Transient Stability of Synchronous Generator in Out of Phase Synchronization

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ABSTRACT

Connecting a synchronous generator to the power system is a dynamic process, requiring the coordinated operation of many components (i.e., electrical, mechanical, and often human). The goal is to connect the spinning generator to the system when the generator matches the system in voltage magnitude, phase angle, and frequency. The failure of the synchronizing procedure results in an out of phase synchronization.

In this paper, this phenomenon has been studied for two different cases. In the first case, the generator voltage leads the network and in the second case, the generator voltage lags. The stability of the synchronous generator has been studied in these two cases. The simulation results show that the first case is very important and can result in the system instability.

I. INTRODUCTION

Electric power systems consist of the interconnection of large numbers of synchronous generators operating in parallel. These generators are connected by transmission lines and supplying the network loads. A disconnected synchronous generator can be paralleled with the network by driving it at synchronous speed and adjusting its field excitation so that its terminal voltage equals to the network bus voltage. The disconnected generator can be paralleled when the two voltages, the generator and the network voltages, are momentarily in phase. In [1], out of phase synchronization of the 3 phase synchronous generator has been studied. Two cases have been considered in [1]. In the first case the generator voltage leads the network voltage and in the second case the generator voltage lags the network voltage. The effect of the out of phase synchronization on the stability of the generator has not been discussed in the former researches. In this paper, it is shown that the synchronism would be lost in the first case of out of phase synchronization.

II. OUT OF PHASE SYNCHRONIZATION

Different causes of the out of phase synchronization have been mentioned in [1-4]. The main causes have been discussed in this section.

FAILURE IN WIRING DURING COMMISIONING OR MAINTAINANCE

The main causes of out-of-phase synchronizing are wiring errors made during commissioning or during maintenance when connecting voltage transformers and synchronizing equipment. These wiring errors lead to particular out-of-phase angles (i.e., multiples of 60º). For example, polarity errors at a voltage transformer can cause synchronizing at 180º.

DELAY DURING BREAKER CLOSURE

If the breaker physically closes slower than anticipated, the systems move outside the designed synchronous conditions before the breaker closes. Once the breaker coil is energized, the close process can not be reversed and out of phase synchronization will happen. Generators, transformers. And associated equipment can be damaged if a breaker closes and connects two systems while they are not synchronous.

FLASH-OVER IN BREAKER'S CONTACTS

Breakers should have the capability of sustaining the voltage that occurs before synchronizing and in the case of inequality of the generator and the network voltage phase. Several causes can reduce the electrical strength of the breaker's insulator and resulting of arcing between contacts before mechanical and galvanic closing. The main causes are listed as follows:

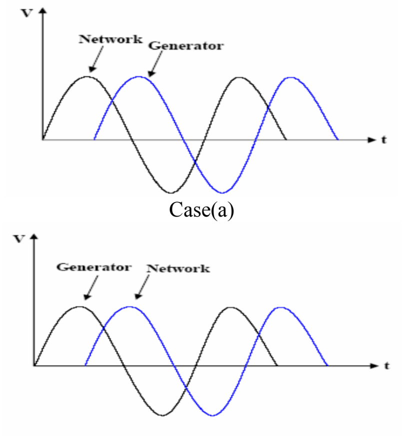
- Internal or external pollution,
- Low pressure dielectric,
- Humidity and
- Decomposition of breaker's insulator

WRONG SETTING OF SYNCHRONIZING SYSTEM

The wrong setting of the synchronizing system which emerges from human mistake, by itself can cause out of phase synchronization.

III. CLASSIFICATION OF OUT OF PHASE SYNCHRONIZATION

When the generator and the network voltages are equal in the sequence, amplitude and frequency but not in the phase, the voltage waveforms are similar to the one of the two cases, shown in Fig.1.



Case(a)

Case(b)

Figure 1. two cases of voltage waveforms during the out of phase synchronization

In case a, the network voltage leads the network voltage, and in case b, the situation is vise versa. In [1], the out of phase synchronization has been simulated for these two cases. The synchronous machine electromagnetic torque in terms of phase difference of the generator and network voltages is shown in Fig.2.

