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A PROPOSAL TO INVESTIGATE THE PROBLEMS OF THREE-PHASE DISTRIBUTION FEEDERS SUPPLYING POWER TO SWER SYSTEMS

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Abstract

Long distribution feeders connected to Single Wire Earth Return (SWER) systems are unique sub-systems of the electric power network in Australia, especially in the State of Queensland. Since the SWER systems are connected between two phases of a distribution line via an isolating transformer, they are inherently unbalanced loads.

In this paper a proposal will be developed to investigate the problems associated with the SWER systems and to suggest possible solutions. The study is based on an actual distribution feeder supplying power to several SWER lines in a rural area of the State of Queensland, Australia. Some issues will be addressed including suggestions for correcting the unbalanced operation, high energy losses, voltage and load profile, and the quality of power supplied to the customers.

1. INTRODUCTION

Single Wire Earth Return (SWER) systems are a well-established low-cost method of providing supply to a widely distributed population with a relatively low power demand. One of the first references on the power supply for rural areas goes back to 1947 [1]. In Australia, SWER systems have been used extensively in rural areas, especially in the State of Queensland, as a cost-effective method of supplying electrical power to the customers. The cost benefits are beginning to be realised by other nations; South Africa, for example, is applying this technology to extend supply in many areas [2], [3]. In its report on ‘reducing the cost of grid extension for rural electrification’, National Rural Electric Cooperative Association (NRECA) International – within the scope of a joint UNDP/World bank Energy Sector Management Assistance Programme (ESMAP) – points to the ‘wider use of single-phase distribution’ as one of the options for reducing the cost of grid extension [4].

The communities served by SWER systems are steadily increasing their energy use. The standard connection transformer rating has risen from 10kVA in 1980 to 25kVA today [5]. The SWER infrastructure is showing its limitations through increased instances of voltage regulation complaints. Since the SWER systems are connected between two phases of a distribution line (through an isolating transformer), they are inherently unbalanced loads. With recent sharp increases in energy demand of the consumers in rural areas, connected via the SWER systems to long three-phase distribution feeders, some concerns have been raised. High energy loss, unbalanced loads, disturbed voltage profile, voltage collapse and poor power quality at the customer level are among these concerns. These problems are more serious during the peak-load times. Although there have been proposals to treat the voltage unbalance on these feeders [5], because of dissimilarities in customer usage patterns and some geographical factors, the several SWER lines connected to a backbone feeder may have their peak loads at different times. Therefore, it is difficult to make the system balanced at all times using these techniques.

One example of a long three-phase feeder that is unbalanced by SWER loads is the distribution system in the central west area of Queensland, between towns of Barcaldine and Alpha. A simplified one-line schematic of the system is shown in Figure 1. As shown in the Figure, a 22kV feeder supplies power from Barcaldine to some small towns, farms, mines and residential customers. This backbone feeder is about 150 km long and has many branches. Among these branches are a number of SWER lines. High-resistance (usually galvanised-steel) conductors are used for the SWER lines. Therefore, the distribution line is not only unbalanced, but also has a relatively high energy loss.

