

Investigation of Voltage Quality and Distribution Capacity Issues on Long Rural Three Phase Distribution Lines Supplying SWER Systems

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ABSTRACT

Single wire earth return (SWER) electric distribution feeders are used extensively in remote parts of Queensland and other states, as an economic means to deliver electrical energy to small customer loads, scattered sparsely over vast areas. These SWER systems are normally supplied from very long (>100 km) three phase distribution feeders. Due to recent strong load growth, voltage quality issues have arisen in these systems including voltage regulation, voltage unbalance, and phase unbalance. Excessive system power losses are also experienced. There are several available methods to combat these issues; however, some have not been applied to this type of distribution system before. Developing simple, economic solutions to these problems is likely to dramatically improve customer power quality, resulting in reduced customer complaints, whilst improving distribution capacity and reducing losses. The emphasis of this research project is the power system modelling to assess available technologies applied to this type of distribution system. The project is being undertaken in conjunction with Ergon Energy Corporation in Central Queensland so that real field data can be used to validate theoretical models.

1. INTRODUCTION

Rural electrification typically involves the distribution of electrical energy to small, sparsely distributed load centres. Load types can include farms, isolated residences, small townships, industrial facilities such as grain depots and quarries, holiday camp grounds and isolated commercial premises such as highway service stations, shops and the like.

These electrical loads are serviced by a combination of three phase and single phase distribution systems. There are several variations used around the world. In Australia and, particularly, in rural Queensland, three phase three wire distribution feeders and single wire earth return (SWER) feeders are predominantly used for rural distribution. Three phase distribution feeders typically operate at 11 kV or 22 kV phase to phase. SWER feeders operate at either 12.7 kV or 19.1 kV phase to earth.

Some of the key factors to be considered in rural distribution are the cost of construction, system reliability and maintenance requirements.

The loads and load density are low; thus, the cost per customer can be high, particularly where there are large distances between customers (in some cases up to 20 km).

Reliability is paramount because customers are typically located in isolated areas, away from distribution company depots. This makes excessive maintenance of such systems expensive and time consuming.

This is where SWER distribution has some advantages over traditional three phase distribution for rural areas. Construction costs for SWER can be up to 30% lower than three phase construction [1] due to simpler pole top arrangements and reduced conductor. The use of steel or steel cored aluminium conductor also leads to longer spans, which is another driver for reduced costs. SWER construction itself is considered inherently more reliable than three phase construction due to the lack of the pole cross arm (and subsequent failure mechanisms) and the lack of multiple conductors which eliminates conductor clash and is also considered to have an improved bird fault performance. This is offset by reliability issues relating to earthing and lightning exposure of the isolation substation [2].

The majority of SWER construction in Queensland is “isolated” type. An isolation transformer is used to isolate the earth return currents from the main three phase feeder. This prevents earth return currents flowing in the earth back to the source substation which could be over 100 km away and helps prevent issues with communications system interference.

Earth resistance at isolation transformers and customer transformers is of critical importance to prevent unsafe step and touch potentials around the substation.

Figure 1 shows the typical rural feeder arrangement and SWER connection.

2. VOLTAGE REGULATION OF LONG THREE PHASE FEEDERS

Power transfer capability and voltage regulation are both well known and readily assessable values. Lightly loaded, long rural distribution lines are typically constructed using medium ACSR conductor such as “Cherry” 6/4.75mm 7/1.6mm at the sending end and changing to small ACSR conductor such as “Gopher” 6/1/2.36mm, “Almond” 6/1/2.5mm or “Banana” 6/1/3.75mm conductor toward the end of the feeder. Voltage drop rather than conductor current rating

typically determines the power transfer capability of these long feeders.

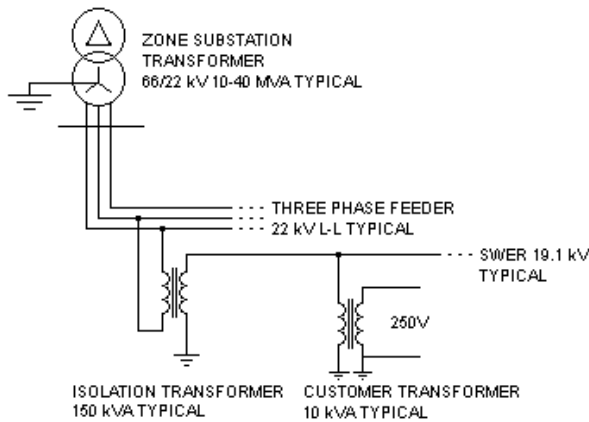


Figure 1 – SWER Connection Diagram

Figure 2 graph shows the power transfer capability of a real 140km 22 kV three phase line constructed from “Cherry” and “Gopher” ACSR conductor. The load power factor is assumed to be 0.95 lagging which is typical of these long lightly loaded systems.

