PV Solar Farm as STATCOM(PV-STATCOM) for Increasing Grid Power

B. Bhaskar
Assistant Proffessor
Department of Electrical and Electronics Engineering ,
Chaitanya Institute of Technology and Science,
Hanamkonda, Warangal, Telangana, India

S. Suresh
M.Tech student, P.E.
Department of Electrical Engineering
Chaitanya Institute Of Technology And Science,
Warangal, Telangana,India

Abstract: This paper presents novel technologies for utilization of PV solar farm inverter in night time for providing multiple benefits to power systems, as well as accomplishing the same objectives during the daytime from the inverter capacity left after production of real power. The new technology transforms a solar farm inverter functionally into a dynamic reactive power compensator known as STATCOM, and termed PVSTATCOM. Novel PVSTATCOM control is employed to significantly enhance the power transfer limit of a long transmission line both in the nighttime and also during daytime even when the solar farm is producing a large amount of real power. This technology can open up new avenues for solar farms to earn revenues apart from the sale of real power.

Keywords: Photovoltaic (PV) Solar Farms, Inverter Modeling, STATCOM, PV-STATCOM, Reactive Power Compensation, Voltage Control, Damping Control

I. INTRODUCTION

Flexible AC transmission system (FACTS) controllers are being increasingly considered to increase the available power transfer limits/capacity (ATC) of existing transmission lines [1]–[4], globally. New research has been reported on the nighttime usage of a photovoltaic (PV) solar farm (when it is normally dormant) where a PV solar farm is utilized as a STATCOM–a FACTS controller, for performing voltage control, thereby improving system performance and increasing grid connectivity of neighboring wind farms [5], [6]. New voltage control has also been proposed on a PV solar farm to act as a STATCOM for improving the power transmission capacity.

Although, [8] and [9] have proposed voltage-control functionality with PV systems, none have utilized the PV system for power transfer limit improvement. A full converter-based wind turbine generator has recently been provided with FACTS capabilities for improved response during faults and fault ride through capabilities.

This paper proposes novel voltage control, together with auxiliary damping control, for a grid-connected PV solar farm inverter to act as a STATCOM both during night and day for increasing transient stability and consequently the power transmission limit. This technology of utilizing a PV solar farm as a STATCOM is called “PV-STATCOM.” It utilizes the entire solar farm inverter capacity in the night and the remainder inverter capacity after real power generation during the day, both of which remain unused in conventional solar farm operation.

Similar STATCOM control functionality can also be implemented in inverter-based wind turbine generators during no-wind or partial wind scenarios for improving the transient stability of the system. Studies are performed for two variants of a single-machine infinite bus (SMIB) system. One SMIB system uses only a single PV solar farm as PV-STATCOM connected at the midpoint whereas the other system uses a combination of a PV-STATCOM and another PVSTATCOM or an inverter-based wind distributed generator (DG) with similar STATCOM functionality.

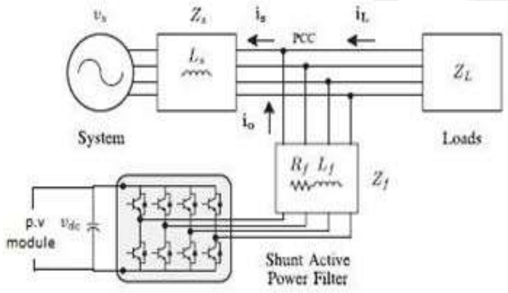
Three-phase fault studies are conducted using the electromagnetic transient software MATLAB, and the improvement in the stable power transmission limit is investigated for different combinations of STATCOM controllers on the solar and wind farm inverters, both during night and day.

II. RELATED WORKS

The transfer function is comprised of a gain, a washout stage, and a first-order lead-lag compensator block. This controller is utilized to damp the rotor-mode oscillations of the synchronous generator and thereby improve system transient stability. The damping controller is activated by toggling “Switch-2” to the “ON” position. This damping controller can operate in conjunction with either the conventional reactive power control model with the PCC voltage-control mode by toggling “Switch-1”to position “B” or “A,” respectively. At first, the base-case generator operating power level is selected for performing the damping control design studies. This power level is considered equal to the transient stability limit of the system with the solar farm being disconnected at night. At this operating power level, if a three-phase fault occurs at Bus 1, the generator power oscillations decay with a damping ratio of 5%. The solar farm is now connected and operated in the PV-STATCOM mode. The parameters of the damping controller are selected as follows. The washout time constant is chosen to allow the generator electromechanical oscillations in the frequency range up to 2 Hz to pass through. The gain, time constants, and are sequentially tuned to obtain the fastest settling time of the electromechanical oscillations at the base-case generator power level through repetitive PSCAD/EMTDC simulations. Thus, the best combination of the controller parameters is obtained with a systematic hit-and-trial technique, and the parameters are given. It is emphasized that these controller parameters are not optimal and better parameters could be obtained by following more rigorous control-design techniques. However, the objective of this paper is only to demonstrate a new concept of using a PV solar farm inverter as a STATCOM using these reasonably good controller parameters. In this controller, although the line current magnitude signal is used, other local or remote signals, which reflect the generator rotor-mode oscillations [1], may also be utilized.

