

## Impact Study of Unequal Voltages of Power Plants (Generators)

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### ABSTRACT

When connecting two generators together (in parallel), there are conditions that must be met and fulfilled before commencing the electrical connection process, which are known as synchronization conditions. In this paper, the loss of equality voltages which is one of the synchronization conditions will be represented when performing the connection process using Matlab and surveying the impact of this on the performance of the system and the extent of damage that may result from it. The presented analysis shows the influence of faulty synchronization on the following physical quantities: internal voltage, stator current, stator voltage, angular mechanical speed, terminal voltages which are the most vulnerable. In addition, knowing the type of fault (short circuit fault) caused by the faulty synchronization condition. In this paper, over and under voltage schemes have been implemented by using MATLAB/SIMULINK.

### Keywords:

Faulty Synchronization; Under-Excited Synchronous Generator; Over-Excited Synchronous Generator; Three Phase Short Circuit Fault.

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## 1. INTRODUCTION

Synchronizing a two generators must be done carefully to prevent damage to the machines and disturbances to the power system. The idea of this article is built on the assumption that a two generators are connected in parallel, although the rms value of the two generator are not equal (bad/wrong/faulty synchronization). Two cases were taken, in the first case, it was assumed that the voltage of the generator that had been connected to the operating generator operates at a voltage lower than the voltage level of running generator (under excitation state). As for the second case, the voltage of the generator is higher than the voltage level of the operating generator (over-excitation condition).

According to these probabilities, the aim of this research is

1. To diagnose the consequences of the insecure situation of the system according to the above hypothesis.
2. Determine the fault type and

3. Survey the deterioration due to the failure to achieve one of the synchronization conditions for connecting electrical networks or electric generators with each other.

This hypothesis was simulated using the Matlab program and the type and nature of the resulting fault was determined when the condition of equal voltages was exceeded.

## 2. PARALLEL CONNECTION OF THE TWO SYNCHRONOUS GENERATORS (SGs)

To meet the changing load requirements, Synchronous generators (SGs) are connected in parallel to feed larger loads and improve the reliability of electrical power systems. When the required conditions occur, the two SGs can be connected in parallel and these generators must be

connected to each other after fulfilling the synchronization conditions [1].

Synchronization is the process of connecting two AC generators according to the identical of

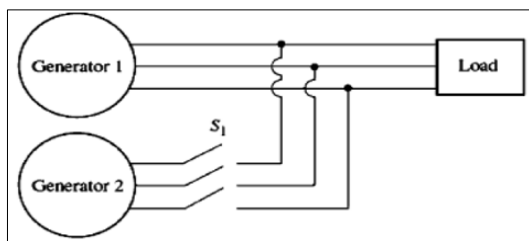
definite issues whereby two or more generators are connected and run in parallel with each other or one generator is connected to the infinite bus bar [2].

The synchronization conditions required to connect the generators together in parallel is shown as follows:

1. Equal frequencies ( $f_1 = f_2$ ).
2. Equal voltages ( $V_1 = V_2$ ).
3. The phase sequences of the SGs are similar.
4. phase shift = 0 [3].

Practically there are numerous main benefits of parallel operation of alternating current generators:

Fig.1, represents a two synchronous generators are paralleled and providing a power to the load, with the switch  $S_1$  closed [4].



**Fig.1** a two synchronous generators are connected in parallel and supplying a power to a load.

Generators are connected or removed from the network for many reasons such as load variations, emergency outages and maintenance. The generator necessity be synchronized with a power system before being connected to it [5].

### 3. CAUSES OF POOR RMS VOLTAGE MATCHING

There is a very poor probability but not impossible of faulty (bad) synchronization of two generators. The main cause of a faulty synchronization is due to, human errors, when voltage transformer and synchronizing equipment are connected or reconnected wrongly during maintenance leads to wiring errors and error ratio of voltage transformers. This deviation produces a high sudden reactive power flow either into the generator or into the power system, according to the voltage difference sign [6].

