SWITCHED BOOST INVERTER FOR STANDALONE DC NANOGRID APPLICATIONS

DISSERTATION

Submitted in partial fulfilment of the

Requirement for the award of the degree

Of

MASTER OF TECHNOLOGY

IN

Power electronics

By

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Under the Esteemed Guidance of

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INDIA'S LARGEST UNIVERSITY*

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May 2015

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This is to certify that the Thesis titled "**SWITCHED BOOST INVERTER FOR STANDALONE DC NANO GRID APPLICATIONS**" that is being submitted by **V.Shivakumar** is in partial fulfilment of the requirements for the award of **Master of Technology Degree (Power Electronics)**, is a record of bonafide work done under my/our guidance. The content of this thesis, in full or in parts, have neither taken from any other source nor have been submitted to any other Institute or university for award of and degree and the same is certified.

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ACKNOWLEDGEMENT

I would like to thank **LOVELY PROFESSIONAL UNIVERSITY** for giving me an opportunity to use their resource and work in such a challenging environment. I am grateful to the individuals whom contributed their valuable time towards my thesis.

I wish to express my sincere and heart full gratitude to my guide “Mr.Srikanth Reddy” Assistant professor, who guides me to take up this thesis in sync with global trends in scientific approach.

I would also like to extend my gratitude to my friends and family who always encouraged and supported me in this thesis work.

Last but not the least; I would like to thank all the staff members of department of Electronics & Electrical engineering who have been very patient and co-operative with us.

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CERTIFICATE

This is to certify that **V. Shiva Kumar** bearing Registration no. 11300063 has completed objective formulation of thesis title "**SWITCHED BOOST INVERTER FOR STANDALONE DC NANOGRID APPLICATIONS"** under my guidance & supervision. To the best of my knowledge, the present work is the result of his original investigation & study. No part of the thesis has ever been submitted for any other degree at any University.

The thesis is fit for submission and the partial fulfilment of the conditions for the award of **Master of Technology (Power Electronics**).

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DECLARATION

I, **V.Shiva Kumar** student of **MASTER OF TECHNOLOGY (POWERELECTRONICS)** under Department of **ELECTRICAL ENGINEERING** of **Lovely Professional University,** Punjab, hereby declare that all the information furnished in this dissertation-2 reports based on my own intensive research and is genuine.

This Dissertation does, to the best of my knowledge, contain part of my work which has been submitted for the award of my degree either of this university with proper citation.

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LIST OF ABBREVIATIONS

PWM – Pulse Width Modulation

DGS- Distributed Generations

SUT- Source under Test

ZSI-Z-Source Inverter

VSI-Voltage Source Inverter.

EMI-Electromagnetic Interference

VSI-Voltage Source Inverter

SBI –Switched Boost Inverter

IWJ – Inverse Watkins Johnson

CIWJ-Complementary Inverse Watkins Johnson

THD-Total Harmonic Distortion

MATLAB-Matrix Laboratory

DAE-Differential Algebraic Equations

MPPT – Maximum Power Point Tracking

FACTS-Flexible AC Transmission System

PFM – Pulse Frequency modulation

AOT – Adaptive On Time

PSP – Phase Shift Pulse

ZVS – Zero Voltage Switching

ZVT – Zero Voltage Transition

ABSTRACT:

In order to supply power from a solar panel or photo voltaic system at a low voltage to a grid at high voltage, a power electronic converter which is capable of voltage boosting and inversion is required. Newly introduced Switched Boost Inverter is capable of achieving both these objectives by a single stage. This paper presents a PWM control strategy based switched Boost Inverter (SBI) for DC nano grid applications. Using Switched boost inverter (SBI), the system can produce an ac output voltage which is either greater or less than that of the dc input voltage. This also exhibits better Electro Magnetic Interference (EMI) noise immunity as compared to the VSI, which enables compact design of the power converter. It allows the shoot through switching state for boosting the input voltage and, compensates the dead time effect which causes the serious output voltage waveform distortion and avoids the risk of damaging the inverter switches. It can supply both ac and dc loads simultaneously from a single dc input source. These features cannot be obtained in the traditional inverters and they are more advantageous for DC nano-grid applications. The whole system is designed, modelled and, simulated in MATLAB software.

CHAPTER-1

INTRODUCTION

Normally in India, Grid system is very traditional (old) one. So the reliability and efficiency is low. Power Gird system is Generation Transmission and Distribution. It is like one way communication. It inter-links one to one. This may lead to affect the system, when the fault occurs in any of the system line. Power transmission is limited. Information technology between the power systems is very poor. We can't create a flexible electric power system because of absences of intelligent and co-operating resources. This poor power system will leads to more power losses. And we can't penetrate non-traditional power generation such as Renewable energy system into our power system.

In this paper presents different trends in smart Grid. The inter linkage of many micro grid is known as smart grid, and this smart grids like two way communications. This two way communication is possible by the connecting more number of the micro grids. From this we can clearly understand we are using more number of the generating units, reliable control and information technology used for the improvement in the grid's efficiency.

We utilize the DC nano network is for the low power dc appropriation framework for the private force applications.In the nano lattice the normal burden interest is for the most part met by the renewable sources like solar,wind,etc.To guarantee the uninterruptible power supply to the basic loads a vitality stockpiling framework is require in the nano matrix and to keep up force offset for the nano matrix frameworks.

Distributed generation systems using conventional sources is gaining popularity due to the environmental problems over the various kind of the burning fossil fuels, deregulation of the electricity industry and various technological advances in the power sources .This natural resources directly connected to the grid by means of the grid inverter. There is another optinal is to combine the different renewable generations with the loads from an independent power systems.

A nano grid is the aggregation of local small scale generators and loads. This loads generally less than 25KW.If nano grid as sufficient generation and the storage, then it is operate as the independent power island. Generally a nano grid is connected to the grid to export excess power and to eliminate the need for the energy storage. Nano grid can be controlled as the decentralized fashion each controlling its power output based on the local information available at the terminals. This decentralized control is fast and reliable, as it wont require to control interconnections, but optimizing the efficiency and the overall nanogrid operation can be difficult.

Three different power converters are used in the DC nano grid to interface the renewable energy source, energy storage unit, and the local ac loads in the system to the bus. The solar panel is associated with a series blocking diode DS to overcome the reverse power conduction.

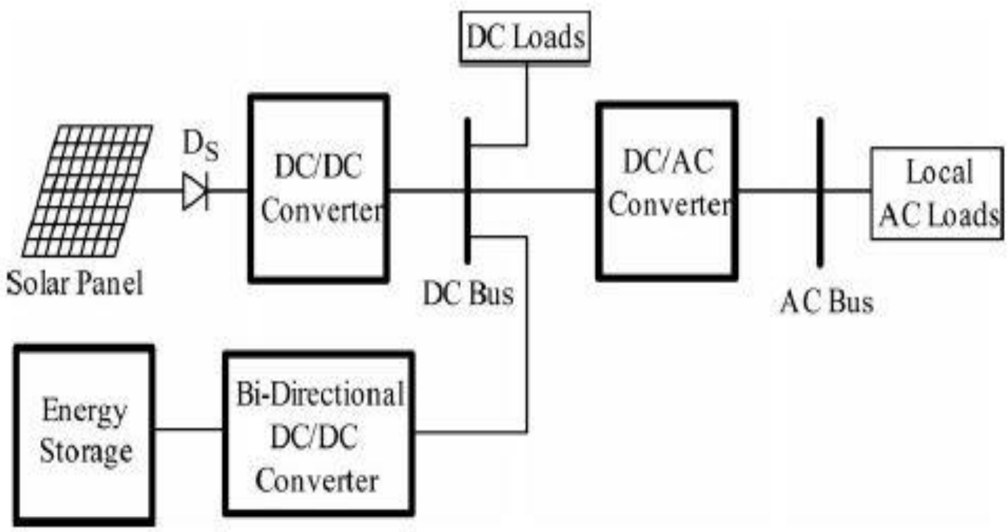

Fig : 1.1 Schematic Diagram of DC Nanogrid.

