# Integration of IEEE 14 Bus with Solar PV and VSG Systems

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## ABSTRACT

*In this research paper IEEE 14 Bus system is connected with SPV (Solar Photovoltaic) for utilization of renewable energy. This interconnection is evaluated during fault condition. Bus number 2 of IEEE 14 bus system is additionally connected with SPV and Salient pole synchronous generator because remaining buses are synchronous condensers and slack bus, thus bus 2 only modifiable. IEEE 14 bus system has three synchronous condensers which required maintaining power factor in the system. The power capacity of salient pole generator and SPV are same. Due to SPV integration on IEEE 14 bus system, total rotational inertia on bus 2 is reduced. Thus during fault condition near bus 2, all output parameters of generator are scared. By the interconnection of VSG (Virtual Synchronous Generator) on the same bus, it is possible to reduce the disturbance on the generator. Moreover, passive filters are used in VSG for harmonic reduction purpose.*

**Keyword**: - *Standard Bus system, Solar generation, Synchronous generator, Fixed Bus, Virtual generator.*

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## 1. INTRODUCTION

Now-a-days electrical power quality is playing very important role in whole power system. To sustain power quality, advanced power electronics and electrical devices are being used. This research paper considers standard IEEE 14 bus system with AC three phase with 60Hz system frequency and 138KV bus voltage.

Basic function of SPV is to generate electrical power with the help of uneven solar irradiation and temperature. When solar irradiations fall on the PV cell, they generate DC power which converts into AC power through the help of 3 phase inverter and filter circuit [1]. This AC power is utilized by the connected fixed or variable load [2]. If load is not connected with SPV then its DC power need to be stored by the assist of battery [3]. Let's observe below block diagram of SPV system without battery unit.

In this system MPPT is used for maximum power point tracking from PV array where incremental conductance type algorithm is used in MPPT. There are two technique are used for MPPT, like perturbation and observation (P&O) and incremental conductance (IncCond) [3][4][5].

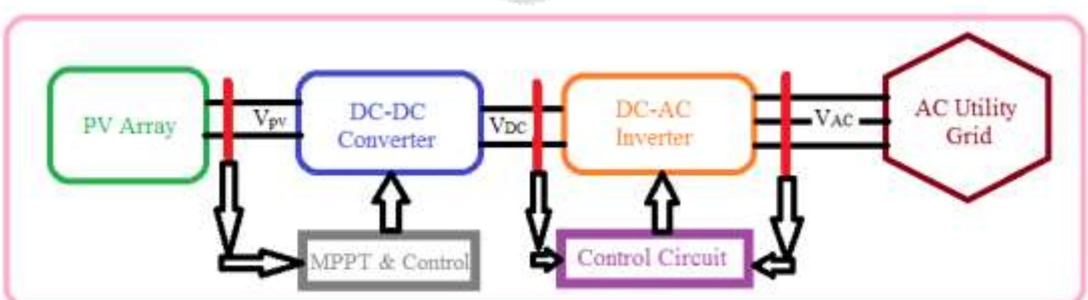



**Fig - 1**: Block diagram of SPV System [4]

To stabilize the power system within the limits can be made possible by providing additional virtual rotational inertia. [6] This can be done by the assist of VSG. The VSG consists of Energy Storage System (ESS), Inverter, Filter and a Control mechanism as shown in below figure.

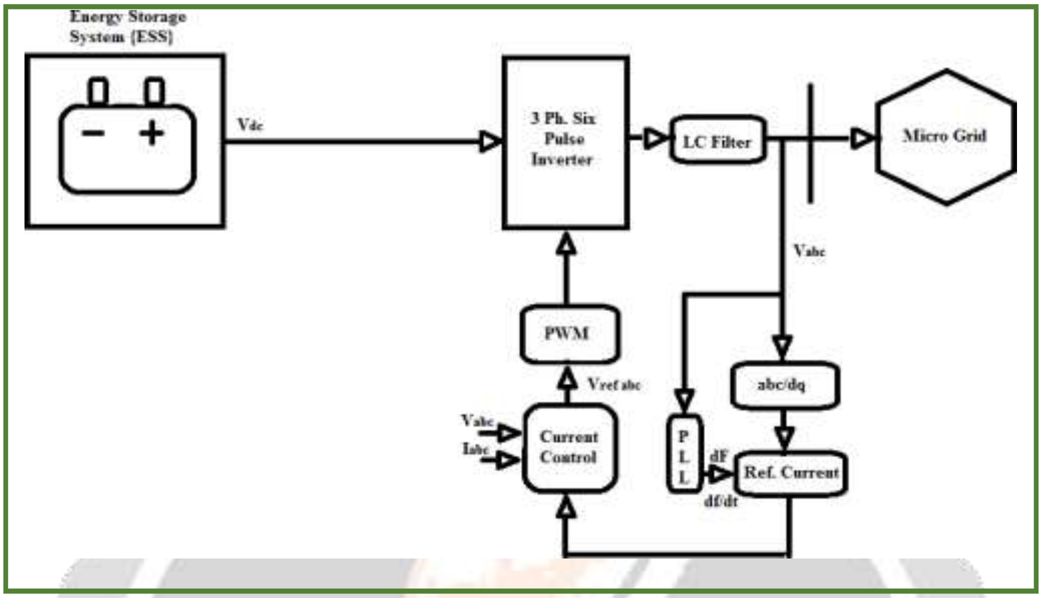



**Fig - 2**: Block diagram of VSG system [7]

Most normally, Li-Ion battery is used as an ESS and 3 phase six pulse voltage source inverter is used as a DC to AC inverter. To reduce harmonic distortion, LC filter system is used along with inverter circuit [8].

