Control Application of PV Solar Farm as PV-STATCOM for Reactive Power Compensation during Day and Night in a Transmission Network

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Abstract-Solar Farms are absolutely idle in the night and even during daytime operate below capacity in early mornings and late afternoons. Thus, the entire expensive asset of solar farms remains highly unutilized. This paper presents novel technologies for utilization of PV solar farm inverter in nighttime 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, Power factor correction.

I. INTRODUCTION

This chapter presents a new application of a grid connected PV solar farm inverter as a PV-STATCOM, during both night and day for increasing transient stability and consequently, the power transmission limit of long transmission line. It utilizes the entire solar farm inverter capacity during 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 second system uses a combination of a PV-STATCOM and another PV-STATCOM or an inverter based wind Distributed Generator (DG) with similar STATCOM functionality. Three-phase fault studies are conducted using the MATLAB/SIMULINK software, and the improvement in stable power transmission limit is investigated for different combinations of STATCOM controllers on the solar and wind farm inverters, during both night and day.

A conventional grid connected Photovoltaic PV solar farm utilizes an inverter for converting the DC power output from PV arrays into AC power to be supplied to the grid. The STATCOM (a FACTS device) is also based on a voltage sourced converter which functions both as an inverter and rectifier. A novel control technology was proposed by which a PV solar farm can be operated as a STATCOM in the night time as well as during day. During the night time the entire inverter capacity of the PV solar farm is utilized as STATCOM, whereas during the day, the inverter capacity remaining after real power generation is utilized for STATCOM operation. Since this STATCOM is based on a PV solar system, it has been given the name PV-STATCOM. This technology can open up new avenues for solar farms to earn revenues apart from the sale of real power. This will require appropriate agreements between the regulators, network utilities, solar farm developers and inverter manufacturers.

Section I describes the introduction about concept. The literature survey is presented in section II. Performances of different proposed controls both during daytime and nighttime are presented. The implications of this new PV-STATCOM technology and the conclusions are presented in Section III and Section IV, respectively.

II. LITERATURE SURVEY

Many investigations have been carried out on the performance of PV-STATCOM and voltage source inverters. A brief review of literature in this regard is presented in this session. Paper [1] proposes a 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. 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 for wind. Three-phase fault studies are conducted using the electromagnetic transient software EMTDC/PSCAD, and the improvement in stable power transmission limit is investigated for different combinations of STATCOM controllers on the solar farm inverters, both during night and day.

Paper [2] presents the real-time digital simulation of a novel control of PV inverter as STATCOM for power factor correction and voltage regulation on a Real-Time Digital Simulator (RTDS). The controller design for the PVSTATCOM is based on controller designs already presented. In addition, a description of the unique research lab facility created at London Hydro is also provided. This Lab will be utilized for testing the PV-STATCOM, in addition to conducting other Distributed Generator Controls research. The PV-STATCOM technology is expected to be showcased on the local distribution company London Hydro‘s distribution feeder for the first time in Canada, in late 2012.

Paper [3] describes modeling and optimization of STATCOM on AC bus of Microgrid. The paper begins with explaining

STATCOM as a potential solution to voltage fluctuations and reactive power demand on the AC bus and extends to dealing with the control strategies required for the operation of STATCOM.

Paper [4] presents a utilization of the PV solar farm inverter as a STATCOM—a FACTS device for voltage control and power correction, both during for voltage control and power factor correction has been developed which provides voltage regulation and load compensation in the nights utilizing the entire capacity of the existing solar systems inverter. During daytime also, the solar system is made to operate as a STATCOM using its remaining inverter capacity (left after what is needed for real power generation).

Paper [5] contains Particle Swarm Optimization (PSO) is an evolutionary technique that is used to solve multi objective optimization problem. In this paper PSO technique is used to estimate the feasible optimal setting for the TCSC device to enhance the power transfer capability of the system to an appreciable limit.

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.

