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Design and Implementation of a Novel Asymmetric 21-Level Inverter Coupled with Photovoltaic System for Motor Load Application

Sri Harsha Giri[1], Narendra Babu Kattepogu[1], Sayena Surendhar[2], Kommu Suresh[2] , Abdul Raheem[2] , Dasari Manikanta[2]

[1]Assistant Professor, Department of Electrical and Electronics Engineering, SRK Institute of Technology-Enikepadu, Vijayawada-521108, Andhra Pradesh, India
[2]Department of Electrical and Electronics Engineering, SRK Institute of Technology-Enikepadu, Vijayawada-521108, Andhra Pradesh, India

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ABSTRACT

The utilization of renewable energy sources (RES) has gained prominence in addressing load demands due to their cost-effectiveness, widespread availability, and minimal maintenance requirements. Particularly in the current context, RES hold significant importance in enhancing motor load functionality, a contrast to their lesser role in the past. This study focuses on leveraging the Sepic converter to augment overall system performance, with particular emphasis on achieving Maximum Power Point Tracking (MPPT) using the ANFIS method. The objective is to expand the operational voltage range of photovoltaic systems (PVs) for optimal efficiency. The deployment of a meticulously configured Multi-Level Inverter (MLI), specifically a 21-level (31L) inverter, effectively mitigates load demand fluctuations, thereby enhancing system reliability. MATLAB Simulink simulations demonstrate the efficacy of the proposed strategy, showcasing a notable reduction in Total Harmonic Distortions (THD) and thereby indicating superior performance.

KEYWORDS: PV System, Sepic Converter, MPPT, ANFIS, MLI, THD

1.INTRODUCTION

Power plants increasingly rely on renewable energy (RE) sources to meet rising demand for electricity and to efficiently compensate for the depletion of fossil fuels; as a result, RE is increasingly favoured in a wide range of residential and commercial settings thanks to its reliability, low cost, low environmental impact, and ease of installation. In addition, the use of these RE sources has gained widespread attention in the modern scenario, as people have difficulty favouring the existing fossil fuels due to the rapid increase in cost, and so they tend to prefer the usage of RE sources to meet the daily power demand. Additionally, the preference for RE sources in contributing to national economic development is vast, and as a result, it has attracted significant attention from a wide range of individuals and organisations [1-4]. When compared to other renewable energy options, solar energy has a number of advantages. It can be installed almost anywhere at a low cost and it has a low impact on the environment. PV's pollution-free nature is in high demand for the improvement of eco-friendly nations [5-6], therefore its usage in a wide variety of applications is preferred because of its many advantages.

Despite PV's numerous benefits, its relatively low output voltage limits its usefulness in many contexts; as a result, DC-DC converters are often used to increase PV voltage throughout a larger operating range. In the first stages, DC- DC converters like as boost and buck boost are used to increase the low voltage regardless of variations in the irradiance level, thereby maximising the PV output to a wide range. Although these converters do have certain benefits, such as increased DC output, they also have some drawbacks, such as a low gain ratio, poorer efficiency, and complicated operation [7-9]. Since the Sepic converter has several positive effects, including maximum efficiency and a high gain ratio, it has been recommended in this research for the purpose of optimising the output voltage across a larger operating range.

By tracking MPP, MPPT methods help improve the overall performance of the motor, making up for PV's intermittent nature in a practical way. Historically, methods like P&O, InC, and Fuzzy have been used to extract maximum power with minimal complexity; however, these methods have all failed to deliver optimal results due to insufficient reliability and accuracy [10–14]. Therefore, the ANTIS method was used to get the most out of PV with the least amount of effort in this research. This study proposes the 21L MLI to acquire the enhanced output with multiple beneficial impacts, as the compensation of load voltage is crucial to the efficient operation of the system. Traditionally, 3-level inverters have been used for this purpose in the initial daystor; however, these inverters have been shown to fall short of optimal performance [15].

Following this abstract, sections II and III model the recommended technique; section IV analyses the results; and section V provides a quick summary of the paper's findings.

2. PROPOSED SYSTEM

In this work, we focus on the process of compensating the load voltage compensation with the 21L MLI in order to boost the overall performance of the system. This block diagram does an excellent job of explaining the steps involved in this method.

