The effect of source stabilisation on the energy consumption and harmonic distortion of a single-phase induction motor-pump configuration for a swimming pool in South Africa.

Source stabilisation of single-phase induction motor-pump configurations

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In this project, a single-phase induction motor pump was used to circulate water in a swimming pool. The pump is supplied with a single-phase voltage source with external noise, causing the efficiency of the induction motor pump to be lower than required. A source stabilisation system was built to improve the quality (i.e. lower the harmonic component) of the input signal and improve the efficiency of the induction motor pump.

Fig. 1 provides the experimental setup of the induction motor-pump configuration for the following two scenarios:

- where the single-phase induction motor pump is operated under normal conditions
- where the source stabilisation system is activated to improve the energy consumption of the induction motor-pump configuration. The harmonic distortion and energy consumption for both scenarios were measured and compared.

The project was limited to a budget of R3000 to prevent the cost-to-saving ratio for this specific single-phase induction motor-pump from becoming too high. Different solutions were therefore simulated (in Matlab Simulink and Orcad), before the actual system was built.

Source stabilisation system design

It was necessary to change the design of the source stabilisation system to stay within the project budget. Fig. 2 provides an equivalent circuit of the source stabilisation system. In this circuit, four Afcap power factor correction capacitors are connected in parallel to provide a total capacitance of 266 µF (total current calculated at 35 A). A Jantzen air core inductor rated at 270 µH (300 W) and an Arcol aluminium house wire wound resistor rated at 1 Ω (50 W) were used.

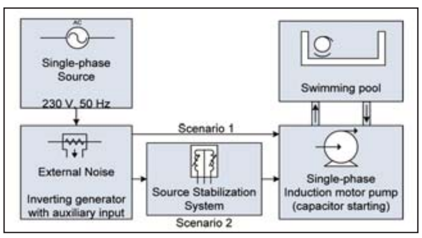

Fig. 1: Experimental setup of the induction motor-pump configuration with the source stabilisation system.

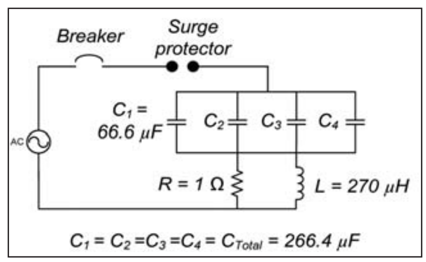

Fig. 2: Equivalent circuit of the source stabilisation system.

Fig. 3 provides the response of the different harmonic filters for this project. It can be seen from this figure that the third harmonic filter has the lowest cut-off frequency. Lower cost components are required for higher harmonic filters as the power dissipation is lower.

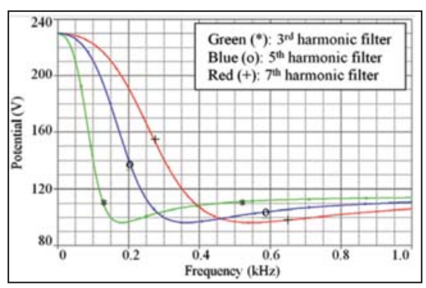

Fig. 3: Second order harmonic filter response.

Table 1 provides the power dissipation of the components at different cut-off harmonics and cut-off frequencies. The table shows that, at the third harmonic cut-off, the power dissipated by the power resistor and inductor are 780 W and 2200 W respectively.

The cost of components at these wattages is very high and it was decided to increase the harmonic cut-off frequency from the third to the seventh harmonic cut-off. Components' cost at this harmonic cut-off frequency falls within the project budget of R3000.

Important to note is that the seventh harmonic filter will not reduce the troublesome third harmonic from the system. The project therefore investigated the influence of the seventh harmonic filter on total energy consumption.

Fig.4: Physical source stabilisation system.

Cut-off harmonic & frequency	C (μF) L (μH)	Current (A)	Power R (W)	Power L (W)
3rd, 100 Hz	1125	80	780	2200
5th, 200 Hz	563	41	51	290
7th, 300 Hz	375	27	10	86
9th, 400 Hz	281	20	3.2	36
11th, 500 Hz	225	16	1.3	19
13th, 600 Hz	188	14	0.6	11

Table 1: Power dissipation at different cut-off harmonics.

Fig. 4 provides an image of the physical stabilisation system and shows the four power factor correction capacitors, the power resistor and the inductor.

