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Regulation of Grid Voltage by the Application of Photovoltaic (PV) Solar Farm as STATCOM

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***Abstract*—**
In this paper, it is shown that a combination of PV solar farm and storage batteries can be advantageous in a distribution system having wind farm in close vicinity to the solar Farm. This concept utilizes the photovoltaic (PV) solar farm (SF) as Flexible ac transmission system controller-static synchronous compensator, to regulate the point of common coupling voltage during night time when the SF is not producing any active power. The proposed control will enable increased connections of WECS to the grid. MATLAB/SIMULINK based simulation results are provided to show the effectiveness of the proposed indirect grid voltage regulation utilizing the PV solar farm and storage batteries.

Index Terms — Battery storage, converter/inverter, photovoltaic (PV) system, solar power, voltage regulation, wind power.

I. INTRODUCTION

Photo voltaic (PV) solar energy is one of the green energy sources which can play an important role in the program of reducing green house gas emissions. Although, the PV technology is expensive, it is receiving strong encouragement through various incentive programs globally. As a result, large scale solar farms are being connected to the grid.

Transmission grids worldwide are presently facing challenges in integrating such large scale renewable systems (Wind Farms (WF) and Solar Farms (SF)) due to their limited power transmission capacity. To increase the available power transfer limits/capacity of existing transmission line, series compensation and various Flexible AC Transmission System (FACTS) devices are being proposed.

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 neighbouring wind farms.

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.

This project presents a novel night-time application of a PV solar farm by which the solar farm inverter is employed as a STATCOM 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.

II. PV SOLAR FARM AS BATTERY CHARGER

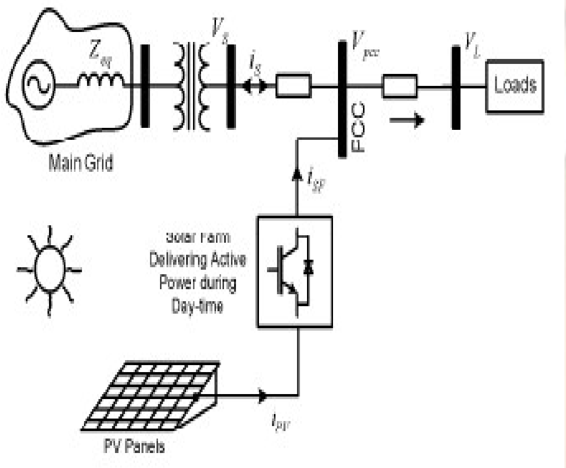
A typical PV solar farm is basically inactive during night-time and the bidirectional inverter used to deliver the PV DC power as three-phase AC power to the grid, remains unutilized as well. Fig.1 (a) & (b) shows the possible operational modes of the solar farm. The point at which the solar farm is connected to the grid is called the point of common coupling (PCC).

In Fig.1, V_S and i_S represents the voltage and current at the secondary of the distribution transformer; V_{PCC} and V_L denote voltages at PCC and load terminal respectively; and i_{PV} is the current delivered by the PV solar panels. AC current drawn/delivered by the solar farm inverter and the DC current flowing through the storage battery are represented by i_{SF} and i_{Batt}, respectively.

