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Application of Integrated Wind Energy Conversion System (WECS) and Photovoltaic (PV) Solar Farm as STATCOM to Regulate Grid Voltage during Night Time

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Abstract. This paper presents the usage of utilizing photovoltaic (PV) solar farm (SF) during night time as flexible ac transmission system controller-static synchronous compensator, to regulate the point of common coupling voltage when the wind farm supply the power to the grid and 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 presented for validation of the system.

Keywords: distributed generation (DG), photovoltaic (PV), solar farm (SF), voltage-source inverters (VSI), doubly-fed induction generator (DFIG), wind energy conversion system (WECS), static synchronous compensator (Statcom), voltage regulation.

1. Introduction

Utilities are presently facing a major challenge of grid integrating an increasing number of renewable-energy-based distributed generators (DGs) while ensuring stability, voltage regulation, and power quality. During the night time, feeder loads are usually much lower compared to daytime, while the wind farms (WFs) produce more power due to increased wind speeds. This potentially causes reverse power to flow from the point of common coupling (PCC) toward the main grid resulting in feeder voltages to rise above allowable limits. To allow further DG connections, utilities need to install expensive voltage regulating devices. Voltage-source inverters are essential components of PV solar farms (SFs), which provide solar power conversion during daytime (normal operation). However, PV SFs are practically inactive during night time and do not produce any real power output. The proposed concept is to use the existing SF inverter as a STATCOM during night time to regulate voltage variations at the PCC due to increased and intermittent WF power and/or by load variations.

With the development of distributed generation systems, the renewable electricity from PV sources became a resource of energy in great demand. The current control scheme is mainly used in PV inverter applications for real power and reactive power control schemes. The emergence of wind generation is the leading source of renewable energy in the power industry, Wind farms totalling hundreds, even thousands, of MW are now being considered. DFIG is the main type of wind generation currently in use (the other is conventional induction generators) due to their variable speed operation, four-quadrant active and reactive power capability, low-converter cost, and reduced power losses.

2. DG System Modeling

Fig. 1 shows the single-line diagram of the wind energy system with battery storage and VSI. A WF modelled as a fully controlled converter–inverter-based doubly-fed induction generator and a PV SF modelled as a voltage-source inverter.

2.1 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. 2 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.2, *vS* and *iS* represents the voltage and current at the secondary of the distribution transformer; *vPCC* and *vL* denote voltages at PCC and load terminal respectively; and *iPV* 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 *iSF* and *iBatt*, respectively. Here a storage battery is connected on DC side of the solar farm inverter. Switch “S1” in Fig.2is utilized to disconnect the PV solar panels especially during night-time and to charge the storage batteries from the main grid [2].

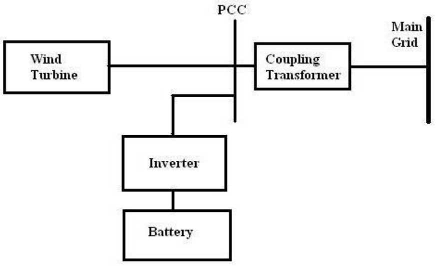


Fig.1 wind energy system with battery storage and VSI configuration

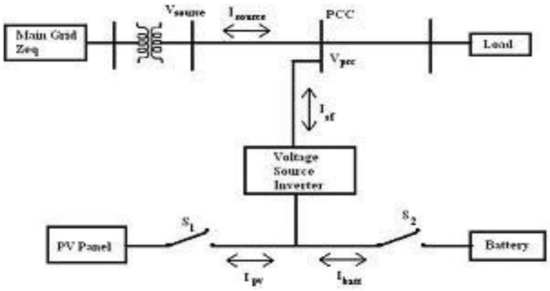


Fig.2 Solar farm inverter as the battery charger system

2.2 Doubly –fed induction generator

DFIG is an abbreviation for Double Fed Induction Generator, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip ring assembly but there are problems with efficiency, cost and size. A better alternative is a brushless wound-rotor doubly-fed electric machine.

