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Power Quality Improvement of PV Solar Farm as STATCOM Night and Day using Fuzzy Logic Control

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Abstract:

A comprehensive testing, validation and installation plan for a new technology which utilizes PV solar farm as a STATCOM during night and Day time. This technology is termed as STATCOM. It will be utilized in the night for power factor correction and voltage control at the terminals of an induction motor operating at poor power factor. PV solar farms produce power during the day and are completely idle in the nights. The proposed new control on PV solar system will help in increase the utilization of the PV solar system. A key component of the PV solar plant is a voltage source converter which is also a core element of STATCOM. Using this fact we present a Fuzzy Logic Control method of using PV solar plant as STATCOM, in dark periods without sunlight, for load reactive power compensation and voltage control. PV system inverter control is not suitable for night time. Improvement of power factor leading to decrease the continuous load KVA load demand and reduction in the line losses.

Index Terms:

Photovoltaic Solar System, FACTS, STATCOM, Distribution systems, Reactive Power Compensation, Power Factor Correction, Voltage Regulation, Power Quality Improvement.

I.INTRODUCTION:

Utilization of renewable energy comes from the perspective of environmental conservation and fossil fuel shortage. Recent studies suggest that in medium and long terms, photovoltaic (PV) generator will become commercially so attractive that large-scale implementation of this type can be seen in many parts of the world [1], [2]. A large-scale PV generation system includes photovoltaic array, DC/AC converter and the associated controllers. It is a multivariable and non-linear system, and its performance depends on environmental conditions. Recently, the increasing penetration levels of PV plants are raising concerns to utilities due to possible negative impacts on power system stability as speculated by a number of studies. Thus, the thorough investigation of power system stability with large scale PV is an urgent task. In an extreme situation new lines may need to be constructed at a very high expense. Cost effective techniques therefore need to be explored to increase transmission capacity.

A novel research has been reported on the night time usage of a PV solar farm (when it is normally dormant) where a PV solar farm is utilized as a Static Compensator (STATCOM) – a FACTS device for performing voltage control, thereby improving system performance and increasing grid connectivity of neighboring wind farms. Nowadays solar energy using PV technology is becoming popular due to government subsidies. Obviously solar forms generate energy during sunny periods only.

When sunlight is not bright enough they remain idle. To make the PV technology cost effective with higher utilization factor it is to be used throughout day and night. Efforts are being made in this direction [7, 11]. Power quality is an important aspect of power distribution. Power is to be distributed with tolerable voltage sags and swells.

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Here Flexible AC Transmission Systems (FACTS) devices play a vital role. It is well known that Static synchronous Compensator (STATCOM) is a FACTS device which acts as a shunt compensating device. A key component of the PV solar plant is a voltage source inverter which is also a core element of STATCOM. Using this fact we present a simple open-loop control method of using PV solar plant as STATCOM, in dark periods without sunlight, for load reactive power compensation and voltage control. Due to improvement in power factor load current reduces. Also the system remains balanced with better efficiency (less transmission losses) and power quality. This paper presents a utilisation of the PV solar farm inverter as a STATCOM—a FACTS device for voltage control and power factor correction, both during for voltage control and power factor correction has been developed which provides voltage regulation and load compensation in the nights utilising 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).

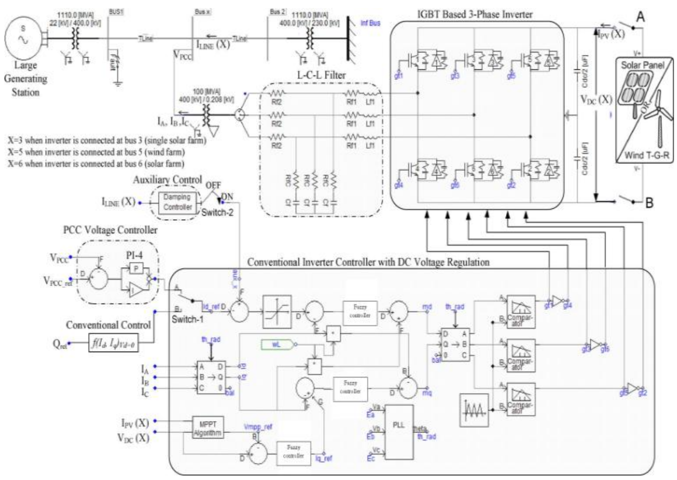

Fig. 1. Complete DG (solar/wind) system model with a Fuzzy logic controller

PHOTO VOLTAIC SYSTEMS:

A photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. Cells may be grouped to form panels or arrays.

