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Direct-coupled stand-alone solar PV system with seven-level inverter and reserve power enhancement using fuzzy logic controller

Karthik Satheesh, Sethulakshmi S
[1]Student, Al Ameen Engineering College, Shornur, Kerala
[2]Associate professor, department of EEE, Al Ameen Engineering College, Shornur, Kerala

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ABSTRACT: This research paper presents a new standalone solar PV system with a seven level inverter and reserve power enhancement. This is done using the fuzzy logic controller. The boost converter converts the output voltage of the solar cell array into independent voltage sources with multiple relationships. The seven-level inverter powered by solar has been proposed to achieve a sinusoidal output voltage with high efficiency and enhanced power quality. The most commonly used solar cell model is introduced, and a generalized PV model using Matlab simulation is developed. This model can be used for analysis of PV characteristics and for simulation with maximum power point tracking. Compared with conventional seven-level inverter topologies, the proposed design has an improved power factor.

KEYWORDS: Fuzzy Logic Controller, Solar Photovoltaic, Multilevel Inverter, Maximum Power Point Tracking (MPPT).

I. INTRODUCTION

Due to their environmental friendliness, photovoltaic (PV) systems have steadily increased in penetration over the past few decades. Since there is no natural inertia in PV systems, power must be set aside for frequency response. Grid laws and network codes are continually updated to address the intermittent nature of PV power and grid security issues. PV systems must therefore have power reserve control (PRC) in order to participate in system frequency regulation. Typically, two approaches can be used to realize this PRC:providing energy storage devices or power curtailment: (i) installation of an energy storage device, such as a battery or a super-capacitor, which has the disadvantage of increasing the system maintenance costs and complexity; (ii) operation of PV systems at a suboptimal powerpoint to reserve partial frequency regulation power, which is simple and cost effective.

Because it transforms the dc electricity produced by a solar cell array into ac power and feeds this ac power into the utility grid, the power conversion interface is crucial to grid-connected solar power generation systems. The power conversion interface needs an inverter to convert DC power to AC power. Small-capacity solar power generation uses a DC-DC power converter because a solar cell array's output voltage is low. System to increase output voltage so that it can match the inverter's DC bus voltage. The power conversion efficiency of the power conversion interface is important to ensure that there is no waste of the energy generated by the solar cell array.

The increased use of renewable energy systems, particularly PV power plants (PVPPs), has led to a development in the infrastructure related to photovoltaic (PV) plants. Because of improvements in PV technology, a drop in the cost of PV panels, and growing awareness of the limited availability of traditional fossil-fuel based energy resources as well as concerns about global warming, the installation of PV systems has increased significantly [2].

II. TOPOLOGY

A. Seven level Inverter

The seven-level triple boost multilevel inverter that is being suggested. Eight switches, two capacitors, and one diode make up the entire topology. Switches S1 and S4 should be capable of stopping reverse voltage. To achieve greater voltage levels, the two capacitors are individually charged to Vdc by connecting them in parallel to the DC source, and then these are discharged in series with the DC source to the load. This topology can generate voltage levels of 0, ±Vdc ,

±2Vdc ,and ±3Vdc . Therefore, the gain of this topology is 3. There are two sets of complementary switches (S5 , S6) and (S7 , S8) to avoid the short circuit of the DC source. The switches in H-bridge (S5 -S8) have the MBV of 3Vdc , the switches S1 and S4 have an MBV of Vdc , and the switches S2 , S3 and diode have an MBV of 2Vdc .

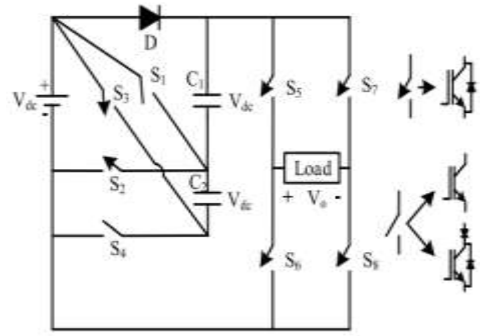

Figure 1: Seven level inverter

As a result, this topology's TSV per unit is 6.66. When charging and discharging capacitors alternately throughout each cycle of output voltage, the voltages across the capacitors are nicely balanced at Vdc. The H-bridge's four switches (S5–S8) each change state (from on to off) just once every cycle, meaning that they run at fundamental frequency, which improves efficiency.