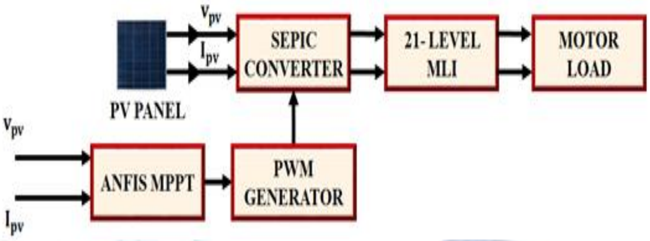

Figure 1 Block Diagram of Proposed Work

Maximum power is extracted with the use of the ANFIS method by comparing the and e in an ideal way, and the low DC output of the PV panel is the input to the Sepic converter, which does this. The PWM generator receives the resultant signal and uses it to provide the necessary pulses to the converter, allowing the latter to operate at peak efficiency while drawing the greatest possible power from the PV array. The 21L MLI then inverts the DC voltage into AC voltage to efficiently compensate the load demand. Thus, the overall performance of the system is efficiently enhanced by the implementation of the proposed methodology.

3. SYSTEM MODELLING

In the following section, extensive background research and explanations of the modelling of the system's components are provided.

PV System

The operating point of PV can shift across a wider range as a result of factors like irradiance and temperature. Fig. 2 is a schematic depiction of the circuitry of the aforementioned PV system.

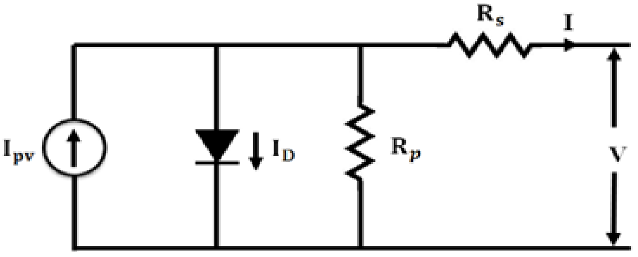

Figure 2 PV system representation

The subsequent equation represents the Fundamental current (I) equation as,

$$I = I_{pvcell} - I_{ocell}\left[exp^{\frac{(qv)}{akT}} - 1\right] \quad (1)$$

$$I = I_{pv} - I_o\left[exp\left(\frac{(v+R_S.I)q}{aV_k}\right) - 1\right] - \frac{(v+R_S.I)}{R_p} (2)$$

Here,

R_s-series resistance

k- Boltzmann constant

v- Voltage across the diode

I_o- Overloaded current

T- Temperature coefficient

R_s- Series resistance

$V_k \rightarrow \frac{kT}{q}$, q indicates the charge of the electron.

a- Ideality factor

R_p- Parallel resistance of PV

I_{pv} - Photovoltaic current

Thus, the preserved power in the PV too gets fluctuated when the irradiance and temperature is varied, which is specified as,

$$I = I_{pv} - I_o\left[exp\frac{(v+R_S.I)q}{akT.N_S} - 1\right] - \frac{(v+R_S.I)}{R_p} \quad (3)$$

Here, the amount of series in PV array is specified asN_S.

4. SEPIC CONVERTER

This converter's various positive effects, including maximum efficiency and higher gain ratio, make it particularly useful for optimising the low DC output. Switch S's duty cycle controls how much voltage is sent to the load, allowing either maximum or minimum performance depending on the situation. In Fig. 3, the Sepic converter's circuit is shown in great detail for clarity.

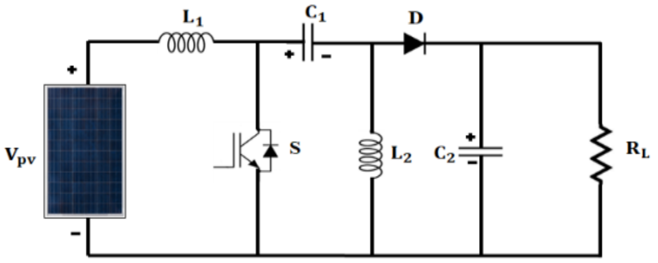

Figure 3 Sepic Converter

Under steady-state conditions, the supply voltage of PV (VPV) and the voltage across C1 are equal because C1 blocks the direct current, making inductor L2. As a result, the average current through L2 and the average current that does not depend on VPV are equivalent. The voltage equation is written as follows:

$$V_{PV} = V_{L_1} + V_{C_1} + V_{L_2} \quad (4)$$

As the V_{PV} and average voltage of the capacitor V_{C1} are similar, Equation 4 is expressed as,

$$V_{L_1} = -V_{L_2} \quad (5)$$

As the magnitude and voltage of the L2 and L1, the mutual inductance value is zero, which is thus represented as,

$$I_D = I_{L_1} - I_{L_2} \quad (6)$$

The operation modes of this converter are remarkably illustrated in the subsequent section