III METHODOLOGY

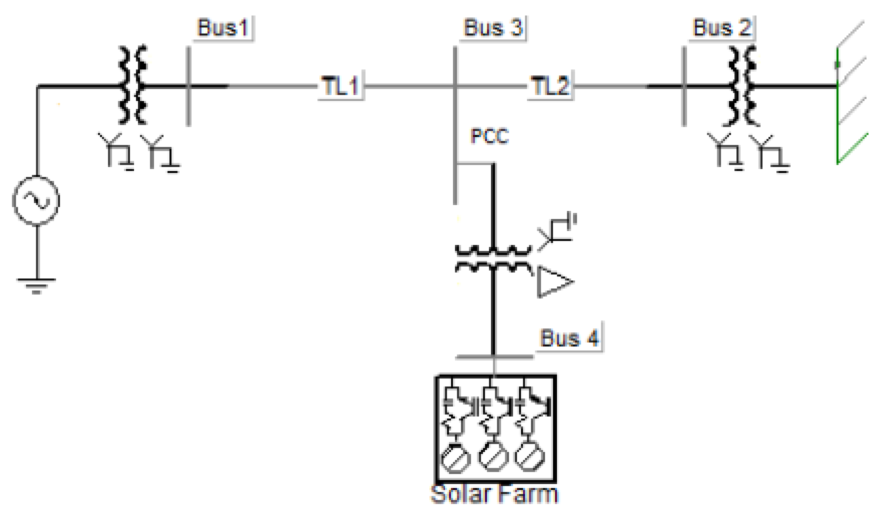


Figure 1: Single line diagram of PV farm connected to grid

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 100 MW PV solar farm (DG) as a STATCOM (PV-STATCOM) is connected at the midpoint of the transmission line.

