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A NovelControl of PV Solar Farm as STATCOM (PV-STATCOM) for Increasing Grid Power Transmission

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ABSTRACT: During daytime, the invertercapacity left after real power production is used to accomplishthe aforementioned objective. Transient stability studies areconducted on a realistic single machine infinite bus power systemhaving a midpoint located PV-STATCOM using EMTDC/PSCADsimulation software. The PV-STATCOM improves the stabletransmission limits substantially in the night and in the day evenwhile generating large amounts of real power. Power transferincreases are also demonstrated in the same power system for:1) two solar farms operating as PV-STATCOMs and 2) a solarfarm as PV-STATCOM and an inverter-based wind farm withsimilar STATCOM controls. This novel utilization of a PV solarfarm asset can thus improve power transmission limits whichwould have otherwise required expensive additional equipment,such as series/shunt capacitors or separate flexible ac transmissionsystem controllers.

KEYWORDS-Damping control, flexible ac transmission systems(FACTS), inverter, photovoltaic solar power systems, reactivepower control, STATCOM, transmission capacity.

I. INTRODUCTION

(PV) solar energy is one of thegreen energy sources which can play animportant role in the program of reducing greenhouse gas emissions. Although, the PV technologyis expensive, it is receiving strong encouragementthrough various incentive programs globally [1],[2]. As a result, large scale solar farms are beingconnected to the grid. Transmission gridsworldwide are presently facing challenges inintegrating such large scale renewable systems(wind farms and solar farms) due to their limitedpower transmission capacity [3]. To increase theavailable power transfer limits/capacity (ATC) ofexisting transmission line, series compensation andvarious FACTS devices are being proposed [3]-[9].In an extreme situation new lines may need to beconstructed at a very high expense [10]. Costeffective techniques therefore need to be exploredto increase transmission capacity. A novel researchhas been reported on the nighttime usage of a PVsolar farm (when it is normally dormant) where aPV solar farm is utilized as a STATCOM – aFlexible AC Transmission System (FACTS) devicefor performing voltage control, thereby improvingsystem performance and increasing gridconnectivity of neighbouring wind farms [11, 12]. Itis known that voltage control can assist inimproving transient stability and powertransmission limits, several shunt connectedFACTS devices, such as, Static Var Compensator(SVC) and STATCOM are utilized worldwide forimproving transmission capacity [13],[14].This paper presents a novel night-time applicationof a PV solar farm by which the solar farm inverteris employed as a STATCOM (with its entire MVAcapacity) for voltage control in order to improvepower transmission capacity during nights. Duringday time also, the solar farm while supplying realpower output is still made to operate as aSTATCOM and provide voltage control using

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itsremaining inverter MVA capacity (left after what isneeded for real power generation). This day timevoltage regulation is also shown to substantiallyenhance stability and power transfer limits. Thesestudies are conducted on a single generator infinitebus system with a PV solar farm integrated midwayin the transmission line. Three phase fault studiesare conducted using the electromagnetic transientsoftware EMTDC/PSCAD [15] and theimprovement in transmission capacity evaluatedboth during night time and day time.

II. SYSTEM MODELS

The synchronous generator is represented by a detailed sixthorder model and a DC1A-type exciter [1]. The transmission-linesegments TL1, TL2, TL11, TL12, and TL22, shown in Fig. 1,are represented by lumped pi-circuits. The PV solar DG, asshown in Fig. 2, is modeled as an equivalent voltage-source inverter along with a controlled current source as the dc sourcewhich follows the - characteristics of PV panels [11]. Thewind DG is likewise modeled as an equivalent voltage-sourceinverter. In the solar DG, dc power is provided by the solarpanels, whereas in the full-converter-based wind DG, dc powercomes out of a controlled ac–dc rectifier connected to the PMSGwind turbines, depicted as “wind Turbine-Generator-Rectifier(T-G-R).”The dc power produced by each DG is fed into thedc bus of the corresponding inverter, as illustrated in Fig. 2. Amaximum power point tracking (MPPT) algorithm based on anincremental conductance algorithm [12] is used to operate thesolar DGs at its maximum power point all of the time and is integrated with the inverter controller [11]. The wind DG is alsoassumed to operate at its maximum power point, since this proposed control utilizes only the inverter capacity left after themaximum power point operation of the solar DG and wind DG.

