Implementation of IOT for Energy Management

Ms. Saswati Kumari Behera¹, Mr. Manish Kumar Gupta²
AsstProfessor,SriSai ram Engineering College, chennai, India¹, Senior Sales Manager .GE India Industrial Private ltd²

Abstract:
Rural areas are suffering from heavy power cut due to generation problems. This kind of generation problems is satisfied only to some extent. Due to the mismatch in power consumption the villages are facing power cut problems. To solve this problem, we propose a system that uses smart meters on the premises of customers embedded in Internet of Things. Advantages of the proposed approach are- Smart meters are flexible with smart capabilities to satisfy consumer demand, monitor and communicate electrical use in real time, Facilitates remote monitoring in real time, Consumers obtain real-time pricing and evaluate the consumption information that is the technological data to be sent to the grid. The whole system works on Internet of Things.

Keywords: Demand side management, Internet Of Things (IOT), smart meter, Independent System Operator (ISO)

I. INTRODUCTION
The smart meter is the smart grid part closer to home and the one that consumers communicate with. Based on their different energy needs, residential, commercial and industrial customers get the advantage, maximize energy consumption and local production, and participate actively in demand-response policies. Nontechnical customers need a clear way of controlling energy consumption and production and sharing power consumption data with energy providers or distributors at the correct level of granularity. This ranges from increasing energy efficiency by using better materials, smart energy tariffs with rewards for certain consumption patterns, and sophisticated monitoring of distributed energy resources in real time. [1].

There was a proposal for the concept of a local smart meter system, looking at the current European Union and international legislation, the technological solutions available on the market and those introduced in different countries and, finally, proposing specific architectures for the proper implementation of a smart meter network for consumers [5]. The smart meter is only one aspect of the broader concept of smart home and smart buildings from the point of view of consumer adoption and penetration. There are four power transfer rates-GENCOS, TRANSCOS, DISCOS and CONSUMERS.
FIG.1. STRUCTURE OF REGULATED POWER SUPPLY

This implies the structure of regulated industry. In this system the low power consumers are also suffering from heavy power shut down due to rapid utilization of energy by high power consumers. In the existing system Load Dispatch Centre (LDC) distributes power according to the demand. The substation (SS) schedules the amount of power to be consumed for a particular period of time per day. If the consumer consumes beyond the supplied power within the scheduled time, then there will be a shutdown for the entire area which is a major problem the rural areas are facing. A brief overview of the power consumption is also limited to current meters.

II. PROPOSED SYSTEM

In proposed system the smart meter measures and monitors the power consumed by individual users. When the consumer is about to consume more than the scheduled power the buzzer circuit alerts the consumer. In case exceeded then power cut occurs to that particular residence by tripping the relay circuit. On the other hand the low power consumer will not be suffering from power shut down as their consumption is less.

In deregulated Industry Independent System Operator plays an important role. This sets controls and tracks the operation of the electrical power network in the areas where an ISO is set up.

The low power consumers can sign a contract with the ISO stating that he can face the shut down for few hours. By doing this he will get low tariffs and incentives.

FIG.2. STRUCTURE OF DEREGULATED INDUSTRY

ISO will satisfy the power demand for high power consumers by intelligent load scheduling system.

III. BLOCK DIAGRAM:

FIG.3. BLOCK DIAGRAM OF SMART METER

Here the potential transformer and current transformer are used to monitor and measure power.

When the consumer is about to consume more than the scheduled power the buzzer circuit alerts the consumer.

In case exceeded then power cut occurs to that particular residence by tripping the relay circuit.

LCD is used for display purpose.

The entire system works on IOT platform and hence we require a 3G modem.
IV. CIRCUIT DIAGRAM:

FIG.4. CIRCUIT DIAGRAM OF SMART METER

DESCRIPTION:

1. MICROCONTROLLER:

The ATmega8 is an AVR RISC-based low-power CMOS 8-bit microcontroller. The ATmega8 achieves throughputs of approximately 1MIPS per MHz by executing powerful instructions in a single clock cycle, allowing the system designer to maximize power consumption versus processing speed.