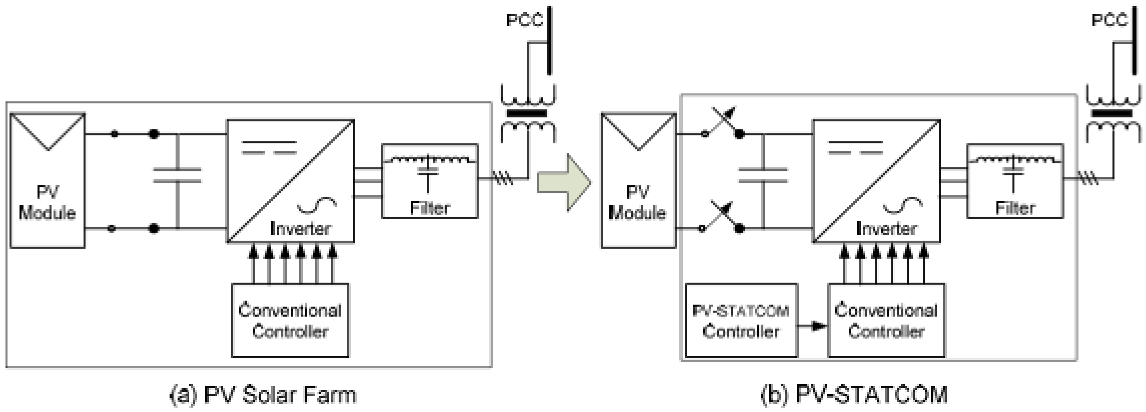


Figure 2: PV solar farm operation as PV-STATCOM during night and day

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

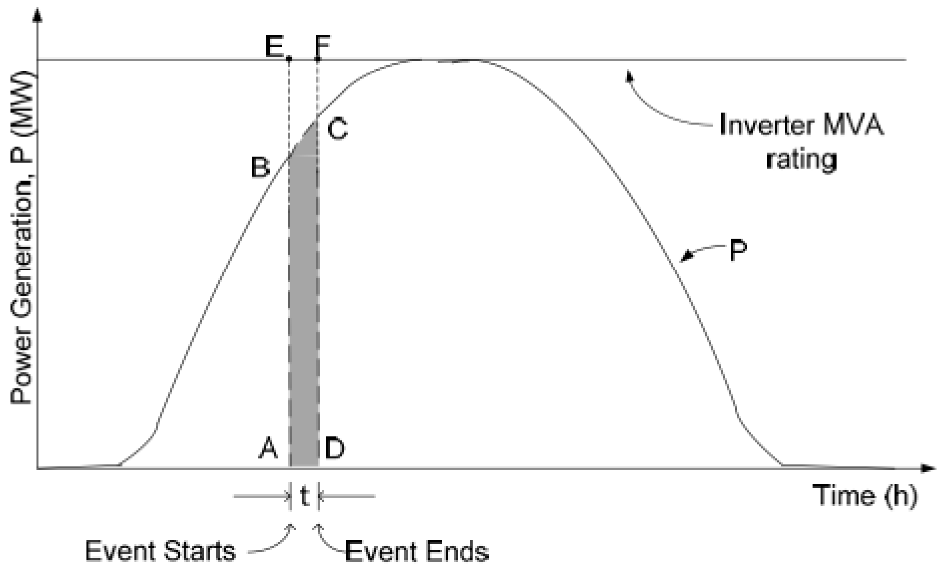
As the PV solar farm remains completely idle during nighttime, the entire capacity of its inverter can be used as STATCOM. However, during daytime the PV solar farm generates real power for the grid either by using the whole inverter capacity (at rated power generation around noon time on sunny days 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 isno 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.



In power systems, there exist critical induction motor loads such as in petrochemical plants, rolling mills, and batch processing plants, where their shutdown, even for a few minutes, could result in a very high loss of revenues, up to millions of dollars. Also during cascading faults, the voltages in the network start sinking, leading to a potential blackout situation.

If PV solar farms are located close to such buses, they can shut down their real power production and operate as PV-STATCOM utilizing their used capacity for a limited duration of time under a pre agreed arrangement with the owners of the critical induction machines or the system operator.

IV. SIMULINK MODEL AND RESULT

Conventional Reactive Power Control: 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 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) of the 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.

