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Reactive Power Compensation in Grid-Connected Photovoltaic Systems with Fixed Capacitors and STATCOM

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ABSTRACT

This paper provides a thorough examination of reactive power compensation in grid-connected PV systems using the complementary applications of Fixed Capacitor (FC) and Static Synchronous Compensator (STATCOM), which are verified by simulations using MATLAB software. The combination of FC and STATCOM offers a dual method for dynamic and steady-state reactive power support, respectively, with the goals of addressing voltage stability and enhancing power factor. With an emphasis on voltage control, power factor improvement, and the effectiveness of reactive power management, the MATLAB-based simulation framework carefully assesses the performance under changing solar irradiance, load variations, and grid disruptions. The results show that applying STATCOM and FC together greatly increases voltage stability and sustains a high power factor, highlighting the usefulness of this strategy in raising the dependability and efficiency of grid-connected PV systems. In order to optimize reactive power adjustment methods and enable the smooth integration of renewable energy sources into the power grid, this study offers important insights.

KEYWORDS: Reactive Power Compensation, Grid-Connected Photovoltaic System, Static Synchronous Compensator (STATCOM), Fixed Capacitor (FC), Voltage Stability, Power Quality

1.INTRODUCTION

Nowadays, the majority of the world's energy demands are satisfied by burning fossil fuels like coal, natural gas, and petroleum, which are fast running out. A major cause of global warming and a major danger to all life on Earth is carbon dioxide, a consequence of burning fossil fuels [1].

Of all the renewable energy sources now in use, photovoltaic array systems are anticipated to be a major contributor to future energy output. Systems that use photovoltaics (PV) turn light into power. For their diverse application needs, solar, wind, and fuel cell systems all require massive step-up dc/dc converters due to their low voltage output. Due to its low initial cost, lack of environmental effect, and ease of maintenance, the photovoltaic (PV) energy conversion system has emerged as a feasible alternative to nonrenewable energy sources, which are becoming increasingly scarce and expensive at the same time. As a result, PV systems that are grid-connected or standalone ought to utilize this energy source more. Although photovoltaic (PV) is a sustainable energy source, its dependability fluctuates based on location, weather, and time of year, and its installation costs are high. Improving the efficiency of PV systems requires operating the system at the MPP in order to obtain the maximum power of the PV array. in order to maximize a solar array's output.

A high efficiency power converter designed to extract the most power from a PV panel is frequently considered in order to optimize the output of PV systems through the use of maximum power point tracking (MPPT) techniques. On the V-I curve, the PV system is often most efficient and produces the greatest power at a single maximum power point (MPP) [l5–17]. Anyway, the position of the MPP is unknown and may be determined using search methods or computing models. Maximum Power Point Tracking Techniques (MPPT) are used to maintain the PV array's operating point at the sweet spot where the most power is produced [26–28]. In the literature, several MPPT algorithms have been studied, including Perturb and Observe (P&O) [2–5], Incremental Conductance (lC) [2–6], Artificial Neural Network (ANN) [7], Fuzzy Logic (FL) [8], and others. IC and P&O are two of the most used techniques. Four MPPT algorithms—P&O, the Particle Swarm Optimization (PSO) approach [l0], the Fuzzy Logic (FL) method [8], and the Incremental Conductance (lC) methodology [2–6]—are investigated in this work. Due to their ease of implementation, these methods have become popular for low-budget applications. Because of its low usage and additional complexity, Sliding Mode [9] and other comparable methods are not covered in this study.

Building a simulation model is the main goal of this effort in order to develop and scale the hybrid system suitably for various loads and weather conditions. To demonstrate that the suggested system functions as planned, a simulation model is performed using Mat Lab and SimPower Systems, and the data that is produced is used. In Figure 1, we can see the hybrid energy generating system that will be linked to the grid.