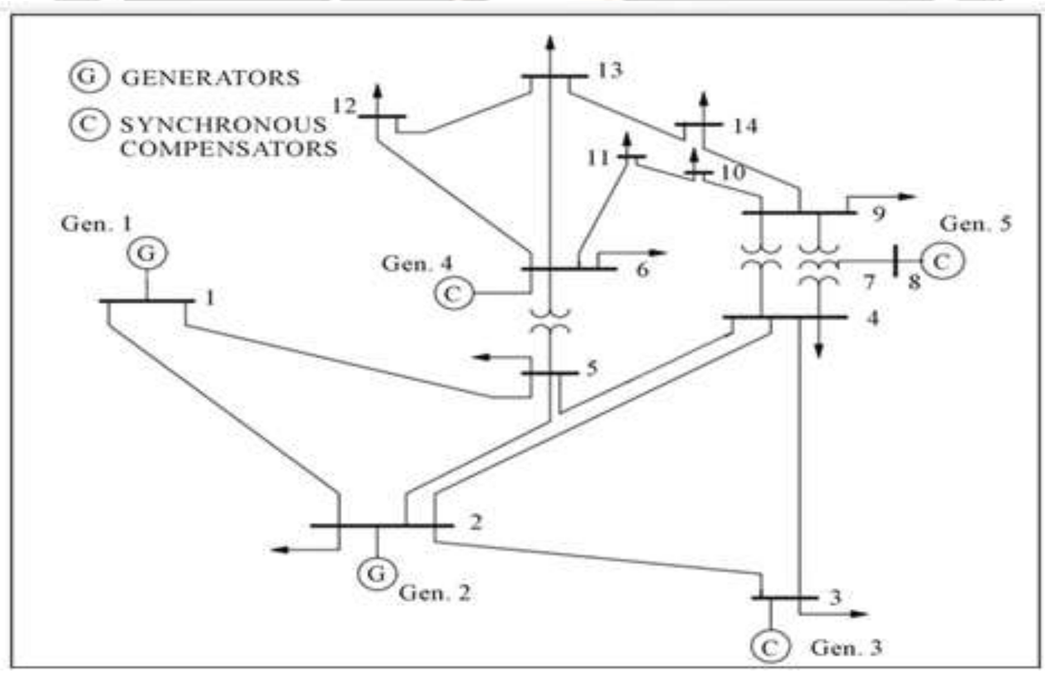



**Fig - 3**: IEEE 14 Bus system [9] [10]

IEEE 14 bus system includes 1 slack bus, 5 generators, 11 constant impedance loads, 8 transformers and 17 transmission lines [9]. This system also includes 4 numbers of PV bus, 9 numbers of PQ bus and 1 Slack bus and consider each transmission line is 100 km long [9][10].

## 2. PROPOSED SYSTEM

**2.1 Basic Information**

In this proposed system, initially we consider IEEE 14 Bus system with modification on bus number 2. On the bus 2, conventional generator 2 is replaced by salient pole synchronous generator of 20 MVA capacities. Moreover SPV unit of 20 MW capacities and VSG unit of 6 MW capacities are added on the same bus.

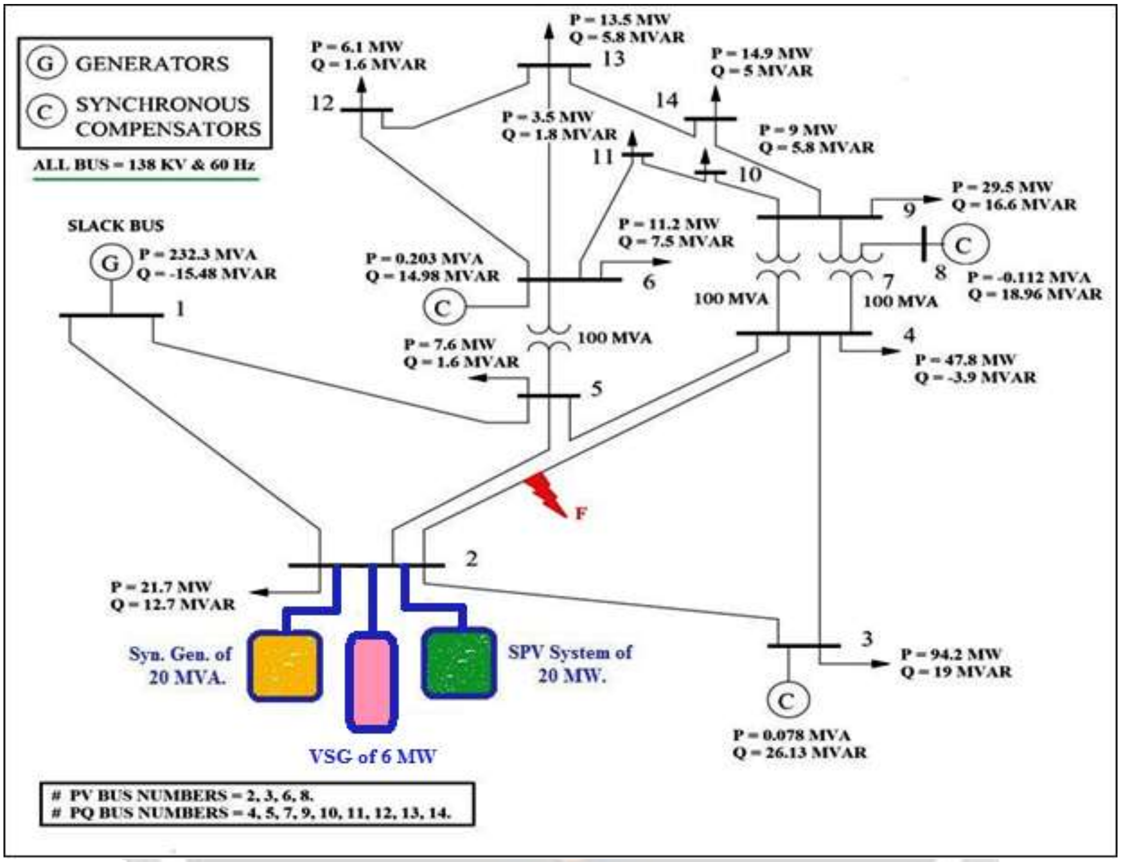



**Fig - 4**: Modified IEEE 14 bus system

In above modified system, Salient pole synchronous generator with 22 poles and 327 rpm is used. In this case SPV unit include PV array, MPPT, DC to DC converter, 3 phase DC to AC Inverter along with filter circuit to reduce harmonic distortion. For VSG unit Li-Ion battery is used as an ESS and DC to AC Inverter along with LC filter circuit is used as an Inverter unit.

When single line to ground fault occurs between lines 2 to 4, then all parameters of synchronous generator vary and system becomes unstable for short time [11]. In this situation VSG helps to maintain stability of the system and it depends on power capacity of VSG. On the other side when output of SPV is uneven (due to unequal input of solar irradiation) then VSG unit helps to provide some of the required power to maintain the load.

**2.2 PSCAD Simulation of Proposed System**

In this simulation IEEE 14 bus system is modified at bus number 2. At bus 2, salient pole synchronous generator is added and conventional generator is removed. Fixed load remains same at bus 2. Moreover, SVP and VSG units are installed on the same bus. Total generating capacity at bus 2 is near to 46 MW. Out of that, 20 MW is for SPV, 20 MVA is for salient pole synchronous and 6 MW for VSG unit. Let's see simulation for proposed system as below figure,

