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Voltage Quality Improvement using a Series Connected Photovoltaic Distributed Generator Svstem

Bibhu Prasad Ganthia [1], Bhabani Patnaik [2], Rosalin Pradhan [3], Madhusmita Pradhan [4], Dr. Subrat Kumar Barik [5]

[1] PhD Research Scholar, School of Electrical Engineering, KIIT University, Bhubaneswar, India, jb.bibhu@gmail.com
[2] PhD Research Scholar, School of Electrical Engineering, KIIT University, Bhubaneswar, India, bhabani.twinkle@gmail.com
[3] Assistant Professor, Electrical Engineering, IGIT Sarang, Dhenakanal, Odisha, rosalin.pradhan@gmail.com
[4] M.Tech, PSE, Electrical Engineering, VSSUT, Burla, Odisha,India, mamipradhan123@gmail.com
[5] Associate Professor, School of Electrical Engineering, KIIT University, Odisha, Bhubaneswar, India, skbarikfel@kiit.ac.in

ABSTRACT

The need for sustainable energy solutions to preserve the fossil fuels for future generations has been a major area of concern due to rising issues like global warming and the depletion of fossil fuel reserves. Photovoltaic (PV) distributed generations integrated into the grid systems has seen a significant growth in the recent years. Introduction of distributed energy resources like solar energy onto the distribution grid has led to increase in voltage quality problems or voltage irregularities on the distribution grid due to its highly nonlinear characteristics [2]. As the proportion of the PV generation increases, several technical challenges occur like the impact of the generators on voltage quality as the solar insulation level is weather dependent and variable. Unless suitable design feature is built for the generators, the injected time-varying solar power could lead to unacceptable voltage quality. In order to reduce the irregularities and improve the voltage quality of the distribution grid, a Series connected Photovoltaic distributed Generator (SPVG) is proposed that not only maximizes the energy harness but also enhances the voltage quality when upstream voltage disturbances occur or when the input solar power fluctuates. If the harnessed solar power is insufficient to maintain the voltage level during an upstream voltage disturbance then the stored energy in a capacitor energy storage system (ESS) in the SPGV is used to enhance the voltage quality by maintaining the load voltage constant. A dc link capacitor energy storage system with an inverter with proper control strategy is useful in tackling the grid output irregularities and in improving the voltage quality issues. The proposed test system is modelled and simulated in MATLAB/Simulink environment along with the design and control of both dc-dc converter and dc-ac converter to study the impact of the SPVG in improving the voltage quality [1].

Key words : PV system, SVPG, ESS, PCU, Insolation, DC link, INC-MPPT.

1. INTRODUCTION

Solar energy is a direct source of energy. Using renewable energy technologies, the solar energy can be converted into electricity. The photovoltaic power generation includes PV modules converting solar energy directly into electrical energy, conversion of dc output voltage of solar modules to achieve the desired maximum dc output voltage through a desired converter topology, an energy storage system along with the inverter topology with a proposed control strategy to improve the voltage quality of the power system in order to keep the load voltage constant with respect to variable insolation and temperature. Depletion of fossil fuels and increasing demand for energy has influenced the search for other sources of energy. The abundant availability of solar energy and the feasibility of extraction of energy from sun make the solar energy a better choice to replace the conventional energy sources for energy conservation. Solar energy can be easily converted into electrical energy with the help of solar panels for various applications. The main disadvantage of PV systems is the variable solar irradiation that causes voltage and power fluctuation problems at the load side. These problems can be solved by using appropriate power converters and control strategies for maintaining the load voltage constant. At present, the large scale photovoltaic power generation has become a vital part of development strategy to guide the development of photovoltaic industry. As the solar power characteristics is nonlinear and is different from conventional power generation, the grid connected PV distributed generation with it's security, stability and reliable operation has become a new challenge for the power grid and PV power plant which is needed to be faced. Grid connected photovoltaic power systems are the power systems energized by the photovoltaic panels which are connected to the utility grid. Grid connected photovoltaic power systems comprise of PV panels, converter with MPPT technique to track maximum solar power, solar inverter, and power conditioning unitor energy storage system and grid connection equipment for the integration of photovoltaic generation with the utility grid. Thus, the grid connected PV generation inverter control system is used to achieve maximum power point tracking (MPPT) through a converter to ensure the high power quality of the electrical power system. This proposed model presents the modelling and simulation of the PV and grid interfaced inverter with a dc link capacitor energy storage system with a control strategy for better synchronization of the RES to the grid that enhances the voltage quality of the system by keeping the load voltage constant [10][23][24].

2. SERIES CONNECTED PHOTOVOLTAIC DISTRIBUTED GENERATOR

Under normal operating state, the PV modules capture photovoltaic power (P_{PV}) from the sun, as shown in Fig. 1 The SPVG injects output power P_i into the external grid-load system. The conversion from P_{PV} to P_i is achieved through a dc-dc boost converter and a dc-ac inverter. P_{PV} depends on the solar insolation level and the operating temperature of the PV modules at the given time for which at each insolation level, there is a unique PV module operating state by which maximum power can be extracted [20][22]. The dc-dc converter is used to achieve maximum power point (MPP) due to the changes in solar insolation level, while the inverter controls the power flow to the grid through regulating the injected complex power P_i + jQ_i. The SPVG output power i.e. P_i = P_{PV} during no losses of the converters. The capacitor (C_{PV}) reduces the ripples. A power decoupling capacitor (C_{DC}) between the two conversion stages of the SPVGprovides an energy buffer medium in the dc-link of the inverter. C_{DC} acts as an energy storage device during grid voltage disturbance. The SPVG includes a coupling transformer to boost the injection voltage and to provide galvanic isolation. So, both SPVG and the upstream source act together to meet the load demand S_L = P_L + jQ_L [12].

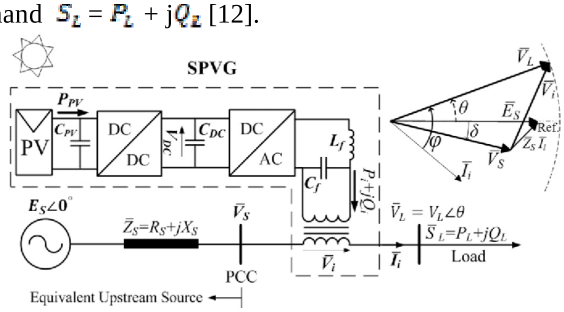

Figure 1: Schematic diagram of the SPVG interconnected to a grid system [1]

According to the SPVG design objectives, P_i is expected to vary with changes in the solar insolation level. Hence, for voltage quality enhancement, the challenge is to maintain the load voltage magnitude (V_L) constant [19]. The inverter control system is to regulate V_L by adjusting the SPVG injected power. Another problem is the occurrence of grid voltage disturbances. Such disturbances are changes in E_S . The control system of the SPVG is proposed to adjust the injected P_i and Q_i to maintain V_L constant at the pre-disturbance level. So, series-connected PV generator (SPVG) system proposed not only maximizes energy harness during daytime, but also attempts to enhance voltage quality when upstream voltage disturbances occur or when the input solar power fluctuates. If the harnessed solar power is insufficient to maintain voltage level during an upstream voltage disturbance, stored energy in a capacitor energy storage system (ESS) in the SPVG shall be used to improve voltage quality by mitigating the sags and swells [18]. There exists a minimum active power injection level for SPVG to enhance the voltage quality. Among different types of energy storage systems, a d.c link capacitor storage system is highly used as it has high specific power density, can undergo continuous charging and discharging, cheap and has high life cycle as compared to a battery storage system. During grid voltage disturbances i.e. voltage sag and insufficient solar power, the capacitor storage system is used to discharge the balance of minimum active power required to maintain the load voltage (V_L) and the SPVG output power (P_i). Similarly, during the upstream voltage disturbance i.e. voltage swell, the capacitor storage system is used to absorb the excess energy from the grid. Therefore, during variable insolation level or upstream disturbances, the objective is to maintain V_L constant by adjusting the SPVG output power [2][3].