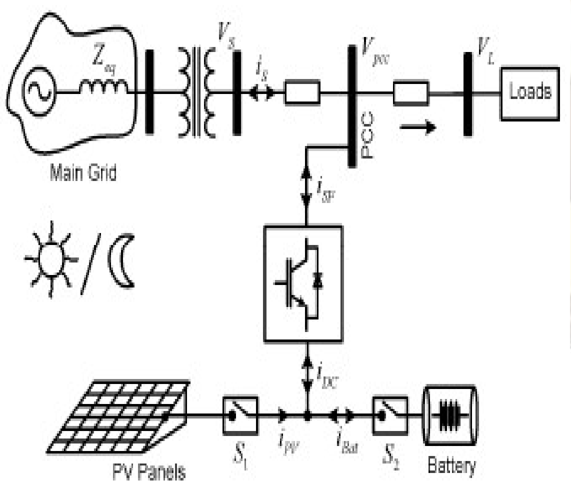
Fig.1 (a) shows the block diagram representation of traditional utilization of a PV solar farm. The PV solar farm in this case supplies power to the main grid during the day-time (remaining unutilized during the night). Fig. 1(b) shows a system configuration to utilize the solar farm inverter as a battery charger. In this case, a storage battery is connected on DC side of the solar farm inverter. Switch "S1" in Fig.1 (b) is utilized to disconnect the PV solar panels especially during night-time and to charge the storage batteries from the main grid. In some cases, the battery charging process can be incorporated in the maximum power point tracking (MPPT) algorithm. An additional DC to DC converter, such as a buck/boost converter may be required to enhance the battery charging/discharging operation. An automatic mechanism or control loop may also be essential to avoid excessive overcharging of the batteries and low battery voltage condition during discharging process.

The advantages offered by the consideration of a battery or sets of batteries on the DC side of the PV solar farm inverter are highlighted below:

- Better utilization of solar farm inverter asset 24/7/365 with multiple value streams i.e. as solar PV generator, energy storage and voltage regulator
- Stored battery energy can be utilized for peakshaving or as an emergency backup
- Improved PV solar pwer dispatch ability and PV output smoothing.
- Increased DG and Distribution system reliability.
- Possibility of utilizing the system configuration as uninterruptible power source (UPS) when used captive (behind the meter).



(a)



(b)

Fig.1.Utilization of PV solar farm bidirectional inverter: (a) Normal operation during day-time to inject real power (b) Solar farm inverter as battery charger system configuration.

III. STATCOM

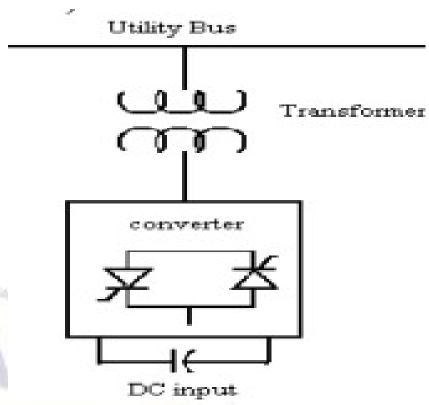


Fig.2.Line diagram of STATCOM

Recently the Voltage Source Inverter (VSI) based Static VAR compensators have been used for reactive power control. These compensators are known as Advanced static VAR compensator (ASVC) or static VAR compensator (STATCOM) in Fig.2 is a shunt connected reactive compensation equipment which is capable of generating and/ absorbing reactive power whose output can be varied so as to maintain control of specific parameters of power system.

The STATCOM provides operating characteristics similar to rotating synchronous compensator with out mechanical inertia, due to the STATCOM employ solid state power switching devices it provides rapid controllability of the three phase voltages, both in magnitude and phase angle. The STATCOM basically consist of step down transformer with a leakage reactance, a three phase GTO or IGBT voltage source inverter (VSI), and a DC capacitor.

IV. PROPOSED UTILIZATION OF COMBINED SOLAR FARM AND STORAGE BATTERY SYSTEM TO REGULATE PCC VOLTAGE

If the power generated by a DG is more than load demand connected downstream of the PCC, the excess power flows back towards the main grid. A substantial amount of this reverse power flow may cause voltage to rise on the distribution feeder. The voltage rise due to reverse power flow is one of the major concerns in any DG system (wind/solar/other) as it may cause the distribution feeder voltage to raise more than the allowable limit (typical ± 5%) specified by the utility standards.

Since wind velocity is generally higher during the night-times, a wind plant may produce more power causing significant amount of reverse power to flow towards main grid. Furthermore, during the night-time the condition worsens as the load on the system is generally lower as compared to the day time levels. On the other hand, it may be noted that solar farms do not produce any real power and remain unutilized during the night-time.

