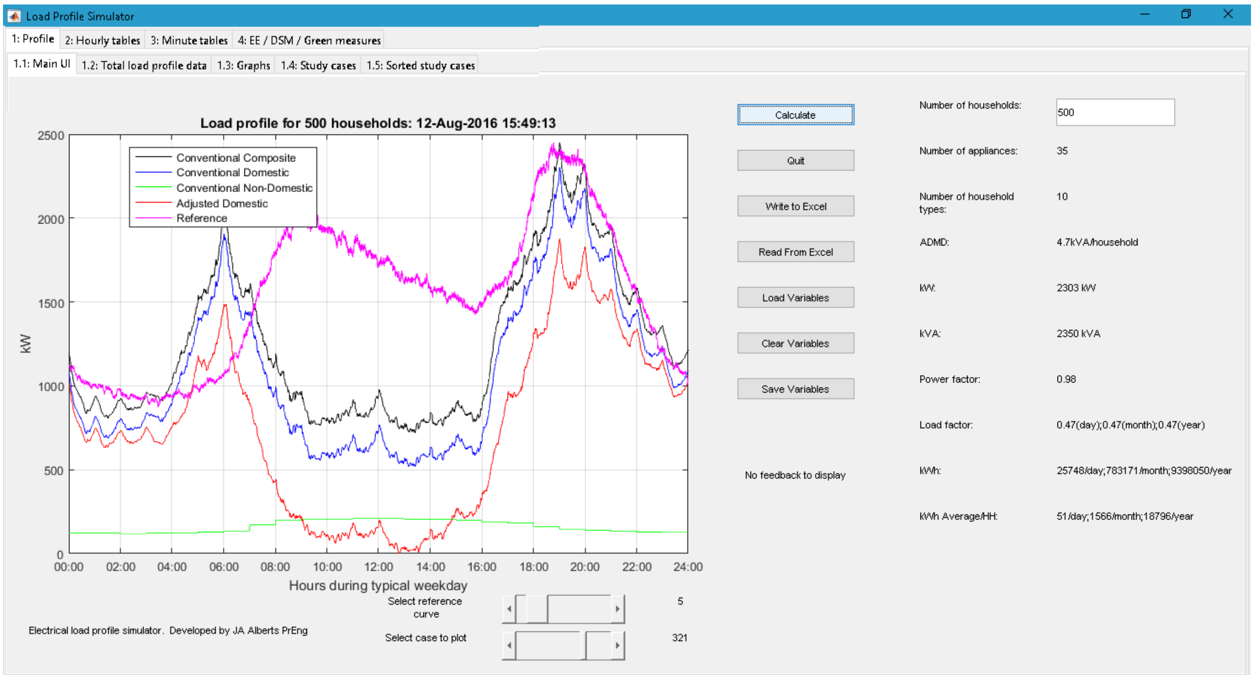


Figure 7-1: Main User Interface (UI) screen / start-up screen

The application displays graphs of the last profile calculated. The following graphs are displayed:

- Calculated composite load profile for a group of consumers: Black curve
- Reference load profile: Magenta curve, from actual, one-minute measured data
- Calculated domestic load profile: Blue curve (the main focus curve for the baseline)
- Calculated adjusted domestic load profile: Red curve (the main focus curve for the adjusted profile)
- Calculated non-domestic load profile: Green curve.

When the application starts up, the last profile previously calculated and stored in the *ProfileVariables.mat* file is displayed. In the event that it is the first profile to calculate, it calculates a profile for 50 households by default, and an adjusted profile for 10% PV penetration with 1.5kW solar PV systems. No solar geysers or gas stoves are applied to the initial start-up adjustment profile. 50 households were chosen so that the program does not take too long to load. Calculating e.g. 1500 households take a considerable time (> 5 minutes).

Calculated profiles are stored in the variable files *ExcelVariables.mat* and *ProfileVariables.mat*. Reference profiles are stored in the variable file *ReferenceProfile.mat*, while case study data are stored in *CaseProfileVariables.mat*.

The *ExcelVariables.mat* and *ReferenceVariables.mat* files must exist. Any of these files do not exist, it is imported from Excel. If the Excel files do not exist, the program cannot function. A default reference profile is selected (Profile 6 of 31). Thereafter, the user can change the reference profile viewed from a selection of 31 consecutive day profiles. If the *ProfileVariables.mat* file does not exist, the program creates it as well as the *CaseProfileVariable.mat* file and initializes it with default values required to perform the first calculation.

7.2.2 **Button functions**

The *Main UI* screen contains the following buttons with functions as described:

- ***Calculate***: This button calls the profile calculation routine which calculates a profile as well as an adjusted profile based on the "*number of households*" input parameter specified on the main UI screen. The adjusted profile takes effects such as solar PV, replacement of appliances with more energy efficient appliances etc. into consideration, while the normal profile is calculated without any form of intervention.
- ***Quit***: This quits the application
- ***Write to Excel***: This button calls a routine to write out the various matrices to Excel. It was used for diagnostic purposes.
- ***Read From Excel***: This button calls a routine which reads the Excel variables required initially, and stores the results in the *ExcelVariables.mat* file.
- ***Clear Variables***: This button calls a routine which clears the variables from memory.
- ***Save Variables***: This button saves the variables to *ProfileVariables.mat*.

7.2.3 **Input variables**

The only input variable on this screen at this stage is the number of households. It is best to keep the input value below 1500. A large household quantity takes a considerable amount of time to calculate. Once the value is edited, a feedback message indicates that a calculation is required.

7.3 **Profile tab: Total load profile data**

The *Total load profile data* sub-tab displays the total composite, domestic and non-domestic load profile matrix data calculated by the application. Only the last profile calculated is displayed. This data corresponds to the graph plotted on the *Main UI* sub-tab.

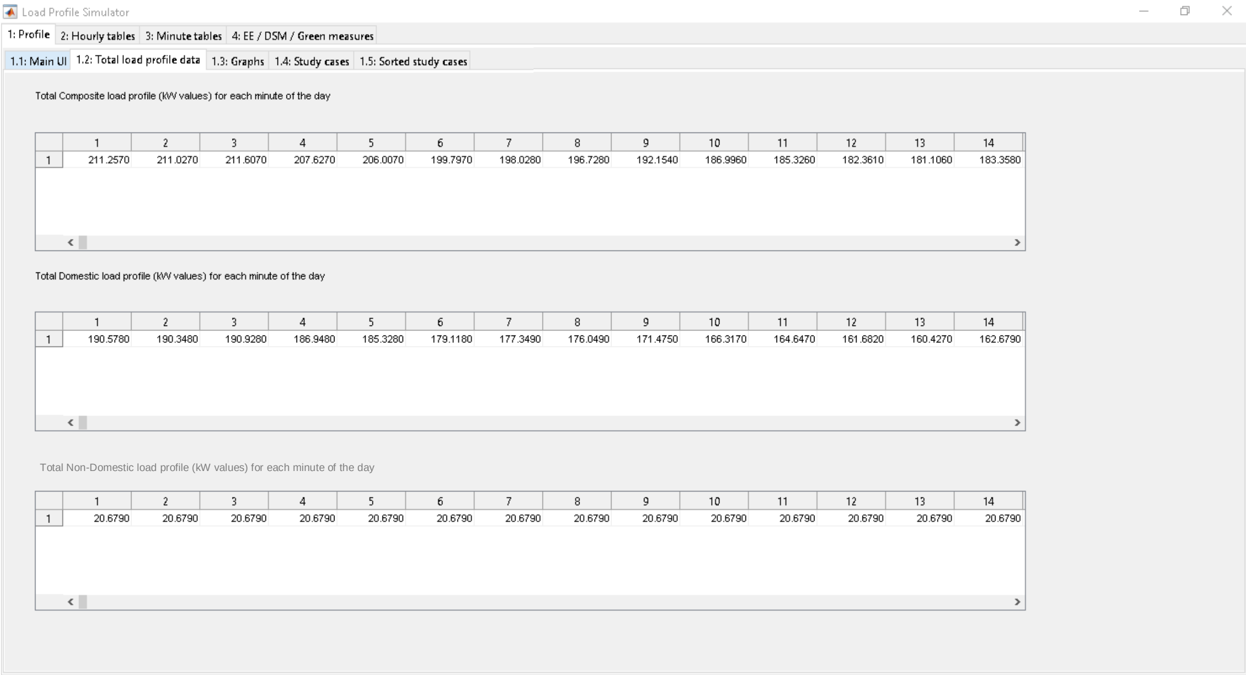


Figure 7-2: One-minute calculated profile screen

The profiles display 1440 columns, one for every minute in a 24-hour day. Column references for the various hours of the day are listed in Table 2.2-1:

Table 7-2: Column headings related to time of the day

Time	Column	Time	Column	Time	Column	Time	Column
01:00	60	**07:00**	420	**13:00**	780	**19:00**	1140
02:00	120	**08:00**	480	**14:00**	840	**20:00**	1200
03:00	180	**09:00**	540	**15:00**	900	**21:00**	1260
04:00	240	**10:00**	600	**16:00**	960	**22:00**	1320
05:00	300	**11:00**	660	**17:00**	1020	**23:00**	1380
06:00	360	**12:00**	720	**18:00**	1080	**24:00**	1440

7.4 Profile tab: Graphs sub-tab

The *Graphs* sub-tab of the *Profile* main tab displays a histogram as well as scatter plots of the study case database.