The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and dc motors. [6] A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited.

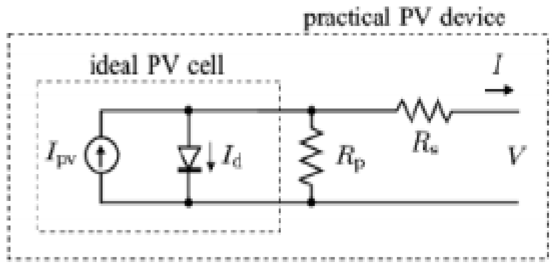

Fig.2. Equivalent Circuit of a PV Device including the series and parallel Resistances.

The equivalent circuit of PV cell is shown in Fig. 1. In the above diagram the PV cell is represented by a current source in parallel with diode. Rs and Rp represent series and parallel resistance respectively. The output current and voltage from PV cell are represented by I and V.

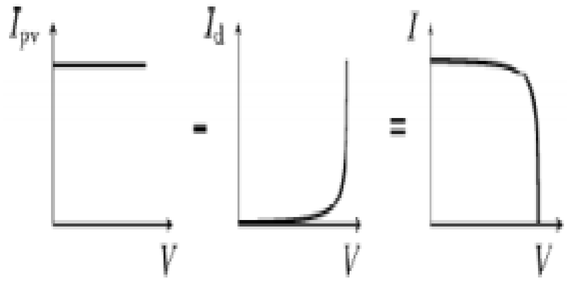

Fig. 2. V-I Characteristic of PV Cell

The I-V Characteristics of PV cell [7] is shown in Fig.2. The net cell current I is composed of the light generated current Ipv and the diode current

$I = I_{pv} - I_d$ (1)

Where

$I_d = I_o \exp(qV/akT)$

I_o = leakage current of the diode

q= electron charge

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k = Boltzmann constant
T= temperature of pn junction
a= diode ideality constant

The basic equation (1) of the PV cell does not represent the I-V characteristic of a practical PV array. Practical arrays are composed of several connected PV cells and the observation of the characteristic at the terminals of the PV array requires the inclusion of additional parameters to the basic equation.

I = Ipv – [exp V +RsIVta− 1] −V+RsI/R p (2)

Where

Vt = NskT/q is the thermal voltage of the array with Ns cells connected in series.

Cells connected in series provide greater output voltages. The I-V characteristic of a practical PV cell with maximum power point (MPP), Short circuit current (Isc) and Open circuit voltage (Voc) is shown in Fig.3.The MPP represents the point at which maximum power is obtained

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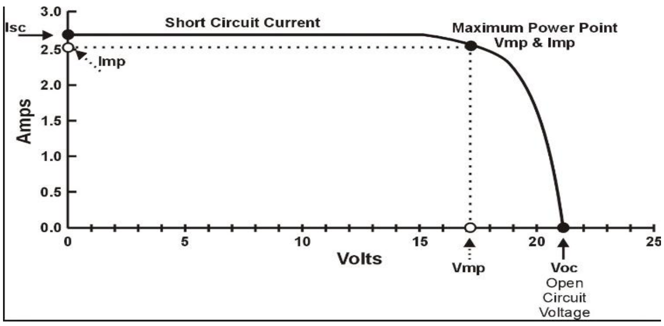

Fig. 3. I-V Characteristic of Practical PV Module

Vmp and Imp are voltage and current at MPP respectively. The output from PV cell is not the same throughout the day, it varies with varying temperature and insulation (amount of radiation).Hence with varying temperature and insulation maximum power should be tracked so as to achieve the efficient operation of PV system.

STATCOM OVERVIEW:

The STATCOM is shunt-connected reactive-power compensation device that is capable of generating and or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system [2].It is in general a solistate switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed

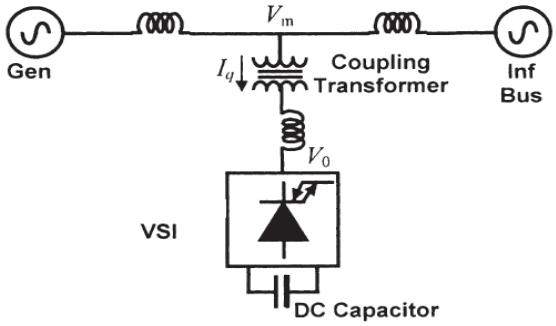

Fig.4.Single Line STATCOM Power Circuit

from an energy source or energy- storage device at its input terminals [6] as shown in fig.4.Specifically, the STATCOM considered as a voltage source converter that, from a given input of dc voltage produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through a relatively small reactance (which is provided by either an interface reactor or the leakage inductance of a coupling transformer). The dc voltage is provided by an energy-storage capacitor. The VSC has the same rate current capability when it operates with the Capacitive- or inductive-reactive current. Therefore, a VSC having certain MVA rating gives the STATCOM twice the dynamic range in MVAR (this also contributes to a compact design)[6].

