

A COMPARATIVE STUDY OF MULTILEVEL INVERTER TYPOLOGIES WITH REDUCED SWITCHES

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering Degree in
Electrical and Electronics Engineering

by

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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119

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This is to certify that this Project Report is the bonafide work of **KRUPA NANDHINI B (38140022)**, **KEERTHANA PRIYA B (38140019)** who carried out the project entitled "**A COMPARATIVE STUDY OF MULTILEVEL INVERTER TYPOLOGIES WITH REDUCED SWITCHES**" under our supervision from December 2021 to April 2022.

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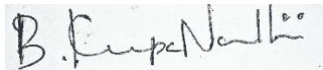
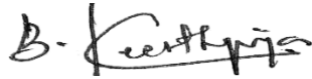
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DECLARATION

We **KRUPA NANDHINI B** and **KEERTHANA PRIYA B** hereby declare that the Project Report entitled “**A COMPARATIVE STUDY OF MULTILEVEL INVERTER TYPOLOGIES WITH REDUCED SWITCHES**” done by us under the guidance of **Dr. D. GODWIN IMMANUEL** is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Electrical and Electronics Engineering.

1. 
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DATE: 20/04/2022

PLACE: CHENNAI

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ABSTRACT

From the past couple of decades, Multilevel inverter (MLI) techniques are best fitted for increased power industrial applications. Multilevel inverter (MLI) synthesizes several DC sources. For that, it is recommended to use switches of high rated values. Matlab / Simulink is used to simulate all of the topologies, and the results are validated and compared. The duty cycles of individual cells in cascade multilevel converters change as a result of the fluctuation in the irradiances of the power cells. However, the MPPT is maintained throughout the process. The difference in cell responsibility cycle, on the other hand, is undesirable because it is associated with the distortion of production voltage and current voltage and current. In order to achieve this, a multilevel design for photovoltaic (PV) applications is proposed, in which a H6 bridge power cell is used in place of an H-bridge is used. Should a mismatch in solar irradiance between the power cells occur, an expected converter will be used to inject power at a lower voltage from the shaded cells without altering the PV voltage, thus maintaining the MPPT functionality. This modification allows us to maintain an identical duty cycle in all power cells, independent of the weather circumstances, and therefore to preserve the yield voltage and current waveform properties of the power cells. Both a sophisticated computer model and a field experiment were used to assess the effectiveness of the proposed remedy. Following the analysis, it has been shown that when compared to conventional H-bridge topologies, the proposed topology provides much better voltage and current characteristics in the production environment. The proposed topology's presentation was also compared to one that improved harmonics presentation in accordance with European competence requirements, resulting in a 2.64 percent increase in overall presentation quality.

CHAPTER NO.	TITLE	PAGE NO.
	ABSTRACT	v
	LIST OF FIGURES	ix
	LIST OF TABLES	xi
	LIST OF SYMBOLS AND ABBREVIATIONS	xii
1	INTRODUCTION	1
	1.1 GENERAL INTRODUCTION	1
2	LITERATURE SURVEY	2
	2.1 LITERATURE SURVEY	2
3	AIM AND SCOPE OF THE PRESENT INVESTIGATION	7
	3.1 AIM OF THE PROJECT	7
	3.2 SCOPE OF THE PROJECT	7
	3.3 ADVANTAGES AND APPLICATIONS OF PROPOSED TOPOLOGY	7
4	MATERIALS, METHODS AND ALGORITHMS USED	8
	4.1 INVERTERS	8
	4.1.1 VOLTAGE SOURCE INVERTER	8
	4.1.2 CURRENT SOURCE INVERTER	9
	4.2 MULTILEVEL INVERTER	12
	4.2.1 CASCADED H BRIDGE MLI	13
	4.2.2 ADVANTAGES OF MULTILEVEL INVERTER	14
	4.3 PULSE WIDTH MODULATION SCHEMES	14
	4.3.2 INTERNAL PULSE CONTROL IN INVERTER	15

4.3.7	SINUSOIDAL PULSE WIDTH MODULATION	19
4.3.8	FEATURES FOR COMPARING VARIOUS PWM TECHNIQUES	20
4.3.9	SPWM HARMONIC ELIMINATION	21
4.3.9.1	ADVANTAGES OF SPWM	22
4.3.9.2	DISADVANTAGES OF SPWM	23
4.4	BOOST CONVERTER	23
4.4.1	OPERATION	24
4.4.2	APPLICATIONS OF BOOST CONVERTER	25
4.5	NEURO-FUZZY CONTROLLER	25
4.5.1	NEURO FUZZY	25
4.5.2	FIREFLY ALGORITHM	27
4.5.2.1	ALGORITHM	28
4.5.2.2	PSEUDO CODE	29
4.5.2.3	FIREFLY ALGORITHM CODE	29
4.6	CONVENTIONAL CASCADED H BRIDGE	34
4.6.1	ANALYSIS OF PARTIAL SHADING IN THE CONVENTIONAL CHB TOPOLOGY	37
4.7	MAXIMUM POWER POINT TRACKING (MPPT)	38
4.7.1	ROLE OF THE MPPT	38
4.7.2	PRINCIPLES OF MPPT	38
4.7.3	WHAT IS MAXIMUM POWER POINT TRACKING?	39
4.7.4	DIFFERENT TECHNIQUES OF MPPT	40
4.7.5	PERTURB AND OBSERVE (P&O) METHOD	41
4.7.5.1	ADVANTAGES	41

	4.7.5.2 DISADVANTAGES	42
4.8	INTRODUCTION TO MATLAB	42
	4.8.1 INTRODUCTION	43
	4.8.2 GRAPHICAL VERSUS COMMAND-LINE USAGE	44
	4.8.3 WHAT IS SIMULINK?	45
5	RESULTS AND PERFORMANCE ANALYSIS	47
5.1	EXISTING SYSTEM	47
	5.1.1 EXISTING MLI TOPOLOGIES WITH REDUCED SWITCHES	47
	5.1.2 LIMITATIONS OF EXISTING TOPOLOGY	47
5.2	PROPOSED SYSTEM	49
	5.2.1 FEATURES OF PROPOSED TOPOLOGY	49
5.3	PROPOSED SYSTEM WITH NEURO-FUZZY CONTROLLER	50
5.4	COMPARISON OF EXISTING AND PROPOSED SYSTEM RESULTS	50
5.5	HARDWARE IMPLEMENTATION	50
	5.5.1 CONTROLLER UNIT	51
	5.5.2 DRIVER UNIT	51
	5.5.3 INVERTER POWER CIRCUIT	52
	5.5.4 SPECIFICATIONS	52
6	CONCLUSION	53
6.1	CONCLUSION	53
	REFERENCES	54

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE NO.
4.1	Voltage Source Inverter	9
4.2	Current Source Inverter	10
4.4	Pulse Width Modulation	13
4.5	Sinusoidal Pulse Width Modulation	17
4.6	SPWM Comparison Signals	19
4.7	Overmodulation	20
4.8	SPWM Wave with odd and half wave symmetry	21
4.9	Block Diagram	23
4.10	Switch OFF Condition	24
4.11	Switch ON Condition	24
4.12	Firefly Algorithm	29
4.13	The Classical dc-dc Boost + H Bridge	34
4.14	Maximum Power Point	40
4.15	P&O Flowchart	41
4.16	Matlab	42
5.1	Topology 1 Circuit Diagram	48
5.2	Topology 2 Circuit Diagram	49
5.3	Topology 2 Extension	49
5.4	Topology 3 Circuit Diagram	50
5.5	Simulink Model	51
5.6	Topology 3 – 7 level THD output	51

5.7	7 level Simulink Output	52
5.8	Circuit Diagram of Proposed Topology	53
5.9	Simulink Model	53
5.10	9 level THD Output	54
5.11	9 level output	55
5.12	Simulink Model	56
5.13	Simulink Model of MPPT	56
5.14	Tracked MPP of 112V	57
5.15	Boost Converter	57
5.16	Neuro-Fuzzy with Phase Locked Loop	58
5.17	THD of Proposed System with Neuro-fuzzy Controller	58
5.18	Block diagram	60
5.19	Arduino UNO Board	61
5.20	TLP250 Driver Circuit	61
5.21	Hardware Implementation	62

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
5.1	Topology 1 Switching Scheme	48
5.2	Topology 2 Switching Scheme	49
5.3	Topology 3 Switching Scheme	50
5.4	9 level Switching Scheme	54
5.5	Comparison of 9 & 7 level	59
5.6	Components Comparison of Proposed Syster with Different Structures of MLI	59
5.7	Comparison of Proposed topology with neuro Fuzzy connected proposed topology	59

LIST OF SYMBOLS AND ABBREVIATIONS

β	-	Attractiveness
γ	-	Coefficient of Absorption
α	-	Parameter of Randomization
ξ	-	Random Number
D_i	-	Duty Cycle
V_{dci}	-	Voltage in i th Power Cell
C	-	Carrier Angular Frequency
h_n	-	Magnitude of n th Harmonic Component
α_n	-	Primary Switching Angle
V_{in}	-	Input Voltage
V_{out}	-	Output Voltage
I_{in}	-	Input Current
I_{out}	-	Output Current
P_{in}	-	Input Power
P_{out}	-	Output Power
AC	-	Alternating Current
MLI	-	Multilevel Inverter
CHB	-	Cascaded H Bridge
DC	-	Direct Current
MPPT	-	Maximum Power Point Tracking
PV	-	Photo Voltaic

PWM	-	Pulse Width Modulation
THD	-	Total Harmonic Distortion
SPWM	-	Sinusoidal Pulse Width Modulation
VSI	-	Voltage Source Inverter
CSI	-	Current Source Inverter
P&O	-	Perturb and Observe
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
DSO	-	Digital Storage Oscilloscope
CRO	-	Cathode Ray Oscilloscope
STC	-	Standard Test Conditions
GUI	-	Graphical User Interface
DSP	-	Digital Signal Processing
INC	-	Incremental Conductance
MATLAB	-	Matrix Laboratory
AI	-	Artificial Intelligence
FFA	-	FireFly Algorithm
TSK	-	Takagi-Sugeon-Kang
EMI	-	Electro Magnetic Interference
MLC	-	Multilevel Converter

CHAPTER 1

INTRODUCTION

1.1 General Introduction

In the previous three decades, renewable energy technology has advanced significantly. Photovoltaic (PV) systems are one of the most promising and rapidly developing renewable energy sources. PV system cumulative installed capacity has increased at an exponential rate over the previous decade, reaching a high of 178 GW recently. The four types of PV system topologies are: (1) central inverter, (2) module-integrated inverter, (3) string inverter, and (4) multi string inverter. Several PV strings (series-connected PV panels) are linked in parallel with one blocking diode per string to form a single dc-link and are connected to the grid via a central inverter in the central inverter topology. This topology provides a straightforward structure, dependable control, and a modest initial investment. The energy yield can be readily lowered by the impacts of panel mismatch and partial shade when there is just one centralised maximum power point tracking (MPPT) control. The difficulty can be mitigated by dividing PV panels into smaller groups with individual MPPT control. One converter runs with only one or a few PV panels in this architecture. As a result, power loss due to panel mismatch may be reduced, and the effect of partial shade can be reduced.

Multilevel Converters (MLCs) are very promising candidate power electronic converters since they offer robust, efficient, and fault-tolerant features. One the other hand, the high-quality voltage allows the use of a less sizable output filter. Among them is the cascaded H-bridge (CHB) converter topology, which consists of series-connected H-bridges, each of which is fed by a separate dc voltage source. This characteristic makes it possible to connect PV panels in each H-bridge; thus, achieving independent maximum power point tracking (MPPT), which in turn, improves the efficiency of the overall system. The commonly used pulse width modulation (PWM) strategy in MLCs is the phase shifted PWM (PS-PWM). The PSPW Min CHB application is described as multi-unipolar carriers, one carrier designated for each H-bridge, where these carriers are shifted by T_s/n with respect to one another. Here, T_s is the carrier's period, and n is the number of H-bridges.

However, in case the power cells are subjected to uneven solar irradiance due to dust on the PV panels or partial shading, the system would be unbalanced. This

imbalance can be grouped into two categories, interphase imbalance and intraphase imbalance. The former is believed to be an old existing problem, which is similar to any interphase imbalance issue, for which there are hundreds of solutions. The intraphase imbalance, however, is a contemporary problem that came as a challenge with MLCs. The main causes of the harmonics generated in the converter output signals when the solar irradiation is not equal over the power cells are the difference in cell duty cycles and dc-link voltages. The controller limits the duty cycle in the shaded power cell in order to match its new MPP current when the solar irradiance decreases; consequently, the modulator receives different duty cycles. In this case, the shaded power cell starts injecting power by some delay (TD) and stops injecting it before the supposed time by TD . However, in MLCs, the cells are grouped together to form the converter output signals (output current and voltage), and the timing is a critical parameter. Several attempts to mitigate this problem are reported. In variable switching angles is the main operation principle, where this strategy offers a cheap solution; however, it is valid only when $n = 3$ due to the complex computation required. A dc–dc boost converter has been added into each power cell where a modified modulation strategy is proposed to keep the energy among the dc-link capacitors at a similar level. Modular cascaded multilevel quasi-Z-source the inverter offers flexibility in the power quality matter as the H-bridges' voltages are independent of the PV voltages only some changes on its modulation and control are required, as elaborated. In this project, power cell based MLC is proposed, where the issue of the difference in duty cycles is disclosed.

CHAPTER 2

LITERATURE SURVEY

2.1 Literature Survey

Asymmetric Nine Level inverter scheme using power semiconductor devices was suggested by M. S. Arif, S. M. Ayob, and Z. Salam (2018). A novel single-phase multilevel inverter architecture is introduced in this study. With fewer devices, the proposed architecture can produce nine-level output voltage. It is accomplished by arranging available switches and dc sources in such a way that the greatest possible combination of addition and subtraction of the input dc sources is attained. In this project, a low frequency switching approach is used. The findings reveal that the suggested architecture can provide a nine-level output voltage, can handle inductive loads, and has a low harmonic distortion content.

Multilevel inverters (MLI) have Adil Sarwar, Md Irfan Sarwar, Md Shahbaz Alam, Seerin Ahmad, and Mohd Tariq (2019) suggested a Nine-Level Cascaded Multilevel Inverter with Reduced Switch Count and Lower Harmonics. MLI's modular design allows the power handling capability to be upgraded without the need for new converters. This study describes a cascaded H-bridge (CHB) converter with a low switch count that uses a single stiff DC source (battery) to produce a nine-level output. Simulation and experimental results back up the mathematical analysis. The effect of modulation index on total harmonic distortion (THD) is also investigated.