CHAPTER-2

LITERATURE SURVEY

Title: DC-bus waving: A distributed switch strategy for a hybrid renewable nanogrid.

- Dc nano network is a hybrid renewable framework since renewable causes supply the normal burden interest, while stockpiling and nonrenewable era moderate the force adjust in the vicinity of the stochastic renewable sources. The framework is force programmed based, with converters being utilized to interface both the sources and burdens to the framework. The nanogrid is controlled utilizing dc-transport flagging (DBS), a circulated representative technique in which the control hubs, the source/stockpiling limit converters, influence voltage-level changes to correspond with the other control nodes.

Title: Low-voltage bipolar-type DC microcomputer grid-iron for splendid high quality supply

- Micro grid is one of the new hypothetical force frameworks for level establishment of different conveyed eras (DGs). While the majority of the smaller scale networks uphold air conditioning dispersion and also traditionalist force frameworks, dc miniaturized scale lattices are proposed and explored for the great association with dc yield sort causes, for example, photovoltaic (PV) framework, power module, and auxiliary battery. Additionally, if stacks in the framework are carried with dc power, the transformation misfortunes from textual styles to loads are lessened connected with air conditioning small scale matrix. As one of the dc microgrids, we propose "low-voltage bipolar-sort dc microcomputer lattice," which can stock super fantastic force with three-wire dc appropriation line.

Title: Highly efficient single-phase transformerless inverters for grid-connected photovoltaic systems

- Between the sources and the voltage source inverter (VSI) an impedence LC system is utilized as a part of Z-source Inverter.Stepping down and going up the info voltage highlight exist in this strategy subsequently the yield voltage is higher or lower than the data voltage according to necessity. This technique additionally contains powerful electromagnetic obstruction commotion invulnerability by which the shoot through of the inverter leg switch.

Title: Inverse Watkins-Johnson topology based inverter.

- There is a strong trend in the photovoltaic inverter technology to use transformer less topologies in order to acquire higher efficiencies combining with very low ground leakage current. In this paper, a new topology, based on the H-bridge with a new ac bypass circuit consisting of a diode rectifier and a switch with clamping to the dc midpoint, is proposed.

Title: Comparison of PWM Techniques and Inverter Performance

- Due to large application of induction motors in industries, it has become prudent to work on its speed control. As the inverter provides better sinusoidal voltage or current, speed control of machines becomes more fine. It is possible only if inverter gets better gate pulses. Hence for testing of quality of inverter output voltage or current, %THD and switching frequency are two important parameter. It also contain the output voltage or current at 3k Hz switching frequency.

Title: Sinusoidal and Space Vector Pulse Width Modulation for Inverter

- Inverters inherently have the property of controlling output frequency but the output voltage can't be varied. Usually to vary output voltage we have to vary supply voltage which is not always possible for this reason PWM techniques gained momentum. Basic aim of PWM technique is to control output voltage and harmonic reduction. Pulse-width modulation (PWM), or pulseduration modulation (PDM), is a commonly used technique for controlling power to inertial electrical devices.

CHAPTER-3
SCOPE OF STUDY

DCNANOGRID is a low-power dc distribution system suitable for residential power applications. The average load demand in the nanogrid is generally met by the local renewable energy sources like solar, wind, etc. An energy storage unit is also required in the nanogrid to ensure uninterruptible power supply to the critical loads and to maintain power balance in the nanogrid. The solar panel is associated with a series blocking diode *Ds* to avoid reverse power conduction. As the dynamic behaviors of all the different units of nanogrid are not uniform, they are interfaced to a common dc bus using power electronic converters. As per the consumer preference, each dc load in the nanogrid also has its own power electronic interface which is not for simplicity.

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3.1 SOLAR PANEL:

The word “photovoltaic” syndicates two terms, “photo” means light and “voltaic” means voltage. A photovoltaic system in this discussion uses photovoltaic cells to directly convert sunlight into electricity. Photovoltaic power group services solar sections tranquil of a number of solar cells having a photovoltaic material. Solar photovoltaic is a maintainable energy foundation where 100 countries are using it. Solar photo voltaics is now, afterwards hydro and wind power, the third most significant renewable energy source in terms of worldwide installed capacity.

In today's climate of growing energy needs and increasing environmental concern, alternatives to the use of non-renewable and polluting fossil fuels have to be investigated.One such alternative is solar energy.

Solar energy is quite simply the energy produced directly by the sun and collected elsewhere, normally the Earth. The sun creates its energy through a thermonuclear process that converts about 650,000,0001 tons of hydrogen to helium every second. The process creates heat and electromagnetic radiation. The heat remains in the sun and is instrumental in maintaining the thermonuclear reaction. The electromagnetic radiation (including visible light, infra-red light, and ultra-violetradiation) streams out into space in all directions.

Only a very small fraction of the total radiation produced reaches the Earth. The radiation thatdoes reach the Earth is the indirect source of nearly every type of energy used today. The exceptions are geothermal energy, and nuclear fission and fusion. Even fossil fuels owe their origins to the sun; they were once living plants and animals whose life was dependent upon the sun. Much of the world's required energy can be supplied directly by solar power. More still can beprovided indirectly. The practicality of doing so will be examined, as well as the benefits and drawbacks. In addition, the uses solar energy is currently applied to will be noted.

Due to the nature of solar energy, two components are required to have a functional solar energy generator. These two components are a collector and a storage unit. The collector simply collects the radiation that falls on it and converts a fraction of it to other forms of energy (either electricity and heat or heat alone). The storage unit is required because of the non-constant nature of solar energy; at certain times only a very small amount of radiation will be received. At night or during heavy cloudcover, for example, the amount of energy produced by the collector will be quite small. The storage unit can hold the excess energy produced during the periods of maximum productivity, and release it when the productivity drops. In practice, a backup power supply is usually added, too, for the situations when the amount of energy required is greater than both what is being produced and what is stored in the container.

Methods of collecting and storing solar energy vary depending on the uses planned for the solar generator. In general, there are three types of collectors and many forms of storage units.

The three types of collectors are flat-plate collectors, focusing collectors, and passive collectors.

Flat-plate collectors are the more commonly used type of collector today. They are arrays of solar panels arranged in a simple plane. They can be of nearly any size, and have an output that is directly related to a few variables including size, facing, and cleanliness. These variables all affect the amount of radiation that falls on the collector. Often these collector panels have automated machinery that keeps them facing the sun. The additional energy they take in due to the correction of facing more than compensates for the energy needed to drive the extra machinery.

