Flicker Transient Phenomena Encountered with Diesel Powered Embedded Generation.

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Abstract: This paper addresses the cause of flicker phenomena associated with diesel powered embedded generation and its interaction with the bulk supply system. Models of the diesel prime mover, the generator and its control system are proposed and these are used to illustrate the transient behaviour of the embedded generator. It is demonstrated that the flicker is a result of fluctuations in the mechanical torque from the diesel prime mover coupled with the fixed frequency and voltage limits imposed by the grid supply. The analysis confirms the results of practical trials in that the phenomena is not noticeable while the generator is operating isolated from the grid.

Keywords: Diesel Driven Generation, Embedded generation, Flicker, Power Systems.

1. INTRODUCTION.

Since the late 1970's there has been considerable social and regulatory encouragement for the connection of small and medium sized generation direct to the local bulk supply network. As a result there are now a large number of diesel powered generating sets connected to the supply network. A consequence of this is an increased level of flicker phenomena. Where the supplies are weak, this leads to voltage flicker, but even when the supplies are relatively strong, current flicker phenomena can be observed. These transients have an immediate impact on the local quality of supply and can cause problems for the embedded generator and the local supply company's system.

Discussions with operators and manufacturers of embedded generators have revealed that current flicker phenomena have several consequences for these systems. These range from the need to use more robust generators for embedded generation than for stand alone units, to greater stresses produced on cabling, and the need to give greater consideration to the limitations imposed by switchgear ratings.

The authors' interest in flicker phenomena associated with diesel powered embedded generation started with field tests of a new technique for detecting loss of grid connection for embedded generation[1,2].

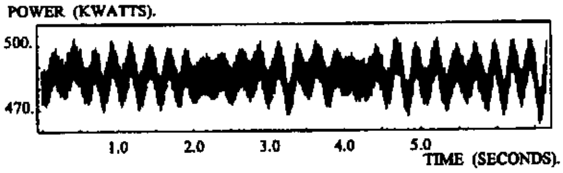

Figure 1(a). Generator Instantaneous Power Flow.

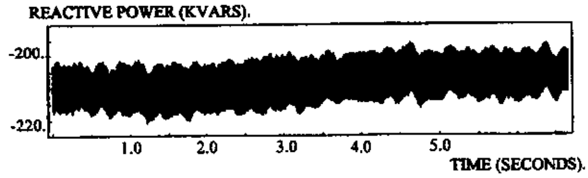

Figure 1(b). Generator Instantaneous Reactive Power Flow.

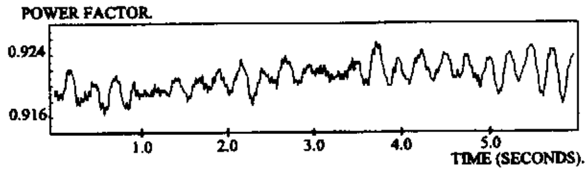

Figure 1(c). Power Factor.

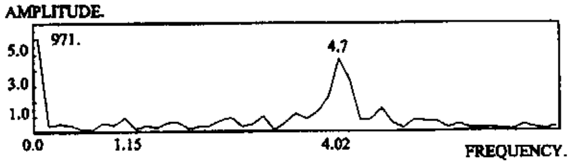

Figure 1(d) Spectrum Analysis of Power Flow.

Figure 1. Field Tests with 626 kVA Embedded Diesel Generator Unit.

During these tests an interesting 'noise' was observed in the synchronising current flowing from the generator to the supply network. The phenomena was likened to a low frequency 'coughing' at a relatively low level, reaching peak levels of between 2 and 7% of the load current. Further tests revealed that the phenomena was only apparent when the embedded generator was operating in parallel with the grid supply and that it appeared to vanish when the generator was operating in isolation.

The results of one of the tests in which the embedded diesel generator is connected in parallel with the grid supply are shown in figure 1. In figure 1(a), the instantaneous power output shows the presence of a low frequency oscillation superimposed onto the steady state level. This oscillation is not so pronounced in the reactive power output, figure 1(b), but is evident in the power factor, figure 1(c). A spectrum analysis of the power output waveform reveals a peak at 4.02 Hz. Further tests revealed that the frequency of this 'noise' varied between 4 Hz at higher power output levels to 3 Hz for lower power output levels. The response shown in these curves shows that the average amplitude of the noise was about 0.5% of the power output, and its peak excursions were up to 6%.

