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Utilizing PV Solar farms in the Night for Added System Benefits and Revenues

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***ABSTRACT*—** *PV solar farms produce power during the day and are completely idle in the nights. This paper presents a novel utilization of a PV solar plant as STATCOM in the night for load reactive power compensation and voltage regulation. This STATCOM functionality will also be available to a substantial degree during the daytime with the inverter capacity remaining after real power production. In the night, when the solar farm is completely idle, this new control technique makes the solar farm inverter behave like a STATCOM – a Flexible AC Transmission System (FACTS) device. The solar farm inverter then provides voltage regulation at the point of common coupling and improves the stability and transfer limits far beyond minimal incremental benefits. During the day also, when solar farm is producing real power, this new control strategy makes the solar farm inverter provide voltage control with the remaining inverter capacity (after meeting the requirements of real power generation) and thereby increases power transfer limits substantially.*

Keywords— PV, Solar power systems, inverter, voltage control, reactive power control, STATCOM, FACTS.

1, INTRODUCTION

PV energy is one of the cleanest forms of renewable energy. Although, the PV technology is expensive, it is receiving strong encouragement through various incentive programs globally. PV solar farms produce real power only during daytime whereas in the nights they are completely idle. Such an expensive asset thus remains entirely unutilized in the night time and brings no revenue to the solar farm owner. A key component of the PV solar farm is a voltage source converter/inverter, which in fact is also the core element of a

Flexible AC Transmission System (FACTS) device- STATCOM. An innovative concept of utilizing the PV solar inverter as a STATCOM during night time for voltage control was proposed. PV solar farm inverters, while generating active power, have also been controlled to provide reactive power compensation for loads connected at its terminals. Some earlier papers have presented sunny mode and night modes of operation of three-phase PV grid connected inverter .In the night mode, the PV solar farm inverter compensates for the reactive power demanded by nonlinear loads. In sunny mode, it not only supplies active power from the PV array to the grid or loads, but also performs power quality control to improve the power factor and reduce the harmonic current. In each of these cases, the PV solar plant is connected at the load terminals.

In a PV system inverter control adjusts the reactive power injection at the connection point in the distribution system in order to maintain the system voltage within an acceptable range. This control has only been demonstrated for daytime operation and not for night time. The power conditioning equipment of a PV solar plant was shown to provide voltage support for the grid by varying its reactive power in response to the measured voltage at the point of connection. The voltage control mode of operation was not shown during daytime. Also, the load reactive power compensation function was not provided.

This paper presents a novel application of the PV solar farm inverter as a STATCOM –a FACTS device for voltage control and power factor correction, both during night time and day time. A comprehensive controller has been developed which provides the voltage regulation and load compensation in the nights utilizing the entire capacity of the existing solar farm inverter. During day time also solar system is made to operate as a STATCOM using its remaining inverter capacity.

2, PV SOLAR SYSTEM CONTROLLER DESIGN

The controller design for a PV solar system to be operated as a STATCOM is presented in this section. The objectives of this control are to provide voltage regulation and power factor correction. Fig1 shows the power circuit of the PV solar farm model together with the component parameters. For the purpose of this analysis, all the PV solar panels are lumped together and presented as a dc source, EDC, interfaced with the grid by

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mean of IGBT – based, 6 – pulse Voltage Source Inverter (VSI) and indicators L. The interface inductors L together with the filter capacitors C are used to filter out the switching harmonics produced by inverter. A three – phase coupling transformer T is used to match the inverter and grid voltages. The dc side capacitor CDC, serves two main purposed: in steady state it maintains the dc voltage constant (with a small acceptable ripple), and during the transients it serves as an energy storage element to supply real power. The dc source EDC is employed when the solar farm injects active power into the grid. In case when only reactive power is injected into the grid (STATCOM mode of operation) the dc source EDC is disconnected. For this reason, its connection to inverter is shown using dashed lines. Current transducers CTi and CTL are used to measure the inverter (ii,a, ii,b, ii,c,) and load (iL,a, iL,b, iL,c,) currents, respectively. The component parameters L, C, CDC, and the dc link voltage level VDC have been determined based on recommendations, and refined through simulations.

