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Solar Generator Design Using MATLAB Simulink

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***Abstract* - This paper presents the modeling and simulation of a solar generator system using MATLAB/Simulink. With the growing interest in renewable energy sources, solar power generation has gained significant attention due to its sustainability and environmental benefits. The proposed system consists of photovoltaic (PV) panels, a DC-DC converter, and an inverter to convert solar energy into usable electricity. The PV panels generate DC power, which is then converted into AC power through the inverter for grid integration or standalone applications. MATLAB/Simulink provides a powerful platform for simulating and analyzing such complex systems. The model incorporates the electrical characteristics of the PV panels, the control algorithms for maximum power point tracking (MPPT), and the dynamics of the power conversion stages. Through simulation, various performance parameters such as efficiency, power output, and voltage regulation are evaluated under different operating conditions and environmental factors. The simulation results demonstrate the effectiveness and reliability of the proposed solar generator system, providing insights for design optimization and integration into renewable energy applications.**

Keywords: Solar Generator, MATLAB, Simulation, Renewable energy sources, Photovoltaic, PV, PV panels.

I. INTRODUCTION

The majority of the world's energy currently comes from fossil fuels, primarily through burning coal. However, this traditional method of electricity generation poses significant challenges due to its contribution to greenhouse gas emissions. Additionally, fossil fuels and other non-renewable resources used for electricity generation are gradually depleting, while the global population continues to increase. In contrast, renewable energy resources offer promising solutions to these challenges. Renewable sources like solar photovoltaic, wind, tidal, wave, and biomass are considered clean and sustainable, providing an alternative to fossil fuels. As a result, there is a growing emphasis on adopting renewable energy sources to address environmental concerns and ensure a sustainable energy future.[1]

Over the last few decades, solar photovoltaic (PV) energy has emerged as a significant renewable energy source due to its low maintenance requirements and lack of noise and pollution. Solar PV panels, when paired with power converters, efficiently deliver power, forming a photovoltaic system. Various configurations of PV systems exist, with standalone and grid-connected systems being the most prominent. Grid-connected solar systems offer several advantages over standalone PV systems.

For instance, in a grid-connected system, electricity can be exchanged with the electric grid based on demand, reducing overall electricity bills by offsetting consumption with surplus generation. Moreover, grid-connected systems can be installed without battery backup, leading to increased power production as no storage losses are incurred. In this paper, a 6.25 kW grid-connected PV system has been modeled using MATLAB/Simulink. The system comprises a solar PV array, a maximum power point tracker for extracting maximum power from the PV array, a DC-DC boost converter to regulate and boost the PV array output, an inverter for converting DC power into AC power, and an LCL filter to mitigate current harmonics from the inverter output. [3,5]

II. LITERATURE REVIEW

The paper titled "Design and Modeling of MPPT for Solar Based Power Source" focuses on the development and simulation of a Maximum Power Point Tracking (MPPT) system specifically tailored for solar-based power sources. It likely discusses various MPPT algorithms and their implementation strategies, alongside simulation results showcasing the system's ability to optimize power extraction from solar panels under changing environmental conditions. The paper may also cover design methodologies, modeling techniques using software like MATLAB/Simulink, and potential applications of the developed MPPT system in enhancing solar energy conversion efficiency.[1]

The paper titled "Photovoltaic System MPPT using Fuzzy Logic Controller" explores the utilization of fuzzy logic control in Maximum Power Point Tracking (MPPT) systems for photovoltaic (PV) systems. It likely discusses the design and implementation of a fuzzy logic controller tailored to optimize the power output of solar panels by dynamically adjusting the operating point to track the maximum power point (MPP) under varying environmental conditions. The paper may cover the principles of fuzzy logic control, its

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application in MPPT algorithms, and simulation results demonstrating the performance of the proposed system. Additionally, the paper may discuss advantages such as improved efficiency and robustness compared to traditional MPPT techniques.[2]

The paper "Design and implementation of MPPT solar system based on the enhanced P&O algorithm using LabVIEW" focuses on the development and practical application of a Maximum Power Point Tracking (MPPT) system for solar energy generation. It likely details the design and implementation process of an enhanced Perturb and Observe (P&O) algorithm using LabVIEW software. This enhanced algorithm may incorporate modifications or improvements to the traditional P&O method to enhance its performance, such as reducing oscillations or improving tracking efficiency under varying environmental conditions. The paper may include experimental results demonstrating the effectiveness of the enhanced P&O algorithm in optimizing power output from solar panels. Additionally, it may discuss the advantages of using LabVIEW for the design and implementation of MPPT systems, such as its graphical programming interface and real-time data acquisition capabilities.[3]