2. CURRENT TRANSFORMER:

Current transformer (CT) is an electrical device that generates, in its secondary, an alternating current (AC) equal to the main AC. Current transformers are known as instrument transformers, along with voltage transformers (VTs) or potential transformers (PTs) that are intended for measurement.

If a current is too high to calculate directly or the circuit voltage is too high, a current transformer can be used in its secondary to provide an independent lower current equal to the primary circuit current. The secondary induced current is then appropriate in electronic equipment for measuring instruments or processing. There is also no influence of current transformers on the primary circuit. Also, the important characteristic of electronic equipment is the distinction between the primary and secondary circuits. Current transformers are commonly used for metering and are used in electronic equipment.

3. POTENTIAL TRANSFORMER:

In the electrical power network, potential transformer or voltage transformer is used to decrease the voltage of the system to a safe value that can be fed to low meter ratings and relays. Commercially available relays and meters are designed for low voltage safety and metering.

A theory of voltage transformer or potential transformer theory is just like a step down transformer theory of general purpose. This transformer's primary contact is between the phase and ground. Like the transformer used for the purpose of stepping down, possible transformer, i.e. PT's secondary has lower turns winding.

4. RELAY:

A relay is a device that is operated electrically. Most relays use an electromagnet to mechanically control a switching mechanism, but other concepts of operation are also used. Relays are used where a low-power signal (with complete electrical separation between control and controlled circuits) is necessary to control a circuit, or where several circuits must be controlled by one signal.

5. BUZZER:

A Piezo buzzer consists of two conductors separated by the crystals of Piezo. We move on one conductor when a voltage is applied to these crystals and pull on the other. A sound wave is the product of this push and pull. For many items, these buzzers can be used, such as signalling when a period of time is up or making a sound while pressing a certain button.
V. PLATFORM FOR THE INTERNET OF THINGS

We have built an IoT platform as a scalable distributed system that can accommodate a home smart grid and multiple concurrent remote monitoring and control applications seamlessly. This is shown below.

FIG.5. IOT PLATFORM

It consists of three main parts: the simulation and control sensor and actuator networks, the IoT application and user interfaces. Sensor nodes and actuators communicate with the IoT server in a secure bidirectional manner. The node-to-IoT server communication is based on the TCP / IP client-server model. Sensors send messages to the IoT server (if necessary via a gateway) in their native format via an encrypted connection. The IoT server transforms the raw payload, which contains information from heterogeneous nodes, into a standard format, containing object description, type of entity, unit of measurement, field of data, geographic position and timestamp. It allows data to be conveniently interpreted, manipulated and aggregated without taking into account the source's contact protocol.

VI. HARDWARE MODEL

FIG.6

The above figure shows the hardware kit of smart meter.

STEP I:

FIG.7

Both heavy and light loads are switched on. The corresponding voltage, power, current, power factor and units consumed are displayed in the smart meter.

STEP II:

FIG.8

Once the consumer reaches the scheduled power the relay driver is activated to trip that
particular user. The low power consumers will not face any difficulties.

STEP III:

Consumers of low power have signed an ISO contract. The ISO will be able to distribute the power according to the need in the situation of demand, thereby satisfying the demand of the heavy power user which is illustrated in fig.

VII. SOFTWARE MODULE:

The software was designed using Visual Basic which will be used in the Substation side.

It keeps track of all the measured values.

VIII. RESULTS AND DISCUSSIONS

Our concept mainly focuses on managing the available power among the consumers. When there is a over usage of power then power is cut off only for the residence whose consumption exceeds the scheduled range. The ISO can supply power to the high power consumers on the basis of contract.

Less power users will be benefitted by incentives.

IX. CONCLUSION:

We have presented the system employing smart meter embedded in internet of things platform. Our proposal will manage power at the customer side through ISO. Since generation is a major problem now the power demand can be satisfied only in the customer side. Hence the smart meters can help in meeting the demand of the high power consumers. We assume that this is the secret to broad acceptance of the smart meter to be installed at home.

