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

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ABSTRACT: During daytime, the inverter capacity left after real power production is used to accomplish the aforementioned objective. Transient stability studies are conducted on a realistic single machine infinite bus power system having a midpoint located PV-STATCOM using EMTDC/PSCAD simulation software. The PV-STATCOM improves the stable transmission limits substantially in the night and in the day even while generating large amounts of real power. Power transfer increases are also demonstrated in the same power system for: 1) two solar farms operating as PV-STATCOMs and 2) a solar farm as PV-STATCOM and an inverter-based wind farm with similar STATCOM controls. This novel utilization of a PV solar farm asset can thus improve power transmission limits which would have otherwise required expensive additional equipment, such as series/shunt capacitors or separate flexible ac transmission system controllers.

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

I. INTRODUCTION

(PV) solar energy is one of the green energy sources which can play an important role in the program of reducing greenhouse gas emissions. Although, the PV technology is expensive, it is receiving strong encouragement through various incentive programs globally [1], [2]. As a result, large scale solar farms are being connected to the grid. Transmission grid worldwide are presently facing challenges in integrating such large scale renewable systems (wind farms and solar farms) due to their limited power transmission capacity [3]. To increase the available power transfer limits/capacity (ATC) of existing transmission line, series compensation and various FACTS devices are being proposed [3]-[9]. In an extreme situation new lines may need to be reconstructed at a very high expense [10]. Cost effective techniques therefore need to be explored to increase transmission capacity. A novel research has been reported on the nighttime usage of a PV solar farm (when it is normally dormant) where an PV solar farm is utilized as a STATCOM—an Flexible AC Transmission System (FACTS) device for performing voltage control, thereby improving system performance and increasing grid connectivity of neighboring wind farms [11], [12]. It is known that voltage control can assist in improving transient stability and power transmission limits, several shunt connected FACTS devices, such as Static Var Compensator (SVC) and STATCOM are utilized worldwide for improving transmission capacity [13], [14]. This paper presents a novel night-time application of a PV solar farm by which the solar farm inverter is employed as a STATCOM (with its entire MVACapacity) for voltage control in order to improve power transmission capacity during nights. During day time also, the solar farm while supplying real power output is still made to operate as a STATCOM and provide voltage control using...
its remaining inverter MVA capacity (left after what is needed for real power generation). This day time voltage regulation is also shown to substantially enhance stability and power transfer limits. These studies are conducted on a single generator infinite bus system with a PV solar farm integrated midway in the transmission line. Three phase fault studies are conducted using the electromagnetic transient software EMTDC/PSCAD [15] and the improvement in transmission capacity evaluated both during night time and day time.

II. SYSTEM MODELS

The synchronous generator is represented by a detailed sixth order model and a DC1A-type exciter [1]. The transmission line segments TL1, TL2, TL11, TL12, and TL22, shown in Fig. 1, are represented by lumped pi-circuits. The PV solar DG, as shown in Fig. 2, is modeled as an equivalent voltage-source inverter along with a controlled current source as the dc source which follows the I-V characteristics of Photovoltaic (PV) panels [11]. The wind DG is likewise modeled as an equivalent voltage-source inverter. In the solar DG, dc power is provided by the solar panels, whereas in the full-converter-based wind DG, dc power comes out of a controlled ac–dc rectifier connected to the PMSG wind turbines, depicted as “wind Turbine-Generator-Rectifier (T-G-R).” The dc power produced by each DG is fed into the dc bus of the corresponding inverter, as illustrated in Fig. 2. A maximum power point tracking (MPPT) algorithm based on an incremental conductance algorithm [12] is used to operate the solar DGs at its maximum power point all of the time and is integrated with the inverter controller [11]. The wind DG is also assumed to operate at its maximum power point, since this proposed control utilizes only the inverter capacity left after the maximum 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).](image-url)
point all the time and is integrated with the inverter controller [11]. The wind DG is also assumed to operate at its maximum power point, as this proposed control utilizes only the inverter capacity left after the maximum powerpoint operation of both the solar DG and wind as an equivalent voltage-DC rectifier “wind- R)." The DC power of the DG.