This paper proposes to design a small-scale photovoltaic system to regulate, store, convert and manage solar power for use in residential settings. The system utilizes a solar panel to supply power to batteries and an AC inverter. Batteries' energy is used to satisfy the power needs of a standard household. The proposed constructed system is a scaled down physical model. The system consists of a programmable controller, photovoltaic panel, a buck converter used to charge the batteries, and a single phase inverter to supply power for the residential loads. The controller monitors every aspect of the system including battery voltage and solar panel voltage and then determines where the home needs to draw its power from. The control system also plays a vital role in the buck converter design. An input from the solar panel is connected to the system, which then determines the duty cycle needed to step down the voltage from the panel to an acceptable and safe voltage to charge the battery. This design of a Photovoltaic system is able to meet the power demanded by an average house located in Statesboro, Georgia, and thus reduce the load on the municipal power grid.[4]

As the consumption of power continues to increase, there will be efforts to increase the amount of power generated from renewable resources. Among different types of renewable energy, solar photovoltaic systems have been developing rapidly in recent years. The design of PV systems installed in city of Baghdad to operate AC loads about six hours a day between 8 a.m. to 2 p.m. was sizing about (2.56) kWp when assessed over the year. The power output of this PV system is dependent on the solar radiation rates of the site. Power production was higher in the summer months due to increased solar radiation rates, dependent on the high environment temperatures during this period relative to the winter months, accumulation of dust, and high temperature of the solar panels, which are the most important factors influencing the system's performance.

III. METHODOLOGY

This is proposed block diagram of our project, from PV array we get dc voltage which is boosted by boost converter. In this converter we use various MPPT methods these methods are;

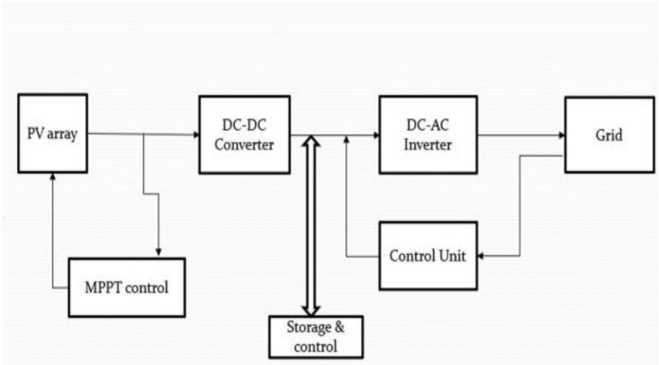

Figure 1: Block diagram

1. Hill climbing/p and o
2. Incremental conductance
3. Fuzzy logic conductance

The converted DC voltage is stored in Lithium-Ion battery. During power outage this stored energy is converted into AC by using DC to AC inverter. In this inverter we get pulsating AC which is converted into pure AC by using LCL filter. This pure AC is supplied to load.

A) PV Array

A solar cell serves as the fundamental component of a photovoltaic (PV) system. PV panels or modules are created by combining solar cells in series. Further, when these modules are connected both in series and parallel, they form PV arrays. The modeling of a PV array has been conducted by incorporating the characteristics of a single diode within a solar cell [1]. The schematic representation and equations utilized for solar cell modeling have been taken into consideration. These equations have been adapted to accommodate the number of solar cells within PV panels and the overall count of these panels connected in series and parallel.

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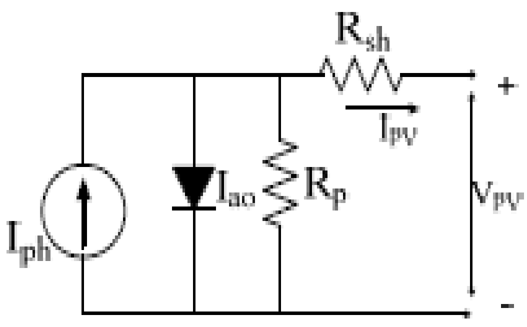

Figure 2: PV array configuration

The mathematical formulation of the output current (Ipv) of the PV module is described as

$$I_{pv} = I_{ph} - I_{ao}\left[e^{\left(\frac{(V_{pv}+R_{sh}.I_{pv})\times q}{N_{cs}kT_c a_{fd}}\right)} - 1\right] - \frac{V_{pv}+R_{sh}I_{pv}}{R_p} \qquad \text{______ (1)}$$

Where, I_{ph} is the photovoltaic current. I_{ao} is cell reverse saturation current or diode leakage current. $V_{pv}$are the module output voltage. R_{sh}(0.221Ω) and R_p(415.5Ω) are equivalent series and parallel resistance, N_{cs} is the number of series cells, q is the charge (of an electron) [1.60217646×10-19 C], the Boltzmann constant is k [1.3806503×10-23J/K], temperature of the cell's is T_c, α_{fd} is ideality factor of the diode (in general its value is 1≤α≤1.5).