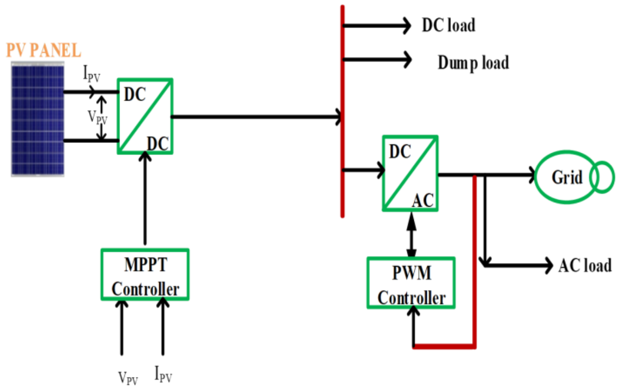

Figure 1: Configuration of proposed grid connected hybrid system

2. LITERATURE SURVEY:

Ciobotaru et al. investigated single-stage photovoltaic (PV) inverter control methods. Two different current controllers have been used in its development and experimental comparison. Additionally, a complete control system for the single-phase PV system is offered. Mahmud et al. proposed a resilient nonlinear distributed controller architecture to maintain active and reactive power equilibrium during isolated micro grid operation. According to this study, micro grids are inverter-dominated networks that comprise battery energy storage systems (BESSs) and renewable energy sources (RESs), such as plug-in hybrid electric vehicles and solar photovoltaic generators. Power electronics converters are essential to the electrical power system's deployment and performance improvement. The growing need for both new power sources and higher-quality power supplies is directly driving the implementation of an increasing number of DERs. Reducing common mode voltages and voltage variations from nominal values across capacitors is the aim of a model predictive controller. In order to demonstrate the effectiveness of the recommended control strategy and the worth of multilayer inverters, a schematic, parameters, and simulation results from a run in the software PLECS are provided at the end..

3. SOLAR SYSTEM:

A solar cell is the fundamental building block of any photovoltaic (PV) system. To generate the necessary current, voltage, and high power, solar cells in a PV array are linked in series or parallel. Each solar cell may be thought of as a diode with a p-n junction made of semiconductor material [5]. By virtue of the photovoltaic effect, it generates currents whenever light is incident onto the junction. Power characteristics at insulation level for PV array are shown in Figure 3. Each characteristic curve for output power displays a maximum power point. The (I-V) and (P-V) properties of the PV array are shown at varying solar intensities in Figure 3. A solar cell's equivalent circuit consists of a forward-biased diode connected in series with the current source. The terminals at the output are hooked up to the load. The solar cell's current equation is as follows:

$$I = I_{ph} - I_D - I_{sh}$$

$$I = I_{ph} - I_o \left[\exp\left(q V_D / nKT\right)\right] - \left(V_D / R_S\right)$$

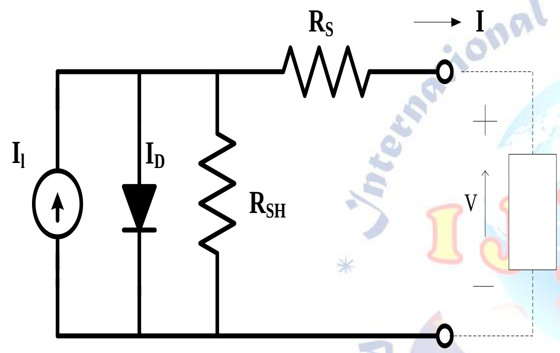

Figure 2: Equivalent circuit of PV Module

Power output of solar cell is P = V * I

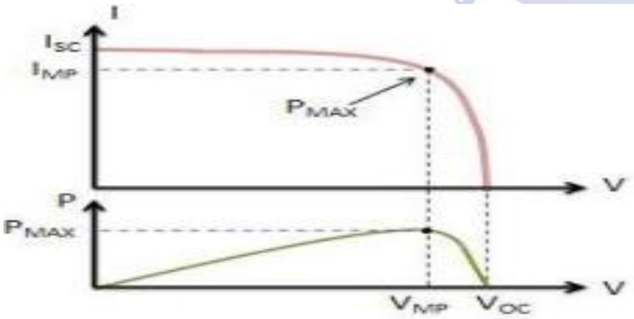

Figure 3: Output characteristics of PV Array

MAXIMUM POWER POINT TRACKING METHOD:

A PV system's irradiance and temperature curves primarily dictate its output power characteristics. Furthermore, for a brief period, temperature and solar radiation maintain these two constants. As previously mentioned, Figure 1 illustrates how the quantities of solar radiation will vary significantly during the day. A typical solar panel converts only around 30 to 40 percent of the sun irradiation into useful power. A circuit's power output is maximized when its thevenin impedance, also known as the source impedance, is in phase with its load impedance, according to the Maximum Power Transfer theorem. To increase the solar panel's efficiency, the maximum power point tracking technique must be applied.

A PWM generator may increase its repetition rate in response to an increase in input voltage or current, which would boost the output current. At the same time, a larger voltage is applied to the inductor, increasing its charge current. The starting voltage and power are determined using sensor-collected current and voltage data [9]. By comparing the current measurement to the previous one, the Vref reference voltage is modified after the real power output has been ascertained.

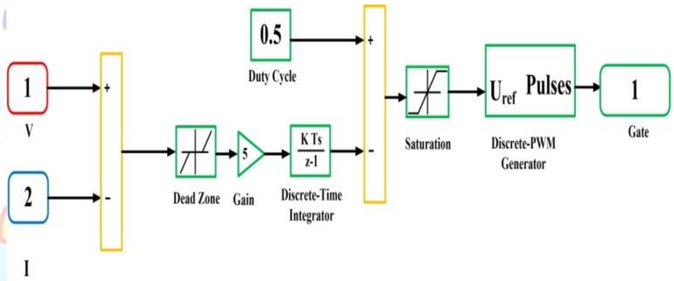

Figure 4: DC-DC converter MPPT Controller

4. PROPOSED SYSTEM:

The quantity of active power that a solar inverter linked to the grid puts into the grid depends on the amount of solar insolation. The solar inverter will not be able to provide the grid with as much active power as planned if the solar irradiation is insufficiently high. This is because the solar irradiance does not reach its maximum throughout the day. It results in underutilization of the inverter. If the inverter is configured to provide reactive power in addition to active power (depending on solar irradiance availability), it can continue to operate at its rated capacity even when the solar resource is not operating at its maximum capacity. Reactive power compensation with a solar inverter is an interesting method for controlling network voltages through the injection and absorption of reactive power.

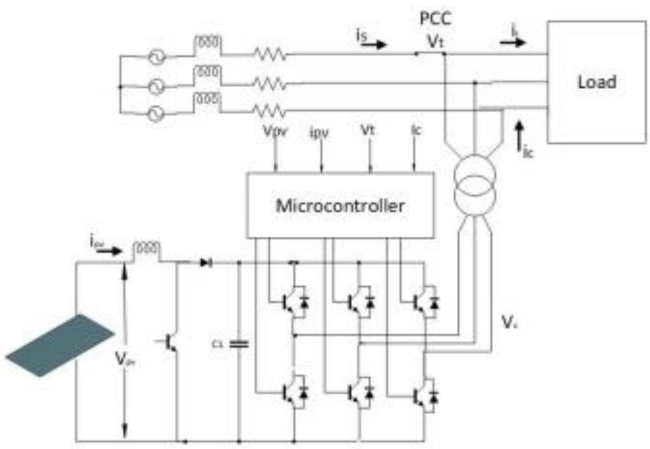

Figure 5: Structure of Grid Connected PV system for Reactive Power Control

Space Vector Modulation Technique:

As an alternative to the standard pulse width modulation method, gate triggering signals may be obtained by using the system's two phase vector components, d and q, in space. Figure 6 depicts the 8 space vector switching pattern locations of the inverter, each of which is represented by a space vector representation of the neighbouring vector V1 and V2.