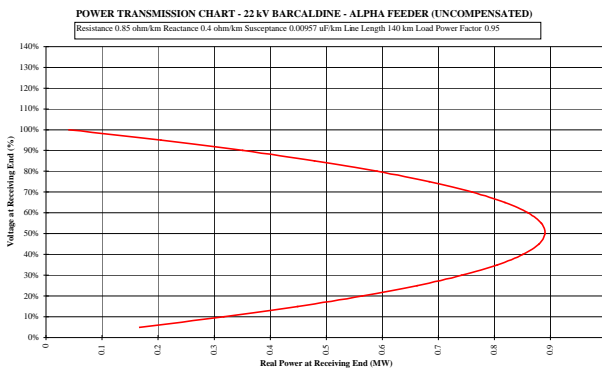


Figure 2 – Power Transfer Diagram

Figure 2 clearly shows a significant power transfer limitation for long distribution lines that are uncompensated.

3. UNBALANCE ISSUES ON THREE PHASE BACKBONE FEEDERS

SWER isolation transformers are connected across two phases of the three phase feeder and cause an unbalanced load. It is possible to manually balance the three phase feeder by judicious allocation of SWER loads across all three phases; however unbalanced loading can still occur due to variable loads on the SWER feeders and in extreme cases from tripping of entire SWER feeders due to faults [3]. Under these conditions unbalanced loading of the three phase feeder can occur. In the more extreme cases unbalancing of the phase angle between the three phases can also occur. This can cause customer voltage quality problems. Synchronous and induction machines are adversely affected by voltage and phase unbalance as it leads to negative sequence current flows and the results in reduced efficiency [4], motor negative torque

pulsations and overheating. Power electronic devices can also suffer problems caused by voltage and phase unbalance.

Unbalanced loading results in uneven voltage drops in the phases and is further exacerbated by utilising long feeders without transposing the conductors. Even a balanced three phase load can cause unbalance on a long untransposed feeder due to differing mutual coupling between phases.

Field measurements [3] have shown uncompensated feeders can exhibit % VUF (V_2/V_1) values of up to 11 % prior to intervention by some form of compensation.

4. CAPACITIVE LOADING AND VOLTAGE REGULATION OF SWER FEEDERS

Due to the very long line lengths and sparse distribution of customer transformers and loads, line charging currents on SWER feeders can be significant. Typical SWER construction in the Ergon Energy network is “Raisin” 3/4/2.5mm ACSR for the main SWER backbone and 3/2.75 SC/GZ conductor for spurs. Depending on the proportion of each type, this construction generates approximately 737 Var/km. Given that individual feeders can have over 300 km of total conductor length it can be seen that the line charging current can exceed the standard 150 kVA or 200 kVA isolation transformer rating. During periods of light loading, significant voltage rise can occur towards the end of the feeder creating quality of supply issues for customers.

To combat this problem it has been usual to install several fixed shunt reactors along each SWER feeder to reduce the capacitive loading and control voltages at light loads. The disadvantage of this is that during peak loading the feeder rating is constrained due to voltage drop caused by the load and shunt reactor combination.

5. SOLUTIONS FOR THREE PHASE FEEDER CAPACITY, VOLTAGE REGULATION AND UNBALANCE

The use of step voltage regulators is the most common method of increasing power transfer capability of distribution feeders whilst maintaining healthy voltages. The most common form of regulator installation is the open delta connection, which only requires two single phase units to regulate a 3 phase feeder. This does not provide optimal regulation of unbalanced feeders [3].

A number of techniques, which could be used to improve the performance of the SWER distribution systems, were proposed in reference [5]. In line with those proposals, a number of methods will be investigated to correct voltage regulation, unbalance and capacity issues with long rural three phase feeders supplying SWER systems including:

- Manual load balancing [3];

- Increasing fault level – negative sequence voltage is inversely proportional to fault level for a given unbalanced load;
- Use of three single phase independently tapped voltage regulators [3];
- Series capacitive compensation;
- Shunt compensation (inductive, capacitive, SVC);
- Special transformer winding connections to cancel unbalance and/or enable connection of distributed generation without effects from unbalance;
- Line transposition; and
- Line voltage increases.

A well known reactive power control text by Miller [6] describes how any unbalanced three phase load can be balanced and power factor corrected by use of purely reactive elements, without changing the active power flow supplied by the source. Application of technologies such as point of wave switching devices and power electronic devices can be used in conjunction with this theory to provide coarse or fine control of passive reactive components to counteract unbalances and regulate voltages.

It is unclear if capacitive compensation will be beneficial given that conductor resistance is very high and line inductive reactance is not the predominant line impedance parameter.

6. SOLUTIONS TO CAPACITY AND VOLTAGE REGULATION ISSUES ON SWER FEEDERS

Reference [7] provides an innovative method of controlling shunt reactance via thyristors to control voltage and free up line capacity as the daily load cycle occurs. Other solutions include the use of saturating reactors [8] which draw a low value of shunt reactive power when voltages are normal or low, but which go into saturation and draw larger values of reactive power when the voltage rises during light load periods. This technique has been successfully used overseas on long transmission systems and the aim is to assess its suitability to SWER feeders.