The mathematical details of I_{ph} and I_{ao} are described as,

$$I_{ph} = \left(\frac{R_p+R_{sh}}{R_p} I_{sc} + K_i\left(T_c - T_{ref}\right)\right)\frac{S}{S_{ref}} \qquad \text{______ (2)}$$

$$I_{ao} = \frac{I_{sc}+K_i\left(T_c-T_{ref}\right)}{e^{\left(\frac{V_{oc}+K_v\left(T_c-T_{ref}\right)}{N_{cs}kT_c a_{fd}}\times q\right)}-1} \qquad \text{______ (3)}$$

Where, I_{sc} and V_{oc} are short circuit current and open circuit voltage, K_i and K_v are coefficient of current (0.0032A/K) and voltage (-0.123V/K), T_c and T_{ref} are cell's working and reference temperature (25℃), S and S_{ref} are the working and reference irradiation (1000W/m^2).

B) Maximum Power Point Tracking (MPPT)

Existing many MPPT techniques with degrees of accuracy and complexity have been proposed. Hill-climbing techniques, such as Incremental Conductance (IC) and Perturb and Observe (P&O), are a very popular alternative due to their flexibility and balance between complexity and accuracy. High tracking efficiency (fraction of electrical energy absorbed as percentage of the total available) can be achieved by employing these algorithms in static applications where irradiance and temperature change slowly. However, the traditional implementation of these algorithms under rapidly changing environmental conditions is especially prone to errors, leading to lower extraction efficiencies. The fast sunshine-to-shade sudden irradiance transient found in moving PV applications lead to wrong decisions in the traditional hill-climbing method.

The **P&O MPPT** algorithm is mostly used, due to its ease of implementation. It is based on the following criterion: if the operating voltage of the PV array is perturbed in a given direction and if the power drawn from the PV array increases, this means that the operating point has moved toward the MPP and, therefore, the operating voltage must be further perturbed in the same direction. Otherwise, if the power drawn from the PV array decreases, the operating point has moved away from the MPP and, therefore, the direction of the operating voltage perturbation must be reversed.

A drawback of P&O MPPT technique is that, at steady state, the operating point oscillates around the MPP giving rise to the waste of some amount of available energy. Several improvements of the P&O algorithm have been proposed in order to reduce the number of oscillations around the MPP in steady state, but they slow down the speed of response of the algorithm to changing atmospheric conditions and lower the algorithm efficiency during cloudy days.

Another very popular hill-climbing MPPT algorithm is the **incremental conductance (INC)** algorithm. This MPPT algorithm is based on the fact that the power–voltage curve of a PV generator at constant solar irradiance and cell temperature levels has normally only one MPP. The INC algorithm compares the instantaneous conductance of a PV generator with its incremental conductance and decides whether to increase or decrease a control parameter accordingly.

As for other hill climbing algorithms, two techniques have been utilized in the literature to implement the INC algorithm. First, reference voltage perturbation in which a reference value for the PV array output voltage is used as the control parameter in conjunction with a PI controller to adjust the duty ratio of the MPPT converter. Second, direct duty ratio perturbation in which the duty ratio of the converter is used directly as the control parameter. Both the P&O algorithm and the INC algorithm have been the subject of many investigations in the literature, but there does not seem to be any general agreement over the relative merits of either algorithm.

C) DC-DC Converter

DC-DC converter is an electrical circuit whose main application is to transform a dc voltage from one level to

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another level. It is similar to a transformer in AC source, it can able to step the voltage level up or down. The variable dc voltage level can be regulated by controlling the duty ratio (on-off time of a switch) of the converter.

Types of DC-DC Converter

There are various types of dc-dc converters that can be used to transform the level of the voltage as per the supply availability and load requirement. Some of them are discussed below.

- Buck converter
- Boost converter
- Buck-Boost converter

D) Boost Converter

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Since power must be conserved, the output current is lower than the source current.

