Performance Analysis of 3 Phase Solar Integrated PV-STATCOM system using MATLAB

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ABSTRACT: This paper introduces novel control method to utilize the solar plant inverter as static synchronous compensator (STATCOM) which is also called as PV- STATCOM to improve the power transmission capacity of the grid system used on the distribution side of power system can be improvised by integrating with renewable energy resources like the photovoltaic system. The proposed system combines both the benefits of distributed generation and active power filtering. Solar integrated PV-STATCOM system consists of back to back series and shunt compensators interlinked by a common DC link capacitor powered by the photovoltaic system. The reactive power compensation is achieved by shunt compensator of PV-STATCOM system. The shunt compensator is also extracting maximum power from solar PV array by operating it at its maximum power point (MPP).The voltage fluctuations like voltage sag/swell are compensated by the series compensator. The performance of the proposed system is simulated in Matlab-Simulink under a nonlinear load consisting of a bridge of diode rectifier with voltage-fed load. PV-STATCOM Conditioner system used on the distribution side of power system can be improvised by integrating with renewable energy resources like the photovoltaic system. The proposed system combines both the benefits of distributed generation and active power filtering. Solar integrated PV-STATCOM system consists of back to back series and shunt compensators interlinked by a common DC link capacitor powered by the photovoltaic system. The reactive power compensation is achieved by shunt compensator of PV-STATCOM system. The shunt compensator is also extracting maximum power from solar PV array by operating it at its maximum power point (MPP).The voltage fluctuations like voltage sag/swell are compensated by the series compensator. The performance of the proposed system is simulated in Matlab-Simulink under a nonlinear load consisting of a bridge of diode rectifier with voltage-fed load.

KEYWORDS: Power Quality, shunt compensator, series compensator, STATCOM, Solar PV.

I. INTRODUCTION

Now a day's due to increasing energy needs and grooving environmental concern, there is a need to focus on the alternative solutions for the non-renewable sources, so that today's trend to use the renewable-energy system. Out of all renewable sources PV solar farm is in the form of green energy sources, which can perform the main part of the program of decreasing the greenhouse-gas emissions. Recently, PV system has become largely popular for the integrated to the grid large as well as small scales. Also, the transmission line faces the problem when renewable systems are connected to the grid due to its limited power transmission capacity. For that purpose, there is need to construct new line which is very expensive. Instead of to construct the new line it is always beneficial to increase the transfer capacity of existing line. To increase the power transfer limit, compensation of the line is done with the use of series and shunt compensators. The major issue in the power system is power quality maintenance due to the implementation of various power electronic circuits. Most of the developed and developing countries rely on renewable energy resources due to the depletion of fossil fuel. In the last ten years, the usage of renewable energy has been increased drastically and to integrate this distributed renewable energy resource usage of power electronic devices becomes necessary. The usage of power electronic devices leads to pollution of the power system by injection of harmonics by these power electronic devices. These harmonics are responsible for the voltage fluctuations in the power system. The voltage fluctuations can affect the sensitive loads and it leads to an increase in operation and maintenance cost in industries [1],[2]. The power quality can be improved by designing appropriate converters. The Power Electronic based Flexible AC Transmission Systems (FACTS) devices improve the quality of power flow in the power system. The main functionality of the FACTS (custom) devices is to provide active and reactive power compensation. Custom power devices such as distribution static compensator (DSTATCOM), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC) are used to mitigate power quality problems caused by loads as well as to protect the sensitive loads from grid side voltage quality problems. DSTATCOM [5] is a shunt connected power electronic system which compensates for the power quality issues caused by loads such as reactive current, harmonics and load imbalance in the system. DVR is a series connected power electronic system which compensates for the grid voltage sag/swells [6]. UPQC [7] consists of back to back connected shunt and series compensator which combines functionality of both DSTATCOM and DVR. Compared to conventional grid connected inverters, the solar PV integrated UPQC has numerous benefits such as improving power quality of the grid, protecting critical loads from grid side disturbances apart from increasing the fault ride through capability of converter during transients. In this paper, model is developed in the environment of MATLAB Simulink model & the performance analysis of a three-phase PV-UPQC is presented.