A dc capacitor bank is used to support (stabilize) the controlled dc voltage needed for the operation of the VSC. The reactive power of a STATCOM is produced by means of power-electronic equipment of the voltage-source-converter type. A number of VSCs are combined in a multi-pulse connection to form the STATCOM [10]. In the steady state, the VSCs operate with fundamental-frequency switching to minimize converter losses. However, during transient conditions caused by line faults, a pulse width-modulated (PWM) mode is used to prevent the fault current from entering

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the VSCs. In this way, the STATCOM is able to withstand transients on the ac side without blocking. A single-line STATCOM power circuit is shown in Fig.4 where a VSC is connected to a utility bus through magnetic coupling.

PRINCIPLE OF STATCOM

A STATCOM is a controlled reactive source, which includes a Voltage Source Converter and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of STATCOM are based on the exact equivalence of the conventional rotating synchronous compensator.

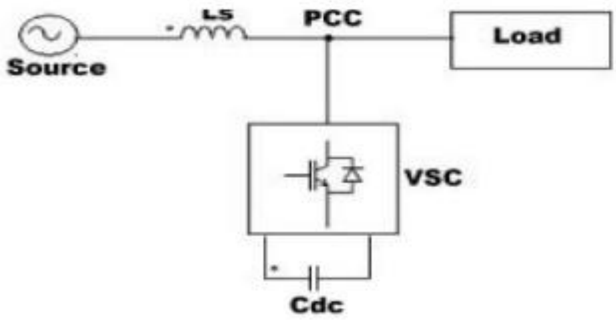


Fig. 5 Circuit Diagram of STATCOM

The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown in Fig.5.The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by a battery source, or could be recharged by the converter itself. If the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the STATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. For a STATCOM used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead the supply voltages;

FUZZY LOGIC CONTROLLER:

The Fuzzy Logic Controller (FLC) is used as controller in the proposed model. The Fuzzy Logic tool was introduced in 1965, also by Lotfi Zadeh, and is a mathematical tool for dealing with uncertainty. It offers to a soft computing partnership ‗the important concept of computing with words„. It provides a technique to deal with imprecision and information granularity. The fuzzy theory provides a mechanism for representing linguistic constructs such as „many" „low" „medium" „often" „few". In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. In fuzzy logic, basic control is determined by a set of linguistic rules which are determined by the system. Since numerical variables are converted into linguistic variables, mathematical modeling of the system is not required. The fuzzy logic control is being proposed for controlling the inverter action. FLC is a new addition to control theory and it incorporates a simple, rule based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically

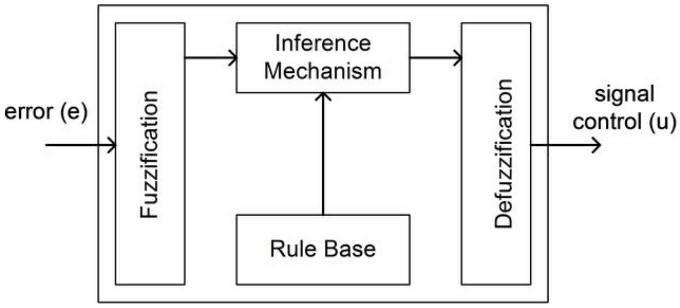


Fig. 6: Block diagram of control system.

A. Error Calculation:

The error is calculated from the difference between supply voltage data and the reference voltage data. The error rate is the rate of change of error.

B.Fuzzification:

Fuzzification is an important concept in the fuzzy logic theory. Fuzzification is the process where the crisp quantities are converted to fuzzy. Thus Fuzzification process may involve assigning membership values for the given crisp quantities.

This unit transforms the non-fuzzy (numeric) input variable measurements into the fuzzy set (linguistic) variable that is a clearly defined boundary, without a crisp (answer). In this simulation study, the error and error rate are defined by linguistic variables such as negative big (NB), negative medium (NM), negative small (NM), zero (Z), positive small (PS), positive medium (PM) and positive big (PB) characterized by membership functions given in Fig. 7.

