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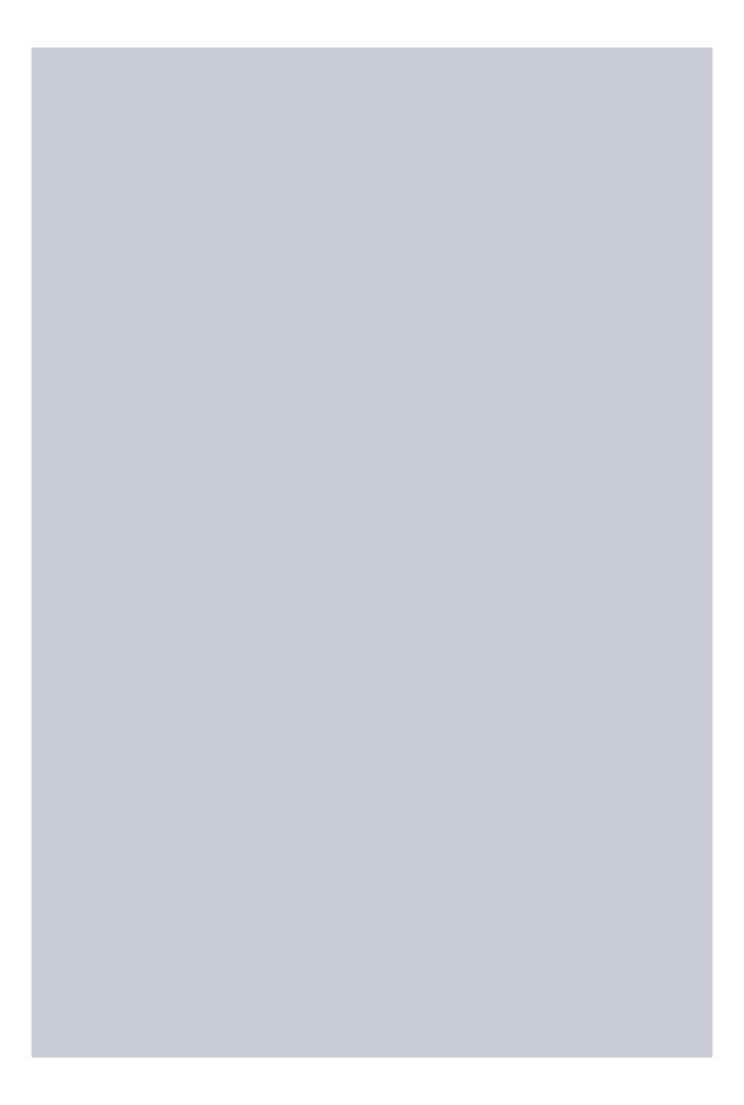
Australian Power Quality and Reliability Centre

Ripple Injection
Load Control Systems

Technical Note 14
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UNIVERSITY OF WOLLONGONG

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1. Executive Summary

This technical note discusses ripple injection load control systems. Ripple injection load control is a communication method used extensively by electricity distributors to turn on and off loads such as off-peak hot water systems and street lighting. Ripple injection control systems work by superimposing a coded control signal on to the normal 50 Hz voltage waveform. This allows for one way communication with loads without additional communications infrastructure. In most cases, ripple injection control systems are an effective and flexible method of performing this control. For residential customers, ripple injection systems allow access to cheaper off-peak electricity.

In most cases, customers are mostly unaware of the operation of the ripple injection control system. However, electricity providers do receive a significant number of complaints related to the system. These are due to signal levels either being too high or too low. If signal levels are too low, receiving relays may not operate and water will not be heated. Signal levels which are too high are caused by network resonance and cause problems with equipment that relies on counting zero crossings of the voltage waveform and can result in flickering lights and audible noise.

Mitigation of ripple signals which are at inappropriate levels is not straightforward as signal levels are not homogenous across networks and will change with network development and addition or loss of load. For signal levels which are too low, the injection level is generally increased at the source. Two main methods are used for mitigation of signal levels which are too high. These are changes to the network in order to change the network resonant frequency and filters.

With the advent of smart metering, ripple injection systems such as those discussed in this technical note may become a thing of the past. This is due to the fact that load control will be available via the smart metering communication infrastructure negating the need for ripple injection signal communication.

