A Novel Self-Healing PV-STATCOM in a Hybrid PV-Wind farm to Alleviate Sub Synchronous Resonance

Arockiaraj S
Department of EEE
Mepco schlenk Engineering college, Sivakasi
Tamil nadu, India

Dr. B. V. Manikandan
Department of EEE
Mepco schlenk Engineering college, Sivakasi
Tamil nadu, India

***Abstract*— Large-scale integration of electrical power in transmission networks has led to several challenges. One of which is the need for increased transmission capacity to transport a bulk amount of power without affecting the voltage. In case of transmitting power for large distances the stability must be maintained. The main approach of this paper is to maintain the voltage stability by utilizing the PV solar farm inverter as PV-STATCOM. The total inverter rating of PV solar farm which remains unused in the night time is utilized with voltage and damping controls to enhance stable power transmission limits. The stability of IEEE second bench mark system with synchronous generator (350MVA) is analyzed with hardware prototype model after applying a larger disturbance at multiple nodes. In view of transmitting power to large distances with better voltage profile of buses in transmission lines, PV-STATCOM is used and it is simulated using MATLAB Simulink and the results obtained are validated. An efficient way of enhancing voltage stability is done in this project with solar farm (100MW) which supplies active and reactive power. PV farm is operated at normal operating state during day time. When a larger disturbance arisen in any part of the study system at any bus bar, it stopped its real power generation and connected with grid to supply reactive power so as to maintain reliability of the wind farm.**

Keywords—Component; formatting; style; styling; insert (key words)

I. INTRODUCTION

The effect of SSR can be alleviated effectively using FACTS devices in real time wind farm. In our country number of power grids and renewable sources have been increasing year by year due to electrical power requirements. So it is not economically possible to purchase large number of FACTS devices for maintaining stability. Also solar power is an interesting area in energy harvesting from renewable source. PV-STATCOM is an important FACTS device to mitigate sub synchronous resonance (SSR) in a wind farm provided with series compensation. In this work, PV solar farm has been acted as a novel PV-STATCOM for providing reactive power compensation. It is proved that PV-farm can be used to generate real power and supplied reactive power for line compensation. Wind farm consist of DFIG and DFIG wind turbines vulnerable to the effect of SSR frequently due to series capacitor connected between wind farm and power grid. In view of increasing the available power transfer limits in transmission lines, voltage stability plays a vital role.

The utilization of solar farm as PV- PV-STATCOM for maintaining the voltage stability limit at the time of voltage instability due to occurrence of fault has been studied and PV-PV-STATCOM helps in increasing the stability limit of transmission lines both during the day and night time by use of real power generated during day time. Along with the usage of solar as PV-PV-STATCOM it also deals with the usage of voltage control together with the auxiliary damping [8].The concept of developing a solar inverter to work as PV-STATCOM which is a FACTS controller and voltage stabilizer by introducing reactive power, the major use of utilizing solar farm as PV-STATCOM helps in improving the power transfer capacity of transmission line and along with increase of transient stability [9].Since environmental pollution and rapid depletion of fossil fuels promoted the usage of renewable energy over the last few decades. The most popular one among them is solar energy this paper deals with the usage of PV farm as static compensator which helps with regulation of voltage at the connected transmission line between the buses with the use of real power generated during daytime with the solar farm.

Modern technology and new inventions has taken it to a greater level of energy production. Due to the cost constraints that are prevailed during the installation and initial cost of the FACTS devices, an alternative way of utilizing the PV-farm as PV-STATCOM is identified. The PV-farm which remains unused in the night time is used as PV-STATCOM, a facts device. Thereby the system performance is improved. In a PV farm a new voltage control has been proposed to act as PV-STATCOM for improving the power transmission capacity. We know that transmission and distribution (T&D) networks are critical parts of a power grid. In view of moving towards a smart-grid, it is essential to modernize the T&D networks and make it Smart-grid ready. The concept of flexible ac transmission systems (FACTS) has been introduced in transmitting high voltages with less losses. The FACTS technology helps the changeover of transmission networks to smart. With increasing amount of distributed generation, the distribution network is seeing unrivalled variation in terms of its fundamental operation and control. Though FACTS controllers play a vital role in place of distribution system, the erection and maintenance cost of FACTS controllers sum up to a larger value which may be difficult in introducing FACTS controllers.Thus PV-STATCOM's are replaced with PV PV-STATCOM in view of reducing the cost. Various cases were done by connecting the PV at different points in the transmission lines and the results were analyzed. The study system used here is the IEEE second benchmark system in which the two transmission lines are used and they are simulated using MATLAB. Hence, transmission of such huge power to long distances is a tedious process and it is not effective i.e., the efficiency is low. So for the mitigation of these transmission process PV-PV-STATCOM is introduced in place of FACTS devices.

