Performance of three-phase synchronous generatorin parallel operation using PSim Software

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Abstract: A three-phase synchronous generator is an electrical machine that it converts the mechanical energy to be an electrical energy. The three-phase synchronous generator operates to supply the load according to its maximum capacity. A parallel operation of two or more three-phase synchronous generators is needed to share the load. The parallel requirements of two three-phase synchronous generator should be fulfilled to achieve the good operation condition. This paper presents a method to operate two three-phase synchronous generator using PSim software. The initial condition, the first synchronous generator operates to serve the load and the second synchronous generator operates for the time of 0.1 s after the initial operation of the first synchronous generator. A parallel switching for the both three-phase synchronous generators is constructed by the elements of elements of 3-ph-Bi-directional switch, On-Off Controller, NOT gate and square generator in PSim software. The results show that the proposed parallel method of two three-phase synchronous generators can operate to share the load.

Keywords: Synchronous generator, Parallel operation, PSim software.

1. Introduction

The three-phase synchronous generator consists of rotor and stator. The rotor and stator have slots to put the rotor and stator winding. The rotor winding is connected to the DC voltage source that it can come from a DC generator coupled to the rotor of synchronous generator or it can come from a separated DC voltage source. The rotor is moved by a prime over, thus a rotating magnetic occurs on the rotor and arrives the stator winding of the synchronous generator and generates the induced voltage on the stator [1].

Some requirements should be fulfilled for parallel operation of two three-phase synchronous generator [1]:

1. The root mean square (rms) value of the two three-phase synchronous generators should be same.
2. The two three-phase synchronous generators have a same phase sequence.
3. The phase angle values of the two three-phase synchronous generators should be same.
4. The frequency of the second three-phase synchronous generator is slightly higher than the first three-phase synchronous generator.

A parallel concept of inverter and synchronous generator is constructed and analyzed by [2] using Matlab software. The rotor of synchronous generator is moved by the micro-hydro water turbine. The principle of virtual machine control and drop control are proposed to analyzed the voltage stability based on the small signal system. The result show that the virtual machine control in the parallel operation of the synchronous generator and inverter operates in a strong device and it can damp the oscillation of voltage system [2].

A parallel condition of synchronous generators in University of Gujrat (UOG) is explained by [3]. The fifteen synchronous generators connected to the transformators operate in interconnection operation system and they are simulated using ETAP software. Load flow and economical aspect in term of payback period are analyzed in the simulation.

The micro-hydro synchronous generator and thermal synchronous generator are operated parallel using Matlab software by [4]. It discussed the parallel operation and stability control, and also controlled voltage and frequency for the various load. The result shows that the parallel systems of the both synchronous generators are in the stable operation for the voltage and frequency in the various loads.

2. Methodology

2.1 Data and Three-Phase Synchronous Generators Before Parallel Operation Condition

Two three-phase synchronous generators with their data sheet as shown in Table 1 are operated by two three-phase induction motors with their data sheet as shown in Table 2. The first synchronous generator, SG1 operates under RL load condition (R= 30 Ω and L= 230 mH), the second synchronous generator, SG2 operates for the time of 0.1 s after the initial operation time of the first synchronous generator, SG1 as shown in Figure 1. Both synchronous generators, SG1 and SG2 have frequency of 51.0 Hz.