A Nine-Level Cascaded H-Bridge Multilevel Inverter was proposed by Divya Subramanian and Rebiya Rasheed (2013). A multilayer inverter arrangement is shown in this work, which is created by inserting a bidirectional switch between capacitive voltage sources and a typical H-bridge module. By increasing the number of output voltage levels, the redesigned inverter may create a better sinusoidal waveform. It is feasible to obtain 9 output voltage levels, including zero, by serially connecting two modified H-bridge modules. To ensure balanced power distribution across the power cells, a multicarrier phase-shifted pulse-width modulation approach is utilised. It is carried out an examination of the output voltage harmonics. According to the findings, when compared to other conventional inverters with the same output, the suggested inverter gives superior output quality with reduced power loss.

A Comparative Analysis of Nine Level Inverter with Two Different Topologies was proposed by M.Nagaraju and D.Ravikiran (2016). Because of its benefits over alternative topologies, the cascaded H-Bridge multilevel inverter is strongly recommended. The number of levels in a cascaded H-Bridge topology may be raised by increasing the number of H-Bridges, which increases the number of switches. The higher the number of output voltage levels, the better the sinusoidal wave shape and the lower the overall harmonic distortion (THD). However, because there are more switches, the size and cost of the inverter increases. As a result, research has begun to minimise the number of switches by increasing the number of levels. This research proposes and analyses a nine-level cascaded H-Bridge multilevel inverter with decreased switch count. When compared to diode clamped, flying capacitor, and cascaded H-bridge inverters, the suggested nine level multilevel inverters use fewer components to achieve the same number of voltage levels. As a result, switching loss and cost are decreased. It also makes the stair-case voltage waveform from many dc sources more regular. The operating concept and critical waveforms are examined, and the suggested multilevel inverter's performance is assessed using simulation.

Dr. Pravin M. Sonawane and Shraddha S. Lohakare suggested a Comparative Study on Five and Nine Level MLI for Percentage THD Reduction (2019). This research uses a phase shifted pulse width modulation technique to compare 3-phase cascaded h-bridge 5-level and 9-level multilevel inverters for grid-connected solar applications. Harmonic content decreased as the levels attained by multilayer inverters grew, although this advantage comes with certain drawbacks. To investigate these trade-offs, this paper's theoretical analysis compares grid-connected 5-level and 9-level cascaded h bridge multi-level inverters.

A Reduced Switch Count and THD Analysis in Cascaded H Bridge Multi-level Inverter Topology was proposed by B.Sathyavania, K.Rajeshwar Reddyb, and DrN.KamalaMoorthy (2021). In a multi-level inverter, the desired output value is determined by the harmonic values in order to raise the output levels. A 9-level cascaded H bridge inverter with fewer switching components is shown in this study. The THD values of the designed H bridge inverter are examined at various loads. In terms of THD values, the created H bridge inverter is compared to PD, POD, and APOD approaches. Based on simulation findings, the designed H bridge inverter system performs well in terms of

voltage and current THD values, as well as achieving excellent efficiency due to lower losses.

Asymmetric Cascaded H-Bridge Multilevel Inverter With Single DC Source per Phase was proposed by Rajesh Vasu, Sumit Kumar Chattopadhyay, and Chandan Chakraborty (2020). This paper offers a binary asymmetric ratio self-balanced cascaded H-bridge multilevel inverter. The inverter only employs one dc source per phase to provide the greatest dc-link voltage to the H-bridge (called main bridge). Floating capacitors form the dc links of all other H-bridges (also known as auxiliary bridges). The notion of a level-doubling network allows floating capacitors to converge to their respective steady-state voltages without the need of any closed-loop control techniques. Each auxiliary bridge's dc-link voltage will be half of the dc-link voltage of the H-bridge before it in a steady state. As a result, there will be an intrinsic binary asymmetry.

CHAPTER 3

AIM AND SCOPE OF THE PRESENT INVESTIGATION

3.1 AIM OF THE PROJECT

The Primary objective of the project is to reduce the number of switches and to increase the output level of the multilevel inverter by doing comparative study with the existing topologies which results in better of the inverter by increasing the efficiency and by reducing the total harmonic distortion.

3.2 SCOPE OF THE PROJECT

The multilayer power converter control approach may be simplified and applied to various levels and other types of power converters and inverters. Further improvements in terms of performance and power quality concerns may be explored and realised using hardware circuits, and the levels of multilayer configuration can be expanded. The same cascaded multilayer inverter structure may be used for various applications such as SVC systems, and the performance of bigger AC systems can be evaluated.

3.3 ADVANTAGES AND APPLICATIONS OF PROPOSED TOPOLOGY

3.3.1 Advantages

- Reduced Switch Count
- Better Sinusoidal Waveform
- Reduced Total Harmonic Distortion
- Increased Efficiency
- Low Cost
- Less Weight

3.3.2 Applications

- Static Var Generation
- Medium to High Voltage Level Applications
- High AC and DC transmission
- Solar PV application

CHAPTER 4

MATERIALS, METHODS & ALGORITHMS USED

4.1 Inverters

The power electrical circuit that transforms DC electricity to AC voltage is known as an inverter. The DC source is usually a battery or the controlled rectifier's output. The inverter's output voltage waveform might be square, quasi-square, or low distorted sine wave. With the aid of switch drives, the output voltage may be regulated. The most frequent approach for controlling the output voltage of inverters is pulse width modulation. PWM inverters are the name for such inverters. When the inverter's output voltage is not sinusoidal, it contains harmonics. By employing correct control systems, these harmonics can be minimised. Inverters may be divided into two categories.

1. Inverter with a Voltage Source (VSI)
2. Inverter with a Current Source (CSI)

In our project, we're employing a Voltage Source Inverter (VSI).

The term "voltage inverter" (VSI) or "voltage fed inverter" refers to a device that maintains a constant DC voltage (VFI). Current source inverters (CSI) or current fed inverters are used when the input current is kept constant. To alter the output, the DC input voltage to the inverter is sometimes regulated. Variable DC link inverters are a type of inverter that works in this way. The output of the inverters might be single phase or three-phase. A stiff dc voltage feeds a voltage source inverter, whereas a stiff current source feeds a current source inverter. By connecting a series inductance to a voltage source and adjusting the voltage to achieve the necessary current, a voltage source may be transformed to a current source.

4.1.1 Voltage Source Inverters (VSI)

- VSI is powered by a DC voltage source with a low or non-existent impedance.
- The input voltage is kept constant.
- The output voltage is not affected by the load.

- The load current's waveform, as well as its magnitude, is determined by depending on the load impedance.
- VSI necessitates the use of feedback diodes.

The commutation circuit is difficult to understand. Power BJT, Power MOSFET, IGBT. In the circuit, GTO with self-commutation can be employed. Figure 4.1 depicts a circuit diagram of Voltage Source Inverter.

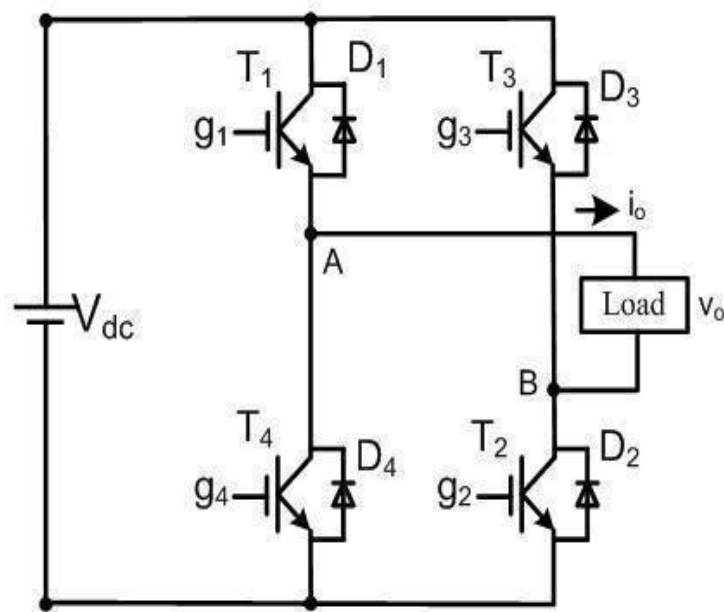


Fig. 4.1 Voltage Source Inverter

4.1.2 Current Source Inverters

- A DC voltage source with a high impedance feeds CSI with variable current.
- The input current is constant, however it may be adjusted.
- The output current amplitude is unaffected by the load.
- The magnitude and waveform of the output voltage are determined by the type of the input voltage.
- The CSI does not necessitate the use of feedback diodes.

Because it simply comprises capacitors, the commutation circuit is simple. The objective of an inverter, as previously stated, is to convert DC electricity to AC power. Inverters are used in a variety of technologies, including uninterruptible power supplies. Inverters

are used in all of these technologies to achieve distinct aims, but they all rely on them. Fig.4.2 shows current source inverter.

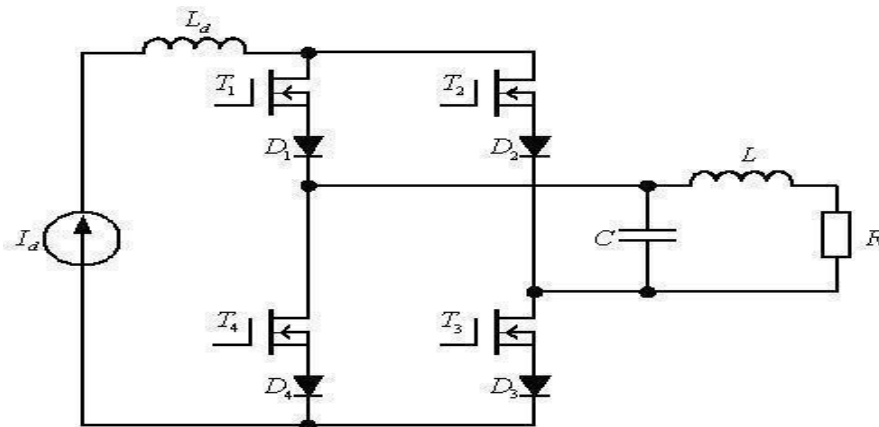


Fig. 4.2 Current Source Inverter

4.2 Multilevel Inverter

Many industrial applications now necessitate a high level of power. Some industrial appliances, on the other hand, require medium or low power to operate. Using a high-power source for all industrial loads may benefit some high-power motors, but it may cause damage to other loads. Medium voltage is required for several medium voltage motor drives and utility applications. Since 1975, the multi-level inverter has been used as an alternative in high-power and medium-voltage applications. The Multilevel inverter is similar to an inverter and is used in industrial settings as a high-power, medium-voltage option.

Multilevel inverters are three types,

- Diode clamped multilevel inverter
- Flying capacitors multilevel inverter
- Cascaded H-bridge (CHB) multilevel inverter
 - Symmetrical CHB
 - Asymmetrical CHB

We are using Asymmetric Cascaded H-Bridge Multilevel Inverter in our project

4.2.1 Cascaded H-Bridge Multilevel Inverter

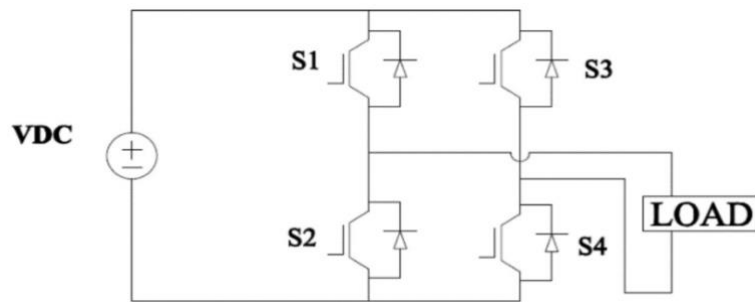


Fig. 4.3 H Bridge

The cascaded H-bridge multilevel inverter employs capacitors and switches, and each level requires less components. H Bridge circuit diagram is shown in Fig.4.3. This topology is made up of a series of power conversion cells that can be scaled easily. An H-bridge is a pair of capacitors and switches that produces a different input DC voltage for each H-bridge. It is made up of H-bridge cells, each of which may produce three different voltages: zero, positive DC, and negative DC. When compared to diode clamped and flying capacitor inverters, one of the advantages of this form of multi-level inverter is that it requires less components. The inverter is less expensive and lighter than the other two inverters. Some of the new switching approaches allow for soft-switching.

Multilevel cascade inverters replace the massive transformer required by traditional multi-phase inverters, as well as the clamping diodes and flying capacitors required by diode clamped inverters and flying capacitor inverters. However, to feed each cell, a vast number of independent voltages are required.

4.2.1.1 Applications of Cascaded H-Bridge Multilevel Inverter

- Motor drives
- Active filters
- Electric vehicle drives
- DC power source utilization
- Power factor compensators
- Back to back frequency link systems
- Interfacing with renewable energy resources.

4.2.2 Advantages of Multilevel Inverter

4.2.2.1 Common Mode Voltage

The multilayer inverters generate common-mode voltage, which reduces motor stress and prevents motor damage.

4.2.2.2 Input current

Multilevel inverters can draw low-distortion input current.

4.2.2.3 Switching Frequency

The multilayer inverter can flip between fundamental switching frequencies of higher and lower switching frequencies. It's worth noting that a lower switching frequency results in lower switching loss and improved efficiency.

4.2.2.4 Reduced harmonic distortion

Because of the selective harmonic elimination technique and the multi-level topology, the total harmonic distortion in the output waveform is reduced without the use of a filter circuit.

4.3 Pulse Width Modulation Schemes

4.3.1 Control techniques for inverter output

This section examines various methods of output voltage control by means of This section looks at how inverter gain control may be used to regulate output voltage. The ratio of output ac voltage to input dc voltage is known as the inverter gain. This type of gain control is helpful in a variety of situations where the changes of the input signal are important. Because of the changes in dc input voltage, ac output voltage cannot be permitted. When induction motor speeds must be controlled in volts/hertz, this is required. The PWM technique is referred to as the PWM method to distinguish these approaches from the PWM method. Because the output voltage is controlled by means of an internal control technique, alterations to the inverter switches' conduction patterns

Various techniques. The following are some examples of inverter output voltage control,

1. Controlling the AC output voltage from the outside
2. Control of the DC input voltage from the outside
3. Inverter output voltage is controlled internally

Extra circuits for controlling either dc input or ac output are used in the first two approaches. The third way, on the other hand, does not necessitate the use of such circuits.

