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Loss of Excitation (LOE) Protection of Synchronous Generator

Hui Hwang, Goh[1]*, Sy yi, Sim[2], Mohd. Nasri Abd Samat[3], Ahmad Mahmoud Mohamed[4], Chin Wan Ling[5], Qing Shi, Chua[6], Kai Chen, Goh[7]
[1,2,3,4,5,6]Department of Electrical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia
[7]Department of Construction Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia
*Corresponding author, e-mail: hhgoh@uthm.edu.my

Abstract

Synchronous generators require certain protection against loss of excitation because it can lead to harmful effect to a generator and main grid. Systems of powers are evolving with applications of new techniques to increase reliability and security, at the meantime techniques upgradation is being existed to save financial cost of a different component of power system, which affect protection ways this report discuss the way of loss of excitation protection scheme for an increase in a synchronous generator. It is obvious that when direct axis synchronous reactance has a high value, the coordination among loss of excitation protection and excitation control is not effective. This lead to restricting absorption capability of the reactive power generator. This report also reviews the suitable philosophy for setting the limiters of excitation and discusses its effect on loss of excitation protection and system performance. A protection scheme is developed to allow for utilization of machine capability and power swing blocking is developed to increase the reliability when power swing is stable.

Keywords: *loss of excitation, protection scheme, synchronous generator*

1. Introduction

When a generator does not develop sufficient excitation for required load, the voltage terminal will decrease and the generator will operate at higher values for power factor and load angle. High increase in load angle leads to loss of stability and pole slipping and turbine would suddenly go into over speed with ac current flowing in the rotor. There are many reasons for loss of field like an exciter or rectifier failure, automatic voltage regulator failure, sudden tripping of the field breaker, field currents short circuit, poor brush contact on slip rings or ac exciters power loss from station power supply or the shaft generated excitation current.

Many types of relays can sense conditions resulting from loss of field, such as reactive power flow to the machine, internal impedance changes as an effect of field changes or decreasing field voltage. On the other hand, there is generator overexcitation. If generator produces greater than the rated voltage at rated speed or rated voltage below rated speed, the field current increase above normal over fluxing of generator stator iron will occur because of generated voltage and the excess current in the rotor. Damage due to overheating result of these components. Overvoltage may lead to a breakdown of insulation, resulting in faults/arcing. However, we focus on the loss of excitation and how to protect generator from this problem.

Protection system for synchronous generators must detect loss or decrease of excitation condition, make an alarm and if the abnormality persists, trip the generator. This can be done by distance relays that are installed at terminals of generator. The effect of loss excitation of a synchronous generator on the machine and the system stability led to effective research in protection scheme development which can sense loss or reduce of excitation early and also immune to power swings or other external problems. The two variants of measurements of impedance included protection schemes can support highly reliable protection for loss of excitation during a different condition of loading [1-3]. Discusses the importance of coordination of loss of excitation relay with generator capability curve (GCC), steady state stability limits and types of excitation control to have suitable protection technique. The

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impedance based method to mal operate during external disturbances and either need time delay or certain logic for preventing their operations.

Recently, specific generator parameters have undergone obvious change because of changes in the design fields of machine. Settings of LOE protection depend on the direct axis synchronous reactance of generator and the direct axis transient reactance value (Xd and Xd'), change in these parameters lead to an effective effect on the performance of protection technique. This study discusses the impact of change in generator parameter on the performance of LOE protection technique and suggests some modifications to the protection existed to allow optimum utilization of machine capability. To tackle the limitation of scheme excited when power swing is stable, the report shows the usage of correlation scheme which can classify the problem as loss of excitation or stable power swing and can block the relay to trip.

2. Synchronous Generator

In terms of protection of LOE, the first form of this technique uses undercurrent or under voltage relay which connected to the circuit of field. Nowadays the known method for sensing depended on the usage relays of Mho distance [4, 5].