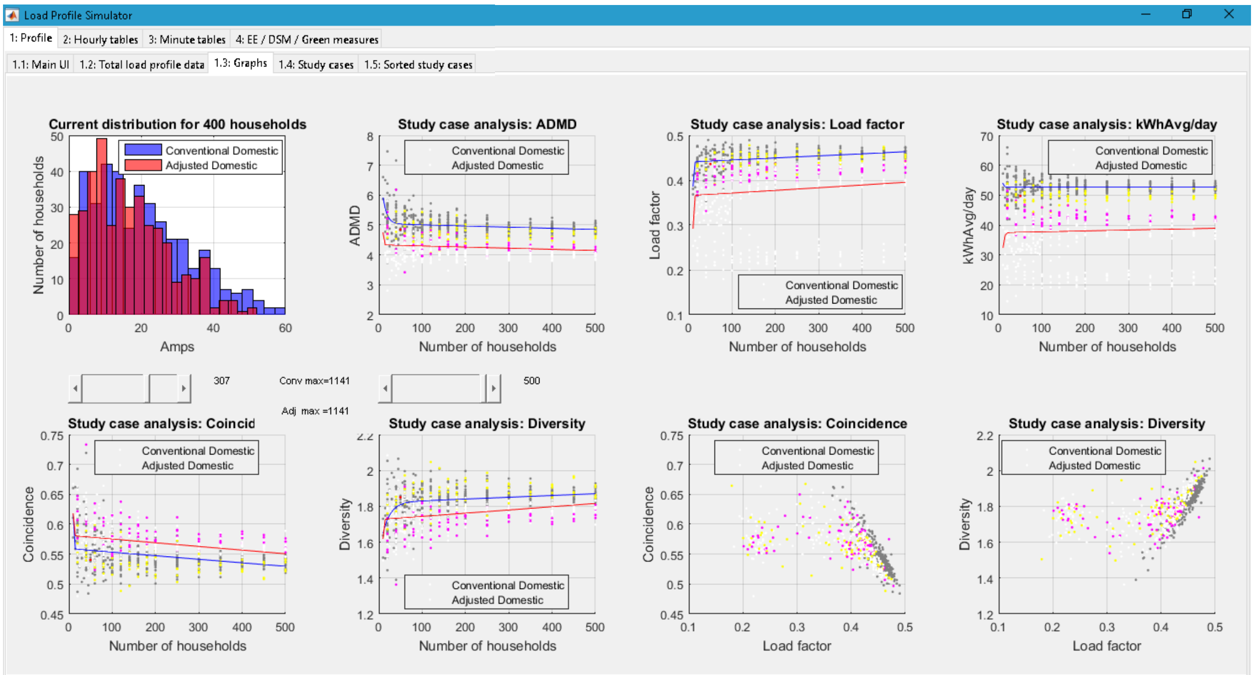


Figure 7-3: Graphs screen

Histograms, scatter plots and two scroll bars are displayed.

The scroll bar to the left is used to select the study case number for the histogram. Text messages display the time of the day (in minutes[6]) the peak was recorded for the Conventional profile (i.e. the profile without any interventions, indicated in blue) as well as the adjusted profile (after "green" interventions, indicated in red). The scroll bar to the right is used to scale the x-axis of the scatter plots.

The histogram displays the current at the time of maximum demand. The time of the maximum demand for the two Conventional and Adjusted profiles may be different. It especially becomes clear when a new peak occurs as a result of excess energy generated by a solar PV system.

[6] The time is displayed in minutes counting from midnight to ensure that the corresponding column in the data tables can be located easily.

Due to limitations by Matlab for the legend, scatter plots were re-generated in Excel from the study case database. The Conventional profile data is displayed in grey dots on the scatter plots, while PV, solar geysers and gas stoves, and the respective combinations, produced different colours using the status indicators in the study case database as RGB bit indicators.

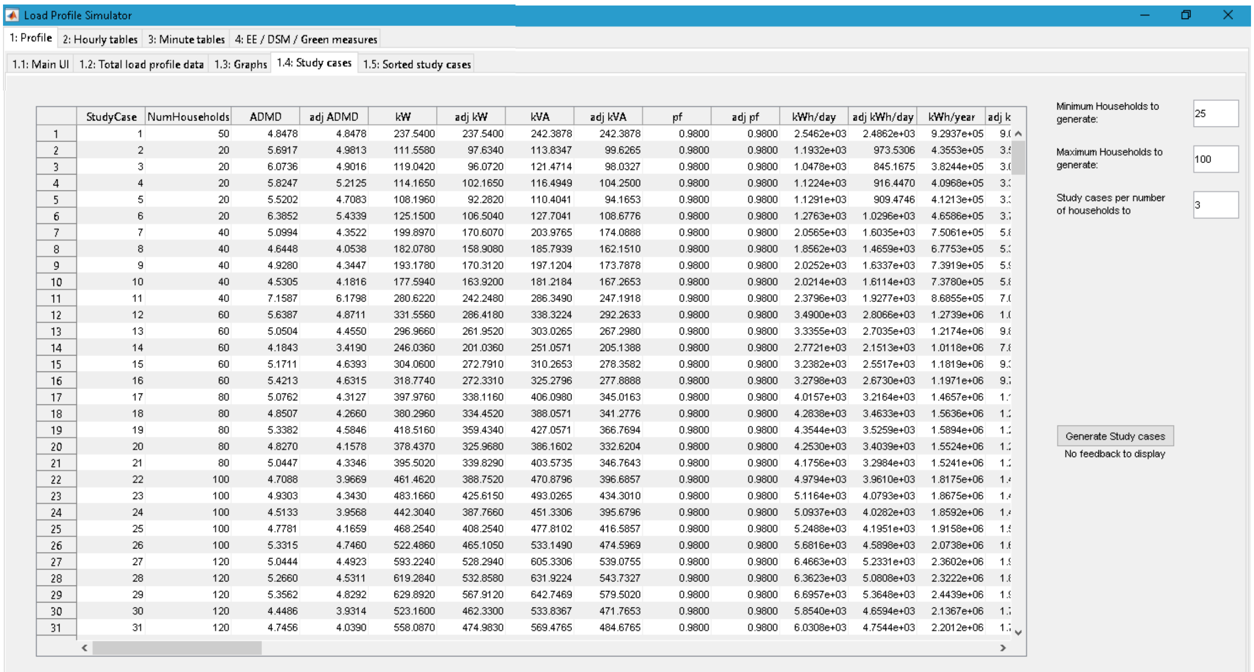
A curve fitting algorithm was used to plot a trend. The conventional load profile trend is displayed using blue while the adjusted profile trend is displayed using red.

7.5 Profile tab: Study cases

The *Study cases* sub-tab shows the study case data. The study case data displays the study case number, the number of households, the profile parameters for a profile without any energy efficiency applied, as well as a modified profile with green measures active. Record of each appliance's status (whether modified or not) is also recorded, as well as PV penetration level and size.

Three input boxes allow the user to select a lower and upper limit for household quantities to generate study cases, as well as the number of simulations per household quantity. The household quantities are increased in steps as follows:

- 0-199: steps of 20
- 200-499: steps of 50
- 500-999: steps of 100
- ≥1000: steps of 1000.