3. MODELLING OF PV MODULE

A photovoltaic cell/module is mathematically modelled using a single diode equivalent circuit. The various parameters which influence the characteristic of a cell are environmental parameters like irradiance and temperature, internal parameters like ideality constant, Boltzmann constant, energy band-gap and charge of electron, electrical parameters like open circuit voltage, short circuit current, series resistance and shunt resistance. Based on current-voltage relationship of a solar cell, a mathematical model of single diode PV cell is developed [15][22]. The representation of an ideal PV cell is represented by a current source connected with an anti-parallel diode. In order to study the photovoltaic system in distributed generation network, the modelling of the PV cell/module is necessary. A photovoltaic device is a nonlinear device and the parameters depend essentially on sunlight and temperature. The photovoltaic cell converts the sunlight into electricity. The photovoltaic array consists of parallel and series of photovoltaic modules. The cell is grouped together to form the panels or modules. The voltage and current produced at the terminals of a PV system can feed a DC load or can be connected to an inverter to produce AC current. The model of photovoltaic array is obtained from the photovoltaic cells and depends on how the cells are connected. Figure 2 shows the single diode equivalent circuit of a solar photovoltaic cell with the internal resistances and diode [5][13][17].

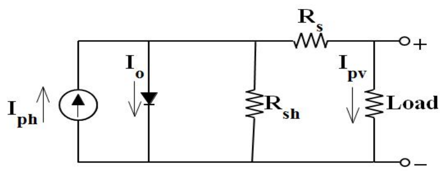

Figure 2: Single diode equivalent circuit of a solar PV cell [1]

The equations that are required for the PV modelling are:

$$I_{PV} = I_{ph} - I_D - I_p \qquad (1)$$

I_{ph} is the photocurrent, I_D is the diode current which is proportional to the saturation current and I_p is the current across shunt resistance giving PV module output current (I_{PV}). Hence, the equation governing PV module is

$$I_{PV} = I_{ph} - I_o\left[exp\left\{\frac{V_D}{V_T}\right\} - 1\right] - \frac{V+IR_s}{R_{sh}} \qquad (2)$$

Where V_D is the voltage imposed on the diode and I_p is the current across R_{sh}.

The expression of V_T is given by

$$V_T = \frac{K.T}{q} \qquad (3)$$

I_{PV} : Current generated by the incident light
I_0: Reverse saturation
q: Electron charge (1.602 ×10^{-19}C)
k : Boltzmann constant
T: The temperature of the p-n junction
V_T :The thermal voltage of the module
R_s: Series resistance
R_{sh}: Parallel resistance.

The problem of modelling a PV array is to calculate the resistance series R_s and resistance parallel R_{sh}. R_s and R_{sh} are determined iteratively, based on the manufacture datasheet. The model is obtained with the parameters of the I-V equation given by manufacturer datasheet such as open-circuit voltage V_{oc}; short-circuit current I_{sc}, maximum output power P_{max}, voltage and current atthe maximum power point (V_{mpp} , I_{mpp}). The model gives the PV characteristics such as P-V curve and I-V curve [6][7][16][25].

The power output of a solar cell is given by P_{PV}=I * V
where: I= Output current of solar cell (A).
V= Solar cell operating voltage (V).
P_{PV} =Output power of solar cell (W).

4. GENETIC ALGORITHM BASED PID CONTROLLER

Genetic algorithm (GA) uses the principles of evolution, natural selection and genetics from natural biological systems in a computer algorithm to simulate evolution. Essentially, the genetic algorithm is an optimization technique that performs a parallel, stochastic, but directed search to evolve the fittest population [23][28].

The structure of a control system with GA-PID as a controller is shown in the Figure 3 and flowchart in figure 4. It consists of a conventional PID controller with its parameter optimized by genetic algorithm. The initial population of size N is generated randomly to start the optimization process. The next generation can be obtained through the genetic operators. The genetic operators are the most important features of GA and are described below [14][27].

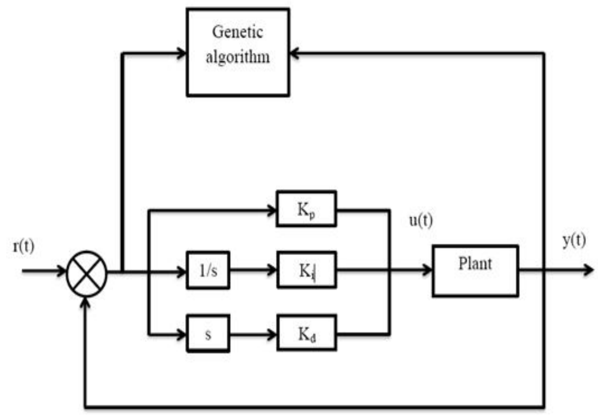

Figure 3: Structure of GA-PID controller[4]

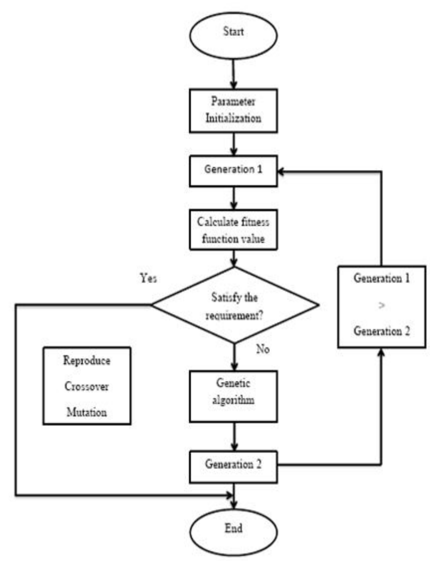

Figure 4: Flow-chart for auto tuning GA-PID controller [2]

5. MODELLING OF BUCK BOOST CONVERTER WITH MPPT

The brief overview of various maximum power point tracking (MPPT) algorithms and topologies are given. Parameters for evaluating MPPT algorithm are discussed and a set of guidelines are proposed for selecting the appropriate MPPT algorithm to track the maximum power of the solar PV module through a desirable converter topology. Through the

MPPT control mechanism, the duty cycle rectification leads to a pulse generation by PWM technique that is when given as input to the gate of the converter; it will operate accordingly to track the maximum power at the operating insolation and temperature. The buck-boost DC-DC converter provides a greater level of capability than the buck converter or the boost converter individually. So, it has some expected extra components which are required to provide the level of functionality needed [8][15][24].

There are several specifications of the parameters that are used for the Buck Boost converters:

- $+V_{in}$, $-V_{out}$ **:** The configuration of a Buck Boost converter circuit consists of the same number of components as that ofsimple buck or boost converters. However, this Buck Boost regulator or DC-DC converter produces a negative DC output voltage for a given positive input DC voltage.

When the switch is closed in the Buck Boost converter circuitry, current builds up through the inductor as shown in Figure 5. When the switch is opened, the inductor supplies the current through the diode to the load. The polarities (including the diode) within the Buck Boost converter can be reversed to provide a positive output DC voltage from a negative input DC voltage [9][14][22].