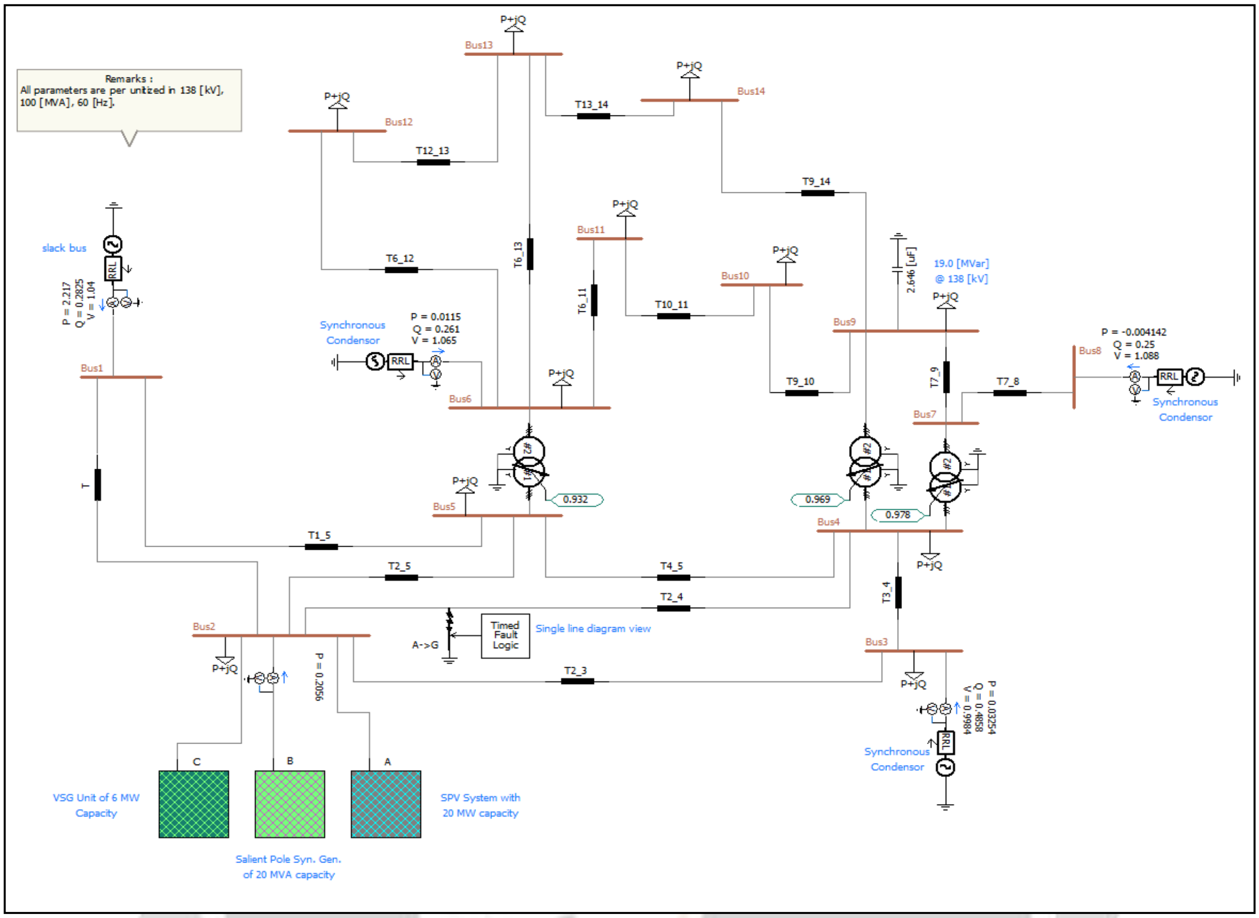



**Fig - 5**: Simulation Modified IEEE 14 bus system

As per above figure, bus 2 is customized by the help of Generator, SPV and VSG unit. In this case single line to ground fault occurs between line 2 to 4 for 0.2 second duration and fault timing is 1.5 second. Due to L-G fault, all parameters on bus 2 are scared and system becomes unstable for short time duration, following which system becomes stable again [12] [13]. In this case VSG helps to provide additional rotational inertia which facilitates to improve the system stability [14].

### 2.3 PSCAD Simulation Results & Discussion of Proposed System

As per above proposed simulation (Figure 5), output waveforms of synchronous generator and SPV are disturbed during fault time. After the fault clearance, system becomes stable again and by adding VSG, system becomes stable with relatively less time which can be sharply understood by following waveforms,

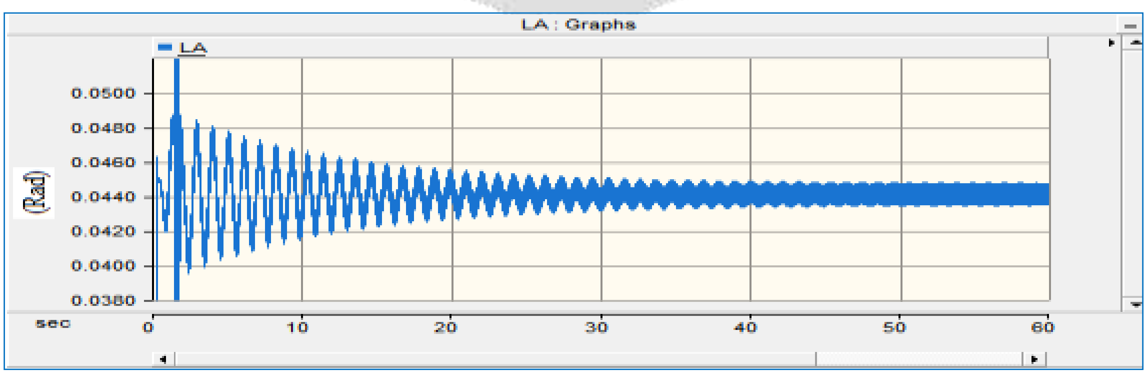



**Fig - 6**: Load angle of Syn. Gen. on bus 2 during fault (Without VSG)

Above graph is showing the performance of LA for 2nd generator at fault time and due to absent of Virtual generator total inertia is low. Thus LA is unstable.

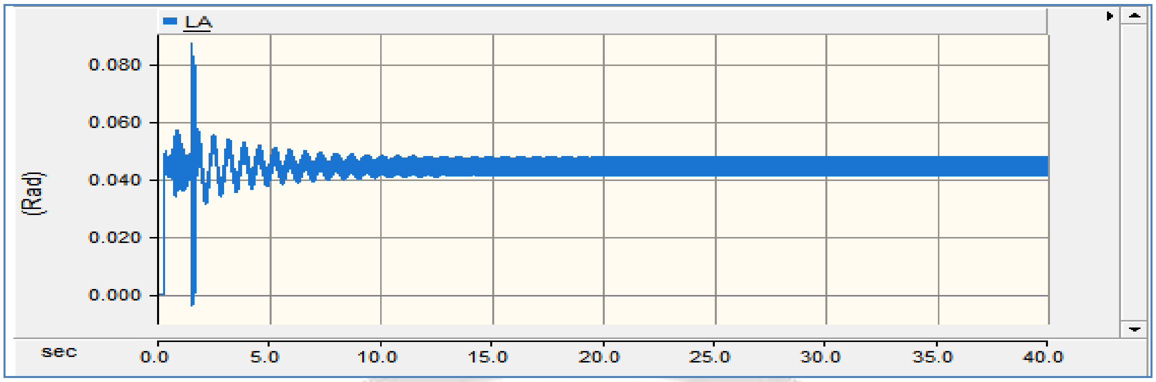



**Fig - 7**: Load angle of Syn. Gen. on bus 2 during fault (with VSG)

Above graph is showing the performance of LA for 2nd generator at fault time and due to present of Virtual generator total inertia is increased. Thus LA goes stable.