REFERENCES


High Voltage Solar Controller
For Hvdc Pv Transmission System & Applications With Closed Loop Mppt Control

Sairam S1, Porselvi T2, Rachana Jadhav3, Bala Kannan S4, Krishna Mote5
15Electrical Design Engineer, TCS, 2Dept of EEE, Sri Sairam Engineering College, 3Vehicle Wiring Engineer, TCS, 4Mechanical Design Engineer, Brainwave CADD

Abstract
The talk of the world today is extracting energy from the renewable resources of energy. The difficulty arises when it comes to Transmission of HVDC generated from Solar Energy. The conventional converters aren't suitable for HVDC Transmission system in which Solar PV is used as a source of energy. HVDC Transmission system involves usage of MMCs (Modular Multi-level converter), which require generation of AC Voltage as it converts High voltage AC to High Voltage DC, thus it lacks the flexibility to operate with Solar PV source.

Thus, a Boost Converter is designed for HVDC Transmission system with Solar PV as source and also for Solar PV Applications yielding High Efficacy. This converter has closed loop control to maintain constant output voltage and uses MPPT Algorithm for high efficiency. Also, for High Boosting with low duty cycle, the converter uses two cascaded Voltage Multiplier cells along with a Single-switched Boost Converter.

I. INTRODUCTION
The talk of the world today is Global warming and its threats to our environment because of increasing carbon foot print. In developing enthusiasm to natural issues, electrical vitality acquired from the Solar PV Panels is centered around the perfect vitality, little ecological effect and low emissions of carbon dioxide. Likewise, accentuation about the advancement what's more, research of environmental advancements identified with Solar Power sources is expanding. During Transmission of Generated DC Power, it would be simple if Voltage is ventured up to higher worth and in the event that it is effectively controlled. Thus, this stresses the significance of DC-DC Boost converter and improving its durability and reliability.

The input current waves which are in the form of ripples are interleaved by utilizing inductors in the circuit. A switched inductor (SL), a switched capacitor (SC) and a multiplier cell (MC) are proposed, which empower the traditional boost converter to improve its step-up ratio with a low obligation proportion. Also, the interleave boost converter when cascaded with TL boost converter is being proposed. By combing all these, a very high step up with less input ripples can be achieved. The scope of this project is introducing the new voltage multiplier circuit by means of doubling the voltage multiplier circuit and increasing the output of the obtained DC voltage as much as possible by means the proposed voltage-doubler circuit. MPPT Algorithm is implemented for effective switching and high efficiency. Closed Loop is implemented for Voltage control at output side.

II. LITERATURE SURVEY
A high gain Step-up Converter for a PV System is designed with a voltage multiplier module. Using MOSFETS at low voltages, the leakage inductance is reduced which also reduces cost and losses. A 40 V input yielded 380V output which operates with a power of 1000W with an efficiency of 96% approximately [6].

The photovoltaic system which is connected to grid is a trending topic to explore as renewable energy is booming and an alternative to non-renewable is being explored. Thus, a parallel connection of PV source with existing grids would be a viable option to study and high gain step-up converters would help a lot in the fields of Low voltage PV sources. Circuits for such topologies for next generation PV grid connected power systems are being studied. The paper studies high efficiency and high voltage DC/DC transmissions with the help of high gain step up DC Converters for the future [9].
The converter proposed in [7] uses a Zeta converter and a coupled inductor to obtain a high voltage output. The paper highlights efficiency in the energy transmission. A DC-DC Converter with three diodes and pulse width-modulated (PWM) technique working at fixed frequency and steady duty ratio is studied in [10]. The proposed converter is a different type of converter with very low input voltage ripples and with very high gains. The prototype with rated power of 40 W and working at 94 kHz is given in this paper and the obtained performance is very good differentiating from traditional converters.

The paper [5] proposes a transformer-less interleaved high step-down transformation proportion DC Converter. This achieves a very low voltage stress and has two input capacitors in series. They are also parallely discharged by two-phase interleaved buck converter for additional higher step-down transformation. The converter will help to pick up lower voltage rated MOSFETs to decrease both the losses (conduction and switching) which improves the overall efficiency.

This paper proposes a circuit to improve the circuit depicted in [1] & [2] by executing MPPT control and arrangement Voltage multiplier cell for better boost, stability and proficiency.