II. SYSTEM MODELING

A. Solar System

To meet the power demand, line losses are needed to be reduced to increase the power transfer limit. To increase the available transfer capacity of the line FACTS devices i.e. shunt and series compensators are used [1]. Solar system produces real power in daytime and inactive during night period. But solar farms operate below the capacity in the early morning and late afternoon period. Maximum power point tracking (MPPT) controllers are used to operate solar plant at its maximum efficiency. There are different MPPT techniques [2]. The voltage source inverter is a main element of solar system which also the main element of STATCOM. Because of this similarity, solar plant inverter can be configured to work as STATCOM to reduce the use of FACTS devices which are very expensive [3]. In paper [4], this technique to control the voltage profile is used for night time working of solar plant inverter. But it is not applicable for the daytime. Solar farm inverters are inactive during nighttime. The 24hrs working of solar farm inverter as STATCOM was proposed in [5], [6]. Different control techniques which are described in some previous papers which are used to control the inverter switching to function as STATCOM to improve the voltage profile [7]. For improvement in the system performance the PV inverter is used to control the voltage and also it increases the connectivity between DG plants and grid system [8].This paper introduces the novel control method with PCC voltage controller, DC voltage regulator and damping controller, for the grid-tied solar plant inverter to work as a STATCOM which is known as 'PV-STATCOM'. This system works in the daytime as well as in the night time to improve the grid transmission capacity as well as improves the power factor of the line. In conventional solar plant, the solar inverters are inactive in period of night and also after the real power generation so that full ratings of inverter remain idle during this period which is utilized to perform the above function. The MATLAB Simulink software is used for simulation purpose. Sec. II gives the description of modeling of all components required for simulation. In Sec. III, results of simulation are explained. Operation of a proposed system in the daytime and in the night time are explained. Sec. IV gives the conclusion. The solar system consists of Photovoltaic cell, energy storage system and an inverter controller. The PV cell converts solar power into the dc power; this DC power is again converted into AC power through inverter in order to feed the grid. The inverter controller controls the output power of solar system.

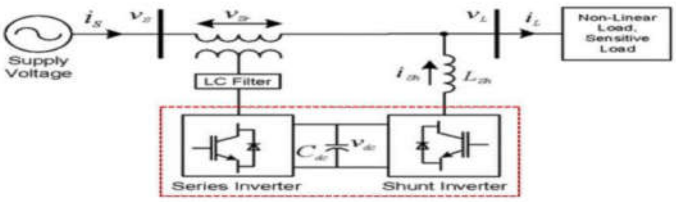

Fig. 1. Basic structure of PV -STATCOM

When grid-tied solar plant is considered, it does not include the battery storage set-up but stand-alone system required battery storage set-up. The structure of the PV-UPQC is shown in Fig...2 . The PV-UPQC is designed for a three-phase system. The photovoltaic system supplies real power generation to the grid as shown in Fig. 1.The structure of the PV-UPQC is shown in Fig...2. The PV-UPQC is designed for a three-phase system. The photovoltaic system supplies real power generation to the grid as shown in Fig. 1.As the solar radiations are not uniform, because of that solar system does not work with full efficiency in the early morning and late afternoon period. To works the solar system at its full efficiency, there is need to track the maximum power point of PV system. For that purpose MPPT controller is used along with inverter controller. According to solar irradiation, MPPT controller adjusts the current and voltage of the PV system in order to produce a constant output power. Considering all natural conditions of sunlight, the maximum power point tracking system which makes the solar system works at its maximum power point. There are different MPPT algorithms like perturb and observe, incremental conductance, constant voltage etc. There is need for rapid tracking due to the more variations in sunlight. An incremental conductance (IC) algorithm is more efficient than other algorithms. IC algorithm is integrated with the PV inverter controller which makes the solar system to operate at its full efficiency in all of the period. The main function of dc link capacitor in photovoltaic system is to maintain a constant dc voltage on input side of the inverter. Also it is used to maintain the power quality on input side which ultimately influences the power quality on output side of inverter. Another function of dc link capacitor is it works as decoupling circuit between the solar system and the input side of inverter. DC-DC converter is used to increase the output voltage of PV system. In order to maintain constant dc voltage across the dc link capacitor, the reference voltage is obtained from MPPT algorithm which is fixed in switching controller of dc-dc converter. Buck converter, boost converter or buck-boost converter is used to provide constant dc voltage across dc link capacitor. In this paper, a single ended primary inductor converter (SEPIC) which is buck-boost converter is used to maintain the constant voltage across the capacitor. Solar dc output is 24 V which is boosted up to the 600 V DC with the use of SEPIC converter.

