MAINS SIGNAL PROPAGATION THROUGH DISTRIBUTION SYSTEMS

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ABSTRACT

This paper looks at a power quality problem termed "Racing Clocks" caused by the amplification of ripple frequency signals in distribution networks. A study of this problem has been undertaken on two 22kV feeder systems within the Sydney area. These two particular feeder systems were chosen as they have caused problems in the past. The purpose of this study was to determine whether the problem still exists in the areas supplied by these feeders. The present and ultimate configurations of these two feeder systems are examined and the resonance frequencies and ripple signal voltage levels are determined. Modelling techniques that were adopted in the simulation are also described. The study showed that for certain ratios of overhead to underground cable, the resonance point might occur near a problematic frequency.

1. INTRODUCTION

Off-peak hot water systems are controlled in most areas using ripple signals. A common frequency which is used is 1050Hz. Resonance frequencies exist in all electricity networks and for pure overhead systems these resonance points lie well away from 1050Hz. By adding underground cables to the network, which is the current trend in developing areas, the additional capacitance which is introduced to the system becomes significant enough that the resulting resonance point can decrease to a problematic frequency. When this occurs, the 1050Hz signal, which is usually around 5Vrms at the point of injection, may be amplified to a much higher level. When the ripple signal is amplified to a critical level, the number of zero crossings of the resultant voltage waveform can increase to more than the normal two per cycle. A typical waveform capture at a padmount substation when a ripple signal is being applied can be seen in Figure 1. The increased number of zero crossings can cause some types of digital clocks to gain time as they use zero crossings for timing purposes. This phenomenon is known as 'Racing Clocks'.

The 'Racing Clock' phenomenon has been a problem in electricity distribution networks for a number of years. Several studies have been undertaken in this area to analyse the problem and attempt to find solutions. A recent study [1] examined a feeder system and looked at modelling techniques adopted in PSCAD®/EMTDC™ to simulate the network. Results from this study indicated high ripple signal levels.

Since the above stated study, the network has been re-configured and a fresh study was required to determine whether the unacceptable signal levels still exist. It was also required to examine another feeder system where the possibility of signal amplification was suspected. New modelling techniques were investigated in the new study, relating in particular to high frequency correction.

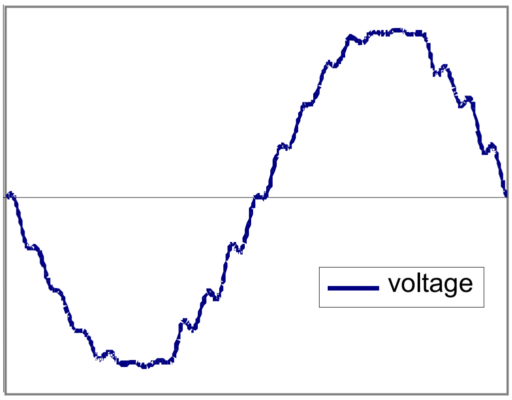

Figure 1 – Voltage waveform with Ripple Signal

2. MODEL DEVELOPMENT

2.1 System Description

The operating characteristics of two feeder systems were investigated in this study. The two feeder systems are different in their overhead to underground cable ratio. The first feeder system, the "underground" system, contains 6.5km of overhead lines and 13.8km of underground cables, with an underground to overhead ratio of two thirds. The second feeder system, the "equally weighted" system, contains 14km of overhead lines and 16km of underground cables. Both feeder systems are in developing residential

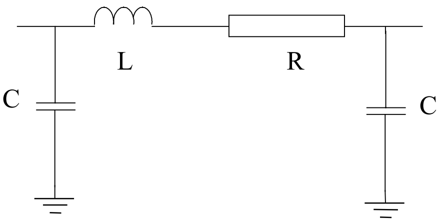

Figure 2– Underground Cable Representation

areas in Sydney and are essentially radial.

In the earlier study [1], the underground feeder system was modelled using PSCAD®/EMTDC™. Re-configuration of the system involved the movement of open points and the transfer of some loads to other feeder systems. Opportunities were taken in the new study to examine new modelling techniques relating in particular to high frequency correction in the models. Two models were developed to investigate the present operational conditions of the two feeder systems. Two further models were developed to examine the future configurations.

In the ultimate configuration of the two feeder systems, approximately half of the load from underground system will be switched over to another feeder system. The underground system will therefore become a very lightly loaded system with equal amounts of overhead line and underground cable. The equally weighted system will become an almost entirely underground system in the ultimate configuration.

2.2 Modelling Details

The models developed in PSCAD®/EMTDC™ were single phase representations of the 22kV network.

Underground cables were represented by the lumped π network as shown in Figure 2. Overhead conductors were represented with a similar model, but the capacitance was assumed to be negligible.

Three different skin effect factors were applied to the resistance of each section of line. These factors were applied to compensate for skin effect at the ripple signal frequency. The factors which were used are seen in Table I.