2. Introduction

Electricity providers have used ripple injection control signals also known as audio frequency injection control (AFIC) in order to control loads connected to the electricity distribution network since the 1960s [1]. The most common examples of these loads are off-peak hot water heaters and street lights. Controllable loads offer many advantages to electricity providers, primarily better use of network infrastructure and generation. For customers, the main advantage is access to cheap off-peak electricity tariffs. Ripple injection control systems work by superimposing a coded control signal on to the normal 50 Hz voltage waveform. This allows for one way communication with loads without additional communications infrastructure. The injection system leads to some distortion of the 50 Hz sinusoidal waveform. Typical ripple injection signal frequencies used in Australia range from 167 Hz to 1050 Hz. A more detailed list of the frequencies and their locations can be found in the NSW Service and Installation Rules (Section 6) [2]. The signals are injected at or near the nominal injection frequency and are applied in bursts. An entire single injection run lasts approximately 3 minutes. The control signal is typically injected at the medium voltage substation. It then propagates throughout the distribution network and is detected by special receiving relays which switch loads on or off as appropriate.

3. Ripple Injection System Technology

3.1. Ripple Signal Injection Methods

As stated above, injection signals are generally applied at the medium voltage substation. This allows propagation of the signal to a wide area. In NSW urban areas, the signal is generally applied at 11 kV, while in more rural areas, application may be at 22 kV, 33 kV and 66kV. There are two methods which may be used to superimpose control signals on to the normal voltage waveform. These are parallel and series injection. Figure 3.1 shows the configuration of the two different injection methods. Both injection methods are used in Australia.
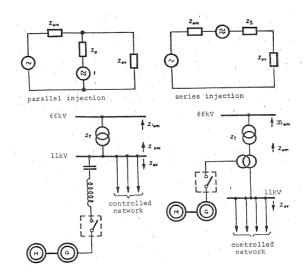

Figure 3.1: Schematic of Parallel & Series Injection Methods [1]

There are two technologies currently in use for generating the injected signals. The first and older technology is the motor generator set. In this case, an electric motor is used to spin a generator which supplies the desired injection frequency. A contactor is used to apply the injection signal to the network via tuning coils and an isolation transformer as appropriate. The second and more modern injection technology is the static frequency converter. Here, electronics are used to generate the injection signals which are again applied to the network via an isolation transformer and tuning coils. A single phase schematic of the two injection signal generation technologies is shown in Figure 3.2. Figure 3.3 shows the ripple injection equipment at a zone substation.
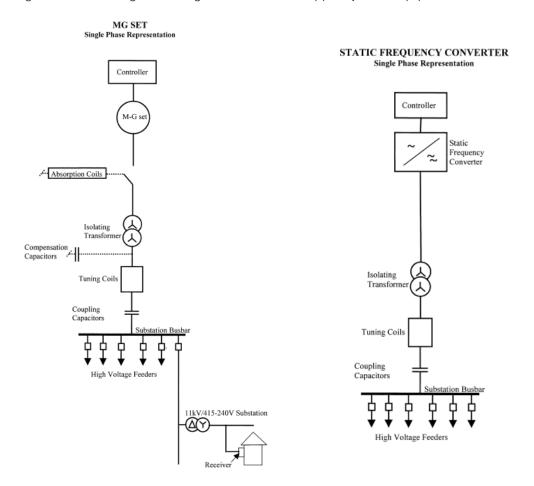

Figure 3.2: Injection System Technology – MG Set and Static Frequency Converter

Figure 3.3: Ripple Injection Equipment at a Zone Substation *(photograph courtesy of Essential Energy)*

Typical 11 kV injection levels are approximately 300 V. This equates to between 2 V and 10 V by the time the signal has propagated through the 11 kV / 400 V distribution transformer which supplies the low voltage loads, depending on losses as the signal propagates through the distribution network.

3.2. Receiving Relay Design & Operation

There are various methods of encoding the signal which is superimposed on to the normal voltage waveform. This in turn leads to two different receiving relay technologies; electro-mechanical and electronic. One encoding method is known as K22 which in many cases is now a legacy technology. This encoding method involves asserting the signal for a given time period during an injection run which lasts for approximately 3 minutes. An example of a K22 coded pulse is shown in Figure 3.4. It can be seen that the signal is divided into a start pulse plus 22 different channels. Each channel occupies a 7.5 s period during the signal run and is turned on if the signal is asserted during that period. The K22 signal is detected by older style electro-mechanical relays. These relays work using a synchronous motor which turns on after the start pulse is detected. The motor spins a timing disc and if the signal is asserted at a time corresponding with the setting of the relay, the relay turns on or stays on, if no signal is asserted the relay turns off or stays off. An example of a K22 receiving relay with and without the cover on is shown in Figure 3.5. In the photograph with the cover off, the timing disc with the 22 channels can clearly be seen.
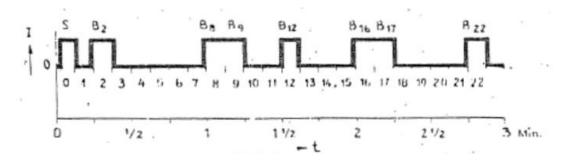