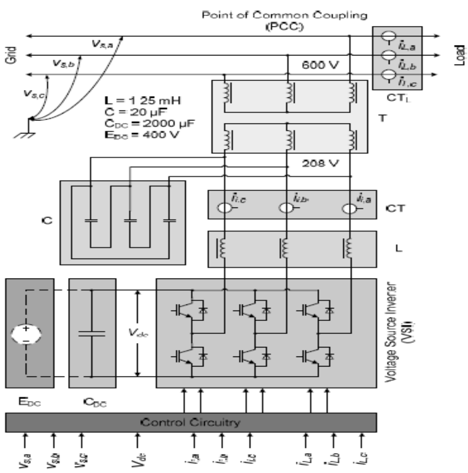

Figure.1 Power circuit

The control circuit together with the control parameters is shown in fig 2. The inverter is controlled in current – control mode, using the inverse sine pulse width modulation technique. The current injected by inverter into the grid is split into two separately regulated components: active Ia and reactive Ir. Two Proportional Integral (PI) controllers are employed for the regulation of Ia and Ir (the total current sqrt Ia2 + Ir2 is limited to 27.758 A rms). The parameters of these PI controllers have been first estimated – Nichotuning rules

[20] and then refined through simulations. A Phase Locked Loop (PLL) circuit is used for synchronizing the injected current with the voltage in the Point of Common Coupling (PCC).

In STATCOM mode of operation, the average voltage across the dc capacitor CDC is maintained constant, at 400V, by means of the PI controller shown on the top of fig. 2, regulating the amount of active current Ia drawn by inverter from the system. This active current component compensates for losses associated with the STATCOM operation. In case when solar system/farm injects active power into the grid, the dc voltage VDC is maintained by the dc source EDC and an appropriate recalculated active current Ia is imposed (see dashed – line connection on the top of Fig. 2 instead of being regulate by the above mentioned PI Controller. The reactive component Ir of the current injector into the grid is regulated to achieve either voltage regulation at the PCC or power control scheme for selecting the desired control objective. The amount of reactive current Ir necessary for voltage regulation is determined using the PI Controller shown in the bottom half of fig.2 The amount of reactive current necessary for power factor correction is determined based on load current measurements (iL) and reference power factor in the bottom of fig 2 factor

3, POWER FACTOR CORRECTION

The control of PV solar system as a STATCOM for power factor improvement is demonstrated in this section. (PFref), as shown in the bottom of fig 2 shows the typical active (Psf) and reactive (Qsf) power production capabilities of a solar system assuming a

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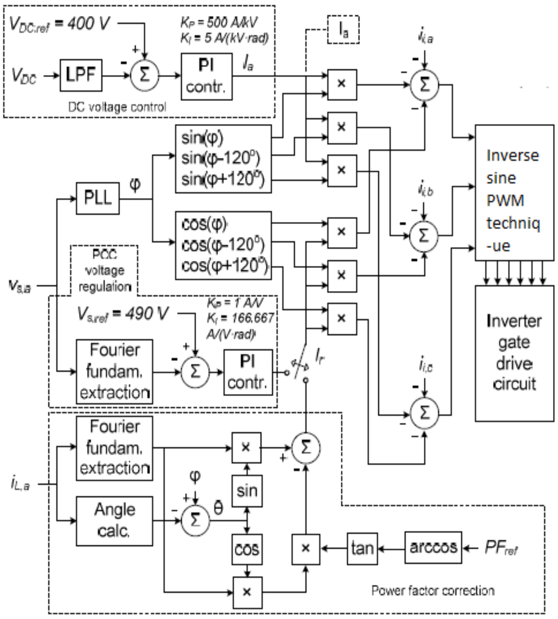

Figure.2 Control Circuit

Sunny day. During the night no active power is produced and hence the entire inverter capacity can be utilized for reactive power generation. During the day the solar system also injects reactive power using the inverter capacity left after real power generation. This is also same to be fairly substantial. Only when the solar farm is producing the rated real power around noon time there is no room for reactive power generation.

Fig 2 depicts the different system variables when the PV solar system is operated as STATCOM in the power factor correction mode. The variables Pm, Qm and Ps are the same as in fig 2. In the night time the solar system provides the entire reactive power need of the induction motor and the reactive power drawn from the electrical system Qs is zero. During the day time, the reactive power contribution from the solar system reduces depending on the available inverter capacity after real power generation.

4, VOLTAGE REGULATION

The PV solar system acts as a STATCOM for providing voltage support during the night time with the full rated inverter capacity, and during the day time with the inverter capacity remaining after real power generation. This corresponding to steady state voltage regulation capability of PV solar systems during night time while connected to the transformer shown in fig 2. As expected, the voltage regulation capability increases with the size of the PV solar system.