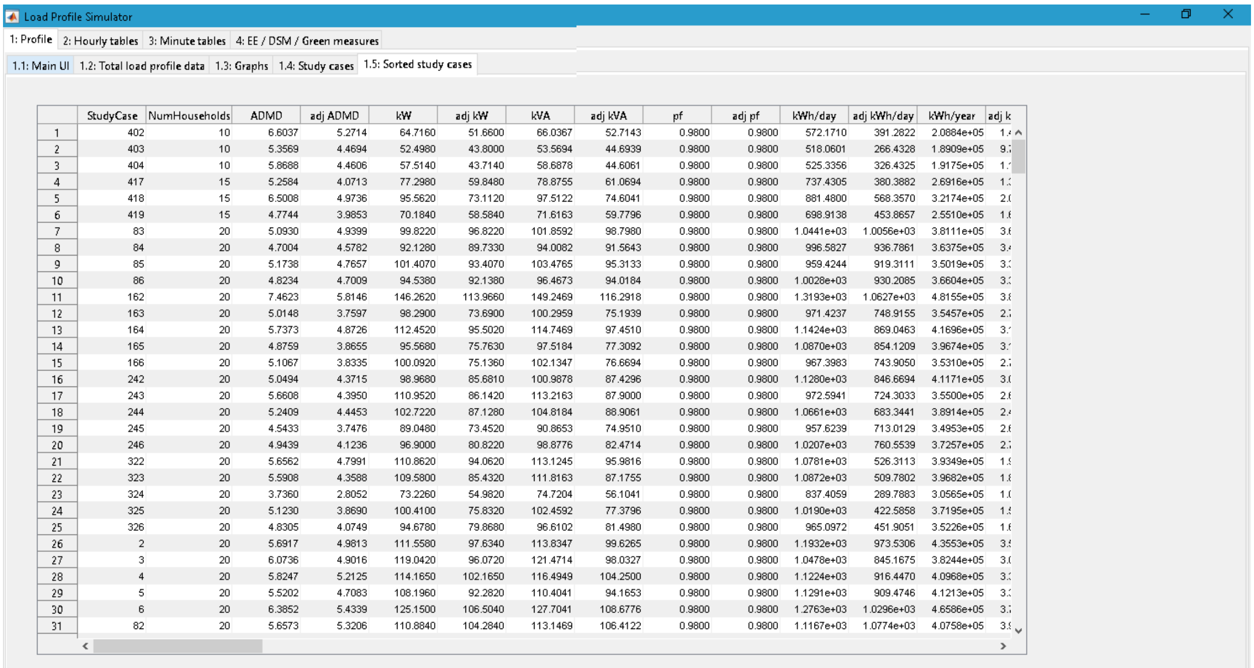


	StudyCase	NumHouseholds	ADMD	adj ADMD	kW	adj kW	kVA	adj kVA	pf	adj pf	kWh/day	adj kWh/day	kWh/year
1	1	50	4.8478	4.8478	237.5400	237.5400	242.3878	242.3878	0.9800	0.9800	2.5462e+03	2.4862e+03	9.2937e+05
2	2	20	5.6917	4.9813	111.5580	97.6340	113.8347	99.6265	0.9800	0.9800	1.1932e+03	973.5306	4.3553e+05
3	3	20	6.0736	4.9016	119.0420	96.0720	121.4714	98.0327	0.9800	0.9800	1.0478e+03	845.1675	3.8244e+05
4	4	20	5.8247	5.2125	114.1650	102.1650	116.4949	104.2500	0.9800	0.9800	1.1224e+03	916.4470	4.0968e+05
5	5	20	5.5202	4.7083	108.1960	92.2820	110.4041	94.1653	0.9800	0.9800	1.1291e+03	909.4746	4.1213e+05
6	6	20	6.3852	5.4339	125.1500	106.5040	127.7041	108.6776	0.9800	0.9800	1.2763e+03	1.0296e+03	4.6586e+05
7	7	40	5.0994	4.3522	199.8970	170.6070	203.9765	174.0888	0.9800	0.9800	2.0565e+03	1.6035e+03	7.5061e+05
8	8	40	4.6448	4.0538	182.0780	158.9080	185.7939	162.1510	0.9800	0.9800	1.8562e+03	1.4659e+03	6.7753e+05
9	9	40	4.9280	4.3447	193.1780	170.3120	197.1204	173.7878	0.9800	0.9800	2.0252e+03	1.6337e+03	7.3919e+05
10	10	40	4.5305	4.1816	177.5940	163.9200	181.2184	167.2653	0.9800	0.9800	2.0214e+03	1.6114e+03	7.3780e+05
11	11	40	7.1587	6.1798	280.6220	242.2480	286.3490	247.1918	0.9800	0.9800	2.3796e+03	1.9277e+03	8.6855e+05
12	12	60	5.6387	4.8711	331.5560	286.4180	338.3224	292.2633	0.9800	0.9800	3.4900e+03	2.8066e+03	1.2739e+06
13	13	60	5.0504	4.4550	296.9660	261.9520	303.0265	267.2980	0.9800	0.9800	3.3355e+03	2.7035e+03	1.2174e+06
14	14	60	4.1843	3.4190	246.0360	201.0360	251.0571	205.1388	0.9800	0.9800	2.7721e+03	2.1513e+03	1.0118e+06
15	15	60	5.1711	4.6393	304.0600	272.7910	310.2653	278.3582	0.9800	0.9800	3.2382e+03	2.5517e+03	1.1819e+06
16	16	60	5.4213	4.6315	318.7740	272.3310	325.2796	277.8888	0.9800	0.9800	3.2798e+03	2.6730e+03	1.1971e+06
17	17	80	5.0762	4.3127	397.9760	338.1160	406.0980	345.0163	0.9800	0.9800	4.0157e+03	3.2164e+03	1.4657e+06
18	18	80	4.8507	4.2660	380.2960	334.4520	388.0571	341.2776	0.9800	0.9800	4.2838e+03	3.4633e+03	1.5636e+06
19	19	80	5.3382	4.5846	418.5160	359.4340	427.0571	366.7694	0.9800	0.9800	4.3544e+03	3.5259e+03	1.5894e+06
20	20	80	4.8270	4.1578	378.4370	325.9680	386.1602	332.6204	0.9800	0.9800	4.2530e+03	3.4039e+03	1.5524e+06
21	21	80	5.0447	4.3346	395.5020	339.8290	403.5735	346.7643	0.9800	0.9800	4.1756e+03	3.2984e+03	1.5241e+06
22	22	100	4.7088	3.9669	461.4620	388.7520	470.8796	396.6857	0.9800	0.9800	4.9794e+03	3.9610e+03	1.8175e+06
23	23	100	4.9303	4.3430	483.1660	425.6150	493.0265	434.3010	0.9800	0.9800	5.1164e+03	4.0793e+03	1.8675e+06
24	24	100	4.5133	3.9568	442.3040	387.7660	451.3306	395.6796	0.9800	0.9800	5.0937e+03	4.0282e+03	1.8592e+06
25	25	100	4.7781	4.1659	468.2540	408.2540	477.8102	416.5857	0.9800	0.9800	5.2488e+03	4.1951e+03	1.9158e+06
26	26	100	5.3315	4.7460	522.4860	465.1050	533.1490	474.5969	0.9800	0.9800	5.6816e+03	4.5898e+03	2.0738e+06
27	27	120	5.0444	4.4923	593.2240	528.2940	605.3306	539.0755	0.9800	0.9800	6.4663e+03	5.2331e+03	2.3602e+06
28	28	120	5.2660	4.5311	619.2840	532.8580	631.9224	543.7327	0.9800	0.9800	6.3623e+03	5.0808e+03	2.3222e+06
29	29	120	5.3562	4.8292	629.8920	567.9120	642.7469	579.5020	0.9800	0.9800	6.6957e+03	5.3648e+03	2.4439e+06
30	30	120	4.4486	3.9314	523.1600	462.3300	533.8367	471.7653	0.9800	0.9800	5.8540e+03	4.6594e+03	2.1367e+06
31	31	120	4.7456	4.0390	558.0870	474.9830	569.4765	484.6765	0.9800	0.9800	6.0308e+03	4.7544e+03	2.2012e+06

Figure 7-4: Study cases sub-tab screen

7.6 Profile tab: Sorted study case

This display is similar to the *Study cases* sub-tab with the exception that study cases cannot be generated from this tab. It simply shows the study cases sorted according to the number of households.



	StudyCase	NumHouseholds	ADMD	adj ADMD	kW	adj kW	kVA	adj kVA	pf	adj pf	kWh/day	adj kWh/day	kWh/year
1	402	10	6.6037	5.2714	64.7160	51.6600	66.0367	52.7143	0.9800	0.9800	572.1710	391.2822	2.0884e+05
2	403	10	5.3569	4.4694	52.4980	43.8000	53.5694	44.6939	0.9800	0.9800	518.0601	266.4328	1.8909e+05
3	404	10	5.8688	4.4606	57.5140	43.7140	58.6878	44.6061	0.9800	0.9800	525.3356	326.4325	1.9175e+05
4	417	15	5.2584	4.0713	77.2980	59.8480	78.8755	61.0694	0.9800	0.9800	737.4305	380.3882	2.6916e+05
5	418	15	6.5008	4.9736	95.5620	73.1120	97.5122	74.6041	0.9800	0.9800	881.4800	568.3570	3.2174e+05
6	419	15	4.7744	3.9853	70.1840	58.5840	71.6163	59.7796	0.9800	0.9800	698.9138	453.8657	2.5510e+05
7	83	20	5.0930	4.9399	99.8220	96.8220	101.8592	98.7980	0.9800	0.9800	1.0441e+03	1.0056e+03	3.8111e+05
8	84	20	4.7004	4.5782	92.1280	89.7330	94.0082	91.5643	0.9800	0.9800	996.5827	936.7861	3.6375e+05
9	85	20	5.1738	4.7657	101.4070	93.4070	103.4765	95.3133	0.9800	0.9800	959.4244	919.3111	3.5019e+05
10	86	20	4.8234	4.7009	94.5380	92.1380	96.4673	94.0184	0.9800	0.9800	1.0028e+03	930.2085	3.6604e+05
11	162	20	7.4623	5.8146	146.2620	113.9660	149.2469	116.2918	0.9800	0.9800	1.3193e+03	1.0627e+03	4.8155e+05
12	163	20	5.0148	3.7597	98.2900	73.6900	100.2959	75.1939	0.9800	0.9800	971.4237	748.9155	3.5457e+05
13	164	20	5.7373	4.8726	112.4520	95.5020	114.7469	97.4510	0.9800	0.9800	1.1424e+03	869.0463	4.1696e+05
14	165	20	4.8759	3.8655	95.5680	75.7630	97.5184	77.3092	0.9800	0.9800	1.0870e+03	854.1209	3.9674e+05
15	166	20	5.1067	3.8335	100.0920	75.1360	102.1347	76.6694	0.9800	0.9800	967.3983	743.9050	3.5310e+05
16	242	20	5.0494	4.3715	98.9680	85.6810	100.9878	87.4296	0.9800	0.9800	1.1280e+03	846.6694	4.1171e+05
17	243	20	5.6608	4.3950	110.9520	86.1420	113.2163	87.9000	0.9800	0.9800	972.5941	724.3033	3.5500e+05
18	244	20	5.2409	4.4453	102.7220	87.1280	104.8184	88.9061	0.9800	0.9800	1.0661e+03	683.3441	3.8914e+05
19	245	20	4.5433	3.7476	89.0480	73.4520	90.8653	74.9510	0.9800	0.9800	957.6239	713.0129	3.4953e+05
20	246	20	4.9439	4.1236	96.9000	80.8220	98.8776	82.4714	0.9800	0.9800	1.0207e+03	760.5539	3.7257e+05
21	322	20	5.6562	4.7991	110.8620	94.0620	113.1245	95.9816	0.9800	0.9800	1.0781e+03	526.3113	3.9349e+05
22	323	20	5.5908	4.3588	109.5800	85.4320	111.8163	87.1755	0.9800	0.9800	1.0872e+03	509.7802	3.9682e+05
23	324	20	3.7360	2.8052	73.2260	54.9820	74.7204	56.1041	0.9800	0.9800	837.4059	289.7883	3.0565e+05
24	325	20	5.1230	3.8690	100.4100	75.8320	102.4592	77.3796	0.9800	0.9800	1.0190e+03	422.5858	3.7195e+05
25	326	20	4.8305	4.0749	94.6780	79.8680	96.6102	81.4980	0.9800	0.9800	965.0972	451.9051	3.5226e+05
26	2	20	5.6917	4.9813	111.5580	97.6340	113.8347	99.6265	0.9800	0.9800	1.1932e+03	973.5306	4.3553e+05
27	3	20	6.0736	4.9016	119.0420	96.0720	121.4714	98.0327	0.9800	0.9800	1.0478e+03	845.1675	3.8244e+05
28	4	20	5.8247	5.2125	114.1650	102.1650	116.4949	104.2500	0.9800	0.9800	1.1224e+03	916.4470	4.0968e+05
29	5	20	5.5202	4.7083	108.1960	92.2820	110.4041	94.1653	0.9800	0.9800	1.1291e+03	909.4746	4.1213e+05
30	6	20	6.3852	5.4339	125.1500	106.5040	127.7041	108.6776	0.9800	0.9800	1.2763e+03	1.0296e+03	4.6586e+05
31	82	20	5.6573	5.3206	110.8840	104.2840	113.1469	106.4122	0.9800	0.9800	1.1167e+03	1.0774e+03	4.0758e+05

