International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 03, March-2019

Solar Farm (SF) Inverter as a STATCOM during Night time to Regulate Grid Voltage

Sagarkumar N. Tank[1], Prof. Shilpa L. Kaila[2]

[1]*Electrical Engineering Department, L. E. College-Morbi,GTU,*
[2]*Electrical Engineering Department, L. E. College-Morbi,GTU,*

Abstract*— PV solar inverter plays essential role for generating the electricity at distribution end. A large scale PV generation includes photovoltaic array, DC/AC converters and related controllers. PV solar farm feed active power during day time and become inactive in the night time. The increasing penetration level of renewable based distributed generators causes a rise in voltage at point of common coupling (PCC) due to reverse power flow. To regulate voltage at PCC; utilities need to install voltage regulating devices like FACTs. In proposed work utilization of voltage source converter of PV solar farm as a STATCOM for grid voltage regulation at night time when there is no generation of PV farm. It avoids the other voltage compensating devices. A MATLAB/Simulink based simulation study is presented to validate the performance of proposed work.

Keywords*— PV solar farm inverter, PV-STATCOM, Reactive power compensation, Grid voltage regulation, Wind farm

1. INTRODUCTION

Photo voltaic (PV) power systems are becoming more essential in modern grid connected network because of abundantly available solar energy. Nowadays, PV power systems have been widely used for major research purposes, because of its simple analysis of the system performance and interface with utility grids with the help of modeling and computer simulation [1-3].Utilities are presently facing a major challenge of grid integrating an increasing number of renewable-energy-based distributed generators (DGs) while ensuring stability, voltage regulation, and power quality [4]. During the night time, feeder loads are usually much lower compared to daytime, while the wind farms (WFs) produce more power due to increased wind speeds. This potentially causes reverse power to flow from the point of common coupling (PCC) toward the main grid resulting in feeder voltages to rise above allowable limits, typically ±5% [4]–[6]. To regulate voltage at PCC utilities need to install expensive voltage regulating devices (e.g., static var compensator (SVC), static synchronous compensator (STATCOM), voltage regulators, etc.)[4], [7]. Voltage-source inverters are essential components of PV solar farms (SFs), which provide solar power conversion during daytime (normal operation). However, PV SFs are practically inactive during night time and do not produce any real power output. The proposed novel concept is to use the existing SF inverter as a STATCOM during night time to regulate voltage variations at the PCC due to increased and intermittent WF power.

2. GRID CONNECTED PV SYSTEM

Fig.1 shows the single-line diagram of the study system. The solar farms are connected to the electrical grid at a bus is known as a PCC (Point Of Common Coupling).

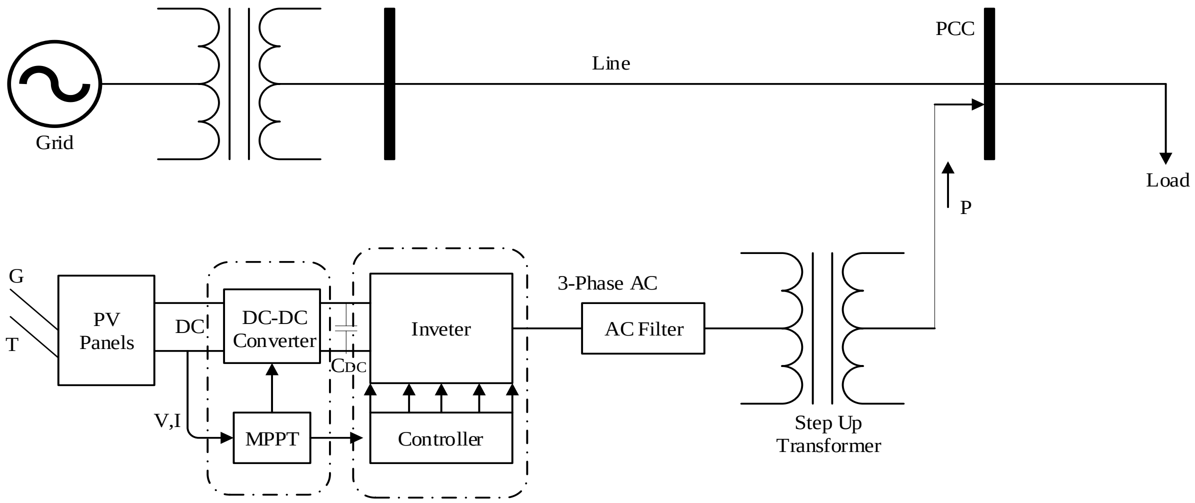

Fig.1 Grid Connected PV System

The electrical grid is an interconnected electrical network which provides the power from supplier to the consumers. The load is considered to be of passive R–L type.