The penalties of bad (faulty) synchronization among two generators or more are:

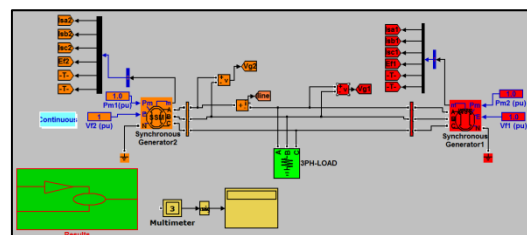
1. Mechanical stresses from rapid acceleration or deceleration lead to damage to the generator and main engine.

2. High currents lead to damage of the generator and transformer windings.
3. Power oscillations and voltage deviances from the nominal.
4. Isolate the generator from staying online and picking up the load [7].

When any of these deterioration occur, it starts to absorb a reactive power from the grid such as the rotor speed increases, and then, the synchronous generator starts to work as an asynchronous (induction) generator. As a result of this mode of operation, currents through stator winding is high, development an excessive pulsating torque, temperature at stator end is increased, and the rotor body suffer from severe thermal heating. In general, an incorrect voltage magnitude has a significant negative effect on the generator. The alternator synchronization with the power system must be carefully done to prevent equipment damage and disturbances in the power system [8,9,10].

### 4. SIMULATIONS AND RESULTS

A two 100 MVA, 11kV simplified synchronous generators were selected, Each Machine is a 3-phase simplified synchronous machine and modeled as an internal voltage behind a R-L impedance. Stator windings are connected in wye to an external ground point. Some simulations are presented by connecting the generator-2 is connected to the generator-1 to study the various voltage conditions. The simulation model is shown in Fig. 2, for correct and faulty voltage synchronizations, which are discussed below.



**Fig. 2** Correct and faulty voltage synchronizations model.

#### 4.1. CORRECT VOLTAGE SYNCHRONIZATION SIMULATIONS

In a first case, correct synchronizations are presented. Fig. 3 shows the currents during

synchronization. As expected, the two generators are correctly synchronization, and both of them can share and supply the load under correct synchronization conditions.

In this case, the two generators were connected after fulfilling the four synchronization conditions, as each generator could contribute to supplying the power needed for the load. But if it happened that the connection between the two generators was done, but with the loss of a basic condition for synchronization, which is the equal root-mean-square values of the voltage at the terminals of the two generators, due to human errors or errors in the measurement circuits (voltage transformers) or errors in the control circuit responsible for the simultaneous connection between the two generators, then there are two possibilities. The first possibility is that the voltage of the second generator is less than the voltage of the first generator shown in Figure 1., meaning to be under excitation. The second possibility is that the voltage of the second generator is higher than the voltage of the first generator shown in Figure 1., meaning to be over excitation.

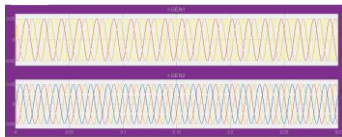


Fig. 3 Stator currents of the two generators at the correct synchronization model.

#### 4.2. SIMULATION AND RESULTS AT UNDER EXCITATION FAULTY SYNCHRONIZATION

Several values were imposed for the field voltage ( $1 > V_f \geq 0$  p.u) of the second generator, which value of the voltage of the terminals of the second generator is less than the voltage of the terminals of the first generator. The deterioration caused by the unequal voltages of the two generator terminals was simulated, as shown in Figures (4,5). It is observing from Figures (4,5), the following:

- 1- Both machines are subject to a symmetrical short circuit three-phase fault.
- 2- The three phase currents of the first machine are greater than the three phase currents of the second machine.

- 3- The value of the fault current increases with the decrease in the excitation of the rotor field of the second generator.
- 4- The first generator feeds the fault current.
- 5- According to the above, the second machine is considered a short circuit for the first machine.

The simulation results for the values of mechanical angular speed ( $W_{m1}$  for the first generator,  $W_{m2}$  for the second generator), terminal voltage, induced electromotive force ( $E_{f1}$  and  $E_{f2}$ ) for each generator, and stator currents ( $I_{s1}$ ,  $I_{s2}$ ), are shown in the Appendix 1-table. 1.

