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Investigation and Simulation Loss of Generator Excitation in Different Power Network Structures

***Abstract**. A generator excitation system plays a key role in both generators protection and power system stability. Therefore, the protective loss of excitation relay has an important effect on the performance of the protection system and can save the generator and the power system against damage and instability, respectively. Often protective loss of excitation relays operate based on generator terminal impedance. In this paper, different structures of a simple power system network are studied, the behaviour of the generators in the loss of excitation situation is simulated, and the results are discussed. Moreover, in the simulations the effect of different external faults, parallel generators and load on the seen terminal impedance of generators is investigated. In addition, the effect of changing generator excitation of one generator on the other generators is discussed.*

***Streszczenie.** W artykule omówiono różne struktury sieci zasilającej, zasymulowano właściwości generator przy statach wzbudzenia I przedyskutowano rezultaty. Zasymulowano też różne zewnętrzne uszkodzenia i różne obciążenia. (**Badania i symulacja straty wzbudzenia gneratora w różnych strukturach sieci energetycznej**)*

Keywords: Loss of Excitation Protection, Power System Network, Synchronous Generator, Terminal Impedance.
Słowa kluczowe: wzbudzenie generatora, sieci energetyczne, zabezpieczenie.

1- Introduction

More than fifty percent of all the faults of generator are due to the excitation system. Since loss of excitation (LOE) can cause serious problems for the generator and power system, a fast LOE detection method can enhance the reliability and performance of power system. Several methods are employed for detecting LOE faults but experience has shown that the approaches based on generator terminal impedance provides more accurate and reliable results in comparison of other approaches [1].

Whenever LOE fault happens, the rotor of generator accelerates and the generator operates as an induction generator. In this condition, the generator draws reactive power, which causes power swing and voltage drop. Sometimes LOE in the large generators has serious influences on the power system stability. During the LOE fault, the LOE relay requires other generators to provide reactive power [2]. In some weak system, the remained generators may not be able to supply the required power of system effectively, which may results in the mal-operating of the relay. In order to ensure the correct operation of LOE relays depends on the generator size and power system there are some instructions which is out of scope of this paper.

When the excitation is lost, the generator starts to draw reactive power from the system. As a result, the terminal impedance ranges between the transient reactance and the synchronous reactance of the machine. The endpoints and the trajectory of the terminal impedance depend on the initial operating point of generator, the generator controllers and the power system structure. The normal setting for the relay in the impedance plane is a circle with the diameter X_d and a negative offset $1/2X'_d$. This circle is operation zone for LOE relay [2,3].

Many researches have already been done to analyse and improve the protection of power system during LOE The operating characteristics of LOE relay in response to changes in voltage and frequency are studied in [4].The LOE fault detection based on the power angle and the slipping of generator is investigated in [1]. In [3] a new loss of excitation protection scheme has been devised in order to minimize the system voltage disturbance caused by LOE fault. It is designed specifically to prevent tripping of a sensitive load adjacent to a generating station with only one unit in operation. In [5] the investigations are conducted with the field winding both open and short-circuited, and for various loading conditions.

The seen impedance by a LOE relay during simultaneous faults is investigated in [6]. In [7] the trajectory of the seen impedance by a distance type relays during sequential disturbances is studied. [10] presents an artificial intelligence-based neural network (ANN) pattern classification and online detection scheme for a single machine infinite bus system. This method is utilized for online classification and detection of fault condition causing first swing transient stability or loss of excitation.

In this paper performance of LOE relay considering changes in the configuration of a simple power network, which, affect the terminal measured impedance, is investigated. The considered effects are included the change of generator load, external faults in the power system and the effect of parallel generators. In addition, the effect of changes in the excitation of a generator on other generator is simulated.

In order to investigate the LOE faults, a simplified model of power system is considered. In this power system model, two generators (G1 & G2) are connected to a common busbar via step-up 13.8/230kV transformers. The common busbar is connected to the load bus via 40 km overhead transmission line. The load is connected to infinite busbar via 60 km transmission line. Fig. 1 shows the configuration of the simulated power system. The power system data is presented in appendix.