III. PROPOSED SYSTEM

III.1. Theory:

III.1A). MPPT:

MPPT or maximum Power Point Tracking is a technique used for extracting the peak power from a Solar PV source. The technique has various types of algorithms viz., Perturb and Observe, etc., which is elaborated in next section. The algorithm focuses on extracting maximum power by increasing or reducing the voltage to operate at maximum point in the Solar PV Voltage-current Curve such that both current and voltage are maximum resulting extraction of maximum power. The algorithm developed is usually implemented through programming.

III.1B). Perturb and observe:

This is one of significant algorithms. In this method, the voltage is incremented in small steps and power is measured simultaneously. If increase in power is observed along the same direction, the voltage is kept increasing till it reaches the maximum point. It is one of simplest and efficient algorithms. The Perturb and Observe Algorithm is used as it yields high efficacy and is easy to implement in coding language. The Fig. 1 depicts the schematic block diagram of the circuit proposed in the paper.

III.2. Module Description

A. Boost converter
B. Voltage multiplier cell
C. Modes of Circuit operation

Figure 1: Schematic diagram of High Voltage Solar Charge Controller
III.2.A. Boost converter:
A Boost converter is a circuit that is used to convert one level of voltage to higher level which usually results in a reduction in current level at the output. Ideal converter is designed in such a way that the maximum power is delivered [11]. The circuit uses switches, diodes and usually a supply. The converters are also embedded with capacitors and inductors such that the input and output ripples are reduced. Usually, high switching efficient MOSFET switches are used and controlled by a microcontroller.

III.2.B. Voltage multiplier cell:
Voltage multiplier cells usually consist of Inductor, capacitor and diode. The role of Inductor is to put the energy off when the switch operates. The capacitor is used as energy transferring and storage device where as diode offers energy transferring medium. The capacitor at the output acts a filter to eliminate ripples in the output after the switching operation. This gives a good gain even before the switching operation is performed.

III.2.C. Modes of circuit operation

![Converter Circuit Diagram of the High voltage Solar Charge Controller](image)

Fig. 2: Converter Circuit Diagram of the High voltage Solar Charge Controller

A very high gain step up converter is in Fig. 1. To accomplish a very high voltage, the converter is cascaded with two Voltage multiplier cells and a switch in the subsequent stage. The voltage is nearly doubled even before it arrives the switch such that high gain is achieved. The circuit contains only one MOSFET Switch. It contains an input inductor Lin, two voltage multiplier cells, output capacitor C0 and output Diode D0. The capacitor C1, C2 and diodes D1, D2 along with a DC Link capacitor C3 makes one voltage multiplier circuit. The circuit is repeated with D3, D4, C4 & C5. The capacitors C3 and C6 act as DC Link capacitors and diode D5 acts as blocking diode. There’s also an inductor L0 placed between the multiplier cells and switch circuit.
The working of converter is studied in four different modes and the operation of each mode is explained. For simplicity, the modes are explained with one voltage multiplier circuit as the same results are seen in second voltage multiplier circuit as well.

Mode 1: In the first mode of operation, the switch S is turned on, the diode D5 is also turned on. Rest of the diodes are in the off-condition. Vin and C1 convey vitality to Lin and Lo. Accordingly, during this activity mode the currents iLin and iLo increment directly, results in energy storage in Lin and Lo separately. During this time, C3 is charged. The same operation happens across the second voltage multiplier cell and Capacitor C6 is charged. The yield output control is provided by the capacitor C0.

Mode 2: During this mode, S is still in on condition and D5 is turned off. The diodes D1, D6 and D0 are reverse biased whereas the diode D2 is forward biased. The energy put away in C3 is discharged and same operation recurs in second voltage multiplier cell. The diode D4 is forward biased and Diode D3 is reverse biased. The capacitors C1 and C2 are currently in charging and releasing stages, separately. The, C3 and C4 currently in charging and releasing stages respectively. The energy is put away by Capacitor C6 through the Inductor Io.

Mode 3: The switch S is killed yet D2 & D4 turns out to be biased reversely. The diodes D1, D3, D5 and D0 are forward-biased. The inductor Lin discharges energy to C2 while C1 conveys energy to C3. The operation repeats again, with C3 discharging and charging C5 where as C4 charges Lo through D5. Furthermore, the output channel capacitor C0 is provided from the energy put away in Lo through D0.