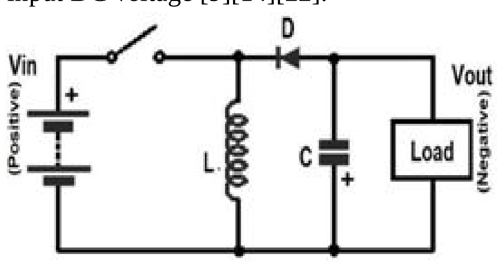

Figure5: DC-DC Buck Boost Converter (negative type)[1]

Maximum power point plays a crucial role in photovoltaic system because it is used to maximize the output power from a PV system for a given set of conditions i.e. temperature and insolation at that operating point and therefore maximizes the PV array efficiency [9][10]. An effective control algorithm called MPPT (Maximum Power Point Tracking) provides the key solution to delivering power efficiently to the battery or load. The current standard controller regarding solar cells is the maximum power point tracker (MPPT) [13][18]. In order to accomplish the MPPT effectively, the controlling of the switch of the switching power supply or converter is done so that the MPPT algorithm employed must be suitable for the desired use. Among the different types of MPPT methods used to track the maximum power point, Incremental Conductance method (INC MPPT) is the most widely used method in PV MPPTs as it is more advantageous with respect to the other MPPT methods [11][17].

6. DC LINK CAPACITOR

The DC link in a PCU (Power Conditioning Unit) is an interconnection of single-phase inverter input port and the buck boost converter output port. The DC link comprises of an energy storage component, which decouples the buck boost converter from the pulsating AC output power. Single-phase voltage source inverters (VSIs) employ capacitors, whereas current source inverters (CSIs) use inductors for energy storage purpose. So, in this proposed model for voltage quality enhancement of the grid with PV system, a DC link capacitor energy storage system has been used [19][22][23].

7. SIMULINK MODELS

The figure 6 represents Simulink model of solar PV module. Figure 7 represents Simulink model of Buck Boost converter with INC MPPT method [20]. Figure 8 represents Simulink model of single phase inverter and figure 9 shows Combined Simulink model of PV module. Figure 10represents Simulink model of the overall test system with R load and Figure 11 represents Simulink model of the overall test system with a nonlinear load. The above models are shown below.

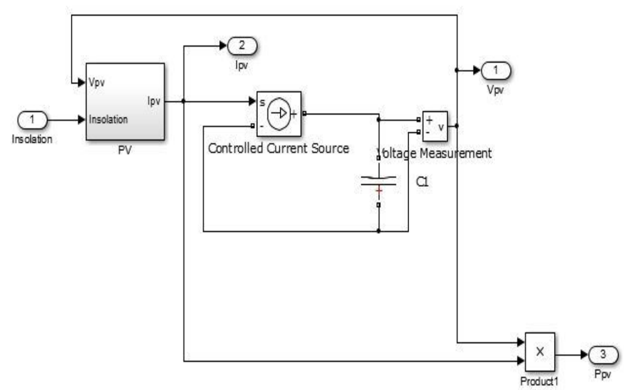

Figure 6: Simulink model of solar PV module

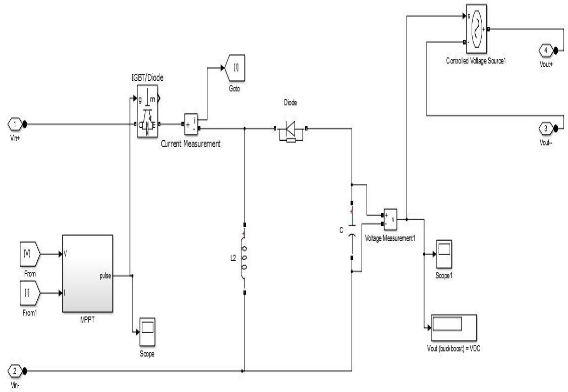

Figure 7: Simulink model of Buck Boost converter with INC MPPT method

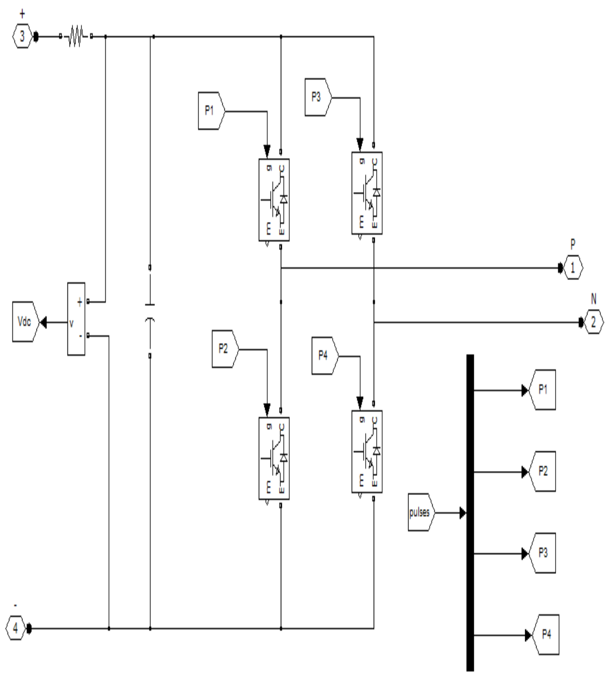

Figure 8: Simulink model of single phase inverter

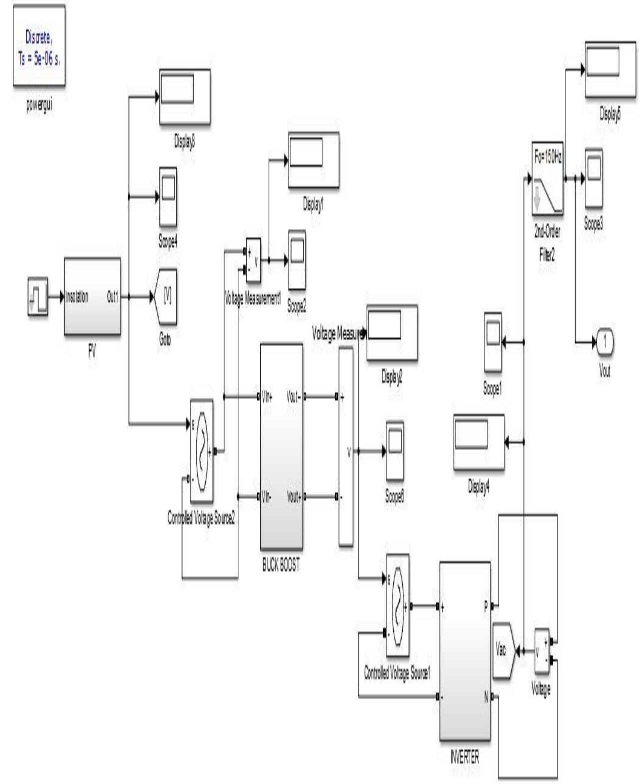

Figure 9: Combined Simulink model of PV module

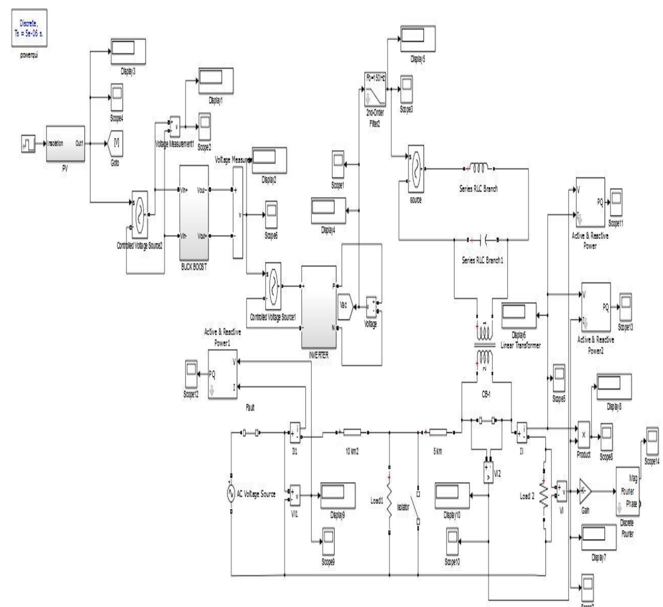

Figure 10: Simulink model of the overall test system with R load

The PV module produces an output voltage of about 19.35 Volt which is when given as input to the Buck Boost converter with INC MPPT, it produces an output voltage of -213 Volt. Then, the Buck Boost converter output voltage is inverted and is given as an input to the single phase inverter which produces an output AC voltage of 213 Volt. When in the designed model, a nonlinear load is added, it leads to the presence of harmonics in the load voltage, current and power due to switching activities.

