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Evaluating the change in the phase difference between the generators of a two-machine system on the short-circuit level grid

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Abstract:

The main goal of regional power companies is transferring the stable and reliable energy. Short circuit is the main threat to a power grid that can lead to instability. Necessary measures have been considered in the generator site to deal with this threat. In this paper, initially a permanent single-phase short circuit to ground fault was created in the mentioned system. Then, the phase angle between the generators was increased. The results showed that 0.3% of the short-circuit level in the power grid decreased for increasing every degree phase angle.

Key words: energy transfer - short circuit - instability – Generator - phase angle

1. INTRODUCTION

Nowadays, the importance of grid short-circuit level is very impressive due to the increasing expansion of energy. Short circuit is the most important problem in the power grids that can lead to irreparable damages to the system if they could not be controlled or limited. Extensive researches have been conducted on the behavior of the electrical parameters of power plants at the moment of short circuit whose aim was reducing the impact of this problem on generators. Jie et al. (2012) have analyzed the double-fed induction generator's short circuit currents [1], while previously it was done in wind power plants [2-3]. Short circuit in synchronous generators was not excluded for these studies. In these researches, the transient behavior of two and three-phase of a salient pole generator was measured and compared exactly with the help of Fluke 435 laser device in addition to being simulated in MATHCAD software [4]. Some of researchers used the results of the short circuit in generators to achieve other parameters. Thermoelectric generators power point tracking (Maximum Power Point Tracking) (MPPT) by sampling the open circuit voltage and short circuit current of generators are some of them [5].

In countries power grids, power plants work in parallel because of the increased stability with the phase difference (δ). This phase difference, which is dependent on the consumption current, should be limited to a defined value so that generators do not reach an unstable state. At the time of short circuit, the mentioned phase difference increases slightly then returns to its original state after fixing. In this paper, the short-circuit level of two synchronous generators were evaluated and compared in two phase difference states of zero and 10 degrees, which were in parallel by a short transmission line of 400 kV. The purpose will be achieving the impact of the phase difference between the generators on the short circuit level, while phase angel changes do not lead to instability.

2. TRANSIENT STABILITY IN TWO-MACHINE SYSTEMS [6]

Stability of a power system is a property of a system that helps electrical machines to maintain their synchronization caused by disruptions with the grid. Studies of power system stability according to the type and scope of the disorder are divided into three categories of steady, dynamic and transient stability. In transient stability, which is caused by sudden and severe disorders in the system such as short circuit, load departure, sudden opening of the transmission line, speed, electric power, and power angle of the machine change severely in different parts of the system. If this disorder to be controlled resolved in a timely manner, the system will be stable, and if it was not resolved timely, the machine gets of synchronization mode and the system becomes unstable. This instability depends on its severity and location.

Equation 1 is the oscillator equation of a transient system, which helps to evaluate the transient stability in a two-machine system along with level criteria.

$$\frac{d^2\delta}{dt^2} = \frac{\pi f^0}{H}(P_M - P_e) \quad (1)$$

In which,

$$P_e = P_{e1} + P_{e2} + \cdots + P_{em}$$
$$P_m = P_{m1} + P_{m2} + \cdots + P_{mm}$$
$$H = H_1\frac{S_1}{S_b} + H_2\frac{S_2}{S_b} + \cdots + H_m\frac{S_m}{S_b}$$

Here, it is assumed that:

This means that all generators' rotor at the power plant oscillate together.

In the above equation (P_e) is the electric power of generators, (P_m) is the mechanical power of generators, (δ) is power angle, (H) is inertia constant, and (S) nominal power of generators.