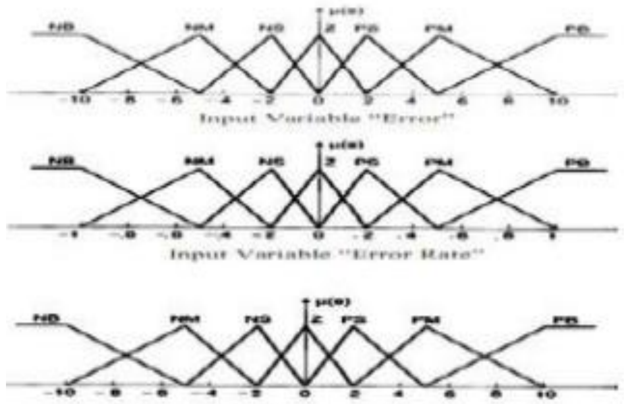


Fig.7. membership function for input and output

C. Decision Making:

Fuzzy process is realized by Mamdani method. Mamdani inference method has been used because it can easily obtain the relationship between its inputs and output [11]. The set of rules for fuzzy controller are represented in Table II. There are 49 rules for fuzzy controller. The output membership function for each rule is given by the Min (minimum) operator. The Max operator is used to get the combined fuzzy output from the set of outputs of Min operator .The output is produced by the fuzzy sets and fuzzy logic operations by evaluating all the rules. A simple if-then rule is defined as follows: If error is Z and error rate is Z then output is Z.

SIMULATION WORK:

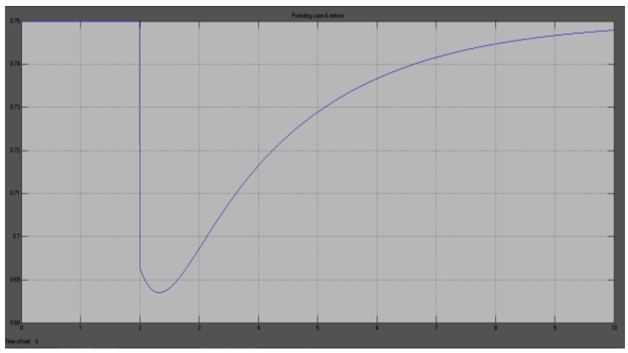
TABLE I

Power flows and voltages for study system **i** for solar dg with the proposed pcc voltage control and damping control during nighttime and day time

Simulation description		Gen. Bus	PCC /Middle Bus(3)			Inf. Bus
		Pg (MW)	V pcc (pu)	Psolar (MW)	Qsolar (MW)	Pinf (MW)
Night time	Conventional Operation of solar DG	731	1.010	0	0	-708
	solar DG with damping controller	850	1.000	-0.20	0.08	-819
Day time	Conventional Operation of solar DG	719	1.008	91.0	-0.20	-786
	solar DG with damping controller	851	1.000	91.0	-0.26	-917

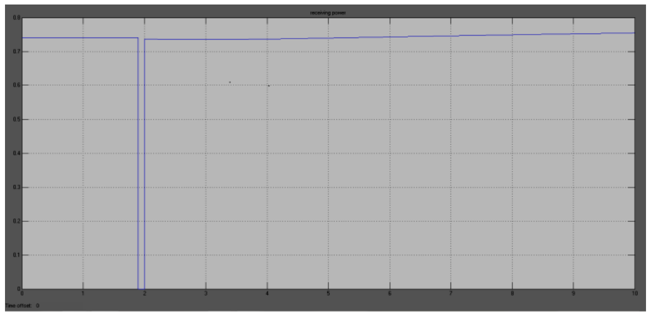
CASE A: Night time Conventional Operation of solar DG

Fig 9(a): CASE A Sending (Pg) end power



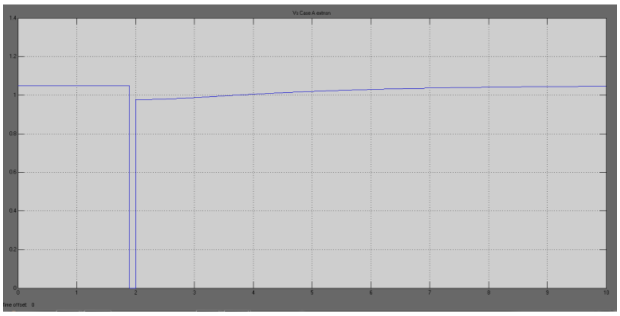
Power [MW] versus time[s]

Fig 9(b): Case A receiving (Pinf) end power



Power [MW] versus time[s]