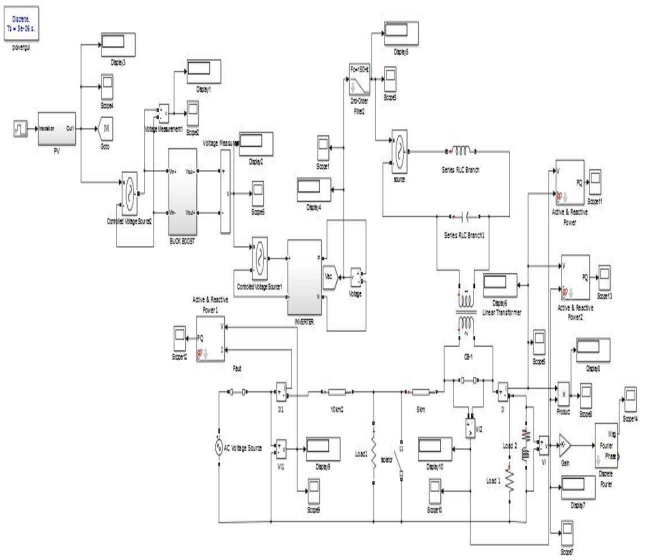

Figure 11: Simulink model of the overall test system with a nonlinear load

Whenever a fault occurs in the power system then according to this present model, the circuit breaker opens in order to avoid the rest of the power system from getting affected by the fault caused due to the upstream voltage disturbances. This model presents how a PV VSI enhances the voltage quality of the system by improving the voltage level injected to the load. When a fault occurs, the circuit breaker opens and isolates the rest part of the system. The isolator gets closed to provide a closed path to allow the current to flow through the load. To mitigate the voltage quality problem, the isolator gets closed and the circuit breaker across the transformer opens to allow the PV inverter to inject the power to the load to maintain constant load voltage [21].

8. SIMULATION RESULTS

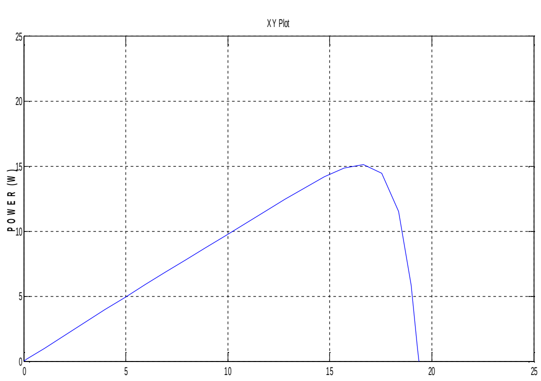

Figure 12: P-V characteristics of PV module

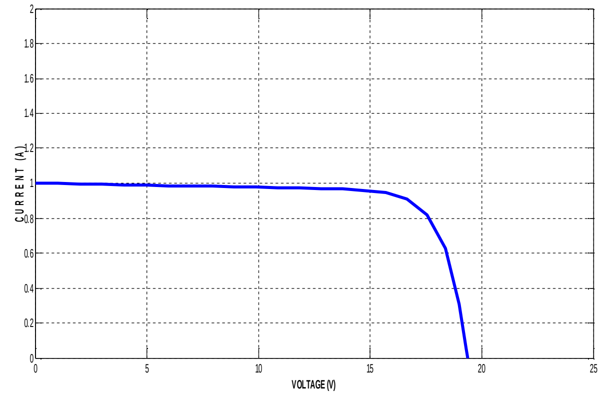

Figure 13: I-V characteristics of PV module

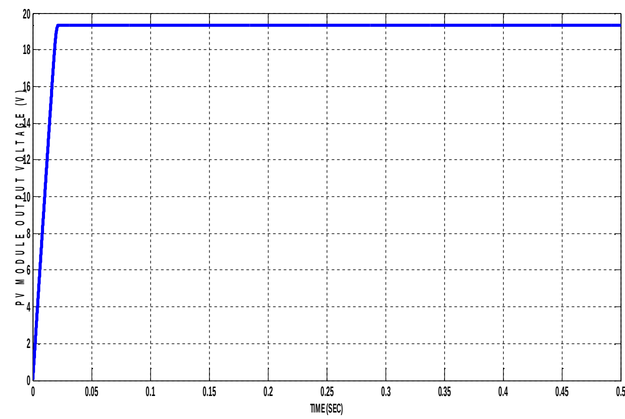

Figure 14: PV module output voltage

These graphs show the characteristics of the PV module with respect to the operating temperature and irradiation. The PV module produces an output power P i.e. P= V×I where the PV output current is 1 A and voltage is about 19.35 V.A constant value of solar irradiation i.e. 1000 W/m^2 is given as the input to the proposed module. The magnitude of the PV module output voltage was found to be 19.35 volt which is given as input to the Buck Boost converter.

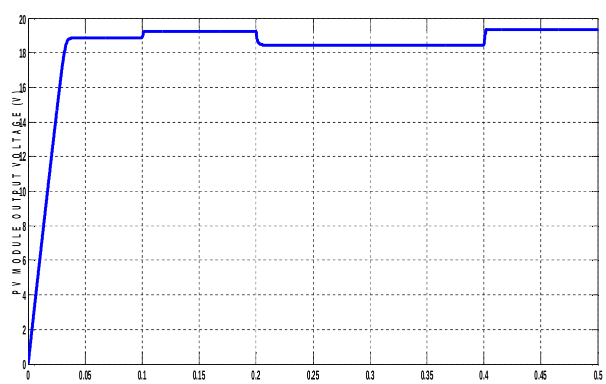

Figure 15: PV module output voltage with variable insolation

Here, the shown waveform is the output of the proposed model with a variable solar irradiance. So, the magnitude of the output voltage varies according to the input solar irradiance.