Now, we examine the situation where the synchronous generator is connected to another synchronous machine instead of an infinite bus as Figure (1). The oscillator equation of these machines is:

$$\frac{d^2\delta_1}{dt^2} = \frac{\pi f^0}{H_1}\left(P_{m_1} - P_{e_1}\right) \qquad (2)$$

$$\frac{d^2\delta_2}{dt^2} = \frac{\pi f^0}{H_2}\left(P_{m_2} - P_{e_2}\right) \qquad (3)$$

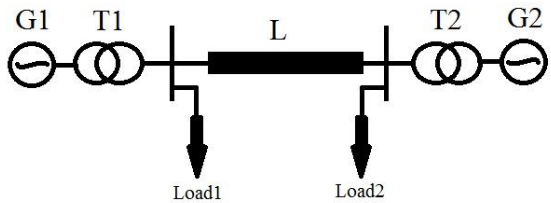


Figure 1: Two-machine system

By subtracting the recent equations from each other, we have:

$$\frac{d^2\delta_1}{dt^2} - \frac{d^2\delta_2}{dt^2} = \pi f^0\left(\frac{P_{m_1} - P_{e_1}}{H_1} - \frac{P_{m_2} - P_{e_2}}{H_2}\right) \quad (4)$$

Both sides of the equation are multiplied by $\frac{H_1 H_2}{H_1 + H_2}$ and then, equation (5) is obtained after sorting.

$$\frac{d^2\delta_{12}}{dt^2} = \frac{\pi f^0}{H_1}\left(P_{m_{12}} - P_{e_{12}}\right) \qquad (5)$$

In which,

$$\delta_{12} = \delta_1 - \delta_2$$

$$H_{12} = \frac{H_1 H_2}{H_1 + H_2}$$

$$P_{e12} = \frac{P_{e1}H_2 - P_{e2}H_1}{H_1 + H_2}$$

$$P_{e12} = \frac{P_{e1}H_2 - P_{e2}H_1}{H_1 + H_2}$$

It can be concluded from Equation (5), which is closely similar to the oscillator equation (1) that $P_m = P_e$ and acceleration is zero until there is no disruption in the system. As a result, the speed of the machine is fixed and the machine is in the stable condition. Due to the sudden disruption in the system, P_e changes, and the acceleration changes the speed and the power angle. If the disruption be severe and be not resolved, the system tends toward instability. Thus, the angular acceleration is variable and the mechanical parameters of the system such as power angle (δ) and the rotor angular velocity (ω) oscillate according to the equation (5) if the disorder was not removed in enough time. Solving the mentioned equation determines the possibility of stability and (δ) changes. If (δ) began to decline after reaching the maximum value and has oscillation, the system remains stable and that oscillations will be amortized.

3. EVALUATING THE IMPACT OF THE PHASE DIFFERENCE BETWEEN THE GENERATORS OF A TWO-MACHINE SYSTEM ON THE GRID SHORT CIRCUIT LEVEL

Consider Figure (1). In this system, two synchronous generators are in parallel with the nominal voltage of 11 kV by 11 to 400 kV transformers with 200 megavolt ampere and 11% impedance by a transmission line with the electrical specifications of $(R = 0.078329\,\frac{ohm}{km}$ ، $xl = 0.4257\,\frac{ohm}{km}$ ، $xc = 0.3742\,\frac{Mohm}{km})$. The consumed load of each generator directly is feed from the Shin connected to power transformers. Each time, it absorbs about 50% of the nominal capacity of the active power of transformers with the power factor of 0.9.

To evaluate the impact of changing the phase difference between the generators on the grid short circuit, initially, we create a permanent single-phase short circuit to ground fault (phase C) in the middle of the transmission line. Figure 2 shows the circuit diagram of a typical two-machine system.

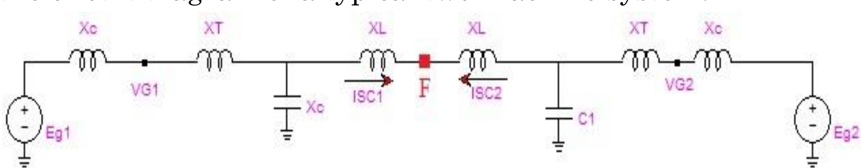


Figure 2: Equivalent circuit of two-machine system

Assuming that the positive and negative sequence is equal and we ignore the load current, we will have:

$$I_{SC1} = \frac{V_{G1}}{X_{th1}^1 + X_{th1}^2 + X_{th1}^0} = \frac{V_{G1}}{2X_{th1}^1 + X_{th1}^0}$$

$$I_{SC2} = \frac{V_{G2}}{X_{th2}^1 + X_{th2}^2 + X_{th2}^0} = \frac{V_{G1}}{2X_{th2}^1 + X_{th2}^0}$$