2- The LOE Faults

Short circuit fault in excitation system of a generator cause the field voltage of a generator falls to zero. Therefore, the current of field winding decays by the field time constant. Different scenarios for this fault presented in this section.

2-1- Single Unit Connected to Infinite Busbar

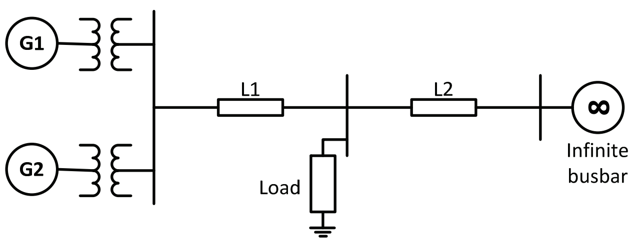


Fig. 1. Single-line diagram of simulated power system

In this case, G1 supplies the load while G2 is disconnected from the network. In order to investigate the operation of LOE relay, two scenarios are considered. In the first scenario, G1 is working at the half of maximum rated capacity and supplying 0.5 per-unit load at the power factor of 0.8.5 lagging. In the second scenario, G1 supplies a full load (1 per-unit) at the power factor of 0.85 lagging. The LOE fault occurs at t=2 seconds, which causes voltage drop, on the generator terminal. When LOE happens in G1, the infinite busbar supplies the reactive current of the generator. The generator terminal voltage (rms value) and rotor rotational speed in the case of full load condition are shown in Fig. 2. As seen in this figure the generator loss the synchronism at 6 s. The active and the reactive powers of G1 are illustrated in Fig. 3. The reactive power decreases after the fault, but the active power keeps almost constant before loss of synchronism. As seen in Fig. 4 the impedance trajectory curve in both simulated scenarios enters the operation zone of LOE relay. The seen impedance in the case of full load takes 4.121 seconds and in the case of half load takes 8.234 seconds to enter the operation zone.