The principle of the DFIG is that rotor windings are connected to the grid via slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents. Thus rotor frequency can freely differ from the grid frequency (50 or 60 Hz). By using the converter to control the rotor currents, it is possible to adjust the active and reactive power fed to the grid from the stator independently of the generator's turning speed. The control principle used is either the two-axis current vector control or direct torque control (DTC). DTC has turned out to have better stability than current vector control especially when high reactive currents are required from the generator

The doubly-fed generator rotors are typically wound with 2 to 3 times the number of turns of the stator. This means that the rotor voltages will be higher and currents respectively lower. Thus in the typical ± 30 % operational speed range around the synchronous speed, the rated current of the converter is accordingly lower which leads to a lower cost of the converter. The drawback is that controlled operation outside the operational speed range is impossible because of the higher than rated rotor voltage. Further, the voltage transients due to the grid disturbances (three- and two-phase voltage dips, especially) will also be magnified. In order to prevent high rotor voltages - and high currents resulting from these voltages - from destroying the IGBTs and diodes of the converter, a protection circuit (called crowbar) is used.

In Fig.3 the crowbar will short-circuit the rotor windings through a small resistance when excessive currents or voltages are detected. In order to be able to continue the operation as quickly as possible an active crowbar has to be used. The active crowbar can remove the rotor short in a controlled way and thus the rotor side converter can be started only after 20-60 ms from the start of the grid disturbance. Thus it is possible to generate reactive current to the grid during the rest of the voltage dip and in this way help the grid to recover from the fault.

The AC/DC/AC converter is divided into two components: the rotor-side converter and the grid-side converter. The Voltage-Sourced Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor connected on the DC side acts as the DC voltage source. A coupling inductor L_f is used to connect grid side converter $_{to}$ the grid. The three-phase rotor winding is connected to rotor side converter by slip rings and brushes and the three-phase stator winding is directly connected to the grid. The power captured by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor windings.

3. Statcom

Recently the Voltage Source Inverter (VSI) based Static

VAR compensators have been used for reactive power control [5]. These compensators are known as Advanced Static VAR Compensator (ASVC) or Static Synchronous Compensator (STATCOM) shown in Fig.5. The Static Synchronous Compensator (STATCOM) is a shunt connected reactive compensation equipment which is capable of generating and/or absorbing reactive power whose output can be varied so as to maintain control of specific parameters of the electric power system. The STATCOM provides operating characteristics similar to a rotating synchronous compensator without the 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 consists of a step-down transformer with a leakage reactance, a three-phase GTO or IGBT voltage source inverter (VSI), and a DC capacitor

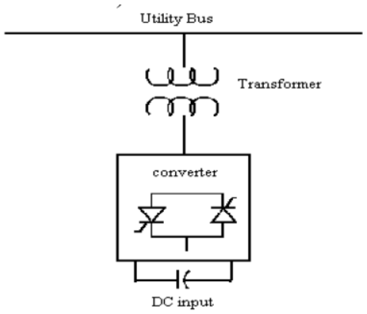


Fig.5: Line diagram of STATCOM

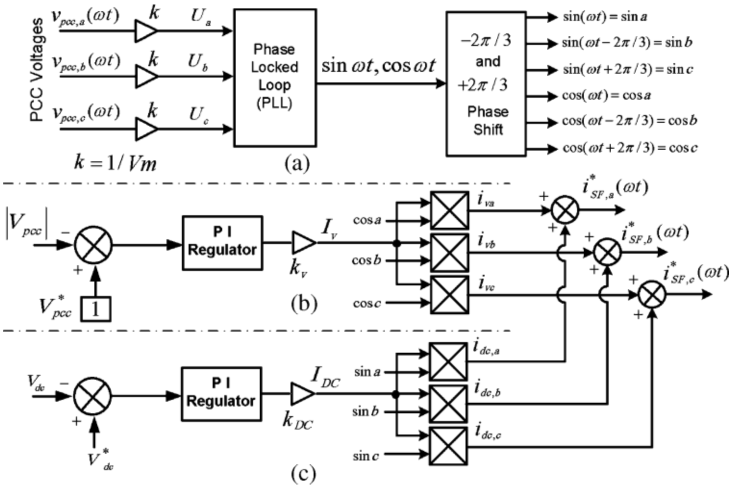


Fig .6: SF as STATCOM—controller diagrams. (a)Synchronization (b) PCC voltage regulation loop. (c) DC bus voltage regulation loop