B. MPPT Technique

Under specific circumstances, the charge controller algorithm known as MPPT, or Maximum Power Point Tracking, is utilized to draw the most power possible from a PV module. The maximum power point, also known as the peak power voltage, is the voltage at which a PV module can produce the most electricity. Solar radiation, the surrounding temperature, and the solar cell temperature all have an impact on maximum power.

The non-linear output efficiency of solar cells, which is brought on by a complicated relationship between temperature and total resistance, can be examined using the I-V curve. The objective of the MPPT system is to sample the output of the PV cells and apply the proper resistance (load) to obtain maximum power under any given set of circumstances. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

C. Fuzzy logic controller

It is possible to make a precise assertion about a complicated system's behavior using fuzzy logic. Fuzzy control is the management of the duty cycle using linguistically fuzzy descriptions. Numerous successful implementations of fuzzy control applications have been made. Fuzzy logic control is used to carry out both the control action and the adjustments. It responds faster than conventional methods. A simple mathematical model is enough to present this control strategy. The central core of a fuzzy controller is a linguistic explanation of the approximates control action for a given condition. Fuzzy linguistic descriptions involve associations of fuzzy variables and procedures for inference. Whereas in a derivative controller, what is modeled is the physical system or process being controlled.

The control operation is not carried out in a single cycle. There should be a sufficient number of control mechanisms. As follows:

• Fuzzification

A fuzzy variable error signal is translated, and some changes made to the error signal are assigned. Seven fuzzy variables are said to be: negative big (nb), negative medium (nm), negative small (ns), zero (zr), positive small (ps), positive medium (pm), and positive big (pb). Also changes the alpha value assigned to seven fuzzy variables. Using sampling intervals to calculate changes in the error signal

Errors and changes in error signals are taken as input sources. Changes in alpha are the same as those in fuzzy controller output.

• Inference engine

Two phases are involved: fuzzy rule foundation and fuzzy implication. Applying the fuzzy operator, applying the fuzzy implication, and aggregating all outputs are the three tasks this part completes. In the interface engine, the rule base is applied to fuzzy input, and its output is identified by fuzzy implication.

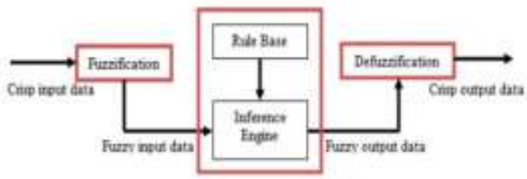

Figure 2: Fuzzy Logic Controller

• Defuzzification

Defuzzification is known as the process of converting fuzzy quantities into crisp quantities. There are many methods available for Defuzzification. The most common one is the centroid method.

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III. DESIGN OF THE PROPOSED SYSTEM

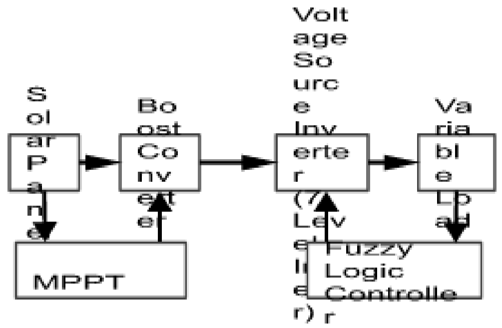

Figure 3: Proposed System

A. Solar Photovoltaic System

As the future's sustainable energy system, PV systems are crucial. They are one of the most important technologies for producing decentralized electricity for private homes globally, and the technology is coming. The components of stand-alone PV systems include a PV panel, a battery bank for storage, and an inverter (for converting DC to AC). The best places for standalone systems, like the one shown in Figure 4, are those with low energy needs and easy access to solar insulation.