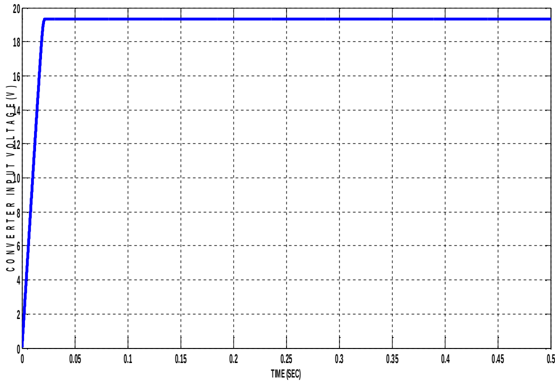

Figure 16: Buck Boost converter input voltage

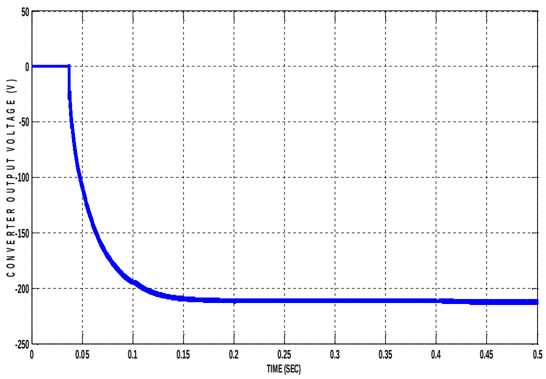

Figure 17(a): Buck Boost converter output voltage

The Buck Boost converter produces a DC output of - 213V, when the model is run for 0.5 sec which shows that there is a switching time of about 0.03 sec. So, when the same model is run for 5 sec, a proper DC output voltage of -213V is produced with a better output waveform as shown in Figure 17 (b).

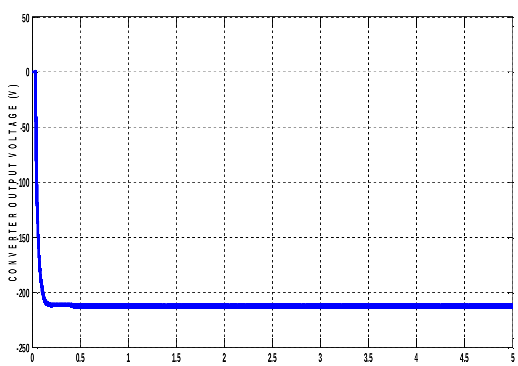

Figure 17. (b): Buck Boost converter output voltage

Both constant and variable magnitude of PV output is fed to the Buck Boost converter. As Buck Boost converter is an inverting converter, a negative DC voltage of magnitude 213 V is observed.

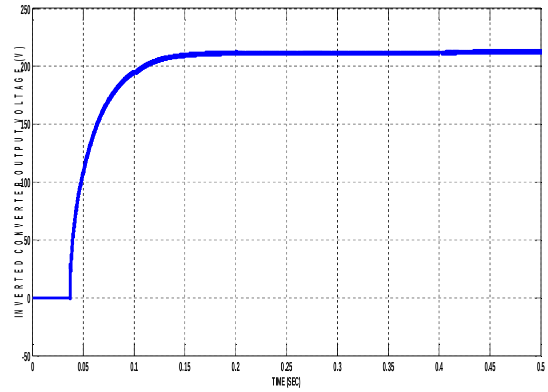

Figure 18 (a): Inverted Buck Boost converter output voltage

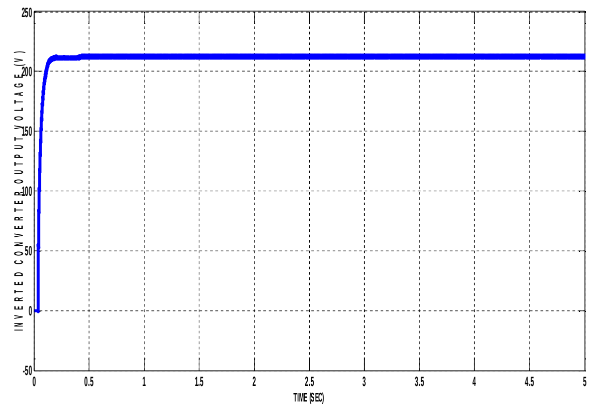

Figure 18 (b): Inverted Buck Boost converter output voltage

Figure 18 (a) and 18 (b) show the inverted output voltage of the Buck Boost converter producing a DC output voltage of 213 V by connecting a voltmeter around the terminals of Buck Boost converter in an inverting manner to get a proper positive output waveform with magnitude of 213 V which is given as an input to the single phase inverter.

The simulink results are shown below in figure 19, figure 20 and figure 21.

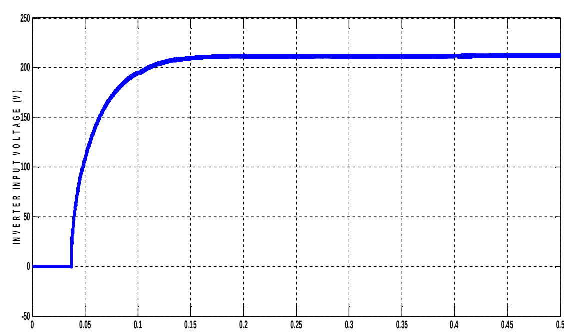

Figure 19: Inverter input Voltage

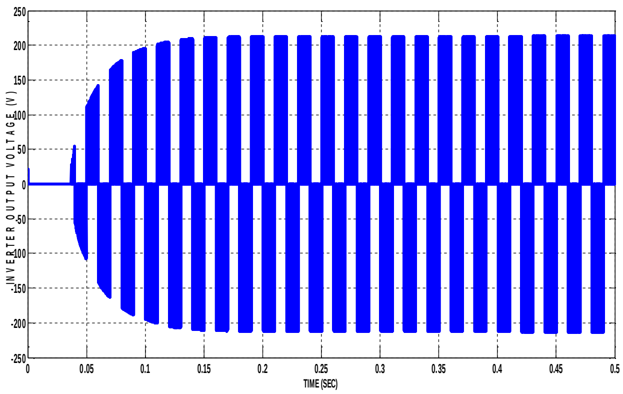

Figure 20: Inverter output voltage

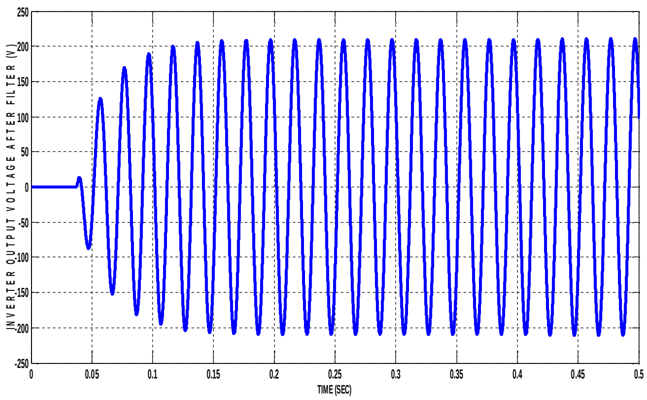

Figure 21: Inverter output voltage after filter

When 213 Volt DC from the buck boost converter is given as an input to the single phase inverter to convert the DC voltage to AC voltage for connecting the PV module with the grid, the output of the inverter contain harmonics in it producing 213 V AC. So, a filter is added to eliminate the harmonics from the AC output of inverter. Now, a sinusoidal AC output of inverter is synchronized with a grid which is supplying power to a certain load. The total synchronized PV generating system act as backup for the overall test system. If due to any fault grid is unable to provide the supply to the load then at that time the proposed PV generating module supplies power to the load through an injection transformer.

The results during fault analysis are shown below in figure 22, 23 and 24.