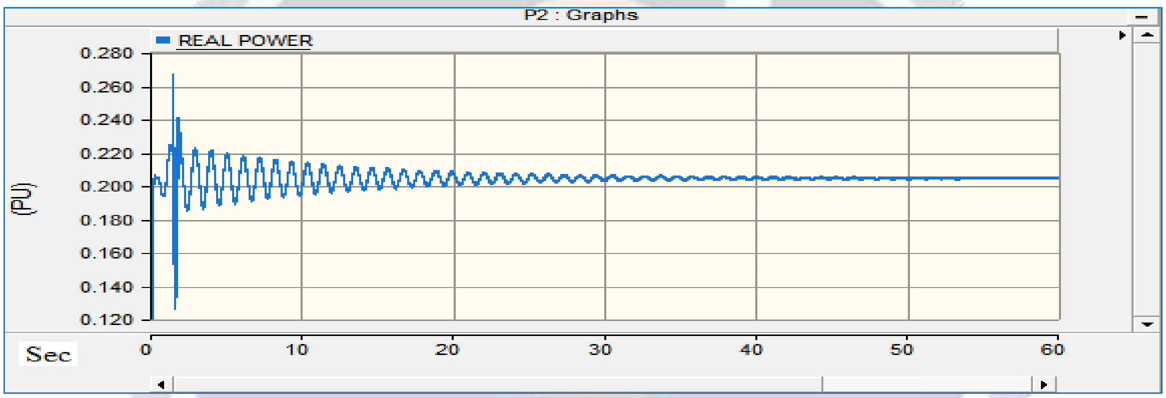



**Fig - 8**: Real Power of Syn. Gen. on bus 2 during fault (Without VSG)

In this graph real power of 2nd generator becomes unstable for long time during fault condition due to absent of VSG.

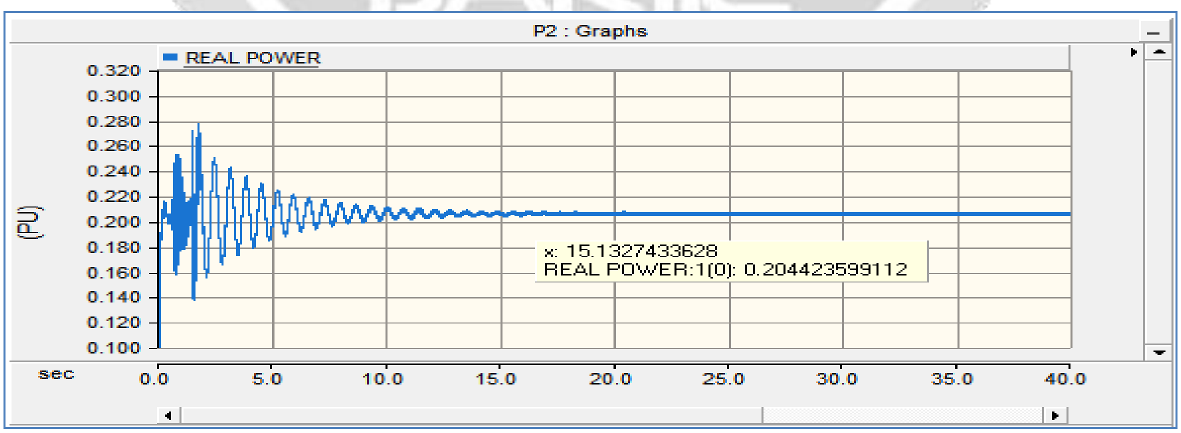



**Fig - 9**: Real Power of Syn. Gen. on bus 2 during fault (with VSG)

In this graph real power of 2nd generator becomes stable after short time during fault condition due to present of VSG.

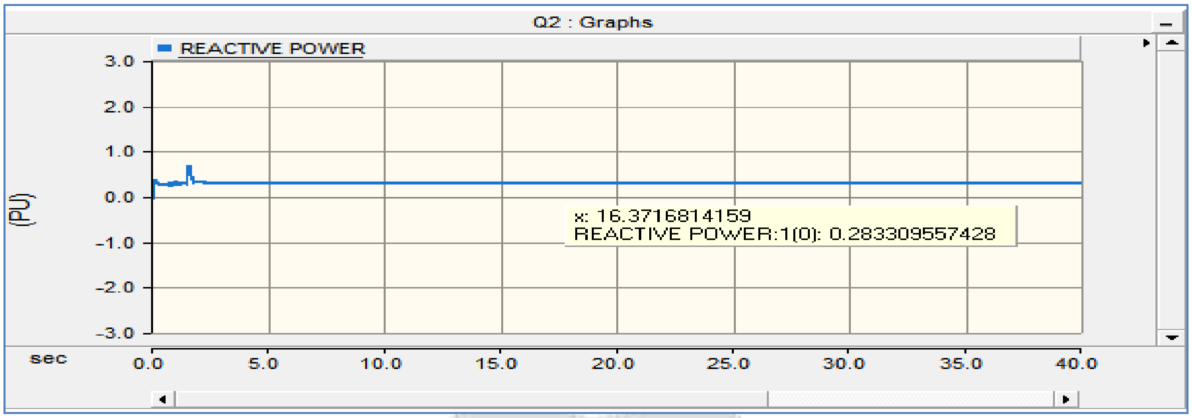



**Fig - 10**: Reactive Power of Syn. Gen. on bus 2 during fault

This graph shows the performance of reactive power of generator 2 during fault time and it is stay stable because of stable voltage.

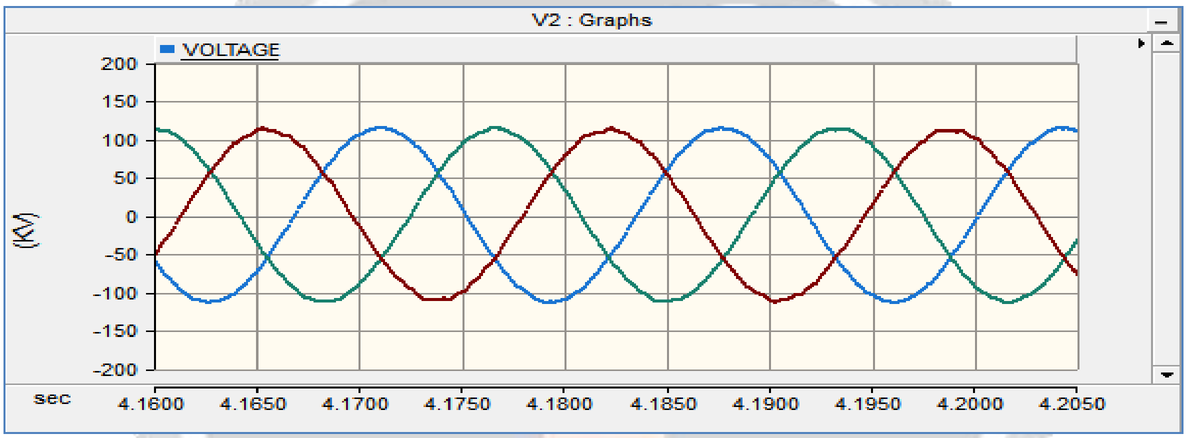



**Fig - 11**: Voltage of Syn. Gen. on bus 2

The output of 3 phase voltage on bus 2 is not disturbed due to installation of filter unit. Thus shape & magnitude of waveform shows unaffected.