III. THE PROPOSED APPROACH

SMIB system in which a large equivalent synchronous generator (1110 MVA) operating at 22kV system supplies power to the infinite bus over a 200 km, 400 kV transmission line. An 1110 MVA, 22/400kV transformer having leakage reactance of 8.66% is coupled with the generator. This line length is typical of a long line carrying bulk power in Ontario. In Study System 1, a 100MW PV solar farm (DG) as a STATCOM (PV-STATCOM) is connected at the midpoint of the transmission line.



a) PV-STATCOM Based on "Un-Used" PV Solar Farm Inverter Capacity:

As the PV solar farm remains completely idle during nighttime, the entire capacity of its inverter can be used as STATCOM. However, during daytime the PV solar farm generates real power for the grid either by using the whole inverter capacity (at rated power generation around noon time on sunny days or partial inverter capacity (at a lower level of real power generation during early mornings and late evenings or anytime in a cloudy day). As a result, substantial inverter capacity is left unutilized during the morning, evening, and on cloudy days. Hence, during the daytime the remaining PV inverter capacity can be used to act as STATCOM during daytime without affecting the normal real power generation functionality of the PV solar farm.

In other words, there is= no real power curtailment due to PV-STATCOM operation and the PV modules do not need to be disconnected from the inverter. From the rated inverter capacity of "S'MVA, the remaining available reactive power "Q' for PV-STATCOM operation is obtained as Q=sqrt (S2-P2) , where P is the real power produced by the solar farm.

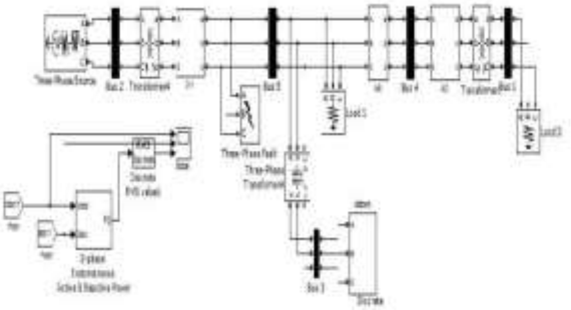
The PV solar farm is operated as a PV-STATCOM for providing controlled reactive power exchange with the transmission system. These results in voltage regulation as well as damping enhancement of electromechanical and inter area oscillations. Both of these functions lead to a much desired increase in transient stability and power transfer capacity across long lines.

b) PV-STATCOM Based on "Used" Solar Farm Inverter Capacity:

Another novel control concept of PV-STATCOM examined in this thesis is the disconnection of PV solar farm modules on an emergency demand basis for a temporary period. The PV modules are disconnected completely or partially from the inverter to curtail the PV generation. The newly made available inverter capacity is now utilized as PV-STATCOM to provide dynamic reactive power support for short durations of time during critical events. These are events which could have serious implications on power systems such as critical Induction Motor (IM) failures, or impending blackouts. In Fig. 3, for an event of duration t, the shaded area ABCD denotes the curtailment of PV solar farm real power generation, whereas the dotted area AEFD denotes the newly made available „Q" support during these events.

IV. RESULTS AND DISCUSSIONS

The conventional reactive power control only regulates the reactive power output of the inverter such that it can perform unity power factor operation along with dc-link voltage control. The switching signals for the inverter switching are generated through two current control loops in d-q-0 coordinate system. In this simulation, the voltage vector is aligned with the quadrature axis, that is, Vd=0, hence, is only proportional to which sets the reference for the upper control loop involving PID1. Meanwhile, the quadrature axis component is used for dc-link voltage control through two PID controllers (PI-2 and PID-3) according to the set point voltage provided by the MPPT and injects all available real power ―P‖to the network. To generate the proper IGBT switching signals (gt1, gt2, gt3, gt4, gt5, gt6), the d – q components (md and mq) ofthe modulating signal are converted into three-phase sinusoidal modulating signals and compared with a high-frequency (5-kHz)fixed magnitude triangular wave or carrier signal.



The simulation circuit is shown in the above Figure 1(a) and figure 1(b) as a STATCOM with improvement of power factor and performance.