This paper presents a digital maximum power point tracking (MPPT) method based on a modified Regula Falsi algorithm. In order to obtain the maximum possible power output from PV modules, it is necessary to operate them at their maximum power point (MPP) where dP/dV = 0 However, PV sources have an output current – voltage (I-V) characteristic that is nonlinear and varies with different irradiation, temperature and load conditions. Our optimization problem is to track and find this MPP and to force the PV panel to operate at this point. In recent years numerous MPPT methods have been developed. The majority of them are based on searching the MPP by utilizing the sign of dP/dV as an indication of the search direction. Also digital implementations of MPPT have gained popularity because of the wide selection and technological advances of low-cost, microcontrollers and digital signal processors, which has enabled researchers the freedom to change the control algorithm, without extensively modifying the system hardware platform.

5, MPPT ALGORITHM

5.1 Modified Regula Falsi Method (MRFM):

In most of the MPPT method the operating point oscillates around the MPP. This method is used to track the MPP without any oscillation around the MPP. Thus the PV panel operate at this point. For a convex or concave function f, the RFM converges to the root very slowly because one of the end points of the bracketed interval is constant, resulting in a constant magnitude for f(x). This problem is improved by the MRFM introduced in [17] which is similar to the RFM except for that when calculating the next root iteration approximation, ci , the following process is taken instead of the aforementioned step of the RFM in (1): If f(xl)·f(xu)<0 and f(xl)>0 then f(xu) is replaced in (1) by f(xu)/2 and if f(xl)·f(xu)<0and f(xl)<0 f(xl) is replaced by f(xl)/2. The main idea behind this method is to decrease the retaining magnitude of f(x) by 1/2 at one of the brackets ends in order to achieve faster convergence, as it is represented in Fig.3

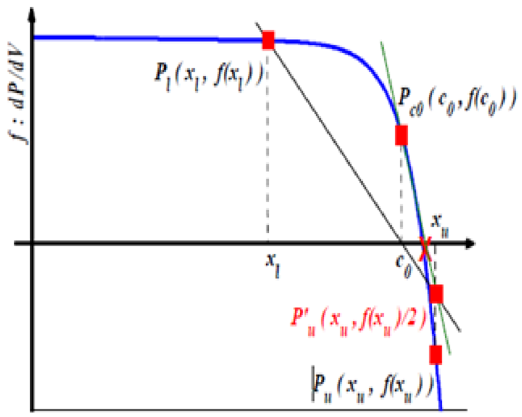

Figure 3. Modified RegulaFalsi Method (MRFM)

5.2 DMPPT Implementation

A low cost digital MPP tracker can be realized with an inexpensive microcontroller that is still fast enough to run each of the DMPPT algorithm within each sampling period (in the order of a msec.), an ADC (the resolution depends on the input signal range), and a DPWM controlled boost converter (Fig. 4). When the dc-dc converter is connected to a battery or a constant voltage load the output voltage of the converter is fixed. In the case of the setup in this work, *Vout* = 48V. A microcontroller running the MRFM algorithm takes the discretized voltage and current values and generates a DPWM duty cycle *D* that regulates the converter input voltage (*Vpv*). In the case of the boost converter used here (other converters can also be used) *Vpv* is

$$Vpv=(1-D)\cdot Vout \quad (4)$$

If the duty cycles *D1* and *D2* correspond to input voltages *Vpv1* ,*Vpv2* , respectively—assuming $Vpv1<Vpv2$, $D1>D2$—then, $\Delta Vpv = Vpv2-Vpv1$, and $\Delta D=D1-D2$. Thus, from (4)

6, EXPERIMENTAL SETUP

To validate the digital MPPT method, the experiments were set up as follows: PV panel were connected in series to generate a maximum of electrical power at S.T.C (Standard

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Testing Conditions: 25oC, 1000W/m2). A digital controller and a power electronics interface (DC-DC Boost Converter) were used to track the MPP.

6.2 PHOTOVOLTAIC MODULE

The PV panels used to track the MPP were connected in series. The models are based on the work .Since the panels are connected in series, the Voc and Vmp is doubled to 44.2V and 36V, respectively, whereas, the Isc and Imp stay the same. Power Electronics Interface Boost converter was used to interface the PV module and the inverter to regulate the operating point of the PV module as shown in Fig.4. The increase in power transfer capacity with the new inverter voltage control is now. Investigated during day time, when the solar farm is supplying real power to the grid. It is emphasized that this voltage control is exercised only through the reactive power capability of the solar farm inverter.