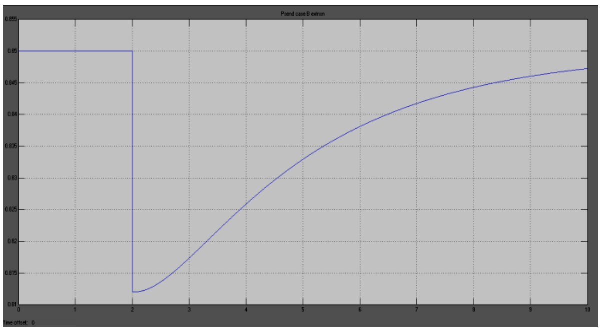
Fig 9(c): Case A sending voltage (Vpcc)



AC voltage [pu] versus time [s]

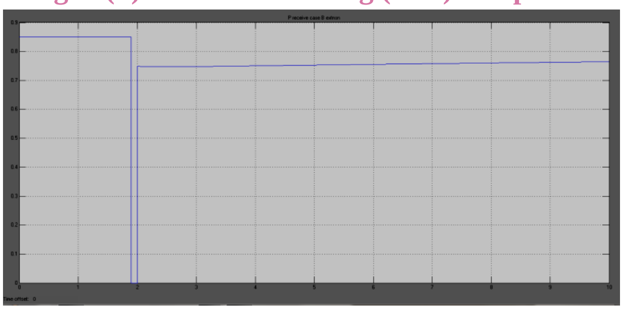
CASE B: Night Time Solar Dg with Damping Controller

Fig 10(a): CASE B Sending (Pg) end power



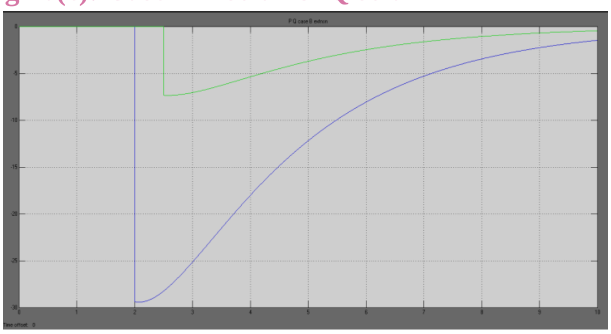
Power [MW] versus time[s]

Fig 10(b): Case B receiving (Pinf) end power



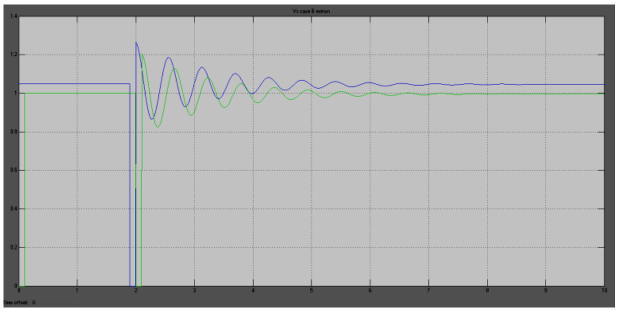
Power [MW] versus time[s]

Fig 10(c): Case B P solar & Q solar



Q (MVAr), Power [MW] versus time[s]

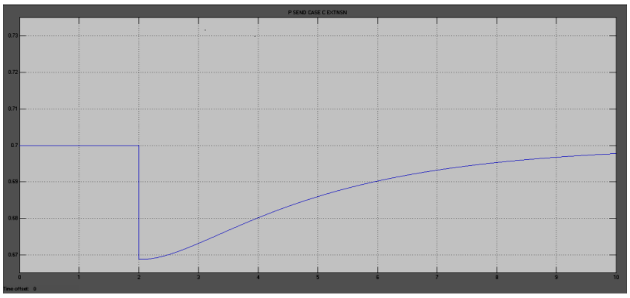
Fig 10(d): Case B sending voltage (Vpcc)



Voltage [pu] versus time [s]

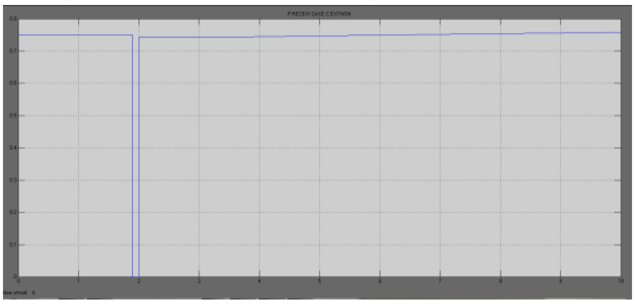
CASE C: Day Time Conventional Operation Of Solar DG

Fig 11(a): CASE C Sending (Pg) end power



Real Power (MW) Vs time(s)

Fig 11(b): Case C receiving (Pinf) end power



Power [MW] versus time[s]