Focusing collectors are essentially flat-plane collectors with optical devices arranged to maximize the radiation falling on the focus of the collector. These are currently used only in a few scattered areas. Solar furnaces are examples of this type of collector. Although they can produce far greater amounts of energy at a single point than the flat-plane collectors can, they lose some of the radiation that the flat-plane panels do not. Radiation reflected off the ground will be used by flat-plane panels but usually will be ignored by focusing collectors (in snow covered regions, this reflected radiation can be significant). One other problem with focusing collectors in general is due to temperature. The fragile silicon components that absorb the incoming radiation lose efficiency at high temperatures, and if they get too hot they can even be permanently damaged. The focusing collectors by their very nature can create much higher temperatures and need more safeguards to protect their silicon components.

Passive collectors are completely different from the other two types of collectors. The passive collectors absorb radiation and convert it to heat naturally, without being designed and built to do so.All objects have this property to some extent, but only some objects (like walls) will be able to produce enough heat to make it worthwhile. Often their natural ability to convert radiation to heat is enhanced in some way or another (by being painted black, for example) and a system for transferring the heat to a different location is generally added.

3.2 NANOGRID :

Matching electricity demand to supply will be a growing challenge in the future. We argue for the need for further research into local power distribution with a focus on “nanogrids”. We define a nanogrid as a small electricity domain with distinct voltage, price, reliability, quality, and administration. We seek to improve upon existing nanogrids (such as USB and PoE) by the addition of electricity price information to enable power distribution to be managed in a distributed bottom-up and fair manner to optimally match demand to supply, and to more easily and efficiently integrate local generation and storage. This approach, modeled on Internet principles, offers the possibility of moving to a less reliable utility grid, providing quality and reliability at the edge, and saving capital and energy. We illustrate the operation of a simple nanogrid driven by rules governing controller and load behavior in response to varying electricity availability from a renewable source.

A nanogrid is a single domain for voltage, price, reliability, quality, and administration. Components of a nanogrid are a controller, loads, storage, and gateways. Electricity storage is optional but adds stability. Electricity sources such as local generation are not part of the nanogrid, but often a source will be connected only to a single nanogrid. Interfaces to other power entities are through gateways. Figure 3.1 is a schematic of a nanogrid showing the key components and their interconnection. Electricity and communications flow via the gateways. Communications with loads or across gateways may take place over the power cabling or out-of-band on other cabling or by wireless. Nanogrids implement power distribution only and not any functional aspects of the loads that connect to the nanogrid. A nanogrid exists for any domain of distinct voltage, quality, and/or reliability. We call nanogrids that do not include communication with loads about power distribution "unmanaged." Nanogrids with power distribution communications we call "managed", and nanogrids that include a local price and the ability to buy and sell power over gateways we call "price managed". The remainder of the paper describes price managed nanogrids, which we will call "nanogrids" for convenience.

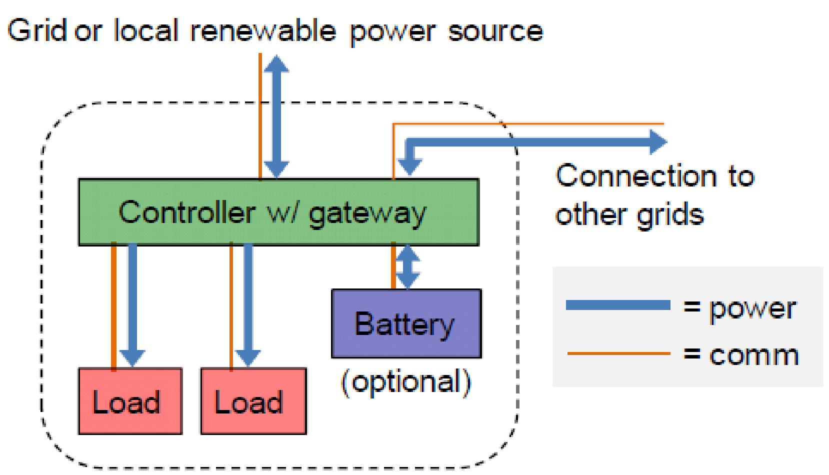


Fig : 3.1 Connection of Different Loads To Nano grid.

3.3 STANDALONE SYSTEMS :

A stand-alone grid has for the most part a few feed in generators, contingent upon the energy sources accessible, including diesel generators or PV plants with PV inverters (e.g. Sunny Boy) alongside stand-alone grid battery inverters (Sunny Island). Every one of these generators and inverters encourage into the AC lattice and constitute the hotspot for the customer's vitality supply as a substitution for the fundamental force grid. The AC grid frames the center region of the off-network framework to be introduced. It gathers the vitality of the feeding generators and circulates and exchanges it to the purchasers. To permit ideal utilization of the vitality being encouraged in, transmission misfortunes ought to be decreased to a base. The size (most prominent separation between the purchasers and sources) of off-framework frameworks with an ostensible voltage of 230 V (single-stage) or 3 x 230 V/400 V (three-stage) is commonly extremely constrained. A lot of force must be financially transmitted over substantial separations if voltage levels are high. The obliged transformers, high-voltage lines and the fundamental defensive innovation can't be secured in this record. Parts of the establishment must be built as a DC framework, for instance the battery framework or the PV circuits. These circuits ought to be kept as little as would be prudent, specifically the battery framework with its 48 V most extreme ostensible voltage, which is low, contrasted with the AC framework voltage. It would be ideal if you take note of that the real working voltage of the battery circuit changes over a wide range around the ostensible voltage, contingent on whether the battery is being charged or released. Battery inverters with 48 V ostensible voltages can create energizing voltages of to 63 V. Despite whether the lattice is an AC or DC matrix, a qualification is made between distinctive framework frames based upon

• The kind of association with ground of the sources, and

• The kind of association with ground of the shoppers.

The lattice structure and the ostensible voltage figure out which defensive measures you can or must utilize. The lattice manifestation of the AC circuits in a plant joined with the utility network is to a great extent foreordained, following the sources lie under the control of the framework administrator. This is distinctive for a stand-alone network where the sources and buyers are independent systems.

3.4 MODULATION TECHNIQUES:

In many industrial applications to control the output voltage of the inverter and cope in the variations of the dc input voltage and to regulate the voltage of the inverter and to satisfy the constant volts and frequency control requirements. There are various techniques to control the output of the inverter. The most effective methodology of the controlling of the gain , output voltage is to incorporate PWM control within the inverters.

Modulation techniques control systems advancement concerns the improvement of procedures to lessen the aggregate symphonious bending (THD) of the current. It is by and large perceived that expanding the exchanging recurrence of the PWM example decreases the lower-recurrence sounds by moving the exchanging recurrence transporter consonant and related sideband music further far from the principal recurrence segment. While this expanded exchanging recurrence lessens sounds, bringing about a lower THD by which superb yield voltage waveforms of sought key R.M.S quality and recurrence Which are as close as would be prudent to sinusoidal wave shape can be gotten. Any deviation from the sinusoidal wave shape will bring about consonant streams in the heap which bring about electromagnetic impedance (EMI), symphonious misfortunes and torque throb on account of engine drives. The nature of the yield waveform will enhance with expansion in exchanging recurrence. Higher exchanging recurrence can be utilized for low and medium force inverters, though, for high power and medium voltage applications the exchanging recurrence is of the request of 1 kHz.