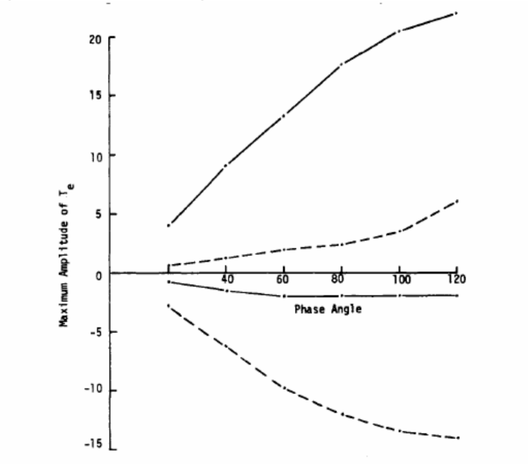


Figure 2. Minimum and maximum of electromagnetic torque during out of phase synchronization
Solid lines: leading generator voltage
Dashed lines: lagging generator voltage

In fig.2, it can be seen that for the phase difference of 40°, the maximum of the electromagnetic torque in the case of leading generator voltage is 10(pu) but in the case of lagging generator voltage is 6.5(pu).

IV. CASE STUDY

The effect of the out of phase synchronization on the stability of the generator has not been studied in [1]. To study the stability of synchronous generator in the two cases, a single machine system shown in Fig.3 is modeled, in this section.

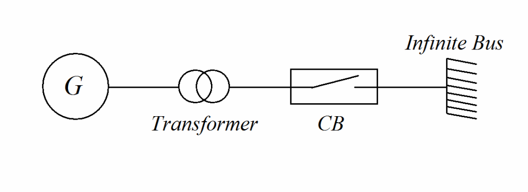


Figure 3. Single line diagram of simulated case

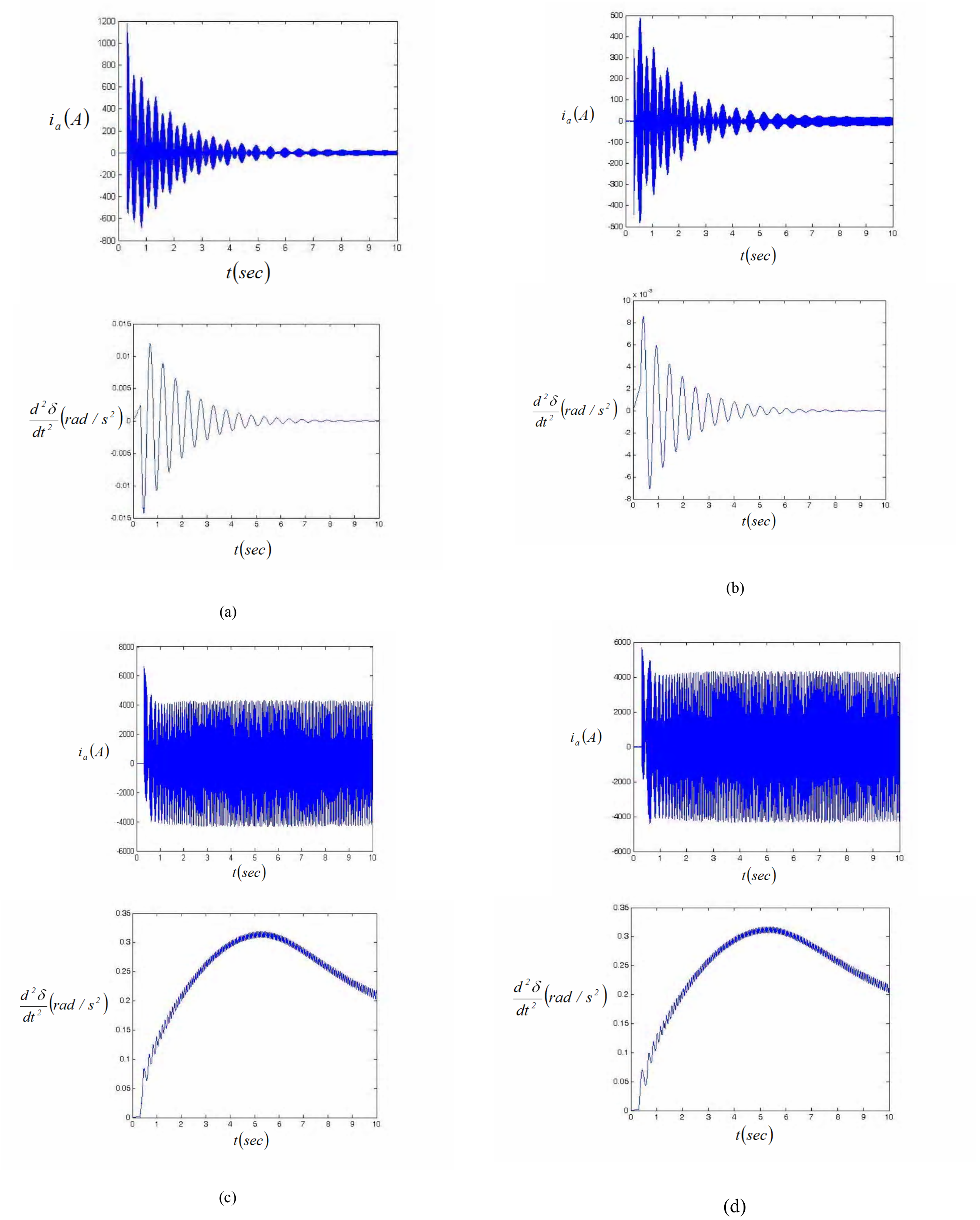
In Fig.3, the synchronous generator of the thermal unit of Neka power plant and Iran's network has been considered. The parameters of the generator, transformer and infinite bus are given in table 1. The simulations carried out by using SIMULINK environment of MATLAB software. In the simulations, the generator is connected to the network at the instant t=0.3s. Phase differences of 80º and 120º have been modeled for the leading and lagging cases. The stator phase current and rotor acceleration have been shown in Fig.4, for different out of phase cases. The network voltage phase has been considered as a reference. As a result, the positive out-of-phase angle means the leading and negative angle means the lagging generator voltage.