Figure 22: Source voltage

Figure 23: Source voltage with fault

Figure 24: Injected voltage

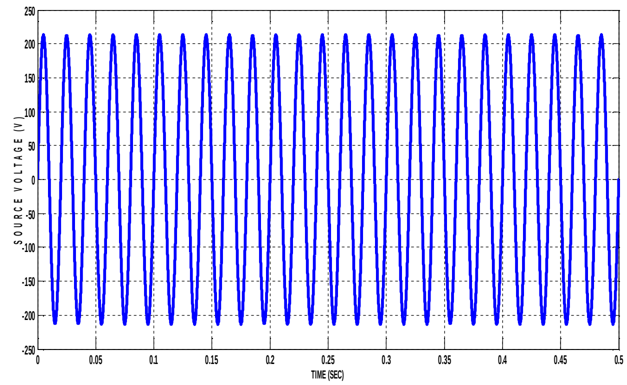

Figure 22: Source voltage

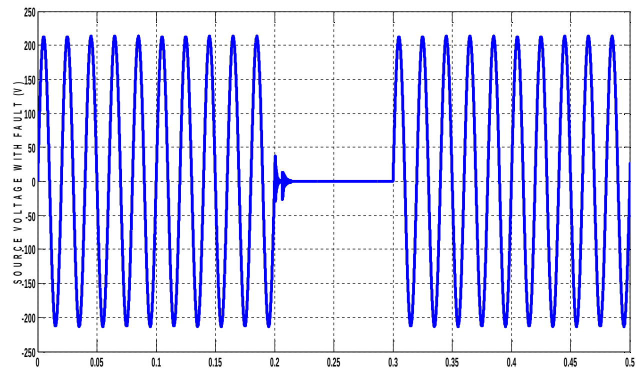

Figure 23: Source voltage with fault

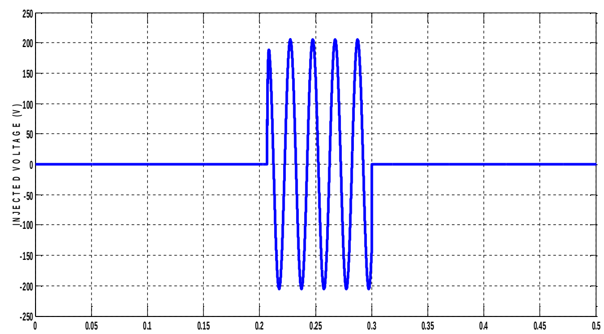

Figure 24: Injected voltage

The above figures show the source voltage with a fault during the time interval of 0.2 to 0.3 sec and hence, the circuit breaker isolates the grid making the supply zero. At that time, the PV generating module supplies the required amount of voltage to maintain the voltage profile. The injected voltage of PV generating module through the injection transformer is also shown. Hence, though the grid is isolated from the supply during fault condition with no power supplied to the load still the load voltage is maintained constant due to the injection of voltage by the PV generating source shown in figure 25 and 26.

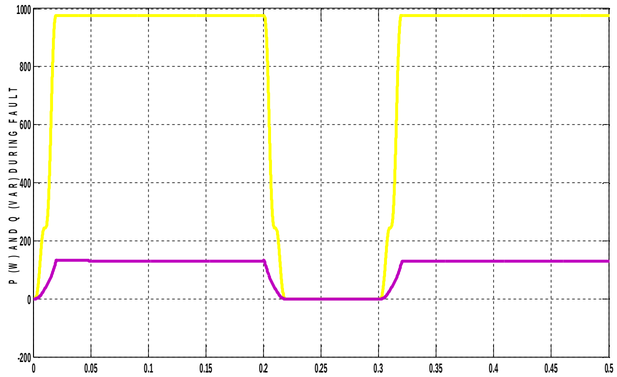

Figure 25: P and Q during fault

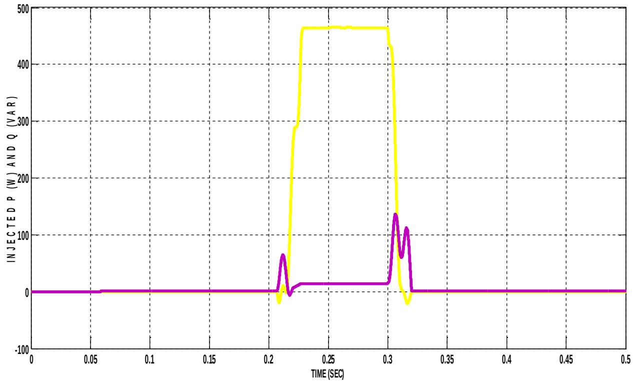

Figure 26: Injected P and Q

The per unit representation of real power and reactive power during the fault and with the integration of PV generating system with grid during the fault are shown in figure 27, figure 28, figure 29 and figure 30.

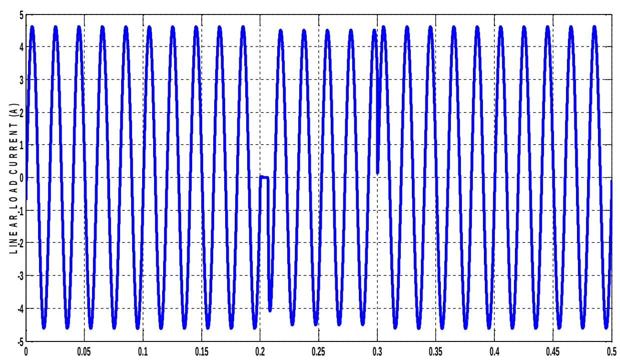

Figure 27: Linear load current

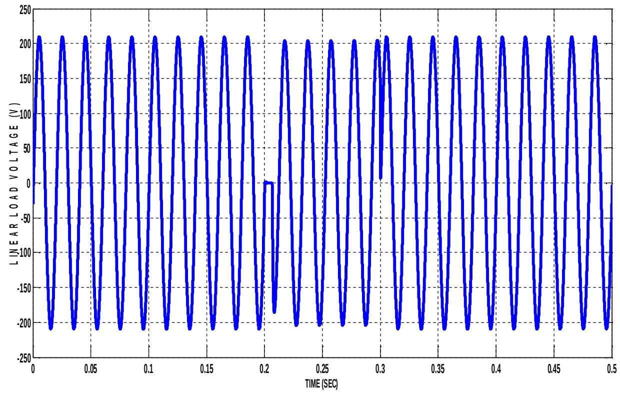

Figure 28: Linear load voltage

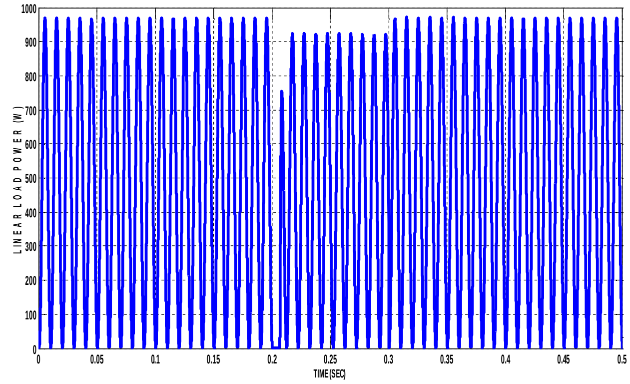

Figure 29: Linear load power

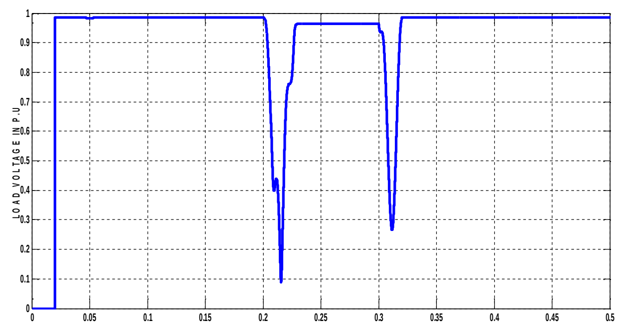

Figure 30: Load voltage in p.u

So, this test system produces an AC output voltage of 213 V peak to peak, current of 4.7 A and power of 1000 W when a linear load is used. The per unit presentation of the load voltage, real power and reactive power have also been observed. When a nonlinear load is used, the presence of harmonics is noticed in the load current, voltage and power respectively.