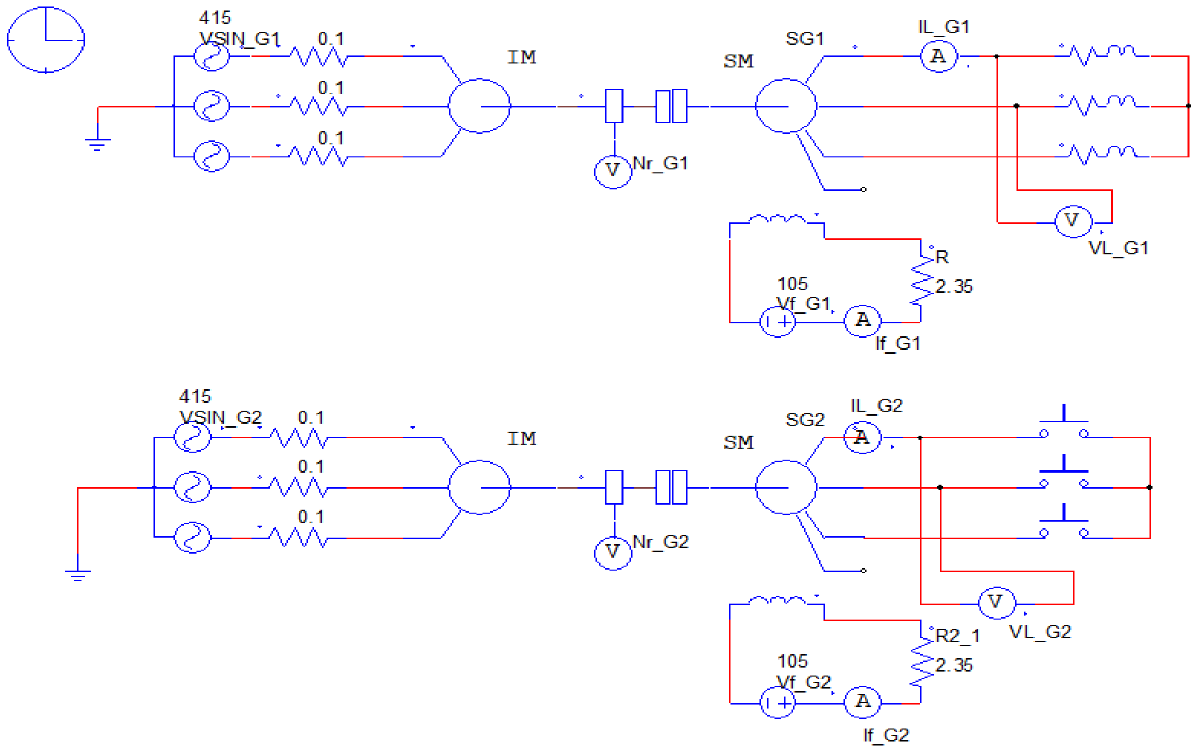


Figure 1: Two three-phase synchronous generators before parallel operation condition

Table 1: Parameters of three-phase synchronous generator

Electrical Parameters	Value
Stator resistance (Ω)	0.1
Stator inductance (H)	0.00079
d-axis magnetic inductance (H)	0.0041
q-axis magnetic inductance (H)	0.002
Field resistance (Ω)	0.016
Field leakage inductance (H)	0.00037
d-axis damping cage resistance (Ω)	0.17
d-axis damping cage inductance (H)	0.00028
q-axis damping cage resistance (Ω)	0.17
q-axis damping cage inductance (H)	0.00091
Number of pole	4

Table 2: Parameters of three-phase induction motor

Electrical Parameters	Value
Stator resistance (Ω)	0.294
Stator inductance (H)	0.000139
Rotor resistance (Ω)	0.156
Rotor inductance (H)	0.00074
Magnetizing inductance (H)	0.041
Moment of inertia	0.4
Number of pole	4

A design of switching for the second synchronous generator is constructed by 3-ph-Bi-directional switch, On-Off Controller, NOT gate and square generator to be able it operates for the time of 0.1 s after the initial operation time of the first synchronous generator, SG1. Their functions or operation principles are stated below

a. Square generator. It has function to generate a pulse wave which switches ON the 3-ph-Bi-directional switch. Its initial condition is ON or high value until duty cycle is given to it. It is due to the square generator generates a square wave, it means that it has period, *T*, frequency, *f* and duty cycle as illustrated in Figure 2.

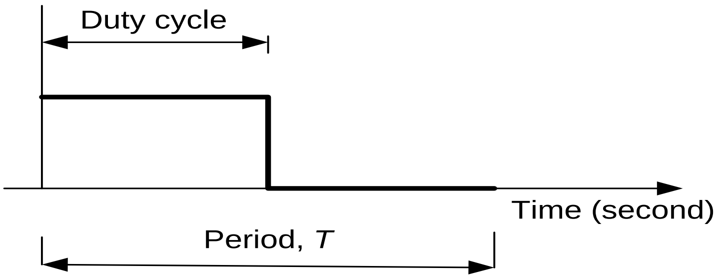


Figure 2: Square wave implemented in the parallel connection

It is due to the simulation has total time of 5 s, thus the period, *T* of pulse wave is 5 s or its frequency, *f* of 0.2 Hz.

It is due to the time of 0.1 s is suitable to operate the second synchronous generators, SG2, thus the duty cycle of square wave is 0.1/5 = 0.02.

These data obtained are filled in the parameters of square generator as shown in Figure 3.