A standout amongst the most vital issues in controlling a VSI with variable plentiful ness and recurrence of the yield voltage is to acquire a yield waveform however much as could reasonably be expected of sinusoidal shape utilizing basic control procedures. In reality, current music brought about by non-sinusoidal voltage sustaining infer force misfortunes, electromagnetic impedance (EMI), and throbbing torques in air conditioning engine drives. Consonant lessening can then be entirely identified with the execution of an inverter with any exchanging method.

Under the part of consonant substance diminishment, inverters are of the most elevated significance. They are especially suitable in high-control applications when the semiconductor gadgets are not ready to work at high.

3.5 SINUSOIDAL PULSE WIDTH MODULATION:

The switches in the voltage source inverter (See Fig 3.2)can be turned on and off as required. In the simplest approach, the top switch is turned on If turned on and off only once in each cycle, a square wave waveform results. However, if turned on several times in a cycle an improved harmonic profile may be achieved.

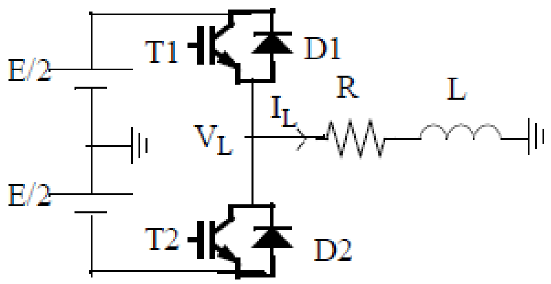


Fig : 3.2 Simple Voltage Source Inverter.

In the most straightforward implementation, generation of the desired output voltage is achieved by comparing the desired reference waveform (modulating signal) with a high-frequency triangular ‘carrier’ wave as depicted schematically in Fig 3.3 Depending on whether the signal voltage is larger or smaller than the carrier waveform, either the positive or negative dc bus voltage is applied at the output. Note that over the period of one triangle wave, the average voltage applied to the load is proportional to the amplitude of the signal (assumed constant) during this period. The resulting chopped square waveform contains a replica of the desired waveform in its low frequency components, with the higher frequency components being at frequencies of an close to the carrier frequency. Notice that the root mean square value of the ac voltage waveform is still equal to the dc bus voltage, and hence the total harmonic distortion is not affected by the PWM process. The harmonic components are merely shifted into the higher frequency range and are automatically filtered due to inductances in the ac system.

When the modulating signal is a sinusoid of amplitude Am, and the amplitude of the triangular carrier is Ac, the ratio m=Am/Ac is known as the modulation index. Note that controlling the modulation index therefor controls the amplitude of the applied output voltage. With a sufficiently high carrier frequency (see Fig 3.4 drawn for fc/fm = 21 and t = L/R = T/3; T = period of fundamental), the high frequency components do not propagate significantly in the ac network (or load) due the presence of the inductive elements. However, a higher carrier frequency does result in a larger number of switching's per cycle and hence in an increased power loss. Typically switching frequencies in the 2-15 kHz range are considered adequate for power systems applications.

$$\frac{f_c}{f_m} = 3k ,(k \epsilon N)$$

Note that the process works well for . For , there are periods of the triangle wave in which there is no intersection of the carrier and the signal as in Fig 3.5 However, a certain amount of this "over modulation" is often allowed in the interest of obtaining a larger ac voltage magnitude even though the spectral content of the voltage is rendered somewhat poorer. Note that with an odd ratio for fc/fm, the waveform is anti-symmetric over a 360 degree cycle. With an even number, there are harmonics of even order, but in particular also a small dc component. Hence an even number is not recommended for single phase inverters, particularly for small
ratios of fc/fm.

Although the SPWM waveform has harmonics of several orders in the phase voltage waveform, the dominant ones other than the fundamental are of order n and n±2 where n = fc/fm. This is evident for the spectrum for n=15 and m = 0.8 shown in Fig.5.

Note that if the other two phases are identically generated but 120 degrees apart in phase, the line-line voltage will not have any triple harmonics. Hence it is advisable to choose, as then the dominant harmonic will be eliminated. It is evident from Fig 5b, that the dominant 15th harmonic in Fig. 3.5 is effectively eliminated in the line voltage. Choosing a multiple of 3 is also convenient as then the same triangular waveform can be used as the carrier in all three phases, leading to some simplification in hardware. It is readily seen that as the where E is the dc bus voltage, that the RMS value of the output voltage signal is unaffected by the PWM process. This is strictly true for the phase voltage as triple harmonic orders are cancelled in the line voltage. However, the problematic harmonics are shifted to higher orders, thereby making filtering much easier. Often, the filtering is carried out via the natural high-impedance characteristic of the load.

Notice that in the SPWM strategy developed above, a large number of switching's required, with the consequent associated switching losses. With the method of *Selective Harmonic Elimination*, only selected harmonics are eliminated with the smallest number of switching's. This method however can be difficult to implement on-line due to computation and memory requirements.

For a two level PWM waveform with odd and half wave symmetries and n chops per quarter cycle as shown in Fig 4, the peak magnitude of the harmonic components including the fundamental, are given by

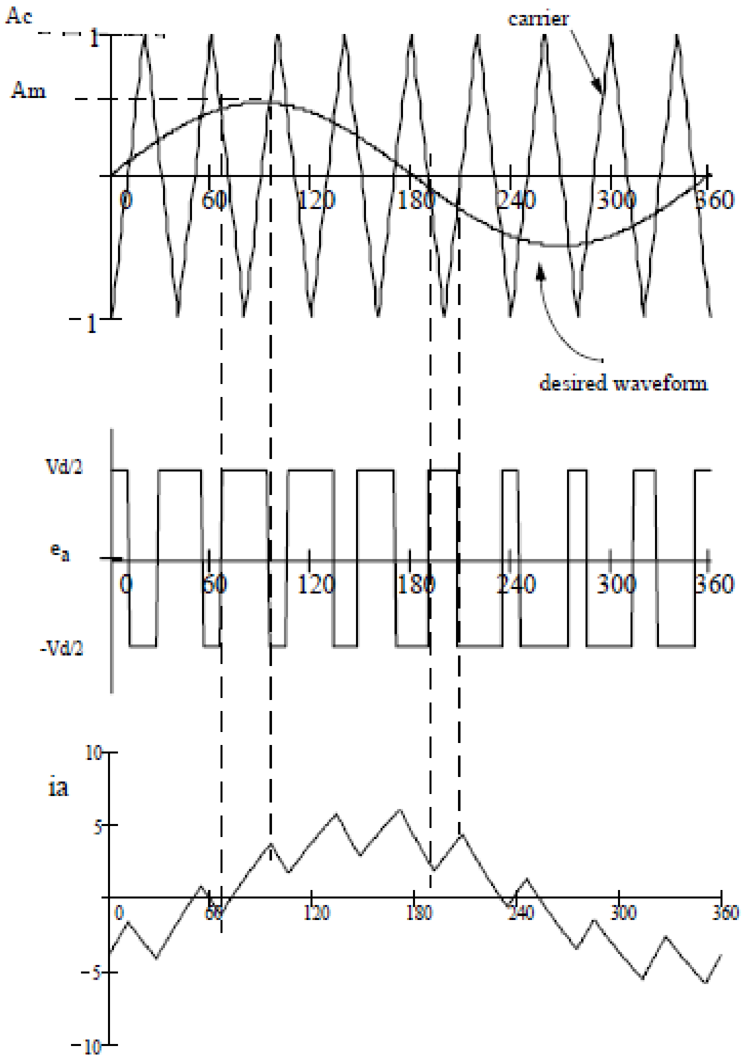


Fig: 3.3 Principle of Pulse Width Modulation.