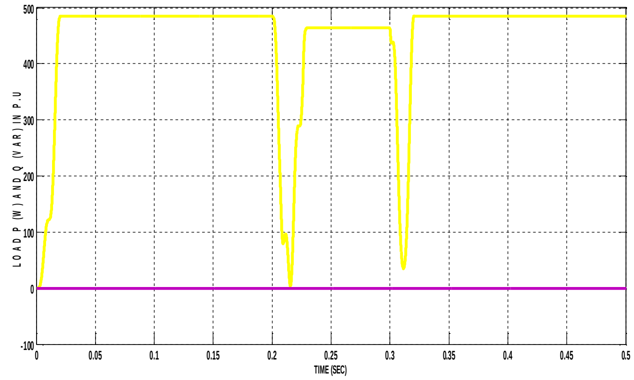

Figure 31: Load P and Q in p.u

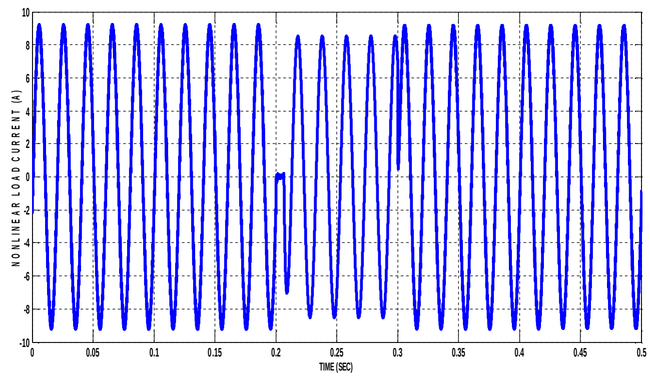

Figure 32: Nonlinear Load current

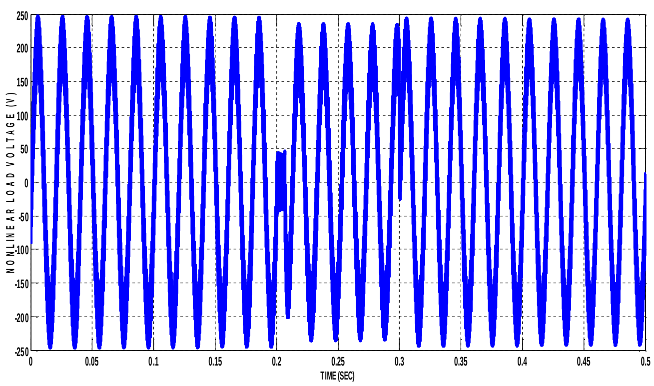

Figure 33: Nonlinear Load voltage

When a nonlinear load is connected in the proposed test model, the presence of harmonics in the load current, load voltage and load power has been observed.

The simulink results for non linear loads are shown in Figure 31: Load P and Q in p.u, Figure 32: Nonlinear Load current Figure 33: Nonlinear Load voltage and Figure 34: Nonlinear Load power.

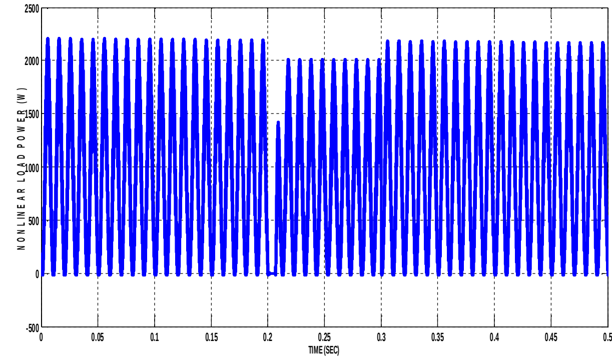

Figure 34: Nonlinear Load power

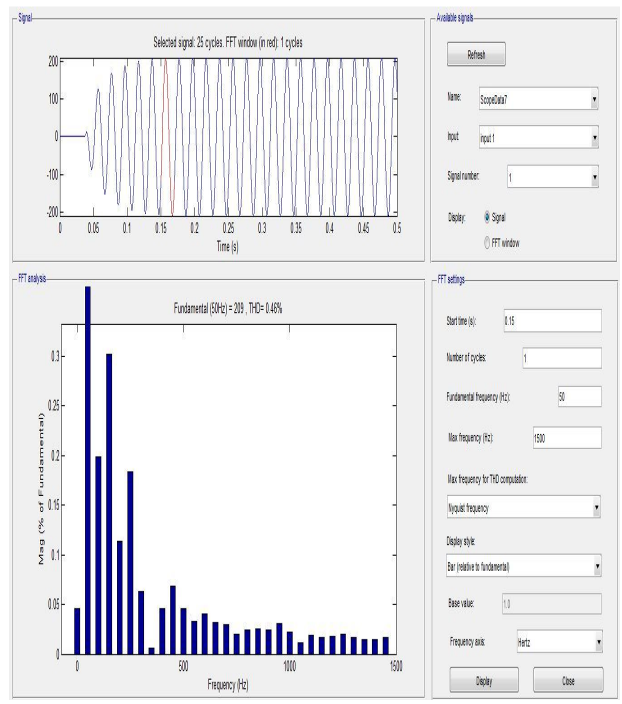

Figure 35: FFT analysis showing percentage of the harmonics

Under the grid operating condition, the FFT analysis shown in above figure 35 that use of this technique has led to reduction in harmonics and it ensures almost sinusoidal current injection into the grid with reduced THD (0.46%) by increasing the fundamental component of the injected grid current. It increases the fundamental component of the injected grid voltage thereby increasing the amount of active power injection by the series connected PV distributed generator by eliminating harmonics as the THD level is about 0.46%.

9. CONCLUSION

The main challenge in developing a practical PV system includes an efficient control mechanism that can extract the maximum output power from the PV arrays under all operating conditions with high performance and low cost ratio. Since, the PV array has a highly nonlinear characteristic due to change in operating conditions such as insolation and temperature, it is technically challenging to develop a PV system that can meet these technical requirements. So, this thesis work deals with the study of a series connected PV distributed generator system for enhancing the voltage quality of the system that maintains constant load voltage during the upstream source disturbances and input solar power fluctuations. The INC MPPT algorithm, dc-dc converter topology and inverter configuration along with the dc link capacitor ESS control mechanism for enhancement of voltage quality of the proposed system have been discussed, modelled and simulated in the MATLAB. The output waveforms and graphs of the desired Simulink models have been studied. The test model has been simulated with a linear and nonlinear load. The use of nonlinear load shows the addition of harmonics. The FFT analyzer verified that by using the SPVG integrated to the grid, there is a reduction in harmonics as the value of THD is 0.46%.