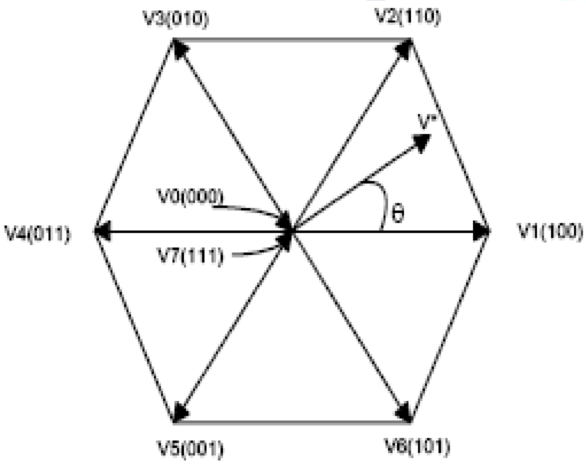

Fig 6: Space Vector Modulation Technique

By using the Space Vector Modulation Technique, which is one of the most common pulse width modulation techniques for three-phase voltage source inverters, it is possible to reduce harmonic distortion in the applied ac motors' voltage and current. In this research, the reference vectors are formed by varying the switching time sequence of space vectors in each of six sectors, as illustrated in figure 6. As shown in Figure 6, six of the sectors are employed for inversion, while two act as null vectors. The following methods may be used to carry out space vector modulation:

Converting three-phase values to their two-phase counterparts.

Calculate T1, T2, and T0 to see how long each event takes.

This formula produces the voltage reference signals, the switching time sequences, and the V0–V7 voltage references.

$$V^* T_z = V1 * T1 + V2 * T2 + V0 * (T0/2) + V7 * (T0/2)$$

5. RESULTS AND DISCUSSION:

Figure 1 depicts the whole hybrid grid-connected system. The photovoltaic system includes a series-connected array of PV modules and a boost converter.

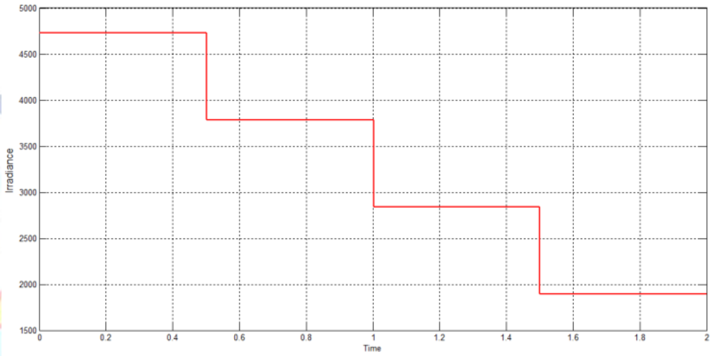

Figure 6: Simulation Waveform for Solar Irradiance (W/m2)

