FUZZY LOGIC-BASED CONTROL OF NINE-LEVEL INVERTER FOR SOLAR APPLICATIONS

B. Durga Naik, *Assistant Professor EEE, TKR College of Engineering & Technology (Autonomous), India*

K. Vineeth, *UG Student EEE, TKR College of Engineering & Technology (Autonomous), India*

D. Vasanth Kumar, *UG Student EEE, TKR College of Engineering & Technology (Autonomous), India*

G. Thirupathi Rao, *UG Student EEE, TKR College of Engineering & Technology (Autonomous), India*

A. Suraj, *UG Student EEE, TKR College of Engineering & Technology (Autonomous), India*

***Abstract*— This article explores the simulation of a Solar-Powered Fuzzy Logic Controlled Nine-Level Inverter Multilevel Inverter (MLI), highlighting the importance of multilevel inverters in improving power quality and efficiency in renewable energy systems. By integrating Fuzzy Logic Control and a nine-level inverter topology, solar energy is seamlessly incorporated, ensuring smooth power supply regulation. Simulation analysis under various conditions enhances understanding of system behavior and performance, aiding in optimization and decision-making for practical solar energy applications. This research advances solar-powered multilevel inverter systems, particularly the nine-level configuration, towards superior power quality in renewable energy.**

***Keywords*— Solar-Powered, Fuzzy Logic Control, Nine-Level Inverter, Multilevel Inverter (MLI), Power Quality, Renewable Energy Systems.**

1. INTRODUCTION

There has been an increase insignificant surge in the application of sustainable energy sources driven by the quest for sustainable and environmentally friendly energy solutions. Among these, solar power has gained prominence as a clean and abundant energy source. Solar energy integration with electricity systems necessitates efficient and sophisticated technologies to harness and convert the harvested energy effectively. Multilevel inverters (MLIs) have emerged as pivotal components in solar power systems, offering various advantages such as reduced harmonic distortion, improved efficiency, and enhanced power quality. This research delves into the simulation of Fuzzy Logic controlled nine-level inverter MLI. The main reason for conducting this research lies in the requirement for advanced inverter technologies capable of efficiently converting the direct current (DC) solar panels' output into high-quality alternating current (AC) suitable for grid integration or standalone applications. Multilevel inverters play an important part in achieving this conversion by synthesizing multiple voltage levels from multiple DC sources.

Introducing a new high-performance multi-level single-phase hybrid inverter.

Because it offers single-phase conversion, small V and I, high gain & efficiency. Impedance-based enhancement converters are commonly used in solar applications. This structure has merits such as improved low power consumption, V gain characteristics, multilayer o/p voltage, and high η [1]. The single-phase multilevel inverter architecture is designed using time-domain optimization techniques to reduce the THD of the o/p V and I at any RL load. This is used to calculate the switching angle of the inverter as an optimization constraint. [2] Other approaches have also been suggested for isolated & networked apps. An original 1-ϕ Direct current -Alternating current multilevel modular converter (CTMLI) has been introduced with a compact number of components at the o/p. In one phase, three full-bridge (FB) circuits are linked in equivalent to a DC to obtain a Nineteen o/p volt at the o/p devices, then three 1-ϕ combined modifiers are linked in sequence. Individually circuit is precise by a certain switching freq. and individual 1-ϕ modifier has a certain turns relation [3]. A five-level (5L) single-phase converter is used to demonstrate the switching strategy and multiple modes of operation. Since only three conductive switches generate each voltage level in each mode of operation, rigorous calculations are proposed to determine the lowest possible conduction and switching costs [4]. Furthermore, the nearest modulation approach is employed to boost overall efficiency by lowering the power converter's switching activity. The amount of switch elements and DC sources in the multilevel inverters for grid integration is kept to a minimum. To evaluate the controller, a stability and sensitivity analysis of the system is performed. This approach for distributed generation uses a multi-resonant proportional-resonant (PR) controller and a multi-resonant proportional-integral (PI) controller with multi-layer inverters to reduce the harmonic content of utility power and fixed disturbances. State error of grid injected power [5]

2. PROPOSED MLI

The many mechanical applications today have begun to demand large control. However, a small number of the enterprises' machinery need medium or moo control function. For certain engines that need large control, using a high-power source for all mechanical loads can prove beneficial, but it could be detrimental to other loads. Medium voltage is needed for utility applications and a few medium voltage engine drives. Since 1975, the multi-level inverter has been offered as an optional solution for large control and medium voltage situations. Similar to an inverter, the multi-level inverter is used as an optional component in large control and medium voltage mechanical applications.