The rely on Mho distance is set to identify generator terminal impedance variation [5]. This method leads to suitable performance in some condition. Some methods are depended on fuzzy algorithm, decision tree and neural networks which all these methods lead to good results with more training [6]. The LOE is sensed through a technique which analysis the change of generator voltage and reactive power of output [7]. There is a technique based on the change of terminal reactance for LOE detecting and other schemes present protection of an adaptive LOE relay with offset Mho technique. This technique improves the reliability of protection system, but we obtain a small trip time gain, because operating ch/c diameter is performed with respect to load of generator without any change at max relay angle of torque.

2.1. Relay for LOE

American National Standards Institute (ANSI) is a private non-profit organization that oversees the development of voluntary consensus standards for products, services, processes, systems, and personnel in the United States. The organization also coordinates U.S. standards with international standards so that American products can be used worldwide. One of the protection function is LOE protection (ANSI code 40) used for any size of generators and will be activated when the excitation reduce or completely lost [1]. Figure 1 shows the standard used by ANSI and the protection for excitation of the generator consist of relay 40Q and 40Z. Relay 40Q is used for protection for a failure of the excitation system based on reactance power, whereas relay 40Z is used to protect from a failure of the excitation system due to impedance based.

Device Number	Function
21	Distance – Backup for system and generator zone phase faults.
24	Volts/Hz – Protection for generator over-excitation.
25	Synchronism Check – Synchronism verification when paralleling
27	Undervoltage – Undervoltage protection.
27-3N	Undervoltage – Third harmonic undervoltage protection.
32	Reverse Power – Anti-motoring protection
40Q	Loss-of-field – Protection for failure of the excitation system, reactance based.
40Z	Loss-of-field – Protection for failure of the excitation system, impedance based.
46	Current Negative Sequence – Unbalance current protection
47	Voltage Negative Sequence – Unbalance voltage protection
49	Temperature – Stator thermal protection
51	Time Overcurrent – Phase Overcurrent protection

Figure 1. ANSI standard for power system protection

The main indicator in capturing the probability of LOE is the significant flow of reactive power into the generator. This will be captured by relay 40 [8-10]. Usually, protection of LOE is built on one or two impedance relays that have functioned in two concentric circles. As the LOE taking place, the measured impedance at the generator's terminal drops within the relay's working characteristics. Figure 2 shows the simple arrangement of relay 40 in the LOE protection of the generator. The operation of tripping work faster in the inner characteristic whereas the outside layer will be delayed for a second during LOE detection. Even with excellence usage of relay for LOE detection, it still tends to misrecognized some power disturbance and captured it as LOE [6]. That is why research has been done to improve and find the new relay and arrangement to assist the relay to quickly sense LOE phenomena but will remain stable during other power system faults and disturbances [8-13].

