Energy Management by means of PLC for a Solar Powered Ultra-capacitor Streetlight System

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Abstract: This paper presents the design of an energy management programmable logic controller (PLC) control program for a solar powered ultra-capacitor and battery powered streetlight system. A PLC is used to control the flow of energy between an ultra-capacitor bank and a deep-cycle battery bank for a solar powered streetlight system. The purposes are to increase the efficiency of the complete solar powered system and to prolong the lifetime of the battery bank, since deep-cycle batteries normally used in solar electrical systems, generally have low efficiencies, have a limited amount of charging and discharging cycles, have long charging times and are temperature sensitive. The designed operational diagram as well as a functional block diagram of PLC control program is presented. The results of five different scenarios pertaining to the functionality and use of the energy between the ultra-capacitor bank and deep-cycle battery bank are presented in this paper.

Keywords: Energy management, programmable logic controller, ultra-capacitors, deep-cycle batteries.

I. INTRODUCTION

A Programmable Logic Controller (PLC) is a computer-type device used to control equipment in an industrial facility [1]. The kinds of equipment that PLCs can control are as varied as industrial facilities themselves. Food processing machinery, auto assembly lines and conveyor systems are some examples where PLCs are used. In a traditional industrial control system, all control devices are wired directly to each other according to how the system is supposed to operate [2]. In a PLC system, however, the PLC replaces the wiring between the devices. Thus, instead of being wired directly to each other, all equipment is wired to the PLC [3]. The control program inside the PLC provides the "wiring" connection between the devices. The control program is the computer program stored in the PLC's memory that tells the PLC what's supposed to be going on in the system. The use of a PLC to provide the wiring connections between system devices is called *softwiring* [4].

This paper presents the design of a PLC control program for a solar powered ultra-capacitor streetlight by means of a software package called Siemens LOGO!Soft Comfort. The PLC control program has the following functionality:

• Three inputs (Ultra-capacitor bank, deep-cycle battery bank and a day/night switch);

• Three outputs (Ultra-capacitor indication light, battery indication light and a streetlight);

• The ultra-capacitors have a voltage range of 12 V to 6 V;

• The ultra-capacitor indication light must show the functioning;

• The battery has a voltage range of 13 V to 11 V. The battery indication light must show the functioning;

• The streetlight must activate only when the day/night switch is activated (therefore only active during daytime);

• The streetlight must first draw energy from the ultra-capacitors, then from the deep-cycle batteries. If the batteries reach its lowest voltage level, then the streetlight must go out;

• There must be no downtime between the switching from the ultra-capacitors to the batteries.

More detail on the functioning of the PLC is presented in the materials and method section. The results section provides detail on five different scenarios relating to the functionality and energy usage of the ultra-capacitor bank and deep-cycle battery bank.

II. MATERIALS AND METHOD

This section provides the materials and method that was used to design the energy management PLC control program for the solar powered ultra-capacitor and battery powered streetlight system.

A. Materials

The following materials were used for this project:

• Ultra-capacitor bank, deep-cycle battery bank and a day/night switch;

• Ultra-capacitor indication light, battery indication light and a streetlight.

For the ultra-capacitor bank, an analogue input was used. As the voltage of the ultra-capacitor varies from 6 V – 12 V, a discrete input will not be sufficient. An analogue input has an infinite number of states. The block properties for simulation were set to a minimum of 6 V and a maximum of 12 V. In the simulation this block will have a slider which can adjust the value in integer intervals from 6 V to 12 V. For the battery bank, the input is also an analogue input. The block properties for simulation were set to a minimum of 11 V and a maximum of 13 V. The slider of this block can be adjusted between 11 V and 13 V. The day/night switch is represented by a digital (sometimes called discrete) input. A digital input can only be 1/0 which is 'ON' or 'OFF'. The three outputs are the ultra-capacitor indicator light, battery indicator light and the streetlight. All three outputs are digital, as a light only needs

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to be ON or OFF. For lights that must be able to dim, for instance in a theatre, an analogue output can be used, but in this case digital outputs are sufficient. More information on ultra-capacitors and a comparison between super-capacitors and batteries can be found in [1, 5].