. It describes a modelling technique for FACTS device, namely the static synchronous compensator which is stimulated by EMTP simulation package. The PV-STATCOM, a solid-state voltage source inverter coupled along with a transformer, is connected along with a transmission line. A PV-STATCOM injects sinusoidal current, of variable magnitude, at the point of connection. This injected current helps in stabilization of the line voltage, thereby emulating an inductive or a capacitive reactance at the point of connection with the transmission line [10]. In this paper, the hybrid power system has been simulated using MATLAB software for real time implementation. Design of the grid connected inverter circuit has been developed for the desired operation. The power transfer limits and voltage profile have been improved by connecting PV-PV-STATCOM with DFIF-DFIG wind farm.

II. MODELLING OF STUDY SYSTEM

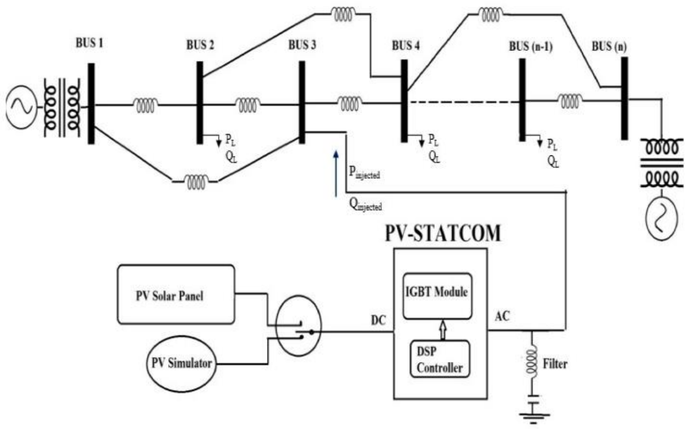

Figure 2.1 PV-STATCOM with transmission system

A DFIG based wind farm coupled with series compensation network is illustrated in Fig. 1.1 An aggregated wind farm with two mass drive train model is considered. A generator is connected with grid through single series compensated transmission network is represented as first bench mark system [6]. SSR studies are carried out in a power network consist of a turbo-generator interconnected with an infinite bus bar through series compensated network. The investigation is realistic to a model of "bench mark" projected by the superior IEEE Power Engineering Society Task Force to research about Sub synchronous Resonance phenomenon for real time power system [21]. SSSC is connected at the terminal of single cage induction generator to limit SSR effect shown in fig.2. The SSSC (between buses Vg and Vs) connected in series with terminal of generator. The SSSC is represented by fundamental voltage source converter in series with variable capacitive reactance. The effect of SSR can be well suppressed at this connection in lesser duration [17].

$I_{drr} \rightarrow d-axis\ rotor\ current\ of\ SCIG$

$I_{qrr} \rightarrow q-axis\ stator\ current\ of\ SCIG$

$V_d \rightarrow d-axis\ induced\ rotor\ voltage\ of\ SCIG$

$V_q \rightarrow q-axis\ induced\ rotor\ voltage\ of\ SCIG$

$E_{dsr} \rightarrow d-axis\ induced\ stator\ voltage\ of\ SCIG$

$E_{qsr} \rightarrow q-axis\ induced\ stator\ voltage\ of\ SCIG$

$T_{\omega t} \rightarrow The\ wind\ turbine's\ mechanical\ torque\ input$

$T_a \rightarrow Electrical\ torque\ output\ of\ the\ generator$

$I_{dl} \rightarrow d-axis\ current\ in\ series\ compensated\ transmission\ line$

$I_{ql} \rightarrow d-axis\ current\ in\ series\ compensated\ transmission\ line$

$C_1 \rightarrow capacitor\ at\ generator\ terminal$

A. Model of mechanical two mass drive train

The drive train includes hub and blades, shaft of rotor, generator and a gear. A wind turbine model with two mass is chosen for the analysis and dynamics of blades are not taken into account. [2] The differential equations are derived for the drive train model as follows.

$$2H_1 \dot{\omega}1 = T - K_{12}\delta_{12} - D_{12}(\omega_1 - \omega_2) \quad (1)$$

The change of inertia of rotor w.r.t speed of turbine is represented in equation (1) to predict the operating point of variation in torsional angle associated with turbine and generator.

$$\delta_{12} = (\omega_1 - \omega_2) \quad (2)$$

$$2H_2 \dot{\omega}_2 = K_{12}\delta_{12} + D_{12}(\omega_1 - \omega_2) - T_1 \quad (3)$$