For a system with a 1050Hz ripple signal, h = 21. Skin effect factors were tested to see the preliminary effect they had on the results when incorporated into the model. None of the factors tested applies directly to a 22kV system for the 21st harmonic. Further studies are required in determining more accurate skin effect correction factors.

Table I – Skin Effect Factors applied to line resistances (h = harmonic order)

Skin Effect Correction Factor	Notes
$0.267+0.485\times\sqrt{h}$	Applied in the range 75kV → 400kV for any harmonic order above 7.6 [2].
$1+\frac{0.646\times h^2}{192+0.518\times h^2}$	Applied to 132kV systems [2].
1	Used as a basis for comparison

System loads were represented at each MV/LV substation by a hybrid model of the type shown in Figure 3. In this model, R_{sh} represents purely resistive loads whereas the series R_{se} - L_{se} branch represents motor type loads.

Allocation of real power to the two parallel branches is an issue for which a clear cut answer is not available. Thus, it was necessary to trial different allocation factors to apportion the total real power at MV/LV substations. The allocation factor was termed x_1 and values for x_1 = 0.4, 0.5, 0.6 were observed.

A load factor, x_2, was incorporated into the load model to allow the system to be modelled under both light and heavy load conditions. Light load was modelled as $x_2 = 0.28$ and heavy load was modelled as $x_2 = 0.70$. The values used to simulate light and heavy load were specific for the systems being modelled in this study and were estimated from field measurements.

The shunt resistance of the load, R_{sh}, is calculated by

$$R_{sh} = \frac{(Voltage)^2}{MDI\times x_1\times x_2\times pf}\Omega$$

Voltage – nominal voltage given in kV
MDI – Maximum demand (MVA)
x_1 – allocation factor for real power
x_2 – proportion of MDI at a load point
pf – total power factor

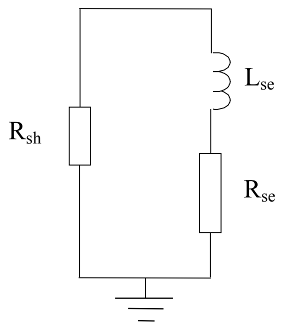

Figure 3 – Load Representation

Table II – Skin Effect Factors applied to load resistances

Skin Effect Correction Factor	Notes
√h	[2]
1	Used as a basis for comparison

The series inductance of the load, L_{se}, is calculated by

$$L_{se} = \frac{(Voltage)^2}{MDI \times \sin(\cos^{-1}(pf)) \times 2\pi f} H$$

The series resistance of the load, R_{se}, is calculated by

$$R_{se} = \frac{(Voltage)^2}{MDI \times (1 - x_1) \times x_2 \times pf} \Omega$$

For all load points the overall power factor was assumed to be 0.9 lagging.

As there is the possibility of skin effect influencing the load resistances, further correction factors were also adopted which are given in Table II.

4. RESULTS

In the underground system, the simulation results showed that the resonance frequency is 800Hz. The amplification of the ripple signal was therefore found to be acceptable. The resonance curves for two different substations in the underground system can be seen in Figure 4 and the amplification levels at 1050Hz are indicated. Sub A is closer to the point of injection of the ripple signal than Sub B. These curves were obtained from simulation results under heavy load conditions with an x_1 of 0.5 and with no line or load correction factors.

In the earlier study [1], the resonance point was found to be at 950Hz. Since the last study, the resonance point has effectively moved further to the left of 1050Hz.

In the ultimate configuration of the underground system, the system contains equal amounts of overhead and underground cable. The resonance point moves across to the right of 1050Hz to 1600Hz. The resonance curve for one substation can be seen in Figure 5 and the amplification at 1050Hz is indicated. This substation is one that is in the underground system in both the present and the ultimate configuration. This curve was obtained from simulation results under heavy load conditions with an x_1 of 0.5 and with no line or load correction factors

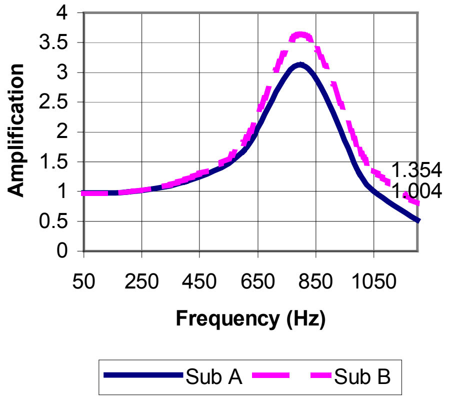

Figure 4 – Resonance curves for the present configuration of the underground system.

The underground system will not be a problem in its ultimate configuration, however in the transition period to its ultimate configuration, the resonance point may move to be close to 1050Hz. In such a situation, the "Racing Clock" problem will re-surface. Therefore care needs to be taken to ensure that as the network is altered, the resonance point never moves to 1050Hz.