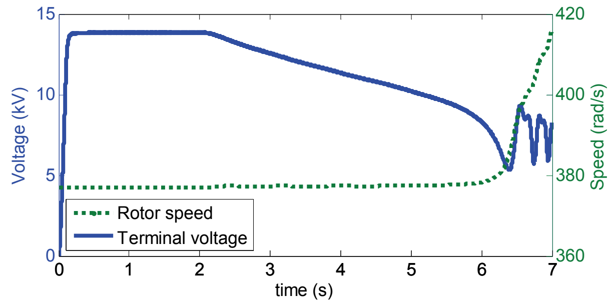


Fig. 2. Voltage drop and rotor acceleration during LOE fault

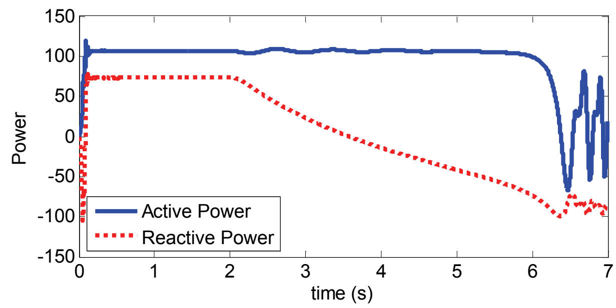


Fig. 3. Active and reactive power of G1

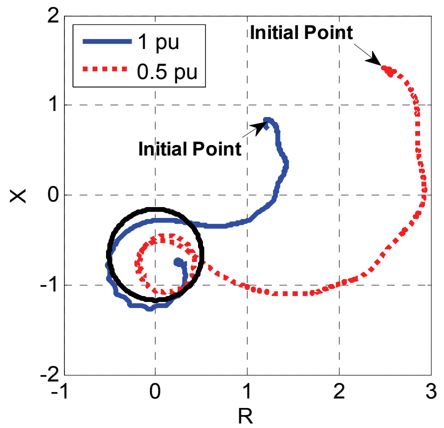


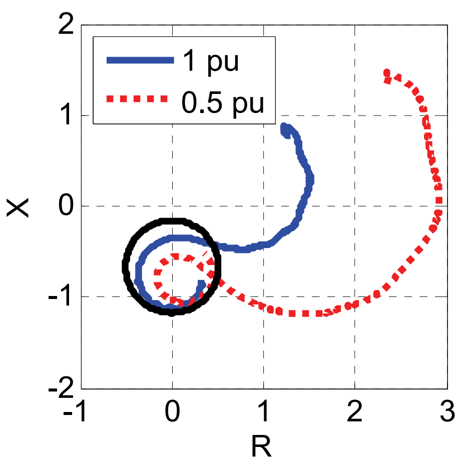
Fig. 4. G1 terminal impedance trajectory in R-X plane

2-2- Two Parallel Units Connected to Infinite Busbar

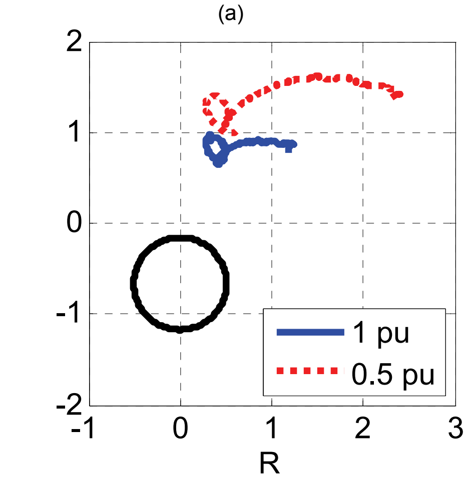
In this case, both generators are connected to the power system. The same scenarios as describe in 2-1 section are simulated which each generators supplying the full and half load at the power factor of 0.85 lagging. In the simulations, the LOE fault happens for G1 at t=2 seconds. The results show that, LOE causes voltage drop on both generator terminals, but only G1 absorbs the reactive power. The trajectory of G1 terminal impedance in the R-X plane is shown in Fig. 5-a. It can be seen that the terminal impedance of both full load and half load conditions enters the trip region of the relay. In the case of full load, the trajectory of impedance enters the operation zone after 4.659 second from fault while in the case of half load it takes 8.749 second. The impedance trajectories of G2 are illustrated in Fig. 5-b. In spite of voltage drop of G2 terminal, the impedance trajectories for both scenarios do not enter the operation zone of relay.

3- External Fault

This section investigate the effect of different external short-circuit faults at the busbar on operation of LOE relay. During busbar short-circuit fault, the terminal generator impedance may enter the LOE protection zone and stays for a short time. Often there is a short time delay for LOE relay and if the maximum duration time exceeds this time delay, LOE relay will mal-operate. In order to investigate the behaviour of LOE relay in external fault situation, different faults are simulated. In all the cases, the fault resistance is o.1 ohm.



(a)



(b)

Fig. 5. (a) G1 and (b) G2 terminals impedance trajectories in R-X plane

3-1- Three-phase to ground busbar short circuit fault

During the fault, the fault resistance and the network impedance determine the generator terminal phase and voltage. In this case, the three-phase to ground short-circuit fault happens on the common bus of generators at t=2 seconds. The initial operating point and the power system structure is the same as section 2-2. The trajectory of G1 terminal impedance in the R-X plane is shown in Fig. 6. It can be seen that the terminal impedance of both full load and half load conditions moves toward the operating zone of the relay but do not enter the zone.