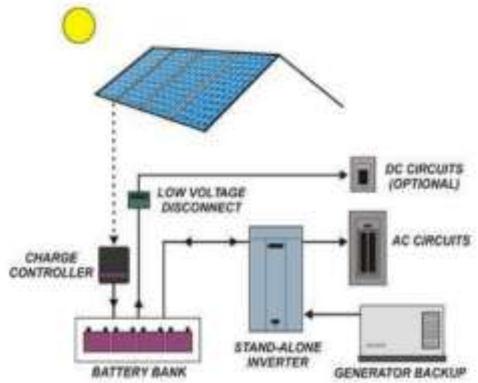

Figure 4: Stand-alone PV system

B. Boost Converter

A power converter class known as a "boost converter" modifies a direct current (DC) source's voltage level by temporarily storing input energy and releasing it to the output at a different voltage. For storage, one option is to utilize magnetic (inductors, transformers) or electric (capacitors) field storage components. A power converter known as a boost DC-DC converter lowers input current while increasing input voltage. It is a class of switched-mode power supply (SMPS) having at least one energy storage element (a capacitor, an inductor, or the two in combination) and at least two semiconductors (a diode and a switch). Boost converters can be designed to transfer power in only one direction, from the input to the output. However, almost all boost converter types can be made bi-directional. A bidirectional converter can move power in either direction, which is useful in applications requiring regenerative braking. The amount of power flow between the input and the output can be controlled by adjusting the duty cycle (the on/off ratio) of the switch. Usually, this is done to control the output voltage, the input current, the output current, or to maintain constant power.

C. P & O MPPT

Before measuring power in this process, the controller slightly adjusts the voltage coming from the array. If the power increases, more changes are tried until the power stabilizes. The perturb and observe method, the most commonly used tactic, can lead to oscillations in the output of power. It is referred to as a hill climbing method because it depends on the rise of the curve of power against voltage below the maximum power point and the fall above that point. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. The perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

Figure 5: P&O MPPT Algorithm

The PV's output terminal voltage is increased or decreased as part of the P&O algorithm's operation. and The power obtained in the most recent cycle is compared to the power obtained in the cycle before it via the P&O algorithm. When this happens, the control system shifts the operating point in that direction; if the voltage stays the same but the power rises, it shifts it in the opposite direction.

Once the direction of the change in current is known, the current is varied at a constant

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rate. This project flowchart algorithm is shown in Figure 5. A modified version is obtained when the steps are changed according to the distance of the MPP, resulting in higher efficiency. This is an excellent method to reach the MPP, and it is independent from the PV panel, although this method may suffer from fast changes in environmental conditions.

The DC load is connected across the boost converter output. The solar PV system operates in both maximum power point tracking and de-rated voltage control modes. To track the maximum power point (MPP) of the solar PV, you can choose between two maximum power point tracking (MPPT) techniques:

- Incremental conductance

Incremental conductance is a technique used in maximum power point tracking (MPPT) algorithms for solar photovoltaic (PV) systems. The goal of MPPT is to maximize the amount of power that can be extracted from a solar PV panel, which varies based on factors such as temperature, shading, and the angle of incidence of sunlight. One advantage of the incremental conductance algorithm is that it can track the maximum power point even when the panel is subjected to rapidly changing weather conditions, such as clouds passing overhead.

- Perturbation and observation

Perturbation and observation are methods used in control systems engineering to identify the transfer function of a system. It involves applying a perturbation or disturbance to the system and observing the response, then using the observed response to estimate the system's transfer function. The perturbation can be a step input, an impulse, or any other signal that causes a change in the output of the system. The response of the system is then measured and recorded. By analyzing the relationship between the input perturbation and the output response, the transfer function of the system can be estimated. This method is particularly useful for systems that are difficult or impossible to model mathematically. By observing the response of the system to different perturbations, engineers can gain insights into the system's behavior and identify the key factors that influence its performance.

D. switching pulse generator

A continuous stream of electrical pulses with exact characteristics including frequency, amplitude, duty cycle, and rise/fall time is produced by electronic circuits referred to as switching pulse generators. They are frequently used in industries like power electronics, telecommunications, and data communications. Power electronics, for instance, employ switching pulse generators to regulate the frequency and duration of power switching events in order to control the voltage and current in a circuit. Different circuit topologies, such as astable, monostable, or bistable circuits, can serve as the foundation for switching pulse generators.

These topologies are based on different types of logic gates and components, such as transistors, diodes, and resistors. Astable circuits are the simplest type of switching pulse generator and produce a continuous series of pulses. Monostable circuits, on the other hand, produce a single pulse of a specified duration and then remain stable until triggered again. Bistable circuits produce two stable states and require an external signal to switch between them. Overall, switching pulse generators are important components in many electronic systems and play a crucial role in controlling the timing and duration of electrical pulses for a variety of applications.

IV. RESULTS AND DISCUSSIONS

In figure 6, solar panel I-V characteristics Curves are basically a graphical representation of the operation of a solar cell or module, summarizing the relationship between the current, voltage, and power. I-V curves provide the information required to configure a solar system so that it can operate as close to its optimal peak power point (MPP) as possible. Photovoltaic I-V characteristic curves provide the information needed for us to configure a solar power array so that it can operate as close as possible to its maximum peak power point.