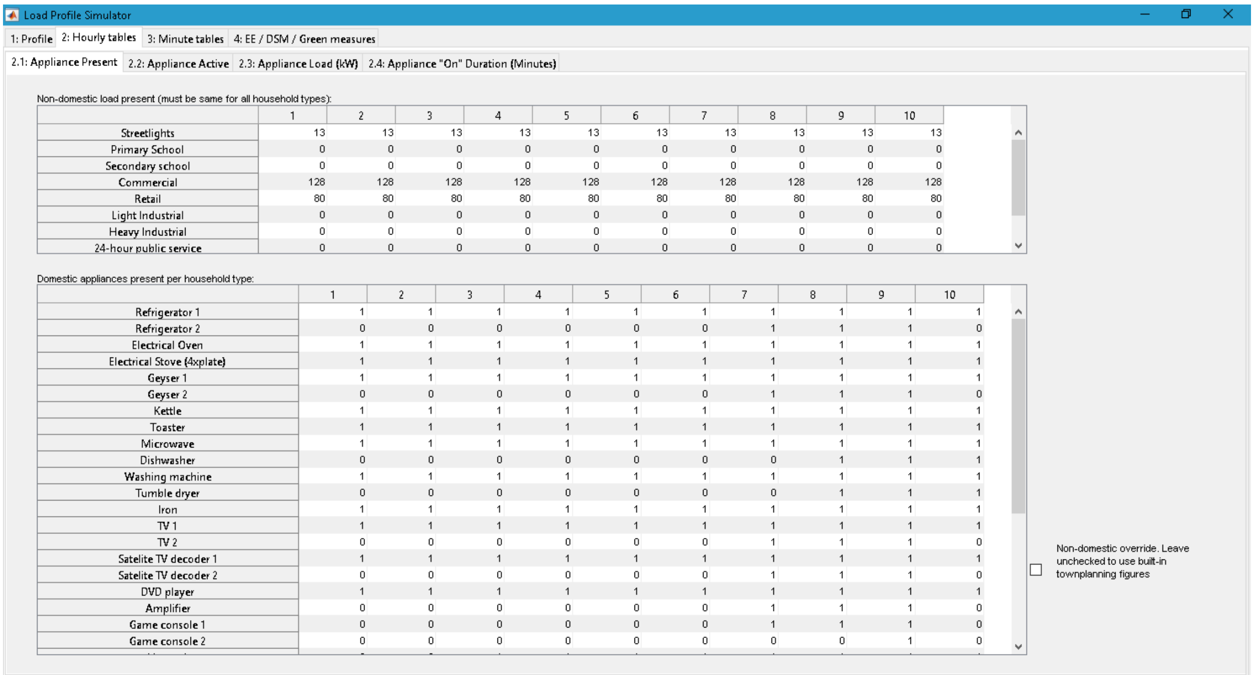
Figure 7-5: Sorted study cases sub-tab screen

7.7 Hourly tables

7.7.1 Appliance Present

The *Appliance Present* sub-tab lists two table views: one for the non-domestic load, and one for the domestic load. A check-box is provided to select whether the non-domestic data as listed in the table view should be used, or as built-in. When selected, the table-view is used. When it is not selected, the built-in parameters as obtained from town planners are used.

The *Appliance Present* sub-tab displays the appliance present per type of household. Household types are defined in table 0.



Non-domestic load present (must be same for all household types):

	1	2	3	4	5	6	7	8	9	10
Streetlights	13	13	13	13	13	13	13	13	13	13
Primary School	0	0	0	0	0	0	0	0	0	0
Secondary school	0	0	0	0	0	0	0	0	0	0
Commercial	128	128	128	128	128	128	128	128	128	128
Retail	80	80	80	80	80	80	80	80	80	80
Light Industrial	0	0	0	0	0	0	0	0	0	0
Heavy Industrial	0	0	0	0	0	0	0	0	0	0
24-hour public service	0	0	0	0	0	0	0	0	0	0

Domestic appliances present per household type:

	1	2	3	4	5	6	7	8	9	10
Refrigerator 1	1	1	1	1	1	1	1	1	1	1
Refrigerator 2	0	0	0	0	0	0	1	1	1	0
Electrical Oven	1	1	1	1	1	1	1	1	1	1
Electrical Stove (4xplate)	1	1	1	1	1	1	1	1	1	1
Geyser 1	1	1	1	1	1	1	1	1	1	1
Geyser 2	0	0	0	0	0	0	1	1	1	0
Kettle	1	1	1	1	1	1	1	1	1	1
Toaster	1	1	1	1	1	1	1	1	1	1
Microwave	1	1	1	1	1	1	1	1	1	1
Dishwasher	0	0	0	0	0	0	0	1	1	1
Washing machine	1	1	1	1	1	1	1	1	1	1
Tumble dryer	0	0	0	0	0	0	0	1	1	1
Iron	1	1	1	1	1	1	1	1	1	1
TV 1	1	1	1	1	1	1	1	1	1	1
TV 2	0	0	0	0	0	0	1	1	1	0
Satelite TV decoder 1	1	1	1	1	1	1	1	1	1	1
Satelite TV decoder 2	0	0	0	0	0	0	1	1	1	0
DVD player	1	1	1	1	1	1	1	1	1	1
Amplifier	0	0	0	0	0	0	1	1	1	0
Game console 1	0	0	0	0	0	0	1	1	1	0
Game console 2	0	0	0	0	0	0	0	0	1	0

Figure 7-6: *Appliance Present* sub-tab screen

These two tables can be edited.

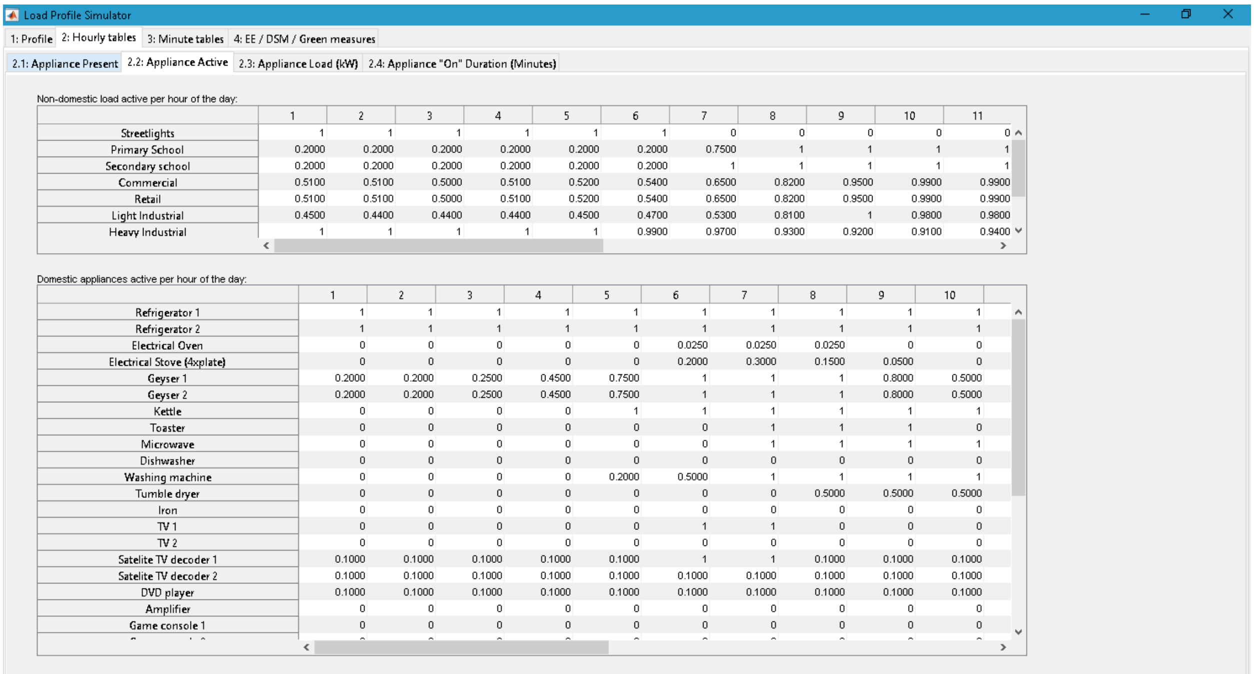
The built-in data was obtained from a town-planner, and is as follows:

Type of installation or parameter	**Criteria**
Household Size	3.2 persons per household
Population (persons)	Number of Households multiplied by Household Size
Creches	1 per 5 000 persons
Primary Schools	1 per 3 300 persons
Secondary Schools	1 per 6 600 persons
Clinics	1 per 5 000 persons
Hospitals	1 per 10 000 persons
Libraries	1 per 25 000 persons
Community Centers	1 per 22 000 persons
Churches	1 per 2 000 persons
Municipal Offices	1 per 50 000 persons
Police Stations	1 per 25 000 persons
Fire Stations	1 per 60 000 persons
Retail Floor Area	1 m^2 per 2 persons - not according to any guideline. Based on actual projects
Business Floor Area	1 m^2 per 1.25 persons - not according to any guideline. Based on actual projects

7.7.2 Appliance Active

The *Appliance Active* sub-tab indicates the appliances which can be switched on during certain times of the day. The table lists 24 hour slots horizontally. Values represent a value between 0 and 1 which effectively doubles as a scaling factor of the full load. Values were initially chosen as either 0 or 1, but modified later to be any value between 0 and 1.

Values are shown for non-domestic as well as domestic load. These two tables can be edited.