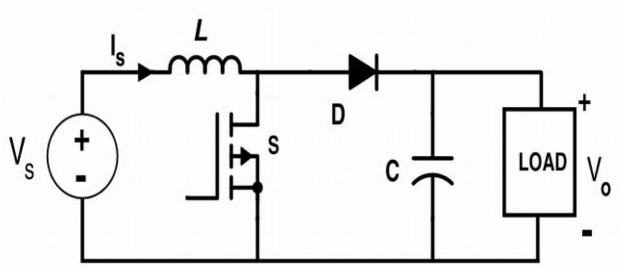

Figure 3: Boost Converter

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage.

(a) When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.

(b) When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current towards the load. Thus, the polarity will be reversed (means left side of inductor will be negative now). As a result, two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

If the switch is cycled fast enough, the inductor will not discharge fully in between charging stages, and the load will always see a voltage greater than that of the input source alone when the switch is opened. Also, while the switch is opened, the capacitor in parallel with the load is charged to this combined voltage. When the switch is then closed and the right-hand side is shorted out from the left-hand side, the capacitor is therefore able to provide the voltage and energy to the load. During this time, the blocking diode prevents the capacitor from discharging through the switch. The switch must of course be opened again fast enough to prevent the capacitor from discharging too much.

E) DC to AC Converter

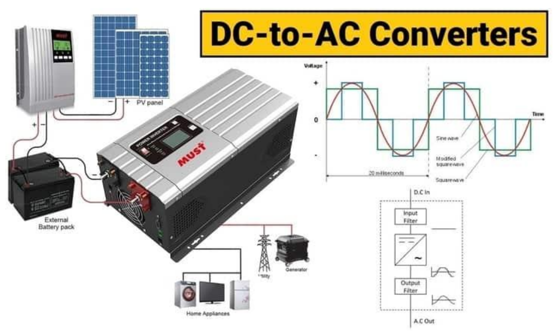

Figure 4: DC-AC Inverter

The post is about 12V DC to 220V AC inverter circuit designed with few easily available components. Inverters are often needed at places where it is not possible to get AC supply from the Mains. An inverter circuit is used to convert the DC power to AC power. Inverter Circuit is very much helpful to produce high voltage using low voltage DC supply or Battery. DC-DC Converter circuit can also be used but it has certain voltage limitations. The 12V DC to 220V AC inverter circuit is designed using IC CD4047. The IC CD4047 acts as a switching pulse oscillating device. The n-channel power MOSFET IRFZ44n acts as a switch. The 12-0-12V secondary transformer.

The Circuit Diagram shown above is the tested 12V DC to 220V AC Inverter Circuit. It uses 2 power IRFZ44 MOSFETs for driving the output power and the 4047 IC as an

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astable multi vibrator operating at a frequency of around 50 Hz. The 10 and 11 pin outputs of the IC directly drive power MOSFETs that are used in push-pull configuration. Use suitable heat-sinks for MOSFETs as it will produce a huge amount of heat. The output transformer has a 12V-0-12V,1 Amps on the secondary and 220V on the primary.

F) LCL Filter

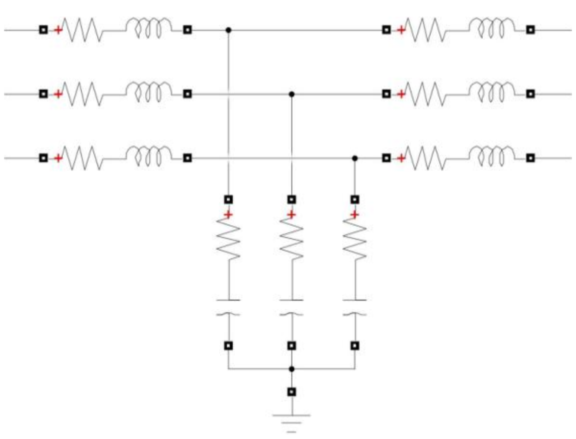

Figure 5: LCL Filter

LCL filters are specially designed to reduce harmonics of current absorbed by power converters, with a rectifier input stage. (Frequency converters for motors, UPS, etc.). Mainly, they are made of a parallel-series combination of reactors and capacitors adapted to reduce the THD (I) of rectifiers. They are specially designed to reduce the THD(I) to values of approximately 8%, in order to comply with IEC-61000-3.4 and IEEE-519 standards. LCL filters must be selected according to the current absorbed by the converter. In case of converters with very low power rating, a unique.