It is quite likely in the near future that wind and solar farms may be located on the same distribution feeder. This complementary operational condition of wind farm producing excessive power while solar farm remaining in idle condition, especially during the night-time, can be utilized to enhance the overall system performance by using the solar farm inverter to perform additional tasks.

In this paper, this approach is utilized to regulate the feeder voltage. The concept is to exchange (store/deliver) the real power from the feeder by incorporating storage batteries on the DC side of the solar farm inverter. In the future as more AC-DC-AC converter- inverter based wind plants are employed, such battery systems can be incorporated in wind plants (to store excess solar/other power)

Fig.4 shows the block diagram representation of the proposed system operational configuration. The distribution system consists of PV solar and wind farms connected on the same feeder. Several rechargeable batteries are connected to DC side of the solar farm inverter. Switches S1 and S2 are utilized to select one or multiple operational modes.

The bidirectional inverter of the solar farm is operated as fully controlled active rectifier to charge the batteries at unity power factor operation. Further, with adequate control, the batteries can be charged by drawing constant charging current to extract power at fixed rate or variable charging current for rapid charging to extract power at different rates if the power generation from wind farm increases suddenly.

The operational modes of proposed utilization of solar farm are explained below:

(i) The voltage and flow of power at PCC is monitored. During night-time, if the PCC voltage is observed to increase beyond a certain level, for example 1.025 pu, or a significant amount of reverse power flow is detected, the battery charging loop is activated. Part of the wind generated real power (ΔPWF) is extracted and utilized to charge the batteries such that the voltage at PCC will be regulated. Several batteries can be charged simultaneously if very high amount of reverse power flow causing significant voltage rise at PCC is noticed.

(ii) During the day-time, this stored energy in the batteries is delivered back to the PCC. For example, during early morning hours or late afternoon hours when the power generated from PV solar farm is not at its peak, the battery will be connected in parallel with solar farm generated output. Thus the PV solar farm and storage battery will simultaneously support the load power demand.

V. SF INVERTER CONTROL

Fig.3 shows the block diagram of the control scheme used to achieve the proposed concept. The controller is composed of two proportional--integral (PI) based voltage-regulation loops. - One loop regulates the PCC voltage, while the other maintains the dc-bus voltage across SF inverter capacitor at a constant level. The PCC voltage is regulated by providing leading or lagging reactive power during bus voltage drop and rise, respectively.

A phase-locked loop (PLL) based control approach is used to maintain synchronization with PCC voltage. A hysteresis current controller is utilized to perform switching of inverter switches. To facilitate the reactive power exchange, the dc-side capacitor of SF is controlled in self-supporting mode, and thus, eliminates the need of an external dc source (such as battery).

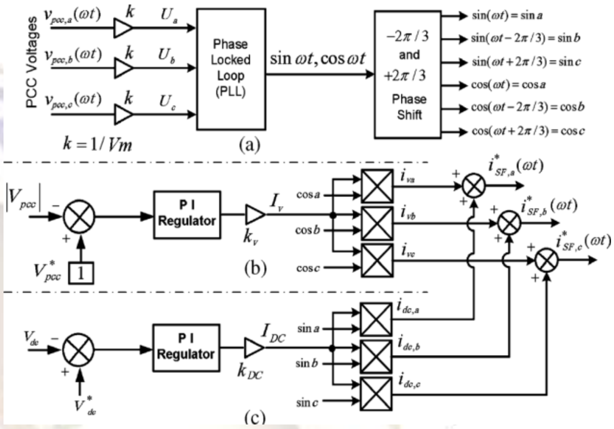


Fig.3.SF as STATCOM—controller diagrams. (a) Synchronization. (b) PCC voltage regulation loop. (c) DC bus voltage regulation loop.