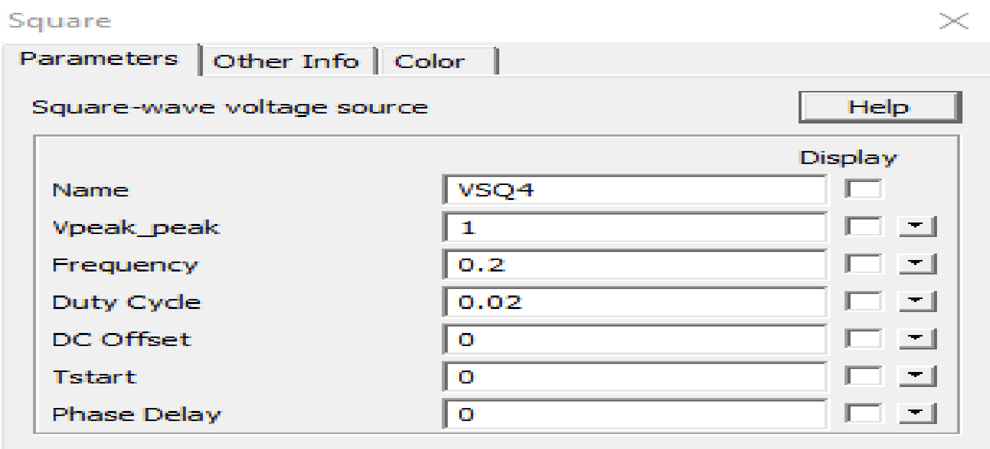


Figure 3. Parameters of square generator

b. NOT gate, it has function to convert the signal (pulse wave) generated by the square generator. It is needed causes the initial condition of 3-ph-Bi-directional switch should be OFF, while the initial condition of square generator is ON. Thus, the signal of square generator should be converted by NOT gate. It means that the 3-ph-Bi-directional switch is not driven to close.

c. On-Off Controller, it has function to control the On-Off condition of the 3-ph-Bi-directional switch following the input signal of On-Off Controller.

d. 3-ph-Bi-directional switch, it has function to switch On the parallel connection of both synchronous generators. The 3-ph-Bi-directional switch is Off in the initial condition after the time of 0.1 s is reached, thus it is driven by a signal from the square generator to close it. Thus, the second synchronous generators operate for the starting time of 0.1 s.

e. The connection of switch to operate the second synchronous generator is shown in Figure 4.