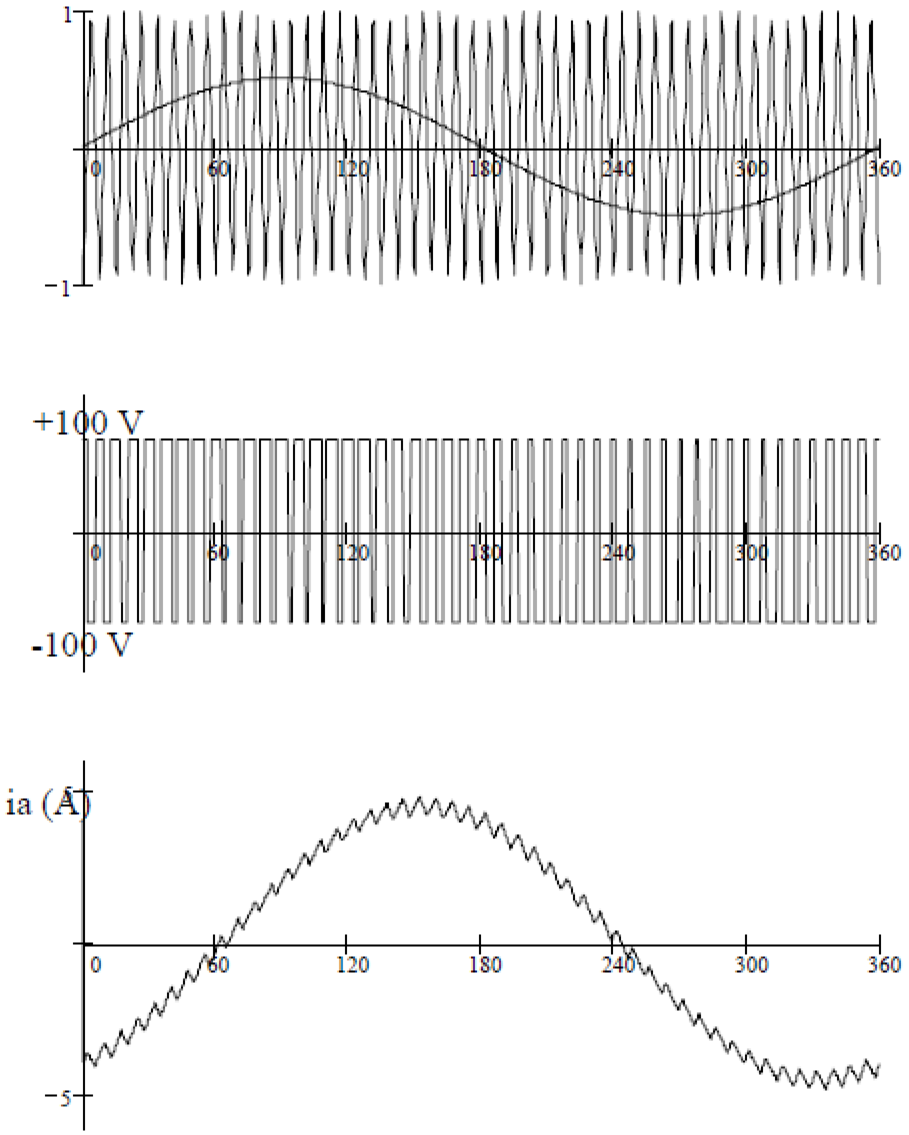


Fig : 3.4 SPWM $\frac{f_c}{f_m}$ = 48 , L/R = $T/3$

It is promptly seen that as the where E is the dc transport voltage, that the rms value of the yield voltage sign is unaffected by the PWM process. This is entirely valid for the stage voltage as triple harmonics requests are scratched off in the line voltage. In any case, the dangerous sounds are moved to higher requests, subsequently making separating much simpler. Regularly, the separating is done through the regular high-impedance normal for the value.

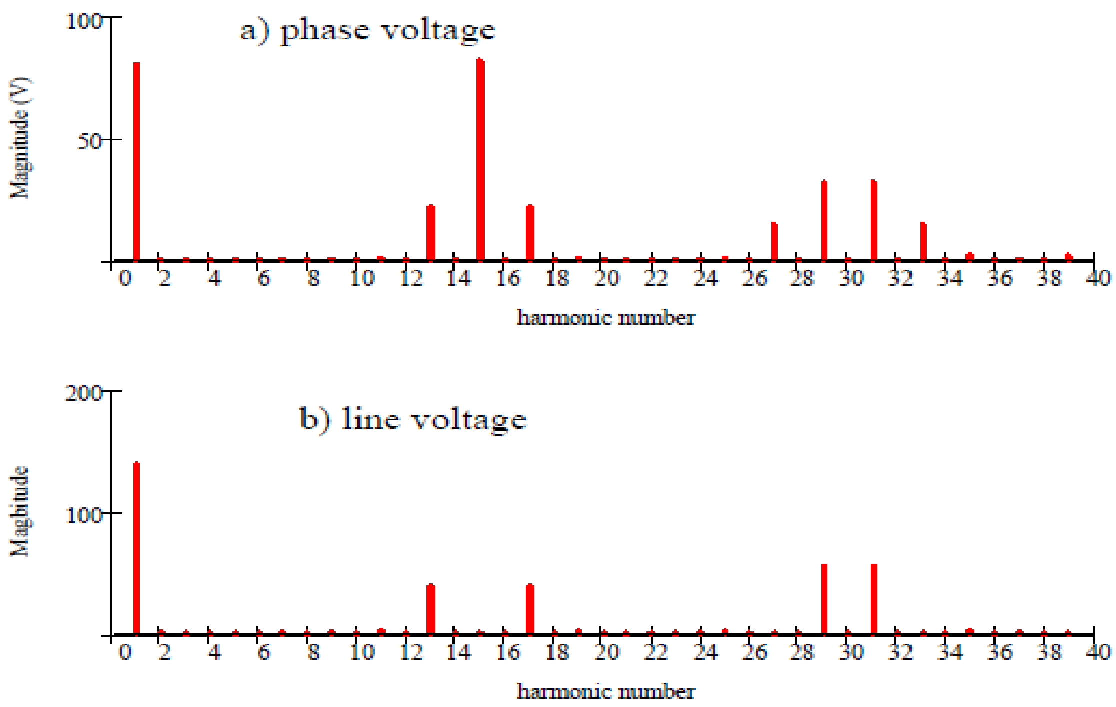


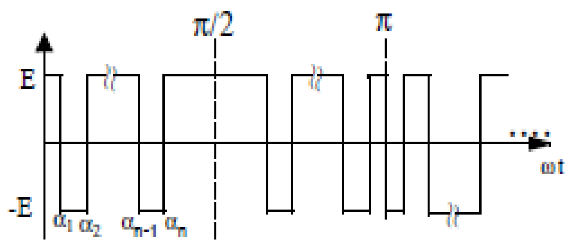
Fig 3.5 : Overmodulation ; m=1.3

Notice that in the SPWM method grew over, an extensive number of switching's are needed, with the ensuing related exchanging misfortunes. With the system for Selective Harmonic Elimination, just chose music are killed with the littlest number of switching's. This strategy however can be hard to actualize on-line because of calculation and memory requirements. For a two level PWM waveform with odd and half wave symmetries and n hacks every quarter cycle.