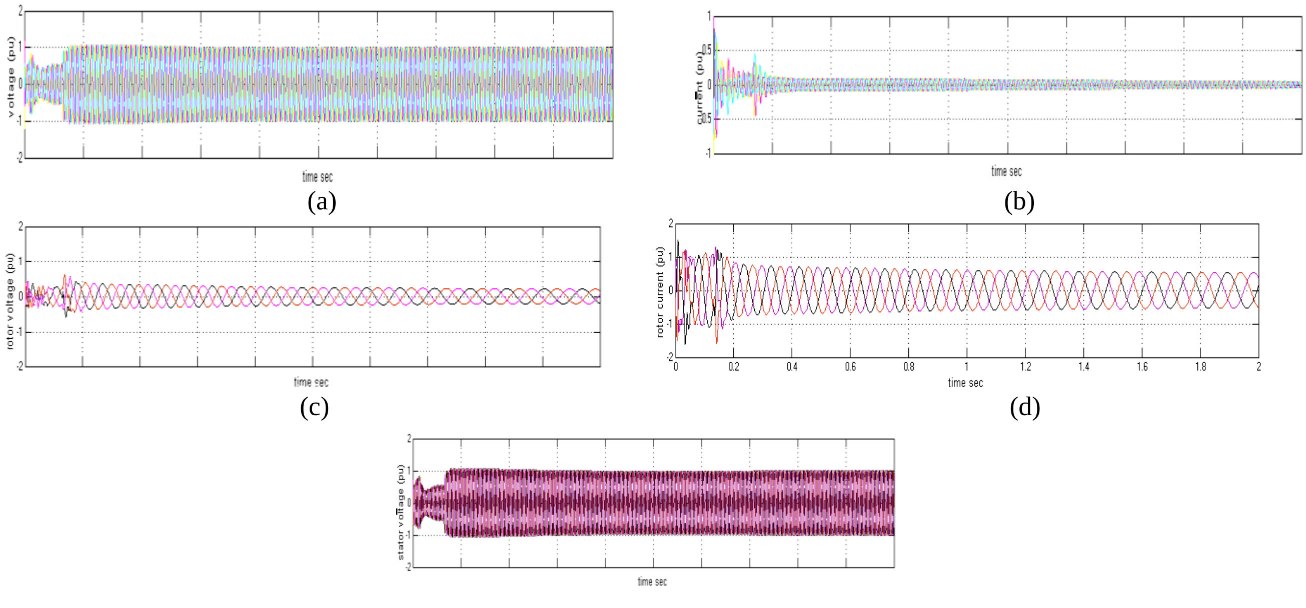
3.1 SF inverter control

Fig .6 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 [5] 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) [1].

4. Simulation Study and Results

To validate the concept presented in the paper, MATLAB/ SIMULINK based simulation study is carried out. A Test system consists of integration of both wind energy system and PV Array system.

Wind turbines using a doubly-fed induction generator (DFIG) consist of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter modeled by voltage sources. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.



(a) (b)

(c) (d)

(e)

Fig.7: (a) grid voltage,(b) current,(c) rotor voltage,(d) current,(e) stator voltage of the turbine

PV array is made to act as DC capacitor for the STATCOM designed and is interfaced to the system at the 25kv bus as in fig 7.