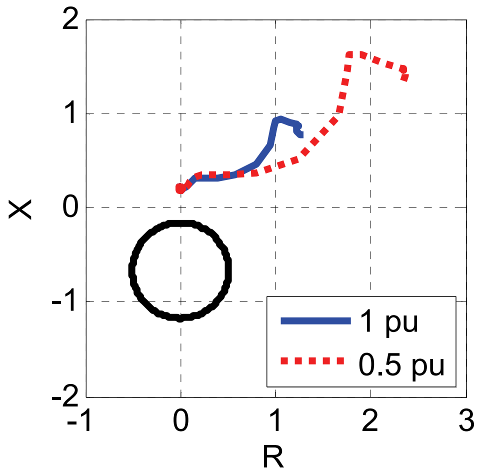


Fig. 6. G1 terminal impedance trajectory in R-X plane

Actually, the trajectory cannot enter the operating zone of LOE relay unless the generator absorbs the reactive power. In order to investigate whether leading loads can cause mal-operation of LOE relay in the case of external faults, two scenarios are simulated. In the first scenario, each G1 and G2 working at the half of maximum rated capacity (0.5 per-unit load at the power factor of 0.8.5 leading). In the second scenario, G1 and G2 working a full load condition (1 per-unit) at the power factor of 0.85 leading.

The trajectory of G1 terminal impedance in the R-X plane is shown in Fig. 7. It can be seen that however in this case the terminal impedance of both full load and half load do not enter the zone, but the trajectory is quit near the operation zone and may enter to this zone in other operating point of generator or power system structure. In order to ensure the reliable operation of LOE relay there is a short time delay between entering time to the operating zone and the initiation of a tripping signal.

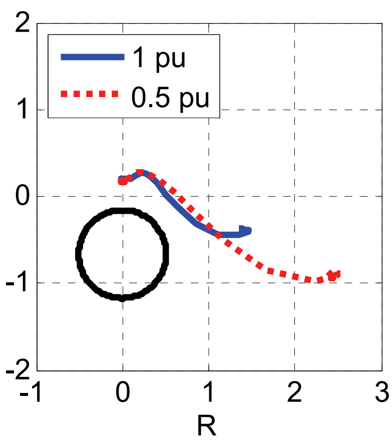


Fig. 7. G1 terminal impedance trajectory in R-X plane

3-2- Single-phase to ground busbar short circuit fault

The fault current of a single phase to ground fault is greater than a three-phase fault, though a three-phase fault is the severest. During single-phase to ground fault, the phase current contains large amount of negative sequence component. The negative sequence can be used to discriminate the LOE and external unsymmetrical faults. In this case, the fault happens on the common bus of generators at t=2 seconds. The initial operating point and the power system structure is the same as section 2-2. Fig 8 depicts the terminal impedance trajectory of G1 in R-X plane.

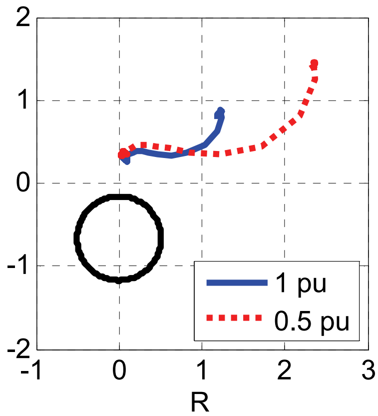


Fig. 8. G1 terminals impedance trajectory in R-X plane

3-3- Two-phase to ground busbar short circuit fault

Busbar phase-to-phase fault is not as severe as three-phase fault. Similar to single phase to ground fault, during the fault, large amount of negative sequence component occurs in phase current. In this case, the fault happens on the common bus of generators at t=2 seconds. The initial operating point and the power system structure is the same as section 2-2. Fig 9 depicts the terminal impedance trajectory of G1 in R-X plane, respectively.