An ultra-capacitor analogue threshold and a battery analogue threshold is further required for this project. The ultra-capacitor analogue threshold will control whether the ultra-capacitor is used to power the streetlight or not. It is also used to convert the analogue signal to a digital signal. This is necessary because the ultra-capacitor indication light is a digital output. The threshold is set so that the ultra-capacitor is used when its voltage is between 6 V and 12 V. In the block parameters, the threshold is set to switch OFF at 6 V and ON at 11 V. The actual input value which is read by the threshold block is calculated as follows: Value = (AI + Offset) x gain. The block work as follows: If the “ON” threshold > ”OFF” threshold, which is true in this case, then Output (Q) = 1 if Value > “ON”, and Q= 0 if Value <= “OFF”. Because the output = 1 when Value > “ON” and not >= “ON”, the “ON” threshold is set to 11 instead of 12.

The battery analogue threshold block determines when the battery can be used to power the streetlight. This threshold work on the same principle as that of the ultra-capacitors, except the “ON” threshold is set to 12 and the “OFF” threshold is set to 11. The “ON” threshold is 12 and not 13 because Value > “ON” for the output to be 1, the analogue input slider can only be moved in integer intervals.

Other blocks that are required is: XOR block, OR block and AND block. This XOR block is used to prevent both of the indicator lights form being in the “ON” state at the same time. If both of the inputs pass their thresholds, only the ultra-capacitor indicator light will be ON, letting the streetlight draw energy from the ultra-capacitor first. When the ultra-capacitor is fully discharged, it will fail the threshold and the streetlight will draw energy from the battery. The OR block requires that either the ultra-capacitor or the battery is supplying energy, for the output to be 1. The AND block requires that all the inputs are 1 for the output to be 1. In this model it means that the day/night switch should be activated as well as a power source, as decided by the XOR and OR blocks, for the streetlight to be ON. More detail on these blocks is presented in [2-4].

B. Method

Fig. 1 provides the operational diagram of the PLC control program. At system initiate, the control program resets all outputs to an OFF status. The control program verifies the status of the day/night switch. If the day/night switch status is High, then the control program verifies if the ultra-capacitors are fully charged. If the day/night switch status is Low, then the control program verifies if the battery is fully charged. If the ultra-capacitor status is High, then the control program turns ON the ultra-capacitor indication light. If the ultra-capacitor status is Low, then the control program verifies if the battery is fully charged. If the battery status is High, then the control program turns ON the battery indication light. If the battery status if Low, then the control program moves to the initiate system status. If both indication lights are ON, then the control program switches the streetlight ON.

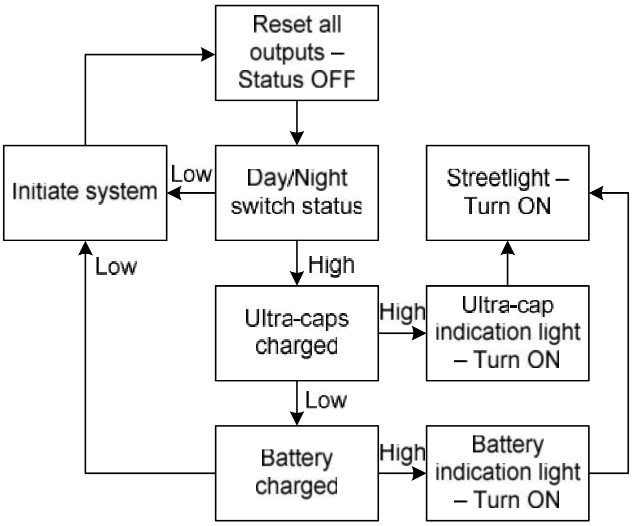

Fig. 1. Operational diagram of the PLC control program.

III. Results

This section provides the results obtained from the designed energy management PLC control program for the solar powered ultra-capacitor and battery powered streetlight system. Fig. 2 provides the designed PLC functional block diagram for this project. The ultra-capacitor and battery are charged during daytime, therefore both will be fully charged when the day/night switch is activated. Analogue inputs are used for the ultra-capacitors, as well as the battery.