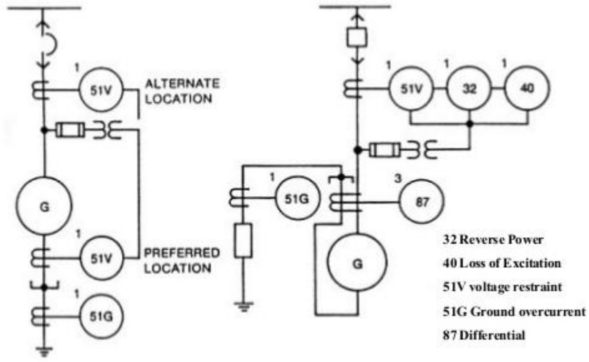

Figure 2. Relay 40 arrangement in simple generator

2.2. Capability Curve of Generator (GCC) against Impedance Methods

The operation of a synchronous generator can be analysed by GCC technique. This analysis is presented on a plane of P, Q. There are many factors which affect operation range of synchronous generators in case of steady state such as: armature current, terminal voltage, limit of stability, field current, primary machine capacity and minimum possible excitation. The condition of system and load require generator to run over a flexible range of voltage. Normally synchronous generator run at constant value of voltage, this value is between 95% and 100% of rated voltage.[14] According to loading condition, voltage varies. During periods of light loads, the voltage drop is minimal through system parts such as transformers and lines. When loading condition increases, voltage drop increases. In addition, the voltage regulation among light and max load is increased or due to the capacitance ch/cs of high voltage lines during lightly loading and also because of inductance during increasing of loading. Generator capability curve supports a suitable guide for power system operator and planners. However, capability curve is seldom analyzed along with protection, even though its process is limited by running ch/cs of protection relay. This is the case of loss of excitation which is affected by parameters of generator and protection settings. Impedance methods limit the operational area of GCC to prevent generator to run in a region close to the minimum excitation and limit of the steady state of stability to achieve operation area of capability curve limited by Loss OE protection technique. Hence, it is important to transfer loss of excitation protection from R, X plane to the plane of P, Q. Figure 3 shows generator capability curve and loss of excitation protection related to the setting of Berdy. Capability curve construction is performed by classical equations proposed in [14] and it considers voltage of the generator. An effective feature is that the capability curve and loss off excitation protection techniques are voltage dependent, but not the same rate. It is clear that if terminal voltage is changed, capability curve area also changes.

The analyzed result of Figure 3 shows that there is an area in the capability curve defined by loss of excitation protection for the machine studied. In steady state conditions, synch generator is unlikely to run in the same region. However, under emergent conditions, the importance of this area will be clear.

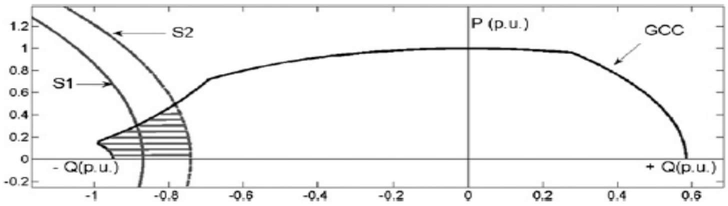

Figure 3. GCC with operational area

2.3. Phenomena of Loss of Excitation

When this phenomenon occurs, the excitation source of generator be completely or removed partially because of cases such as open circuit of the field, unintended breaker trip, voltage regulation failure, LOE and short circuit [5]. When loss of excitation occurs, generator becomes induction producer. It will operate, operating beyond sync speed in which accept reactive power inside. This phenomenon leads to voltage reduction. The effect of loss of excitation is determined the ability of a system to prevent not simply losing the real power, losing reactive output. It will also be enormous Var demand by the ruined generator.

During loss of excitation, stator current will increase double or triple from the original value. When generator operates as induction for a long time, it leads to heating of stator and rotor, reduces sync and burdening the rest of generator.

During loss of excitation, load-loss occur to the generator will highly affecting the possible destruction of the system. As lighter-load will be abolished during LOE, thus reducing potential damage, the final slip during full-load will damage even further on the generator. It gives an unclear common statement in which system operates excited, but it can be assessed and categorize in few minutes or seconds thus reliable and fast approach for LOE protection is required to detect the event to prevent most damages to system or generator [15].

2.4. Power Swing Blocking Scheme Technique

Research by Nitesh Kumar et all proposed the usage of Power blocking scheme as a protection for generator loss of excitation [5]. Figure 4 shows the logic schematic circuit for power blocking scheme in LOE detection. LOE will create a difference in resistance pattern variation. Power blocking scheme uses this advantage as their main technique in tackling the faulty. During LOE, the starting variation of resistance is oscillatory and becomes almost direct with respect to time. As the machine goes out of step, over the erratic variation of resistance, we can still detect the linear pattern. We can get the linear variation in resistance by overlying the impedance trajectory during LOE phenomena at the characteristic of relay as long as the trajectory works within the characteristic zone. Figure 5 and 6 show the variation of resistance under normal swing and during LOE phenomena.