Mode 4: The S is still in killed state and D1 and D3 turns out to be biased reversely. Diodes D5 and D0 are forward-biased. The stored energy in Lin, C1 and C4 is moved the step up converter side charging the yield capacitor channel C0 by means of diodes D5 and D0.

The proposed voltage converter has been explained by breaking down its operation into four different stages. Apparently, its clear from the circuit that there are two stages of Voltage doubling and one stage of Boost operation. Thus, Voltage proportion ratio (M) which is expressed as ratio of output to input can be obtained with the following equation:

\[ M = \frac{V_o}{V_{in}} = \frac{4}{(1-D)^2} \]  \hspace{1cm} (1)
From equation 1, it's apparent that the voltage converter gives a very high output even with very less duty cycle, D. The output is nearly a gain of 40 times the input voltage with very less duty ratio.

Fig. 3(b) outlines the converter efficiency against the output load power. It is found that the efficiency of the converter proposed is around 90%.

**Load:** Resistive Loads of 4kΩ and 400kΩ are respectively used for simulation purpose and in hardware.

### IV. SIMULATION

#### IV.A. GENERAL

The simulation results are taken using MATLAB software. Different types of existing system circuit are compared with the proposed model. Their output voltage and current are compared. The simulation is performed step by step. The first circuit simulated is a boost converter with one single Voltage multiplier cell. The second circuit has two cascaded multiplier cells, with modes explained as in previous title. The third simulation circuit has the last circuit with MPPT control algorithm to extract maximum power from the Solar PV input voltage source. Finally, the last circuit has reduced duty cycle and loads in such a way that output voltage is reduced to safe level of operation and ease lab testing.

#### IV.B. TECHNIQUES USED

- 1. Single Voltage multiplier cell
- 2. Two cascaded multiplier cells
- 3. Two multiplier cells with MPPT.
- 4. Hardware circuit

#### IV.B.1. Single Voltage multiplier cell

The below circuit in Fig. 4(a) shows the circuit of existing system with single voltage multiplier cell. The Voltage is multiplied by the factor of $1/(1-D)$ and then boosted by the boost circuit.

![Fig. 4(a). Simulation circuit of the Existing system with single voltage multiplier cell](image.png)

Fig 4 (b) depicts the Output voltage waveform and output current waveform of the conventional circuit.
**INFERENCE:**
For the above circuit, Output Voltage Obtained was 510V and 1A output for 20V input.

**IV.B.2. Two cascaded multiplier cells**

The below circuit in Fig. 5(a) shows the Circuit diagram of converter circuit with Two cascaded voltage multiplier cells in series with a boost converter. Thus the Voltage gets multiplied by the factor of $4/(1-D^2)$

![Fig. 5(a). Simulation Circuit with double voltage multiplier](image)

Fig. 5(b) depicts the output voltage and current for the multiplier circuit.

![Fig. 5(b). Output voltage and current waveform for double voltage multiplier system](image)

From the above graph it is observed that the

1. The output Voltage of this circuit reached 3500V with output current of 7A for 20V input. But this circuit will fail practically as the power is very high.
2 Thus, for low voltage at input side the circuit would draw more current, thus practically not stable.

**IV.B.3. Two multiplier cells with MPPT**

The below circuit in Fig. 6(a) is the Proposed one for simulation purpose. The circuit is slightly modified from the previous one. MPPT Controller is added to extract maximum power from Solar PV Source and the feedback is given to it. Thus, the output Voltage is constant despite the load varies. Further modification in Output voltage is done by changing the coding logic fed in PIC Microcontroller, such that the duty cycle is made to vary accordingly.

Fig.6(a). Simulation Circuit for proposed system

**Input voltage waveform and output current waveform:**

Fig.6(b). Input Voltage and current waveform of proposed circuit

The above image shows the Voltage and current waveform at input side from Solar PV Source. The current is 15A and Voltage is made fluctuating around 20V.
Output voltage waveform and output current waveform:

![Waveform Image]

Fig.6(c). Output Voltage and current waveform of proposed circuit

**It is found from Fig. 6(c) that** the output Voltage obtained was 1200V and current obtained was around 0.25A. It’s difficult to implement practically as 1200 V is very high to deal with. Thus, Program dumped in Microcontroller is altered to generate low duty cycle and response from output side is given to maintain constant output voltage of 300V. The simulation results for practically implemented circuit is given below.