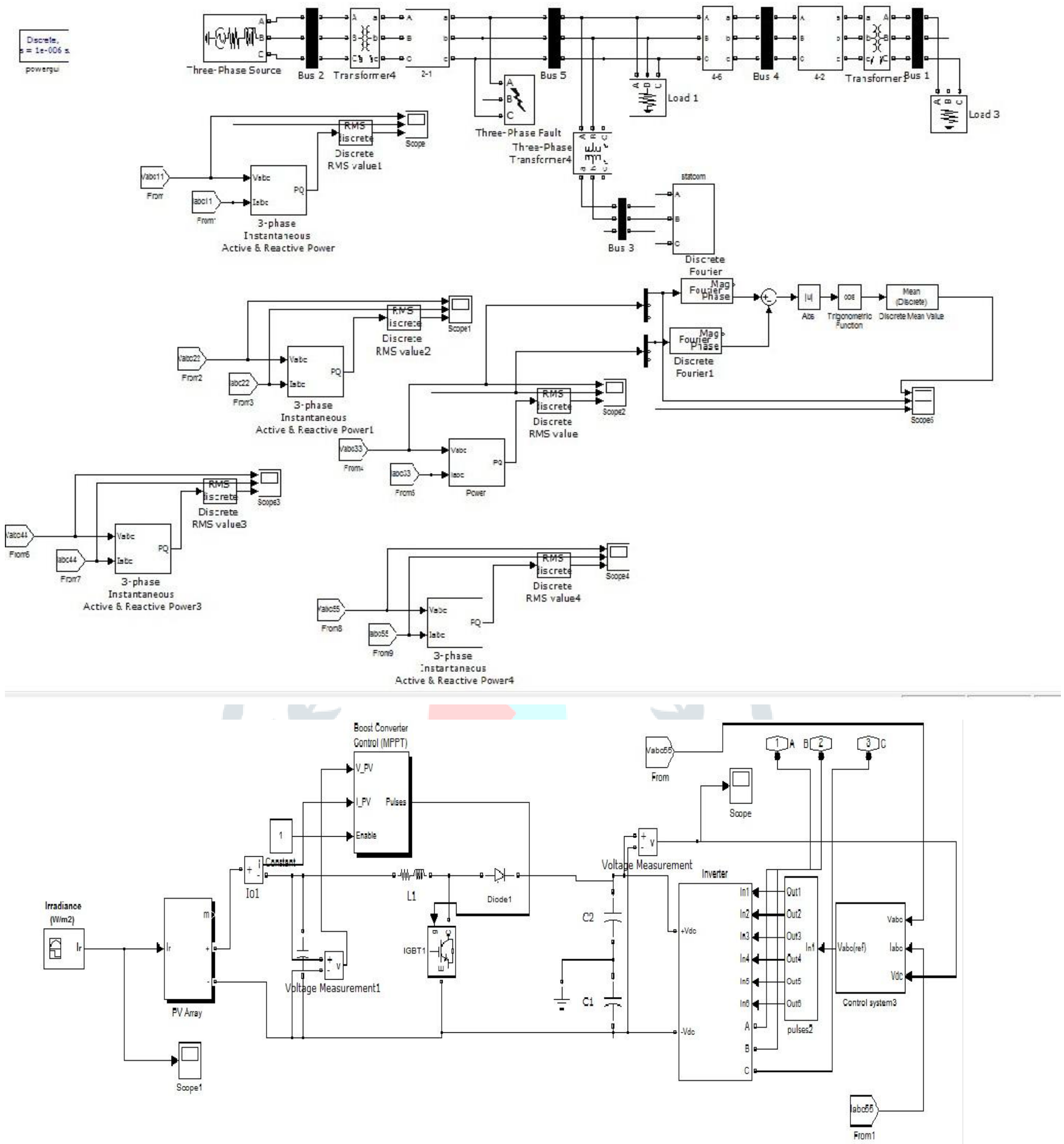


Figure 4: (a) SIMULINK model of Grid connected PV_STATCOM
(b) PV-STATCOM control system

The simulation circuit is shown in the above Figure 4(a) and figure 4(b) as a STATCOM with improvement of power factor and performance.