PV solar farms produce DC power with its Photovoltaic solar modules which are affect solar radiation and temperature. A DC-DC converter is used to collect maximum DC power output from the solar modules at the solar radiation and temperature by including the Maximum Power Point Tracking (MPPT) Control [8]. At the input terminal of the inverter by using the DC link capacitor constant voltage is maintained. The Inverter convert DC power into AC form and feed to the Electrical Grid. The inverter consists of semiconductor switches and the controller which control the switching of the device [9]. The AC filter is used to maintain power quality of output AC power via step up coupling transformer the output voltage of PV system connected with grid. [10]

3. CHALLENGES OF GRID INTEGRATION

The increasing penetration levels of Renewable energy sources at Point of Common Coupling. The major challenges facing by utilities for integration of DG into Grids are elaborated as below [11] [12]:

A. Voltage Rise

The interconnection of Distributed Generations in distributed end may change the feeder voltage profiles and causes voltage rise at Point of Common Coupling (PCC). This voltage rise can substantially when larger DG systems are integrated at long and lightly loaded feeders. This situation is shown generally in rural areas. This may lead the operations of overvoltage protections.

B. Voltage Fluctuations

The variations in Output due to the intermittent natures of DG like PV solar farms; Wind Farms; can significant impacts on feeder voltages. The fluctuations in voltages can degrade the power quality and raises complaints from the customer's side.

C. Interactions with Voltage Regulating Devices

Voltage fluctuations and voltage rise may lead the frequent operations of voltage regulating devices like Load Tap Changer (LTC); capacitor banks and line voltage regulators which may rise maintenance and affect on equipment life cycles.

D. Reverse Power Flow

Increasing penetration levels of Distribution Generations on utility grid can offset the feeder loads and lead to reverse power flow from PCC toward the Grid. It can cause problems for the protection system; mostly in relay coordination and setting of over current limits of fuses. Generally the Distribution feeder designed for unidirectional power flows; the condition of reverse power flow may affect relay coordination of the over current protection and the operations of line voltage regulating devices.

A Distributed Generation dominated by wind energy; especially during night-time; feeder loads is lower as compared to daytime. Due to rise in wind speed; the wind farms generate more power. This increased power generated from wind farms causes reverse power flow from the PCC towards the main grid. Since the present distribution system was designed and operated with that power always flow from the main grid to end users; This condition causes the feeder voltage rise above their rated values which may excess the permissible voltage limits typically ±5%) according to IEEE Standard for Interconnecting distributed Resources with Electric Power Systems (IEEE 1547-2003). The DG must be disconnected from the grid during voltage violation is higher than permissible limits during such situations [13] [14]. To maintain the voltage within acceptable limits; traditionally on load tap changing (OLTC) Transformers and Power electronics based voltage regulating FACTs devices like a static var compensator (SVC); Static synchronous compensator (STATCOM) etc. are used to maintain voltage profiles in the distribution network [15].

Static synchronous compensator (STATCOM)

A STATCOM is a shunt connected static var compensator that is able to generate and/or absorb reactive power at a given bus location and in which the output can be varied. A Schematic Diagram of the STATCOM is shown in Fig.2

The STATCOM is connected to the AC system with a coupling transformer. The operational characteristic of STATCOM is dependent on the voltage of the VSC and the reactance of the coupling transformer. The typical coupling transformer reactance has values between 10 and 20% of the voltage drop. It corresponds to 10 or 20% of nominal voltage of the network in the range of the STATCOM nominal current [14].

Fig.3 shows that the terminal characteristic of the VSC based STATCOM. It is observed that the STATCOM can capable to supply rated capacitive current at very low voltage level. For voltage Regulated mode; if the output voltage of the inverter Vvsc > Vgrid the reactive power flow from the STATCOM to the grid and in contrast reactive power absorbed from the system while Vvsc < Vgrid If Vvsc = Vgrid no reactive power flows to the system that is known the floating condition of the STATCOM [16].