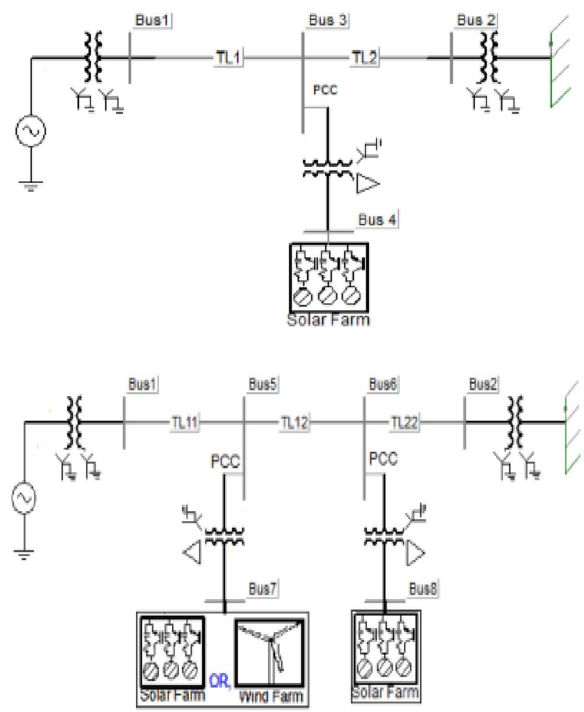

Fig. 1. Single-line diagram of (a) study system I with a single solar farm (DG)and (b) study system II with a solar farm (DG) and a solar/wind farm (DG).

A. System Model

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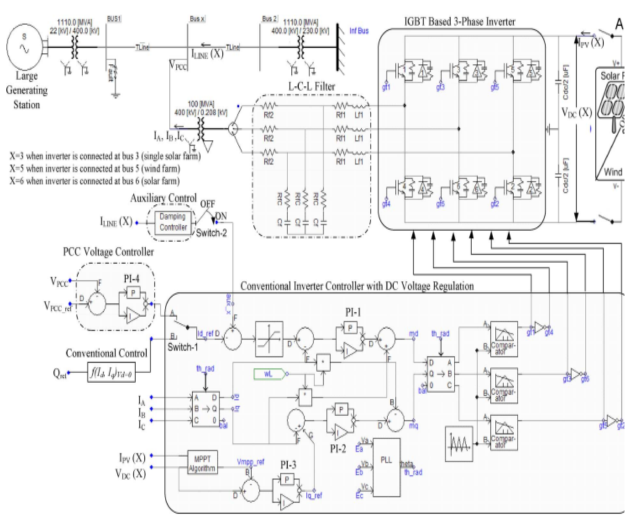

Fig. 2. Complete DG (solar/wind) system model with a damping controller and PCC voltage-control system.

B. Control System

In PWM switching technique, the magnitude ofvoltages and the angle of voltages at the inverteroutput are directly dependent on modulation index(MI) and modulation phase angle, respectively.To control the modulation index and modulationphase angle, two separate PI control loops areintegrated with the inverter, simultaneously.The top PI control loop in 'control system' block ofFig. 2 controls the modulation angle to maintain theDC bus voltage, whereas the bottom PI control loop'V controller' is used to control the modulationindex according to the set point voltages at PCC. Itis noted that, as the reactive power output dependsupon the magnitudes of voltages at PCC andinverter terminal, therefore the reactive power flowis controlled indirectly by controlling the magnitudeof voltages through modulation index in this studysystem.

III. SYSTEMSTUDIES

Transient stability studies are carried out usingPSCAD/EMTDC simulation software, for both the studysystems during night and day, by applying a 3
Ground (3LG) fault at bus 1 for 5 cycles. The damping ratiois used to express the rate of decay of the amplitude of oscillation.This reflects the losses in the inverter IGBT switches,transformer and filter resistances caused byreal current from the grid into the solar farm inverter tocharge the DC link capacitor and maintain its voltageconstant while operating the PV inverter as STATCOMwith the damping controller (or even with voltagecontroller). During nighttime, the reference DC Linkvoltage Vmpp_ref is chosen around the typicalmaximum power point (MPP) voltage .Therefore, for a 5% damping ratio of the rotor modehaving oscillation frequency of 0.95 Hz, as considered inthis study, the post-fault clearance settling time of theoscillations to come within 5% (typically within 3 timesthe time constant) of its steady state value [1] isalmost 10 seconds. The peak overshoot of PCC voltage isshould also be limitedwithin1.1 pu of nominal voltage. The maximum stable generatorpower limit for the system is determined through transientstability studies for different modes of operation of the solarDG in study system 1, and those of the solar DG and thesolar/winds DGs in study system 2.