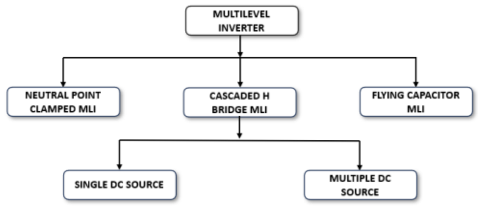

Fig. 1 Classification of Multi-level Inverters

H-Bridge Multilevel Cascaded Inverter:

With the cascaded H-bride multilevel inverter, less parts are needed at each level and capacitors and switches will be used. This topology is made up of a configuration of control transformation cells, and control is easily scalable. An H-bridge is a configuration of switches and capacitors that provides the isolated DC voltage input for each H-bridge. It is made up of H-bridge cells, each of which is capable of producing one of three unique voltages: zero, positive DC, and negative DC. Compared to diode clamped and flying capacitor inverters, this type of multi-level inverter has the advantage of requiring fewer components.

Applications of the Cascaded H-Bridge Multilevel Inverter include:

- back-to-back frequency link systems
- motor drives
- active filters
- electric vehicle
- drives usage of DC power sources
- power factor compensators
- interfaces with renewable energy sources.

2.1 PROPOSED SIMULATION SYSTEM

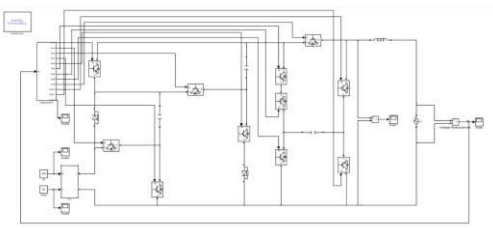

Fig. 2 Proposed System Simulation

Circuit Description:

Fig.2 shows the circuit diagram of the proposed 9 level PV inverter. This inverter circuit constitutes nine power switches (S1–S6 and S8–S10), and one bidirectional switch S7 configured by connecting two switches in anti-series (S7U + S7D), two power diodes (D1 and D2), and two SCs (C1 and C2) and one virtual dc-link capacitor (C3). SC1 and SC2 work simultaneously in the proposed inverter to facilitate four different dc voltages. Each SC cell comprises two switches, one in series and the other in shunt with the input. The series switch enhances the voltage level, and the shunt switch serves to charge their cell's capacitor. SC1 cell works as input for SC2 cell. SC1 cell has two switches, S1 (series) and S2 (shunt), with one capacitor, C1, and one power diode, D1. Likewise, the SC2 cell is made with three power switches, S3 (series), S4 (shunt), and S5 (helps in generating some negative voltage steps), one power diode D2, and capacitor C2. SC1 cell produces the first two levels of voltage +Vd (S2 gets on and C1 gets charged) and +2Vd (S1 gets on and C1 gets discharged). Likewise, the SC2 cell is for the other two voltage levels generation, +3Vd [S2 turned on (from SC1 to charge C1) and S3 turned on (from SC2)] and +4Vd (S1 and S3 on). It is noticeable here that the SC2 cell's output voltage depends on the SC1 cell's output voltage. Series switches of each cell are accountable for generating even voltage steps (+2Vd and +4Vd) and shunt switches for odd voltage steps (+Vd and +3Vd). The proposed pulse width modulation (PWM) scheme manages the capacitors' charging and discharging times.

The PWM technique is based on basic logic gates trying to utilize the charging of capacitors if they are not in the power-delivering loop. Table 1 shows the switching states with output voltage levels with the state of charging and discharging SC's (C1 and C2) and virtual dc-link capacitor (C3). This inverter works in nine different modes and eight zones for nine-level voltage generation with four times boosting for a grid cycle. The MI value is responsible for zone distribution and the number of voltage step generations for this inverter.

Table I. Switching States

ZONE	MODE	LEVEL	V_{AB}	SWITCHES
I	2	1	0	$S_1\ S_3\ S_7\ S_9\ S_{10}$
II	1	2	$+V_D$	$S_2\ S_5\ S_6$
III	3	3	$+2V_D$	$S_1\ S_4\ S_5\ S_6$
IV	4	4	$+3V_D$	$S_2\ S_3\ S_6$
	5	5	$+4V_D$	$S_1\ S_3\ S_6\ S_7\ S_{10}$
V	2	1	0	$S_1\ S_3\ S_7\ S_9\ S_{10}$
VI	6	6	$-V_D$	$S_2S_3\ S_7\ S_9$
VII	7	7	$-2V_D$	$S_1S_4S_5\ S_7\ S_9$
-VIII	8	8	$-3V_D$	$S_2S_5S_7\ S_9$
	9	9	$-4V_D$	$S_1\ S_4\ S_5S_8\ S_9$

3. PROPOSED CONTROLLER

The fuzzy logic controller is made up of three fundamental parts.