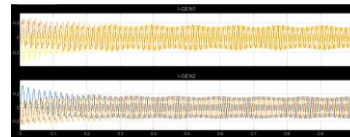


Fig.4 stator currents of gen-1 and gen-2 at  $V_f=0.5$  p.u.

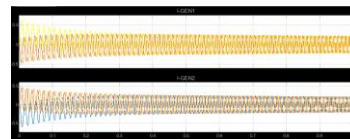


Fig.5 stator currents of gen-1 and gen-2 at  $V_f=0$  p.u.

As a result of the wrong synchronization resulting from the unequal values of voltages, a disturbance occurred in the various variables of both machines. It is assumed that the angular velocity of both machines and therefore the frequencies are equal, but due to the wrong synchronization, the difference increases between them due to growth of the reduction in the excitation level of the rotor of the second machine, and as shown in the figures (6,7). Because of the wrong synchronization, the terminal voltage of both machines decrease with the decrease in the excitation level of the second generator rotor, as shown in the figure (8). With an increase in the decrease in the excitation current of the rotor of the second generator, the electromotive force of the first machine is higher than the voltage of the terminals. This machine works as a generator that supplies the reactive power and the real power. In contrast, the induced e.m.f of the second machine is less than the voltage of the terminals of the same machine. This deterioration is caused by a decrease in the level of excitation of the rotor of this machine, and therefore this machine is forced to withdraw

reactive power from the first generator to compensate for the decrease in its excitation, and the worst case when excitation is zero. This behavior and the deterioration in the performance of the two machines is shown in the figure (9).

The deterioration in false synchronization also includes the stator current of the first generator and the stator current of the second generator, where  $I_{s1}$  is higher than the stator current of the second generator  $I_{s2}$ . The small difference between these two currents is caused by the presence of a load in the circuit. The fault current increases with the increase in the level of decrease in the excitation of the second generator, as shown in the figure (10).

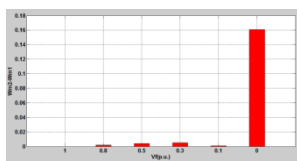


Fig.6 Deference between  $W_{m1}$  and  $W_{m2}$  at under excitation faulty synchronization.

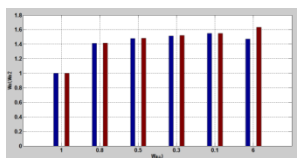


Fig.7 The values of  $W_{m1}$  and  $W_{m2}$  under excitation faulty synchronization at different values of  $V_f$ .

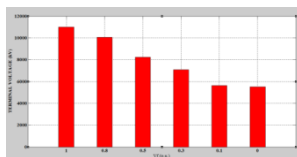


Fig.8 Lower terminal voltages with lower excitation of the second generator rotor.

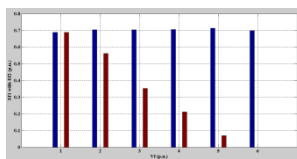


Fig. 9 Deterioration in values ( $E_{f1}$ ,  $E_{f2}$ ) with further decrease in the excitation of the rotor of the second generator.

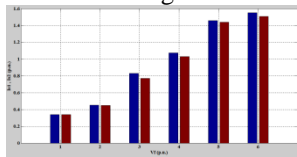


Fig.10 Comparison between  $I_{s1}$  and  $I_{s2}$  at different values of excitation current of GEN-2.

### 4.3. SIMULATION AND RESULTS AT OVER EXCITATION FAULTY SYNCHRONIZATION

Several values were imposed for the field voltage ( $2 \geq V_f > 1$  p.u) of the second generator, which value of the voltage of the terminals of the second generator is greater than the voltage of the terminals of the first generator. The deterioration caused by the unequal voltages of the two generator terminals was simulated, as shown in Figures (11,12).

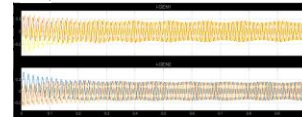


Fig.11 stator currents of gen-1 and gen-2 at  $V_f=1.5$  p.u .