4.3.7 Sinusoidal Pulse Width Modulation

There are numerous output pulses each half cycle in this modulation method, and the pulses are of varying widths. Each pulse's breadth varies in proportion to the amplitude of a sine wave calculated at the pulse's centre. A sinusoidal reference is compared to a high frequency triangle signal to create the gating signals. PWM with a sinusoidal waveform is seen in Figure 4.5. The rms ac output voltage ,

$$V_s = V_s \sqrt{\frac{p\delta}{\pi}} \rightarrow V_s \sqrt{\sum_{n=1}^{\frac{p}{2}} \frac{\delta_n}{\pi}}$$

Where p=number of pulses and δ = pulse width

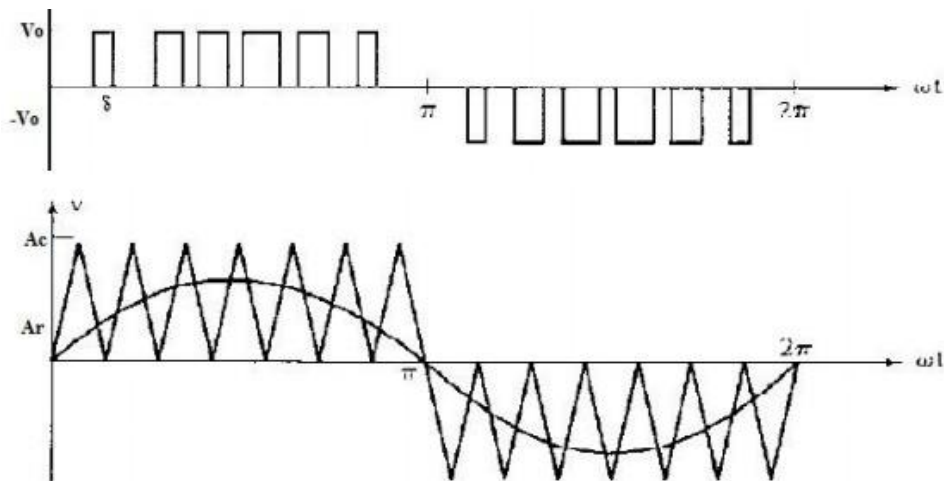


Fig. 4.5 Sinusoidal Pulse Width Modulation

4.3.8 Features for comparing various PWM Techniques

- Switching Losses.
- The use of a dc power supply to give a greater output voltage with the same DC power supply.
- Voltage and current control linearity.
- In the voltage and current, there are harmonics.

Comparing a low-power sine wave reference with a high-frequency triangle wave is the easiest approach to generate the SPWM signal. Switches can be controlled using this SPWM signal. The output of a Full Wave Bridge Inverter with SPWM signal will yield a wave that is almost comparable to a sine wave after passing through an LC filter. This approach generates an AC waveform that is significantly more comparable to that of others. The core harmonic is still there, and the signal contains a large number of higher-level harmonics. SPWM is seen in Figure 4.6.

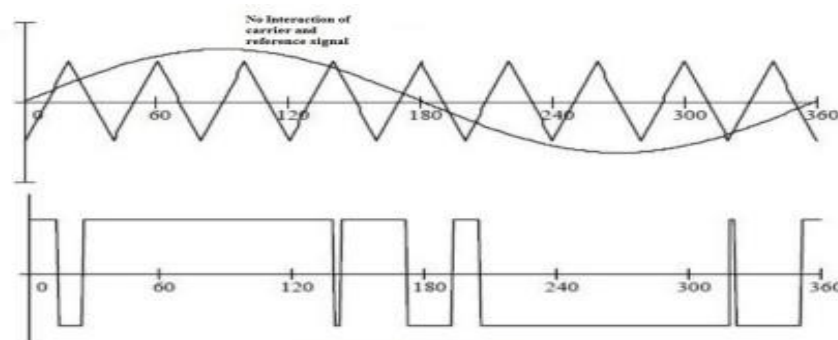


Fig. 4.6 SPWM Comparison Signals

4.3.9 SPWM Harmonic Elimination

In the phase voltage waveform of the SPWM waveform, there are harmonics of various orders; the prominent ones are the fundamental and others of order n and n^2 , where $n = f_c/f_m$. Only chosen harmonics are deleted with the minimum amount of switches when using the Selective Harmonic Elimination technique. SPWM wave with odd and half wave symmetry (Fig.4.8).

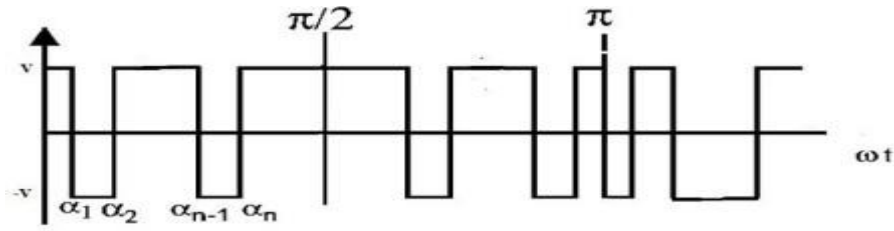


Fig.4.8 SPWM Wave with odd and Half Wave Symmetry

The Fourier coefficients of the waveform seen above may be calculated as follows,

$$h_1 = \left(4 \frac{V}{\pi}\right) [1 - 2 \cos \alpha_1 + 2 \cos \alpha_2 - 2 \cos \alpha_3 + \dots 2 \cos \alpha_n]$$

$$h_3 = \left(4 \frac{V}{3\pi}\right) [1 - 2 \cos 3\alpha_1 + 2 \cos 3\alpha_2 - 2 \cos 3\alpha_3 + \dots 2 \cos 3\alpha_n]$$

$$h_n = \left(4 \frac{V}{n\pi}\right) [1 - 2n \cos \alpha_1 + 2n \cos \alpha_2 - 2n \cos \alpha_3 + \dots 2n \cos \alpha_n]$$

Where h_n represents the magnitude of n th harmonic component and α_n is the primary switching angle, n is the no of chops. Fourier sine and cosine coefficients are,

$$a_o = \frac{1}{2\pi} \int_0^{2\pi} f(\theta) d\theta$$

$$a_k = \frac{1}{\pi} \int_0^{2\pi} f(k\theta) \cos(k\theta) d\theta$$

$$b_k = \frac{1}{\pi} \int_0^{2\pi} f(k\theta) \sin(k\theta) d\theta$$

Only odd no. harmonics exist due to half cycle symmetry of waveform. Using quarter cycle symmetry, the Fourier coefficients become,

$$b_k = 4 \frac{V}{\pi} \left(\int_0^{\alpha_1} \sin(k\theta) d\theta - \int_{\alpha_1}^{\alpha_2} \sin(k\theta) d\theta + \int_{\alpha_2}^{\alpha_3} \sin(k\theta) d\theta - \dots \int_{\frac{\pi}{2}}^{\pi} \sin(k\theta) d\theta \right)$$

$$= 4 \frac{V}{n\pi} [1 - 2 \cos \alpha_1 + 2 \cos \alpha_2 - 2 \cos \alpha_3 \dots 2 \cos k\alpha_n]$$

4.3.9.1 Advantages of SPWM

- Low energy consumption
- High energy efficiency
- High power handling capacity
- There was no drifting or loss in linearity due to temperature variations or ageing
- It's simple to set up and manage
- Today's digital microprocessors are compatible.

4.3.9.2 Disadvantages of SPWM

- Attenuation of the desired fundamental component of the waveform.
- Significantly increased switching frequencies, resulting in increased pressures on related switching devices and, as a result, device de-rating.
- Harmonic component generation at high frequencies.

4.4 Boost Converter

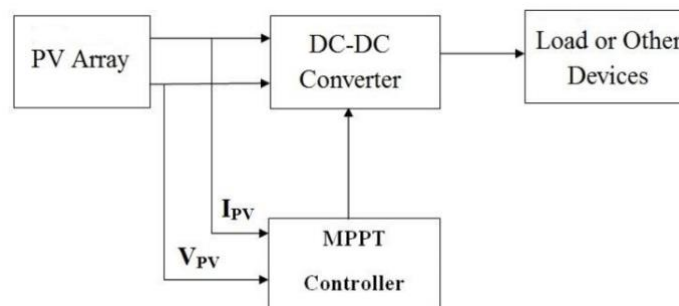


Fig. 4.9 Block Diagram

One of the most basic forms of switch mode converter is the boost converter. The block diagram of a boost converter is shown in Figure 4.9. It takes an input voltage and boosts

or enhances it, as the name implies. All it consists of is an inductor, a semiconductor switch (usually a MOSFET these days because they're so wonderful), a diode, and a capacitor. A source of a periodic square wave is also required. This might be as basic as a 555 timer or as complex as a specialized SMPS IC like the MC34063A.

As you can see, a boost converter is made up of simply a few components. It's not as bulky as an AC transformer or inductor. Figure 4.10 depicts the switch in the off .

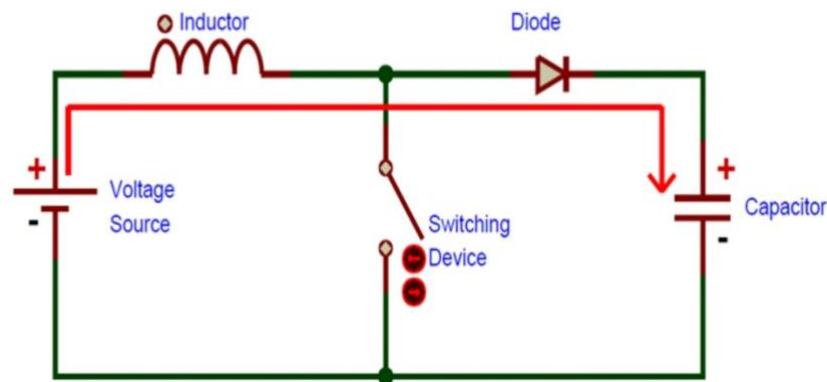


Fig.4. 10 Switch OFF Condition

- It's now time to turn on the device.
- All current is routed via the inductor to the MOSFET when our signal source reaches high, turning on the MOSFET.
- Because the output capacitor cannot discharge via the newly back-biased diode, it remains charged. Of course, the power supply isn't instantaneously short-circuited since the inductor slows the current ramp-up.
- In addition, a magnetic field forms surrounding the inductor. Keep in mind that the voltage applied across the inductor is polarised. Figure 4.11 depicts the switch being turned on.

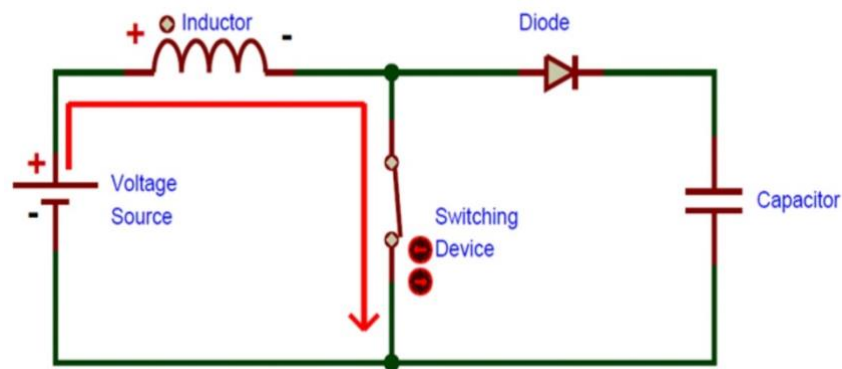


Fig. 4.11 Switch ON Condition

4.4.1 Operation

- The MOSFET is switched off, and the current flowing through the inductor is quickly cut off. An inductor's nature is to keep current flowing smoothly; it doesn't like rapid swings in current.
- As a result, it dislikes when the current is abruptly turned off. To sustain current flow, it generates a huge voltage with the opposite polarity of the voltage initially provided to it, using the energy stored in the magnetic field.
- If we ignore the other components of the circuit and focus just on the polarity symbols, we can see that the inductor now operates as a voltage source in series with the supply voltage.
- The output capacitor is now charged to a greater voltage than before, indicating that the anode of the diode is now at a higher voltage than the cathode (remember, the cap was previously charged to supply voltage in the beginning) and is forward biased.

4.4.2 Applications of Boost converter

- It's a component of self-regulating power supply.
- It's stocked with consumer gadgets.
- It's a component of battery-powered systems.
- Applications that use adaptive control.

- Applications using power amplifiers.

4.5 Neuro-Fuzzy Controller

4.5.1 Neuro Fuzzy

Neuro-fuzzy is a term used in artificial intelligence to describe the combination of artificial neural networks with fuzzy logic.

By merging the human-like reasoning style of fuzzy systems with the learning and connectionist structure of neural networks, neuro-fuzzy hybridization produces a hybrid intelligent system. In the literature, neuro-fuzzy hybridization is referred to as a fuzzy neural network (FNN) or a neuro-fuzzy system (NFS). Through the use of fuzzy sets and a language model consisting of a set of IF-THEN fuzzy rules, a neuro-fuzzy system (the more popular name) includes the human-like reasoning style of fuzzy systems. The fundamental advantage of neuro-fuzzy systems is that they are universal approximators capable of generating IF-THEN rules.

The strength of neuro-fuzzy systems is based on a conflict between two fuzzy modelling requirements: interpretability and accuracy. In practise, one of the two traits is more important than the other. The discipline of neuro-fuzzy fuzzy modelling research is separated into two areas: linguistic fuzzy modelling, which focuses on interpretability and uses the Mamdani model; and precise fuzzy modelling, which uses the Takagi-Sugeno-Kang (TSK) model.

A neuro-fuzzy system is a fuzzy system that determines its parameters (fuzzy sets and fuzzy rules) by processing data samples using a learning algorithm developed from or influenced by neural network theory.

- A neuro-fuzzy system is a three-layer feed-forward neural network. Input variables are represented by the first layer, fuzzy rules are represented by the middle (hidden) layer, and output variables are represented by the third layer.
- Connection weights are used to encode fuzzy sets. To apply a learning method to a fuzzy system like this, it is not essential to describe it. However, because it depicts the data flow of input processing and learning within the model, it might be useful.