In which:

$$X_{th1}^1 = X_{th2}^1 = XT^1 + (XL^1 \| XC^1) \cong XT^1 + XL^1$$

$$X_{th1}^2 = X_{th2}^2 = XT^2 + (XL^2 \| XC^2) \cong XT^2 + XL^2$$

$$X_{th1}^0 = X_{th2}^0 = XT^0 + (XL^0 \| XC^0) \cong XT^0 + XL^0$$

If we assume that in the transmission line $XL^0 = 2XL^1$, in transformers $XT^0 = XT^2 = XT^1$, and for generators $XG^0 = \frac{1}{3}XG^1$, then:

$$Z_{Base} = \frac{{V_{Base}}^2}{S_{Base}} = \frac{400^2}{200} = 800\ ohm$$

$$XL^1 = 35 \times (0.078329 + j0.4257) = 2.741515 + j14.9$$
$$= 0.0034 + j0.018\ p.u$$

$$XT^1 = j0.11\ p.u$$

As a result:

$$\begin{cases} X_{th}^1 = XT^1 + XL^1 = 0.0034 + j0.128\ p.u \\ X_{th}^2 = XT^2 + XL^2 = 0.0034 + j0.128\ p.u \\ X_{th}^0 = XT^0 + XL^0 = j0.11 + 2(0.0034 + j0.018) = 0.0068 + j0.14\ p.u \end{cases}$$

If the phase difference between the generators is zero ($VG1\angle 0 = VG2\angle 0$), then the short-circuit current in the fault:

$$I_{SC1} = I_{SC2} = \frac{1\angle 0}{0.0136 + j0.402} = 2.486\angle\text{-}88.06$$

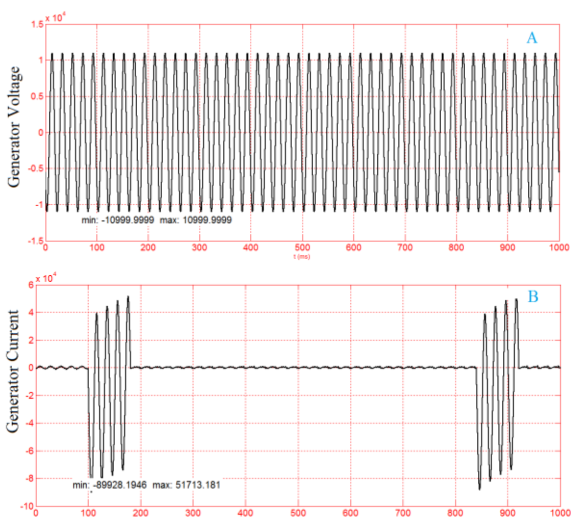
And if the phase difference between the generators is 10 degrees ($VG1\angle 10 = VG2\angle 0$), then short circuit current is:

$$I_{SC1} = \frac{1\angle 10}{0.0136 + j0.402} = 2.486\angle\text{-}78.06$$

$$I_{SC2} = \frac{1\angle 0}{0.0136 + j0.402} = 2.486\angle\text{-}88.06$$

4. THE TWO-MACHINE SYSTEM SIMULATION

We applied EMTP/WORK software to study the impact of changing the phase difference between the generators of a two-machine system on the grid short circuit. In this simulation, keys are the power related to each transformer in the form of single bridge and they are equipped by Auto recloser and synchronous relays. In this simulation, the single-phase fault caused in phase C was permanent, which was established at the moment of 100 milliseconds. The key is opened at the moment of 180 milliseconds and it gives the connection order again by Auto recloser relay and coordination with synchronous relay after 660 milliseconds. While this time can be different [7]. Considering the permanent phase fault, the corresponding phase bridge will be cut off again at the time of 920 milliseconds. Figure (3) shows the created oscillation on the different parts of the grid at single-phase permanent short circuit to ground fault at the time of zero phase difference between the generators under the circumstances described above.