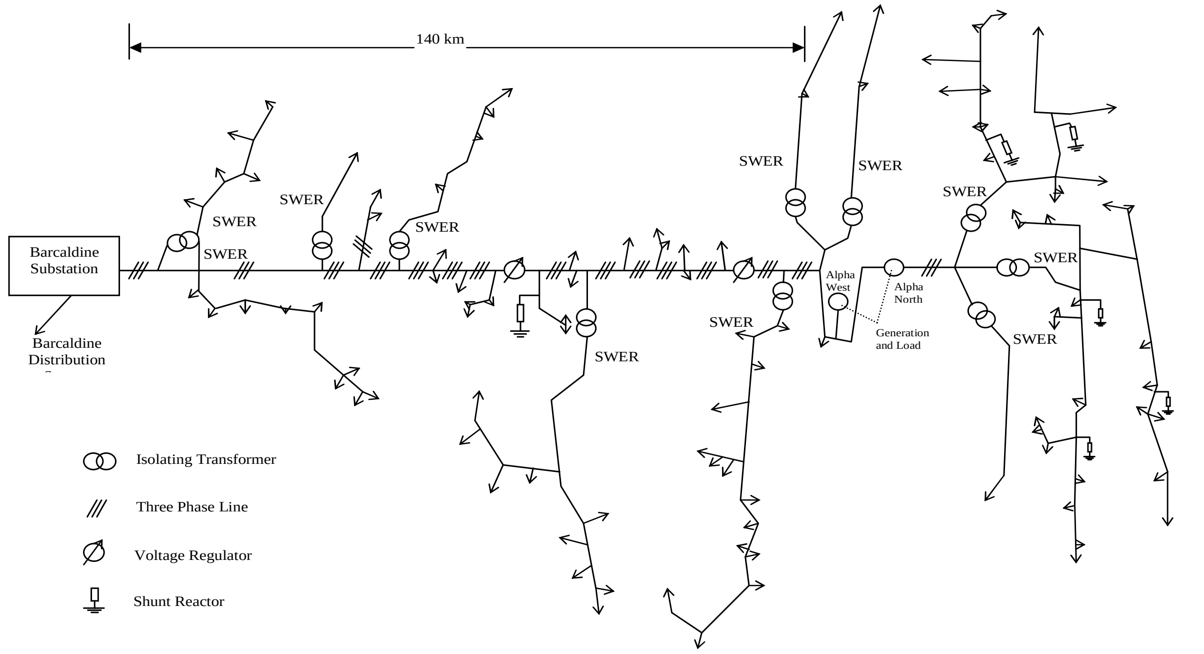

Figure 1. A single-line diagram of an actual distribution system in rural areas of Queensland

The current practice on lines of this type is to apply transformer voltage regulators that attempt to control the magnitude-balance of the line-to-line voltages. These can limit the magnitude unbalances to around 6% [5]. However, this approach cannot control the phase angle. This may cause a serious power quality issue, especially for the users of induction machines. In one instance, where diesel generation was deployed at a remote township to provide real-power support, repeated trips due to negative sequence alternator currents occurred.

With regard to the energy loss, when the SWER systems are connected to the remote end of the distribution feeder with relatively heavy loads, the energy loss will be significant. The system shown in Figure 1 has such a characteristic. There are six SWER lines branching from the backbone feeder at the town of Alpha, which is located about 140 km from the supplying end of the feeder located at the town of Barcaldine. The increase in energy loss due to the growth of load has become significant and necessitates an improvement in the efficiency of the feeder.

There are two options for improving the efficiency of electrical energy transfer in the feeder. One option is restructuring or augmenting the feeders. Another option is using the new technologies to improve the efficiency with the existing feeder. Many studies have been reported about improving the operation of distribution systems; however, they are mostly about the so-called four-wire distribution networks [6]-[15].

The SVC technology can be adapted to distribution level systems [12] and can solve the negative sequence issues for local generators [13]. More sophisticated approaches that include combinations of series and shunt connected converters are available that can assist with balance, harmonic control and voltage regulation [14]. Correction of unbalanced load in single-phase electric traction systems have been reported [16] and may be used in this application, too.

2. PROPOSED SOLUTIONS

Figure 2 shows a schematic of a few methods that can be used to improve the performance of the system. A particular innovation will be the examination of the use of lower cost alternatives to SVCs for negative sequence control. Phase balance can be performed with capacitors alone, or with inductors alone. A set of capacitors can always be found that compensates an unbalanced load to produce a balanced but leading load. Likewise, inductors can provide phase balancing but result in a balanced lagging load. These approaches have not been seen in the literature, however, since for this application the reactive component ratings are not that high (a few hundred KVA), these techniques may have the capacity to provide a viable solution.

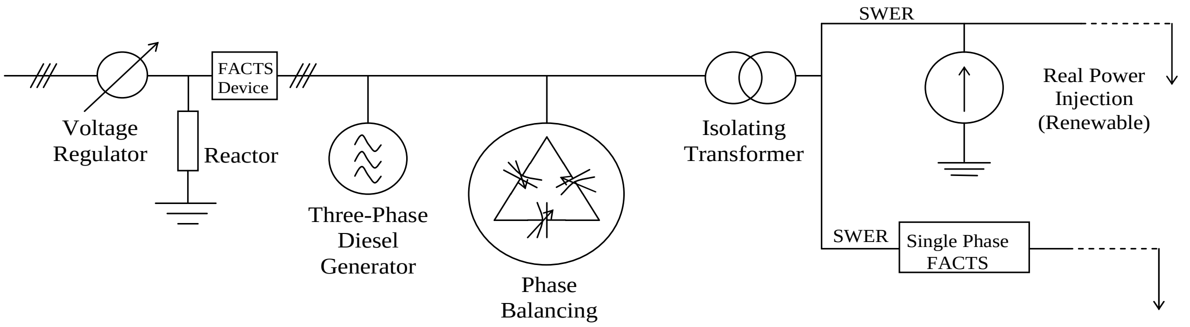

Figure 2. Various schemes to enhance the performance of the three-phase feeder and SWER lines

Three cases can be studied:
1) The use of binary weighted, point-on-wave switched capacitors for controlling the negative sequence loading of alternators provided for local voltage support. An under-excited alternator can absorb any leading VARs.
2) The potential for the thyristor control (or binary weighted switching) of existing line shunt reactors that are provided for voltage regulation. Given voltage unbalances as of more concern at high load level, this option is less likely.
3) If passive only approaches are employed, then reliable studies must be done to ensure that system interactions do not occur with other loads. Additional filtering or system damping may be required and these issues should be considered in the overall design. Ancillary benefits may be obtained using active devices to improve the characteristics of the passive solutions. These hybrid active-passive approaches have been demonstrated in other power system applications, but must be explored for integration into the solutions proposed by this study [16]-[19].