Fig 11(c): Case C P solar & Q solar

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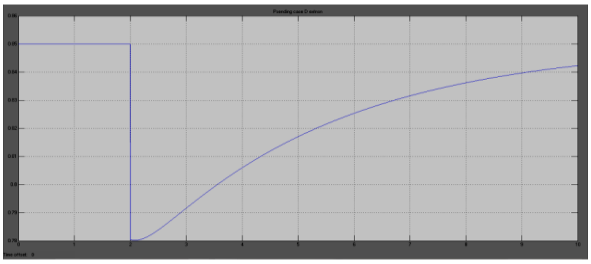
Q (MVAr), Power [MW] versus time[s]

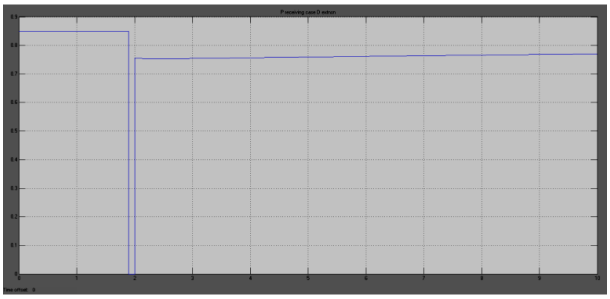
CASE D: Day time solar DG with damping controller

Fig 12(a): CASE D Sending (Pg) end power



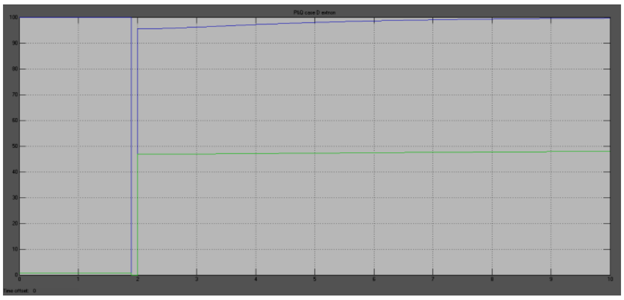
Power [MW] versus time[s]

Fig 12(b): Case D receiving (Pinf) end power



Real Power (MW) versus time(s)

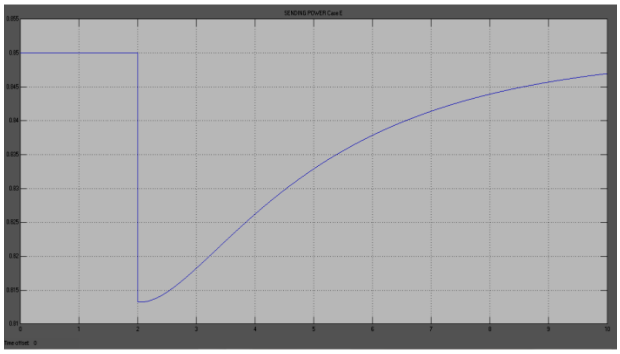
Fig 12(c): Case D P solar & Q solar



Q (MVAr), Power [MW] versus time[s]

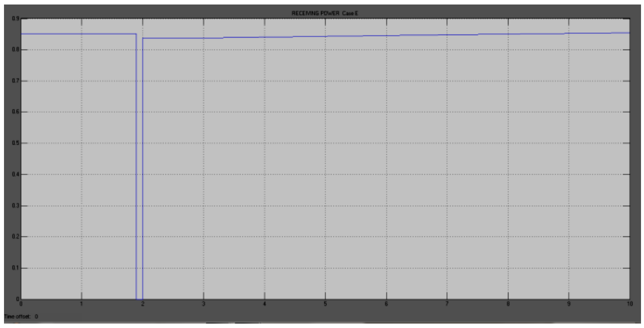
CASE E: Night Solar DG with Both voltage and damping controller

Fig 13(a): CASE E Sending (Pg) end power



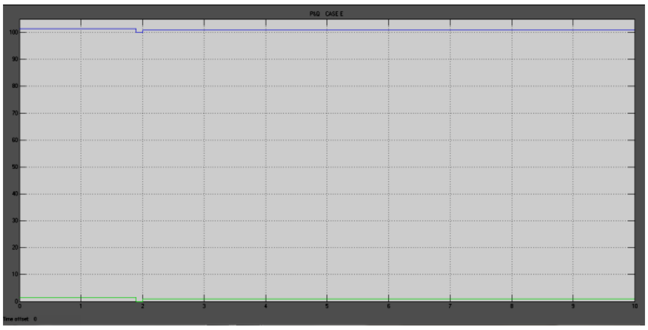
Power [MW] versus time[s]

