Design and Study of a Switch Reactor for Central Queensland SWER system

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Abstract-- **Single Wire Earth Return (SWER) systems are a widely applied, low cost electrification method used in many rural areas. In Central Queensland a single SWER system supplying approximately 100kW may extend more than 300km. Many SWER systems include shunt reactors to control the effects of the line charging capacitance. One effect, the Ferranti effect, causes the line voltage to rise with the distance. In three phase distribution systems this effect is not visible but in SWER systems, this effect makes it difficult to maintain the consumers supply within the acceptable regulation range. As the second effect, the loading of the SWER system supply transformer increases. Controllable shunt reactors are used as one solution to the aforementioned problems.**

Stanage Bay feeder in Central Queensland area has been chosen for the installation of the designed shunt reactor. Stange Bay feeder is supplied by an isolating transformer with the total capacity of 150kVA and the voltage level of 22kV.

Using the Stanage Bay feeder, this paper details the process of design and simulation of a suitable switch reactor. This step has been carried out by firstly, the design of the switch reactor and secondly, the proper modelling of the designed reactor for the voltage regulation studies.

Index Terms-- **SWER system, Rural electrification, Switch reactor, Central Queensland**

I. Introduction

Single Wire Earth Return systems have been widely installed in Australia and New Zealand over 50 years, [1-3]. This approach is promoted by the World Bank as a lowest cost technology and will find growing applications in bringing supply to the estimated two billion persons globally without power, [3]. SWER systems typically supply loads of 100kW to 200kW scattered over a line length that might exceed 300km.

In the state of Queensland, a SWER task force has been established to investigate the load growth issues faced by these systems. An important option is to apply new technologies into aging SWER systems to release capacity for load growth.

Many long SWER systems include shunt reactors to control the effects of the line charging capacitance. In SWER systems, as a result of Ferranti effect, it is very difficult to maintain the consumer voltage within the acceptable regulation range. The line charging current without reactors may be as high as twice the SWER system isolating transformer rating.

The industry has always recognized the immediate advantages in removing the reactors at higher loads. Switchable reactors at 19.05kV will require a high voltage motorized switch, a voltage transformer, and a designed control element. The costs of switch and voltage transformer are a bottleneck in final cost evaluation of the technology.

Alternatively, it is possible to install the switch reactor at lower voltages on a transformer secondary. 25kVA consumer transformers are produced in large quantities and are moderately priced. In this case, the 19.05kV switch reactors could be replaced by 480V inductors connected across the centre tap transformer of 240-0-240V. Thyristor controlled reactors, contactor switched reactors, and contactor controlled reactors connected via dedicated consumer transformers are three proposed solution for the SWER system voltage problem.

This paper explains the design and study process of a typical switch reactor for one of the SWER systems in the state of Queensland, Australia. The paper is organized in four sections. Introduction of the paper is explained in section I. Problem formulation and the modelling of the SWER system is explained in section II. Section II is dedicated to the switch reactor design and associated studies. And finally conclusion in section IV would close the paper.

II. Problem formulation and modelling of the SWER system

Stanage Bay SWER system is one of the many SWER branches supplied by the 66/22kV Pandoin Zone substation. It is connected through a 22kV(3ph)/19.05kV(1ph) and 150kVA isolating transformer. The connection point of the isolating transformer is 70km away from the Pandoin Zone substation. The connection schematic of the isolating transformer is shown on figure 1.

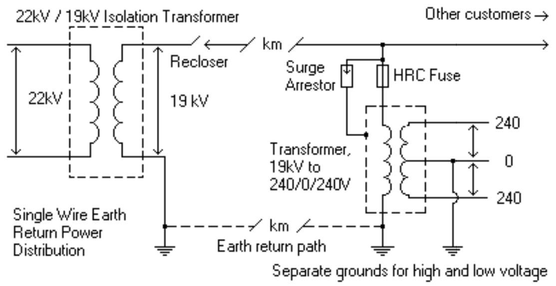

Figure 1, the connection schematic of the isolating transformer

Table 1 represents the electrical specifications of isolating transformer used for Stanage Bay feeder.

TABLE 1: ELECTRICAL CHARACTERISTICS OF ISOLATING TRANSFORMER OF STANAGE BAY FEEDER

Un1 (kV)	Un2 (kV)	Smax (kVA)	uk (%)	ur (%)	Vector Group	R0/X0 (p.u.)
22	33	150	4.1231	1.6	YND1	0.4211

A typical load pattern of the isolating transformer recorded during the January 2007 with 5 minutes intervals has been shown through figure 2.