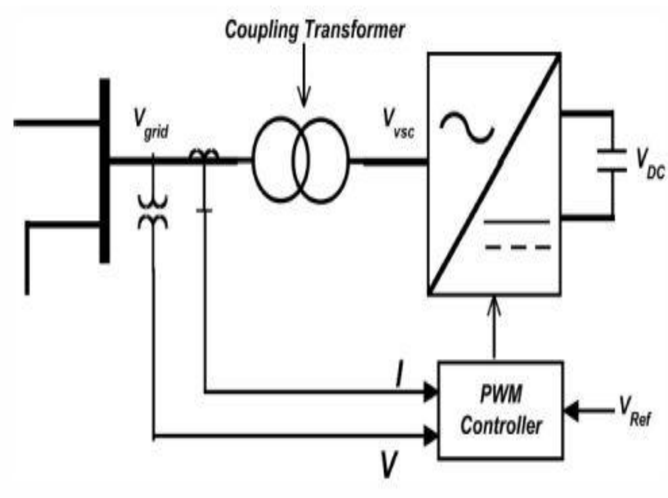

Fig.2 Schematic Diagram of STATCOM

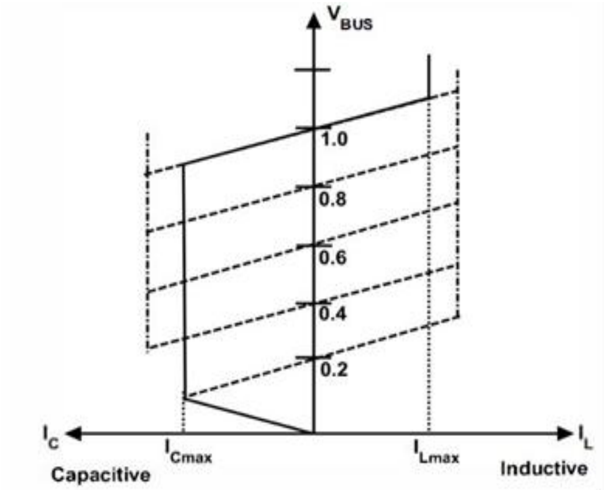

Fig.3 Terminal Characteristic of STATCOM

4. PV SOLAR SYSTEM CONTROLLER DESIGN

In proposed research work; VSI (voltage source inverter) is proposed for utilizing a PV solar farm inverter as a STATCOM during night time for voltage regulation at PCC. It converts DC output of Solar Panels into the AC form during day time in all conditions. The STATCOM operation for the proposed work is based on the charged DC Link capacitor voltage is inverted during Night mode apart from absorption of the power from the grid.

The fig.4 and fig.5 shows the block diagram of the PV Inverter control scheme used to achieve the proposed concept.