Fig 13(b): Case E receiving (Pinf) end power



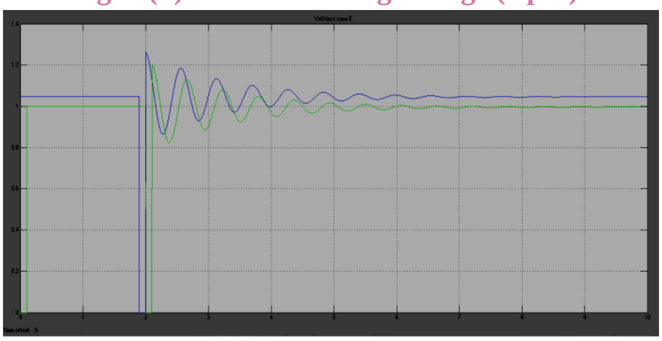
Power [MW] versus time[s]

Fig 13(c): Case E Psolar &Qsolar



Q (MVAr), Power [MW] versus time[s]

Fig 13(d): Case E sending voltage (Vpcc)



Voltage [pu] versus time [s]

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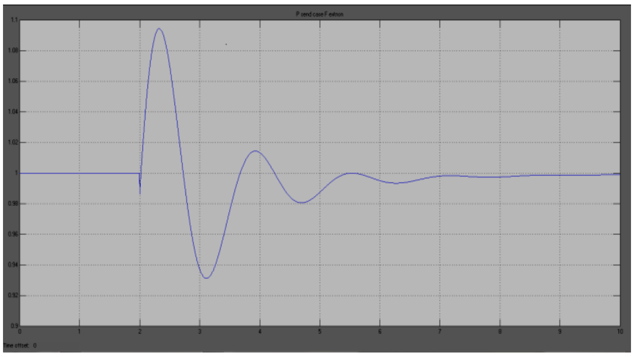
TABLE COLUMN II:

Power flows and voltages for study system ii for both solar dg and wind dg with conventional reactive power control and proposed damping control both during nighttime and daytime

Simulation description		Gen. Bus	PCC /Middle Bus(3)			Inf. Bus	
		Pg (MW)	V pcc (pu)	Psolar (MW)	Qsolar (MW)	Pinf (MW)	
Night time	Conventional Operation of solar DG	731	1.010	0	0	-708	
	solar DG with damping controller	850	1.000	-0.20	0.08	-819	
Day time	Conventional Operation of solar DG	719	1.008	91.0	-0.20	-786	
	solar DG with damping controller	851	1.000	91.0	-0.26	-917	

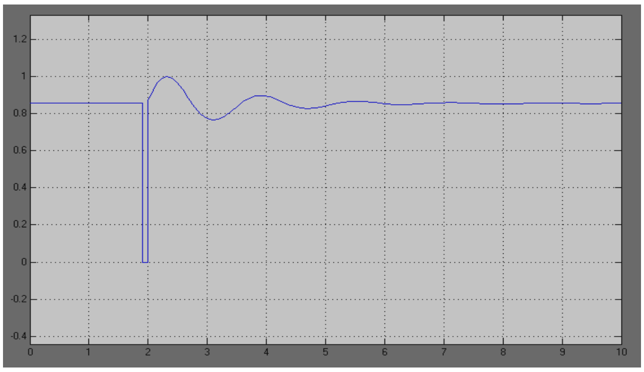
CASE F: Night time (P solar=0) both DGs with damping controller

Fig 14(a): CASE F Sending (Pg) end power



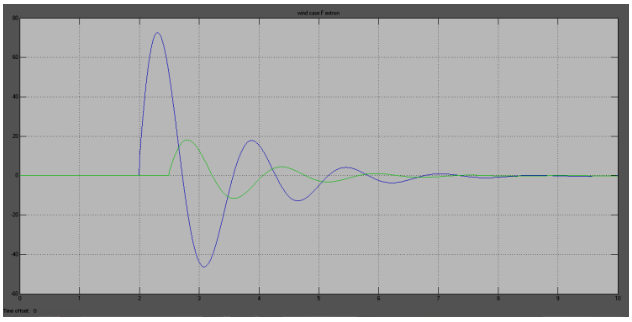
Power [MW] versus time[s]