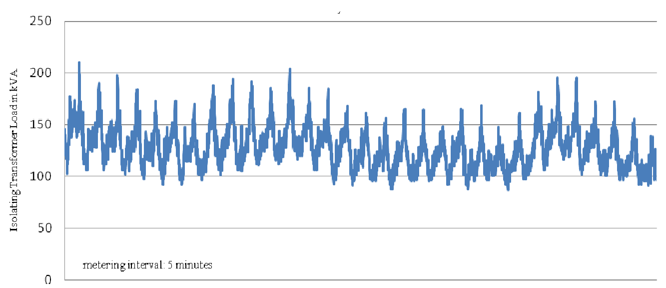

Figure 2, the load pattern of the isolating transformer recorded during the January 2007

19.05kV Stanage Bay SWER system has the total length of around 95km and total maximum connected demand of 180kVA on average. The conductor is 3/4/2.5 ACSR/GZ with the table 2 parameters.

TABLE 2: CONDUCTOR SPECIFICATIONS OF THE STANAGE BAY FEEDER SYSTEM

Conductor	Parameters
3/4/2.5 ACSR/GZ	R0: 2.02 Ω/km; X0: 0.802 Ω/km; B1: 2.086 µmho/km

The Stanage Bay SWER system conductors are modelled as the Pi for the system studies.
Since the LV consumers supplied by the Stanage Bay SWER system have the same pattern of consumption, a recorder has been installed close to the installation point of the switch reactor and the collected data has been used for the loading of the other consumer transformers. The pattern of consumption for all consumer transformers is like the reference consumer transformer, to which the data logger is connected. The scaling factor calculated based on the maximum capacity of a specific transformer and the reference transformer is used for finding the load of the consumer transformer.

The following two formulas are used for the load allocation to the consumer transformers based on the reference consumer transformer recorded data.

$$SF_n = \frac{S_{Max(n)}}{S_{Max(ref)}} \quad (1)$$

$$S_n(kVA) = SF_n \times S_{ref}(kVA) \quad (2)$$

Figure 3 shows the real loading data of the reference consumer transformer on the second of January and the scaling factor concept.

The geographical distribution of the Stanage Bay SWER system and the modelled network in PSS-SINCAL are shown through figures 4 and 5.

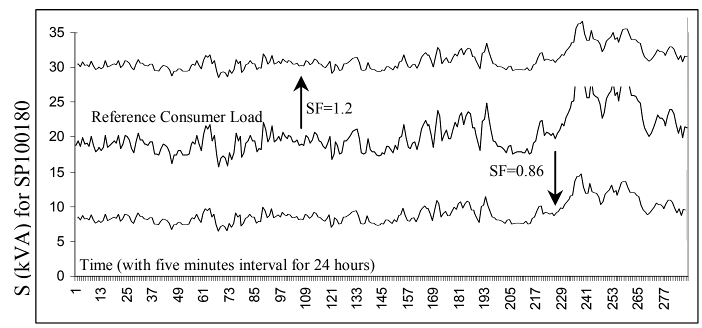

Figure 3, loading data of the reference consumer transformer on the second of January

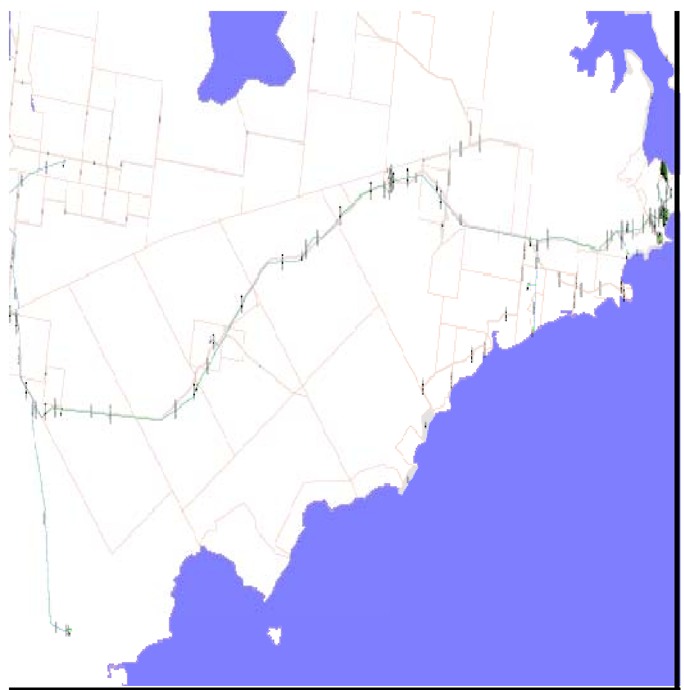
Figure 4 the geographical distribution of the Stanage Bay Feeder