**III. SYSTEM STUDIES**

Transient stability studies are carried out using PSCAD/EMTDC simulation software, for both the study systems during night and day, by applying a 3-Ground (3LG) fault at bus 1 for 5 cycles. The damping ratio is 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 by real current from the grid into the solar farm inverter to charge the DC link capacitor and maintain its voltage constant while operating the PV inverter as STATCOM with the damping controller (or even with voltage controller). During nighttime, the reference DC Link voltage \( V_{mpp\_ref} \) is chosen around the typical maximum power point (MPP) voltage. Therefore, for a 5% damping ratio of the rotor mode having oscillation frequency of 0.95 Hz, as considered in this study, the post-fault clearance settling time of the oscillations to come within 5% (typically within 3 times the time constant) of its steady state value [1] is almost 10 seconds. The peak overshoot of the PCC voltage should also be limited within 1.1 pu of nominal voltage. The maximum stable generator power limit for the system is determined through transient stability studies for different modes of operation of the solar DG in study system 1, and those of the solar DG and the solar/winds DGs in study system 2.

**A. Case Study 1: Power Transfer Limits in Study**

Conventional Reactive Power Control with the Novel Damping Control

In this study, the solar DG is assumed to operate with its conventional reactive power controller. The DG operates at near unity power factor. For the nighttime operation of solar DG, the DC sources (solar arrays) are disconnected and the solar DG inverter is connected to the grid using appropriate controllers, as described below. Power transmission limits are now determined for the following four cases. The stable power transmission limit from transient stability studies and the corresponding loadflow results are presented where ve Q represents...
the inductive power drawn and +ve Qcapacitive power injected into the network.

i) solar DG operation during night with conventional reactive power controller:
The maximum stable power output from the generator Pis 731 MW when the solar DG is simply sitting idle during night and is disconnected from the network. This powerflow level is chosen to be the base value against which the improvements in power flow with different proposed controllers are compared and illustrated later. The real power from generator Pg and that entering into the infinite bus Pinf for this fault study are shown in Fig 3(a). The sending end voltage at generator is shown in Fig 3(b).

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

Case 3 – None of the DGs Generate Real Power But Both DGs Operate With Damping Control: The different variables, generator power, infinite bus power, real power of wind DG, reactive power of the wind DG, real power of the solar DG, and the reactive power of the solar DG are 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 Both DGs Operate on Damping Control: There is only a marginal improvement in the power limit with decreasing power output from the wind DG.

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 for Study System II shown in Fig. 1(b). A three-phase-to-ground fault 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.

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

Fig. 4. Maximum nighttime power transfer from the generator with both DGs using 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 output from both DGs increase.
Fig. 5. Maximum daytime power transfer from the generator while both DGs generate 95 MW, each using a damping controller.

Case 6 – Only Solar DG Generates Power: The power transfer limit from the generator decreases as the power output from the solar DG increases. However, no substantial changes in power limits are observed compared to the case when both DGs generate power (Case 5).

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

Case 8 – Only Solar DG Generates Real Power But Both DGs Operate on Damping Control: The power limit does not appear to change much with increasing power output from the solar DG.

IV. SIMULATION RESULTS

By plotting the impedance magnitude versus frequency obtained 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 injected by a harmonic source on the network matches with this resonance frequency, the corresponding harmonic voltage may become amplified based on corresponding impedance magnitudes. The MATLAB software is used to plot the data exported from the EMTDC/PSCAD frequency scan simulation in the feeder network for various network conditions.
Novel Control proposed for PV Solar Farm inverter as STATCOM, termed PV-STATCOM utilizes voltage and damping control with “unused” capacity of PV inverter. This provides significant enhancement of transient stability and power transfer capacity, very cost-effectively. Similarly STATCOM controls can be implemented on inverter-based wind turbine generators. New revenues to solar farms during night and day and better network performance for utilities.

REFERENCES


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