21-Level MLI

Without inductors, capacitors, or diodes, the MLI architecture consists of 10 controlled switches connected to three asymmetric DC sources. The asymmetrical design of the three DC sources results from their having different voltage levels. This MLI architecture reduces the impact of certain power quality problems.

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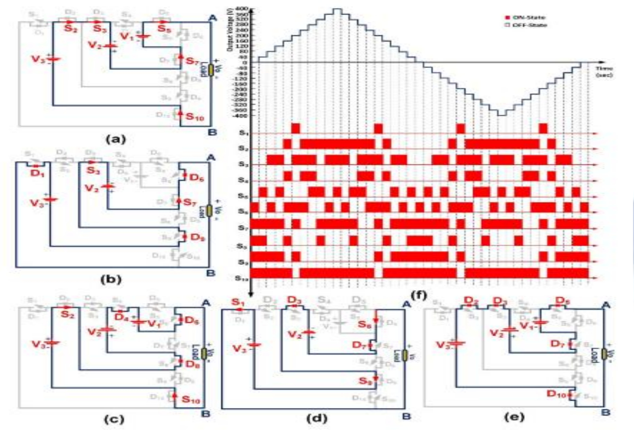

Figure: 4 Operating modes of the proposed 21-Level MLI topology (a): Mode-1, (b) Mode-6, (c) Mode-7, (d) Mode-16, (e) Mode-21, (f) 21-Level expected output voltage waveform with switching pulse

In mode-1 operation of the circuit, the switches,S_{10}, S_3, S_7,S_5, S_2 turn on forming a load current path of V_B-S_{10}-V_3- S_2- S_3- V_2- S_7- V_1- S_5- V_A, whereV_1, V_2 and V_3 sources act in the circuit and produce a voltage of 40V, 80V and 280V respectively and get a maximum voltage of 400V Therefore, the 21-level MLI output waveform is achieved with a simulation THD of 3.49%.

5. ANFIS MPPT

A newANFIS based MPPT method is proposed to achieve tracking the maximum power of the PV module under changing the weather conditions. The duty cycle is the output variable used to regulate the DC-DC switching SEPIC converter so that it maintains a constant maximum power output.

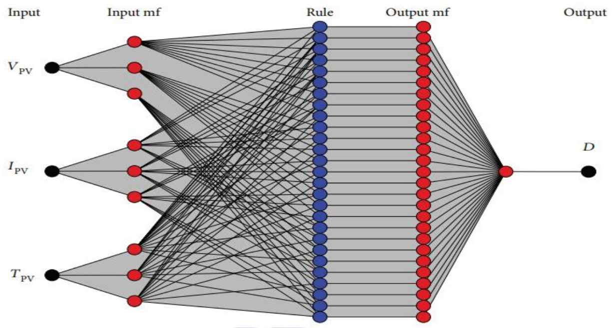

Figure 5 ANFIS model structure

The input-output mapping of training data sets may be developed via ANFIS. To ensure that the generated set of fuzzy rules is suitable for a wide range of input values, ANFIS modifies the values of membership functions. Membership functions' parameters are tinkered with till the error reaches a minimum. Again, if the resulting error is too high, the membership function parameters are tweaked to a more manageable level.

6. RESULTS AND DISCUSSION

The converter feeds data into the 21-level MLI, which then uses a multicarrier PWM generating mechanism to toggle the switch. The techniques used to synchronise the 21-level inverter's output with the grid are also detailed in this paper. To keep the grid in sync, engineers use the ANFIS controllers. To reduce the need for extensive training data, the ANFIS controller makes advantage of the FL system's trained membership function. As a result, it allows for reliable and speedy grid synchronisation. The converter both boosts the voltage at the PV panel's output and smooths out any voltage ripples that may otherwise be present.