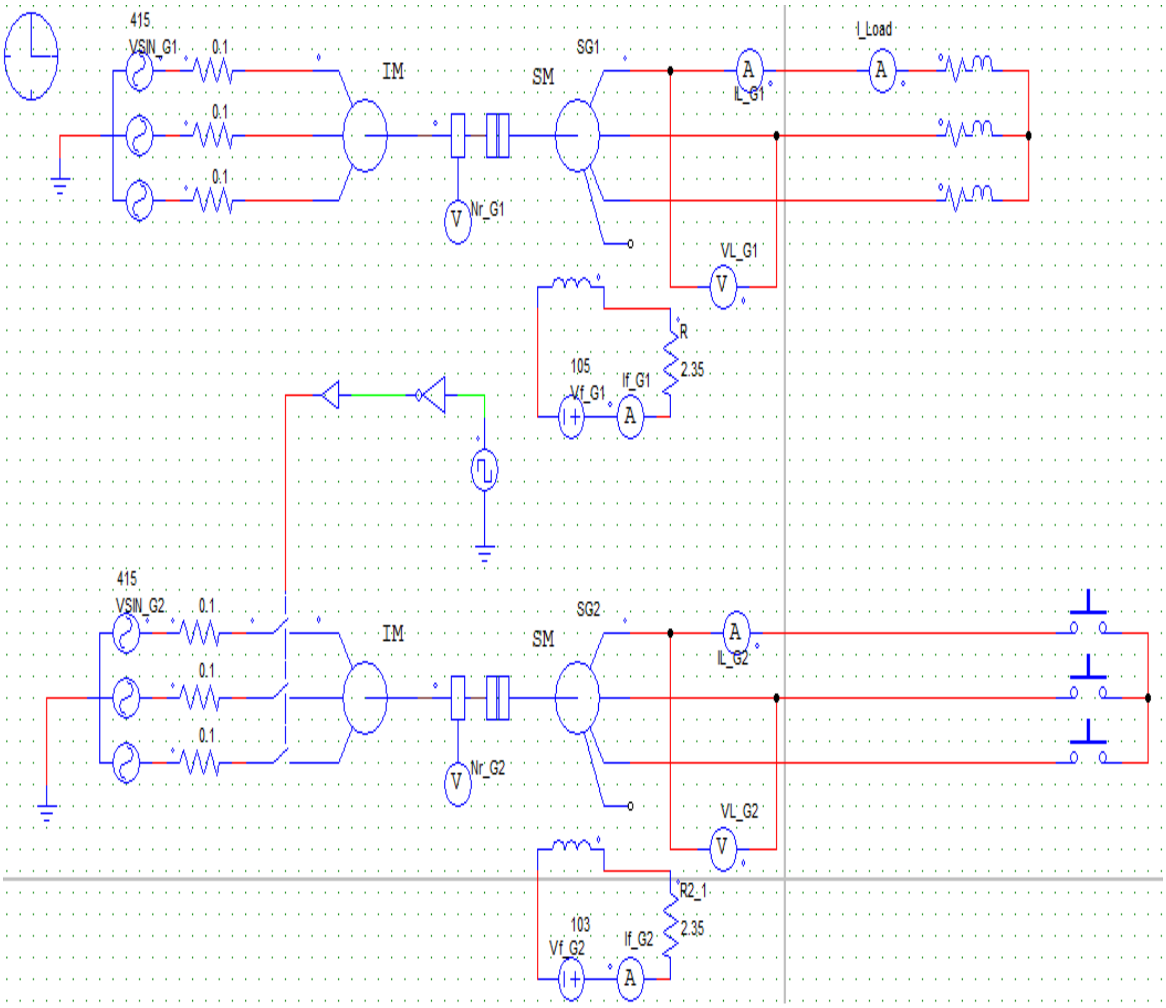


Figure 4. Parameters of square generator

2.2 Design of Two Three-Phase Synchronous Generators in Parallel Operation Condition

A design of two three-phase synchronous generators in parallel operation condition is based on the line voltage of the both synchronous generators as in Figure 5 that it still refers to Figure 4.

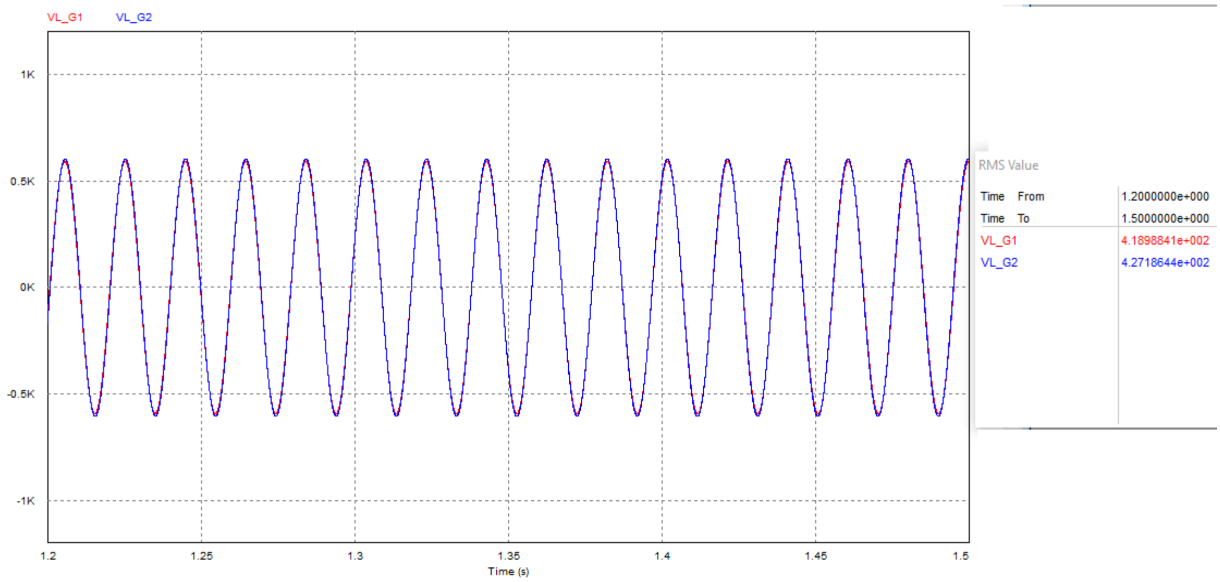


Figure 5: Line voltage waveform of the three-phase synchronous generators

The conditions should be fulfilled for paralleling the two three-phase synchronous generators based on Figure 5 as stated below:

a. The rms line voltage of the two generators should be same.
Figure 5 shows that the synchronous generator, SG1 and SG2 have rms line voltages of 419 V and 427 V, respectively. Both rms line voltages are not same, thus one of the rms line voltages should be equaled to the other.

b. In this case, the rms line voltage of synchronous generator, SG2 should be decreased in to around 419 V by decreasing the filed current, I_f through the decreasing of field voltage, V_f.

c. For V_f = 103 V, the field current, I_f of 25.6 A flows through the field winding of synchronous generator, SG1and generates the rms line voltage of 419 V as shown in Figure 6.