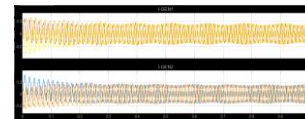


Fig.12: stator currents of gen-1 and gen-2 at  $V_f=2$  p.u.

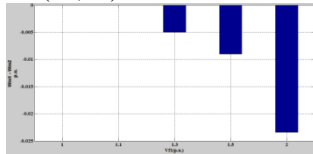
It is observing from Figures (11,12), the following:

- 1- Both machines are subject to a symmetrical short circuit three-phase fault.
- 2- The three phase currents of the first machine are less than the three phase currents of the second machine.
- 3- The value of the fault current (short circuit level) increases with the increase in the excitation of the rotor field of the second generator.
- 4- The second generator feeds the fault current.
- 5- According to the above, the first machine is considered a short circuit for the second machine.

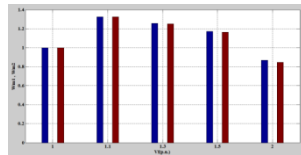
At this condition, the simulation results for the values of mechanical angular speed ( $W_{m1}$  for the first generator,  $W_{m2}$  for the second generator), terminal voltage, induced electromotive force ( $E_{f1}$  and  $E_{f2}$ ) for each generator, and stator currents ( $I_{s1}$ ,  $I_{s2}$ ), are shown in the Appendix 1- table. 2.

Due to the wrong synchronization,  $W_{m1}$  and  $W_{m2}$  are not equal and the difference increases between them due to increasing in the excitation

level of the rotor of the second machine as shown in the figures (13,14).

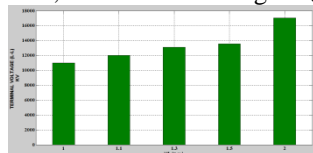


**Fig.13** Deference between  $W_{m1}$  and  $W_{m2}$  at over excitation faulty synchronization.



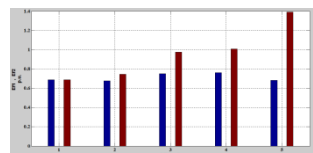
**Fig.14** The values of  $W_{m1}$  and  $W_{m2}$  at over excitation faulty synchronization at different values of  $V_f$

Because of the wrong synchronization, the terminal voltage of both machines increase with the increase in the excitation level of the second generator rotor, as shown in the figure (15).



**Fig.15** Upper terminal voltages with over excitation of the second generator rotor.

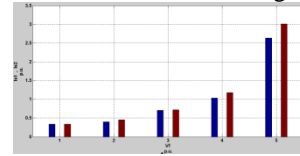
With an increase in the excitation current of the rotor of the second generator, the electromotive force of the first machine is lower than the voltage of the terminals. This machine works as a generator that draws the reactive power and supplies the real power. In contrast, the induced e.m.f of the second machine is greater than the voltage of the terminals of the same machine. This deterioration is caused by a increase in the level of excitation of the rotor of this machine, and the worst case when excitation is two. This behavior and the deterioration in the performance of the two machines is shown in the figure (16).



**Fig.16** Deterioration in values ( $E_{f1}$ ,  $E_{f2}$ ) with further increase in the excitation of the rotor of the second generator.

The deterioration in false synchronization also includes the stator current of the first generator and the stator current of the second generator,

where  $I_{s1}$  is lower than the stator current of the second generator  $I_{s2}$ . The small difference between these two currents is caused by the presence of a load in the circuit. The fault current increases with the increase in the excitation of the second generator, as shown in the figure (17).



**Fig.17** Comparison between  $I_{s1}$  and  $I_{s2}$  at different values of over excitation current of GEN-2.

### 5.CONCLUSIONS

This paper has presented the modelling of power grid synchronization failure on sensing bad voltage. Synchronizing a two generator must be done carefully. This article presents the simulation results of two generators bad synchronization due to the difference in the voltages of the two generators terminals as a result of one of them being in an under-excited or over-excited state. A two simplified synchronous generators were used to perform the simulation results in matlab software. over and under voltage schemes have been implemented by using programming in MATLAB/SIMULINK.