Experimental results

This section provides the experimental results obtained from the induction motor-pump configuration for a swimming pool with the source stabilisation system.

Fig. 5 provides a graph of the voltage analysis before and after activation of the stabilisation system. The stabilisation system reduces the noise but increases the peak amplitude of the waveform.

Fig. 6 provides the Fast Fourier Transform (FFT) of the voltage analysis before and after activation of the stabilisation system. The top (blue) profile shows the normal operation condition and the bottom (red) profile shows the improved condition (with the stabilisation system activated).

Fig. 7 shows the current analysis before and after activation of the stabilisation system. The stabilisation system reduces the noise but increases the peak amplitude of the waveform.

Fig. 8 provides the FFT of the current analysis before and after activation of the stabilisation system. The top (pink) profile shows the normal operation condition and the bottom (green) profile shows the improved condition (with the stabilisation system activated).

Fig. 9 shows the current analysis of the total motor and stabilisation (filter) system. The absolute value of the motor current is lower than that of the total current, where the consumption of the stabilisation system is also taken into account. More detail on this figure is available in Table 2, which provides a summary of the results on the harmonic components and energy consumption for the following two conditions:

- Normal condition operation
- Where the source stabilisation system is activated

The total harmonic voltage distortion (THVD) and total harmonic current distortion (THCD) increased when the

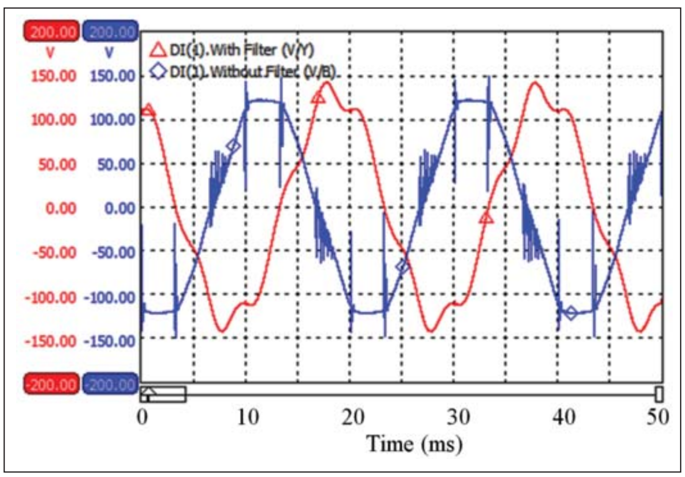

Fig. 5: Voltage analysis before and after stabilisation.

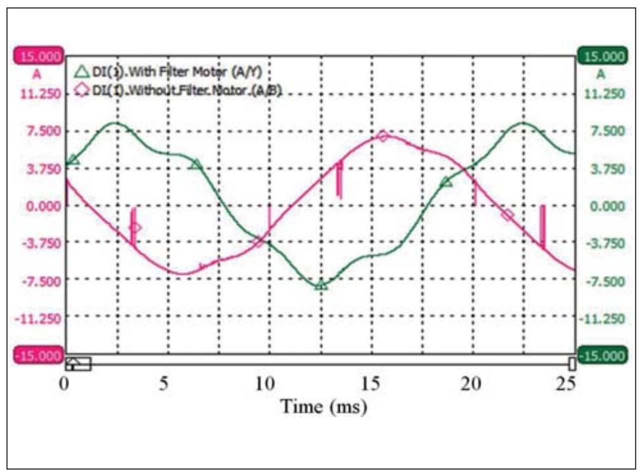

Fig. 7: Current analysis before and after stabilisation.

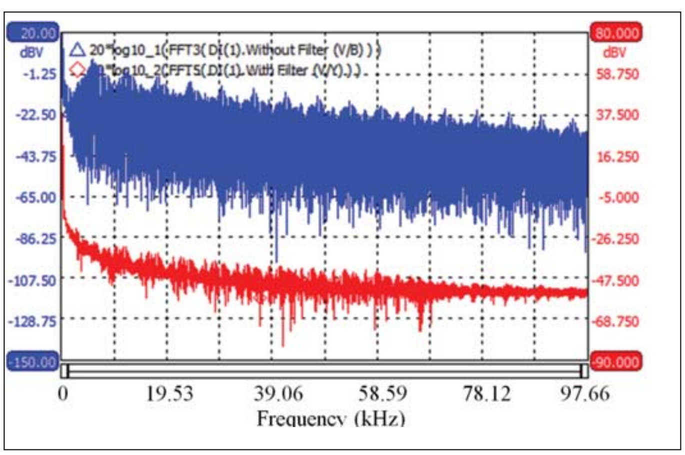

Fig. 6: FFT of the voltage analysis before and after stabilisation.