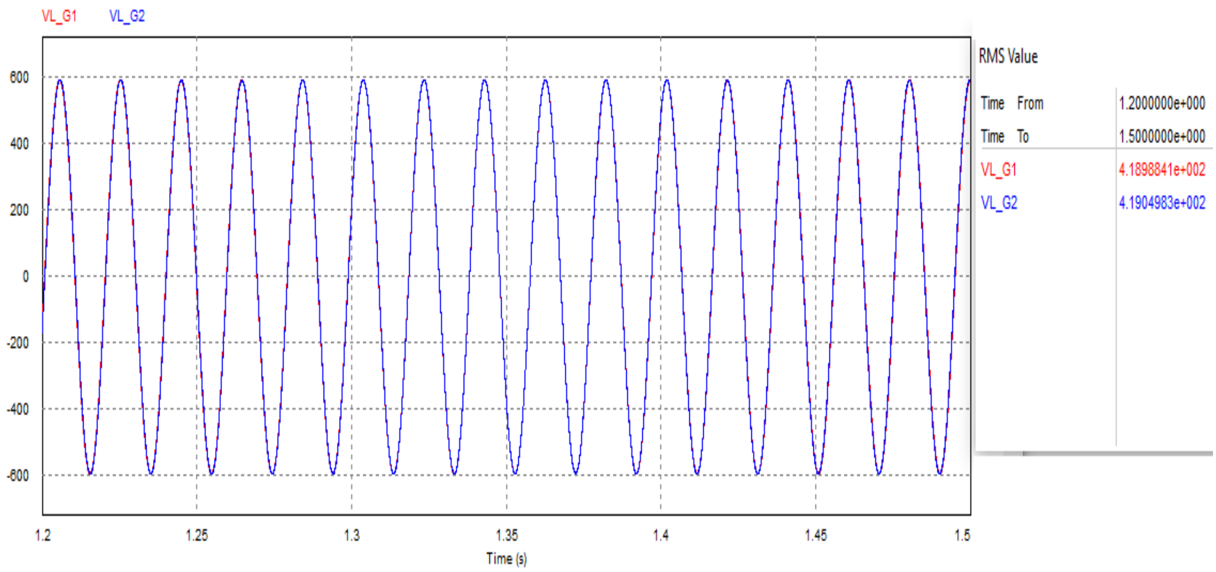


Figure 6: Line voltage waveform of two three-phase synchronous generators with same rms values

The design of parallel connection of the two synchronous generators is shown in Figure 7. They are connected at the time of 1.36 s based on Figure 6, it is due they are started in phase for one cycle. And it is due to that the simulation total time of 5 s, thus the parameters of square generator are set for the frequency of 0.2 and duty cycle of 0.272.

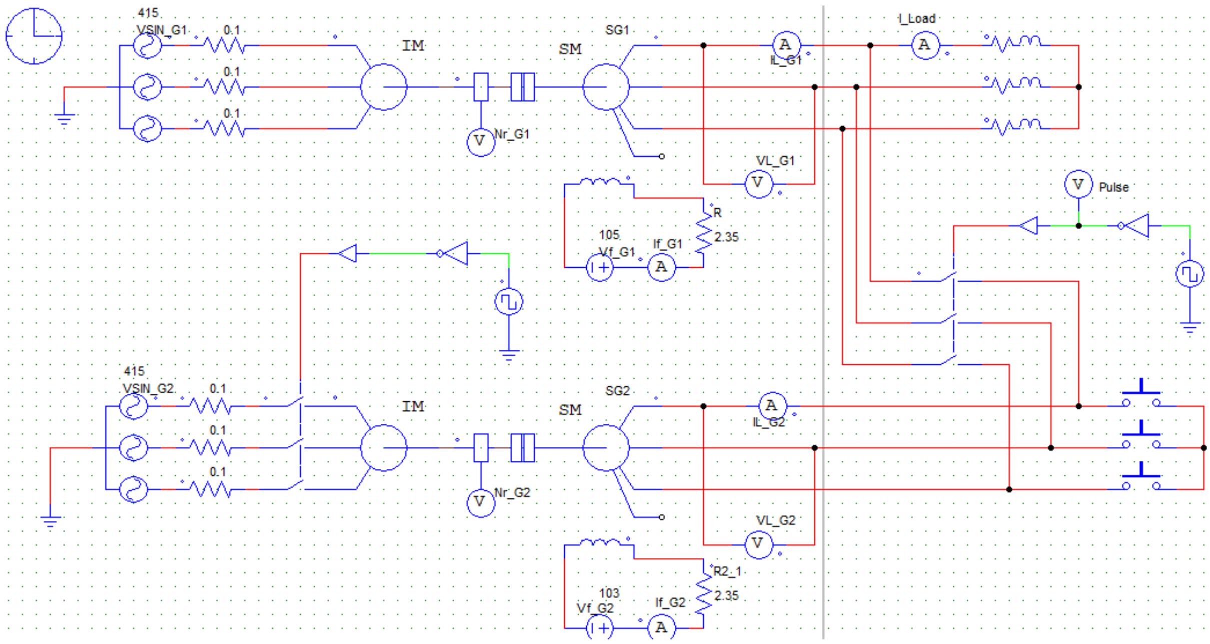


Figure 7: Design of parallel connection of the two synchronous generators

3. Results and Discussion

The line current waveform of both synchronous generators and load before and after paralleling conditionare shown in Figure 8.