B. Inverter Modeling

An inverter is the core element of the solar system. That converts the voltage generated by solar that is DC voltage to corresponding AC values. There are two types of inverter configurations are available. One of them is string technology, in which modules are connected into the string form and fed into the inverter. Second is AC module technology also called as micro-inverters in that all the module have the separate inverter and collecting all outputs of each inverter together to feed the grid.

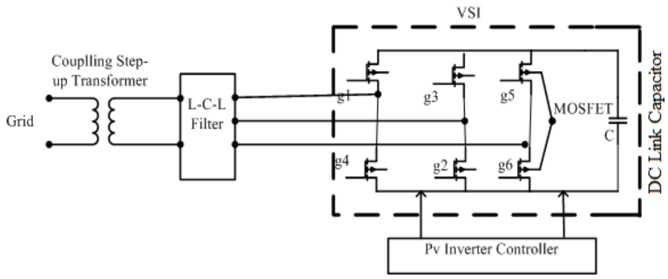

Fig.2.TypicalPVSolarFarmInverter

To construct inverter circuit, the manufacturer uses a different kind of switches like MOSFET, IGBT, GTO, SCR and diode etc. But for high power application IGBT and MOSFET switches are more preferred because of less loss and also smooth switching operation. Fig. 2 shows a typical solar farm voltage source inverter based on MOSFET switches. For the switching operation of the inverter different technologies like PWM (pulse width modulation), hysteresis control or sinusoidal vector pulse width modulation technique (SVPWM) is used. For high power rating inverters the PWM technique is more efficient than other techniques. In inverter modeling, two control methods are preferred one of those is VSI (voltage source inverter) and another is CSI(current source inverter).In VSI which is also known as VSC, the inverter input is a constant voltage which is maintain with the use of DC link capacitor. The output of VSI based inverter is a controlled voltage. Second is current source inverter (CSI) in which inverter input is constant current which is maintain by the use of inductor on dc side of inverter. The output of this control scheme is controlled voltage. Frequently for high power application the VSI based inverters are used.

c. STATCOM

STATCOM is reactive power compensation device which is shunted to the grid to generate and absorb the reactive power to control the grid voltage. So that it controls the definite constraints of the electric power system. By using the power electronic processing STATCOM performs the reactive power compensation to control the power flow, additional compensating devices not required. STATCOM has compressed design, lesser footprint and also less magnetic impact. STATCOM require constant voltage at its DC terminal side. DC link capacitor at its input terminal side maintains a constant voltage. It does not participate in reactive power exchange. DC link capacitor compensates the real power loses, thereby dropping DC link Voltage. PV array and the inverter setup are having the same structure as the conventional STATCOM. As shown in Fig. 3, the system having the structural benefit that helps in use of PV inverter configuration to work as STATCOM.

Fig.3.Conventional STATCOM vs. PV based Basic STATCOM Configuration

Furthermore, inverter design is made to operate as the converter in the PV array arrangement. So PV array along with inverter has been conveniently used as STATCOM for the assumed system. So PV array along with inverter has been conveniently used as STATCOM for the assumed system.*Proposed System Modeling*Fig.4 represents the block diagram of grid-tied solar farm inverter. A point at which the PV system is connected to the grid is called as PCC (point of common coupling). In this system, the line voltage is 22kV and step down to 11kV.The PV farm generates the DC power based on solar irradiations. The MPPT algorithm is set into the DC-DC converter to extract the maximum power from the solar plant. DC-DC converter step-up the 24 V solar dc output up to the 600 V.