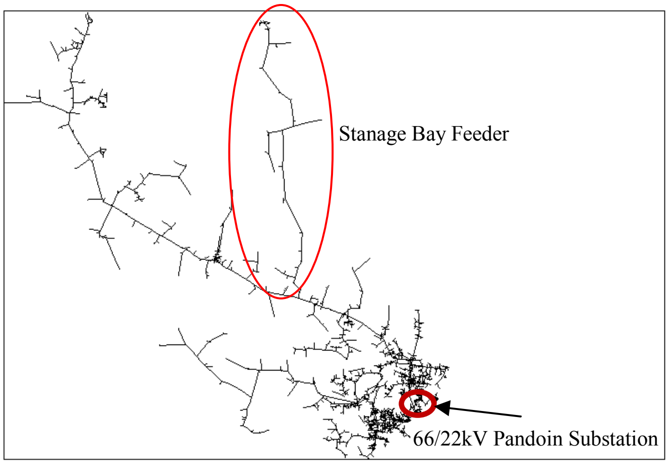

Figure 5 the 66/22kV Pandoin substation and Stanage Bay Feeder modelled in PSS-SINCAL

Considering the aforementioned specifications of the under study SWER system, the next section would cover firstly, the switch reactor design and then studying the Stanage Bay feeder with and without switch reactor for validating the effectiveness of the scheme.

III. SWITCH REACTOR DESIGN AND ASSOCIATED STUDIES

This section firstly explains the design process of the switch reactor and then studies the effects of installed switch reactor in two scenarios. First scenario models the Stanage Bay feeder without switch reactor and the second scenario models the Stanage Bay with switch reactor.

A. Design of the switch reactor

The design of the controlled reactor system can be seen in two stages. The first stage is the reactor design and the second one is the controller design. These two stages are explained through subsections A.1 and A.2.

A.1 Reactor Design

Two 460V, 54mH, 12.5kVA reactors are used. The reactors were bench tested for temperature rise and quality factor. Figure 6 shows a 12.5kVA reactor in and enclosure with parallel capacitors and current transducers. The inductors were tested in a parallel resonant arrangement to allow easy excitation with a small variac.


Figure 6 bench testing of reactor quality factor and temperature rise

On the left limb of the inductor a red search coil can be seen. The search turn voltage can be integrated by a digital oscilloscope with a mathematical capacity to produce an indication of flux and flux density B. In combination with the inductor current, a direct indicator of magnetomotive force, H, a B-H curve can be developed and the susceptibility of the inductor to saturation can be determined. The inductors showed no saturation at 532V, a 16% overvoltage and the limit of the test system. This corresponds to a reactive power of 17kVA. Magnetically the design is conservative.

The measured inductor Q is 55. A thermocouple was inserted between the coil former and core to estimate the hot spot temperatures. This thermocouple could be inserted more than 50mm and is a good indicator of internal temperature. The core was seen to stabilize in an eight-hour temperature rise test. This resulted in a 35^0C surface temperature rise and a 50^0C rise at the coil/core interface. The air temperature was 44^0C and the maximum observed temperature at the coil core interface was 94^0C. The inductor insulation system is class H (180^0C). The insulation life is estimated at better than 20 years.

A 25kVA SWER transformer has been used for testing. It was tested based on the open circuit and short circuit tests which could be conducted by energising the transformer from the low voltage side. The short circuit impedance, 3.3% was in line with the values used for the simulation models and in agreement with the name plate data. The magnetising current, 0.36%, and core loss, 0.21%, was significantly smaller than expected for the transformers which are connected to the system.

The transformer has two 250V windings. This allowed further testing to be performed on the effects of DC unbalance which could be present for a thyristor controlled reactor design. Figure 7 shows an arrangement in which the transformer could be easily subjected to a DC offset current.