1) Fuzzifier
2) Inference Engine
3) Defuzzifier

3.1 FUZZIFIER

To be employed with the fuzzy controller, every variable used to create the control signal must be specified using fuzzy rules notations and linguistically labels. Positive Big (PB), Positive Medium (PM), Positive Small (PS), Zero (ZE), Negative Small (NS), Negative Medium (NM), and Negative Big are the seven fuzzy subsets that

make up each discourse universe (NB). Here, the normalized values of e and ce are [-1,1], and the range of mn is [-1,1]. Any combination of error (e) and change in error (ce) results in a maximum of forty-nine rules being used.

Error(e) = Vref -Vin

Rate of error(ce) = error(n) – error(n-1)

Table II. Fuzzy Rule Table

e/ce	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

3.2 Defuzzifier:

Before being employed in the control system, a fuzzy set that represents the output of the controller in linguistic notation must be converted into crisp decision variables. For this, a defuzzifier is employed. There are numerous methods for digitizing. The Mean of Maxima (MOM) and the Centre of Area (COA) are the two methods that are most frequently utilized. The majority of monitoring applications employ the COA technique. The method computes the control plane and yields results that are responsive to all relevant rules. A rule-based fuzzy controller is used to control the reference voltage on any load, although the outcome frequently eludes management. The fuzzy controller's inputs are the defect and its degree of fluctuation. Controller and inverter system apps are created using the full Simulink environment. The centre of the control surface is calculated by the method, which also yields results that are responsive to any rules used. Results thus frequently go outside the control surface.

A fuzzy controller that is based on rules is used to keep an eye on the reference voltage under all load conditions.

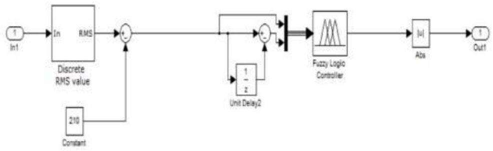

Fig. 4 FLC Simulation Diagram

4. SIMULATION RESULTS

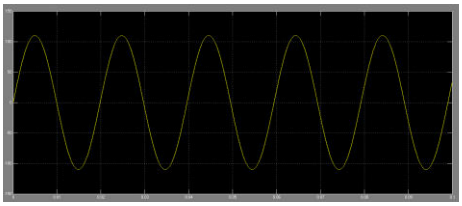

Fig. 5 MLI output voltage vs time

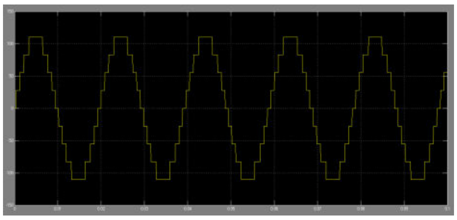

Fig. 6 Grid voltage vs time

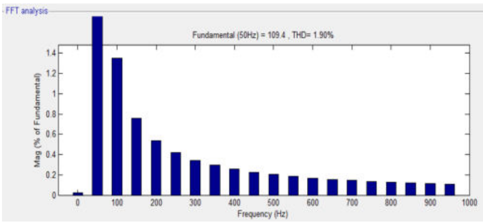

Fig. 7 THD plot without Fuzzy controller

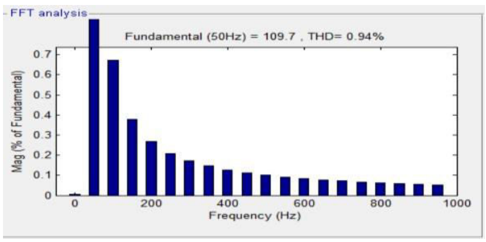

Fig. 8 THD plot with Fuzzy controller

Implementing a fuzzy controller in the system significantly reduces Total Harmonic Distortion (THD) from 1.90% to 0.90%. Operating with a PV voltage of 50V and a grid voltage of 110V, the effectiveness of the fuzzy controller in enhancing power quality is evident. By employing advanced control techniques such as fuzzy logic, the system achieves improved stability and efficiency, ensuring cleaner power delivery to the grid, thus enhancing overall performance and reliability.

5. CONCLUSION

In conclusion, the simulation of a solar-powered Fuzzy Logic Controlled nine-level inverter Multilevel Inverter (MLI) marks a significant advancement in incorporating renewable energy into electrical grids. The study concentrated on leveraging photovoltaic panels for solar energy and efficiently utilizing the generated power by employing a sophisticated nine-level inverter with Fuzzy Logic Control.

The simulation results illustrate the efficiency of the proposed system in voltage regulation, harmonics reduction, and overall grid performance. The nine-level inverter, with its expanded voltage levels, yields smoother voltage waveforms, mitigating harmonic distortions and enhancing the overall power quality injected into the grid.

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