**IV.B.4. Hardware circuit**

The below circuit in Fig. 7(a) is same as the previous one and it is slightly modified to produce low duty cycle by changing the coding logic fed in the microcontroller. Since it is difficult to produce 1200V in hardware as the Components used would become more costly, the hardware is limited to produce maximum of 500V.

![Hardware Circuit Diagram]

Fig.7(a). Simulation circuit of implemented hardware circuit

![Simulation Waveform Image]

Fig. 7 (b). Output voltage waveform and output current waveform

The above circuit shows the output waveform obtained by simulation. This circuit is implemented practically. For 4 kΩ Load, the output obtained was 325V and 0.08A.
EXPECTED INPUT AND EXPECTED OUTPUT
Input : 20V DC
Output : 400V DC, 60mA &100mA for various loads.

ADVANTAGES
- Low Ripples
- Low Losses as the circuit uses only one single MOSFET switch.
- Low voltage stress & losses
- High Step-up for low duty cycle
- Constant output Voltage.
- Can be used for Direct HVDC Transmission with Solar PV as Source.

V. HARDWARE & SOFTWARE DESCRIPTION

The implemented hardware circuit has PIC microcontroller has its main controller. The PIC microcontroller is used to generate pulses with certain frequency to obtain desired duty cycle. Also, the PIC microcontroller has continuous feedback system, measuring input/output voltage. Software like Mplab, proteus are used to code PIC microcontroller. The perturb and observe algorithm is also achieved using coding in PIC Microcontroller by continuously monitoring the input source as shown in the simulation circuit 7(a). The fig. 8 shows the implemented hardware circuit.

![Fig 8. The implemented hardware circuit.](image)

Table 1 gives the input and output parameters of the proposed circuit. Table 2 gives the same parameters for hardware circuit.

<table>
<thead>
<tr>
<th>Proposed circuit parameter</th>
<th>Parameter</th>
<th>Voltage</th>
<th>Current</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>20</td>
<td>15</td>
<td>4k Ω</td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>1200</td>
<td>0.13</td>
<td>4k Ω</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 : The output and input parameters for the simulation circuit designed for hardware.

<table>
<thead>
<tr>
<th>Hardware Circuit parameter</th>
<th>Parameter</th>
<th>Voltage</th>
<th>Current</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>20</td>
<td>1.6</td>
<td>400Ω</td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>400V</td>
<td>0.08A</td>
<td>400 Ω</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 : The results obtained for the hardware circuit.
Hardware Result

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Voltage</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>20</td>
<td>1.4</td>
</tr>
<tr>
<td>Output</td>
<td>325V</td>
<td>0.08A</td>
</tr>
</tbody>
</table>

Efficiency 92%

The tables 1, 2 & 3 shows the output and input parameters for Simulations of Proposed circuit, Proposed hardware circuit and results of implemented hardware circuit. The efficiency achieved is approx. 92% and can be improved by using more efficient drives, quality solar panels, and by implementing High voltage circuits as IFR losses would be reduced.

VI. CONCLUSION

This paper has improved an existing DC/DC Converter with one single voltage multiplier cell by adding another voltage multiplier cell and MPPT algorithm making it a reliable converter circuit for Solar PV Source. In this way, the proposed converter is reasonable for photovoltaic framework voltage gain. The activity rule and unfaltering examination just as a correlation with other boost converters are displayed. At long last, a model with 20V voltage input and 400V yield output is worked for execution check of the converter. The results obtained are good and satisfactory, confirming the efficacy of the proposed converter. Japan has the technology to interlink 50Hz and 60Hz AC power to its grid. It also has technology to connect HVDC to AC grid. Thus, this project in future after implementation might make it easy to convert HVDC into HVAC Directly with help of converters like MMC, and connect to AC grids.

References

Comparison of THD Values of Seven Level CHB Inverter with Single DC Source for various Multi Carrier PWM Techniques

T. Porsei, B. Meenakshi, S. Sairam
1,2 Electrical and Electronics Engineering, Sri Sairam Engineering College, Chennai
3 Global Design Engineer, Tata Consultancy Services, Chennai.