Figure 3.4: K22 Coded Pulse Example (from Zellweger Australia)

Figure 3.5: Photograph of K22 Receiving Relay with and without Cover

Another signal encoding method is known as Decabit. The Decabit system comprises of a start pulse plus 10 coded pulses an example of which is shown in Figure 3.6. Each Decabit injection comprises of 5 asserted pulses and 5 non-asserted pulses. Different channels may be specified by the arrangement of these asserted and non-asserted pulses. A receiving relay turns on if it receives the 5 asserted pulses corresponding to its programmed channel. The relay turns off if it receives the inverse of the on code. Each injection lasts 600 ms and an entire Decabit injection can fit into one of the 7.5 s K22 pulses. Figure 3.7 shows photographs of Decabit receiving relays.
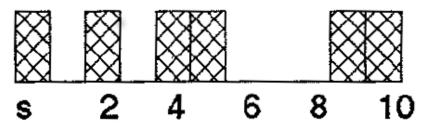

Figure 3.6: Example of a Decabit Coded Pulse

Figure 3.7: Photographs of Decabit Receiving Relays

4. Impact of Ripple Injection Control Signals on Customer Equipment

4.1. Normal Operation

Under normal operating conditions, there is little impact on equipment due to ripple injection signals. In fact operation of the system is unlikely to be noticeable unless something goes wrong, for example, hot water not heating due to the signal being too small for the receiving relay to detect and turn on the water heater. Figure 4.1 shows the impact of a 1050 Hz signal of magnitude approximately 6 V (2.6% of 230 V) on a waveform measured in the field. The injection signal can be seen to commence approximately 1.5 cycles after the start of the waveform capture.
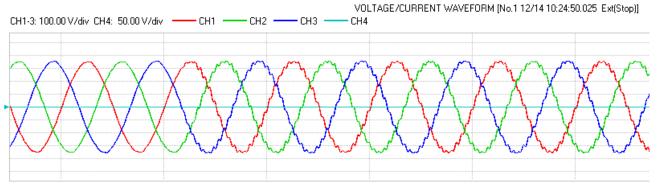

Figure 4.1: Field Measurement of 1050 Hz Injection Signal

Ripple injection signal compatibility levels are often specified using the Meister Curve which is referenced in AS/NZS 61000.2.2 [3] and reproduced in Figure 4.2 below. Compatibility levels are disturbance levels which should be able to be tolerated by most equipment without any operational problems. From the curve, appropriate levels for 750 Hz and 1050 Hz signal appear to be approximately 6% and 4% respectively.
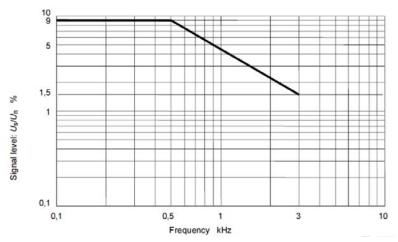

Figure 4.2: Meister Curve for Ripple Injection Signal Compatibility Levels [3]

4.2. Ripple Signal Attenuation

If signal losses in the network are too high or if the injection level at the signal source is too low, the magnitude of the signal when it reaches the receiving relay may not be sufficient for the relay to operate. In general, receiving relays will operate for signal levels down to approximately 2 V. The main impact of receiving relays not

operating is that the load which is controlled by the relay will not turn on or off as appropriate. This is a particular problem for relays which control off-peak hot water systems. If the receiving relay does not turn on the water heater as appropriate, the water will not heat and the customer will be left with the inconvenience of cold water. Conversely if loads that are meant to be turned off stay on, it can adversely affect network loading levels and defeats the purpose of the injection control system. Some receivers have a 'back-up' functionality where they revert to a simple 'time clock' in the event an injection signal is missed.