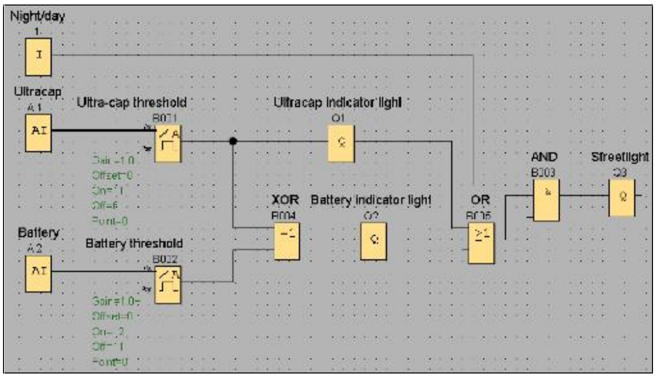

Fig. 2. PLC functional block diagram.

Fig. 3 provides the control program simulated with the day/night switch in the OFF status. The simulation figure shows the system in normal state. This is when the day/night switch is “OFF”, when the ultra-capacitors are down to 6 V and when the battery is down to its lowest level, which is 11 V.

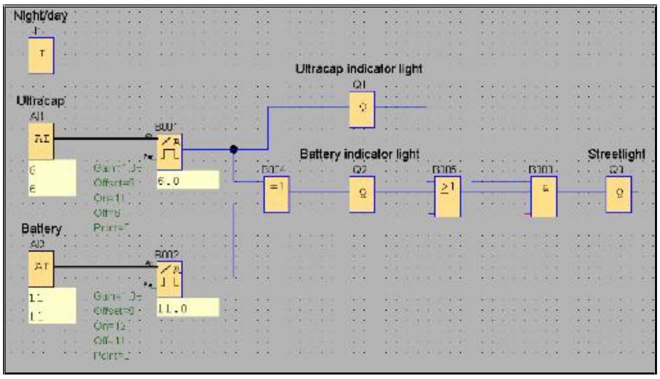

Fig. 3. Control program - simulation day/night OFF.

Fig. 4 provides the control program simulated with the day/night switch in the ON status, ultra-capacitor operation. The figure shows that the streetlight is "ON" when the day/night switch is activated and when the ultra-capacitor is from 11 V to 6 V. When the ultra-capacitor is on 6 V, it will switch OFF. The battery indication light is "OFF" because, as specified, the light should first draw energy from the ultra-capacitors then from the battery.

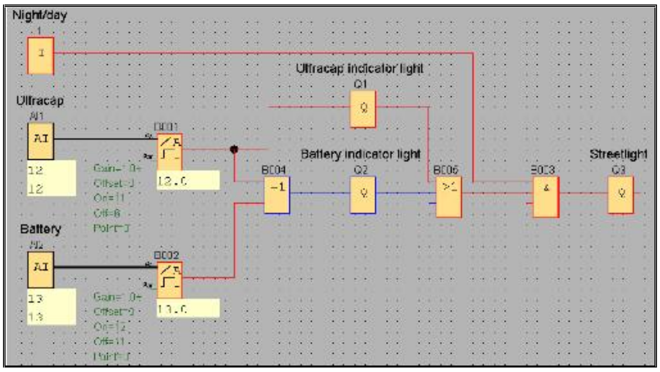

Fig. 4. Control program - simulation day/night ON, ultra-cap operation.

Fig. 5 provides the control program simulated with the day/night switch in the ON status, battery operation. The figure shows that the light is still active when the ultra-capacitor is out of power. The ultra-capacitor light shows that the power is down to 6 V. Now the battery takes over, the battery indication light is "ON".

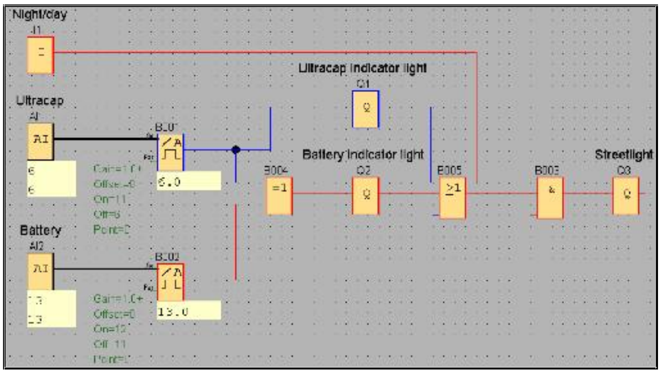

Fig. 5. Control program - simulation day/night ON, battery operation.