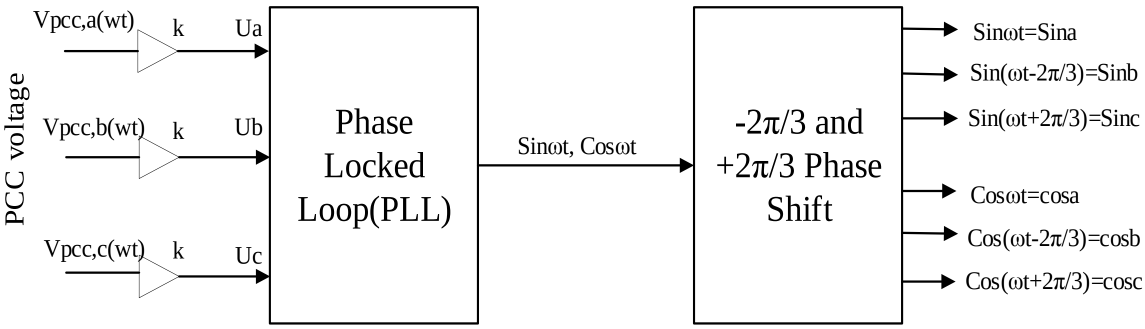

Fig.4 PV STATCOM Controller of Grid Voltage Regulation Synchronization

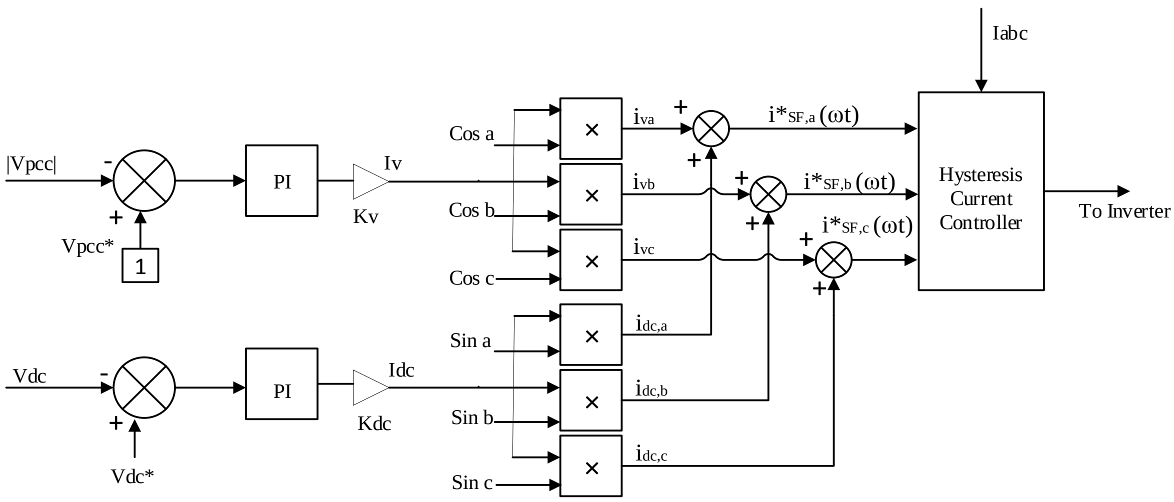

Fig.5 PCC Voltage Regulation Loop, DC Link Voltage Regulation Loop

The main block diagram of the proposed controller scheme for inverter in current control mode is shown in Fig.6. The controller is composed of two voltage regulation loop based on proportional-integral (PI) controllers. Here first loop regulates PCC voltage and second loop regulates DC link voltage constant over solar farm inverter capacitor.

The inverter output current (Iinv) injected into the distribution system is divided into two individually regulated components; the active component IA and reactive component IR which are controlled by two PI controllers. The IR injected into the grid is regulated to maintain the voltage at PCC by loop-l and loop-2 maintained the constant voltage across the capacitor by regulating the amount of IA drawn by inverter from the system which compensated the losses related with the STATCOM operation.

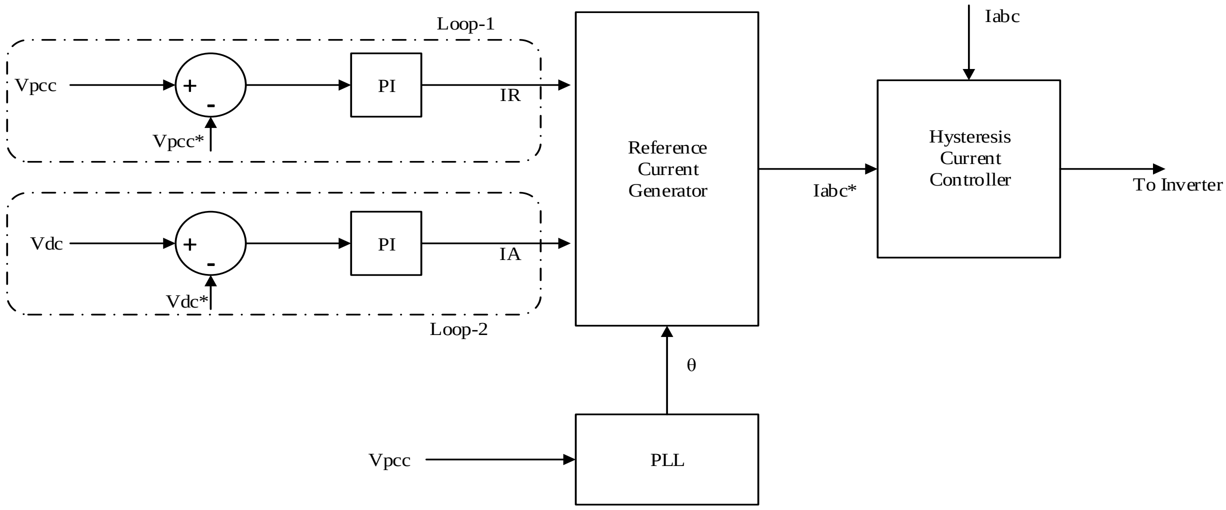

Fig.6 Block Diagram of inverter Control Scheme

The voltage across PCC is regulated by supplying lagging or leading power during the bus voltage rise and drop above and below the specified limit (±5%);respectively. A phase locked loop (PLL) issued to maintain synchronization of the injected current with the PCC voltage. The output gives by PLL in the terms of cosine and sine functions [17]. The cosines functions are used to produce the reference quadrature components of current that maintain the voltage across PCC. The sine functions are used to produce the in phase current components that maintain the DC link voltage at predefined reference value. The hysteresis current control technique is used to perform switching of the inverter with the band value of HB =0.5 and switching frequency of Fs=10 kHz.