B. Transmission Network Model

It is modeled as connection among the shunt capacitor at the generator terminal, transformer, and the series compensated line. The saturation of the transformer and line charging capacitances are not considered into analysis [2]. The differential equations of transmission line in d-q axis frame are:

$$C_1 \dot{E}_{dsr} = I_{dsr} - I_{dl} + \omega_{syn} C_1 E_{qsr}$$

$$C_1 \dot{E}_{qsr} = I_{qsr} - I_{ql} + \omega_{syn} C_1 E_{dsr}$$

The dynamic behavior of transmission line is represented in d-q axis currents and voltages induced depends on line capacitive reactance. The series capacitance of transmission line produced an impact on fundamental component of stator voltage which made a change of power frequency is represented from (8) to (13).

$$L \dot{I}_d = E_{dsr} - RI_{dl} + \omega_{syn} LI_{ql} - V_{cd} - V_{bd}$$

$$L \dot{I}_q = E_{qsr} - RI_{ql} + \omega_{syn} LI_{dl} - V_{cq} - V_{bq}$$

The current flow in transmission line is liable w.r.t the change of inductive reactance and line charging admittance

[6]. The effect of reactance variation replicated in line current [2].

$$C\dot{V}_{cd} = I_{dl} + \omega_{syn} C V_{cq}$$
$$C V_{cq} = I_{ql} + \omega_{syn} C V_{cd}$$

$\delta_{12} \rightarrow$ *Torsional angle of turbine and generator*
$\omega_1 \rightarrow$ *wind turbine speed*
$\omega_2 \rightarrow$ *generator speed*
$H_1 \rightarrow$ *wind turbine's Inertia constant*
$H_2 \rightarrow$ *generator's Inertia constant*
$K_{12} \rightarrow$ *Shaft stiffness of turbine and generator*
$D_{12} \rightarrow$ *Damping coefficient of turbine and generator*
$R_{sr} \rightarrow$ *Stator resistance per phase*
$R_{rr} \rightarrow$ *Rotor resistance per phase*
$\omega_{syn} \rightarrow$ *Synchronous frequency*
$I_{dsr} \rightarrow$ *stator current of SCIG in d axis*
$I_{qsr} \rightarrow$ *stator current of SCIG in q axis*

III. RESULTS AND DISCUSSION

A. Power Flows and Voltages during Nighttime and Daytime

This simulation implies that in the absence of PV-STATCOM with compensatory compensation, the electromagnetic torque (Te) begins to oscillate. When PV-STATCOM it reduces the effect of Torsional interaction by reducing the oscillation of the torque with K=50% . From this simulation we can see that the voltage and current are affected in the same fault line while the actual and operating voltage is less affected due to the active support provided by PV-STATCOM. From the diagram above we see that whenever an error is set to be zero as it is a single line of errors one current phase is subtracted when the actual power becomes zero once provided by PV-STATCOM. While the energy used is slightly reduced.

In this simulation it is assumed that whenever an error occurs the PV-STATCOM voltage becomes zero and its current starts to erupt. At a time when there is a need for energy it supplies the energy it serves and consequently its energy consumption is reduced only during the fault. From this we can say that PV-STATCOM provides practical power where less power is used. In this simulation we can see that whenever a double fault line appears the voltage of the two phases becomes smaller and the increase in the current during the fault occurs. Real and effective power increases abruptly and stabilizes and then suddenly drops off when an error occurs. Since the fault occurs near bus 2 it is particularly affected, by measurement we can see that when an error occurs the increase in current and true strength decreases during the fault, while the operating capacity increases abruptly and is maintained during the fault.In this simulation we can see that in the event of only one phase fault remaining while the other is turned on rotation and so does the current decrease due to the wire reduction while the actual and effective power goes up to zero. This means that when the capacitor releases all the energy stored in the actual and active power it increases the current fall time of the output capacitor. From this simulation we can see that PV-STATCOM provides practical supportive power.

TABLE 3.1 Study system data

Pg (MW)	V_{pcc} (pu)	Q_l(VAR)	P_{inf}(MW)
789	0.988	-95.8	-761
830	1.000	-9.5	-801
855	1.000	4.0	-824
899	1.010	8.0	-866