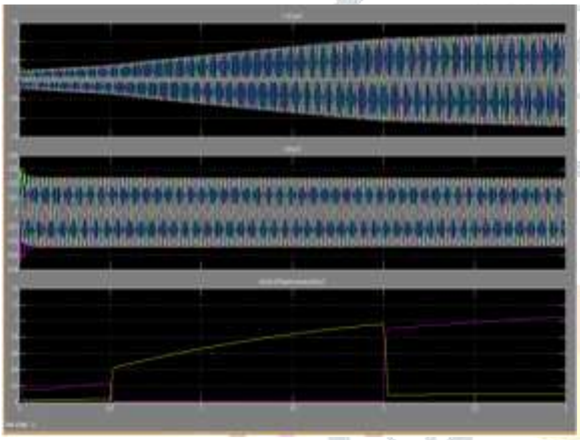


Figure 2: Simulation results at bus3

Figure 2 shown above represents the voltage, current, real power and the reactive power at the bus5. These are measured for three phases. After the connection of PV-STATCOM the voltage increases as shown in the figure.

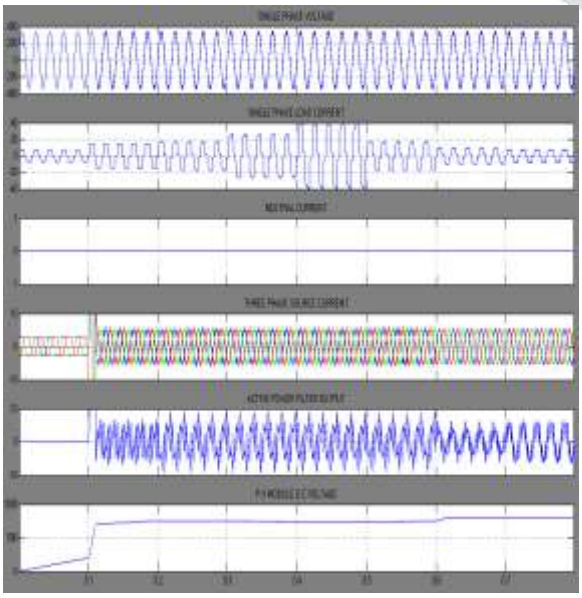


Fig 3 Proposed Matlab/Simulink Output

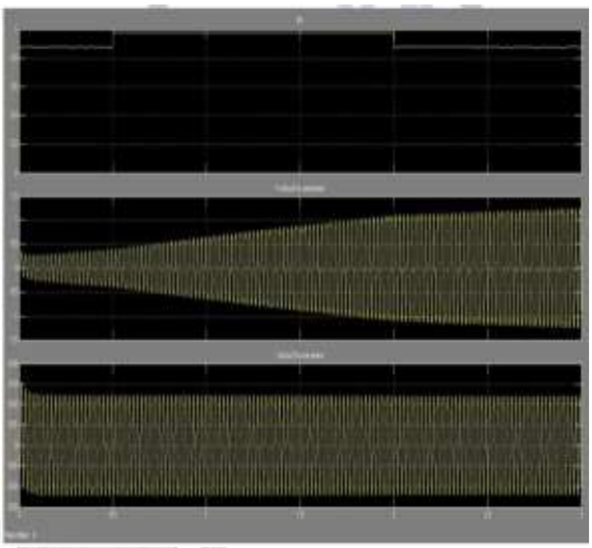


Figure 3: represents the power factor waveform

From the figure it clearly shows that the power factor increases after the connection of PV-STATCOM in the night time. Power factor increases from 0.8 to 0.98.

Voltage correction

a) Steady State Performance: The PV solar system acts as a STATCOM for providing voltage support during the night time with the full rated inverter capacity, and during the daytime with the inverter capacity remaining after real power generation capability of PV solar system during night time. As expected the voltage capability increases with the size of the PV solar system.

b) Transient performance: The transient response of the controller of the PV solar system following a 5 cycle three phase fault at a neighboring substation is shown in Fig.4. The fault occurs at 0.20seconds. The PV inverter controller responds rapidly achieving a steady state voltage in approximately 4-5 cycles.