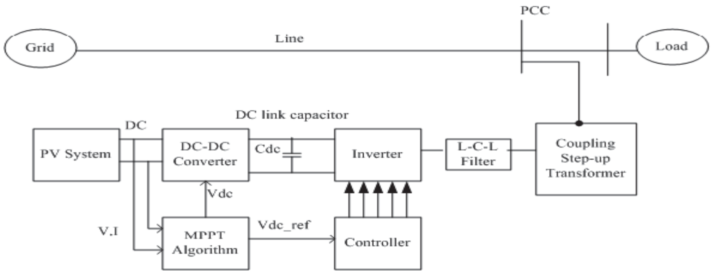

Fig.4.ProposedSystemBlockDiagram

At the input side of inverter, a dc link capacitor is used to keep a constant dc voltage. Three phase inverter converts this DC voltage into the AC voltage. This AC voltage is stepped up using a step-up transformer rating 450/11kV and the output is fed to the grid at PCC.A controller is used to generate the pulses for switching operation of the inverter. L-C-L filter is used to remove the dc ripples from the AC output which maintain the power quality at output side. During daytime, solar panel produces the real power and objective of improvement in

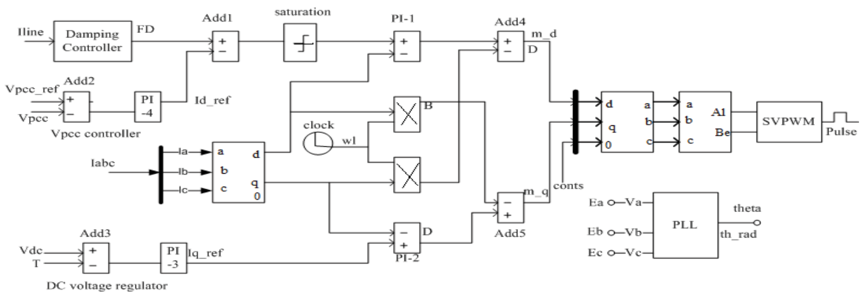

Fig.5.ProposedControlDesign

power is done along with generation of real power .In period of night, the PV system is inactive and solar power output is zero. A very little power is drawn from the grid which is used to charge the dc link capacitor. Then inverter performs a function of STATCOM. *Proposed Control Design* Fig. 5 shows the controller design involves damping controller, DC voltage regulator and PCC voltage controller. In d-q-0 system, the pulses for switching operation of the inverter are generated by the two current control loops. The line current magnitude is taken as a control signal and these line quantities are converted into to d-q-0 by d-q-0 transformation. These d and q values which have to be compensated are compared with reference values which are set by the controllers. This design includes 4PI controllers which are used to regulate the d and q values, dc output voltage and PCC feedback voltage. After regulating these values again it converted into the alpha-beta value to generate the pulse for inverter switching.*PCC Voltage Controller:* In this mode of operation, the feedback is taken from the PCC and one reference *value* PCC voltage is set by using trial and error method that is Vpcc_ref. these two values are regulated by the PI-4 controller to generate the Id_ref.*DC Voltage regulator:* In this process, the output voltage of solar system (Vdc) is compensated with the time constant to set the Iq_ref through PI-3 controller. *Damping controller:* The system generator produces the oscillations into the line current. To damp these oscillations damping controller is used. It utilies the transfer function as expressed in [9] Parameters of damping controller are selected as given in [9]. It utilizes the magnitude of line current for controlling purpose. It operates along with the PCC voltage controller. The output of this controller is added to the Id_ ref. It uses the whole inverter capacity when solar panels are inactive during nighttime to control the power flow. Even if the solar plant is not working in nighttime, it produces very less amount of negative solar power. This negative power causes the losses in inverter switches, filter resistance and in the transformer. Because of that current flows from grid to the solar inverter which results in charging of dc link capacitor. Damping controllers also maintain the constant voltage at PCC.