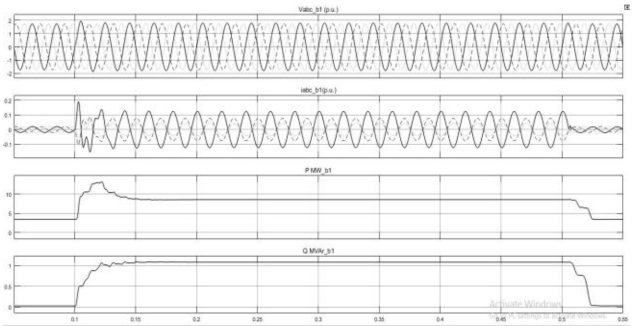

Fig 3.1Voltage, active power and reactive power

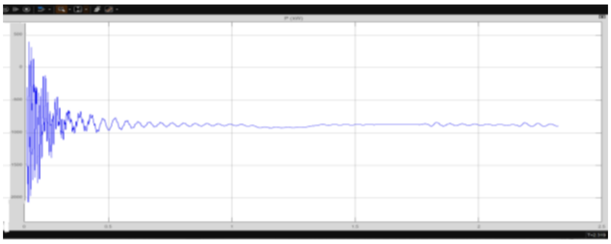

Fig 3.2The real power injection

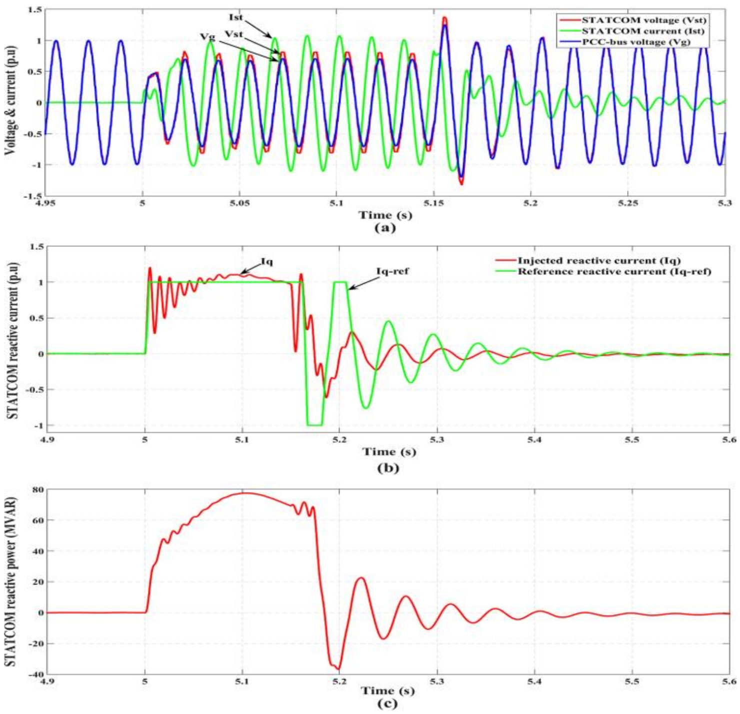

Fig.3.3 a.Statcom voltage& current b. Statcom reactive current c.Statcom reactive power

The above figure depicts the total real power injection from the PV solar farm to the grid at PCC in the transmission line.

The reactive power requirement for the bus voltage stabilisation is injected from the PV farm through voltage source converter.

B. Hardware

Fig 3.4Solar Panel (250W*4=1000W)

Fig 3.5PV-STATCOM control with RL load

Fig 3.6Solar power control

TABLE 3.2 Solar system configuration

Open Circuit Voltage	44.64 V
Short Circuit Current	7.57 A
Rated Voltage	36 V
Rated Current	6.94 A
Max System Voltage	1000 V

In this case, the solar panels are directly connected to the Transmission and Distribution (i.e., Grid) so that the maximum power can be drawn in times of need and also it can feed power to the grid when there is more generation . In view of safely transmitting electricity to the loads and to make comply with your power providers grid-connection requirements. In making these connections certain number of equipments are required that Power conditioning equipment, Safety equipment and instrumentation

INPUT (DC):
Max. DC input power – 1200V
MPPT Range (V) - 60-400V
Max. DC current per MPPT*number of MPPT - 9*1
OUTPUT (AC):
Rated output power (W)-1000
Max. AC output power (A)-4.5
EFFICIENCY:
Max.efficiency-96.90%
Euro-efficiency-96.0%
MAKE: INVT Shenzhai Co.Ltd

Fig 3.7Grid-tie Inverter

Since our project needs to be tested on transmission line along with the grid but it cannot be done due to lack of approval from electricity board and assurance cannot be made to ensure safe operation to attain voltage stability .So we made a test using normal hose load components which includes AC motor, tube light choke, LED bulb. The specifications of the loads used are LED Bulb-18W, AC Motor-40W and tube Light Choke-40W

Fig 3.8Load Connections

TABLE 3.3Output of RL load

Reactive power	15.27VAR
Execution (pole)	4
Type	C Curve
Current	2.15A
Voltage	415 V
Q_{max} at power factor	0.85

CONCLUSION

Thus in the both night time and daytime to increase the revenues in addition to the real power generation in the PV solar DGs ,the PV-PV-STATCOM makes its way into it due to its operation. This will of course require appropriate agreements between the regulators, network utilities, solar farm developers and inverter manufacturers. This helps in making the present grid codes to allow certain inverter based renewable generators to experience the damping control, thus it increases the power transmission capability over the transmission and distribution network.

As we know that the solar panels remain unused in the night times and thus it can be utilized for this operation of using this PV as PV-STATCOM. It can be operated in the night time with full inverter capacity and during the day time it can be operated with the remaining capacity of the inverter after the real power generation, for providing significant improvements in the power transfer limits of transmission systems.

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