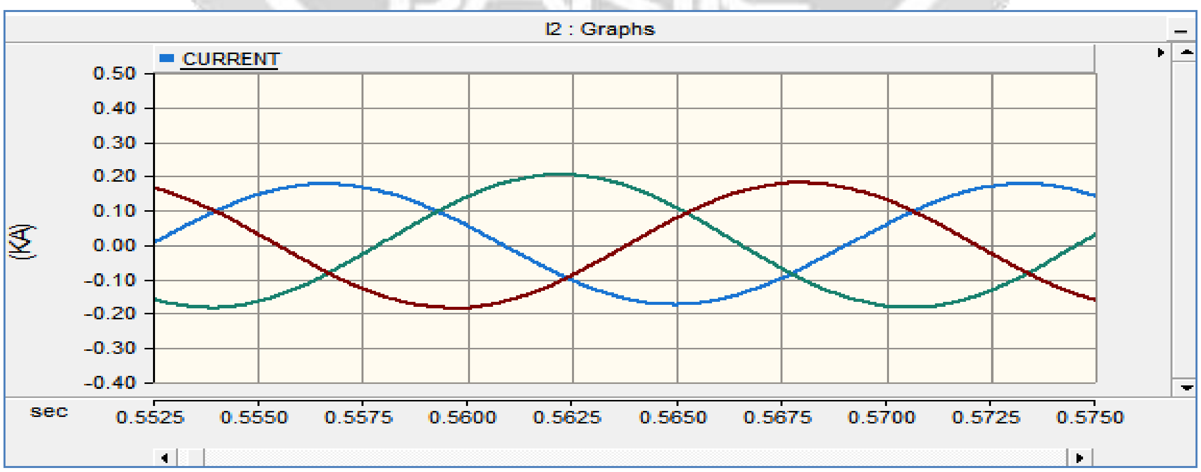



**Fig - 12**: Current of Syn. Gen. on bus 2

Due to fixed load, the output of current is also not distressed as in shown above figure.

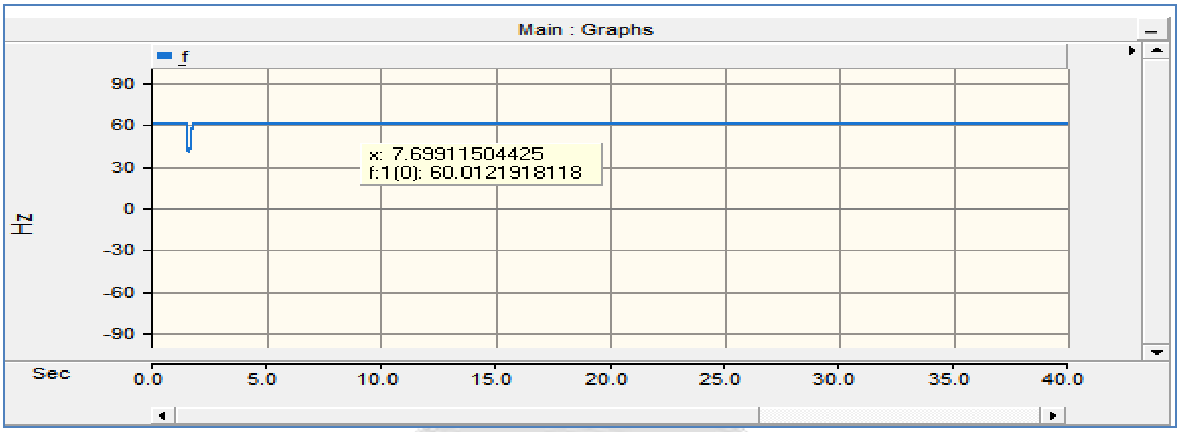



**Fig - 13**: Frequency of Syn. Gen. on bus 2 during fault

The bus frequency goes deep during fault time only, like 0.2 seconds after becomes stable due to closed loops feedback system in SPV.

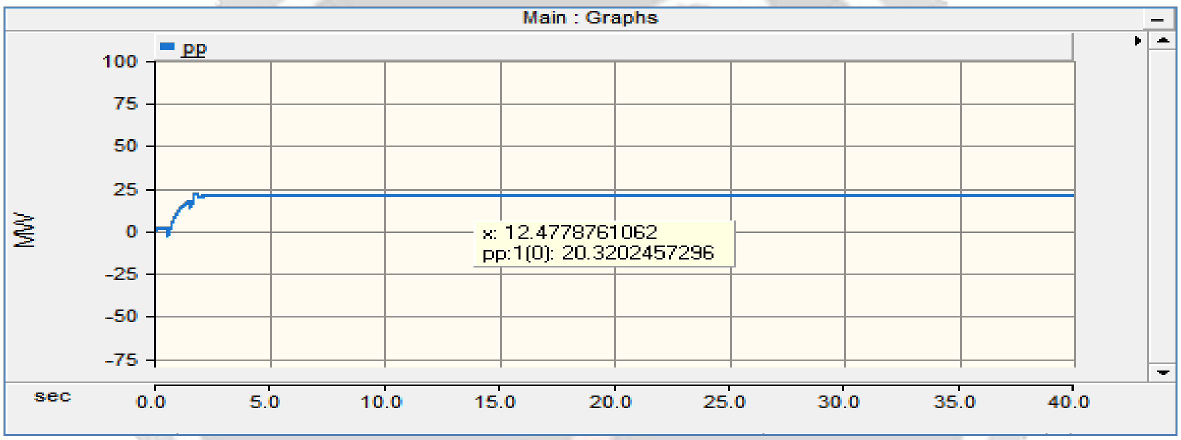



**Fig - 14**: Real Power of SPV on bus 2 during fault

As per above result, the Real power of solar unit is constant after the clearance of fault. In this case the load is constant and the input of SPV also assuming constant with 1000 w/m$^2$ irradiation and 25 degree centigrade temperature. When input of SPV will fluctuate same way output will also vary but by modifying the inverter parameter, this problem can resolve.