	1	2	3	4	5	6	7	8	9	10	11
Streetlights	1	1	1	1	1	1	0	0	0	0	0
Primary School	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.7500	1	1	1	1
Secondary school	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	1	1	1	1	1
Commercial	0.5100	0.5100	0.5000	0.5100	0.5200	0.5400	0.6500	0.8200	0.9500	0.9900	0.9900
Retail	0.5100	0.5100	0.5000	0.5100	0.5200	0.5400	0.6500	0.8200	0.9500	0.9900	0.9900
Light Industrial	0.4500	0.4400	0.4400	0.4400	0.4500	0.4700	0.5300	0.8100	1	0.9800	0.9800
Heavy Industrial	1	1	1	1	1	0.9900	0.9700	0.9300	0.9200	0.9100	0.9400

	1	2	3	4	5	6	7	8	9	10
Refrigerator 1	1	1	1	1	1	1	1	1	1	1
Refrigerator 2	1	1	1	1	1	1	1	1	1	1
Electrical Oven	0	0	0	0	0	0.0250	0.0250	0.0250	0	0
Electrical Stove (4xplate)	0	0	0	0	0	0.2000	0.3000	0.1500	0.0500	0
Geyser 1	0.2000	0.2000	0.2500	0.4500	0.7500	1	1	1	0.8000	0.5000
Geyser 2	0.2000	0.2000	0.2500	0.4500	0.7500	1	1	1	0.8000	0.5000
Kettle	0	0	0	0	1	1	1	1	1	1
Toaster	0	0	0	0	0	0	1	1	1	0
Microwave	0	0	0	0	0	0	1	1	1	1
Dishwasher	0	0	0	0	0	0	0	0	0	0
Washing machine	0	0	0	0	0.2000	0.5000	1	1	1	1
Tumble dryer	0	0	0	0	0	0	0	0.5000	0.5000	0.5000
Iron	0	0	0	0	0	0	0	0	0	0
TV 1	0	0	0	0	0	1	1	0	0	0
TV 2	0	0	0	0	0	0	0	0	0	0
Satelite TV decoder 1	0.1000	0.1000	0.1000	0.1000	0.1000	1	1	0.1000	0.1000	0.1000
Satelite TV decoder 2	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
DVD player	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
Amplifier	0	0	0	0	0	0	0	0	0	0
Game console 1	0	0	0	0	0	0	0	0	0	0

Figure 7-7: *Appliance Active* sub-tab screen

7.7.3 Appliance load (kW)

The appliance load in kW is shown for domestic appliances and non-domestic load classes. These values can be edited.

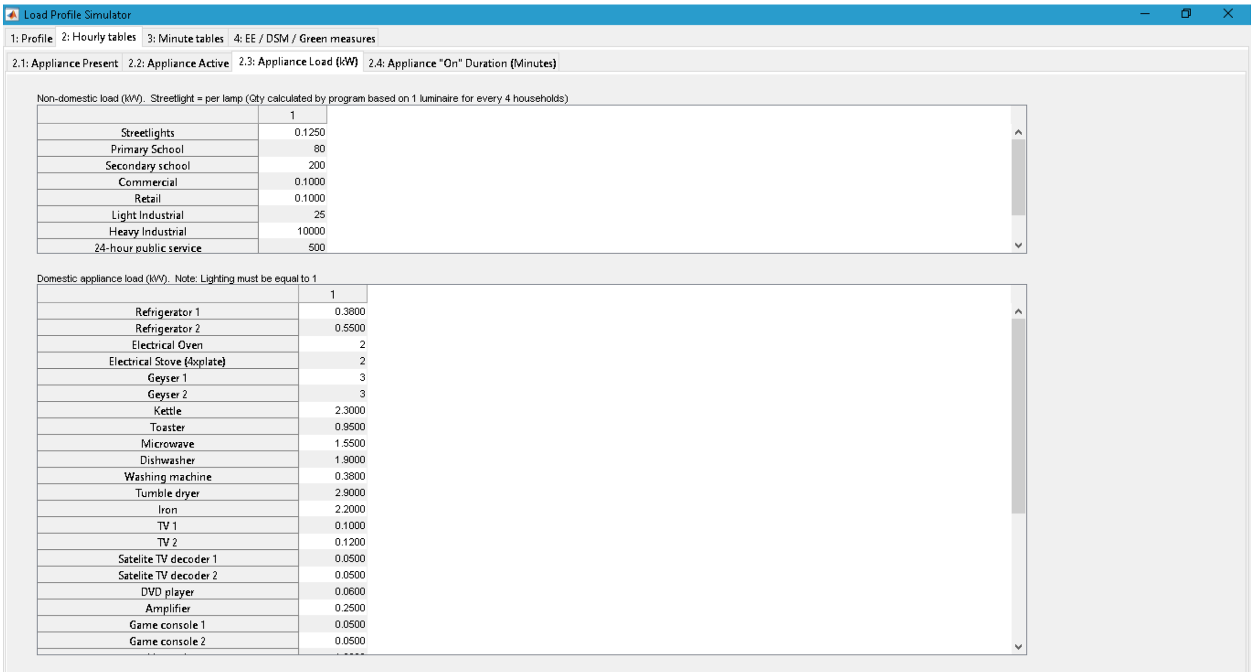


Figure 7-8: Appliance load sub-tab screen

7.7.4 Appliance "On" Duration (Minutes)

The appliance load duration, in minutes, from the moment it is switched on, is displayed for non-domestic load classes and domestic appliances. The duration of non-domestic load classes is by default 60 minutes. Random starting minutes are not generated for load with a 60-minute or longer duration per hour. In such a case the load starts at minute and continues for 60 minutes.

These two tables can be edited.

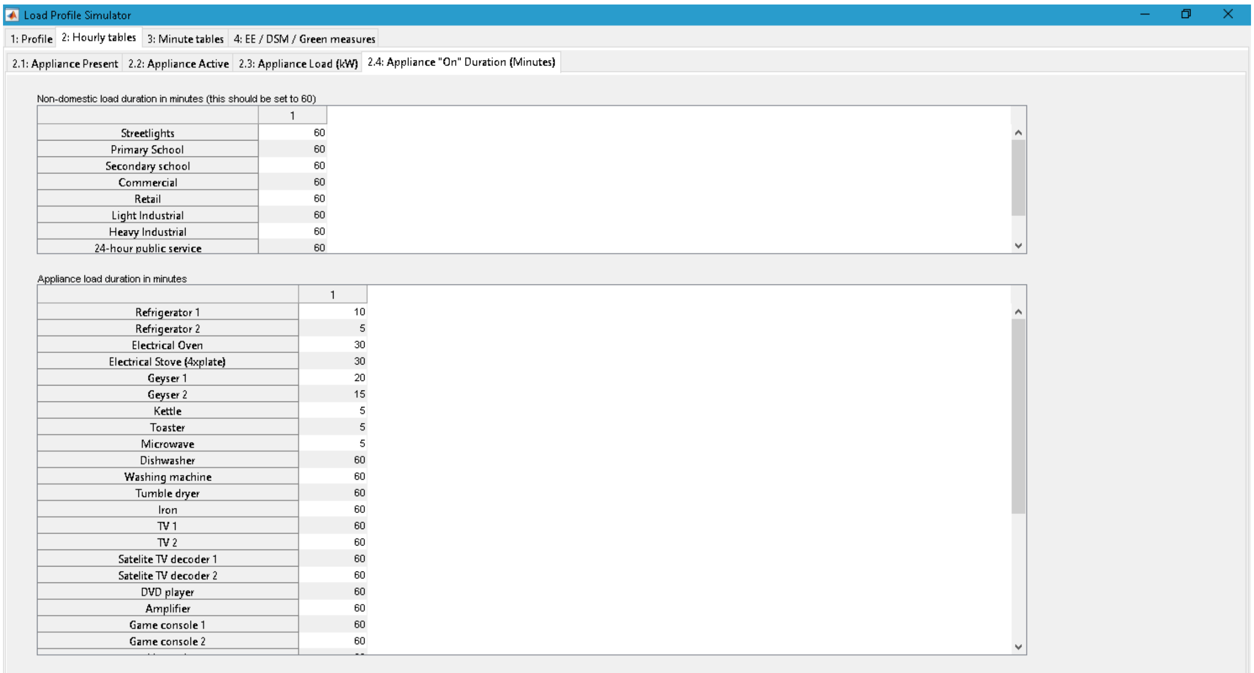
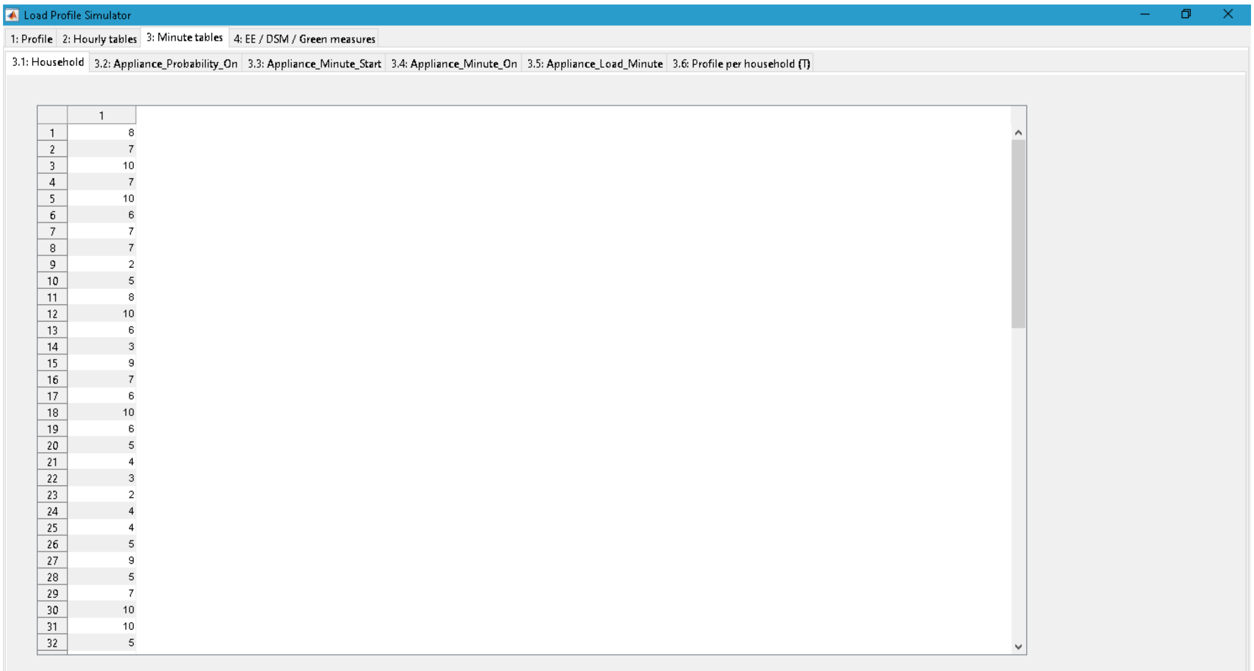


Figure 7-9: Appliance "On" duration sub-tab screen

7.8 MINUTE TABLES

7.8.1 Households

The *Households* sub-tab shows the table after the random values of household types it belongs to, has been generated. The table is generated for every profile or case study calculated. The table cannot be edited.