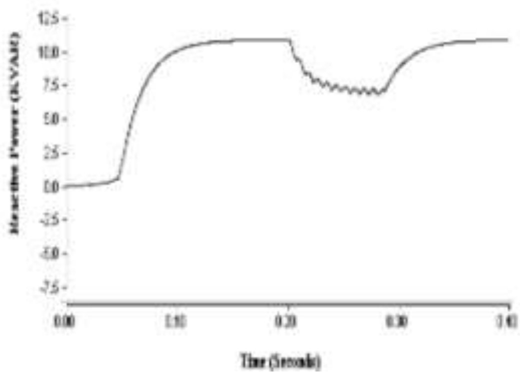


Figure 4: Transient response of PV solar system acting as a STATCOM during Voltage Regulation mode

V. CONCLUSION

PV solar farms remain absolutely unutilized during the night and are only partially utilized during the day. This chapter presents the concepts of a novel use of a PV solar farm inverter as a PV-STATCOM, which can potentially lead to complete utilization of the PV solar farm inverter asset both during night and day. Two sets of novel PVSTATCOM technologies are presented: one based on the ―unused‖ capacity of the solar inverter, and the other based on ―used‖ capacity of the solar inverter. These new applications of PV solar farms can help to improve the performance of power systems. In addition, they can potentially bring new sources of revenue for PV solar farms by providing these benefits, in addition to those earned from the sale of real power.

REFERENCES

[1] R. M. Mathur and R. K. Varma, Thyristor-Based FACTS Controllers forElectrical Transmission Systems. Hoboken, NJ, USA: Wiley/IEEE,2002.

[2] S. A. Rahman, R. K. Varma, and W. Litzenberger, “Bibliography ofFACTS applications for grid integration of wind and PV solar powersystems: 1995–2010, IEEE working group report,” presented at theIEEE Power Energy Soc. Gen. Meeting, Detroit, MI, USA, Jul. 2011.

[3] Y. Xiao, Y. H. Song, C.-C. Liu, and Y. Z. Sun, “Available transfercapability enhancement using FACTS devices,” IEEE Trans. PowerSyst., vol. 18, no. 1, pp. 305–312, Feb. 2003.

[4] Cross Texas Transmission, Salt fork to gray project. 2014. [Online].Available: http://www.crosstexas.com/SFWind.htm

[5] R. K. Varma, V. Khadkikar, and R. Seethapathy, “Nighttime application of PV solar farm as STATCOM to regulate grid voltage,” IEEETrans. Energy Convers., vol. 24, no. 4, pp. 983–985, Dec. 2009.

[6] R. K. Varma and V. Khadkikar, “Utilization of solar farm inverter asSTATCOM,” U.S. Provisional Patent, Sep. 15, 2009.

[7] R. K. Varma, S. A. Rahman, and R. Seethapathy, “Novel control ofgrid connected photovoltaic (PV) solar farm for improving transientstability and transmission limits both during night and day,” in Proc.World Energy Conf., Montreal, QC, Canada, 2010, pp. 1–6.

[8] R. A. Walling and K. Clark, “Grid support functions implemented inutility-scale PV systems,” in Proc. IEEE Power Energy Soc, Transm.Distrib. Conf. Expo., 2010, pp. 1–5.

[9] F. L. Albuquerque, A. J. Moraes, G. C. Guimaraes, S. M. R. Sanhueza,and A. R. Vaz, “Photovoltaic solar system connected to the electricpower grid operating as active power generator and reactive powercompensator,” Solar Energy, vol. 84, no. 7, pp. 1310–1317, Jul. 2010.

[10] A. Beekmann, J. Marques, E. Quitmann, and S. Wachtel, “Wind energyconverters with FACTS Capabilities for optimized integration of windpower into trans. and dist. systems,” in Proc. CIGRE, Calgary, AB,Canada, 2009.

[11] S. A. Rahman and R. K. Varma, “PSCAD/EMTDC model of a 3-phasegrid connected photovoltaic solar system,” in Proc. 43rd North Amer.Power Symp., Boston, MA, USA, 2011, pp. 1–5.

[12] K. H. Hussein, I. Muta, T. Hoshino, and M. Osakada, “Maximumphotovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions,” Proc. Inst. Elect. Eng., Gen., Transm. Distrib.,vol. 142, no. 1, pp. 59–64, Jan. 1995.

[13] K. Chatterjee, B. G. Fernandes, and G. K. Dubey, “An instantaneousreactive volt–ampere compensator and harmonic suppressor system,”IEEE Trans. Power Electron., vol. 14, no. 2, pp. 381–392, Mar. 1999.

[14] M. H. Rashid, Power Electronics Handbook. London, U.K.: Academic, 2001, pp. 355,363–364.

BIODATA

B. Bhaskar, Assistant Proffessor
Department of Electrical and Electronics Engineering ,
Chaitanya Institute of Technology and Science,
Hanamkonda, Warangal, Telangana, India

S. Suresh Pursuing M.Tech (PE), Department of Electrical Engineering from Chaitanya Institute Of Technology And Science, Kakatiya University, Hanamkonda, Warangal, Telangana, India.