A. Case Study 1: Power Transfer Limits in Study
Conventional Reactive Power Control with the Novel Damping ControlIn this study, the solar DG is assumed to operate with itsconventional reactive power controller the DG operates atnear unity power factor. For the nighttime operation ofsolar DG, the DC sources (solar arrays) are disconnectedand the solar DG inverter is connected to the grid usingappropriate controllers, as described below. Power
transmission limits are now determined for the followingfour cases. The stable power transmission l from transient stability studies and the corresponding loadflow results are presented where–ve Qrepresents

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the inductive power drawn and +ve Qcapacitive power injected into the network.

i) solar DG operation during night with conventionalreactive power controller:

The maximum stable power output from the generator Pis 731 MW when the solar DG is simply sitting idle duringnight and is disconnected from the network. This powerflow level is chosen to be the base value against which theimprovements in power flow with different proposedcontrollers are compared and illustrated later.The real power from generator Pg and that entering into theinfinite bus Pinf for this fault study are shown in FigThe sending end voltage at generator is shown. 3(a).The sending end voltage at generator is shown in Fig 3(b).

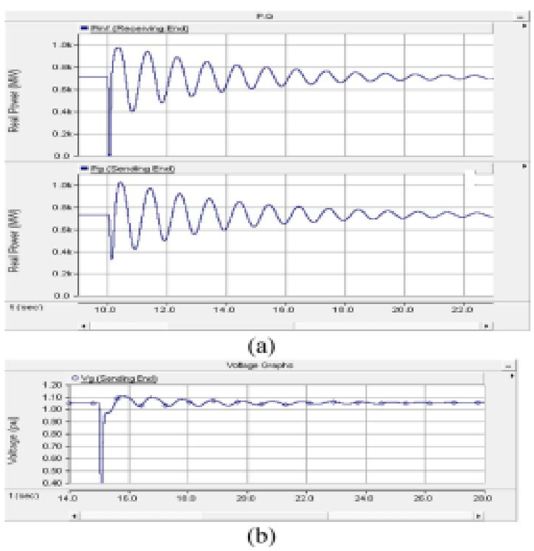

Fig. 3. (a) Maximum nighttime power transfer (731 MW) from the generatorwhen solar DG remains idle. (b) Voltage at the generator terminal.

B. Case Study 2: Power Transfer Limits in Study System II

In this study, the proposed damping control strategy is compared with the conventional reactive power control strategy forStudy System II shown in Fig. 1(b). A three-phase-to-groundfault of 5 cycles is applied to the generator bus at 8 s/.

1) Nighttime:

Case 1 – None of the DGs Generate Real Power: The maximum power transfer limit is 731 MW .

Case 2 – Only Wind DG Generates Real Power. Both DGs Operate With Conventional Reactive Power Control: Thepower transfer limit decreases slightly with increasing windpower output.

Case 3 – None of the DGs Generate Real Power But BothDGs Operate With Damping Control: The different variables,generator power , infinite bus power , real power of windDG , reactive power of the wind DG , real powerof the solar DG , and the reactive power of the solar DGare shown in Fig. 4. Even though the entire ratings(100 MVar) of the wind DG and solar DG inverters are not completely utilized for damping control, the power transfer limit increases significantly to 960 MW.

Case 4 – Only Wind DG Generates Real Power But BothDGs Operate on Damping Control: There is only a marginalimprovement in the power limit with decreasing power outputfrom the wind DG.