Fig 14(b): CASE F receiving (Pinf) end power



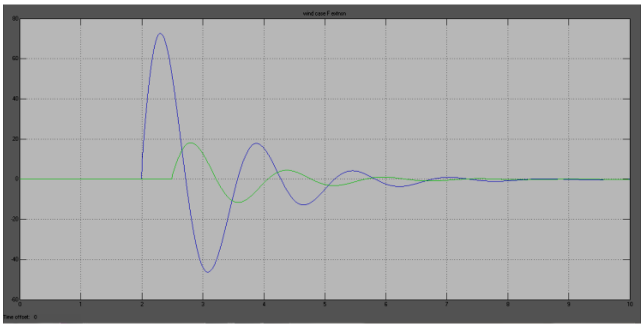
Power [MW] versus time[s]

Fig 14(c): Case F Psolar & Qsolar



Q (MVAr), Power [MW] versus time[s]

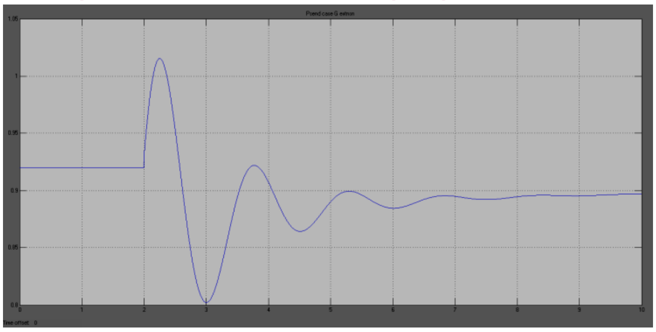
Fig 14(d): Case F Pwind &Qwind



Q (MVAr), Power [MW] versus time[s]

CASE G: Day time (Psolar ≠0) both DGs with damping controller

Fig 15(a): CASE G Sending (Pg) end power



Power [MW] versus time[s]

Fig 15(b): CASE G receiving (Pinf) end power

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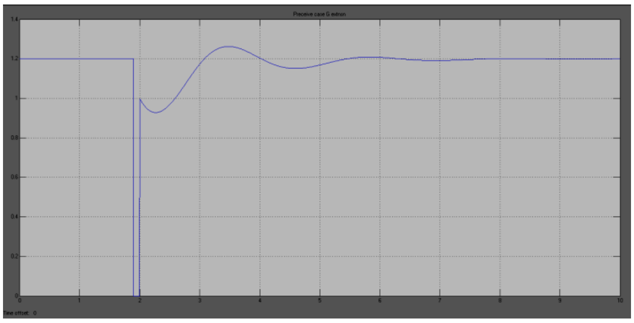
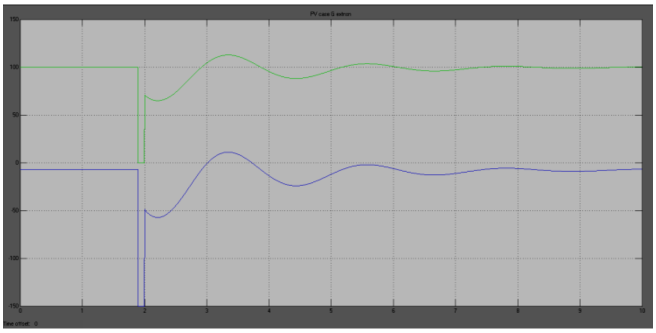


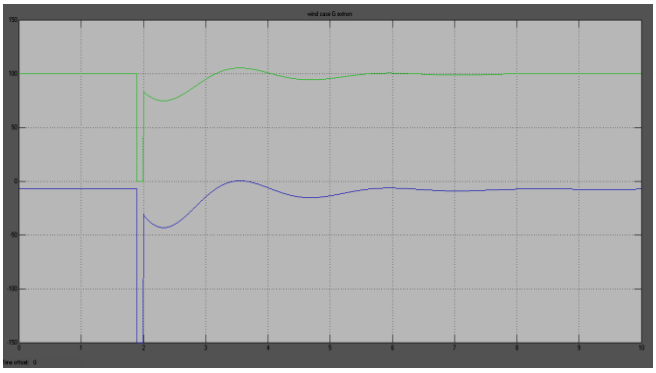
Power [MW] versus time[s]

Fig 15(c): CASE G Psolar &Qsolar



Q (MVAr), Power [MW] versus time[s]

Fig 15(d): CASE G Pwind &Qwind



Q (MVAr), Power [MW] versus time[s]

CONCLUSION:

A normal solar plant remains idle when sunlight is not good. Voltage source inverter is a key component of both solar plant and STATCOM. Hence solar plant is used as STATCOM during dark periods to improve voltage regulation and power factor. Due to improvement in power factor load current reduces. Also the system remains balanced with better efficiency and less transmission losses.

Simulated distribution system's results validate these points. Hence the power quality and electrical performance of the distribution system is improved.

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