- A 5-layer design is sometimes utilised, with fuzzy sets represented in the second and fourth layer units. A neuro-fuzzy system can be always (i.e. before, during and after learning) interpreted as a system of fuzzy rules. It is also possible to create the system out of training data from scratch, as it is possible to initialize it by prior knowledge in form of fuzzy rules.
- neuro-fuzzy system's learning technique takes into consideration the semantic features of the underlying fuzzy system; however, not all neuro-fuzzy models provide learning procedures for fuzzy rule construction. As a result, the types of changes that may be made to the system settings are limited.
- This trait isn't shared by all neuro-fuzzy techniques.
- A neuro-fuzzy system approximates a n -dimensional (unknown) function specified in part by training data. The fuzzy rules embedded inside the system are only prototypes of the training data, and have nothing to do with fuzzy logic in the strict sense..

The Firefly Algorithm is utilised to optimise the neuro-fuzzy controller's if-then rules, and the entire system is simulated using Matlab / Simulink. The firefly algorithm is used to optimise the Neuro-Fuzzy controller rules.

4.5.2 FireFly Algorithm

The "firefly algorithm" (FFA) is a recent metaheuristic algorithm based on firefly behaviour. Many continuous optimization problems have been successfully solved using this approach and its modifications. The FFA's performance in tackling combinatorial optimization issues is investigated in this paper. The original FFA is expanded and modified for self-adaptation of control settings, and therefore more directly balancing exploration and exploitation in the search process of firefly, in order to improve the outcomes. To strengthen selection pressure, we utilise a novel population model in which the following generation picks only the fittest between a parent and offspring population. The landscape of the goal function influences or determines the brightness of a firefly. The brightness of a maximisation problem can simply be proportional to the objective function's value. Other types of brightness can be established in a similar fashion to how genetic algorithms define the fitness function.

The firefly algorithm is based on three major assumptions:

1. A firefly is attracted to all other fireflies regardless of sex.

2. A firefly with a lower brightness is drawn to a firefly with a higher brightness. If there isn't anything brighter or more interesting, If there is a more appealing firefly than a certain one, it will travel at random.

3. The landscape of fitness functions is affected by light intensity.

The equation may be used to assess the attractiveness of a fire fly.

$$\beta = \beta_{0e} - \gamma r^n$$

where β_0 is the attractiveness at $r = 0$

γ is the coefficient of absorption

It is calculated the Cartesian distance between any two firefly i and j at coordinates x_i and x_j .

$$r_{ij} = \sqrt{\sum_{k=1}^d (x_{i,k} - x_{j,k})^2}$$

The movement of a firefly is determined,

$$x_i = x_i + \beta_0 e^{-\gamma r^2} (x_j - x_i) + \alpha \epsilon$$

where α is the parameter of randomization and ϵ is a random number

4.5.2.1 Algorithm

1. Define the goal function.
2. Make a starting population
3. Determine the light intensity l_i
4. Decide on an absorption coefficient.
5. from 1 to n for $i = 1$ to n (where n is the total number of fireflies)
6. from 1 to n for $j = 1$ to n
7. If l_j is bigger than l_i , shift the i th firefly to the j th firefly.
8. Update the light intensity by analysing fresh values.
9. Finish the j loop
10. Bring the loop to a close.
11. Sort the firefly and choose the best one.

12. Repeat steps 3–12 until all iterations have been completed.

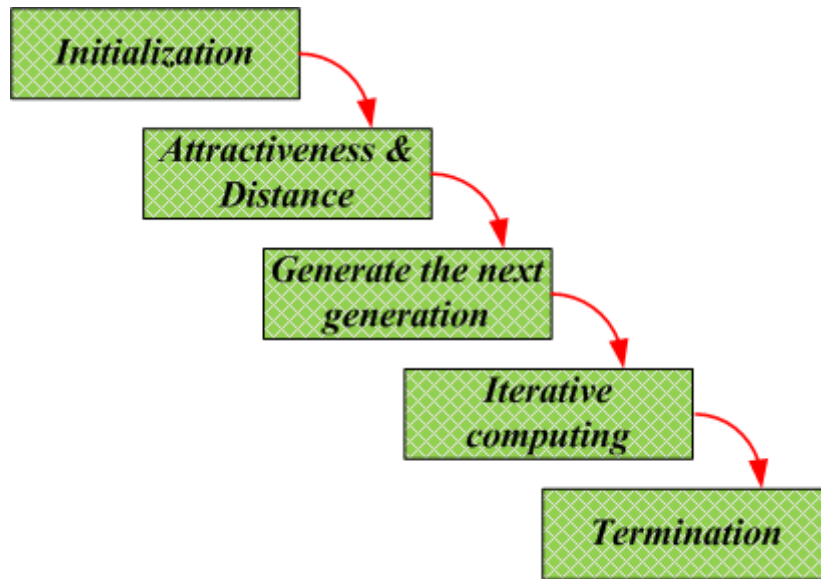


Fig. 4.12 Firefly Algorithm Flowchart

4.5.2.2 Pseudo Code

Begin

1. Initialisation max iteration
2. Generate initial population
3. Define the Objective function $f(x)$,
4. Determine Intensity(I) at cost(x) of each individual by $f(x_i)$
5. While($t < \text{Iter max}$)
 - For $i=1$ to n
 - For $j=1$ to n
 - if($I_j > I_i$)
 - Move firefly i towards j in K dimension
 - endif
 - Evaluate new solutions and update light intensity
 - end for j
 - end for i
 - Rank the fireflies and find the current best
- end while
6. Post process results and visualization

End procedure

4.5.2.3 FireFly Algorithm Code

```
function bestfis=FireFlyFCN(fis,data)
% Variables
p0=GettingFuzzyParameters(fis);
Problem.CostFunction=@(x) FuzzyCost(x,fis,data);
Problem.nVar=numel(p0);
alpha=1;
Problem.VarMin=-(10^alpha);
Problem.VarMax=10^alpha;
%
% FireFly Parameters
Params.MaxIt=10;
Params.nPop=6;
%
% Starting FireFly Algorithm
results=Runfly(Problem,Params);
%
% Getting the Results
p=results.BestSol.Position.*p0;
bestfis=FuzzyParameters(fis,p);
end
%%
function results=Runfly(Problem,Params)
% disp('Starting FireFly Training');
%
% Cost Function
CostFunction=Problem.CostFunction;
% Number of Decision Variables
nVar=Problem.nVar;
% Size of Decision Variables Matrixv
VarSize=[1 nVar];
% Lower Bound of Variables
```

```

VarMin=Problem.VarMin;
% Upper Bound of Variables
VarMax=Problem.VarMax;
% Some Change
if isscalar(VarMin) && isscalar(VarMax)
dmax = (VarMax-VarMin)*sqrt(nVar);
else
dmax = norm(VarMax-VarMin);
end
%
%% FireFly Algorithm Parameters
% Maximum Number of Iterations
MaxIt=Params.MaxIt;
% Number of Fireflies (Swarm Size)
nPop=Params.nPop;
% Light Absorption Coefficient
gamma = 1;
% Attraction Coefficient Base Value
beta0 = 2;
% Mutation Coefficient
alpha = 0.2;
% Mutation Coefficient Damping Ratio
alpha_damp = 0.98;
% Uniform Mutation Range
delta = 0.05*(VarMax-VarMin);
m = 2;
%
% Second Stage
% Empty Firefly Structure
empty_firefly.Position = [];
empty_firefly.Cost = [];
% Initialize Population Array
pop = repmat(empty_firefly, nPop, 1);
% Initialize Best Solution Ever Found

```

```

BestSol.Cost = inf;
% Create Initial Fireflies
for i = 1:nPop
    pop(i).Position = unifrnd(VarMin, VarMax, VarSize);
    pop(i).Cost = CostFunction(pop(i).Position);
    if pop(i).Cost <= BestSol.Cost
        BestSol = pop(i);
    end
end
% Array to Hold Best Cost Values
BestCost = zeros(MaxIt, 1);
%
%% Firefly Algorithm Main Body
%
for it = 1:MaxIt
    newpop = repmat(empty_firefly, nPop, 1);
    for i = 1:nPop
        newpop(i).Cost = inf;
        for j = 1:nPop
            if pop(j).Cost < pop(i).Cost
                rij = norm(pop(i).Position-pop(j).Position)/dmax;
                beta = beta0*exp(-gamma*rij^m);
                e = delta*unifrnd(-1, +1, VarSize);
                newsol.Position = pop(i).Position ...
                + beta*rand(VarSize).*(pop(j).Position-pop(i).Position) ...
                + alpha*e;
                newsol.Position = max(newsol.Position, VarMin);
                newsol.Position = min(newsol.Position, VarMax);
                newsol.Cost = CostFunction(newsol.Position);
                if newsol.Cost <= newpop(i).Cost
                    newpop(i) = newsol;
                end
            end
            if newpop(i).Cost <= BestSol.Cost
                BestSol = newpop(i);
            end
        end
    end
end

```

```

end
end
end
end
% Merge Operation
pop = [pop
newpop];
% Sort Operation
[~, SortOrder] = sort([pop.Cost]);
pop = pop(SortOrder);
% Truncate Operation
pop = pop(1:nPop);
% Store Best Cost Ever Found
BestCost(it) = BestSol.Cost;
% Show Iteration Information
disp(['In Iteration ' num2str(it) ' : BBO-FireFly Fittest Cost Is = '
num2str(BestCost(it))]);
% Damp Mutation Coefficient
alpha = alpha*alpha_damp;
end
disp('BBO-FireFly Algorithm Came To End');
% Store Res
results.BestSol=BestSol;
results.BestCost=BestCost;
% Plot FireFly Training Stages
figure;
set(gcf, 'Position', [600, 300, 500, 300])
plot(BestCost, '-', ...
'LineWidth', 2, ...
'MarkerSize', 3, ...
'MarkerEdgeColor', 'k', ...
'Color', [0.1, 0.1, 0.1]);
title('FireFly Algorithm Training', 'FontSize', 10, ...
'FontWeight', 'bold', 'Color', 'b');

```

```

xlabel('FireFly Iteration Number','FontSize',10,...
'FontWeight','bold','Color','k');
ylabel('FireFly Best Cost Result','FontSize',10,...
'FontWeight','bold','Color','k');
legend({'FireFly Algorithm Train'});
end

```

4.6 Conventional Cascaded H-Bridge

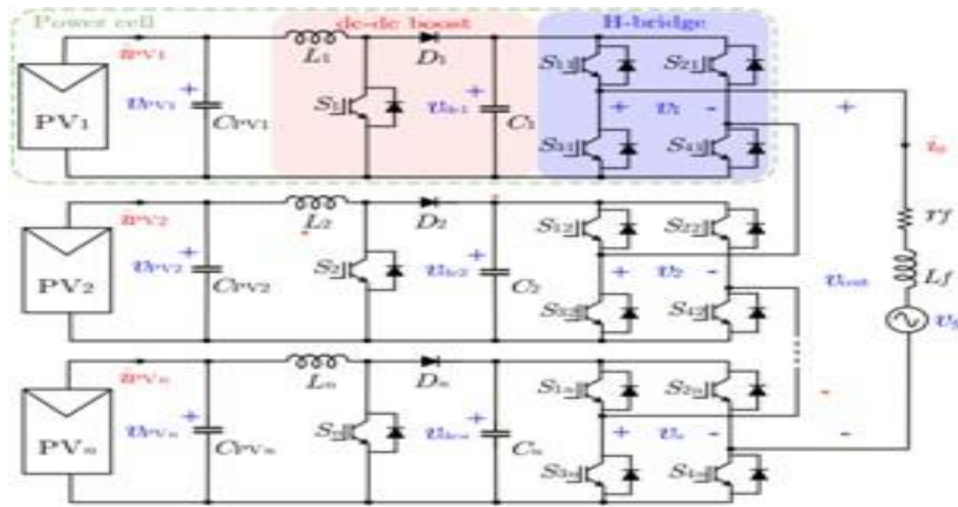


Fig. 4.13 The classical dc-dc boost + H-bridge based power cell MLC(CHB)

Figure 4.13 illustrates an MLC based on a standard dc-dc boost + H-bridge power cell (CHB). The basic operation concept is variable switching angles, and this method provides a low-cost solution; nevertheless, it is only applicable when $n=3$ owing to the extensive calculation required. Furthermore, altering the carrier shift angles does not enhance the output signal quality to an acceptable level with severe partial shadings. In the case of $n=2$, an additional battery-fed power cell is used to solve the problem. Each power cell contains a dc-dc boost converter, with a modified modulation approach proposed to keep the energy among the dc-link capacitors at a same level, allowing all the cells to operate at similar duty cycles. components especially inductors in the power cells, and in some cases, higher switching frequency is required, which not only increases the size, weight, and cost of the converter, but also degrades the system's overall efficiency.

4.6.1 Analysis of Partial Shading in the Conventional CHB Topology

Fourier expansion is one of the most basic and accurate signal processing techniques, and it will be utilised in this research to assess the quality of the converters' output signals. Any periodic function $f(t)$ may be written as a dc-offset plus a sum of sines and cosines as follows, according to the Fourier hypothesis.

The coefficient a_h and b_h are defined as,

$$a_h = \frac{1}{\pi} \int_0^{2\pi} f(t) \cos(h\omega t) d(h\omega t)$$

$$b_h = \frac{1}{\pi} \int_0^{2\pi} f(t) \sin(h\omega t) d(h\omega t)$$

The output voltage of the converter, which is the total of all power cell voltages, is the function to be examined in this study. The output voltage of the i th power cell is modelled as a square pulse train with a variable duty cycle, which can be written as,

$$v_i(t) = v_{dci} D_i, \text{ where } i = 1, \dots, n$$

The duty cycle and voltage of the i th power cell are, respectively, D_i and v_{dci} . The output voltage of each power cell may therefore be represented using the Fourier expansion as follows: such the i th power cell.