Single phase power injection using renewable sources such as photovoltaics at the end of SWER feeders may also provide support to these feeders during daily load peaks, considering the outback locations where yearly sunshine hours are high. Increasing line voltage is also an option that will be investigated, however this will be an expensive option due to the need to re-insulate the line and replace the isolation and customer transformers. The problem of high capacitive line charging power will also be worsened; however, full load voltage drop performance should be improved.

The series capacitor may also provide assistance with voltage regulation and has been described in the literature [9]. However due to the very high resistance

values of the SWER conductors, this method may return limited results.

7. EXAMPLE SYSTEM

The example feeder that will be the subject of this project is located between the towns of Barcardine and Alpha in Central Queensland. Key parameters of this rural distribution feeder system are as follows:

- 1800 km total line length (three phase and SWER);
- 140km of three phase backbone feeder;
- 49 km of three phase spurs;
- 390km of SWER backbone ACSR conductor;
- 1220km of SWER steel conductor feeder and spurs;
- 1 x 12.7kV and 9 x 19.1kV SWER feeders;
- 295 individual customer loads (average 6km between customer loads);
- Loads approx 50:50 three phase and SWER;
- Total 1700kW of load plus losses of 600kW;
- Three phase load distribution of 15% beginning, 20% middle, 45% end, 20% scattered; and
- SWER load distribution of 30% middle, 70% end.

Figure 3 shows a geographical extract of the feeder system taken from Ergon Energy's PSS Adept software model.

8. CONCLUSION

Several potential solutions to combat voltage regulation, unbalance and distribution capacity issues will be investigated for feasibility throughout the course of the project. The emphasis of this project is on identifying potential solutions that may have been used in other areas of transmission and distribution and assessing their suitability to this application the power system modelling.

9. ACKNOWLEDGEMENTS

This project is being carried out in conjunction with Ergon Energy Corporation Ltd. in Rockhampton, Queensland. The support of Anthony Loveday and Jonathan Turner of Ergon Energy is much appreciated.

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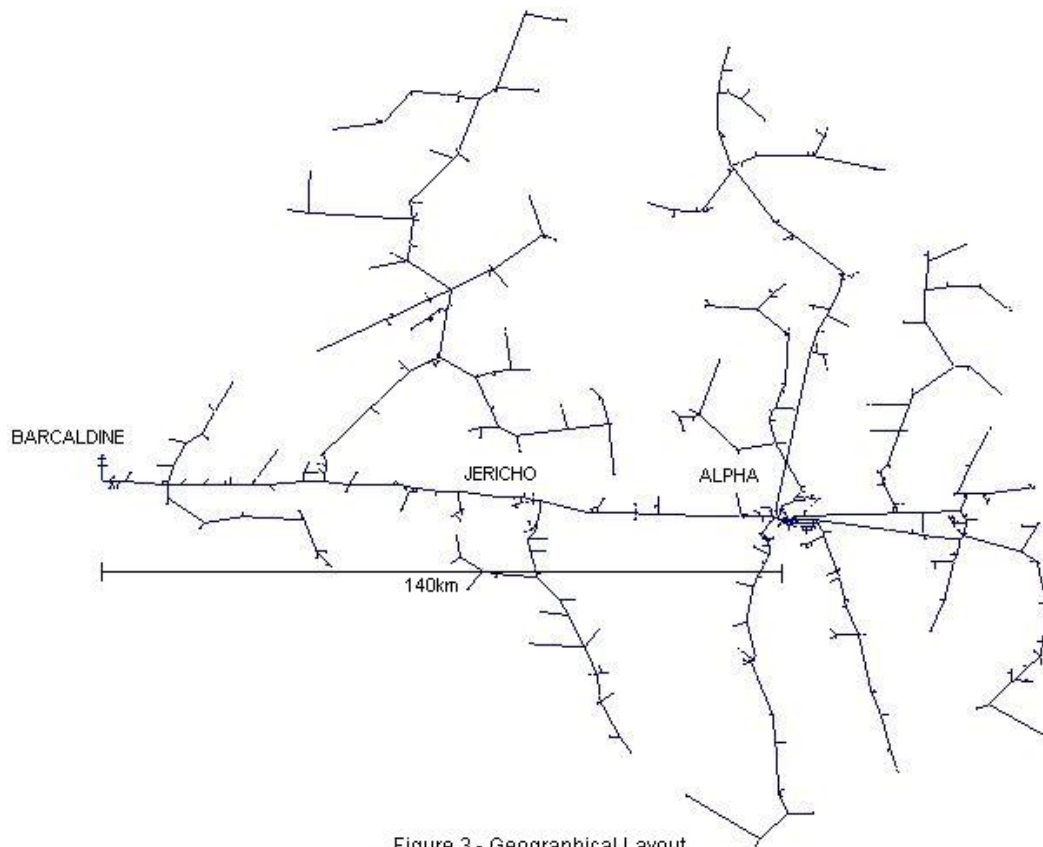


Figure 3 - Geographical Layout