In the equally weighted system the resonance frequency is 1700Hz. The amplification of the ripple signal was therefore found to be acceptable. The resonance curves for two different substations in the equally weighted system can be seen in Figure 6 and the amplification at 1050Hz is indicated. Sub C is closer to the point of injection of the ripple signal than Sub D. These curves were obtained from simulation results under heavy load conditions with an x_1 of 0.5 and with no line or load correction factors.

The simulation results showed that under light load conditions the ripple signal levels increase in

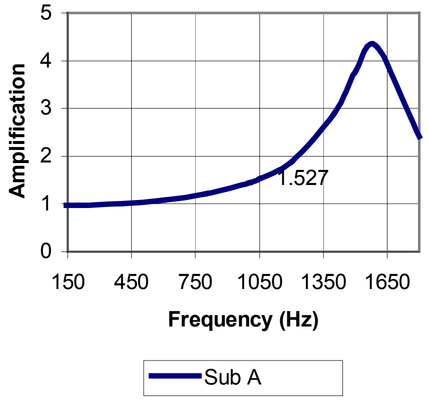

Figure 5 – Resonance curve for the ultimate configuration of the underground system.

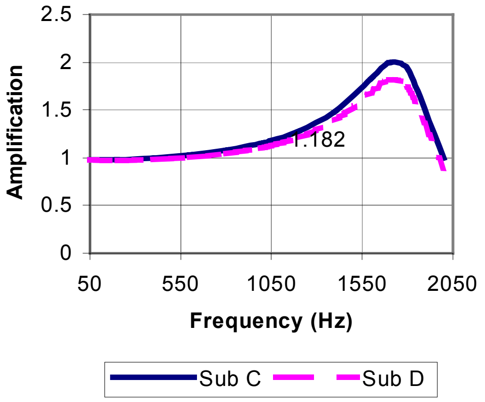

Figure 6 – Resonance curves for the present configuration of the equally weighted system.

comparison to what is obtained under heavy load. The high frequency correction applied to aggregate loads tends to increase the signal levels whereas when applied to lines the signal levels decrease. As expected, the resonance frequencies did not change when these factors were applied to the resistive components of the models. Determining the combination of factors which produces the most accurate model requires further studies.

The simulation results indicate that problems do not currently exist in either of the two feeder systems which were modelled. The voltage levels were deemed acceptable based on the Meister Curve which is given in the CENELEC standard [3]

Measurements were carried out in the field to verify the accuracy of the models and to check the status of ripple signal problem. These measurements were carried out using PM30 POWERMonic monitors on a warm but not excessively hot summer day. Light load measurements were made at 4pm and heavy load measurements were made at 7pm. The results indicated an overall reduction in the signal levels both under light and heavy loads conditions when compared to what was observed in the previous study in relation to one of the feeders. The signal levels were found to be acceptable for both of the feeder systems investigated. There was generally a good correlation between the simulation results and the field results as can be seen in Table III.

5. CONCLUSIONS

In general it was shown that the modelling techniques adopted had a degree of accuracy which was acceptable for this study.

This study showed that for the systems containing approximately equal amounts of overhead and underground cable, the resonance point was not at a problematic frequency and to the right of 1050Hz. However, for a system where two thirds is underground, the resonance point was seen to be to the left of 1050Hz. Therefore in a system where more than half and less than two thirds is underground, the resonance point may be at a problematic frequency. It was also observed that for an entirely underground system, the resonance point is to the right of 1050Hz and not at a problematic frequency. This study has not taken into consideration the effect of power factor correction capacitors on the overall capacitance of the system.

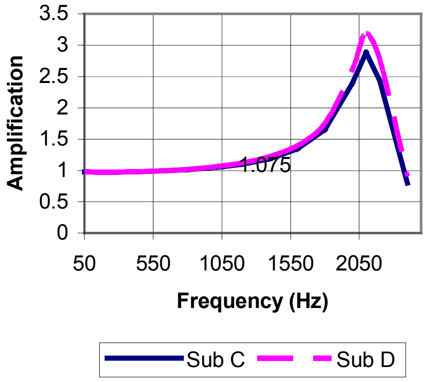

Figure 7 – Resonance curves for the ultimate configuration of the equally weighted system.

After examining the field and simulation results of the two 22kV feeder systems, it would appear that at present "Racing Clocks" is not a problem in these areas. This does not mean that the problem does not or cannot exist in other areas of a network. It is therefore recommended that during planning and development stages of new distribution networks, the ratio of underground and overhead cables be taken into consideration and the resonance frequency be given due attention.

In terms of developing a more accurate model for simulating the "Racing Clock" problem, future research efforts are required. Further work could be

Table III – Amplification of Simulation Ripple Signal vs Field Ripple Signal

	Amplification of Ripple Signal in Simulation	Amplification of Ripple Signal in Field	% Difference
Sub A	1.004	0.937	-6.719
Sub B	1.354	1.285	-5.124
Sub C	1.182	1.157	-2.124
Sub D	1.128	1.198	6.230

done to determine appropriate high frequency correction factors applicable to lines and loads. Further work also could be done on the modelling of loads to incorporate the effects of non-linear type loads.

6. REFERENCES

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