The θ which is obtained by PLL is used for reference current Iabc* is compared with inverter output current Iabc. The error in the form of signal is fed to the hysteresis current controller; which generates gating pulses for inverter. The output of both PI controllers is obtained from comparing Vpcc and Vdc separately loop mention as above in the synchronous reference frame Fig.6.

5. SIMULATION

The proposed scheme is simulated for 1MW solar power plant with the voltage level of 33kV; 50Hz in the MATLAB / Simulink Environment. The Simulink model of the study system is shown in the Fig. 7. The model consists of radial distribution feeder; loads; PV solar farm and distributed generator.

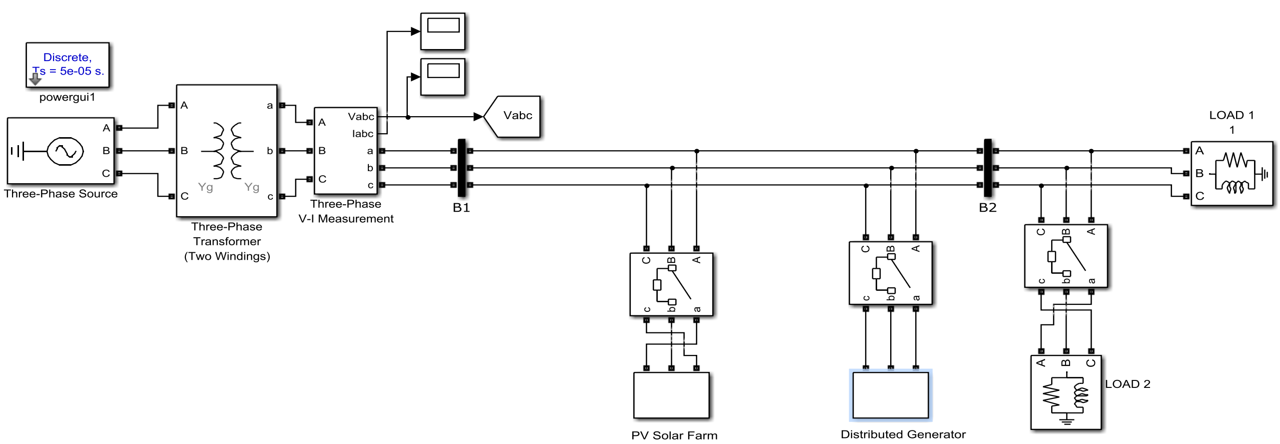

Fig. 7 MATLAB-Simulink Model of Study System

During night time; PV solar farm and DG of wind power plant of 1MW are connected with 33kV radial distribution feeder. The loads are considered to passive RL type. The parameters are used in the simulation is shown in the Table 1.

In the given case; DG is already connected to the system to support the energy demand of the load. The switching of load L2 is disconnected at the instant of T1=0.3s. And the generation of DG is increased (1.5pu) to make prototype change in actual wind speed at the instant T2=0.4s. Initially at T=0s; PV solar farm is not operated as STATCOM which is observed in simulated output results. Line voltage profile at PCC without any compensation is stated as Fig.10. Which indicates that voltage rise during 0.3-0.4s because of light loading. After the instant T2=0.4s; the voltage at PCC rises due to reverse power flow from DG and exceeding the utility specification of ±5%.

The PV solar farm should be now operated as STATCOM. The regulated Vpcc is obtained and indicated as Fig.11. It has been observed that; by the PV STATCOM; the voltage variation (11%) is controlled within the allowable limit according to IEEE 1547.The MATLAB-Simulink Model of Subsystem of PV solar farm and MATLAB-Simulink model of Proposed Controller are shown in the Fig.8 and Fig.9 respectively.