The use of simulation and representation of the hypothesized problem in MATLAB was very efficient, as we obtained the expected results for the disturbances caused by faulty synchronization. It is concluded from the case of faulty synchronization at the under-excited state of the second machine that it leads to a symmetric three-phase fault, and this fault is the most severe type of short-circuit faults, and the level of this fault increases with the decreasing in the excitation of the second generator, and as a result, the amount of reactive power withdrawn from it, is increased to cover the shortage in excitation of the magnetic field of the rotor of this machine, as well as the acceleration of this machine increases as a result of the decrease in the electromagnetic flux of it, which is reflected on the performance of the turbine associated with it, and that the worst case is when the flux becomes zero. The same conclusion applies to the over-excited state of this machine, but in reverse meaning that the first machine becomes less excited than the first. In summary, the wrong synchronization in both cases is very dangerous and leads to great deterioration and destruction as an inevitable result of the faulty synchronization.

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### Appendix 1

**Table.1:** Simulation results of GEN-1 and GEN-2 at various under excitation faulty synchronization conditions.

$V_{F2}$ p.u	$W_{m1}$ p.u	$W_{m2}$ p.u	V (Kv)	$I_{S1}$ p.u	$I_{S2}$ p.u	$E_{F1}$ p.u	$E_{F2}$ p.u	K. $\phi_2 = E/W_{m2}$ p.u
1	1	1	11e3	0.3392	0.3392	0.6886	0.6886	1
0.8	1.412	1.414	10.07e3	0.4519	0.4485	0.7036	0.5615	0.688
0.5	1.479	1.483	8231	0.8297	0.7715	0.7042	0.3523	0.5045
0.3	1.514	1.519	7093	1.072	1.031	0.7047	0.2111	0.4245
0.1	1.547	1.548	5634	1.457	1.438	0.7135	0.0699	0.33086
0	1.472	1.633	5512	1.553	1.508	0.6998	0	0

**Table.2:** Simulation results of GEN-1 and GEN-2 at various over excitation faulty synchronization conditions.

$V_{F2}$ p.u	$W_{m1}$ p.u	$W_{m2}$ p.u	V (Kv)	$I_{S1}$ p.u	$I_{S2}$ p.u	$E_{F1}$ p.u	$E_{F2}$ p.u
1.1	1.326	1.326	12E3	0.4536	0.3989	0.6779	0.7441
1.3	1.256	1.251	13.11E3	0.7088	0.7217	0.7503	0.9755
1.5	1.172	1.163	13.57E3	1.039	1.176	0.7605	1.008
2	0.8688	0.8454	17.03E3	2.635	3.01	0.6823	1.391

## دراسة تأثير عدم تساوي الفولتيات لمحطات القدرة (المولدات)

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### الملخص

عند ربط مولدين تزامنيين على التوازي يجب ان يكون هناك التزامن بين المولدين لتمام عملية ربط التوازي بين المولدين. ان عدم تساوي الفولتيات الذي هو شرطا من الشروط الاربعة لتحقيق التزامن، ينشأ عن كون احدى المولدات تكون اثارها اعلى او اقل من الحدود المطلوبة لتحقيق تساوي الفولتية لمولدة ما مع المولدة الاخرى. في هذا البحث تمت دراسة و تحليل التزامن الخاطئ الناجم عن عدم تساوي فولتيتي الاطراف للمولدين باستخدام الماتلاب. حيث تم تحليل التزامن الخاطئ بسبب عدم تساوي جهد الاطراف لكليتي المولدين على تيار الملف الساكن، فولتية الاطراف، السرعة الميكانيكية. اضافة الى ذلك، بيان وتحديد نوع العطل (عطل القصر) الناجم عن التزامن الخاطئ بسبب الفولتية

### الكلمات الدالة:

التزامن الخاطئ، مولد تزامني دون الاثارة، مولد تزامني باثارة مفرطة، عطل قصر ثلاثي الطور