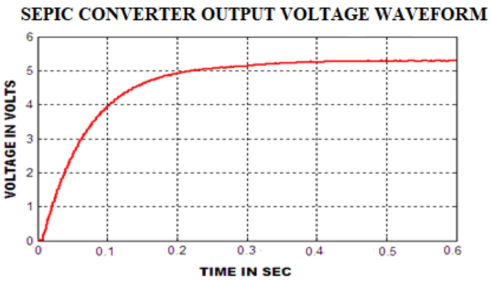

Figure6 Result of the DC voltage of SEPIC Converter to the MLI

The 21-level multilevel inverter with fewer switches receives the converter's output voltage. The multilayer inverter is controlled using a pulse-width-modulation (PWM) technique that uses several references. The reference signal is compared with the single high frequency carrier signal to modify the modulation index and to obtain output voltage.

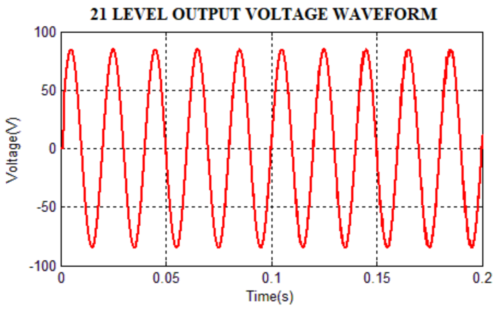

Figure 7 Waveform of twenty one-level voltage with ANFIS controller

The output of the MLI is injected into the single-phase power grid. The inverter switches are pulsed depending on the synchronisation level of grid current and voltage. Four distinct algorithms are used to adjust the duration of the control pulses.

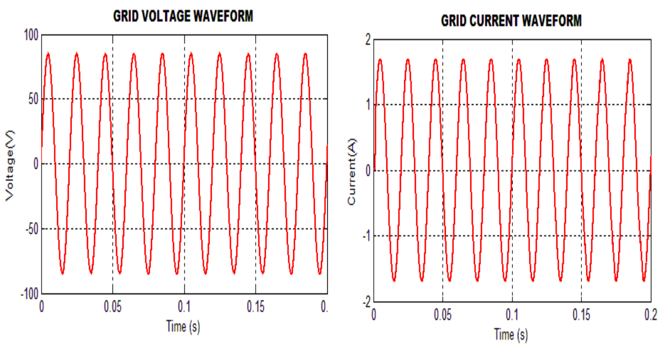

Figure 8 Grid voltage and current waveforms with ANFIS controller

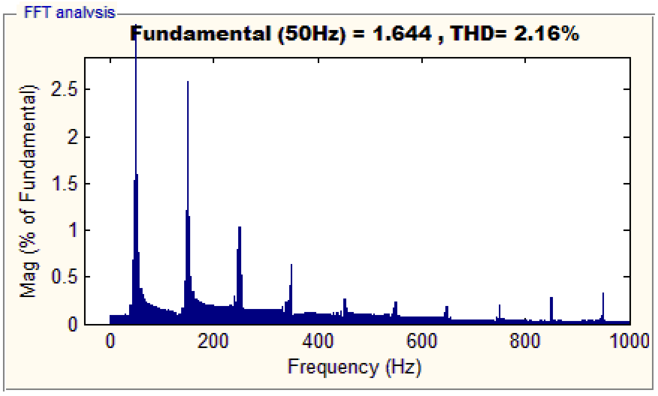

Figure 9THD waveform with ANFIS Controller,

Grid synchronisation techniques are evaluated using MATLAB's THD analyser tool. To lower the THD, the DC link voltage is raised by increasing the output voltage utilization.

7. CONCLUSION

Based on the findings of the recent study, the 21L MLI has been proposed as a method to effectively boost the low DC output of PV output, so making it feasible to compensate for load demand. To do this, a Sepic converter will need to be developed. The ANFIS methodology provides the best possible service to the overarching objective of MPPT. Remarkably, 21L MLI is used to carry out load modification, which, as a result, improves the system's overall efficiency without requiring any downtime. The simulation is carried out in MATLAB Simulink, and the results demonstrate that the new method effectively decreased the THD value. As a consequence, the whole system is now dependable enough to experience an increase in performance without experiencing any interruptions.

Conflict of interest statement

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

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