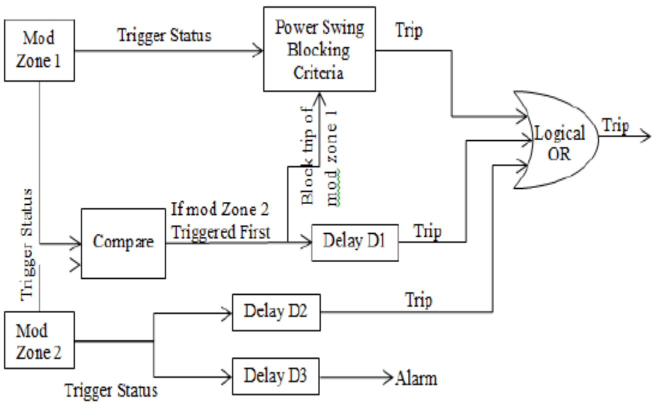

Figure 4. Relay schematic for trip logic

The oscillatory variation in resistance can be detected even when the power swing locus trespasses into LOE relay characteristics. Frequency (foss) of 1Hz is the typical oscillate frequency for the power swing situations of the resistance variance. LOE commonly occur during very low initial loading (naturally lower than 5% of the rating of the machine), as the difference of resistance is very slow, we can determine that the resistance value acts as a constant inside the power swing blocking criteria time frame consideration. These create the inability of the power blocking scheme in detecting the LOE in a very low initial loadings. Mod zone 2 was recommended to be used in extremely low initial loading LOE thus the power blocking criteria is not advisable to be used in the detection of the impedance trajectory as it enters the zone 2 mod. However, with the very slim probability of power swing entering the relay characteristic through this small region, we can conclude any impedance trajectory is entering through this region act as LOE [16-17].

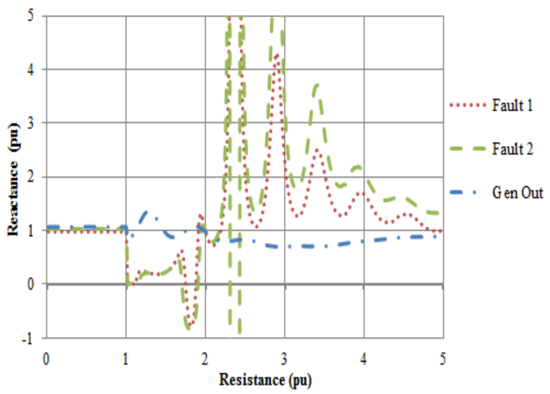

Figure 5. Normal swing resistance variation

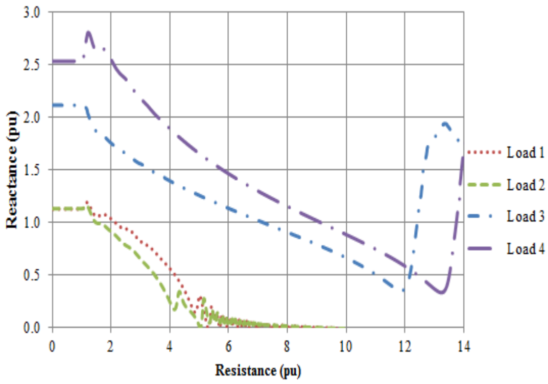

Figure 6. Resistance variance during LOE

2.4. Modified Two Zone Scheme

Study has been done by Nitesh Kumar et all on modified two zone scheme. The impedance trajectory during LOE occurring at light loading conditions enters the relay operating zone from the bottom part of the characteristic and does not penetrate too deep. Figure 7 shows the trajectory of LOE at different initial loading [3].

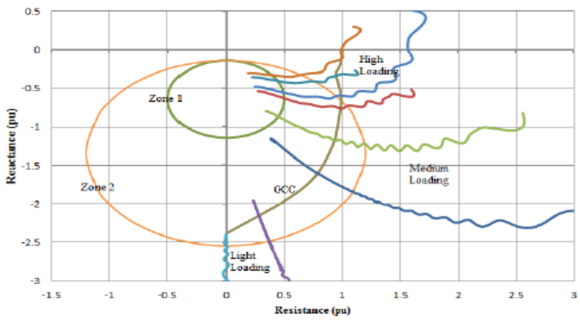

Figure 7. Trajectory of LOE at different initial loading

For the extreme situation where the generator is operating as a synchronous condenser, the impedance trajectory ends at the coordinates - [0,-Xd]. Dropping the zone two diameters and creating an additional zone such that it shields those impedance trajectories which will not enter the reduced zone two, optimal LOE protection pattern can be attained. The mentioned scheme is shown in Figure 8 prove that it can capture all LOE (including the low mode) and consequently allow the generator an improved capability of utilization.