The solution can be simplified by nulling $v(i)$ on the assumption that the time origin is chosen in a way the function $v_i(t)$ shows an even symmetry. In this way, Fourier coefficients can be found as,

$$c_{hi} = \frac{1}{\pi} \int_0^{D_i\pi} v_i(t) d(\omega_c t) = v_{dci} D_i$$

$$a_{hi} = \frac{2}{\pi} \int_0^{D_i\pi} v_i(t) \cos(h\omega_c t) d(\omega_c t) = \frac{2v_{dci}}{h\pi} \sin(h\pi D_i)$$

In Fourier expansion form, the output voltage of the i th power cell may be represented as,

$$v_i(t) = v_{dci}D_i + \sum_{h=1}^{\infty} \frac{2v_{dci}}{h\pi} \sin(h\pi D_i) \cos(h\omega_c t)$$

Thus, the total o/p voltage can be written as,

$$v_{out}(t) = \sum_{i=1}^n \left(v_{dci}D_i + \sum_{h=1}^{\infty} \frac{2v_{dci}}{h\pi} \sin(h\pi D_i) \cos(h\omega_c t + \theta_i) \right)$$

where i is the i th carrier shift angle, which can be analysed as,

$$\theta_i = \frac{2\pi}{n}(i-1)$$

from the below equation, the h th harmonic content of the total o/p voltage can be written as,

$$v^h = \sum_{i=1}^n \frac{2v_{dci}}{h\pi} \sin(h\pi D_i) \cos(h\omega_c t + \theta_i)$$

If suppose converter have three power cells, the h th harmonic content is shown below,

$$\begin{aligned} v^h &= \frac{2v_{dc1}}{h\pi} \sin(h\pi D_1) \cos(h\omega_c t) \\ &+ \frac{2v_{dc2}}{h\pi} \sin(h\pi D_2) \cos\left(h\omega_c t + \frac{2\pi}{3}\right) \\ &+ \frac{2v_{dc3}}{h\pi} \sin(h\pi D_3) \cos\left(h\omega_c t + \frac{4\pi}{3}\right) \end{aligned}$$

The dc-link voltages, as well as the duty cycles, must be identical in order to eliminate the h th harmonic content in the overall output voltage. In the event of partial shading, the control would lower the duty cycle of the shaded power cell to limit its current to a lower level based on the severity of the partial shading. To better understand the mathematical derivations, an exemplary example has been performed and is shown in this paper. Its

duty cycle drops, leading the cell to begin injecting power with a delay TD relative to the expected time, and to cease injecting power before the expected time by a TD.

4.7 Maximum Power Point Tracking (MPPT)

MPPT is a method that allows solar panels to produce more power by altering the operation state of the electrical module. The solar cell panel's DC electrical system may be efficiently emitted and stored in a battery, successfully solving home and industrial electricity consumption in distant places and tourist destinations that are not served by traditional power lines without polluting the environment.

The MPPT controller can monitor the voltage generated by the solar panel in real time and track the maximum voltage and current values, allowing the system to charge the battery with the highest possible power output. It is the brain of solar photovoltaic systems, coordinating the activity of solar panels, batteries, and loads.

4.7.1 Role of the MPPT

The job of MPPT may be summarised in one sentence: the photovoltaic cell's output power is proportional to the MPPT controller's operating voltage, and its output power will have a unique maximum value only when it operates at the most appropriate voltage.

The output power of solar cells is modified as a result of external factors such as light intensity and the surroundings, and the electric light intensity radiated by the more with MPPT. The purpose of an MPPT inverter is to make full use of the solar energy battery by allowing it to run at maximum power. That is, given the same conditions as before MPPT, the output power after MPPT will be higher than before MPPT.

4.7.2 Principles of MPPT

A DC/DC converter circuit is usually used to complete MPPT control. Through a DC/DC circuit, the solar cell array is linked to the load. The maximum power tracking device continually monitors the solar array's current and voltage fluctuations, and the DC/DC converter is adjusted accordingly. The PWM driving signal's duty cycle is changed.

When the load resistance equals the internal resistance of the power supply in linear circuits, the power supply has the maximum power output. Despite the fact that

solar cells and DC/DC converter circuits are significantly nonlinear, they can be called linear circuits for a short period of time. As a result, as long as the DC-DC conversion circuit's equivalent resistance is tuned to be constant.

4.7.3 What is Maximum Power Point Tracking?

Panel tracking occurs when the panels are mounted on a mount that moves with the sun. The Zomeworks are the most prevalent. These maximise production by tracking the sun as it moves across the sky. These normally provide a 15% boost in the winter and up to a 35% increase in the summer.

For MPPT controllers, this is the polar opposite of seasonal fluctuation. Because the temperature of the panels is lower in the winter, they produce more electricity. Due to the shorter days, winter is generally when you require the most electricity from your solar panels.

As the price of solar reduces and utility prices rise, grid tie solutions are becoming increasingly popular. Grid-tie only (no battery) inverters are offered from a number of manufacturers. MPPT is included in each of these. On them, the MPPT conversion efficiency ranges from 94 percent to 97 percent.

Maximum Power Point Technology (MPPT) is a term that refers to the use of Any solar-powered satellite must be capable of tracking. We all know that power equals voltage times current, so increasing voltage or current, or both, makes sense if you want greater power. In the case of solar panels, however, if you use more current or voltage past a certain threshold, the maximum output power will decrease.

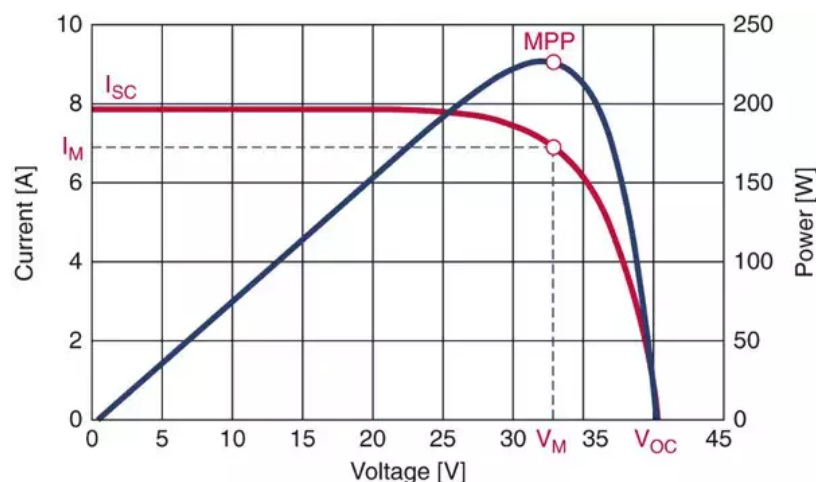


Fig. 4.14 Maximum Power Point

As can be observed from the maximum power point in Fig.4.14, when this system draws more than roughly 33V at 7A, the net power production begins to decrease.

MPP of a solar panel may be determined on the ground, and the system can be optimised to draw the most electricity. The difficulty is that the MPP is highly dependent on the panel's temperature, which becomes a big issue in the vacuum of space, where temperature differentials between shade and sun might be as high as 300°.

Enter MPPT, or the ability to know exactly where the maximum power point is and alter the system accordingly, ensuring that we squeeze every last watt of electricity from the panels.

4.7.4 Different Techniques for MPPT

- Fixed Voltage
- Fractional Open Circuit method
- Perturb and Observe technique (P&O)
- Incremental Conductance (INC)

Among these techniques for MPPT we are using Perturb and Observe technique (P&O) in our project.

4.7.5 Perturb and Observe (P&O) Method

P&O is one of the most widely utilised MPP tracking methods. The reference voltage or current of PV systems is altered in this technique.

The method's purpose is to force the PV system to function at V_{mpp} , causing the PV voltage to track V_{mpp} at all times. The PV voltage is perturbed in modest, consistent increments to achieve this.

The fluctuation in output power (dP) is monitored after each disturbance. If the dP is positive, the output power will approach MPP. As a result, in the following step, a positive perturbation is applied to the voltage. If dP is negative, however, a negative perturbation is applied.

These stages are continued until the system's MPP is attained, at which point dP equals zero. The P&O flowchart is shown in Figure 4.15.

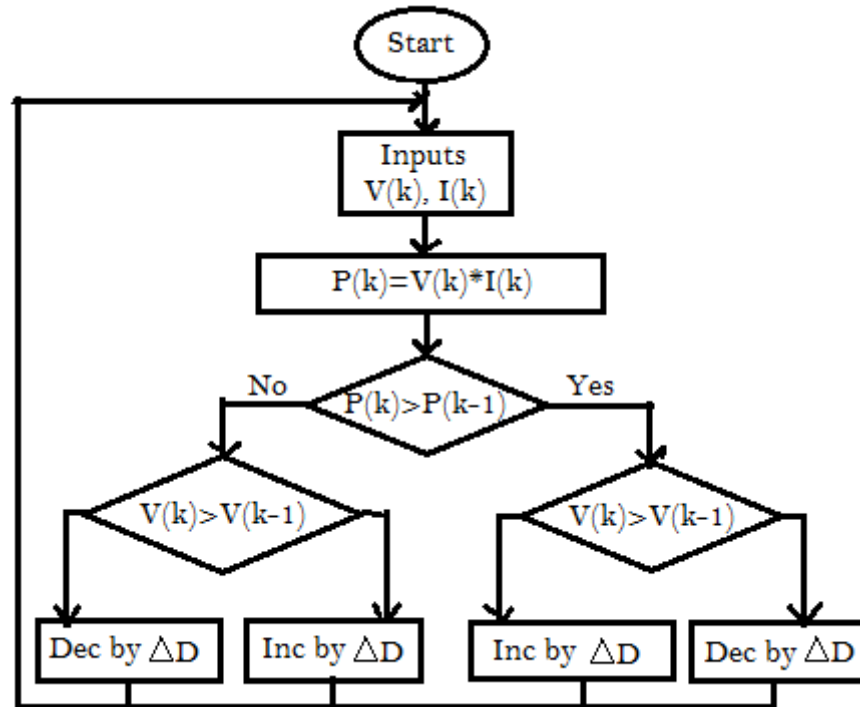


Fig. 4.15 P&O Flowchart

4.7.5.1 Advantages

- The algorithm is simple to implement with processors (digital implementation using microcontrollers or DSP)
- The MPP calculated by the algorithm is nearly equal to the true MPP (theoretically calculated)
- The speed of the MPP determination can be easily controlled by adjusting the perturbation value

4.7.5.2 Disadvantages

- It's tough to figure out what the appropriate perturbation value is. To estimate the perturbation value, a careful trade-off between algorithm speed and accuracy should be made.
- When the irradiation and/or cell temperature change, the P&O algorithm's inaccuracy increases.

4.8 Introduction to Matlab



Fig. 4.16 Matlab

Matlab comes with a sophisticated programming language, fantastic visuals, and a wealth of professional information. The MathWorks, Inc. publishes and trademarks MATLAB. MATLAB is a programming language that focuses on computing rather than mathematics: symbolic expressions and manipulations are not supported (except through the optional Symbolic Toolbox, a clever interface to maple). Because of the rounding mistakes inherent in computer arithmetic, all of the findings are not just numerical but also inexact. The lack of numerical calculation might be considered as a disadvantage, but it can also be seen as a strength: when it comes to numerics, MATLAB is far superior to Maple, Mathematical, and other similar programmes.

MATLAB, on the other hand, is more easier to use and comes with a large standard library when compared to other numerically oriented languages like C++ and FORTRAN. The negative contrast here is a speed difference in execution. This chasm isn't necessarily as wide as folklore suggests, and it may often be bridged or closed with competent MATLAB programming. Furthermore, additional scripts may be linked into MATLAB and vice versa, and MATLAB now supports parallel computation as an option. However, when it comes to high-performance computing, MATLAB is rarely the tool of choice.

Numerical computing on workstations for non-experts is a MATLAB specialty. This is a large niche, as seen by the amount of MATLAB-related books available on mathworks.com. Even for supercomputer users, MATLAB can be a useful tool for exploring and fine-tuning algorithms before committing to more time-consuming coding in another language.

4.8.1 Introduction

MATLAB instructions written at the prompt, `>>`, can be entered here. MATLAB is an interpreted environment, unlike FORTRAN and other compiled computer languages. You provide a command, and MATLAB tries to run it straight away before asking for another.

The Current Directory may be seen in the upper left corner. MATLAB is generally only aware of files in the current directory (folder) and their paths, which can be changed. `cd`, `what`, `add path`, and `edit path` (or choose "File/Set path... " from the menus) are commands for working with the directory and path. You may add commands to MATLAB by adding files to a directory on the path.

The Workspace tab is located next to the Current Directory tab. The workspace displays the current variable names as well as some information about their contents. Another difference from compiled environments is that variables generated in the workspace remain available for you to study and alter even after code execution has ended. The Command History window is located beneath the Command Window/Workspace window. This is where you'll keep track of your commands as you type them in. This record is persistent over MATLAB sessions, and commands or groups of commands can be copied or saved to files from here.

4.8.2 Graphical versus command-line usage

MATLAB was designed from the ground up to be a command-line environment, and it still is. However, graphical interfaces—menus, buttons, and so on—can now access a large portion of the capability. These interfaces are very helpful for newcomers since they clearly lay out the options accessible. In general, graphical interfaces are more natural for some sorts of interactive work, such as annotating a graph or debugging a programme, but written instructions are preferable for sophisticated, precise, repetitious, or repeatable operations. However, one does not always have to make a decision; for example, by pointing and clicking, one may store a figure's styles as a template that can be used with alternative data.

4.8.3 What is Simulink?

Mathworks Inc.'s Simulink (Simulation and Link) is a MATLAB extension. It integrates with MATLAB to provide graphical user interface (GUI) modelling, simulation, and analysis of dynamical systems. The building of a model is made easier by using mouse click-and-drag actions. Simulink comes with a large collection of toolboxes for both linear and nonlinear analysis. Models are hierarchical, allowing top-down and bottom-up techniques to be used. Because Simulink is a component of MATLAB, it is simple to switch back and forth during the analysis process, allowing the user to take full advantage of both environments' features.

CHAPTER 5

RESULT AND PERFORMANCE ANALYSIS

A simulation circuit was developed and produced in MATLAB simulink software version 2017 to empirically validate the idea. PV strings with a voltage range of 120 to 190V are supplied into the proposed inverter, which is paralleled to 2mF capacitors in each cell. The PV panel specifications were derived from a datasheet of an actual one made by Alfasolar GmbH, model SI S21-170.A1. Under typical test settings, these PV panels have the following specifications: $v_{OC}=96V$, $v_{MPP}=76V$, $i_{SC}=2.83A$, and $i_{MPP}=2.2A$. (STC). Two PV panels of those were simulated to be linked in series in each cell, where the cells count is three, in order to achieve the requisite voltage level acquiescing to grid connection.

System specifications: To validate the idea experimentally, it was designed and simulated in detail as a 1-kW single-phase inverter in MATLAB simulink. According to local standards, the grid fundamental magnitude and angular frequency have been set at 2230V and 50Hz, respectively. In all converters under test, the H-bridge switching frequency has been set at 2kHz. The inductance for the output filter has been set at 3.5mH. The MPPTs were the traditional Perturb and Observe (P&O) kind, with voltage increase and frequency set at 0.5V and 10Hz, respectively.