Before paralleling time:

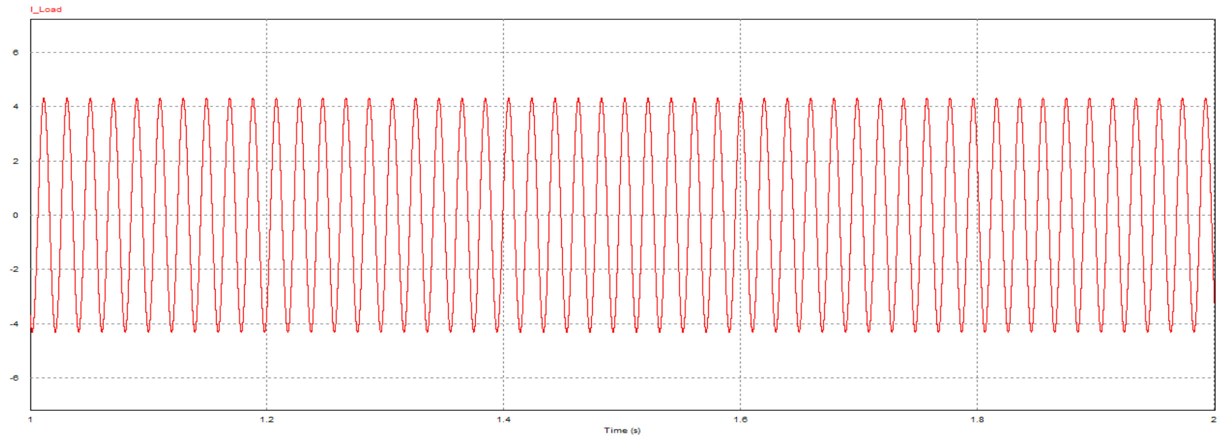
The RL load drags a rms current of 3.05 A. It is dragged totally from the synchronous generator, SG1. It means that the load current equals to the line current of synchronous generator, SG1. It is due to there is no current is supplied from the synchronous generator, SG2 (the synchronous generator, SG2 has not connected to the synchronous generator, SG1 and load).

On paralleling time:

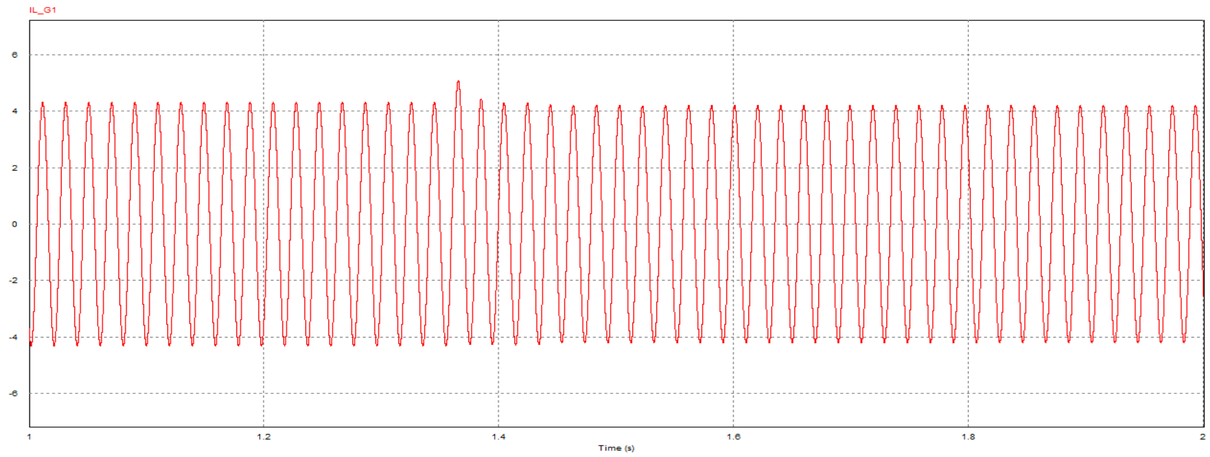
The transient currents occur on the synchronous generator, SG1 and SG2. It is due to the effect of switching process of parallel connection. The current will reach back their steady state in some milli seconds as the capability of field current that injected to the field winding of generator.

After paralleling time:

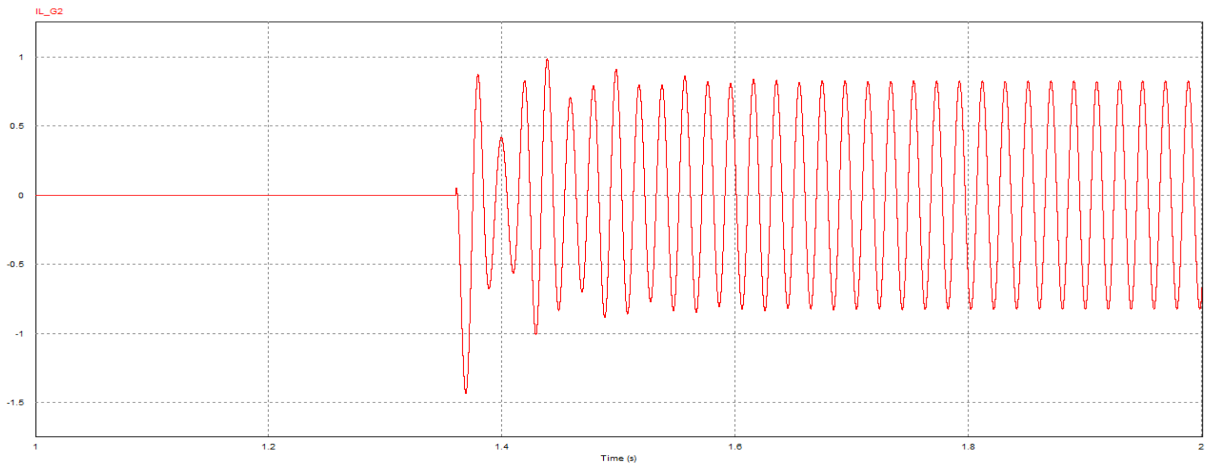
The load is supplied by both synchronous generators, SG1 and SG2, thus the rms load current is summation of the rms line current of synchronous generator, SG1 and SG2.