At virtually the same time as these trials, Anderson and Mirheydar[3] reported voltage flicker phenomena with a well head generator connected to the local utility via a long and hence high impedance feeder circuit. They concluded that the flicker effects were caused by contamination of the fuel used and consequent firing failures in the prime mover and were able to correlate the flicker characteristics with the cylinder firing. The waveforms presented were similar to those observed during the field trials, albeit of a higher amplitude.

More recently Funabashi et al[4] presented their findings of a generator's power oscillations and the resultant flicker phenomena observed of a low-speed diesel driven machine. The low speeds of these generators and natural resonant frequencies produced flicker effects in the frequency range of between 1 and 4 Hz. with amplitudes of up to 10% of the machines rated power. To promote the flicker they had assumed that the diesel's fuel system was maladjusted and that there were pressure dispersions among the engine's cylinders.

The immediate difficulties with the field trials were that the diesel generators used during the field trials were well balanced, a high standard clean fuel was used and there was no suggestion of firing failures or malfunctions. Furthermore the question was raised as to why did the phenomena appear to vanish when the generator was operated in isolation of the grid supply irrespective of its loading?

2. SYSTEM MODELS.

The system modelled included the diesel engine, a synchronous generator, a system load and a grid supply network which could either be connected to the embedded generator or isolated from it. The model for grid connected operation of the embedded generator is shown in figure 2. A similar model was used for the generator operating in isolation of the grid, but without the inputs from the system bus voltage and frequency. A detailed representation of this is shown in figure 3.

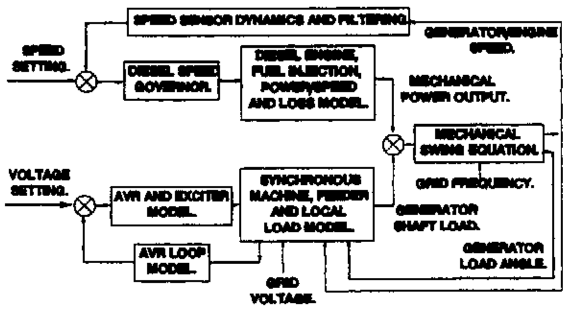

Figure 2. Model of Embedded Generator operating in Parallel with Grid Supply.

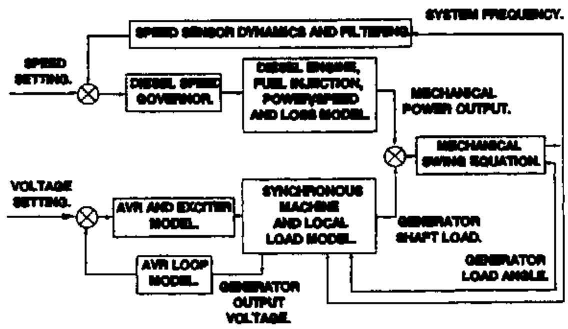

Figure 3. Model for Isolated Operation of Generator with Local Load.

The diesel engine model was based on the engine used for the field trials and was a 12 cylinder, 4 stroke, 600 kwatt, 1500 rpm engine with a mechanically driven fuel injection system and fitted with a turbo-charger. The model was represented by two elements, the engine and the governor.

Any reciprocating engine delivers a pulsating power to the generator. Operating at 1500 rpm, this has a frequency of 150 Hz.. Each cylinder's power output is cyclic repeating at a frequency of 12.5 Hz. and will contain harmonics of this frequency. The model of the power output of the diesel used the summation of the power output from each cylinder which was represented in a scaled look-up table of the pulsating power output.

The engine's governor controlled the fuel rack position and was set to have a droop of four percent, similar to the setting on the field trials engine.

A conventional direct/quadrature axis representation of the synchronous generator was used with the field winding exciter current generator being fitted on the main shaft. Thus the exciter's field current was controlled by the AVR. This was modelled using a proportional control with no follow-up system.

The local load was modelled using a simple R-L circuit and the grid model was of an infinite grid with a reactive connection circuit.

3. SIMULATION STUDIES.

Initial studies concentrated on examining the differences between the operation of the diesel generator when connected to the grid supply and when operating in an isolated mode in order to detect any inherent instability while grid connected. In all cases where sensible settings were used it was found that the system was generally stable. Although the studies demonstrated that the level of damping was reduced by connecting the embedded generator to the grid supply, where instability could be produced, the characteristics were not of a similar characteristic to the flicker phenomena. Limit cycling was identified as a potential cause of problems, but analysis demonstrated that this also was unlikely to be the cause of the flicker phenomena.