V. SIMULATION STUDY AND RESULTS

To validate the concept presented in the paper, MATLAB/ SIMULINK based simulation study is carried out. A SIMULINK model in Fig.5 is developed for the system in Fig.4. The length of line L1, L2 and L3 are: 5 km, 1 km and 0.5 km, respectively. All parameters are in per unit (pu) with base value of 10 MVA and 12.7 kV. The simulation results are given in Fig 6 to 10.

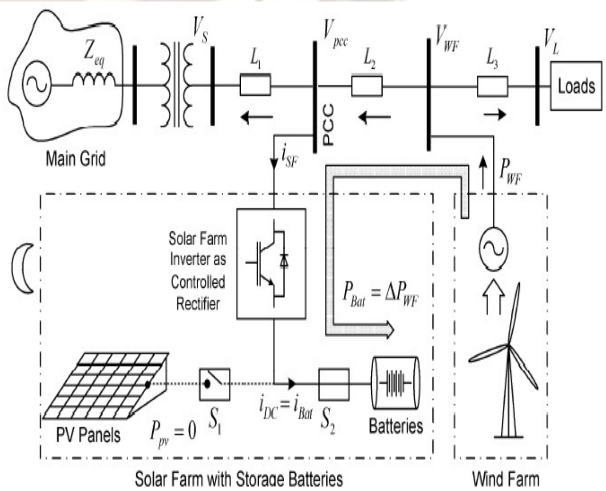


Fig.4.Block Diagram representation of proposed utilization of solar farm inverter during night time.

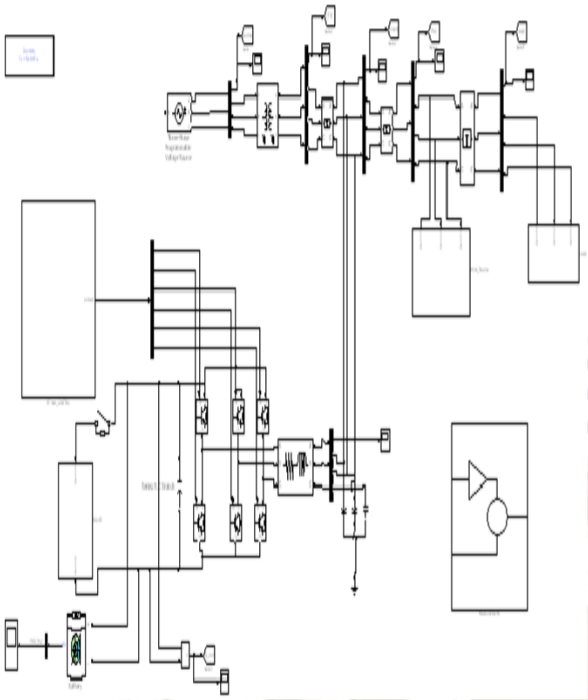
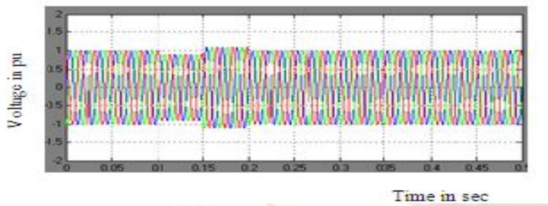
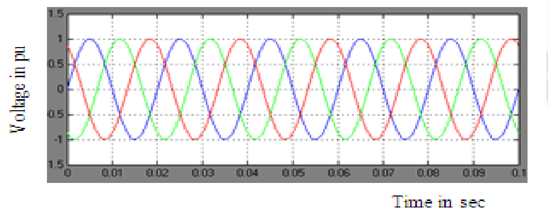


Fig.5.Simulation model of the proposed system.

The Fig.6 (a) and Fig.7 (a) shows the grid voltage and PCC voltages with lot of power quality disturbances when the SF inverter is not acted as STATCOM. Fig.6 (b) and Fig.7 (b) shows the regulated grid voltage and PCC voltage with out any disturbances when the SF inverter is acted as STATCOM.