Abstract— Multilevel inverters are commonly used for high power applications because they cause less harmonic distortion. This paper compares the total harmonic distortions of the output voltage of the single-phase seven-level cascaded H-bridge multilevel inverter with a single DC source for various multi carrier pulse width modulation techniques. The total harmonic distortions of the output voltage of the inverter are compared for varying amplitude modulation index values. The simulated waveforms and the FFT analysis of the output voltage are shown for the various carrier disposition multicarrier pulse width modulation techniques. The simulation is carried out using MATLAB/Simulink.

Keywords— Cascaded H-Bridge Multilevel Inverter; Single DC source; Multi Carrier PWM techniques; Total Harmonic Distortion.

I. INTRODUCTION

Multilevel inverters (MLIs) are becoming popular for their high voltage and power levels. The capability of the multilevel inverters to produce high voltage with less total harmonic distortion at reduced switching frequency, using switching devices of low voltage ratings, makes them to be the best choice for medium and high voltage and power applications like solar and wind power applications [1-2]. These inverters are of three categories namely, 1. Neutral Point Clamped (NPC) multilevel inverter, 2. Flying Capacitor (FLC) multilevel inverter and 3. Cascaded H-Bridge (CHB) multilevel inverter. Of the three categories, the CHB inverter does not require any clamping diodes and capacitors and hence it is simple in construction. The only disadvantage of the CHB inverter is that it requires separate DC source for each H-bridge. To reduce the number of independent DC sources, methods were introduced in recent years; replacing reactors [3] or capacitors [4]. However, these approaches also need a minimum of three independent sources for three-phase inverter. The bidirectional switching method has been proposed [5] to ensure that the galvanic isolation between the input and the output; although it employs one input source, it has a complex circuit configuration because of the use of the bidirectional switches. This paper proposes a CHB inverter, which uses a single DC source and isolating transformers depending on the number of levels. For an m-level inverter, m-1 isolation transformers are required. The output of the inverter is connected through the transformer to the load. The paper also presents the comparison of THD values for the four carrier disposition techniques.

The paper is arranged as follows. Section II describes the proposed CHB MLI, while section III presents the multilevel carrier PWM techniques. Simulation and results are brought in section IV and the conclusions are brought out in section V.

II. PROPOSED CHB MULTILEVEL INVERTER

Figure 1 shows the proposed seven-level CHB MLI inverter. It uses a single DC source and three transformers. The output of the inverter is connected through the transformer to the load. The secondary winding of the transformers are connected in series and the load is connected to the series connected secondary windings [6-7].

![Fig. 1. Single-phase seven-level CHB inverter with a single DC source](image)

III. MULTICARRIER PWM TECHNIQUE

The most popular control technique used in the MLI is the multilevel PWM technique. It is more popular due to its simplicity and good results in all operating conditions. It can be used for any MLI and can be easily implemented. It can be categorized into two groups: carrier disposition methods (CD) and phase shifted (PS) methods [8]. For an m-level inverter, m-1 carrier (triangular) waves with the same amplitude and frequency are required for this PWM technique.
The frequency modulation index is the ratio of carrier signal frequency to the modulating signal frequency and is given by equation (1).

$$m_f = \frac{f_{cr}}{f_m}$$  \hspace{1cm} (1)

Where, $f_m$ is the modulating signal frequency and $f_{cr}$ is the carrier signal frequency. The amplitude modulation index $m_a$ is given by equation (2).

$$m_a = \frac{V_m}{v_{cr}(m-1)}$$  \hspace{1cm} (2)

Where, $V_m$ is the peak value of the modulating wave and $v_{cr}$ is the peak value of each carrier wave. There are two major classifications of multi-carrier PWM techniques namely, carrier disposition and phase shifted techniques. In the carrier disposition techniques, the carrier waves are vertically shifted from each other. In the phase-shifted technique, the carrier waves have an horizontal phase shift. The various disposition techniques are [9-13]

1. Phase Disposition (PD)
2. Phase Opposition Disposition (POD)
3. Alternate Phase Opposition Disposition (APOD)
4. Inverted Sine PWM (ISPWM).

Phase Disposition (PD) employs (m-1) triangular carrier waves with all carrier waves in phase with each other.