$$h_1 = \left(4 \cdot \frac{E}{\pi}\right) \cdot [1 - 2\cos\alpha_1 + 2\cos\alpha_2$$
$$- 2\cos\alpha_3 \ldots 2\cos\alpha_n]$$
$$h_3 = \left(4 \cdot \frac{E}{3\pi}\right) \cdot [1 - 2\cos 3\alpha_1 + 2\cos 3\alpha_2$$
$$- 2\cos 3\alpha_3 \ldots 2\cos 3\alpha_n] \qquad (1)$$
$$\cdot$$
$$\cdot$$
$$\cdot$$
$$h_k = \left(4 \cdot \frac{E}{k\pi}\right) \cdot [1 - 2\cos k\alpha_1 + 2\cos k\alpha_2$$
$$- 2\cos k\alpha_3 \ldots 2\cos k\alpha_n]$$

Here h_i is the magnitude of the i^{th} harmonic and α_j is the j^{th} primary switching angle. Even harmonics do not show up because of the half-wave symmetry.

The n chops in the waveform afford n degrees of freedom. Several control options are thus possible. For example n selected harmonics can be eliminated. Another option which is used here is to eliminate n-1 selected harmonics and use the remaining degree of freedom to control the fundamental frequency ac voltage. To find the α's required to achieve this objective, it is sufficient to set the corresponding h's in the above equations to the desired values (0 for the n-1 harmonics to be eliminated and the desired per-unit ac magnitude for the fundamental) and solve for the α's.



$$a_0 = \frac{1}{2\pi}\int_0^{2\pi} f(\theta)d\theta$$

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

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

Because of the half-cycle symmetry of the waveform of Fig. 4, only odd order harmonics exist. Also, it is easy to see that the Fourier Cosine coefficients disappear with the choice of coordinate axes used. Utilizing the quarter cycle symmetry, the Fourier Sine coefficients become:

$$b_k = \frac{4}{\pi}\int_0^{2\pi} f(k\theta)\sin(k\theta)d\theta) \qquad (3)$$

Substituting the two-valued pwm waveform for $f(\theta)$, one obtains (see Fig. 4):

$$\begin{aligned} b_n &= \frac{4E}{\pi}\left(\int_0^{\alpha_1}\sin(k\theta)d\theta - \int_{\alpha_1}^{\alpha_2}\sin(k\theta)d\theta + \int_{\alpha_2}^{\alpha_3}\sin(nk)d\theta \ldots \int_{\alpha_n}^{\frac{\pi}{2}}\sin(k\theta)d\theta\right) \\ &= \frac{4E}{\pi k}\left(-\cos(k\theta)\Big|_0^{\alpha_1} + \cos(k\theta)\Big|_{\alpha_1}^{\alpha_2} - \cos(k\theta)\Big|_{\alpha_2}^{\alpha_3}\ldots\right) \\ &= \frac{4E}{\pi n}[1 - 2\cos n\alpha_1 + 2\cos k\alpha_2 \quad - 2\cos k\alpha_3 \ldots 2\cos k\alpha_n] \end{aligned} \qquad (4)$$

The following example illustrates the use of three chops per quarter cycle which allow for three degrees of freedom. We may use these to eliminate two harmonics and control the magnitude of the fundamental to any desired value:

(5)

$$v1 = \frac{4 \cdot E}{\pi} \cdot (1 - 2 \cdot \cos(\alpha 1) + 2 \cdot \cos(\alpha 2) - 2 \cdot \cos(\alpha 3))$$

$$v3 = \frac{4 \cdot E}{\pi \cdot 3} \cdot (1 - 2 \cdot \cos(3 \cdot \alpha 1) + 2 \cdot \cos(3 \cdot \alpha 2) - 2 \cdot \cos(3 \cdot \alpha 3))$$

$$v5 = \frac{4 \cdot E}{\pi \cdot 5} \cdot (1 - 2 \cdot \cos(5 \cdot \alpha 1) + 2 \cdot \cos(5 \cdot \alpha 2) - 2 \cdot \cos(5 \cdot \alpha 3))$$

We require:

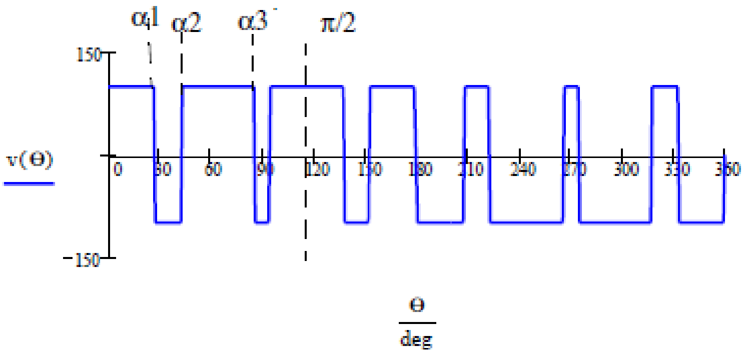
$v1 := 50 \cdot \sqrt{2}$ (peak)

$v3 := 0$

$v5 := 0$

This gives us three equations in the three unknowns $\alpha 1$ $\alpha 2$ and $\alpha 3$. Solving numerically we get:

$\alpha 1 = 27.432 \cdot deg$ $\alpha 2 = 42.131 \cdot deg$ $\alpha 3 = 85.62 \cdot deg$



In the single-pulse width modulation technique ,there is the stand out heartbeat every half cycle and the width of the beat is changed to control the inverter yield voltage. Figure represents the era of the gating signals and the yield voltage of single-stage full extension inverters. This gating signals were created by looking at the different rectangular reference sign of sufficiency with the triangular transporter wave of adequacy A_c. The frequency of the reference sign decides the key recurrence of the yield voltage record is characterized as the proportional ratio of the A_r to A_c

$$M = \frac{A_r}{A_c}$$

3.6 MULTI-PULSE-WIDTH MODULATION:

This harmonic content can be reduced by the using a few pulses as a part of every half cycle of output voltage . The gating signs for turning on and off of transistor is indicated by contrasting a reference sign and a triangular wave. The frequency of reference sign sets the output frequency fo and the carrier frequency fc decides the quantity of pulses every half cycle P.The balance list controls the output voltage. This sort of tweak is otherwise called uniform pulse width Modulation (UPWM).The number every pulses for every half cycle.

$$p = \frac{f_c}{2f_0} = \frac{m_f}{2} \; A_c$$

$m_f = \frac{f_c}{f_0}$ is defined as the frequency modulation ratio.