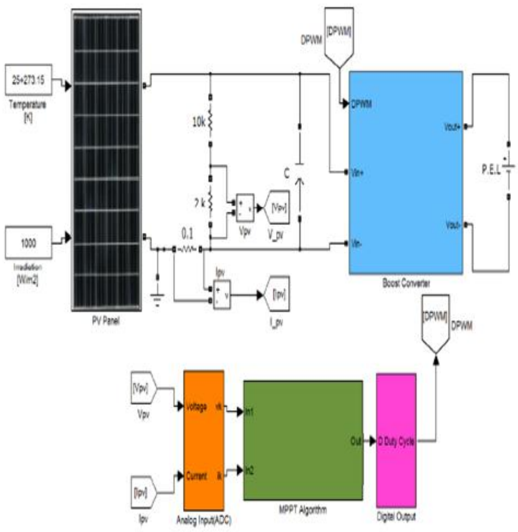

Figure.4 MPPT system

In an ideal situation when the solar farm is generating its rated real power output, no reactive power is available for voltage control and consequently for power transfer improvement. However, from the typical output data available from solar farms, it is seen that for almost 30-40% of the day time, the solar farm generates less than its rated power output. This implies that a finite reactive power capability is still available in the solar farm. The proposed control utilizes this remnant reactive power capacity of the solar farm

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to enhance the power transmission capacity, even during the day time. The maximum generator power flow limits are now ascertained for conventional operation of solar farm during day time. In this situation, solar farms inject real power at unity power factor

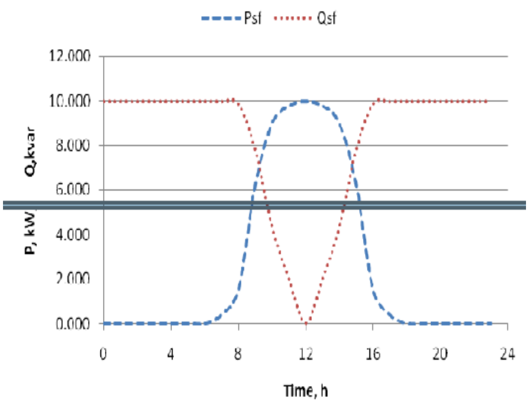

Figure.5 Active and reactive power production capabilities of a solar system

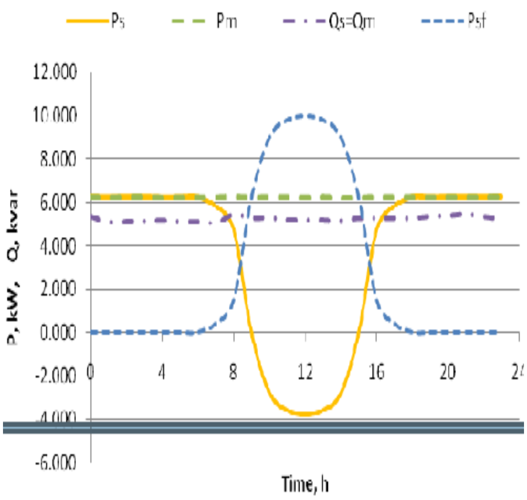

Figure.6 P and Q Consumption/production when the power factor is not compensated by solar farm

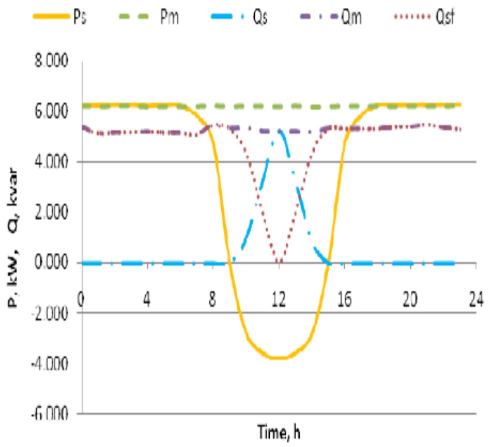

Figure.7 P and Q consumption/production when the power is compensated by the solar system.

7, CONCLUSION

This paper presents a novel application of a PV Solar system as a STATCOM. The actual PV system with the novel control will be tested and then installed in the utility network The proposed new control on PV solar system will help accomplishing the following objectives:

1. Increasing the utility of the PV solar system
2. Voltage regulation
3. Improvement of power factor leading to a decrease in the continuous load kVA demand and reduction in line losses.
4. Overall electrical system performance improvement.
5. Potential of additional revenue earning for solar system for providing the above services, both during night and day.

From the simulation and experimental results, several features of the proposed modulation strategy from the aspect of line voltage have been identified. The line voltage yields better spectral performance for unipolar ISPWM compared to the conventional hysteresis modulation technique and this reduces the need for output filter. By employing this new technique it has been proved that fundamental voltage is improved throughout the working range and is greater than the voltage obtained using conventional method.

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