For the seven-level inverter, six carrier waves are compared with the sine wave. The six carrier waves are arranged with a vertical shift. Figure 2(a) shows the PD modulation for seven level MLI.

Phase Opposition Disposition (POD) employs (m-1) triangular carrier waves where all carrier waves above the zero reference are in phase, but shifted by 180° from those below the zero reference. The six carrier waves are arranged with a vertical shift. Figure 2(b) shows the POD modulation for seven level MLI.

Alternate Phase Opposition Disposition (APOD) employs (m-1) vertically shifted triangular carrier waves with each carrier wave shifted from the adjacent wave by 180°. Figure 2(c) shows the APOD modulation for the seven-level MLI.

Inverted sine PWM employs (m-1) inverted sine carrier waves with all the carrier waves shifted vertically from each other. Figure 2(d) shows the inverted sine PWM for the seven-level MLI.

IV. SIMULATION AND RESULTS

The proposed seven level MLI is simulated in MATLAB using the four carrier disposition techniques by changing the amplitude modulation. The output voltages and their voltage THDs are obtained for different PWM techniques for $m_a = 0.4, 0.5, 0.6, 0.7, 0.8$. Figures 3-6 show the simulated output voltage and the FFT of output voltage for the four carrier disposition techniques.
Fig. 3 Output Voltage and FFT analysis for PD Technique (a) ma= 0.4 (b) ma= 0.5 (c) ma= 0.6 (d) ma= 0.7 (e) ma= 0.8
Fig. 4. Output Voltage and FFT analysis for APOD Technique (a) ma= 0.4 (b) ma= 0.5 (c) ma= 0.6 (d) ma= 0.7 (e) ma= 0.8
Fig. 5 Output Voltage and FFT analysis for POD Technique (a) $m_a=0.4$ (b) $m_a=0.5$ (c) $m_a=0.6$ (d) $m_a=0.7$ (e) $m_a=0.8$
Fig. 6. Output Voltage and FFT analysis for ISINE Technique (a) $m_a=0.4$ (b) $m_a=0.5$ (c) $m_a=0.6$ (d) $m_a=0.7$ (e) $m_a=0.8$
Table 1 shows the voltage THD values of the MLI for varying $m_a$ for the four carrier disposition techniques

<table>
<thead>
<tr>
<th>$m_a$</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage THDs for the PD</td>
<td>24.85%</td>
<td>19.84%</td>
<td>16.37%</td>
<td>17.77%</td>
<td>20.43%</td>
</tr>
<tr>
<td>Voltage THDs for the APOD</td>
<td>25.48%</td>
<td>20.07%</td>
<td>16.12%</td>
<td>18.2%</td>
<td>20.39%</td>
</tr>
<tr>
<td>Voltage THDs for the POD</td>
<td>25.58%</td>
<td>20.28%</td>
<td>16.46%</td>
<td>18.34%</td>
<td>20.95%</td>
</tr>
<tr>
<td>Voltage THDs for the ISPWM</td>
<td>26.38%</td>
<td>20.95%</td>
<td>16.43%</td>
<td>18.56%</td>
<td>21.18%</td>
</tr>
</tbody>
</table>

Fig 7 shows the graph of the voltage THDs vs. $m_a$ for the five techniques. From the Table 1 it is found that the voltage THDs are better for PD method for all the values of $m_a$. In addition, it can be seen that for $m_a=0.6$, the THD value is the least for all the PWM techniques.

![Fig. 7: Voltage THDs vs. $m_a$ for APOD, POD, PD, ISPWM techniques](image)

V. CONCLUSION

Cascaded H-Bridge Inverter is widely used because of its many advantages. The only disadvantage of requiring separate DC sources is eliminated in this paper with the proposed CHB inverter. The various carrier disposition techniques have been discussed. The proposed topology is simulated with the various carrier disposition techniques for varying amplitude modulation indices. The voltage THDs for the five carrier disposition PWM techniques are compared for varying modulation indices and the phase disposition technique produces the least THD value. In addition, it is found that the voltage THD is the least for $m_a=0.6$ for all the five PWM techniques. Hence, the phase disposition technique may be used in the Cascaded H-Bridge Inverter.

REFERENCES