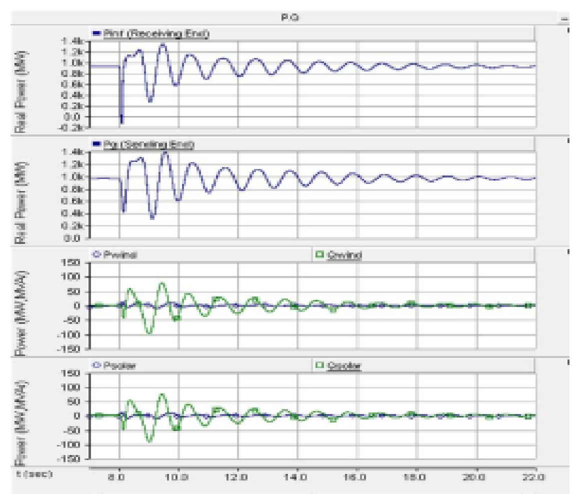

Fig. 4. Maximum nighttime power transfer from the generator with both DGsusing the damping controller but with no real power generation.

2) Daytime:

Case 5 – Both DGs Generate Real Power: The power transfer limit from the generator decreases as the power outputfrom both DGs increase.

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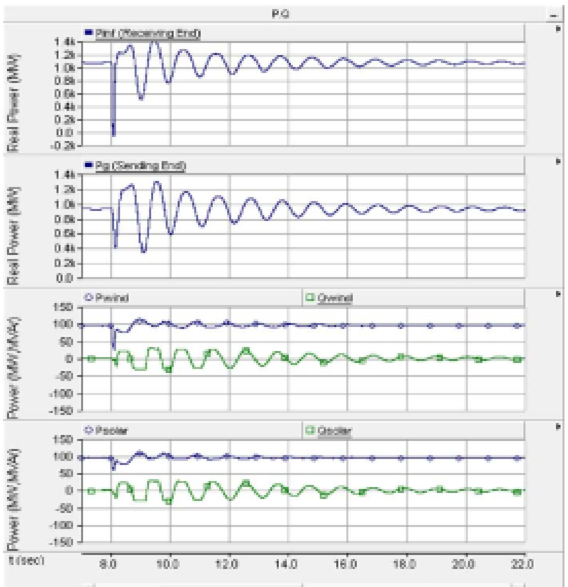

Fig. 5. Maximum daytime power transfer from the generator while both DGsgenerate 95 MW, each using a damping controller.

Case 6 – Only Solar DG Generates Power: The powertransfer limit from the generator decreases as the power outputfrom the solar DG increases. However, no substantial changesin power limits are observed compared to the case when bothDGs generate power (Case 5).

Case 7 – Both DGs Generate Real Power and Operate onDamping Control: This case is illustrated by different variables in Fig. 5. The powerlimit does not change much with increasing power output fromboth DGs.

Case 8 – Only Solar DG Generates Real Power But BothDGs Operate on Damping Control: The power limit does notappear to change much with increasing power output from thesolar DG

IV. SIMULATION RESULTS

By plotting the impedance magnitude versus frequencyobtained from this frequency scan, the network resonance frequency can be identified as that at which the impedance exhibits a peak. If one of the harmonic frequencies injectedby a harmonic source on the network matches with this resonance frequency, thecorresponding harmonic voltage may become amplified based on corresponding impedance magnitudes. The MATLAB software is used to plot the dataexported from the EMTDC/PSCAD frequency scan simulation in the feeder network forvarious network conditions.

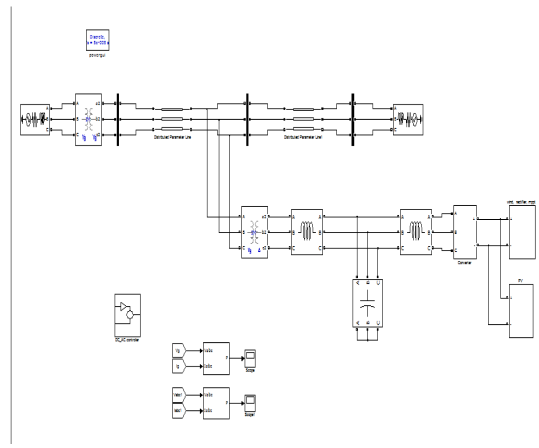

Fig 6 MATLAB/SIMULINK Diagram of Complete DG (solar/wind) system model with a damping controller and PCC voltage-control system.