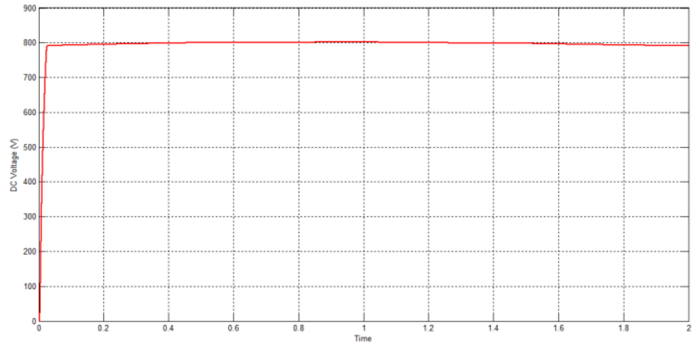

Figure 7: Simulation Waveform for Solar DC Voltage

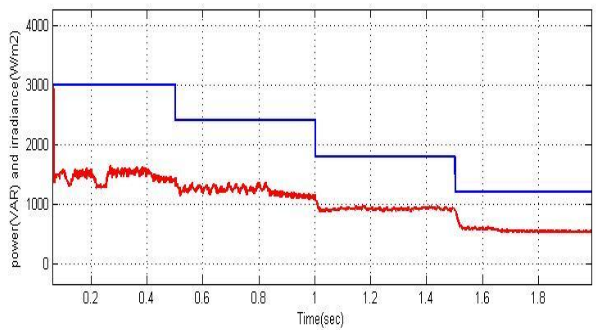

Figure 8: Simulation Waveform for Active and Reactive Powers of PV System

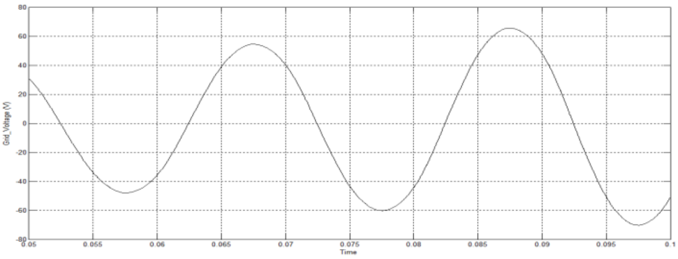

Figure 8: Simulation Waveform for Grid Voltage

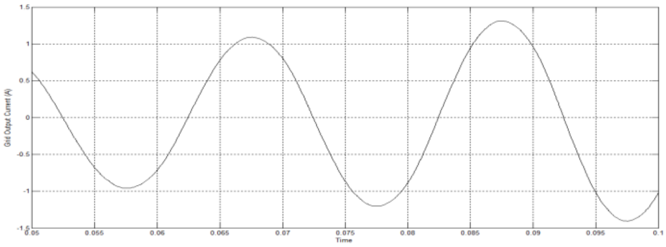

Figure 9: Simulation Waveform for Grid Current

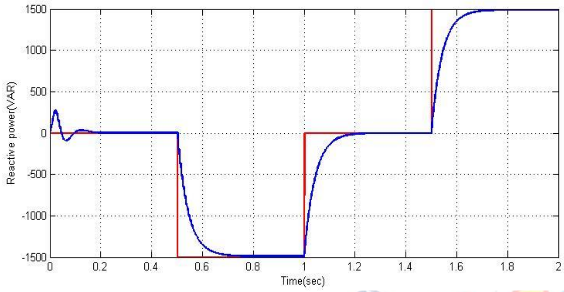

Figure 10: Simulation Waveform for Reference and Actual Reactive Power under fixed Q-Mode

Table-1: Comparative Analysis Between Conventional and SVM Controller

PARAMETER	PWM CONTROLLER	SVM CONTROLLER
POWER FACTOR	0.79	0.84
DC VOLTAGE (V)	495	847
ACTIVE POWER (W)	750	750
REACTIVE POWER (VAR)	385	236.3
LOAD VOLTAGE (V)	232	221
LOAD CURRENT (A)	17.5	40
THD (%)	7.27	0.32

6. CONCLUSION

In this article, we provide a grid-connected SVM-controlled photovoltaic system that may be utilized to balance reactive power needs. Whether the system is grid-tied or runs autonomously, the article also explains which converters are ideal for each MPPT approach. We will discuss the most recent hybrid MPPT methods and their benefits in this post. This evaluation is intended to serve as a helpful resource for PV system designers and commercial manufacturers. This study demonstrates that the extreme value theory is the basis of both P&O and IC. If the maximum value requirement is satisfied, they need to be able to precisely track the maximum power point. However, it is challenging to ensure the precision and stability of the numerical approximation of differentiation that both approaches rely on because of factors like noise and quantization error. The algorithms have a basic weakness that makes them constantly oscillate about the sweet spot.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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