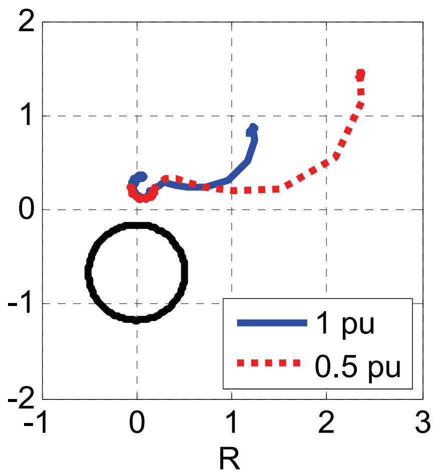


Fig. 9. G1 and G2 terminals impedance trajectory in R-X plane

4- Excitation variations on Parallel Units

The abrupt change in the excitation of parallel generators can cause transient conditions, which may lead to mal–operation of LOE relays. In order to investigate this case, the same scenarios as section 2-2 are considered. The field reference changes from 1 per-unit to 1.5 per-unit at t=2 seconds. Fig 10 depicts the terminal impedance trajectory of in R-X plane, respectively.

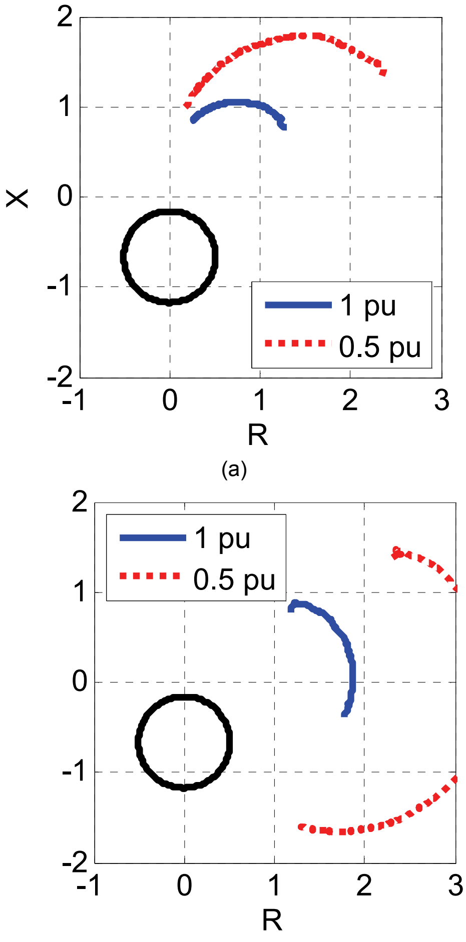


Fig. 10. G1 terminal impedance trajectory in R-X plane

6- Conclusion and Recommendations

In this paper, loss of excitation fault was investigated. In order to investigate the LOE fault, a simplified model of power system was modelled and simulated in PSCAD software. In order to study the behaviour of loss of excitation relay in different condition, different structures of the network were considered. In the simulations, the effect of generator operating point in the network was examined. Moreover, the effect of parallel generators on the seen impedance by loss of excitation relay was studied and the way excitation variation of one generator affects another generator was investigated.

It was observed that the closer the generators to each other, the higher their effects on each other. Loss of excitation relay properly distinguishes the LOE fault in parallel units, based on the impedance movement. In some cases, it was shown that loss of excitation of a generator might lead to the incorrect operation of the loss of excitation relay in the other generators.

Appendix

The parameters of the simulated power system are presented in Table 1.

Table 1. Parameters of the studied power system

Parameter	***Value***
Frequency	*60 Hz*
Rated Power	*120 MVA*
Generator Rated Voltage	*13.8 kV*
internal resistance	*0.0052*
Steady state reactance	*1.014*
Transient reactance	*0.314*
Excitation system	*AC1A*
Infinite bus (R=0)	*230 kV*
Rated Load	*104 MW, 58 MVar*
Transformer 1 and 2	*13.8kV/230kV*
Pos. sequenc leakage reactance	*0.1 p.u*
Line 1 length	*40 km*
Line 2 length	*60 km*
Pos. sequence line reactance	*0.3 Ω/km*
Pos. sequence line resistance	*0.03 Ω/km*
Pos. sequence line shunt admittance	4.08×10^{-6} *S/km*
Zero sequence line reactance	*0.9 Ω/km*
Zero sequence line resistance	*0.3 Ω/km*
Zero sequence line shunt admittance	2.88×10^{-6} *S/km*

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