Studies of diesel engine operation and of practical engines highlighted combustion fluctuations as a prime candidate for causing the flicker.

The combustion process itself produces a wide range of high frequency noise since the fuel burn in the cylinder is not a smooth process. Considering the frequency of this noise and coupled with the firing rate of 150 Hz., it was considered that they would not account for the flicker phenomena.

A more promising explanation of the flicker phenomena was offered by considering the slight variations between the firings of the cylinders and the slight differences in the quantity of fuel delivered to each cylinder[5] by the injector. These were included in the model by using a random number generator modified to produce a truncated gaussian distribution which was then applied as a multiplying perturbation to the mechanical power of each cylinder's contribution to the mechanical torque of the engine.

Simulations using a 2% standard deviation random gaussian combustion power variation in each cylinder and limiting this to ± 4% of both the individual firing and cylinder efficiency produced the power output curves shown in figures 4 and 5. The local load for these studies was 40% of the full rating of the generator.

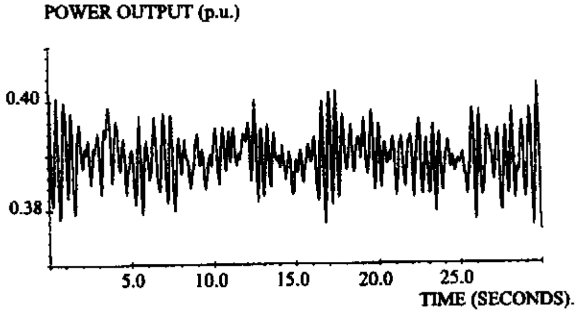

Figure 4. Generator Output Power Fluctuations while Operating in Parallel with the Grid Supply.

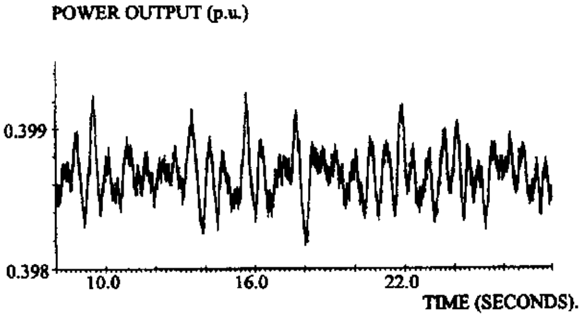

Figure 5. Generator Output Power Fluctuations while Operating Isolated from the Grid Supply.

Figure 4 considers the condition where the generator is operating in parallel with the grid supply and figure 5 is where it is isolated from the grid. While operating in parallel with the grid, the power output curve shows the characteristic flicker phenomena seen in field trials, albeit at a frequency of 2.25 Hz. and of peak amplitude of ± 2.5 %. While operating isolated from the grid, there is a significantly lower level of flicker at a frequency of 1.5 Hz. and of peak amplitude ± 0.25 %.

Comparing these results, an obvious flicker phenomena was present in the power output while the generator was operating in parallel with the grid supply, but was dramatically reduced while the machine was operating in isolation of the grid supply.

Attributing the flicker phenomena to pulsating mechanical torque from the prime mover, it is apparent that while the embedded generator is operating in parallel with the grid supply, the generator's frequency and voltage are fixed by the grid supply and that any attempt by the generator to absorb these mechanical fluctuations is resisted by the grid supply. The pulsating mechanical torque therefore produces pulsating electrical power flow between the embedded generator and the grid.

While the generator is operating isolated from the grid, the frequency and voltage constraints imposed by the grid are removed and the generator is better able to absorb the mechanical torque fluctuations by changes to its operating frequency and voltage. The inertia in the system is therefore able to maintain the output power from the generator.

4. CONCLUSIONS.

The study identified the fuel delivery system as the prime cause for the synchronous current flicker phenomena in diesel powered embedded generators. The interesting feature that these currents appeared to be absent while the generator was operating in isolation of the grid supply was also demonstrated.

As yet there appears to be no simple solution to this phenomena since fluctuations in the mechanical torque from the diesel appear to be an inherent characteristic of this type of engine.

This inherent nature of the current flicker phenomena may prove to be of value since it offers the basis of a method to automatically determine whether or not the diesel generator is operating in parallel with a grid connected supply network or whether it is operating in isolation of the grid.

Flicker phenomena has implications for other aspects of power system operation. It is a cause of concern for maintenance of quality of supply, it introduces stresses into the operation of the embedded generator and it can be detrimental to the operation of adjacent plant.

5. ACKNOWLEDGEMENTS.

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