The following tasks are a part of the research in this area:

- The development of a generic power system model for three-phase distribution lines, having SWER lines as their loads in addition to other loads, taking into account the unbalanced nature of the system and the variability of the load patterns;
- Conduct several detailed studies for reducing energy losses, balancing the system and improving the power quality. These issues are discussed as follows in the next sections;
- Compare those studies with respect to cost effectiveness and environmental impact;
- Make recommendations on the preferred improvement methods.

The studies will include:

- The impact of enhancing the transmission capacity of SWER lines on the backbone feeder. This will focus on the impact of higher capacities of the SWER lines on the backbone distribution feeder. A key outcome will be determining the expected unbalance range as an input to the phase balance study;
- Traditional balancing schemes to minimise the effect of unbalanced loads on the feeders - Various balancing schemes based on transformer regulators will be studied to minimise the undesirable effects of unbalanced loads (specifically SWER lines) on the backbone distribution feeder.

2.1 Possible methods

SVC based balance schemes – both full SVCs and reduced SVCs with solely capacitive or inductive components will be studied. Methods of cost reduction including binary weighted switching either with semiconductors or mechanical switches, or the use of single-phase autotransformers for the control of reactive elements will be considered.

Flexible AC Transmission Systems (FACTS) devices will be investigated for both energy-loss reduction and balancing the system in the context of distribution systems.

Power and voltage quality studies - Studies will be performed to investigate the quality of voltage and power at the customer level. Impact of load management schemes at the low-voltage side on the high-voltage side (distribution feeder) will be studied.

Distributed voltage regulators - Single-phase voltage regulators are used to control the SWER system voltage profile. It is technically possible to increase capacity up to the thermal limits of the lines by deploying more voltage regulators if appropriate controls can be applied. A doubling of system capacity is within the thermal ratings of the typical SWER conductors, but the transmission loss and voltage drops are high.

Multiple regulators with local controls have been observed to exhibit hunting behaviour, where the tap changers on adjacent regulators interact continuously. In these cases the local control of regulators will need additional remote supervision. A range of modern communications technologies can be applied to existing regulators to provide linkage into modern SCADA systems. This allows a remote line to be set to a desired voltage profile and prevents the hunting problem. Ergon Energy is currently making major investments in improved state-wide SCADA systems. As satellite-communications costs decrease, these approaches become possible. If taken to the extreme on SWER systems this approach can double system capacity but potentially at the cost of extreme transmission losses. On typical systems it is likely that the system losses could exceed the power delivered to consumers' loads!

Partial reconstruction and additional regulators - Partial reconstruction of the feeders and the use of voltage regulators is one of the approaches most likely to provide a useful result. Several test cases will be examined to develop guidelines on how the best combinations may be found.

Reactive Compensation - In a typical transmission system, switched inductors are often used to limit the line voltage rise at light load. Likewise, switched shunt capacitors are used in raising the line voltage at peak load. Unfortunately, a SWER line has a high resistance relative to the line inductance; therefore, these techniques of reactive compensation will be rather limited in the case of SWER systems. The resistive line loss will remain high in any case.

Use of Power Electronic Devices - A significant amount of literature is available related to the use of power electronic devices for the solution of many power quality problems. Shunt compensators inject current into the systems at a particular point. These can be used to compensate for unbalanced loads, reactive power and harmonic distortion due to current-stiff loads. Series compensators add a series voltage source to the distribution line and can be used to enhance power flows at the fundamental frequency, whilst reducing power flow at harmonic frequencies. These compensators are suitable for voltage-stiff systems.

The voltage/current sources required for this form of compensation are typically achieved by using PWM voltage source inverters. The requirement to compensate for harmonics and fundamental related problems imposes system requirements of high rating and high bandwidth, which are competing requirements. Although power electronic converters are steadily falling in price and now cost a few hundred dollars per kVA, the competing requirements of ratings and bandwidth still make these solutions costly.

To reduce the overall system costs, the use of hybrid combinations of passive and active elements has been reported in the literature. This allows the ratings of the active element to be reduced by using passive elements to perform much of the compensation. The active element is then only used to improve the characteristics of the passive network. It has been found that if the system is optimized for particular conditions, then the ratings of the active element can be very small, whilst still providing near-ideal compensation. An example of this is shown in Figure 3, which shows a set of binary weighted, point on wave switching capacitors, combined with a high bandwidth element for harmonic compensation and a low bandwidth element for reactive compensation [20]. This integration of passive and active elements allows the entire system to be optimized for the best performance/cost.