D. SIMULATION ANDRESULTS

A. Simulation Design of Proposed System

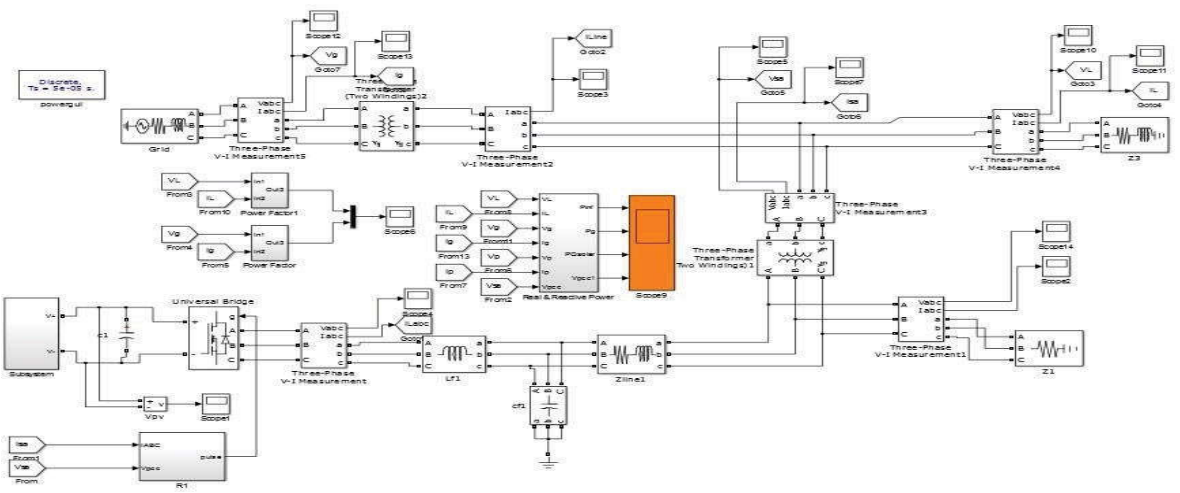

Fig.6.MATLAB Design of Proposed System

Above Fig. 6 describes the simulation model of proposed PV-STATCOM. The proposed controller operation is divided into two modes daytime and nighttime. The simulation design is simulated by using the designed controller to improve the power transmission

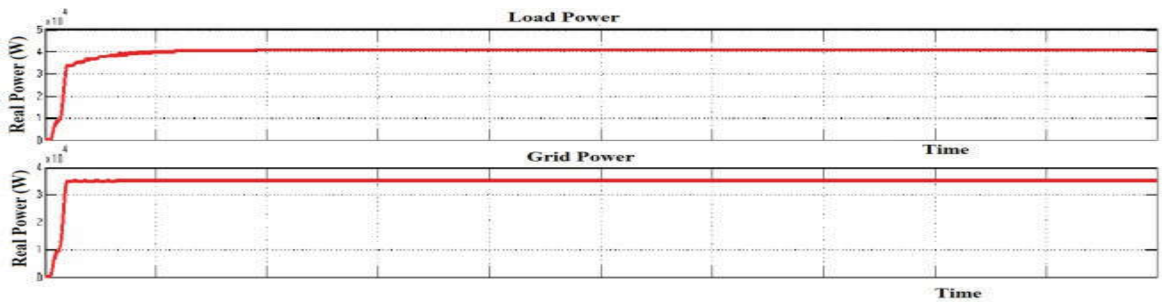

Fig.7.Power Outputs of Grid and Load during Daytime

limit and power factor of the line. Case I-Solar operation during daytime In the daytime operation of the solar plant, it generates the real power and along with that power transfer limit is improved with help of designed controller generates real power which increases power transfer capacity. At grid, the measured real power is 35 kW which is then increased upto40kWbyusing aproposed controller