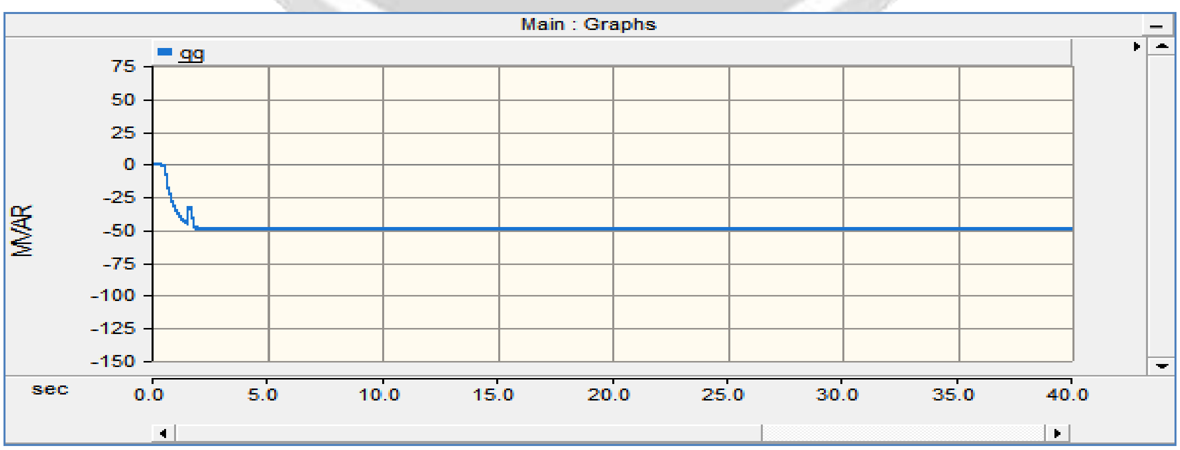
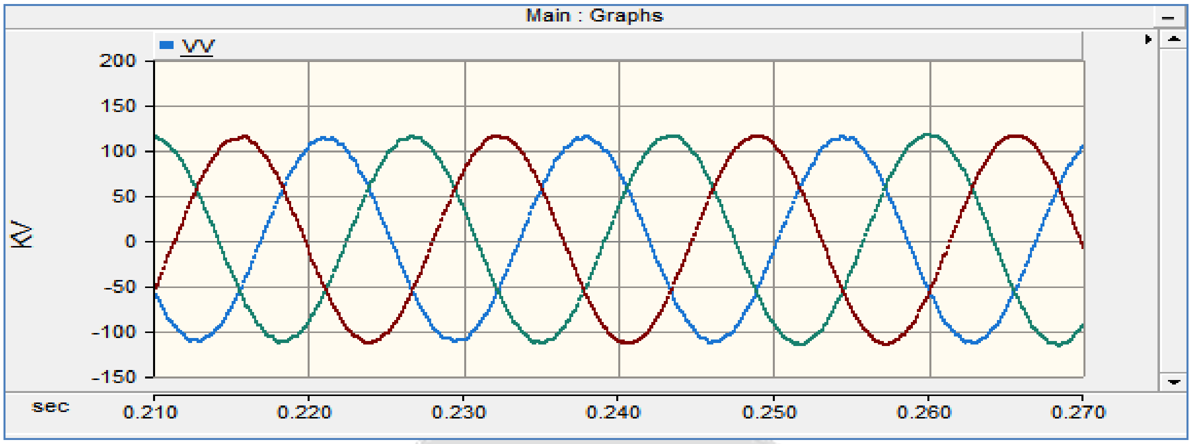
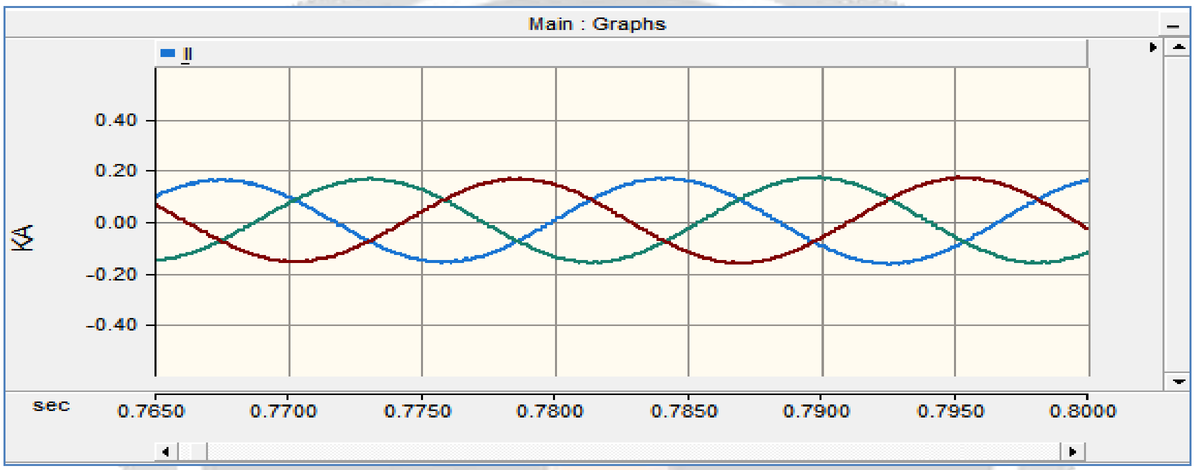



**Fig - 15**: Reactive Power of SPV on bus 2 during fault

As above result of reactive power for SPV on 2$^{nd}$ bus, Negative part is covered. This is because of absent of inertia in SPV unit.



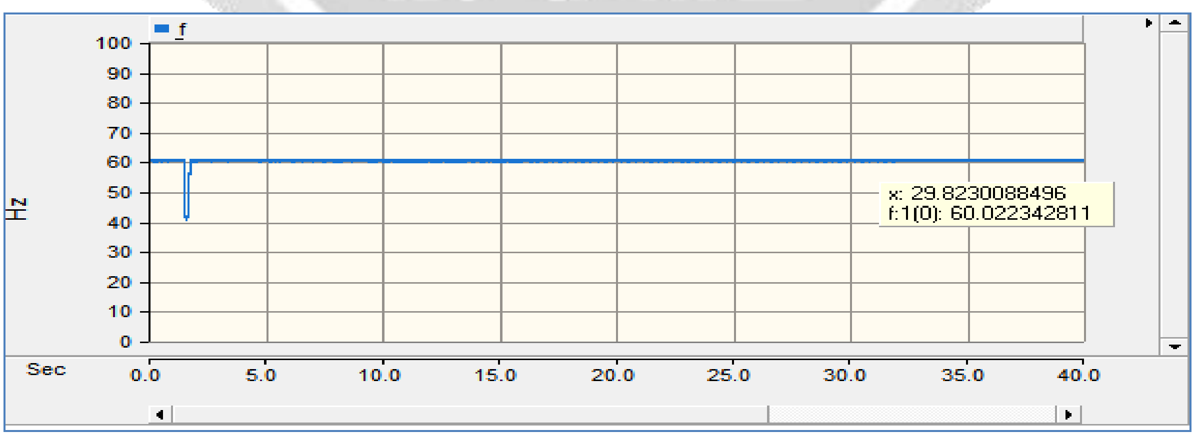

. **Fig - 16**: Voltage of SPV on bus 2



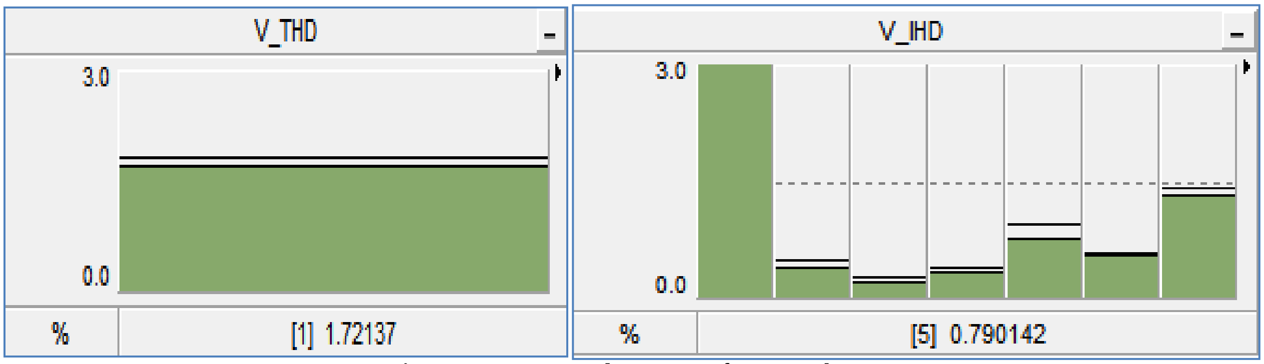

. **Fig - 17**: Current of SPV on bus 2

In figure 16 and 17, it shows that voltage and current of SPV system are unaffected due to installation of filter system with the SPV.