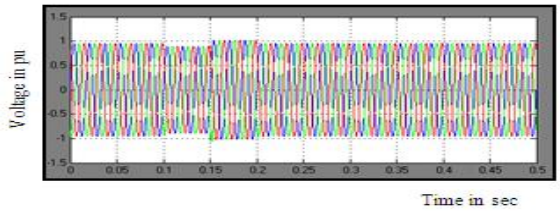


(a)

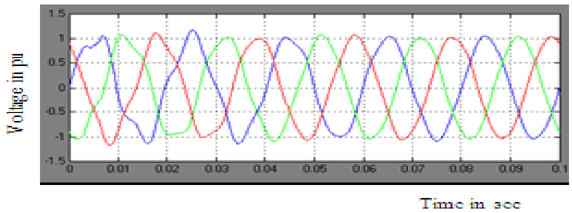


(b)

Fig.6.Grid voltage (a) Before the connection of inverter as STATCOM (b) After the connection of inverter as STATCOM



(a)



(b)

Fig.7.PCC voltage (a) Before the connection of inverter as STATCOM (b) After the connection of inverter as STATCOM

Fig.8 shows the single phase voltage waveforms of source, PCC, and load in per unit after the connection of inverter as STATCOM. The DC link voltage across the SF inverter is also shown in Fig.8. The Fig.9 shows the voltage magnitudes of source, PCC and load in per unit after the connection of inverter as STATCOM.

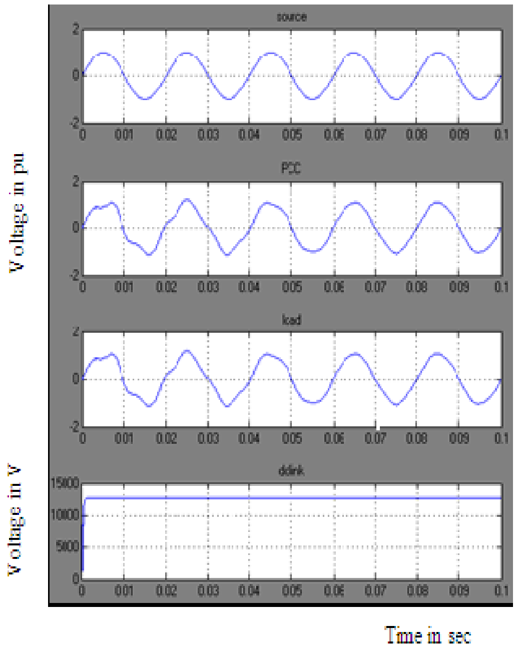


Fig.8.Single phase voltage waveforms of source, PCC, and load in pu and DC link voltage in volts.

Fig.10 shows discharging properties of the battery used in this project with the rated capacity of 50 Ah. The SOC% indicates state of charge present in the battery. 100% indicates a fully charged battery and 0% indicates an empty battery. Fig.11 (a) and Fig.11 (b) shows the battery discharge characteristics with voltage plotted against Ampere hours (Ah) and Time in hours (hrs).