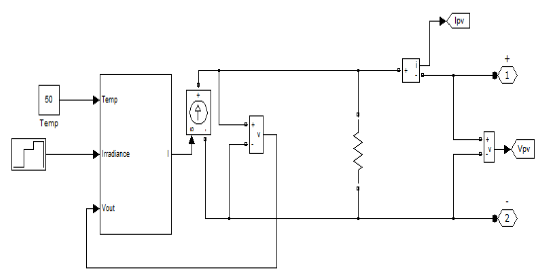

Fig 7 PV subsystem

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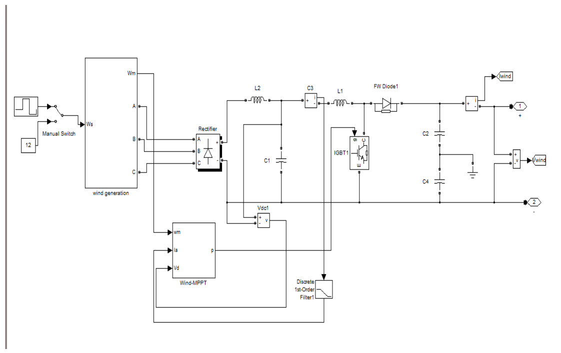
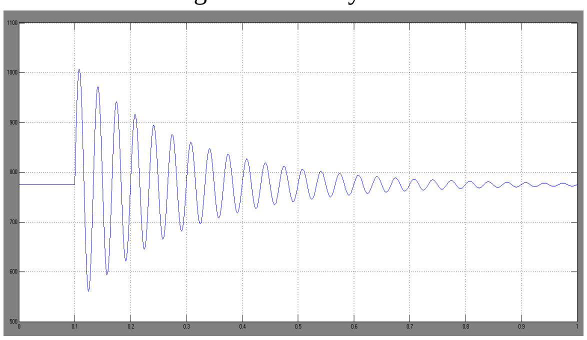
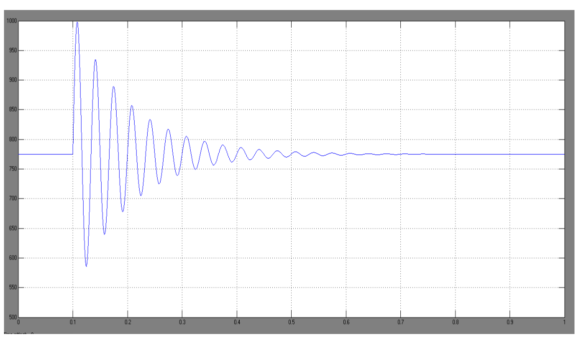


Fig 8 wind subsystem

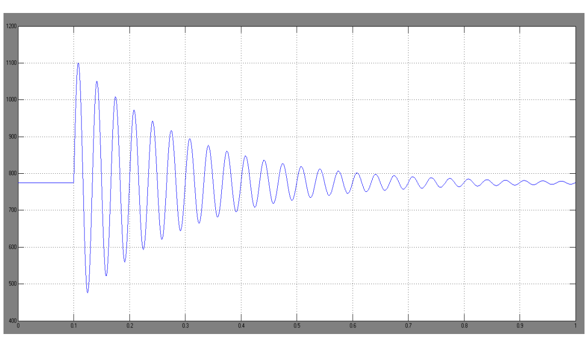


(a)

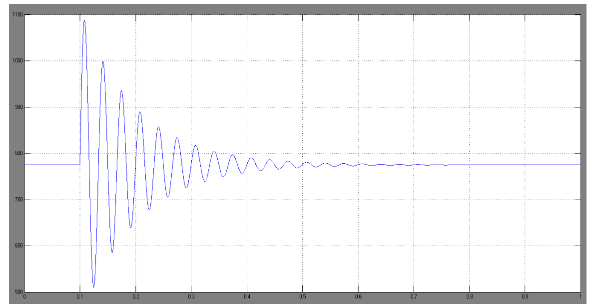


(b)

Fig 9 Night time (a) generator power Pg (B) infinite bus power Pinf



(a)



(b)

Fig 10 Day time (a) generator power Pg (B) infinite bus power Pinf

V. CONCLUSION

Novel Control proposed for PV Solar Farm inverter as STATCOM, termed PV-STATCOM utilizes voltage and damping control with"unused" capacity of PV inverter.Thus provides significant enhancement of transient stabilityand power transfer capacity, very cost-effectively.Similarly STATCOM controls can be implemented oninverter based wind turbine generators.be selected. New revenues to solar farms during night and day and better network performance for utilities.

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