4.3. Ripple Signal Amplification

Under certain conditions, ripple injection signals may be amplified to levels which can cause problems ranging from customer annoyance through to equipment maloperation. The main mechanism for signal amplification is network resonance. Under certain conditions, the impedance of the network is such that there is resonance at the approximate frequency of the injected signal. This causes injected levels to be amplified; sometimes significantly. Signal levels due to amplification of up to 30 V have been recorded in the field regardless of the fact that the injection level at the zone substation was only approximately 5 V. Traditionally, amplification of injected ripple signals is most common in areas where the network construction consists of significant amounts of both overhead line and underground cable. In addition, the amount of load connected to the network has a significant impact on signal amplification; the greater the load, the less the amplification. Consequently, signal amplification problems often occur in new subdivisions where older overhead lines are connected to newer underground cable and where the load is relatively light until the subdivision is finished.

High signal levels can cause the 'racing clock' phenomena where timekeeping devices which rely on fundamental frequency zero crossings run fast due to the additional zero crossings caused by waveform distortion. Figure 4.3 shows a waveform which has approximately 30 V of 750 Hz superimposed on to the 230 V voltage waveform. The multiple zero crossings under this condition can be seen in the red circle.
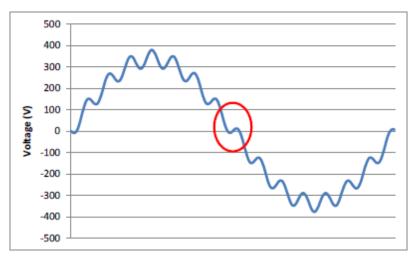

Figure 4.3: One Cycle of Waveform with Nominal 13% Superimposed 750 Hz

Other effects of high ripple signals include flickering of dimmed lights or touch lamps. This is due to the injection signal interfering with the operation of the electronic dimmers attached to these lights. Audible noise through speakers as well as devices with laminated motors such as ceiling fans can also be caused by ripple injection signals.

4.4. Mitigation of Ripple Injection Signals

Mitigation of ripple injection signals is generally not straightforward. The ripple injection signal receiving relay only responds to the signal frequency for which it has been built. As such, different relays are used for each different injection frequency. This makes changing the frequency of the ripple injection signal almost impossible as all of the receiving relays in an area would need to be changed.

If ripple injection signal levels become too high, there are 2 main methods which may be used for mitigation. These are changes to the network in order to move the network resonant frequency away from the injection signal frequency and signal filtering. It is generally very difficult to mitigate ripple injection problems by modification of the injected signal levels at the source (zone substation).

Adjustment of the network resonant frequency is achieved by adding either capacitance which lowers the resonant frequency or inductance which raises it. This may be achieved either by physical changes to the network (e.g. additional cable, installation of capacitors or inductors) or by network switching to change the supply characteristics. It is important that care is taken so that any mitigation strategies do not change the resonant frequency in such a way that it may lead to amplification of dominant low order harmonics such as the 5th or 7th. In many cases it is very costly and may be impractical to make significant changes to the network. In addition, especially in newer areas, ripple signal amplification problems may be a 'moving target' which may continually change as the network develops and as load is connected. This makes mitigation using the methods described above particularly difficult.

The second method of signal level mitigation is the use of filters. Filters work by reducing the signal level before it reaches equipment. These filters may be installed at or near the equipment or on the electricity network. In recent years, a number of electricity providers have had success with filters installed on the network. Figure 4.4 shows an example of the impact of a filter on injection levels before and after installation. The main drawbacks of filters are cost, a potential to reduce signal levels too far and the fact that they are not a wide-area solution.
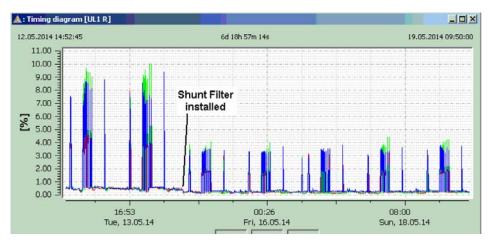

Figure 4.4: Impact of Filter on Ripple Injection Signal Levels

Use of the Decabit injection system also reduces the impact of ripple signals where there are problems due to the fact that the injection length is much shorter (seconds compared to 3 minutes). However, the amount of legacy K22 equipment distributed throughout networks means that K22 technology will still be in use for many years to come.