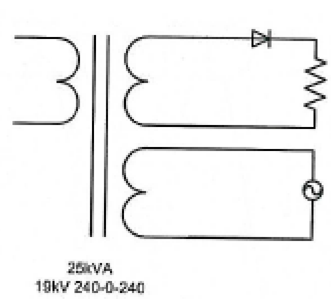

Figure 7 DC offsets on core magnetisation

In designing the controller, a decision was made to follow a low technology analogue design path to produce a controller that was robust, easy to test, and ultimately very easy to maintain. The controller contains the following functional blocks;

- A linear power supply that is connected from the line to neutral;

- A precision differential amplifier;
- A precision rectifier;
- An extreme low pass second order filter;
- An error amplifier;
- Two hysteresis comparators;
- Relay drivers;
- Relay with potential contacts.

The controller directly drives the 240V holding coils of two 63A three phase contactors. Each contactor drives one switched inductor. The switch reactor unit requires a three wire 240V-0-240V connection. While the reactors are switched line to line the control unit power supply and holding coils are 240V devices and are powered from one line to neutral.

Based on the design of the switch reactor, three scenarios of load have been studied. In the heavy-load scenario, all two inductors are out. Reactor number 1 with the capacity of 12.5kVA comes in during the medium –load scenario and finally, both reactors are in during the light-load scenarios.

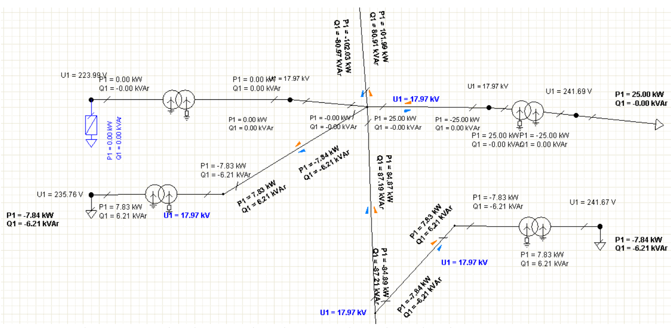

Figure 8: The heavy-load scenario when both reactors are out

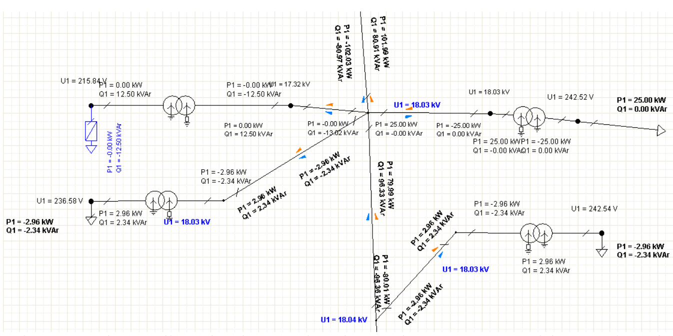

Figure 9: The medium-load scenario when only one reactor with capacity of 12.5kVA is in

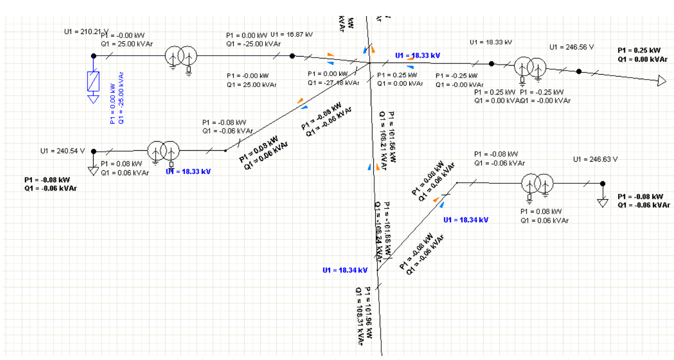

Figure 10: The light-load scenario when both reactors are in with the total capacity of 25kVA