	1
1	8
2	7
3	10
4	7
5	10
6	6
7	7
8	7
9	2
10	5
11	8
12	10
13	6
14	3
15	9
16	7
17	6
18	10
19	6
20	5
21	4
22	3
23	2
24	4
25	4
26	5
27	9
28	5
29	7
30	10
31	10
32	5

Figure 7-10: *Households* sub-tab screen

7.8.2 Appliance_Probability_On

The *Appliance_Probability_On* sub-tab shows the matrix once random numbers have been generated. The random numbers are generated between 0 and 100, then divided by 100 and rounded to the nearest integer. Either a 0 or 1 will be obtained. This table cannot be edited. The random numbers are generated for every profile calculation or study case. The user can scroll through each household's table.

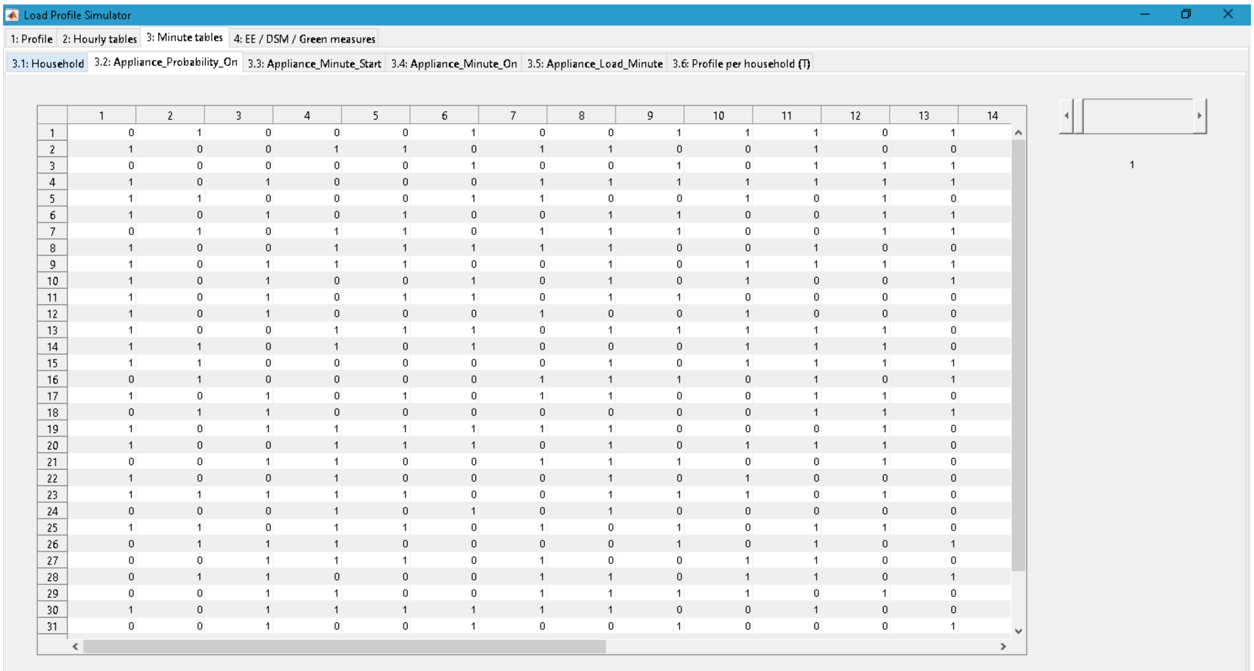
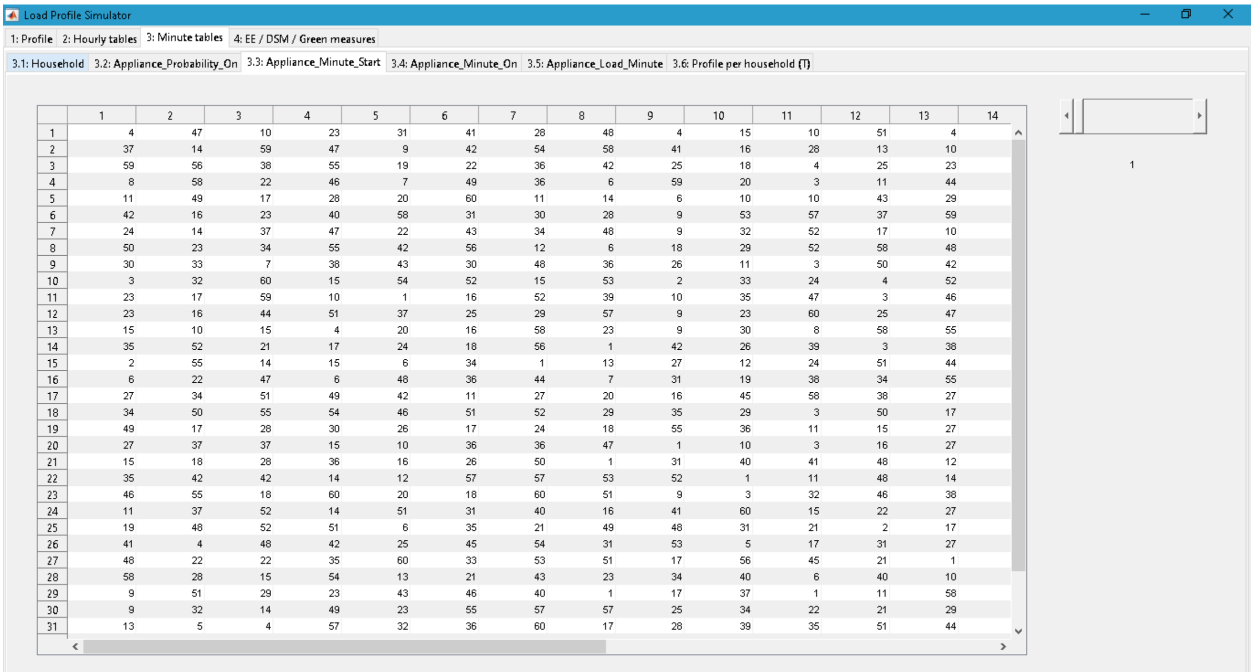


Figure 7-11: *Appliance_Probability_On* sub-tab screen

7.8.3 Appliance_Minute_Start

A random starting minute is generated for every hour in a 24-hour day per appliance per household. The values, once generated, cannot be edited. The values are generated for every profile calculation or study case. The user can scroll through each household's table.