5. Future of Ripple Injection Load Control Systems

With the roll out of smart metering infrastructure, there may be no need in the future for ripple injection control systems. Where required, smart meters incorporate load switching relays negating the need for a separate ripple signal receiving relay. In addition, the smart metering communication infrastructure can be used to send the signals needed for the smart meters to turn loads on and off negating the need for signals to be injected on to power lines. However, a full roll out of smart meters appears to be some way off particularly in NSW. As such, it is likely that ripple injection load control systems will be in service for some time yet.

6. Conclusion

This technical note described ripple injection load control systems which are used extensively by electricity distributors to turn on and off controllable loads such as off-peak hot water systems and street lights. Ripple injection control systems allow for one way communication with loads without additional communications infrastructure. In most cases, ripple injection control systems are an effective and flexible method of performing this control. For customers, ripple injection systems allow access to cheaper off-peak electricity.
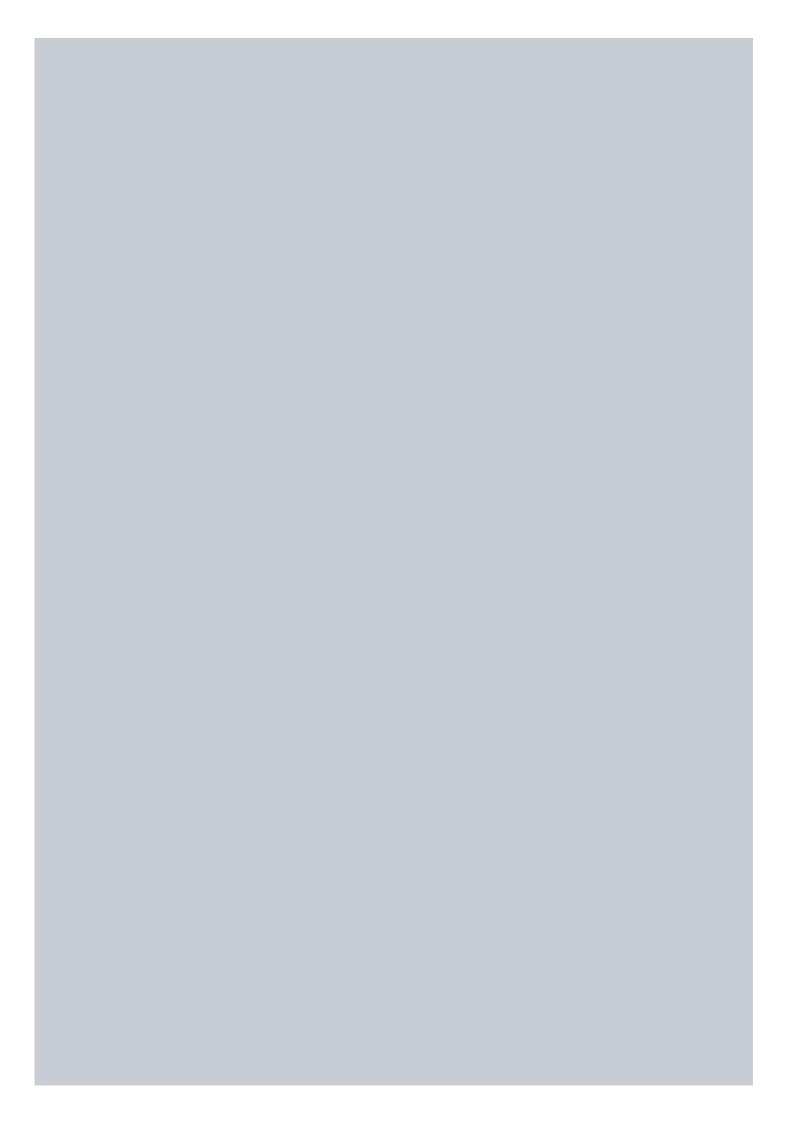
In most cases, customers are not aware of the operation of the ripple injection control system. However, if signal levels are either too high or too low there can be problems. For levels which are too low, receiving relays may not operate. Signal levels which are too high are caused by network resonance and cause problems with equipment that relies on counting zero crossings of the voltage waveform and can also result in flickering lights and audible noise.

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7. References

[1] F. J. Backer, "An Introduction to Ripple Control - Lecture Held 29th July 1970 at the NSW Institute of Technology," 1970.

[2] NSW Government Trade & Investment Resources & Energy, "Service and Installation Rules of New South Wales", August 2012.

[3] Standards Australia, "Electromagnetic compatibility (EMC) - Part 2.2: Environment—Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems", AS/NZS 61000.2.2, 2003.