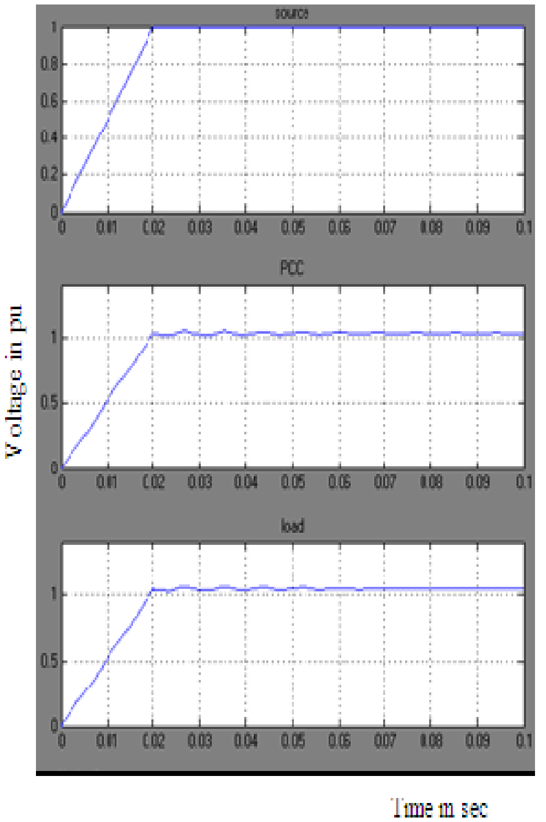


Fig.9.Voltage magnitudes of source, PCC, and load in pu

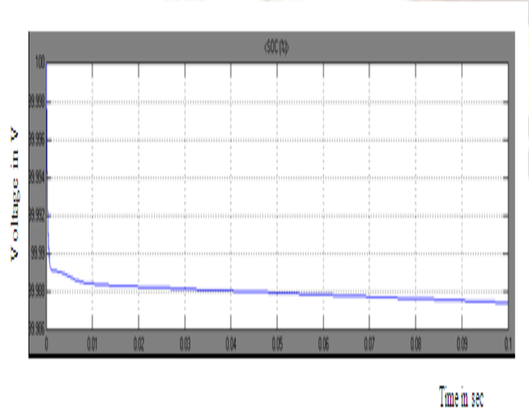
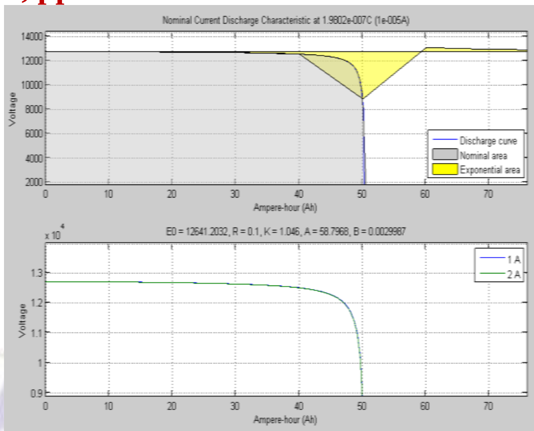
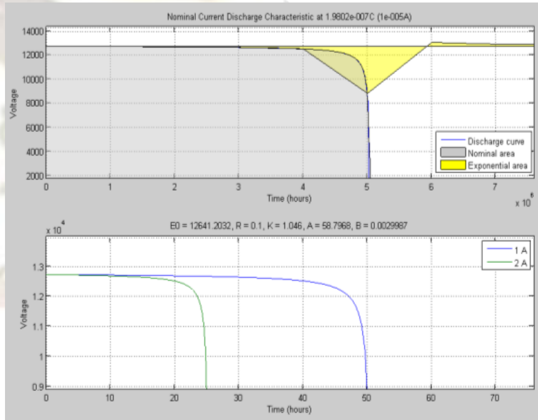


Fig.10.State of charge in the battery (SOC) in %



(a)



(b)

Fig.11.Battery discharge characteristics a) Voltage vs Ampere hour (Ah) b) Voltage vs Time (hours)

VI. CONCLUSIONS

A PV solar and wind plant based distributed generation system with battery storage is studied in this paper. The bidirectional inverter of PV solar farm is utilized as a battery charger especially during the night-time to charge the batteries. A new concept of indirect feeder voltage control is presented in which the voltage rise (due to a substantial amount of reverse power flow from the wind farm) is controlled by utilizing the solar farm inverter to charge the batteries. The solar farm inverter is operated as a three-phase controlled rectifier which draws sinusoidal currents at unity power factor operation. MATLAB/SIMULINK based simulation results confirm the feasibility and effectiveness of the proposed approach to regulate the feeder voltage by exchanging real power through the storage batteries. In future work, the proposed approach will be expanded for a medium voltage large scale PV Solar- wind power based distribution system.

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