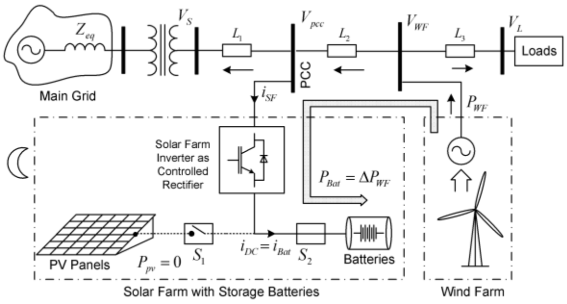
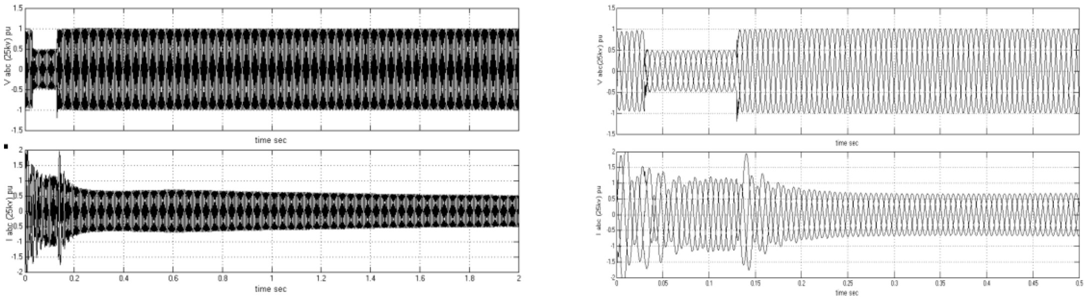


Fig .8: Block diagram representation of proposed utilization of solar farm during night time

The simulation results are given in Figs 9 to 11. Case1: under normal condition the voltage and current profile in the 25kv bus is as shown in figure 8(a) here after an initial fluctuation for about 0.2 sec the voltages and currents profile are well within the ±5% Pu value criteria. The reason for the fluctuation is due to change over of speed from 8m/s to 14m/s. The simulation is conducted for duration of 2 sec. Also the zoomed view of the voltages and currents is shown in fig 8(b)



(a) **(b)**

Fig.9: voltage and current at 25kv bus under normal condition

Case2: when the system in acting under normal condition single phase short circuit fault is set on the "phase A" line at the 25kv bus at the instant of 0.8 sec. The voltage decreases and current increases after the instant at 0.8 as shown in the fig 10 and propagates till the complete cycle of the simulation.

Case3: In this case the fault is implemented at 25kv bus at about 0.8 sec and is allowed to propagate. At 1 sec PV array STATCOM is brought into action and after 1.2 sec system is compensated and system is restored to normal condition after 1.2 sec as shown in fig 11

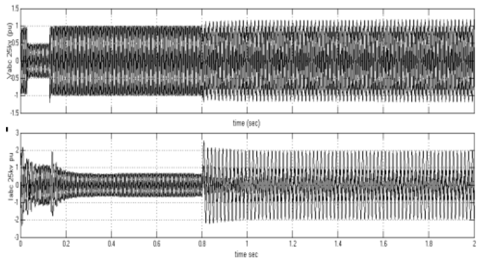


Fig .10: Voltages and current profile at the 25KV bus after fault

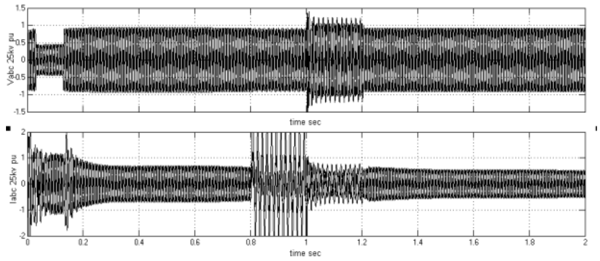


Fig .11: Voltages and current profile at 25KV bus after STATCOM action

5. Conclusion

A novel concept of optimal utilization of a PV SF as a STATCOM has been proposed and validated through MATLAB/SIMULINK simulation. The proposed strategy of PV SF control will facilitate integration of more wind plants in the system without needing additional voltage-regulating devices. PV Solar farm virtually inactive during night time in terms of active power generation is used to regulate the distribution voltage at PCC within utility specified limits even during wide variations in WF output and loads. This novel strategy implies operating PV solar plant as a generator during the day [providing megawatts (MW)] and ancillary services provider at night [providing mega volt amperes (Mvars)]. In effect, the PV solar plant becomes a utility tool at night (control is passed on to the utility supervisory control and data acquisition (SCADA) operator). This may pose interesting questions on ownership/partnership/lease options, license to operate, etc., and possible code changes by the regulator. These aspects are outside the scope of the letter. The technical aspects, however, warrant a look at such mixed usages.

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