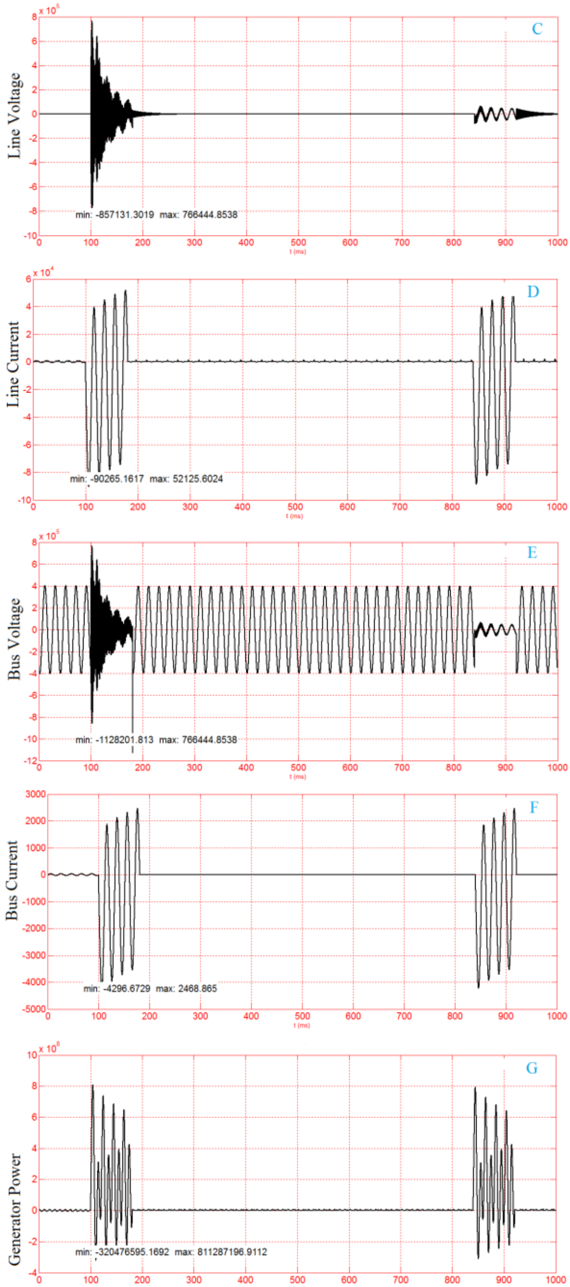


Figure 3: (A: Generator Voltage- B: Generator Current- C: Line Voltage- D: Line Current- E: Bus voltage- F: Bus Current- G: generator Power)

Undoubtedly, a short circuit can cause transient oscillations on the grid that Figure 3 represents this issue. To study the impact of changing the phase difference on the short circuit level, we initially obtain the fault location current at the moment of fault by the software when the phase difference between the generators is zero degrees. Then, we calculate the mentioned current by creating phase difference up to 10 degrees. Results are shown in Figure 4.

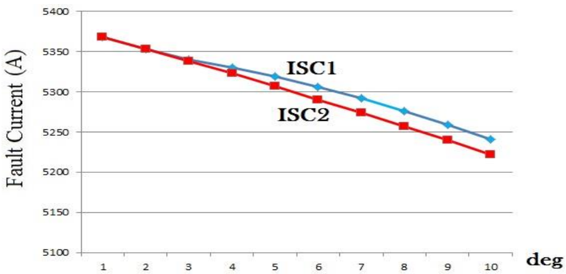


Figure 4: Changes to short circuit current at the time of the phase difference between the generators

5. CONCLUSION

The phase angle between the generators always is kept at a standard level. Because changes in the phase angle, depending on the consumed load can lead to instability of the system. However, increasing the phase angle up to the standard level reduces the grid short-circuit level. According to Figure 4, by increasing the phase angle in a two-machine system, the short-circuit current, which is fed by two generators, is declined. As was shown in part two of the paper, the short circuit current of the generator, in which the phase angle has been increased declines relative to the second generator with a constant phase angle with less slope. While 0.3% of the short-circuit level in the power grid decreased for increasing every degree phase angle.

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