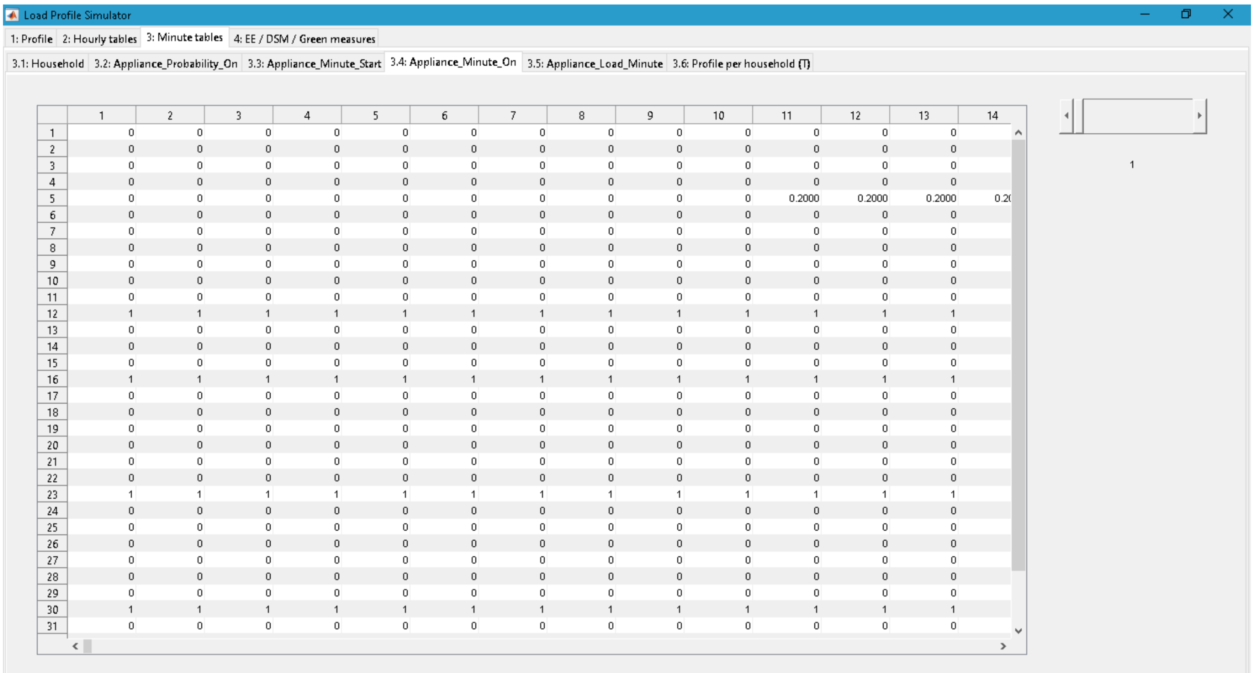


	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	4	47	10	23	31	41	28	48	4	15	10	51	4	
2	37	14	59	47	9	42	54	58	41	16	28	13	10	
3	59	56	38	55	19	22	36	42	25	18	4	25	23	
4	8	58	22	46	7	49	36	6	59	20	3	11	44	
5	11	49	17	28	20	60	11	14	6	10	10	43	29	
6	42	16	23	40	58	31	30	28	9	53	57	37	59	
7	24	14	37	47	22	43	34	48	9	32	52	17	10	
8	50	23	34	55	42	56	12	6	18	29	52	58	48	
9	30	33	7	38	43	30	48	36	26	11	3	50	42	
10	3	32	60	15	54	52	15	53	2	33	24	4	52	
11	23	17	59	10	1	16	52	39	10	35	47	3	46	
12	23	16	44	51	37	25	29	57	9	23	60	25	47	
13	15	10	15	4	20	16	58	23	9	30	8	58	55	
14	35	52	21	17	24	18	56	1	42	26	39	3	38	
15	2	55	14	15	6	34	1	13	27	12	24	51	44	
16	6	22	47	6	48	36	44	7	31	19	38	34	55	
17	27	34	51	49	42	11	27	20	16	45	58	38	27	
18	34	50	55	54	46	51	52	29	35	29	3	50	17	
19	49	17	28	30	26	17	24	18	55	36	11	15	27	
20	27	37	37	15	10	36	36	47	1	10	3	16	27	
21	15	18	28	36	16	26	50	1	31	40	41	48	12	
22	35	42	42	14	12	57	57	53	52	1	11	48	14	
23	46	55	18	60	20	18	60	51	9	3	32	46	38	
24	11	37	52	14	51	31	40	16	41	60	15	22	27	
25	19	48	52	51	6	35	21	49	48	31	21	2	17	
26	41	4	48	42	25	45	54	31	53	5	17	31	27	
27	48	22	22	35	60	33	53	51	17	56	45	21	1	
28	58	28	15	54	13	21	43	23	34	40	6	40	10	
29	9	51	29	23	43	46	40	1	17	37	1	11	58	
30	9	32	14	49	23	55	57	57	25	34	22	21	29	
31	13	5	4	57	32	36	60	17	28	39	35	51	44	

Figure 7-12: ***Appliance_Minute_Start*** **sub-tab screen**

7.8.4 Appliance_Minute_On

The *Appliance_Minute_On* sub-tab shows the result of the conversion from hourly tables to a minute table. This table cannot be edited, and is recalculated for every profile calculation or study case. The user can scroll through each household's table. The table has 1440 columns horizontally, representing 60 minutes per hour for 24 hours.

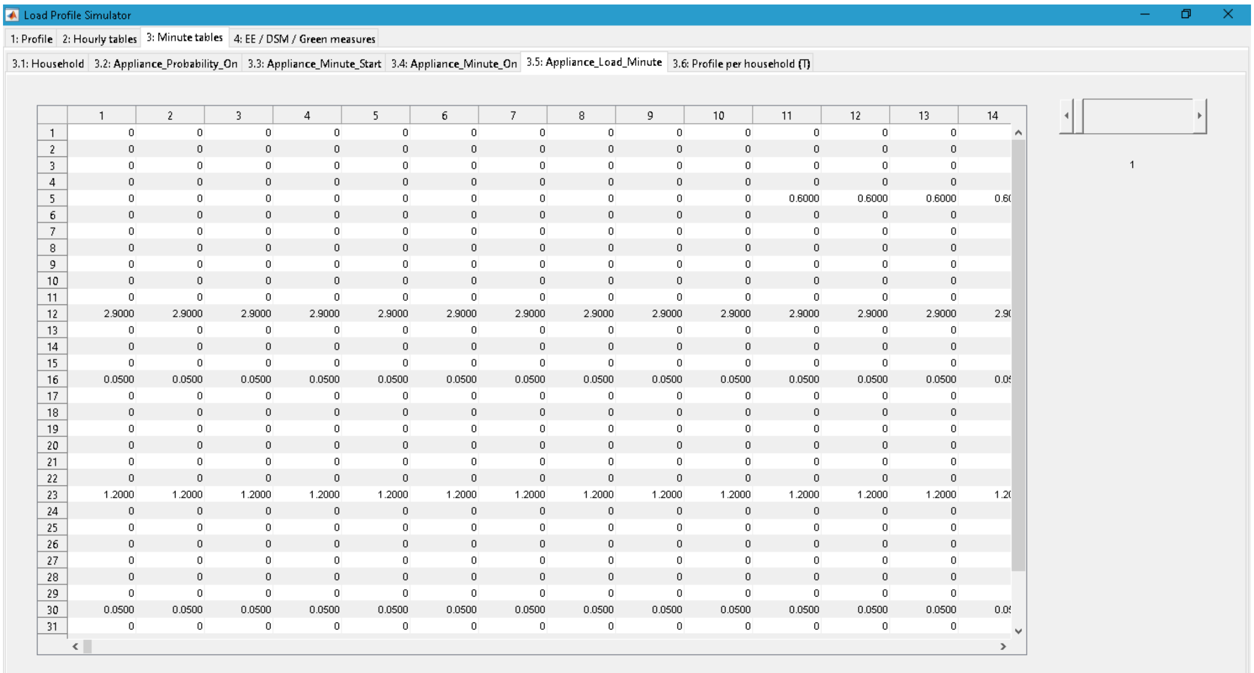


	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0	0	0	0	0	0	0	0	0	0	0.2000	0.2000	0.2000	0.2(
6	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	0	0	0	0	0	0	0	0	0	0	0	0	0	
8	0	0	0	0	0	0	0	0	0	0	0	0	0	
9	0	0	0	0	0	0	0	0	0	0	0	0	0	
10	0	0	0	0	0	0	0	0	0	0	0	0	0	
11	0	0	0	0	0	0	0	0	0	0	0	0	0	
12	1	1	1	1	1	1	1	1	1	1	1	1	1	
13	0	0	0	0	0	0	0	0	0	0	0	0	0	
14	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	0	0	0	0	0	0	0	0	0	0	0	0	0	
16	1	1	1	1	1	1	1	1	1	1	1	1	1	
17	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	1	1	1	1	1	1	1	1	1	1	1	1	1	
24	0	0	0	0	0	0	0	0	0	0	0	0	0	
25	0	0	0	0	0	0	0	0	0	0	0	0	0	
26	0	0	0	0	0	0	0	0	0	0	0	0	0	
27	0	0	0	0	0	0	0	0	0	0	0	0	0	
28	0	0	0	0	0	0	0	0	0	0	0	0	0	
29	0	0	0	0	0	0	0	0	0	0	0	0	0	
30	1	1	1	1	1	1	1	1	1	1	1	1	1	
31	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 7-13: *Appliance_Minute_On* sub-tab screen

7.8.5 Appliance_Load_Minute

The *Appliance_Load_Minute* is simply the product of the *Appliance_Minute_On* matrix with the *Appliance_Load* vector. The values cannot be edited by the user, and are recalculated for every profile or study case calculation. The user can scroll through each household's table. The table has 1440 columns horizontally, representing 60 minutes per hour for 24 hours.

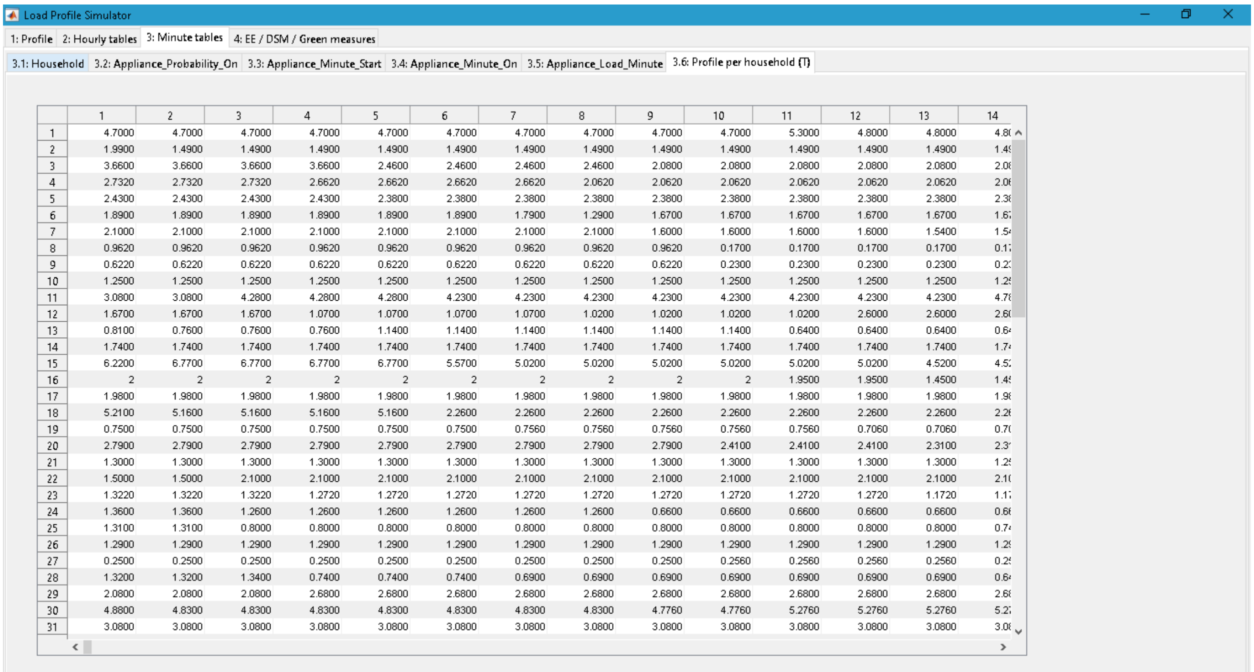


	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0	0	0	0	0	0	0	0	0	0	0.6000	0.6000	0.6000	0.6…
6	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	0	0	0	0	0	0	0	0	0	0	0	0	0	
8	0	0	0	0	0	0	0	0	0	0	0	0	0	
9	0	0	0	0	0	0	0	0	0	0	0	0	0	
10	0	0	0	0	0	0	0	0	0	0	0	0	0	
11	0	0	0	0	0	0	0	0	0	0	0	0	0	
12	2.9000	2.9000	2.9000	2.9000	2.9000	2.9000	2.9000	2.9000	2.9000	2.9000	2.9000	2.9000	2.9000	2.9…
13	0	0	0	0	0	0	0	0	0	0	0	0	0	
14	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	0	0	0	0	0	0	0	0	0	0	0	0	0	
16	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0…
17	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2000	1.2…
24	0	0	0	0	0	0	0	0	0	0	0	0	0	
25	0	0	0	0	0	0	0	0	0	0	0	0	0	
26	0	0	0	0	0	0	0	0	0	0	0	0	0	
27	0	0	0	0	0	0	0	0	0	0	0	0	0	
28	0	0	0	0	0	0	0	0	0	0	0	0	0	
29	0	0	0	0	0	0	0	0	0	0	0	0	0	
30	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0…
31	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 7-14: *Appliance_Load_Minute* sub-tab screen