3.7 SWITCHED BOOST INVERTER:

The proposed Switched Boost Inerter uses PWM control technique for the DC NANOGRID applications. This inverter has the following special features which are listed below SBI is a single or one stage power converter which converts dc voltage into ac voltage and supplies both ac and dc loads simultaneously from a single dc input (dc input is obtained from the solar panel).So it performs the functions of both dc to dc converter for solar panel and dc to ac converter in a single stage. Therefore it reduces the size and cost of overall system. SBI can produce an ac output voltage, which is either greater or less than the available dc input and thereby it has an advantage of wide range of obtainable output voltage for a given dc input voltage SBI has better Electro Magnetic Interference(EMI) noise immunity as compared to the traditional Voltage Source Inverter(VSI), because shoot-through event due to EMI noise will not damage the switches of SBI and thereby it eliminates the requirement of converter protection circuits and helps in realization of compact design of the converter circuit.

As SBI allows shoot-through event, it does not has the requirement of dead time circuit and thereby it eliminatesthe complex dead time compensation technologies, which are required to minimise or compensate the waveform distortion caused by the dead time of VSI.

The below shown As shown in Fig. 3, the SBI has one active switch (*S*), twodiodes (*Da* , *Db*), one inductor (*L*), and one capacitor (*C*) connected between voltage source *Vg* and the inverter bridge. Alow-pass *LC* filter is used at the output of the inverter bridge to filter the switching frequency components in the inverter outputvoltage *v*AB. As shown in Fig. 3.6 the capacitor *C* (connected between node *V*DC and ground) of SBI acts as a dc bus for dc loads while the capacitor *Cf* (connected between nodes *AO* and *BO*) of SBI acts as an ac bus for ac loads. The operating principle and pulsewidth modulation (PWM) control of the SBI

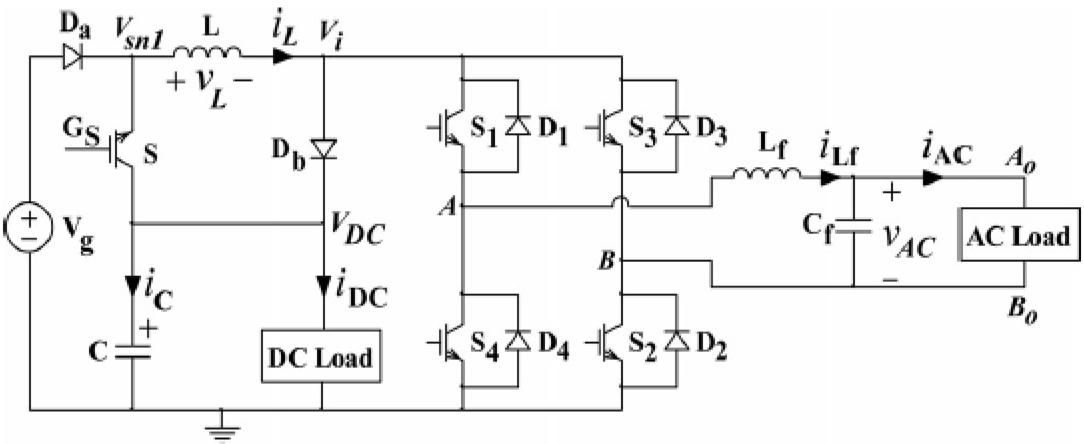


Fig 3.6 : Circuit Diagram of Switched Boost Inverter

The steady state operation of the Switched Boost Inverter (SBI) with its two modes of operation is explained below. It consists of two modes of operation and is capable of handling both positive and negative polarities by changing the switch operation. In the first mode, the inverter is in shoot-through zero state and switch S is turned ON. The diodes Da and Db. are reverse biased as VDC > Vg. In this interval, capacitor C charges the inductor L through switch S and the inverter bridge. So, the inductor current equals the capacitor discharging current minus the dc load current. In second mode, the inverter is in non-shoot through state and the switch S is turned OFF. The inverter bridge is represented by a current source in this interval as shown in the equivalent circuit of Fig 5.6. Now, the voltage source Vg and inductor L together supply power to the dc load, inverter, and the capacitor through diodes Da and Db. The inductor current in this interval equals the capacitor charging current added to the inverter input current and the dc load current. Note that the inductor current is assumed to be sufficient enough for the continuous conduction of the diodes *Da* , *Db* for the entire interval (1 – *D*)·*TS*

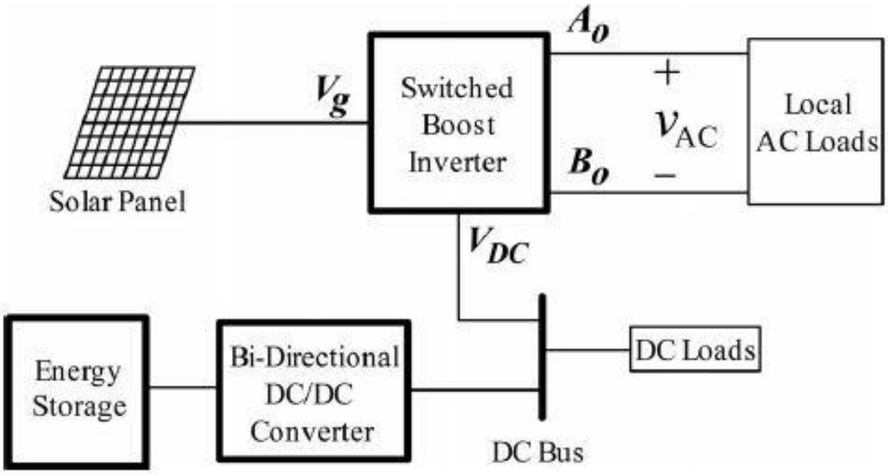


Fig 3.7 : Structure Of the Proposed SBI Based on Nanogrid

3.8 TOTAL HARMONIC DISTORTION:

Total harmonic distortion (THD) is a complex and frequently befuddling idea to handle. On the other hand, when separated into the essential meanings of sounds and twisting, it gets to be much simpler to get it. Presently envision that this heap is going to tackle one of two essential sorts: direct or nonlinear. The sort of burden is going to influence the force nature of the framework. This is because of the current draw of every kind of burden. Direct loads draw current that is sinusoidal in nature so they for the most part don't twist the waveform. Most family unit machines are classified as straight loads. Non-straight loads, then again, can draw current that is not consummately sinusoidal. Since the current waveform strays from a sine wave, voltage waveform bends are made. Consequently waveform mutilations can radically adjust the state of the sinusoidal.

CHAPTER -4

RESEARCH METHODLOGY

4.1 SIMULATION THEORY:

MATLAB (**mat**rix **lab**oratory) is a numerical computing environment and fourth-generation programming language. Developed by Math Works, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran. Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing capabilities. An additional package, Simulink, adds graphical multi-domain simulation and Model-Based Design for dynamic and embedded systems.

In 2004, MATLAB had around one million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics. MATLAB is widely used in academic and research institutions as well as industrial enterprises.