Phases of testing: The planned converter was put to the test at three different times. The system runs on the STC until the MPPTs stabilise, at which point the switches S5i and S6i are turned on at the same time to replicate the functioning of the CHB. By the end of this phase, the converter has seen a rapid reduction in solar irradiance in the third cell by 50% for 1.5s, which is considered a second time interval. The switches S5i and S6i were still switched on simultaneously throughout the second time interval, simulating the operation of the CHB. Because they are consistent with the first power cell, the power lines in cells one and two are not evident. The voltage and current distortions in the two harmonic spectrums are due to high order harmonics at the switching frequency and its multiples ($2f_{sw}$). There are grid rules and standards that must be followed in order to inject electricity into the grid, which might be on the converter's output current, voltage, or both. Total harmonic distortion (THD) was determined for both converter output voltages and currents up to the 30th, 50th, and 100th harmonic orders, taking into account the three test time intervals, i.e. balanced CHB, unbalanced CHB, and unbalanced cascaded H6. The darkened cell

grew over this cycle, eventually reaching approximately unity after 0.2s. The higher duty cycle is due to the fact that the cell's instantaneous supplied power has been cut in half since the voltage visible at the converter's output has been cut in half.

5.1 Existing System

5.1.1 Existing MLI Topologies with Reduced Switch/es

5.1.1.1 Topology 1

To achieve stair case output voltage, numerous half-h-bridges are linked in series to the H-bridge in this topology. The half h-bridge is made up of two switches that must be switched on simultaneously. This architecture employs ten switches and three DC sources at the input for seven level MLI. The topology1 circuit diagram is shown in Fig.5.1. The topology1 switching technique is shown in Table 5.1.

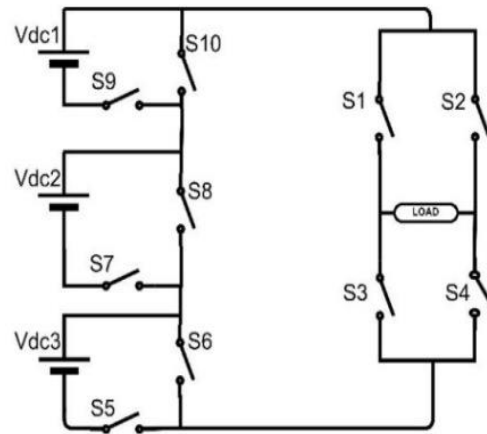


Fig. 5.1 Topology 1 Circuit Diagram

Table 5.1 Topology 1 Switching Pattern

S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Output Level
ON	OFF	OFF	ON	OFF	ON	OFF	ON	ON	OFF	V_{dc1}
ON	OFF	OFF	ON	OFF	ON	ON	OFF	ON	OFF	$V_{dc1} + V_{dc2}$
ON	OFF	OFF	ON	ON	OFF	ON	OFF	ON	OFF	$V_{dc1} + V_{dc2} + V_{dc3}$
OFF	OFF	OFF	OFF	OFF	ON	OFF	ON	OFF	ON	0
OFF	ON	ON	OFF	OFF	ON	OFF	ON	ON	OFF	$-V_{dc1}$
OFF	ON	ON	OFF	OFF	ON	ON	OFF	ON	OFF	$-(V_{dc1} + V_{dc2})$
OFF	ON	ON	OFF	ON	OFF	ON	OFF	ON	OFF	$-(V_{dc1} + V_{dc2} + V_{dc3})$

5.1.1.2 Topology 2

Depending on the switching mechanism of the switches, this MLI architecture with decreased yields four distinct levels. On the input side, it has nine switches and three DC sources. The topology2 circuit diagram is shown in Fig.5.2. Topology2 Switching Pattern (Table.5.2).

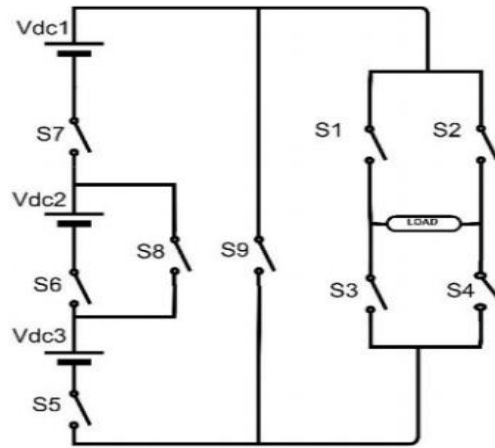


Fig. 5.2 Topology 2 Circuit Diagram

The basic device, which consists of two switches and one DC source, may be coupled in series to increase the number of output voltage levels. These units can be joined in series for higher output levels. In this method, output levels may be increased while using fewer switches.

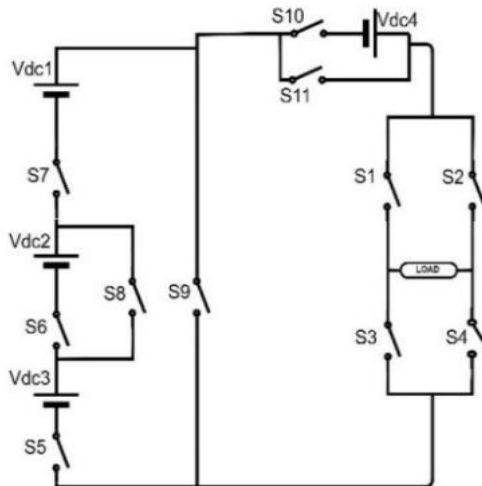


Fig. 5.3 Topology 2 Extension

Table 5.2 Topology 2 Switching scheme

S1	S2	S3	S4	S5	S6	S7	S8	S9	Output Level
ON	OFF	OFF	ON	ON	OFF	ON	ON	OFF	$V_{dc1} + V_{dc2}$
ON	OFF	OFF	ON	ON	ON	ON	OFF	OFF	$V_{dc1} + V_{dc2} + V_{dc3}$
OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	0
OFF	ON	ON	OFF	ON	OFF	ON	ON	OFF	$-(V_{dc1} + V_{dc2})$
OFF	ON	ON	OFF	ON	ON	ON	OFF	OFF	$-(V_{dc1} + V_{dc2} + V_{dc3})$

5.1.1.3 Topology 3

This is the most recent existing topology, which has nine switches and three DC sources for seven levels, and the suggested topology's results will be compared to it.

For the 7-level output voltage, this configuration uses five switches, three DC voltage sources, and one H-bridge, for a total of nine switches and three DC voltage sources. The H-bridge is used to reverse polarity, and this topology produces three positives, three negatives, and one ground. The topology3 circuit diagram is shown in Fig.5.4. The topology3 switching pattern is shown in Table 5.3.

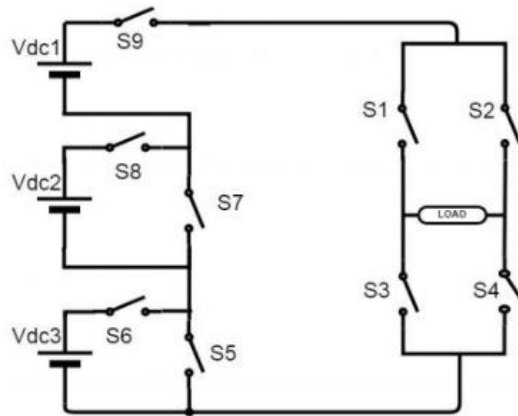


Fig. 5.4 Topology 3 Circuit Diagram

Table 5.3 Topology 3 Switching Scheme

S1	S2	S3	S4	S5	S6	S7	S8	S9	Output Level
ON	OFF	OFF	ON	ON	OFF	ON	OFF	ON	V _{dc1}
ON	OFF	OFF	ON	ON	OFF	OFF	ON	ON	V _{dc1} +V _{dc2}
ON	OFF	OFF	ON	OFF	ON	OFF	ON	ON	V _{dc1} +V _{dc2} +V _{dc3}
OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	0
OFF	ON	ON	OFF	ON	OFF	ON	OFF	ON	-V _{dc1}
OFF	ON	ON	OFF	ON	OFF	OFF	ON	ON	-V _{dc1} -V _{dc2}
OFF	ON	ON	OFF	OFF	ON	OFF	ON	ON	- V _{dc1} -V _{dc2} -V _{dc3}

5.1.1.3.1 Existing Topology Analysis

9 switches – 3 DC source – 7 level

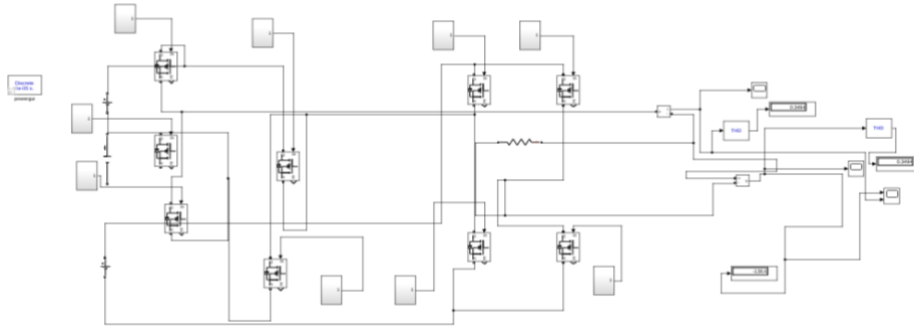


Fig. 5.5 Simulink model

Efficiency Calculation,

$$\begin{aligned}
 \eta &= P_{\text{out}} / P_{\text{in}} \\
 &= (V_{\text{out}} * I_{\text{out}} / V_{\text{in}} * I_{\text{in}}) * 100 \\
 &= (430 * 4.5 / 400 * 9) * 100 \\
 &= 50 \%
 \end{aligned}$$

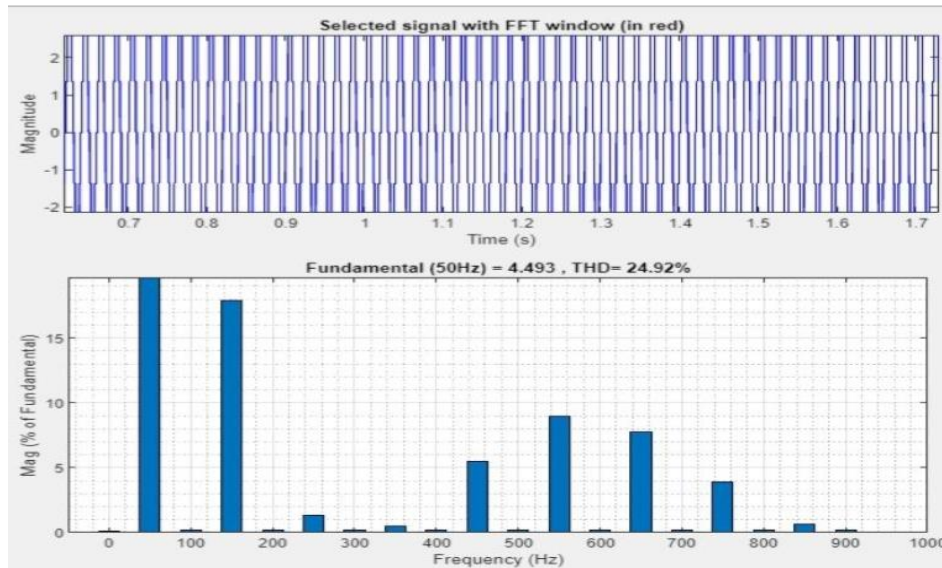


Fig. 5.6 Topology 3 – 7 level THD output

THD=24.92%

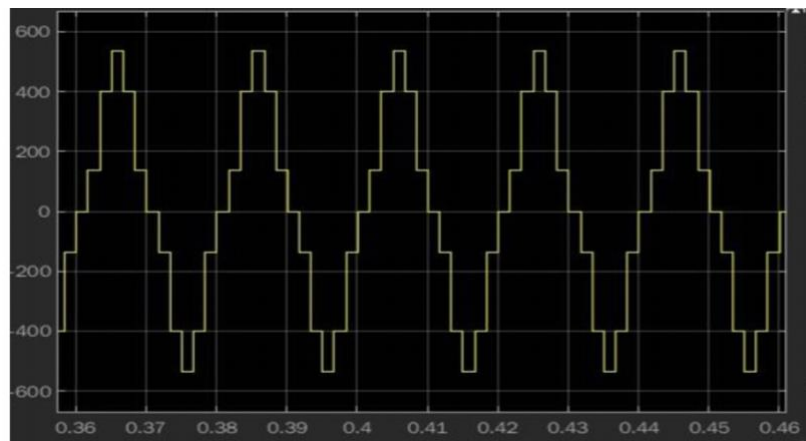


Fig. 5.7 7 level Simulink output

5.1.2 Limitations of Existing Systems

- More no. of switches and dc sources are required
- Switching scheme is complex
- Less efficiency
- High THD
- High cost

5.2 Proposed System

The proposed topology overcome all the drawbacks of the existing topology.

It has 8 switches and uses 2 DC source for 9 level.

The findings were compared using MATLAB / Simulink for the validation of this structure. The Circuit Diagram of the Proposed Topology is shown in Figure 5.8. The suggested system's simulink model is shown in Figure 5.9.