The value of frequency for SPV is also becomes fixed at 60 Hz. But during fault time frequency goes deep up to 42 Hz. But after 0.2 seconds, its boost up with standard value like, 60Hz.The detailed graph shown below,

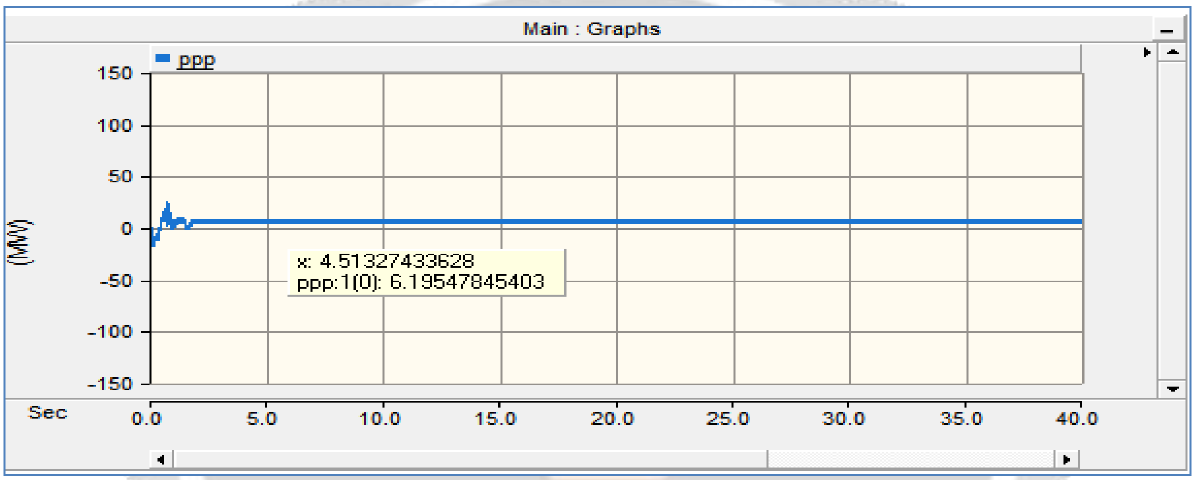



. **Fig - 18**: Frequency of SPV on bus 2 during fault



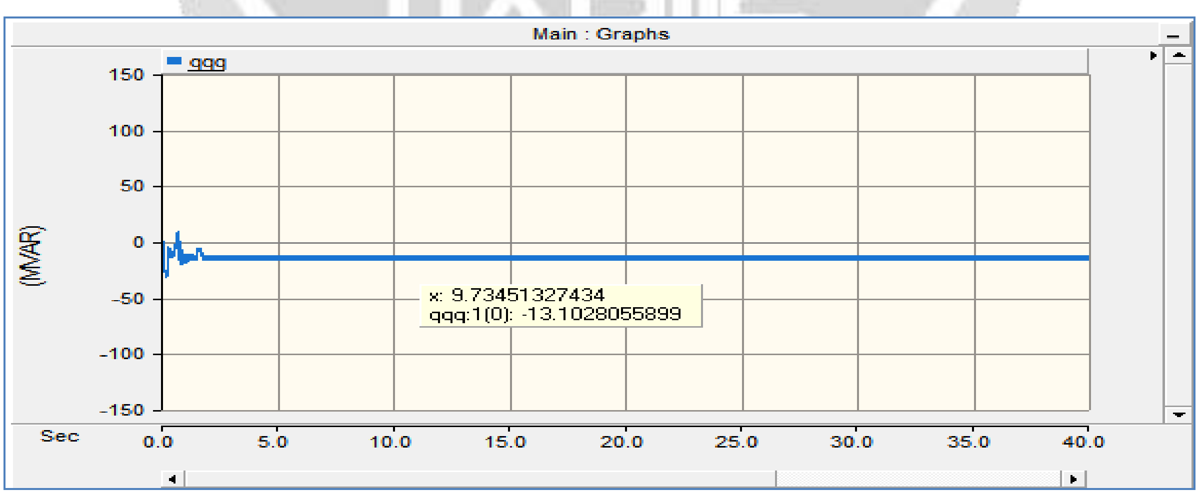

. **Fig - 19**: Harmonic distortion of SPV on bus 2

Due to Non-linear load in the system, Harmonics are present on SPV unit as shown above. But it is very less and within the IEEE standard limit because of installation of Passive filter circuit.



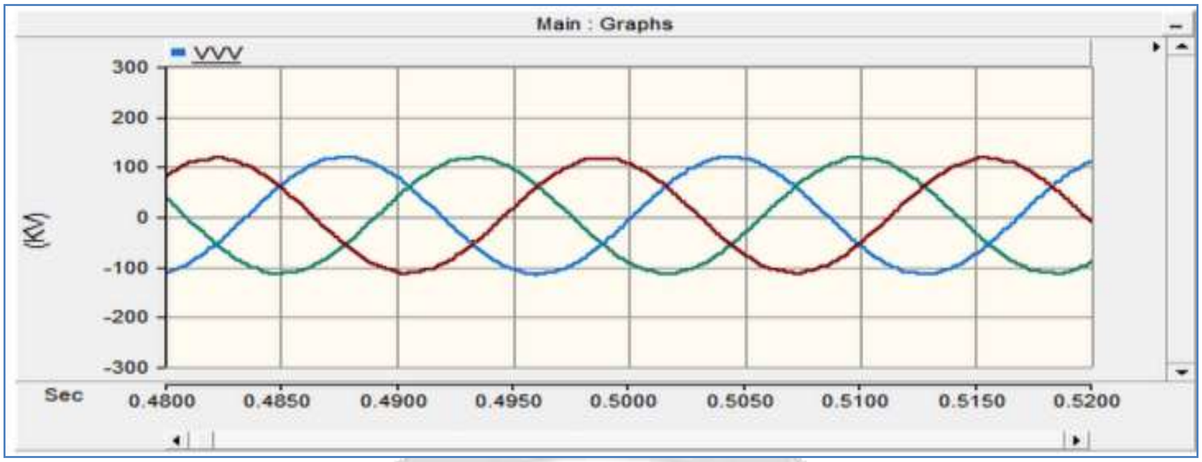

. **Fig - 20**: Real Power of VSG on bus 2 during fault

The Real power of VSG is positive and near to 6 MW which helps to improve stability of the system. During fault time VSG can differ and adjust itself to maintain the stability of the system as shown above result.