TABLE I.
parameters of generator, transformer and infinite bus

Generator
Rotor type: Round
Nom. Power : 517 MVA
L-L volt (Vrms) :21 kv
Freq : 50 Hz
Reactances $([X_d, X'_d, X''_d]_{(pu)})$: *[2.296 , 0.308 , 0.217]*
Time Constants $([T'_d, T''_d, T'_{d_o}, T_a]_{(Sec)})$: *[0.99, 0.018, 7.4 , 0.38]*
Stator Resistance $(Rs_{(pu)})$: 1.267×10^{-3}
Coeff of inertia : 37
Pole pairs : 2

Transformer
Nom. Power : 520 MVA
Freq : 50 Hz
Winding 1 parameters
$V_{1\ ph\text{-}ph}$ (V_{rms}) : *21 kv*
$R_{1\ (pu)}$: *0.0027* $L_{1(pu)}$: *0.08*
Winding 1 (ABC) Connection : Delta (D)
Winding 2 parameters
$V_{2\ ph\text{-}ph}$ (V_{rms}) : *400 kv*
$R_{2\ (pu)}$: *0.0027* $L_{2(pu)}$: *0.08*
Winding 2 (abc) Connection : Y_n

Infinite Bus
L-L volt (V_{rms}) : *400 kv*
Freq : 50 Hz
X/R ratio : inf
3- phase short circuit level at base voltage (VA) : 40000 MVA



(a)

(b)

(c)

(d)

Figure 4. stator phase current (i_a) and rotor acceleration $(\frac{d^2\delta}{dt^2})$, for the phase the lagging generator voltage a) -120° b) -80° c) +120° d) +80°

Considering the simulation results shown in Fig.4, it is obvious that in the two cases of the out phase synchronization, synchronous generator has different behavior. It can be seen that the amplitude of the stator phase current in the case of leading generator voltage is more than the case of lagging generator voltage. But in both cases, the peak values are in the permitted range. The important point about the stator phase current is that in the case of the lagging generator voltage, after closure of breaker at t=0.3s, the amplitude of current increases instantaneously but after this moment, the current decreases gradually and in t=7s, nears to its steady state. The current waveform in this case is like three phase short circuit that is cleared after t=7s. But in the case of leading generator voltage, it can be seen that after instantaneous increment of current at t=0.3s, the amplitude of the current doesn't reach to its steady state condition till the end of the simulation.

In the rotor acceleration curves it can be seen that in the case of lagging generator voltage, rotor acceleration increases instantaneously at the instant t=0.3s and shows an oscillation and finally at t=7s, nears to its steady state. But in the case of leading generator voltage, the first point is that the maximum rotor acceleration in this case is more than the case of lagging generator voltage and the second point is that the rotor acceleration doesn't become zero or generator is unstable. Table (2) shows the comparison results between these two cases for the phase difference of 80 degree.

TABLE II.
comparison between two cases of out of phase synchronization

Phase angle	$\left(\frac{d^2\delta}{dt^2}\right)_{\max}$	$\left(\frac{d^2\delta}{dt^2}\right)_{\min}$	$(i_a)_{\max}$	$(i_a)_{\min}$
80°	0.32 (rad/s^2)	0.2 (rad/s^2)	5900 (A)	4000 (A)
-80°	0.0083 (rad/s^2)	0 (rad/s^2)	500 (A)	40 (A)

V. CONCLUSION

In this paper, the out of phase synchronization has been studied and the stability of the synchronous generator in the two cases of leading and lagging generator voltage has been modelled and discussed. The simulation results have shown that in the case of the lagging generator voltage, generator is stable. But in the case of leading generator voltage, generator is unstable.

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