(a) Load current waveform



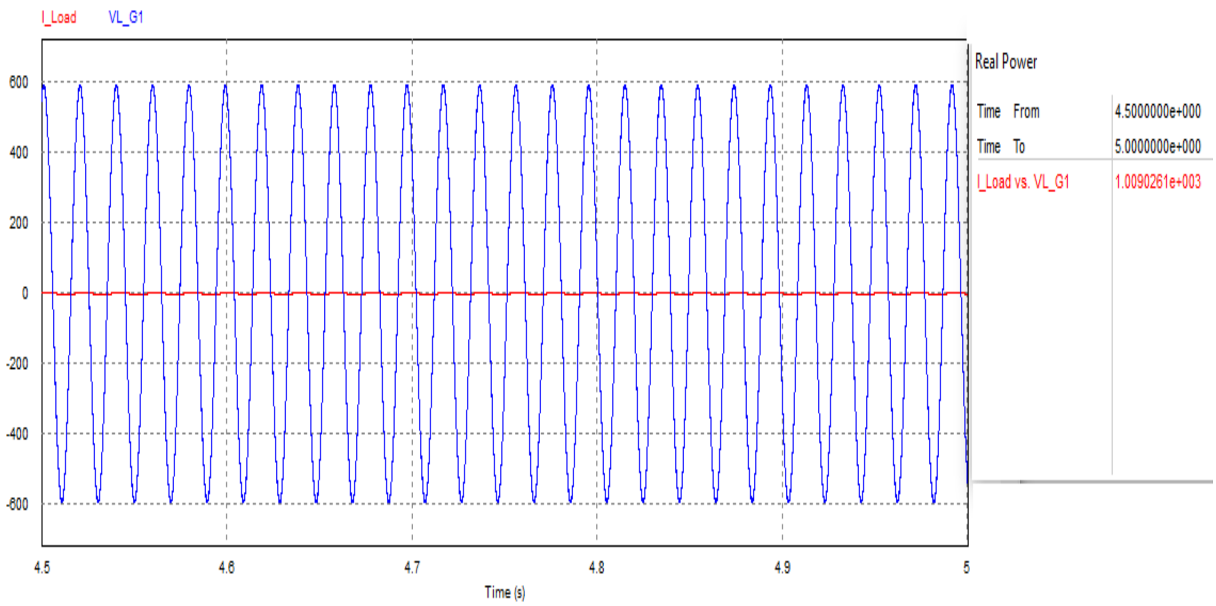
(b) Line current waveform of synchronous generator, SG1