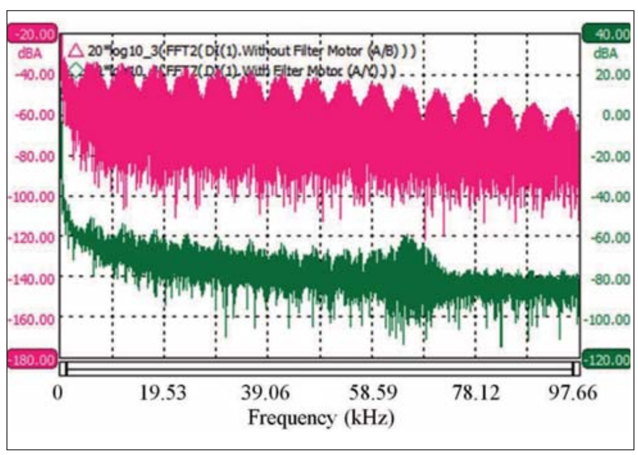

Fig. 8: FFT of the current analysis before and after stabilisation.

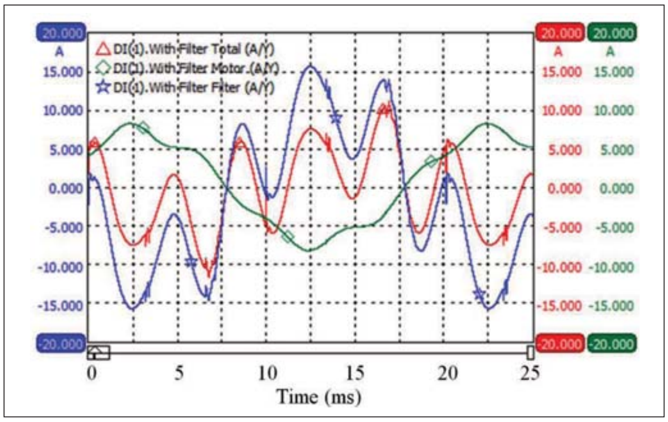

Fig. 9: Current analysis of the total, motor and stabilisation (filter) system.

stabilisation system was activated. The harmonic voltage distortion (HVD) for the seventh harmonic and harmonic current distortion (HCD) for the seventh harmonic decreased when the stabilisation system was activated.

The induction motor-pump configuration showed an average improvement of 2,9% in energy consumption where the stabilisation system is activated, but an average decrease of 11% in overall energy consumption (when the energy consumption of the stabilisation system is also taken into account). The stabilisation system consumed an average of 53 W over the time period.

Conclusion

It is therefore concluded that the intervention does not reduce overall energy consumption. The total power dissipated by the source stabilisation system was 53 W. The percentage loss caused by the stabilisation system could be less for larger induction motor-pump configurations as the operating power of the induction motor is much higher.

Measurement	Condition	Amount	% Change
THVD	Normal operation	11,0%	
THVD	Stabilisation system	11,3%	
HVD (7th harm)	Normal operation	10,0%	
HVD (7th harm)	Stabilisation system	5,55%	
THCD	Normal operation	5,12%	
THCD	Stabilisation system	5,98%	
HCD (7th harm)	Normal operation	1,32%	
HCD (7th harm)	Stabilisation system	0,85%	
P_{Motor}	Normal operation	359 W	
P_{Motor}	Stabilisation system	349 W	-2,9%
P_{Total}	Normal operation	359 W	
P_{Total}	Stabilisation system	402 W	11,0%
$P_{Stabilisation}$	Stabilisation system	53 W	

Table 2: Harmonics and energy consumption.

Component cost of the seventh harmonic filter is a lot lower than that of the third harmonic filter. If cost were not a factor, a lower order filter could have resulted in a reduction of total power consumption. The cost of the intervention compared to the cost of the single-phase induction motor must, however, be taken into account as the payback period will not be feasible.

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