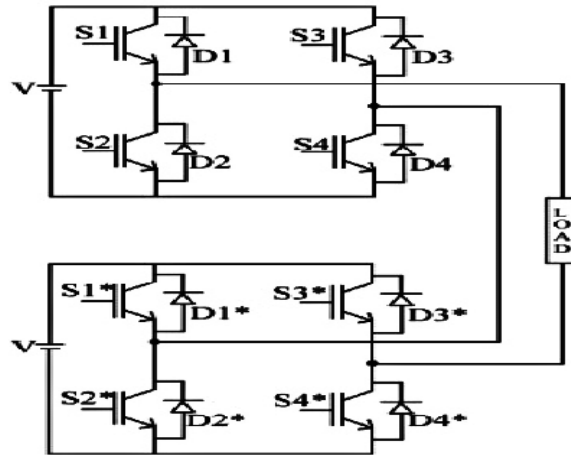


Fig. 5.8 Circuit Diagram of Proposed Topology

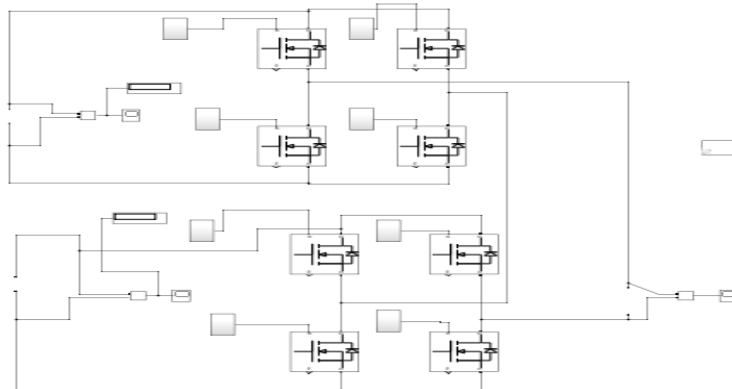


Fig. 5.9 Simulink Model

Efficiency Calculation :

$$\begin{aligned}\eta &= P_{\text{out}} / P_{\text{in}} \\ &= (V_{\text{out}} * I_{\text{out}} / V_{\text{in}} * I_{\text{in}}) * 100 \\ &= (530 * 1.7 / 500 * 27) * 100\end{aligned}$$

= 64 %

Table 5.4 9 level Switching Scheme

VOLTAGES	0	1	2	3	4	3	2	1	0	-1	-2	-3	-4	-3	-2	-1	0
s1	1	1	0	0	1	0	1	1	0	0	1	0	0	0	1	0	1
s2	1	1	0	0	0	0	1	0	1	1	0	1	0	0	0	1	1
s3	0	1	1	0	1	1	0	0	1	0	0	1	1	1	0	1	0
s4	0	1	0	1	1	1	0	1	0	0	1	1	0	1	1	0	0
s5	1	0	1	1	1	1	1	0	1	0	0	0	0	0	0	0	1
s6	1	0	0	0	0	0	0	0	1	0	1	1	1	1	1	0	1
s7	1	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	0
s8	0	1	1	1	1	1	1	1	0	1	0	0	0	0	0	1	0
MODES	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

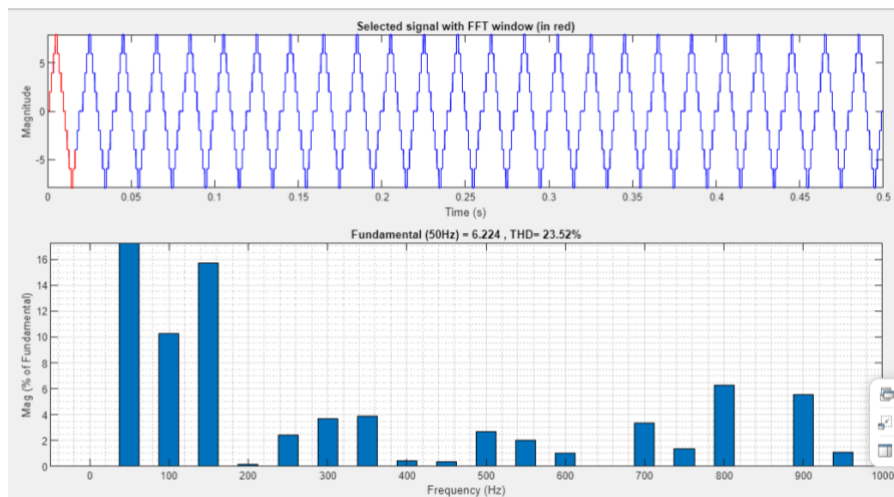


Fig. 5.10 9 level THD output

THD=23.52%

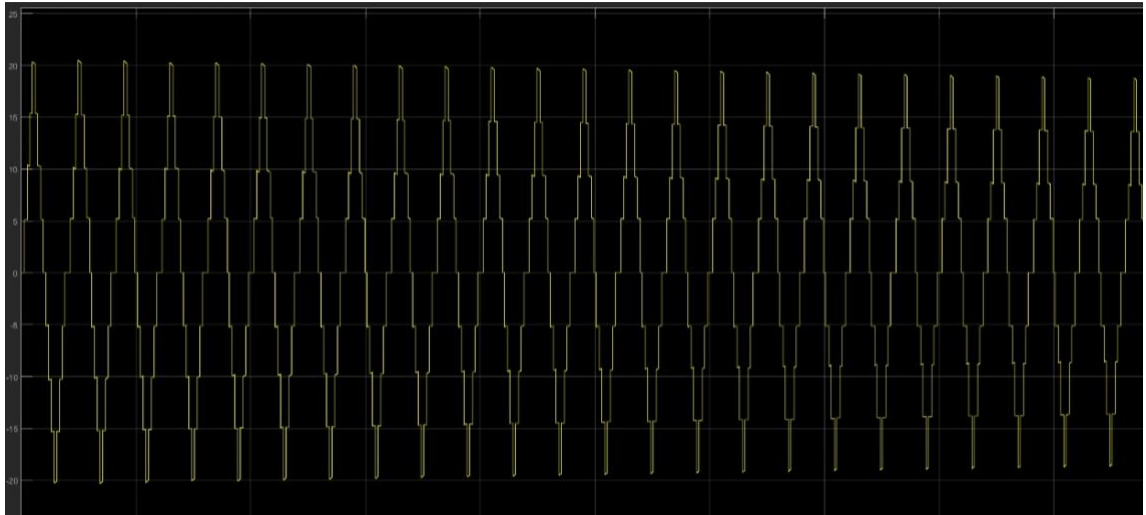


Fig. 5.11 9 level Output

5.2.1 Features of Proposed topology

- Reduced Switch Count
- Better Sinusoidal Waveform
- Reduced Total Harmonic Distortion
- Increased Efficiency
- Low Cost
- Less Weight

5.3 Proposed System with Neuro-Fuzzy Controller

Solar Photovoltaic is used as input source. A solar PV collects energy from the sun in the form of heat or light and converts it to electrical energy. Two solar panels are used. Each cell produce 0.6V. One panel supplies 100 DC voltage as input and another panel will produce 300 DC voltage as input. Fig.5.12 shows simulink model.

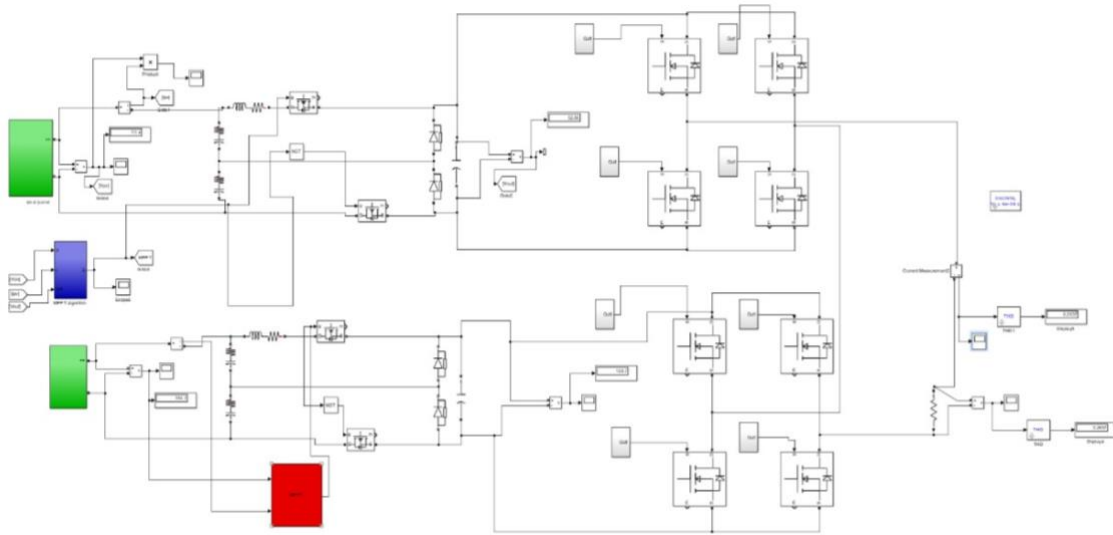


Fig. 5.12 Simulink model

Because solar PV is a fluctuating power source, an MPPT is utilised to track the maximum power point. With PV solar systems, this is the most prevalent strategy. The Perturb and Observe (P&O) approach is the MPPT technique utilised here. P&O is one of the most widely utilised MPP tracking methods. The reference voltage or current of PV systems is altered in this technique. The MPPT Simulink Model is shown in Figure 5.13.

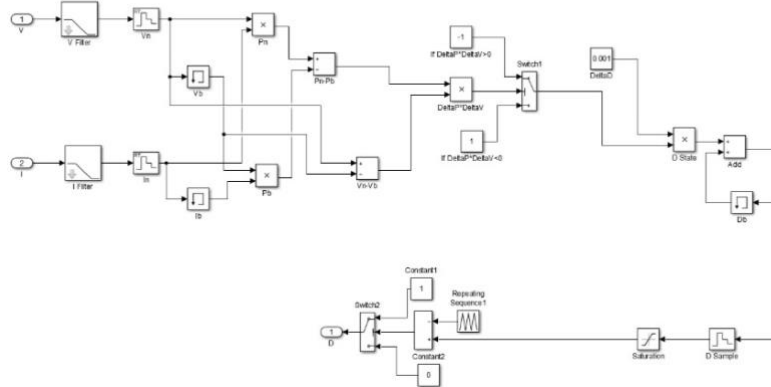


Fig. 5.13 Simulink Model of MPPT

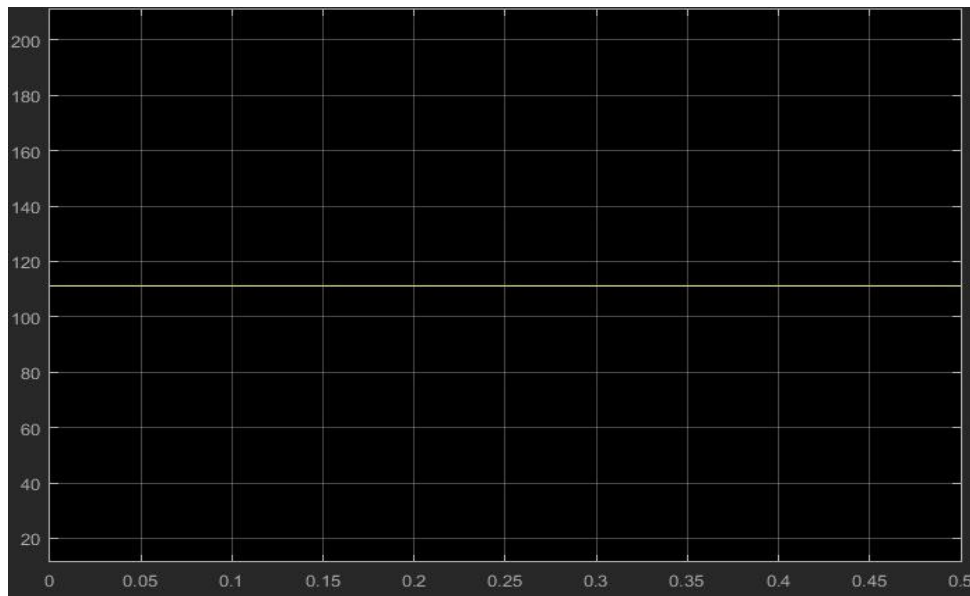


Fig. 5.14 Tracked MPP of 112V

A Boost Converter is a DC-DC power converter that is utilised in this application. It's used to boost an input voltage to a level that the load requires. The Boost Converter is seen in Figure 5.15.

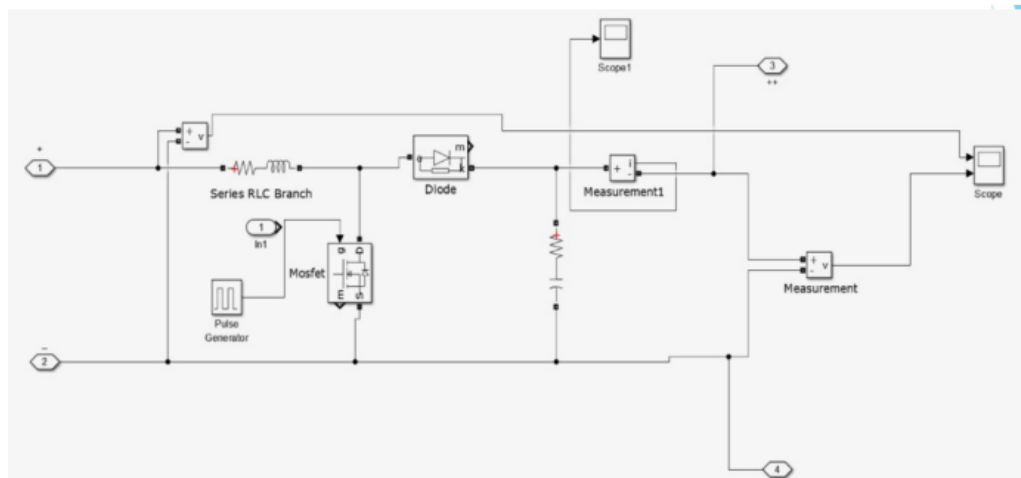


Fig. 5.15 Boost Converter

Artificial Intelligence (AI) technology is the Neuro-Fuzzy Controller. The Neuro-Fuzzy system may be used to design rules that are more convenient for humans. The data flow from input to output will be kept in a constant state by employing this system. In this system, we must first initialise the data, after which we must examine the rules in order to keep the input and output in a constant state. This system is used to establish

precise parameters for fuzzy sets as well as fuzzy rule systems using an algorithm influenced by Artificial Intelligence.

A conventional Controller is used to adjust the voltage across the load side whereas neuro-fuzzy controller does the same work in a fast way by producing accurate value. Fig.5.16 shows Neuro Fuzzy with Phase Locked Loop.