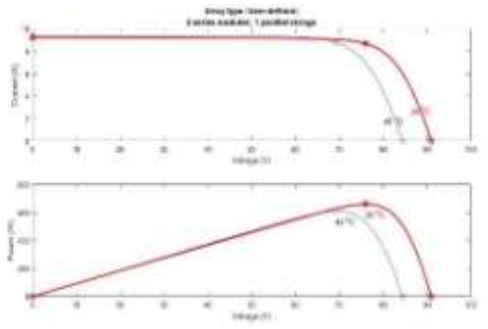

Figure 6: PV graph of a solar panel

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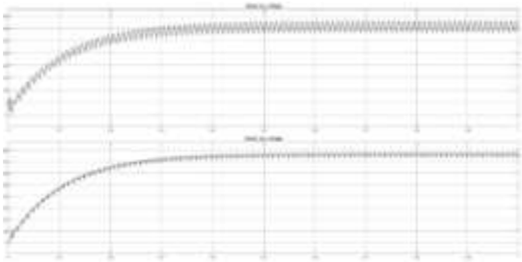

Figure 7: Input voltage of the boost converter

Figure 7 shows the input and output voltages of the boost converter. The output of the boost converter is given to the MPPT.

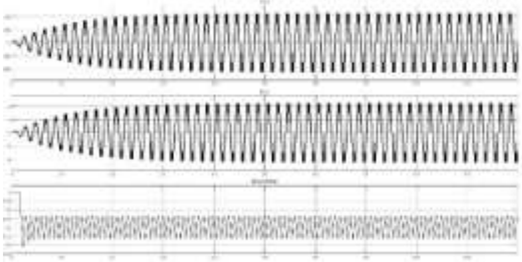

Figure 8: Output Characteristics of a Solar Panel Without a Controller

Figure 8 shows the output voltage, current, and power factor of a solar panel without a controller.

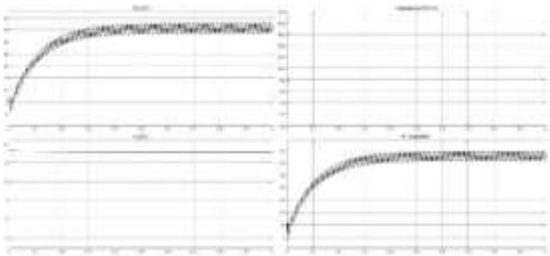

Figure 9: Voltage, current, power, and irradiance of MPPT output

Figure 9 shows the voltage, current, power, and irradiance of the solar panel. Irradiance is the quantity of light incident on the solar panel. Figure 10 shows the final output of the solar panel with the controller, which has power factor 1.

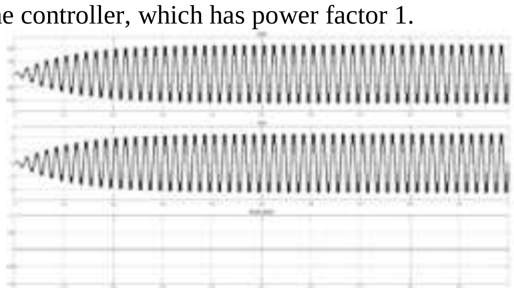

Figure 10: Final Output

Table 1 explains the relationship between PF and gain in various conditions. In this case, the PV source has a fuzzy relation to the PF and gains more value.

Table 1: Comparison of power factor and gain

DC source w/o controller	DC source with controller	source w/o controller	PV source controller	Pv source with fuzzy
PF=1	PF=1	PF=0.86	PF=0.8	PF=1
Gain = 3	Gain = 4	Gain = 3.8	Gain = 4	Gain = 7.69

V. CONCLUSION

A direct-coupled stand-alone solar PV system with a seven-level inverter and reserve power enhancement using a fuzzy logic controller for tracking the maximum power point of a photovoltaic source was proposed and simulated in MATLAB Simulink. The controller was based on the basic blocks of the fuzzy system, which are fuzzification, inference, and defuzzification. The whole system, including PV, boost converter, fuzzy controller, and load, was modeled and simulated under different voltages and currents. If the output will get maximum power, then extract the voltage and current at that time. This system is cost effective to implement in small scale applications. Compared to conventional methods, the gain and power factor of this system are improved.

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