REFERENCES

1. NimaSaadat, S. S. Choi, and D. Mahinda Vilathgamuwa, "**A series-connected photovoltaic distributed generator capable of enhancing power quality," IEEE Transactions on Energy Conversion**, vol. 28, no. 4, pp. 1026-1035, Dec. 2013. https://doi.org/10.1109/TEC.2013.2278379
2. A. Woyte, V. Thong, R. Belmans, and J. Nijs, "**Voltage fluctuations on distribution level introduced by photovoltaic systems**,"IEEE Trans EnergyConvers., vol. 21, no. 1, pp. 202–209, Mar. 2006.
3. W. A. Omran, M. Kazerani, and M. M. A. Salama, "**Investigation of methods for reduction of power fluctuations generated from large grid-connected photovoltaic systems**,"IEEE Trans. Energy Convers., vol. 26, no. 1, pp. 318–327, Mar. 2011. https://doi.org/10.1109/TEC.2010.2062515
4. A. Chatterjee, A. Keyhani, and D. Kapoor, "**Identification of photovoltaic source model**s,"IEEE Trans Energy Convers., vol. 26, no. 3, pp. 883–889, Sep. 2011. https://doi.org/10.1109/TEC.2011.2159268
5. Dezso Sera, Remus Teodorescu, and Pedro Rodriguez, "**PV panel model based on datasheet values**," IEEE, 1-4244-0755-9, pp. 2392-2396, July 2007.
6. Ariya Sangwongwanich, Yongheng Yang, and FredeBlaabjerg, "**High-Performance Constant Power Generation in Grid-Connected PV Systems**," IEEE Transactions on Power Electronics, vol. 31, no. 3, pp. 1822-1825, March 2016.
7. T. Esram, and P. L. Chapman, "**Comparison of photovoltaic array maximum power point tracking techniques**,"IEEE Trans. Energy Convers., vol. 22, no. 2, pp. 439–449, Jun. 2007. https://doi.org/10.1109/TEC.2006.874230
8. Ahmed M. Atallah, Almoataz Y. Abdelaziz, and Raihan S. Jumaah, "**Implementation of Perturb and Observe MPPT of PV system with direct control method using buck and buckboost converters**,"Emerging Trends in Electrical, Electronics & Instrumentation Engineering: An international Journal (EEIEJ), vol. 1, no. 1, pp. 31-44, Feb. 2014.
9. B. Wang and G. Venkataramanan, "**Evaluation of shunt and series power conditioning strategies for feeding sensitive loads**," in Proc. Appl. PowerElectron. Conf. Exp., vol. 3, pp. 1445–1451, 2004.
10. R. Mastromauro, M. Liserre, T. Kerekes, and A. Dell'Aquila, "**A single-phase voltage-controlled grid-connected photovoltaic system with power quality conditioner functionality**," IEEE Trans. Ind. Electron., vol. 56, no. 11, pp. 4436–4444, Nov. 2009.
11. R. K. Varma, V. Khadkikar, and R. Seethapathy, "**Nighttime application of PV solar farm as STATCOM to regulate grid voltage**," IEEE TransEnergy Convers., vol. 24, no. 4, pp. 983–985, Dec. 2009. https://doi.org/10.1109/TEC.2009.2031814
12. F. Kong, C. Rodriguez, G. Amaratunga, and S. K. Panda, "**Series connected photovoltaic power inverter**," in Proc. Int.Conf. Sustainable Energy Technol. (ICSET), pp. 595–600, 2008.
13. S. Kjaer, J. Pedersen, and F. Blaabjerg, "**A review of single-phase grid-connected inverters for photovoltaic modules**," IEEE Trans Ind. Appl., vol. 41, no. 5, pp. 1292–1306, Sep. 2005. https://doi.org/10.1109/TIA.2005.853371
14. Mahmoud Salem, YousryAtia, "**Control scheme towards enhancing power quality and operational efficiency of single-phase two-stage grid-connected photovoltaic systems**," Journal of Electrical Systems and Information Technology, pp. 314–327, 2015.
15. Aurobinda panda, M. K. Pathak and S. P. Srivastava, "**A single phase photovoltaic inverter control for grid connected system**,"Indian

Academy of Sciences ,pp. 15–30, vol. 41, no. 1, January 2016.

16. Pradipta Kumar Sahoo, Pravat Kumar Ray, Pranati Das,"**Power Quality Improvement of Single Phase Grid Connected Photovoltaic System**," International Journal of Emerging Electric Power Systems, 20160097, 2016.
17. J. Salazar, F. Tadeo, C. Prada, L. Palacin, "**Simulation and Control of a PV System connected to a Low Voltage Network**," xxxi Jornadas De Automática, pp 1- 6, September 08-10, Jaén, Spain, 2010.
18. E. Roman, R. Alonso, P. Ibanez, S. Elorduizapatarietxe, and D. Goitia, "**Intelligent PV module for grid-connected PV systems**,"IEEE Trans. Ind.Electron., vol. 53, no. 4, pp. 1066–1073, Jun. 2006. https://doi.org/10.1109/TIE.2006.878327
19. R.-J. Wai, W.-H. Wang, and C.-Y. Lin, "**High-performance stand-alone photovoltaic generation system**,"IEEE Trans. Ind. Electron., vol. 55, no. 1, pp. 240–250, Jan. 2008.
20. Marcelo GradellaVillalva, Jonas Rafael Gazoli, and Ernesto RuppertFilho,"**Comprehensive Approach to Modeling andSimulation of Photovoltaic Arrays**,"IEEE Trans. on Power Electronics, vol. 24, no. 5, pp. 1198-1208, May 2009.
21. DhananjayChoudhary,Anmol RatnaSaxena,"**DC-DC Buck-Converter for MPPT of PV System**,"International Journal of Emerging Technology and Advanced Engineering (IJETAE), ISSN 2250-2459, ISO 9001:2008 Certified Journal, vol. 4, Issue 7, pp. 813-821, July 2014. https://doi.org/10.1049/cp.2016.1497
22. Ganthia, B.P.; Rana, P.K.; Pattanai, S.A. "**Space Vector Pulse Width Modulation Fed Direct Torque Control of Induction Motor Drive Using Matlab-Simulink**". In Proceedings of the 3rd International Conference on Electrical, Electronics, Engineering Trends, Communication, Optimization and Sciences (EEECOS), Tadepalligudem, India, 1–2 June 2016.
23. Ganthia B.P., Pritam A., Rout K., Singhsamant S., Nayak J. (2018) **Study of AGC in Two-Area Hydro-thermal Power System.** In: Garg A., Bhoi A., Sanjeevikumar P., Kamani K. (eds) Advances in Power Systems and Energy Management. Lecture Notes in Electrical Engineering, vol 436. Springer, Singapore.
24. B. P. Ganthia, R. Pradhan, S. Das and S. Ganthia, "**Analytical study of MPPT based PV system using fuzzy logic controller**," 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS), Chennai, India, 2017, pp. 3266-3269.
25. Bibhu Prasad Ganthia, Prashanta Kumar Rana, Tapas Patra, Rosalin Pradhan, Rajashree Sahu, **Design and Analysis of Gravitational Search Algorithm Based TCSC Controller in Power System**, Materials Today: Proceedings,Volume 5, Issue 1, Part 1,2018, Pages 841-847, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2017.11.155.
26. Bibhu Prasad Ganthia, Aditi Abhisikta, Deepanwita Pradhan, Anwes Pradhan, **A Variable Structured TCSC Controller for Power System Stability Enhancement**, Materials Today: Proceedings, Volume 5, Issue 1, Part 1, 2018, Pages 665-672, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2017.11.131.
27. B. P. Ganthia, S. Mohanty, P. K. Rana, P. K. Sahu, "**Compensation of voltage sag using dvr with pi controlle**r", Electrical Electronics and Optimization Techniques (ICEEOT) International Conference, pp. 2138-2142, 2016.
28. Ganthia Bibhu Prasad and Rout Krishna 2016 **DEREGULATED POWER SYSTEM BASED STUDY OF AGC USING PID AND FUZZY LOGIC CONTROLLER** Int. J. of Adv. Res. **4** 847-855 www.journalijar.co https://doi.org/10.21474/IJAR01/823