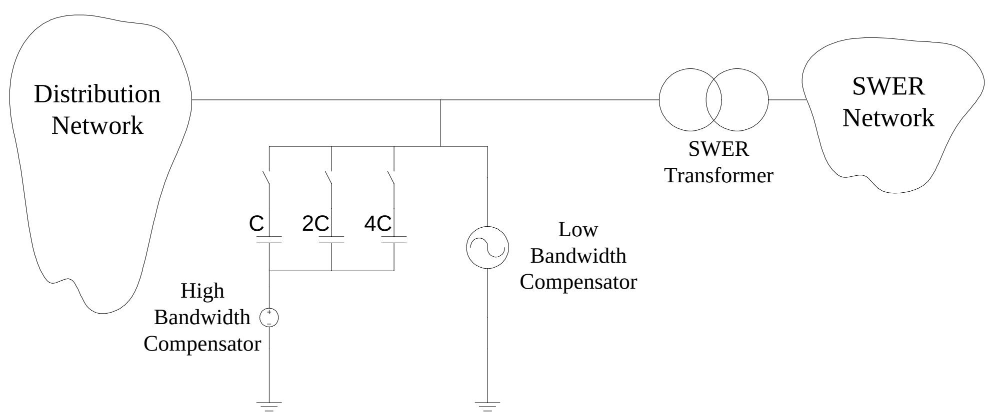

Figure 3. One-line diagram of a possible integrated solution for compensation of unbalance caused by SWER connections

The binary weighted capacitors may be switched into each phase according to the amount of unbalance caused by the SWER loads, providing stepped compensation in steps of C. The low bandwidth element provides reactive compensation to compensate the leading power factor produced by the switched capacitors. This power factor will vary according to the load conditions, so an active control is desirable here. The high bandwidth element in series with the capacitors provides compensation for harmonics in the SWER system and the low bandwidth compensator. This element also prevents resonant interaction between the capacitors and the rest of the distribution network. Considering this system as an integrated unit and optimizing the system will give advantages in cost and performance. This study will examine the scope of power electronics devices to make such a contribution in SWER applications.

Distributed Generation - On a weak system with a significant resistive component to the line impedance, the injection of real power is a very effective form of voltage support. The transmission loss will be significantly reduced if a proportion of the total feeder power can be injected in the last 50% of the line. This real power could realistically be produced by diesel or renewable sources or a combination of these (typically 50-200kW). The incremental costs of installing generation capacity are low compared to the other infrastructure costs so the quantum of injected power will be high.

The following topics can be included in the studies:

- The optimum ratings and operational parameters for a diesel-based system;
- The opportunities for a renewable component;
- Identification of the point at which peak-lopping generation becomes viable;
- Identification of the limit beyond which peak-lopping generation viability is extinguished;
- Impacts on the feeder voltage regulation, protection and control.

Ideally a diesel system would seek to operate the diesel at its optimum fuel efficiency point, for that period of the day when the real power demands are sufficiently high. The avoided transmission loss are expected to provide a significant financial and green house emission saving. It is likely that the injection of diesel energy will yield a greenhouse benefit by avoiding this loss alone. The study will quantify the likely benefits for a typical feeder load cycle. Ergon Energy has significant experience with remote diesel systems and is well placed to provide the inputs required for a useful financial model. A 3-phase "powermonic" PQ recorder (with remote modem) has already been prepared for installation at Alpha to commence the monitoring process. A key issue with a significant real power injection is voltage regulation. It is desirable that the diesel is regulated primarily for fuel efficiency and that the feeder voltage is controlled by other means. A key feature of the study will be an investigation of the requirements for distributed voltage regulation or power electronic devices to provide adequate controls.

A significant renewable fraction, perhaps some tens of kilowatts of photovoltaics, could readily be included at the point of injection. The study will examine the costs and greenhouse savings for this option, taking into account the avoided transmission losses. SWER sites are significantly more valuable in terms of green house impacts than urban sites because of the transmission loss savings. Experience elsewhere has shown that the generation profile of photovoltaics is often well matched to the consumer load profile, especially if air conditioning and refrigeration is a significant load component. If a renewable energy source is to be included it is likely that the grid connection inverter may provide some ancillary services such as VAR compensation. These cases will be especially considered to determine if any cost benefits can accrue to a renewable energy source for the provision of these services.

3. CONCLUSION

A significant contribution of this study will be a better understanding of the opportunities to enhance SWER line operations. The work will have a direct impact on Ergon Energy's future directions and possible implications for the Australian Greenhouse Organisation (AGO) policy.

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