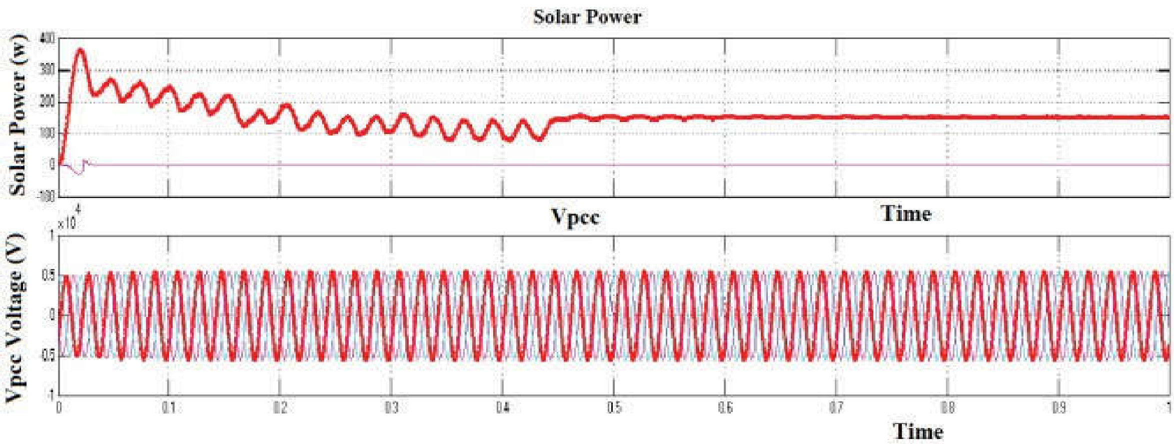

Fig.8.Power Outputs of Solar and Vpcc Voltage during Daytime

Fig. 8 shows the result of solar power generated during daytime which is 150W and the voltage at the PCC which is maintained constant by using the proposed controller.

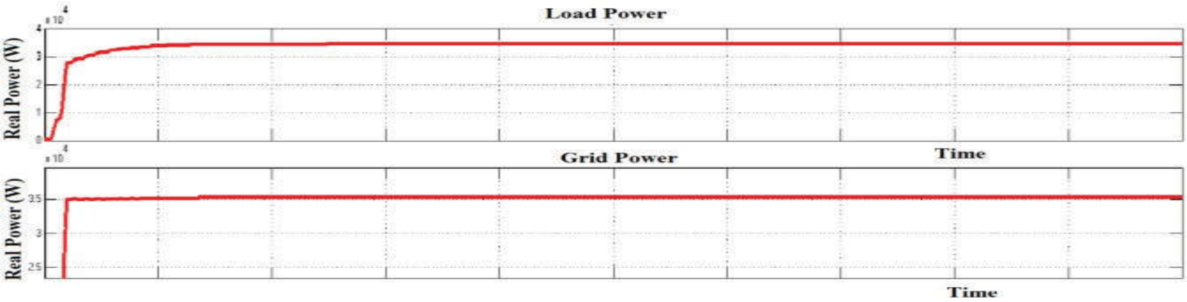

Fig.9.Power Outputs of Grid and Load during Night time

Fig. 9 shows experimental results of the real power of grid and load. When the solar plant is inactive the power is same on grid side that is 35kW and on the load side. There is no loss of power due to the STATCOM function