TABLE 1: SYSTEM PARAMETERS

Parameters	**Value**
Grid Voltage	33 kV
Grid Frequency	50 Hz
DC bus voltage	850 V
Filter Inductor	3.5 mH
PV Interfacing transformer	
MVA rating	1 MVA
Transformation Ratio	0.5/33 kV
Grid Transformer	
MVA rating	10 MVA
Transformation ratio	120/33 kV
Load-1	2000 kW,20 kVar
Load-2	7000 kW,10 kVar

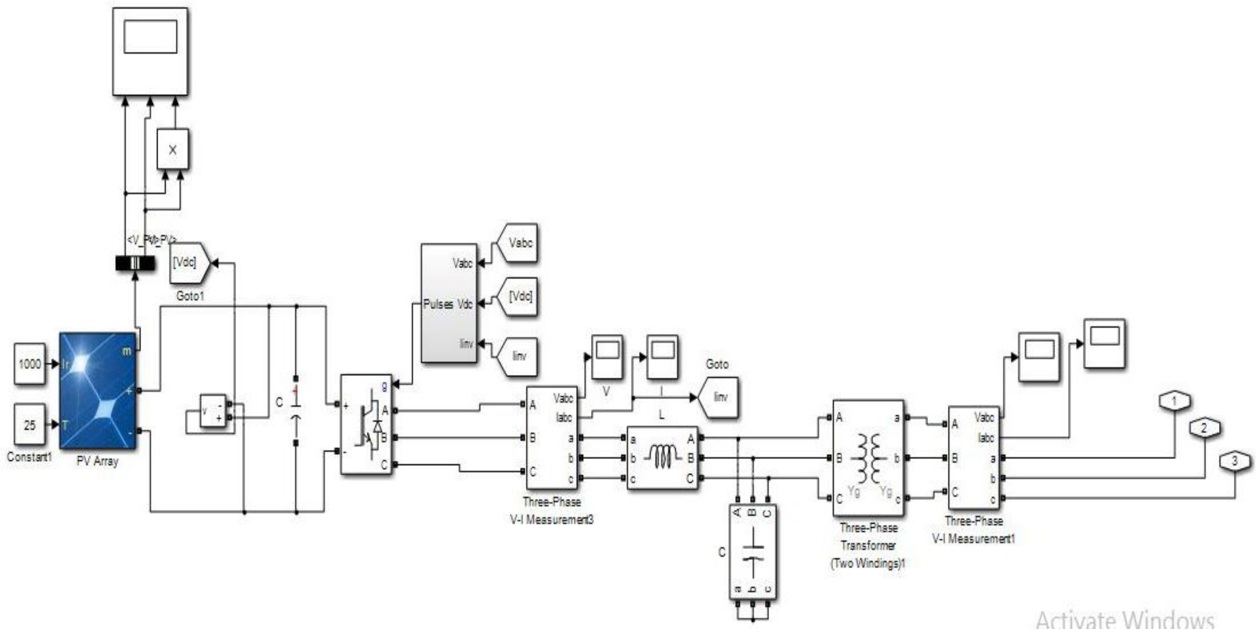

Fig.8 MATLAB-Simulink Model of Subsystem of PV solar farm

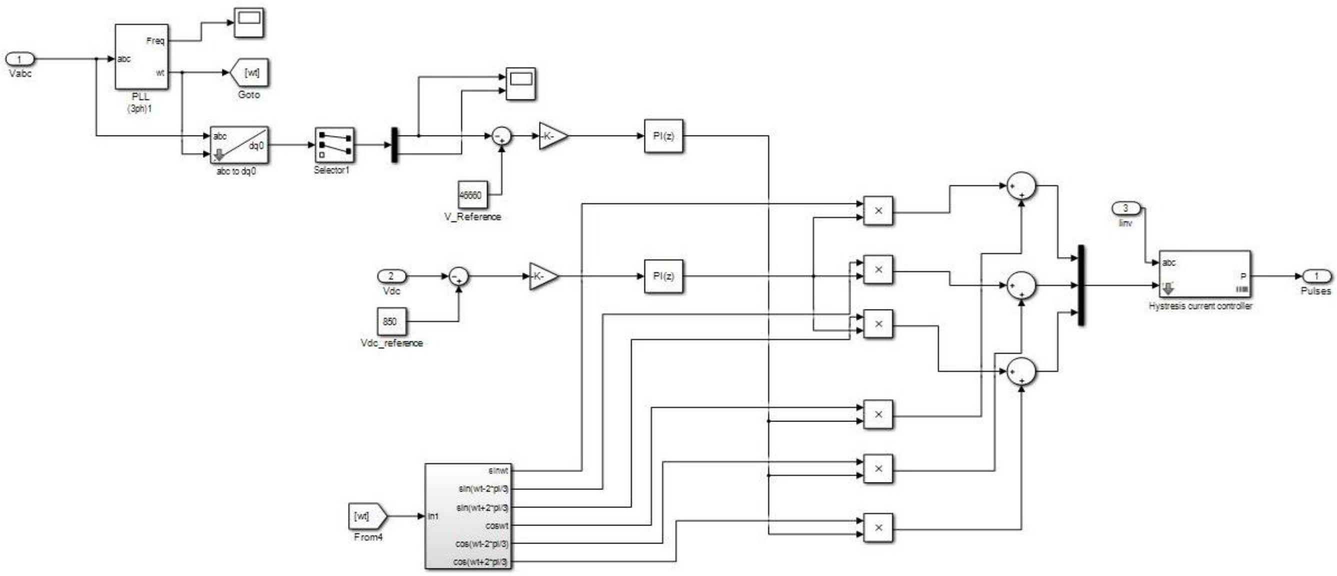

Fig.9 MATLAB-Simulink model of Proposed Controller

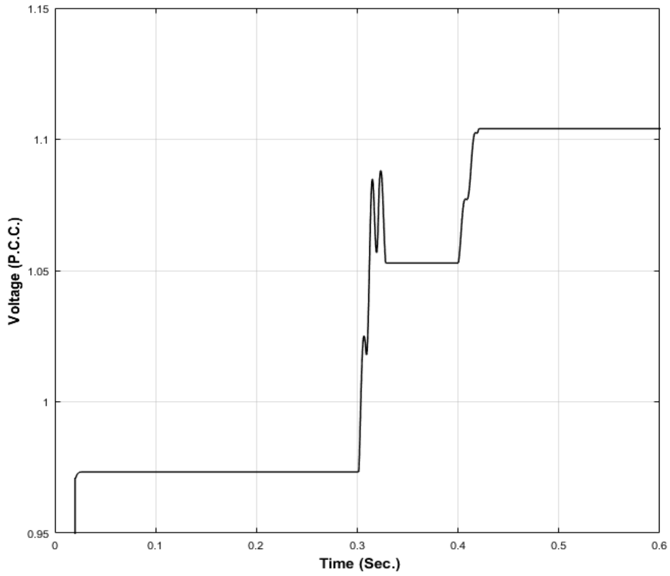

Fig.10 PCC Voltage Profile before PV Solar Farm as STATCOM

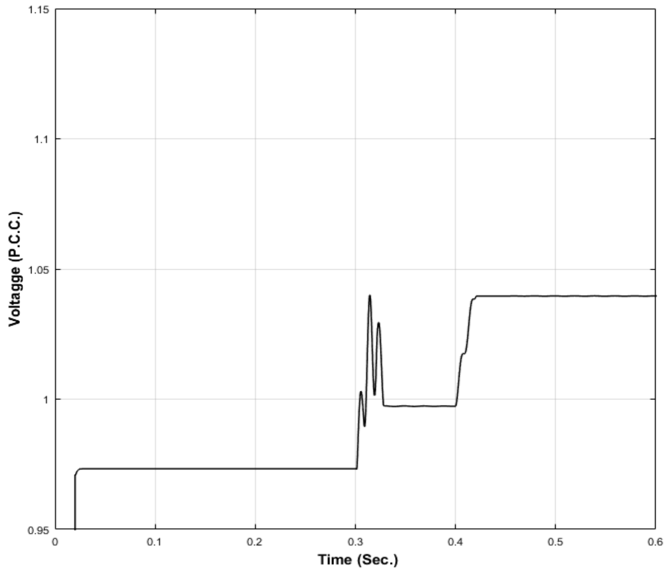

Fig.11 PCC Voltage Profile after PV Solar Farm as STATCOM

Fig.10 Shows the PCC voltage profile before PV Solar Farm as STATCOM, It has been observed that the voltage variation is about 11% and that will regulated within allowable limit specified by utilities by utilizing the PV Solar Farm as STATCOM. Fig11 Shows the regulated PCC voltage profile after the PV Solar Farm as STATCOM. It is also observed that after time T2; a significant amount of reverse power flow at PCC has been maintained within the permissible limit by PV STATCOM is achieved and shown in Fig.11.

6. CONCLUSION

A Novel concepts of optimal utilization of PV SF as a STATCOM for a weak grid to regulate the voltage variation during night time has been proposed and results are validated through MATLAB/Simulink Simulation. The solar farm inverter is utilized to regulate the distribution voltage at PCC within the limits specified by utilities even during large variation in wind farm outputs and loads. Here PV solar farms generate active power during daytime and provides ancillary services during nighttime When solar plant is inactive, can result 24hrs utilization of solar farm inverter. This PV-STATCOM operation gives a new chance for PV solar farm to earn revenues in night time with addition to the deal of real power during the day.