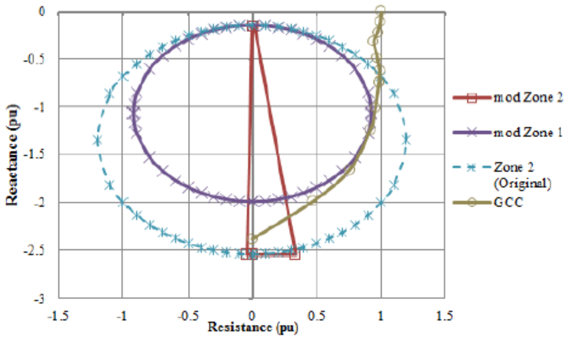

Figure 8. Proposed adjustments for the protection of LOE scheme

The mod zone one is offset by a figure of –Xd'/2 and alteration of the diameter done in direction with GCC. As a smaller mod zone one reach, the trajectory of the impedance entry time for the altered zone one is higher than entry time for the initial zone two reach. These lead the usage of a typical original zone two time delay of 1second may be insufficient to trip the generator before the synchronous loss is taking place. A power swing conditions are selected to control and enhance the performance of the protection scheme in steady power swing [3].

The suggested mod zone two is of quadrilateral features with its reactive reach beginning from the point –1.1*(Xd'/2). Just before the system losing the synchronous criteria, the resistive reach is defined as an angle with respect to Y-axis. This creates a condition of overlapping between zone two impedance trajectories of LOE with the modified zone one area. As the angle reduces fewer than 10 degrees, it will create a capability of capturing any LOE arising at any loading state. To initiate the trigger for LOE detection, mode two will be used as the reference base whenever the impedance trajectory reaches the zone and trip the system with a setting period of delay. These stated at Figure 9 where the circle shows the point of the overlapping of both zone one and two with the LOE. [18-19].

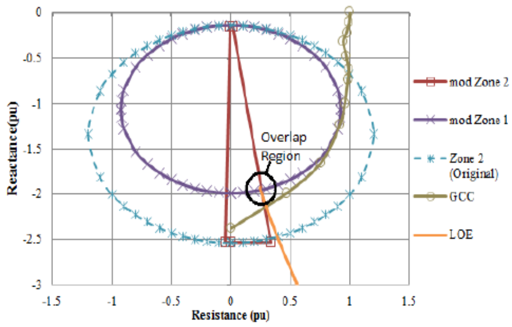

Figure 9. Overlapping of all zone (one, two and LOE)

3. Conclusion

Loss of excitation face by a generator is one of the major problems faced in the industries. Due to these phenomena, it will affect the system and can lead to generator damage and disturbance towards the power grid. Relay 40 ANSI have been used as a tool to cater the loss of excitation detection. However as good, the arrangement of the relay was, it tends misunderstood a normal non-dangerous turbulence and disturbance as a loss of excitation face by the generator. As a result, research and development have been done to improve and assist the detection function of the system to become dependable, accountable, and reliable in handling the generator loss of excitation situation. Mainly development focus on capturing the loss of excitation at the earliest and also having an immune protocol for power swing and other external disturbances. There are modified two zone scheme presented in this paper in which it modifies to zone one and two and adjust the overlapping region to safeguards that the scheme at any loading condition can detect the loss of excitation. A scheme of power swing blocking criteria also presented in this paper in which introduce the usage of correlation function to differentiate and to group the normal and steady power swing with the loss of excitation scenario thus increasing the recognize ability towards the loss of excitation of generator. The paper also presents the usage of analytical procedure relay trip logic in which it combines the overvoltage relay and adaptive Mho characteristic, with directional. This method provides the ability to have enhanced loss of excitation security and GCC coordination. Another advantage of using the adaptive method is friendly user ability compared to conventional method.

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