Fig. 6 provides the control program simulated with the day/night switch in the ON status, battery and ultra-capacitor fully discharged. This is the scenario where the battery may run out of power. The battery should switch off when the battery is down to 11 V to avoid damage. The figure shows the battery on 11 V, this turns the battery indication light as well as the streetlight "OFF". The day/night switch is still active, but there is no power to support the light from either the ultra-capacitor or the battery.

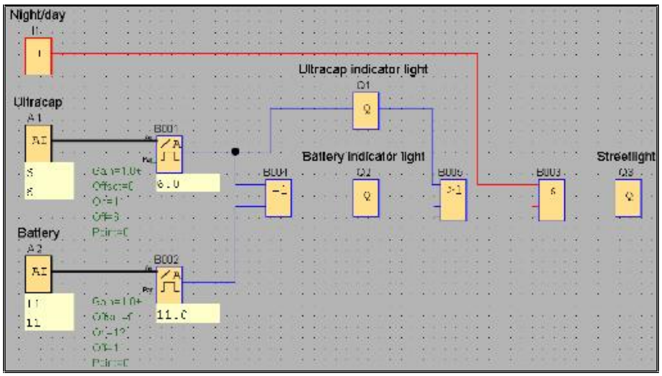

Fig. 6. Control program - simulation day/night ON, battery and ultra-cap fully discharged.

Fig. 7 provides the control program simulated with the day/night switch in the OFF status, battery and ultra-capacitor fully charged. Although both the ultra-capacitor and the battery are fully charged, the streetlight is inactive because the day/night switch is "OFF". The reason why the battery indication light is "OFF" is because the light may not use power from both the ultra-capacitor and the battery at the same time. The value "13 V" shows that the battery is fully charged. When the ultra-capacitor is down to 6 V, the battery indication light will switch ON as showed in the figure.

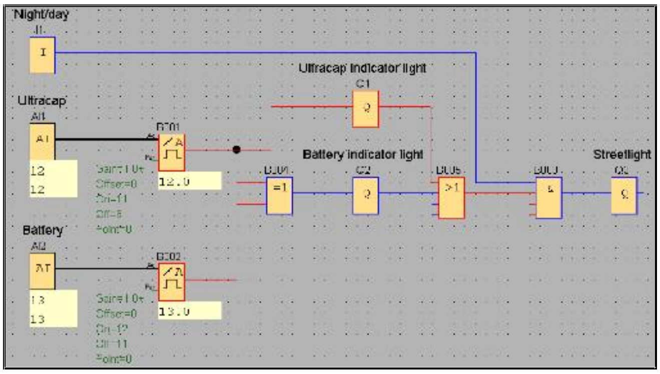

Fig. 7. Control program - simulation day/night OFF, battery and ultra-cap fully charged.

IV. CONCLUSION

This paper shows that the designed operational diagram of the PLC is sufficient for this specific project. The control program is created and simulated in the Siemens LOGO! Soft Comfort simulation package. This project showed how different blocks react on the simulation package when different inputs and outputs are connected to it. Complex simulations can be created and the number of blocks is only limited to the memory space and the device series of the PLC. To optimize the circuit program different arrangements can be made in the simulation. The general use of PLC's makes the industrial environment a lot easier and quicker. Once a problem is experience the coding just needs to be updated and not the whole wiring system. A simulation program is very cost effective way and test runs can be simulated at no additional costs whereas test runs for wiring installation consume a lot of time. Memory intensive blocks can be replaced with a structure consisting of several blocks, which altogether require less memory space. If the various optimization attempts are unsuccessful, then an additional PLC can be added to optimize the system.

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Rupert Gouws holds a Ph.D. degree in Electrical and Electronic Engineering from the North-West University (Potchefstroom campus). He consulted to a variety of industry and public sectors in South Africa and other countries in the fields of energy engineering and engineering management. Currently he is appointed as a senior lecturer specialising in energy engineering, electrical machines and control at the North-West University. The Engineering Council of South Africa (ECSA) registered him as a Professional Engineer and the Association of Energy Engineers (AEE) certified him as a Certified Measurement and Verification Professional (CMVP).