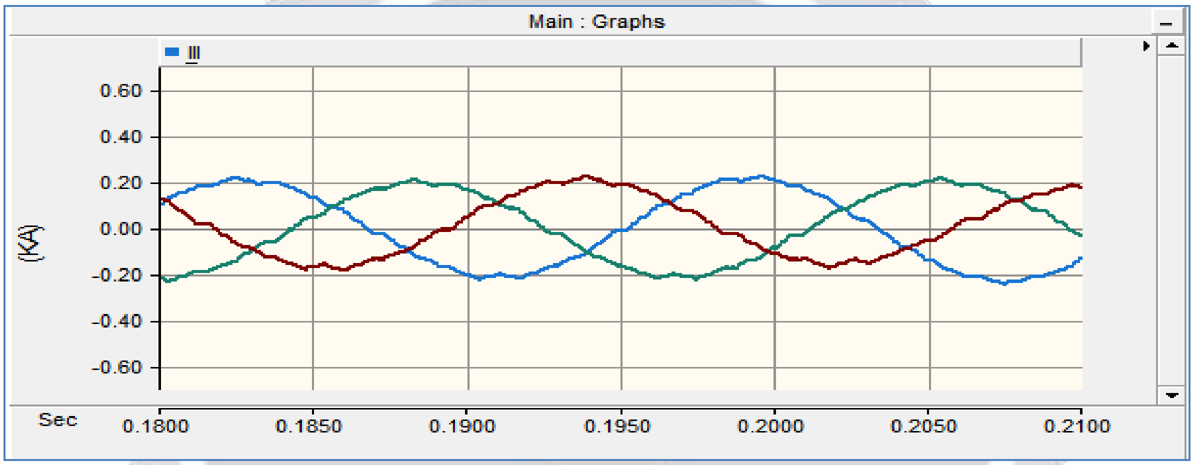



. **Fig - 21**: Reactive Power of VSG on bus 2 during fault

As per above graph, the reactive power of VSG also become negative due to non-linearity of the system. As per above graph, the reactive power of VSG also become negative due to non-linearity of the system.




. **Fig - 22**: Voltage of VSG on bus 2




. **Fig - 23**: Current of VSG on bus 2

As per figure 22 and 23, output voltage and current of VSG may slightly disturb due to harmonics. The value of harmonic can be reducing by adding active filter but it requires high cost.

The value of harmonic on VSG system shown below,

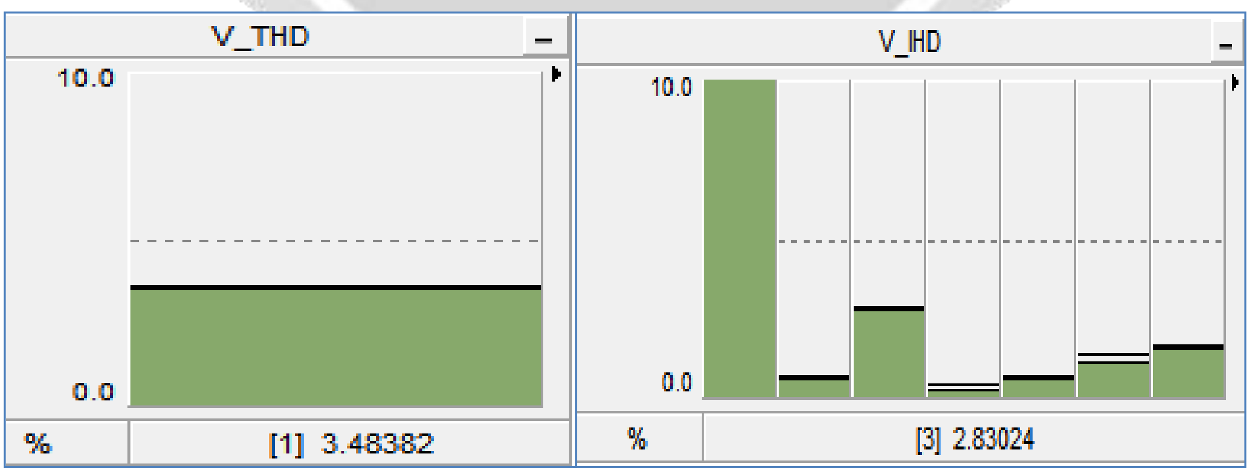



**Fig - 24**: Harmonic distortion of VSG on bus 2

## 3. CONCLUSION

By performing this simulation, it is manifestly understood that, during fault occurrence in transmission line, all parameters on bus 2 are disturbed and after clearance of fault the system becomes stable again. However, load angle and real power of synchronous generator take few seconds to become stable due to no inertia in SPV system. After connection of VSG, some virtual rotational inertia is added to the system and stability of the system is improved. Moreover, in absence of VSG, load angle and real power of synchronous generator on bus 2 take more time to become stable. i.e. 55 to 60 seconds. But by addition of VSG it takes only 15 to 20 seconds to become stable.

## 4. REFERENCES


[1] D. Rekioua and E. Matagne, "Modeling of Solar Irrandiance and Cells," in Optimization of Photovoltaic Power Systems Modelization, Simulation and Control, 1st ed. London, England: Springer, ch. 3, pp. 31-87, 2012.

[2] IEEE Application Guide for IEEE Std. 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE Std. 1547.2-2008, pp. 1-207, 2009.

[3] Genesis Alvarez, Hadis Moradi, ‘’Modeling a Grid-Connected PV/Battery Micro-grid System with MPPT Controller’’ at IEEE Smart Village Volunteer, Piscataway, NJ, 08854, USA in 2013.

[4] V. H. Mok and Vigna K. Ramachandaramurthy, “Impact of Partial Shading on the P-V Characteristics and the Maximum Power of a Photovoltaic String” in www.mdpi.com/journal/energies, published on 17 July 2018.

[5] M. Yagami, N. Kimura, M. Tsuchimoto, and J. Tamura, "Power System Transient Stability Analysis in the Case of High-Penetration of Photovoltaics (Part 2)," IEEE Eindhoven PowerTech., Eindhoven., Netherlands, pp.1-6, 2015.

[6] Haritha M. S. & Nair D. S., “Review on virtual synchronous generator (VSG) for enhancing performance of micro-grid.” In International Conference on Power, Signals, Control and Computation (EPSCICON), Published by IEEE on June 2018.

[7] Pengkun Li, Yue Wang, Yonghui Liu, Hui Zhou, Guoqing Gao & Wanjun Lei, “Transient Stability Analysis of Virtual Synchronous Generator Connected to an Infinite Bus.” In IEEE Energy Conversion Congress and Exposition (ECCE), Published by IEEE on 2019.

[8] Shintai T., Miura Y. & Ise T., “Oscillation damping of a distributed generator using a virtual synchronous generator.” In IEEE Trans Power Delivery, pp. 668–676, 2014.

[9] P.K. Iyambo, and R. Tzoneva, “Transient Stability Analysis of the IEEE 14-Bus Electric Power System” In IEEE Trans. on Power System, pp. 142-158, 2012.

[10] “IEEE 14 bus system knowledge base," https://hvdc.ca/knowledge- base/read,article/26/ieee-14-bus-system/v:, accessed: 03-08-2016.

[11] Bhakti Nitve and Ramesh L. Chakrasali, “Transient Stability Analysis and its Intensification in Microgrid”, in International Journal of Engineering Research and General Science Volume 3, in March-April 2015.

[12] Hadi Saadat, “Power System Analysis” (WCB McGraw-Hill International Editions, 1999).

[13] Kundur P., “Power System Stability and Control” (New York: McGraw-Hill, 1993).

[14] P. Kundur, G. K. Morison and L. Wang, “Techniques for on-line transient stability assessment and control”, In Power Engineering Society Winter Meeting IEEE Xplore-1, pp.46-51, 2011.


## BIOGRAPHIES

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