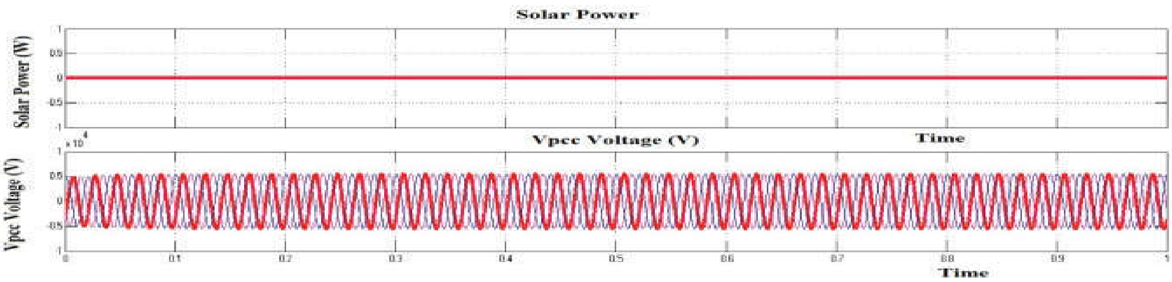

Fig.10.Power Outputs of Solar and Vpcc Voltage during Nighttime

Above Fig. 10 represents the results of solar output power and PCC voltage. In nighttime solar is inactive, the power output of solar is zero. The voltage at PCC maintained constant during nighttime by using a proposed controller.

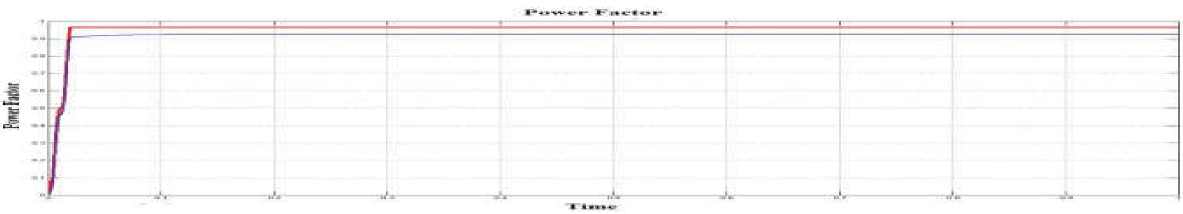

Fig.11.Power Factor during Daytime and Night time

TABLEI.COMPARATIVEANALYSISOFSIMULATIONRESULT

Simulation Description	Grid power	Load power	Solar power	Grid power factor	Load power factor
Daytime	3.5×10^4	4×10^4	150W	0.92	0.966
Nighttime	3.5×10^4	3.5×10^4	0	0.92	0.966

Table I gives the comparative analysis of the designed system.

While implementing the large scale PV system to operate as a PV-STATCOM, the following issues have to examined and addressed.

1) It is complex to implement the PV-STATCOM in large scale PV system.

2) It is difficult to adopt PV-STATCOM concept for different configuration inverters.

3) More issues related to control co-ordination amongst the multiple inverters in PV plant.

E. CONCLUSION

PV inverters are effectively used as STATCOM for controlling a grid power. The construction of PV inverter is configured as a STATCOM is known as 'PV-STATCOM'. With the use of this PV-STATCOM after result discussion, it is concluded that there is an improvement in power transmission limit and power factor during daytime and nighttime using the proposed controller. When solar plant is in active, the full inverter rating is used to perform the given objective. Because of that 24hrs utilization of solar farm inverter is possible which are idle during night time. The cost of installation of extra FACTS devices is also reduced because the solar inverter can be utilized as STATCOM in a solar farm.

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APPENDIX

System parameters	
AC Line Voltage	415 V
Line Frequency	50 Hz
Bridge Rectifier Load with R-C	10Ω,1mF
DC-link Voltage	700V
DC-link Capacitor	9.3 mF
Shunt compensator interfacing inductor	1 mH
series compensator interfacing inductor	3.6 mH
Series Injection Transformer	5.35kVA,239.6V/69V
Rating of series compensator	5.35kVA
Rating of shunt compensator	24.8kVA
Ripple Filter	10μF, 10Ω
DC link PI controller gains	Kp=1.5,Ki=0.1
MPPT controller voltage step size	2V
MPPT Sampling time	0.03sec
Series VSC PI gains for d and q axis	Kp=-1,Ki=0
Shunt VSC hysteresis controller band	0.01A
Series VSC voltage hysteresis controller band	0.1V
PWM Switching frequency of VSC	10 kHz

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