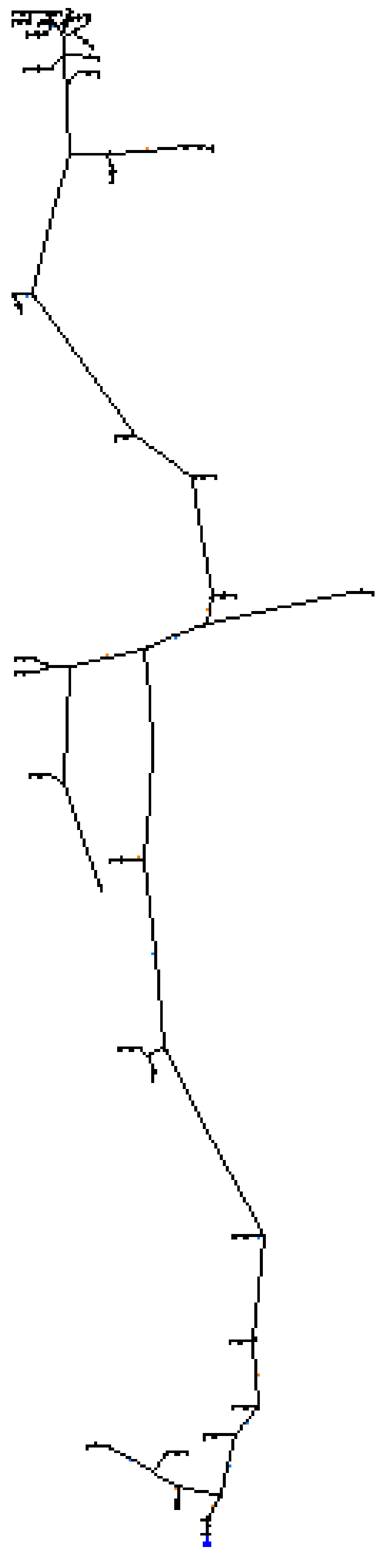

Figure 11: Single line diagram of the Stanage Bay SWER system

As it is clear from figure 8 through 10, in heavy load scenario both reactor are out and the voltage at the connection point of the switch reactor is about 17.97kV line-to-neutral. In case of medium load scenario only one of the inductors is in and the voltage at the connection point of the switch reactor is about 18.03kV. Finally, for light-load scenario when both reactors are in with the total capacity of 25kVA, the voltage at the connection point of the designed switch reactor is around 18.33kV.

Based on the field data, figure 12, shows the switching pattern of the reactors for one operating day. Figure 13 is the voltage pattern of the connection point of the switch reactor. Figures 12 and 13 are based on the practical data collected from the installation point of the switch reactor.

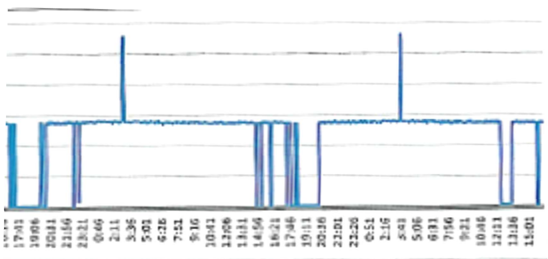

Figure 12: switching pattern of the switch reactor for one operating day

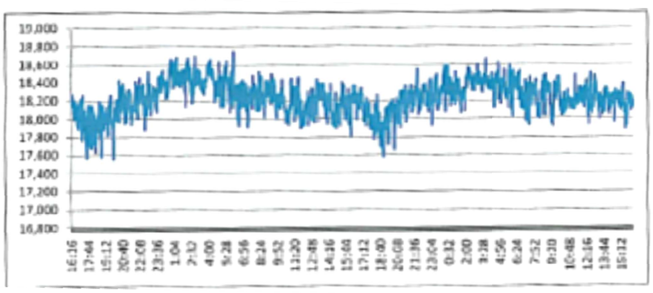

Figure 13: voltage pattern of the switch reactor for one operating day

Based on the filed data, when both reactors are out the voltage at the connection point of the switch reactor is about 17.9kV. Similarly, in the case of one reactor in, the voltage level is about 18.02kV and finally when both reactors are in, the voltage at the connection pint of the switch reactor is about 18.4kV.

The field data collected from the installation point of the switch reactor is completely in line with the simulation results and shows the smooth working of the installed switch reactor.

Next section would close this paper with its concluding remarks.

IV. Conclusion

This paper deals with the design and study of a prototype switch reactor for central Queensland SWER system. The main issue of SWER systems is the charging current of parallel capacitors and its associated over voltage along with the occupied capacity of the transmission lines. The many fixed reactors installed in the central Queensland SWER system could mange the voltage rise and keeping the voltage in the permitted voltage band. However, the problem rises when the SWER system is heavy loaded and the fixed reactors make the situation much worse in terms of the provided voltage to the end-user consumers. Addressing the problem, this paper discussed the design and study of a contactor-based switch reactor which can adjust the connected reactors to the SWER system based on the sensed voltage level. For economic purposes, the design of the reactors has been done based on the 240V which could be provided by the secondary of a SWER transformer.

The next step of this project would be optial allocation application of the designed switch reactor to the Central Queensland SWER system.

V. Refrences

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