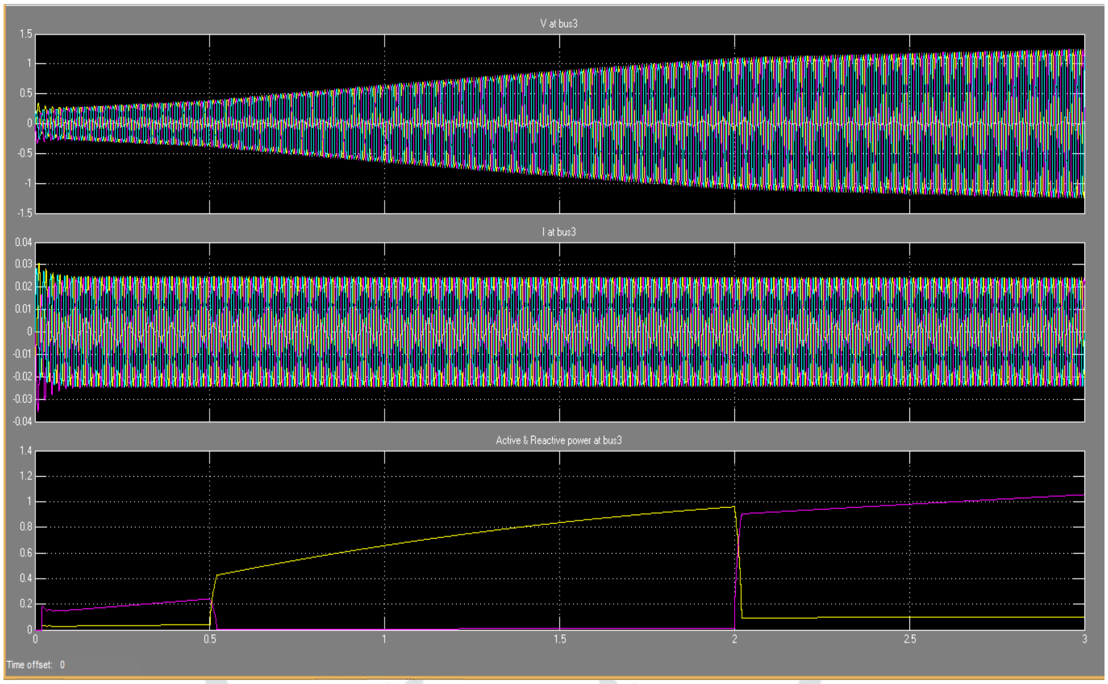


Figure 5: Simulation results at bus3

Figure 5 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.

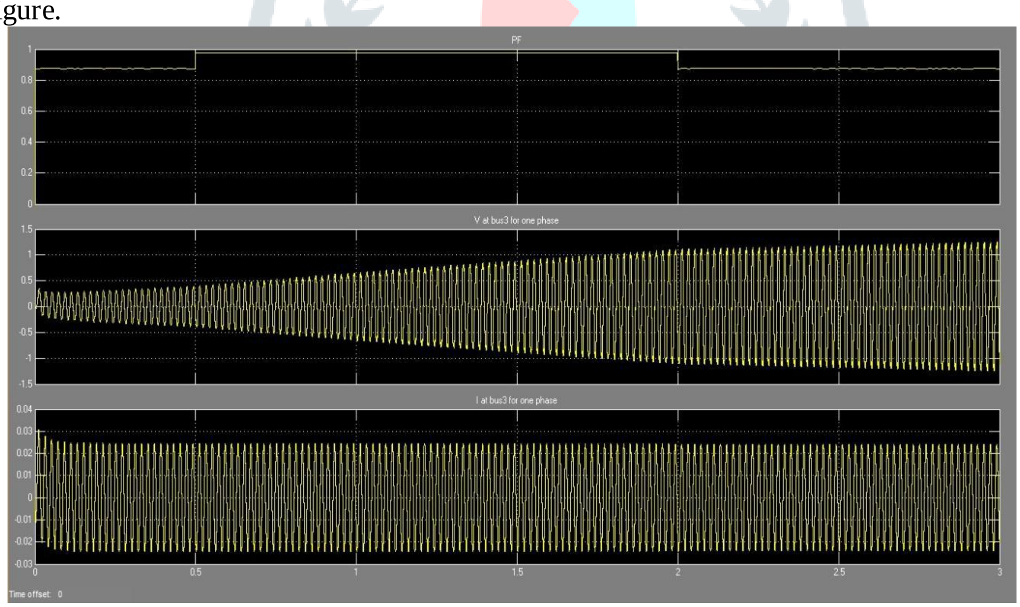


Figure 6: represents the power factor waveform.

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 ratedinverter 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.7. The fault occurs at 0.20seconds. The PV inverter controller responds rapidly achieving a steady state voltage in approximately 4-5 cycles.

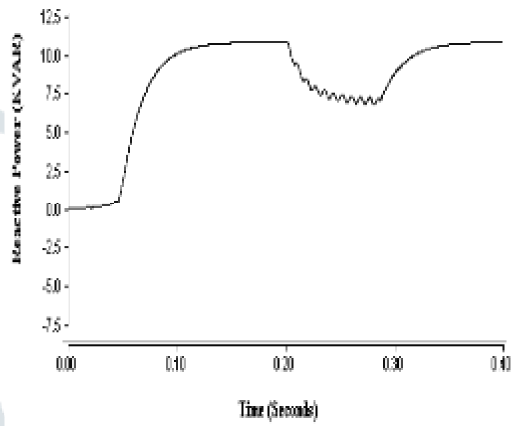


Figure 7: Transient response of PV solar system acting as a STATCOM during Voltage Regulation mode.

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.

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