REFERENCES

[1] Rajiv K. Varma, Shah Arifur Rahman, Tim Vander Heide, “New control of PV solar farm as STATCOM (PVSTATCOM) for increasing grid power transmission limits during night and day”, IEEE transactions on power delivery, vol.30, no.2, pp.755-763, April 2015.

[2] Weidong Xiao, Fonkwe Fongang Edwin, Giovanni Spagnuol and Juri Jatskevich, "Efficient Approaches for Modeling and Simulating Photovoltaic Power Systems", IEEE journal of photovoltaics, vol. 3, no. 1, pp.500-508, January 2013.

[3] R. K. Varma, S. A. Rahman, and R. Seethapathy, "Novel control of grid connected photovoltaic (PV) solar farm for improving transient stability and transmission limits both during night and day," in Proc. World Energy Conf., Montreal, QC, Canada, pp. 1–6,2010.

[4] R. Zavadil, N. Miller, A. Ellis, E.Muljadi, E. Camm, and B. Kirby, "Queuing up," IEEE Power Energy Mag., vol. 5, no. 6, pp. 47–58, Nov./Dec. 2007.

[5] J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galvan, R. C. P. Guisado, Ma. A. M. Prats, J. I. Leon, and N. Moreno-Alfonso, "Power electronic systems for the grid integration of renewable energy sources: a survey," IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1002–1016, Jun. 2006.

[6] D. Patel, R. K. Varma, and R. Seethapathy, "Impact assessment of distribution generation on medium voltage distribution systems of Hydro One Networks Inc.," presented at the CIGRE Canada Conf. Power Syst., Winnipeg, MB, Canada, Oct. 19–21, 2008, pp. 1–7, Paper 544.

[7] N.G.Hingorani and L. Gyugyi, Understanding FACTS: Concept and Technology of Flexible AC Transmission System, New York/Piscataway, NJ: Wiley/IEEE Press, 2000.

[8] Muhammad H. Rashid, "power electronics handbook, devices, circuits, and applications." Academic Press is an imprint of Elsevier, 2007.

[9] Thomas Ackermann, Valery Knyazkin, "Interaction between Distributed Generation and the Distribution Network: Operation Aspects", in Transmission and Distribution Conference and Exhibition 2002: Asia Pacific. IEEE/PES, Oct 6-10, 2002, vol 2, pp. 1357-1362.

[10] C. Dai and Y. Baghzouz, "On the Voltage Profile of Distribution Feeders with Distributed Generation", in Power Engineering Society General Meeting, IEEE, Jul 13-17, 2003, vol 2

[11] Agu'ero; J.R.; Steffel; SJ. "Integration challenges of photovoltaic distributed generation on power distribution systems"; Power and Energy Society General Meeting;2011 IEEE; on page(s):1-6

[12] F. Katiraei and J. R. Aguero; "Solar PV Integration Challenges; "IEEE Power and Energy Magazine; vol. 9; issue.3; pp 62-71; 2011.

[13] "IEEE application guide for IEEE Std 1547; IEEE Standard for interconnecting distributed resources with electric power systems, "in IEEE Std 1547.2-2008; 2009; pp. 1-207.

[14] ANSI C84.1-20 II. Table. I; Revision of. ANSI C84.1-2006.American National Standard. For Electric Power Systems and Equipment.

[15] R. M. Mathur and R. K. Varma; "Thyristor-Based FACTS Controllers for Electrical Transmission Systems"; New York: Wiley-IEEE Press; 2002.

[16] Farhad Shahnia; Sumedha Rajakaruna; Arena Ghosh. "Static Compensators (STATCOMs) in Power Systems". Springer International Publishing. 20 IS.

[17] Sumathi, S., Ashok Kumar, L., Surekha, P. "Solar PV and Wind Energy Conversion Systems", Green Energy and Technology, Springer International Publishing. 2015.

[18] Niraj Solanki, Jatinkumar Patel. "Utilization of PV Solar Farm for Grid Voltage Regulation during Night; Analysis & Control" IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES-2016).

[19] Viral Kumar Patel, Jatinkumar Patel. "Power Quality Improvement of Grid Using Solar Photovoltaic Farm". International Conference on Innovations in Power and Advanced Computing Technologies [i-PACT2017]