7.8.6 Profile per household (T)

The *T* Matrix originated as a transposed interim step between the *Appliance_Minute_Load* matrix and the summated matrix of all households. It ended up as a useful matrix displaying each household's profile. The transposition was necessary since initially, each household is effectively a page, but in the *T* matrix, each household is represented by a row. The table has 1440 columns horizontally, representing 60 minutes per hour for 24 hours. Summating each column provided the total profile, listed on the *Main Profile* Tab.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	4.7000	4.7000	4.7000	4.7000	4.7000	4.7000	4.7000	4.7000	4.7000	4.7000	5.3000	4.8000	4.8000	4.8
2	1.9900	1.4900	1.4900	1.4900	1.4900	1.4900	1.4900	1.4900	1.4900	1.4900	1.4900	1.4900	1.4900	1.4
3	3.6600	3.6600	3.6600	3.6600	2.4600	2.4600	2.4600	2.4600	2.0800	2.0800	2.0800	2.0800	2.0800	2.0
4	2.7320	2.7320	2.7320	2.6620	2.6620	2.6620	2.6620	2.0620	2.0620	2.0620	2.0620	2.0620	2.0620	2.0
5	2.4300	2.4300	2.4300	2.4300	2.3800	2.3800	2.3800	2.3800	2.3800	2.3800	2.3800	2.3800	2.3800	2.3
6	1.8900	1.8900	1.8900	1.8900	1.8900	1.8900	1.7900	1.2900	1.6700	1.6700	1.6700	1.6700	1.6700	1.6
7	2.1000	2.1000	2.1000	2.1000	2.1000	2.1000	2.1000	2.1000	1.6000	1.6000	1.6000	1.6000	1.5400	1.5
8	0.9620	0.9620	0.9620	0.9620	0.9620	0.9620	0.9620	0.9620	0.9620	0.1700	0.1700	0.1700	0.1700	0.1
9	0.6220	0.6220	0.6220	0.6220	0.6220	0.6220	0.6220	0.6220	0.6220	0.2300	0.2300	0.2300	0.2300	0.2
10	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2500	1.2
11	3.0800	3.0800	4.2800	4.2800	4.2800	4.2300	4.2300	4.2300	4.2300	4.2300	4.2300	4.2300	4.2300	4.7
12	1.6700	1.6700	1.6700	1.0700	1.0700	1.0700	1.0700	1.0200	1.0200	1.0200	1.0200	2.6000	2.6000	2.6
13	0.8100	0.7600	0.7600	0.7600	1.1400	1.1400	1.1400	1.1400	1.1400	1.1400	0.6400	0.6400	0.6400	0.6
14	1.7400	1.7400	1.7400	1.7400	1.7400	1.7400	1.7400	1.7400	1.7400	1.7400	1.7400	1.7400	1.7400	1.7
15	6.2200	6.7700	6.7700	6.7700	6.7700	5.5700	5.0200	5.0200	5.0200	5.0200	5.0200	5.0200	4.5200	4.5
16	2	2	2	2	2	2	2	2	2	2	1.9500	1.9500	1.4500	1.4
17	1.9800	1.9800	1.9800	1.9800	1.9800	1.9800	1.9800	1.9800	1.9800	1.9800	1.9800	1.9800	1.9800	1.9
18	5.2100	5.1600	5.1600	5.1600	5.1600	2.2600	2.2600	2.2600	2.2600	2.2600	2.2600	2.2600	2.2600	2.2
19	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0.7560	0.7560	0.7560	0.7560	0.7560	0.7060	0.7060	0.7
20	2.7900	2.7900	2.7900	2.7900	2.7900	2.7900	2.7900	2.7900	2.7900	2.4100	2.4100	2.4100	2.3100	2.3
21	1.3000	1.3000	1.3000	1.3000	1.3000	1.3000	1.3000	1.3000	1.3000	1.3000	1.3000	1.3000	1.3000	1.2
22	1.5000	1.5000	2.1000	2.1000	2.1000	2.1000	2.1000	2.1000	2.1000	2.1000	2.1000	2.1000	2.1000	2.1
23	1.3220	1.3220	1.3220	1.2720	1.2720	1.2720	1.2720	1.2720	1.2720	1.2720	1.2720	1.2720	1.1720	1.1
24	1.3600	1.3600	1.2600	1.2600	1.2600	1.2600	1.2600	1.2600	0.6600	0.6600	0.6600	0.6600	0.6600	0.6
25	1.3100	1.3100	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.7
26	1.2900	1.2900	1.2900	1.2900	1.2900	1.2900	1.2900	1.2900	1.2900	1.2900	1.2900	1.2900	1.2900	1.2
27	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2560	0.2560	0.2560	0.2560	0.2
28	1.3200	1.3200	1.3400	0.7400	0.7400	0.7400	0.6900	0.6900	0.6900	0.6900	0.6900	0.6900	0.6900	0.6
29	2.0800	2.0800	2.0800	2.6800	2.6800	2.6800	2.6800	2.6800	2.6800	2.6800	2.6800	2.6800	2.6800	2.6
30	4.8800	4.8300	4.8300	4.8300	4.8300	4.8300	4.8300	4.8300	4.7760	4.7760	5.2760	5.2760	5.2760	5.2
31	3.0800	3.0800	3.0800	3.0800	3.0800	3.0800	3.0800	3.0800	3.0800	3.0800	3.0800	3.0800	3.0800	3.0

Figure 7-15: Profile per household (*T* Matrix) sub-tab screen

7.9 EE/DSM Green measures

The *Appliance Modify* sub-tab allows the user to adjust appliance loads. A load can only be edited if it has been selected. A check box exists to include or omit PV. The PV curve is adjusted by changing the size of the PV. The display shows only integer values, although the actual value entered, e.g. 1.5 will be used (will show as 2 after entering the value of 1.5). The PV penetration level is entered as a value without a percentage sign (e.g. to enter 20%, enter the value 20).

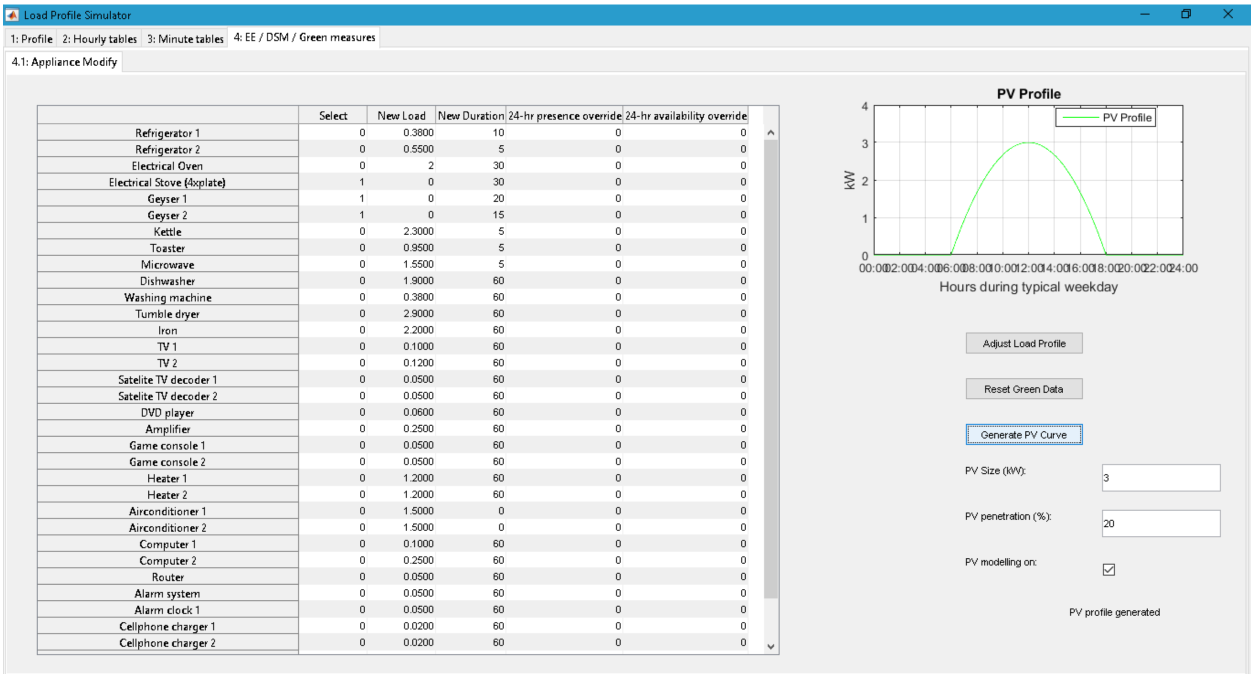


Figure 7-16: Appliance modify sub-tab screen