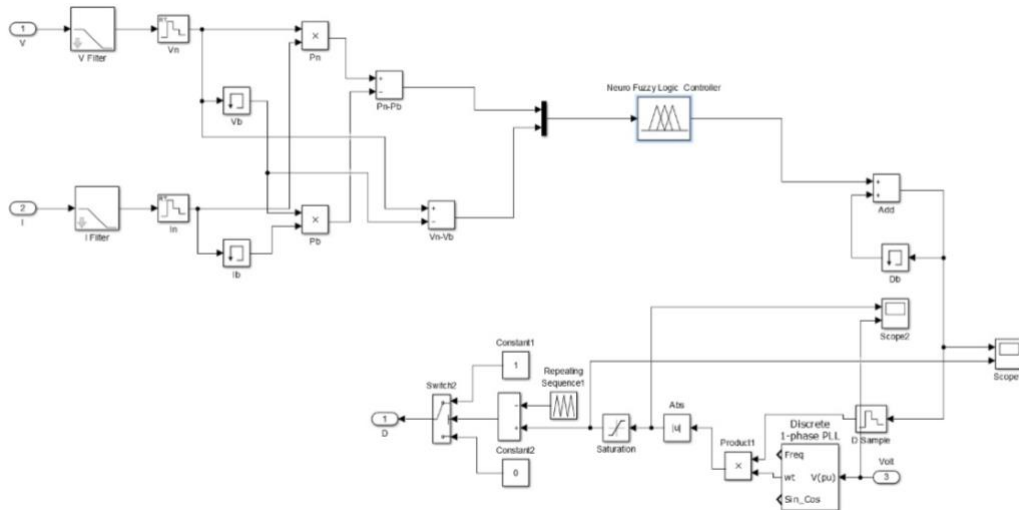
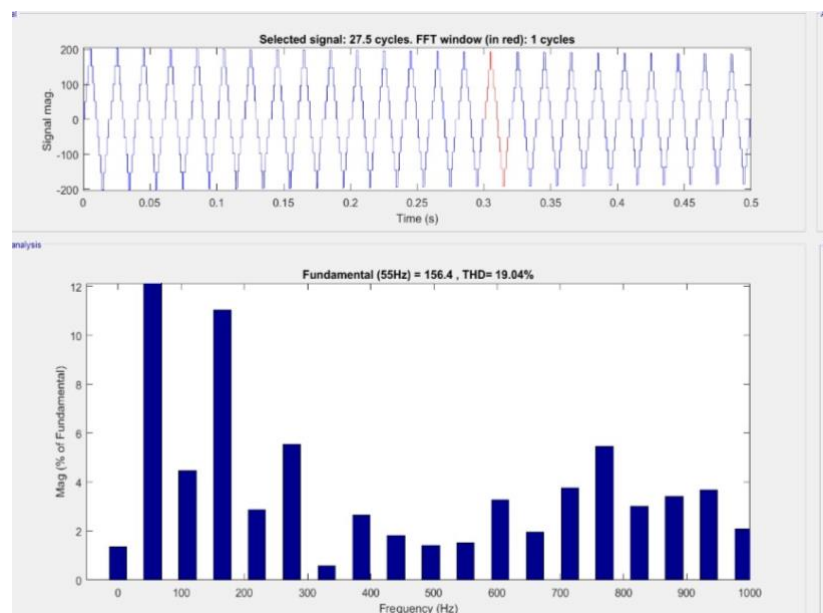


Fig. 5.16 Neuro Fuzzy with Phase Locked Loop



**Fig. 5.17 THD of Proposed System with Neuro Fuzzy Controller
THD=19.04%**

5.4 Comparison of Existing and Proposed System Results

Table 5.5 Comparison of 9 level & 7 level

	9 level	7 level
switch count	8	9
DC source count	2	3
Efficiency	64	50
THD	23.52	24.92

Table 5.6 Components Comparison with Different Structures of MLI

MLI Structure	Diode Clamped	Cascaded H Bridge	Flying Capacitor	Asymmetric CHB
DC Sources	1	4	1	2
Clamping Capacitors	-	-	6	-
DC Split Capacitors	4	-	4	-
Clamping Diodes	12	-	-	-
Main Switches	16	16	16	8
Total Components Count	33	27	27	10

Table 5.7 Comparison of proposed topology with Neuro-Fuzzy connected proposed topology

9 Level	
With Neuro Fuzzy	Without Neuro Fuzzy
THD = 19.04%	THD = 23.52%

5.5 Hardware Implementation

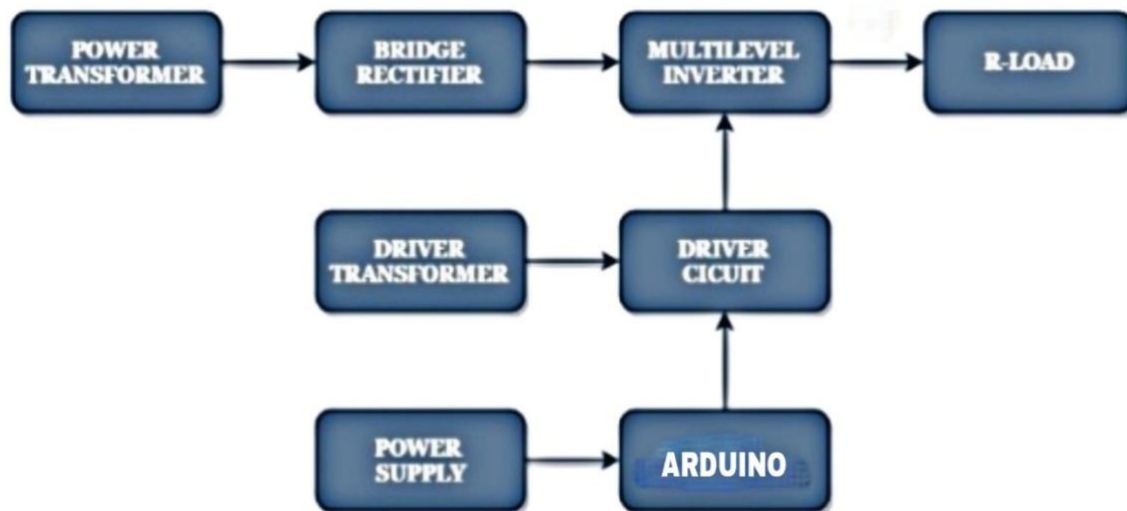


Fig. 5.18 Block Diagram

5.5.1 Controller Unit

Arduino UNO pulse generator is used for a generating pulses which is powered up by 5V supply. It is a open source microcontroller based on the microchip ATmega328. Pulse generator from the controller unit will be around 5V but power devices will be switched on at minimum of 9V to 15V. So the pulses from the controller unit will be converted, amplified and isolated or 12V or 15V at same frequency and duty ratio. The Transistor will act as amplifier. For this conversion, isolation and amplification purpose pulses from the controller unit will be given to the input of driver circuit. Fig.5.19 shows Arduino UNO Board.

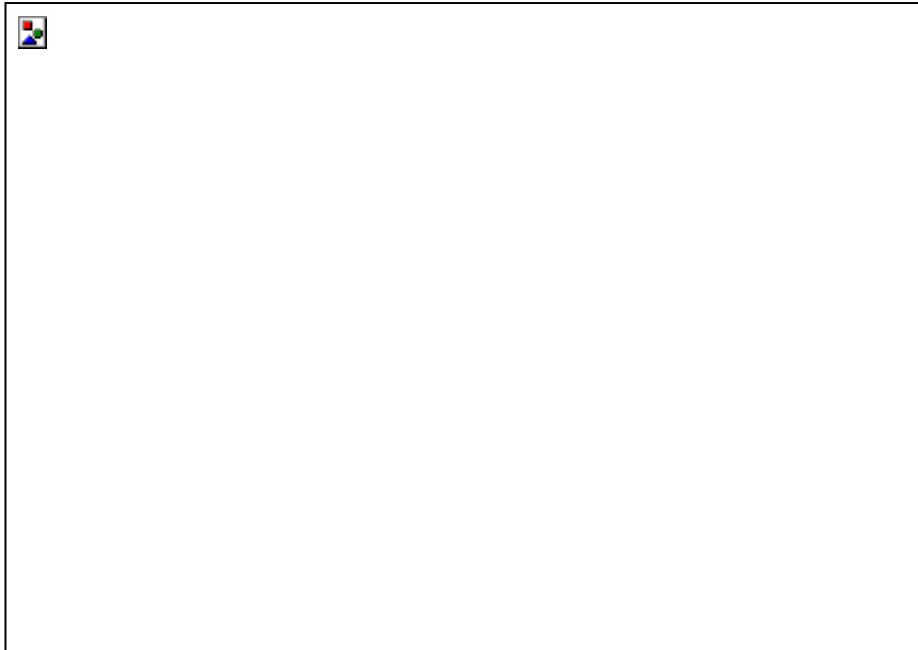


Fig. 5.19 Arduino UNO Board

5.5.2 Driver Unit

Driver unit is used to isolate and amplify the pulse generated by controller and this driver pulse is fed to the power devices like MOSFET, IGBT etc. Pulse from controller will be of 3.3V or 5V this voltage level is amplified to 12V or 15V at the same frequency and duty ratio. This unit should also have gate protection. Fig.5.20 shows TLP250 Driver Circuit.



Fig. 5.20 TLP250 Driver Circuit

A driver IC TLP250 is used. To supply this driver circuit two single phase step down AC transformer of 12V is used. A 12V AC is rectified and filtered and pure DC will be given to driver circuit. 18V zener diode acts as a gate protection by protecting the reverse voltage. Each Two driver circuits are used each has four legs totally eight legs are used in the driver unit. Each four leg will apply pulses to the single inverter circuit.

5.5.3 Inverter Power Circuit

The isolated and amplified pulses in the output of the driver unit will be applied to the power devices. For two DC input source two single phase step down transformers of 15V 1A and 6V 500MA is used. This AC voltage is converted as DC voltage by using bridge rectifier. Now the input sources are 21V and 8V total of 29V is given to the inverter circuit. The inverter circuit has eight IRF840 MOSFET switches. A resistive load of 5W is used. The output voltage received at the R load is of 58V and the output waveform can be viewed in DSO or CRO. Fig.5.21 shows hardware implementation.

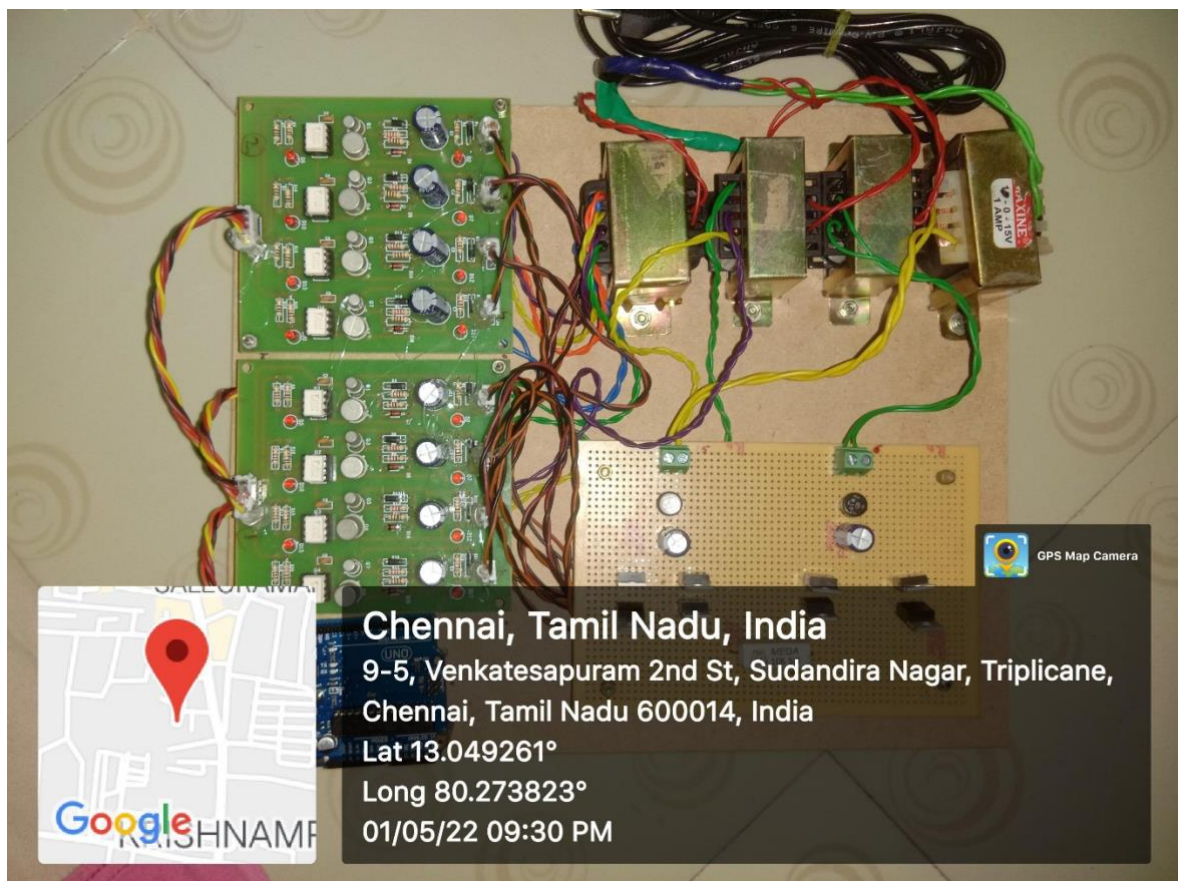


Fig. 5.21 Hardware Implementation

5.5.4 Specifications

- Arduino UNO Controller
- TLP250 Driver Board
- 12V Tapping Stepdown Transformer for driver board
- 6V & 15V Stepdown Transformer for Inverter power circuit
- 5W Resistive Load
- IRF840 MOSFET

CHAPTER 6

CONCLUSION

6.1 Conclusion

This research looked at the underlying reasons of output current and voltage aberrations in cascaded MLCs in the presence of partial shadowing among the power cells. As a result, a cascaded MLC was proposed, with each cell capable of delivering less voltage than the total cell voltage, allowing the cell duty cycle to be brought back to unity after it had reduced due to partial shadow. In compared to its competitors, the design was more cost-effective, lighter, and smaller in total size because it did not require any additional passive components.. The update only featured a few active components. The proposed converter significantly improved output voltage and current qualities in the presence of partial shading, as demonstrated by simulation and experiment, with THD according to 50th harmonic orders as defined by the EN50160 standard decreasing from 15.23 percent to 10.75 percent in the case of voltage and current.

In general, $2(n - 1)$ switches and $n - 1/2$ DC sources may provide n -level output in a cascaded H bridge inverter, therefore 16 switches and 4 DC sources are required to generate 9 level output. However, we may dramatically minimise the switch count by using an asymmetric-cascaded h-bridge. We also deduced that when the level rises, the sinusoidal waveform will improve.

The suggested asymmetric cascaded H bridge inverter is utilised to minimise the number of switches while also increasing the level. A multilevel inverter is used to synthesis a nearby sinusoidal voltage from various levels of DC voltages. When compared to diode clamped, flying capacitor, and cascaded multilevel inverters, the suggested nine level multilevel inverter requires fewer components to achieve the same number of voltage levels.

Finally by adding neuro-fuzzy controller to the proposed topology we reduced total harmonic distortion further.

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