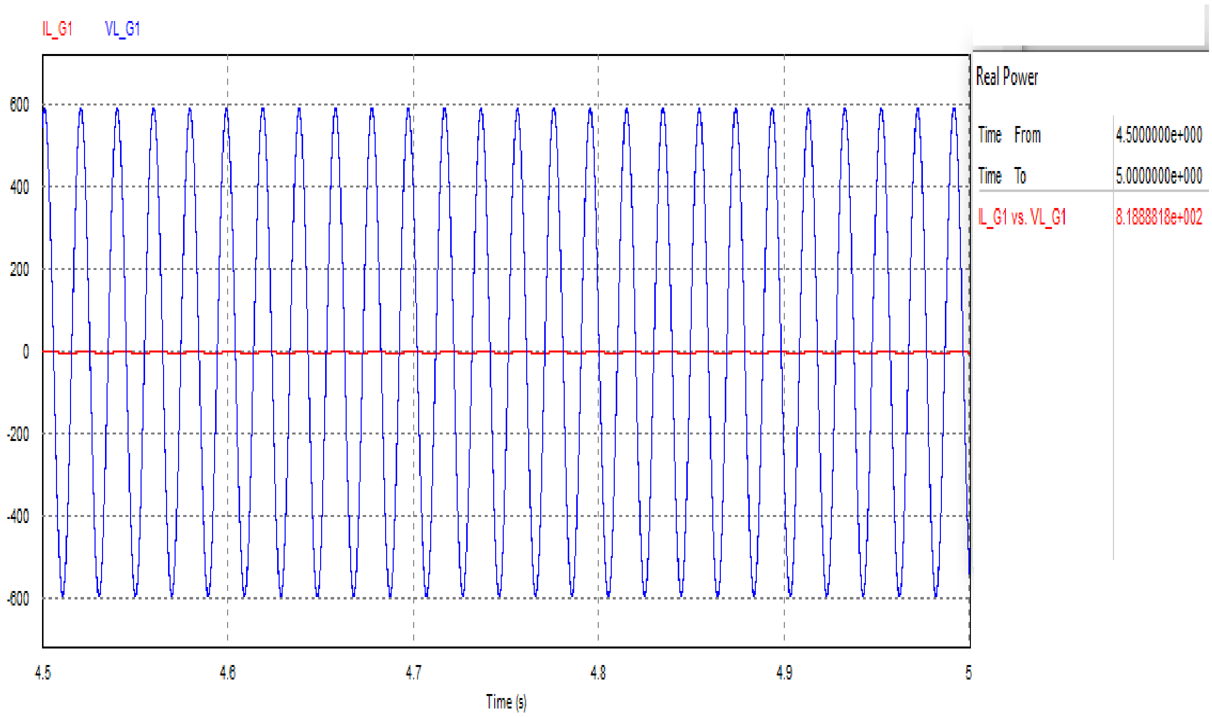
(c) Line current waveform of synchronous generator, SG2

Figure 8: Line current waveform of both synchronous generators and load before and after parallel condition

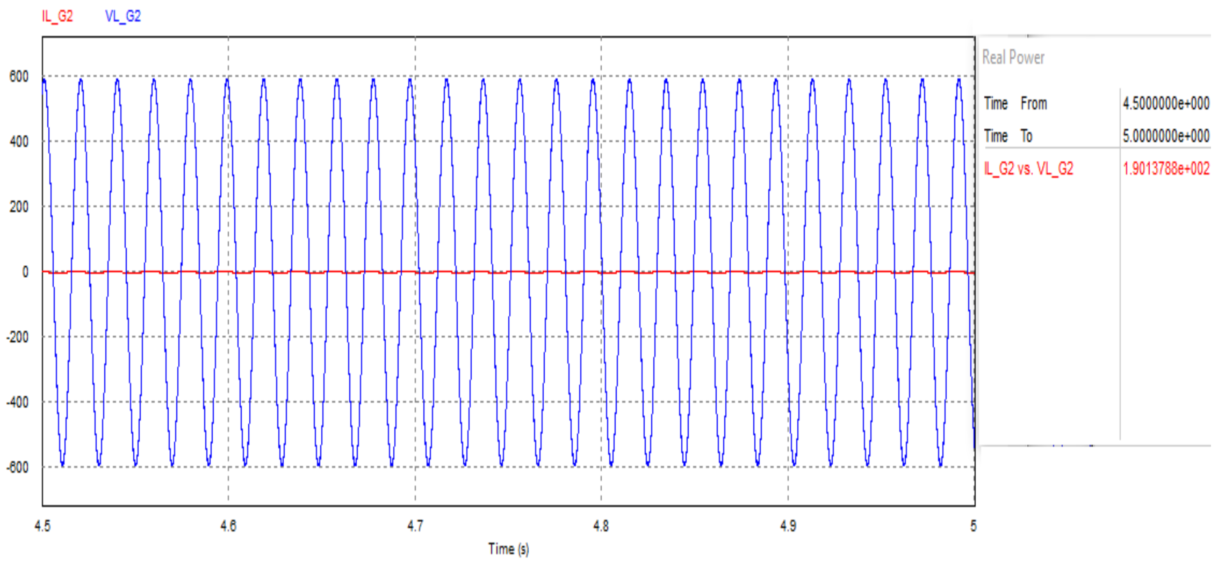
The current and voltage waveform of both synchronous generators and load after paralleling condition for the time of 4.5 to 5 s and their real power are shown in Figure 9. The load real power of 1009 W is supplied by the real power of 819 W and 190 W from the synchronous generator, SG1 and SG2, respectively. It shows that the load real power as the summation of real power of the synchronous generator, SG1 and SG2 after parallel connection condition.



(a) Load



(b) Synchronous generator, SG1



(c) Synchronous generator, SG2

Figure 9: Current waveform, voltage waveform and real power

4. Conclusion

The two or more three-phase synchronous generators can be simulated for the parallel operation condition. The elements of 3-ph-Bi-directional switch, On-Off Controller, NOT gate and square generator in PSim can be applied for parallel switching. The parallel condition should be fulfilled for the requirement of parallel of two three-phase synchronous generators.

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