LCL filter may be used to supply several converters, but only in case the all start and stop at the same time. If several converters starting and stopping separately are supplied by the same LCL filter, the system is not effective on filtering the harmonics. In such case an individual LCL should be used for each converter. LC filter at the output of the inverter is used to reduce inverter current harmonics. 50 Hz was selected as cut off frequency of the filter. Suitable inductor and capacitor values are selected using.

$$f = (1/2\pi\sqrt{LC})$$

Where L is inductor inductance and C is capacitor capacitance. Complete grid connected system is shown in the Figure 6.

IV. SIMULATION AND RESULTS

The designed grid connected system was tested with three phase 2.75 kW load. The generated PV array power, the power available at the inverter output and that flowing to and from the grid was observed with varying solar insulation and temperature values.

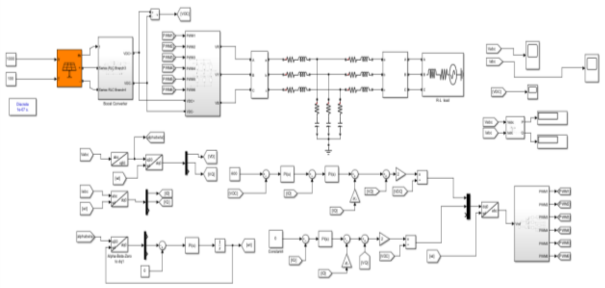

Figure 6: Solar Generator in Matlab Simulink

PV array power, Boost converter output, Inverter and the grid powers under different temperatures and solar insulations.

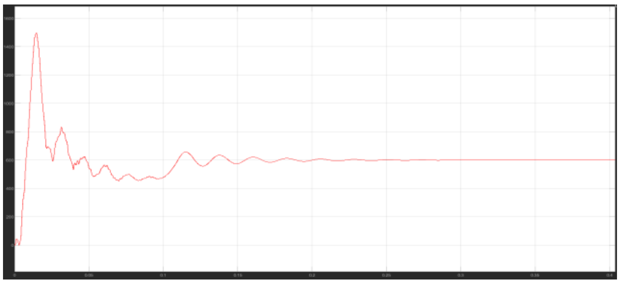

Figure 7: PV voltage after Boost

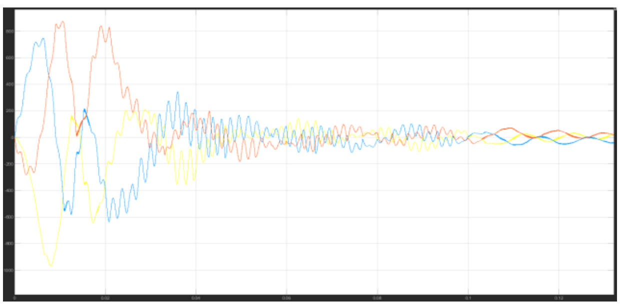

Figure 8: Output voltage and current after passing through Inverter (Pulsating AC)

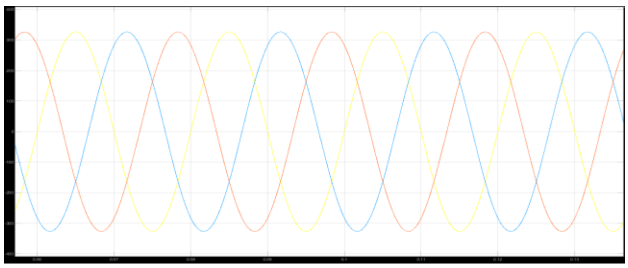

Figure 9: Pure form of AC Output

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From the simulation results shown above, it can be seen that change in solar irradiance affects power generation more than the change of temperature. Initially at high irradiances, inverter output is more than the load demand and hence power flows from the system to the grid. This is shown in grid power graph. On the other hand, at zero or very low the irradiance, Inverter output power is less than the requirement and therefore, the grid supplies the power. This is shown as negative power in the same graph. Negative power shows the supplying of power from the grid whereas positive power indicates sending of power to the grid from the PV system.

V. CONCLUSION

The paper proposed the modeling a grid connected PV system. The detailed modeling of the components that are used in the system has been described in detail. PV array modeling using datasheet values was presented. To maximize the output power of PV array, incremental conductance with internal regulator technique was used along with the DC-DC boost converter. A DC to AC PV inverter along with an LC filter was designed to convert DC voltage and current to AC values. Controlled SPWM modulation technique to generate reference signals for inverter IGBT switches has been utilized. For testing, System was simulated under varying temperature and solar insolation values. It was observed that the system output power is more affected by solar irradiance than with varying temperature. The presented model can be used to study system output characteristics at any condition of temperature and solar irradiance.

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