4.2 MATLAB HISTORY:

Cleve Moler, the chairman of the computer-science department at the University of New Mexico, started developing MATLAB in the late 1970s. He designed it to give his student’s access to LINPACK and EISPACK without them having to learn Fortran. It soon spread to other universities and found a strong audience within the applied mathematics community. Jack little, an engineer, was exposed to it during a visit Moler made to Stanford University in 1983. Recognizing its commercial potential, he joined with Moler and Steve Bangert. They rewrote MATLAB in C and founded Math Works in 1984 to continue its development. These rewritten libraries were known as JACKPAC. In 2000, MATLAB was rewritten to use a newer set of libraries for matrix manipulation, LAPACK.

MATLAB was first adopted by researchers and practitioners in control engineering, Little's specialty, but quickly spread to many other domains. It is now also used in education, in particular the teaching of linear algebra and numerical analysis, and is popular amongst scientists involved in image processing.

4.3 SIMULINK:

Simulink, developed by Math Works, is a commercial tool for modeling, simulating and analyzing multi-domain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in control theory and digital signal processing for multi-domain simulation and Model-Based Design

Simulink is a block diagram environment for multi-domain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with MATLAB, enabling you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis.

4.4 BUILDING THE MODEL:

Simulinkprovides a set of predefined blocks that you can combine to create a detailed block diagram of your system. Tools for hierarchical modeling, data management, and subsystem customization enable you to represent even the most complex system concisely and accurately.

4.4.1 Selecting Blocks:

The Simulink Library Browser contains a library of blocks commonly used to model a system. As shown in **Fig.4.2**, these include:

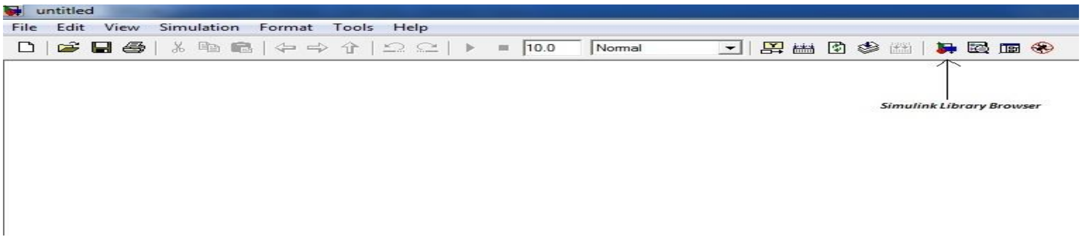


Fig 4.1 : Building a New Model

- Continuous and discrete dynamics blocks, such as Integration and Unit Delay
- Algorithmic blocks, such as Sum, Product, and Lookup Table
- Structural blocks, such as Mux, Switch, and Bus Selector

We can build customized functions by using these blocks or by incorporating hand-written MATLAB, C, Fortran, or Ada code into the model. The custom blocks can be stored in their own libraries within the Simulink Library Browser.

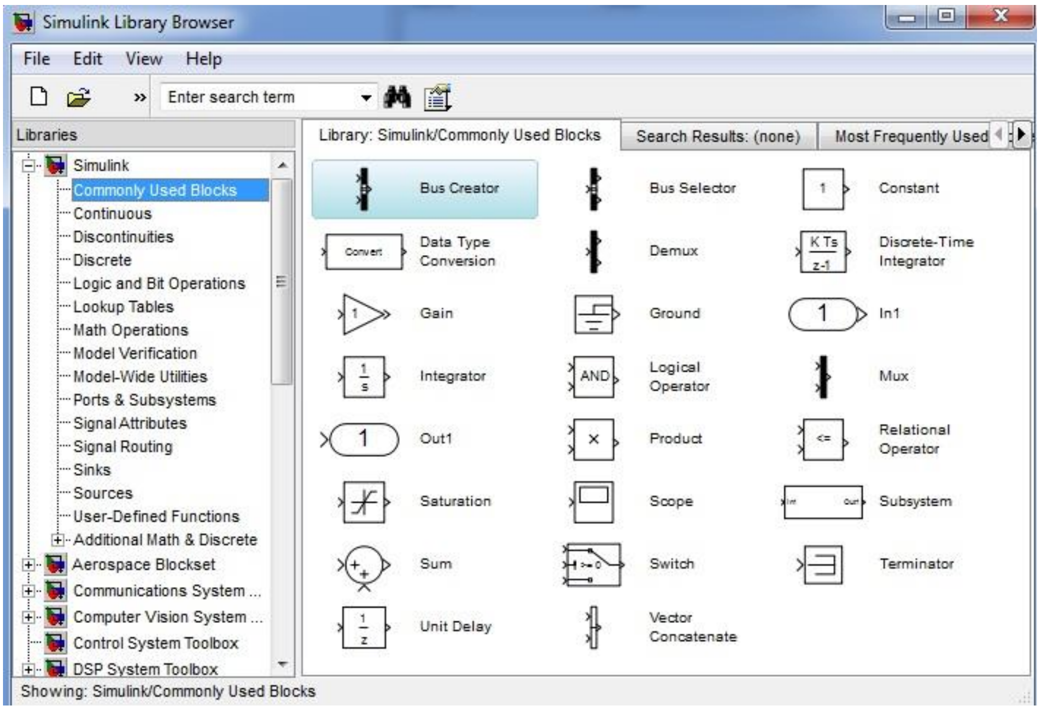


Fig 4.2 : Commonly Used Blocks

Simulink add-on products let you incorporate specialized components for aerospace, communications, PID control, control logic, signal processing, video and image processing, and other applications. Add-on products are also available for modeling physical systems with mechanical, electrical, and hydraulic components.

To build a model as shown in **Fig 4.1** by dragging blocks from the Simulink Library Browser into the Simulink Editor, we then connect these blocks with signal lines to establish mathematical relationships between system components. Graphical formatting tools, such as smart guides and smart signal routing, help we control the appearance of the model as webuild it. We can add hierarchy by encapsulating a group of blocks and signals as a subsystem in a single block.

The Simulink Editor gives a complete control over what we see and use within the model. For example, we can add commands and submenus to the editor and context menus. We can also add a custom interface to a subsystem or model by using a mask that hides the subsystem's contents and provides the subsystem with its own icon and parameter dialog box.

4.5 SIM POWER SYSTEM:

A Components provided in SimPowerSystems as shown in **Fig 4.3**include:

Electrical elements: Linear and saturable transformers; arrestors and breakers; and transmission line models.

Electric machinery: Models of synchronous, permanent magnet synchronous, and DC machines; excitation systems; and models of hydraulic and steam turbine-governor systems

Power electronics: Diodes, simplified and complex thyristors, GTOs, switches, IGBT models, and universal bridges that allow selection of standard bridge topologies

Control and measurement: Voltage, current, and impedance measurements; RMS measurements; active and reactive power calculations; timers, multimeters, and Fourier analysis; HVDC control; total harmonic distortion; and abc-to-dq0 and dq0-to-abc transformations

Electrical sources: To implement sinusoidal current source, sinusoidal voltage source, generic battery model, Controlled AC Current and Voltage sources, DC Voltage Source. To implement three-phase voltage source with programmable time variation of amplitude, phase, frequency, and harmonics, and to implement three-phase source with internal R-L impedance. The entire blocksets is shown in **fig 4.3.**

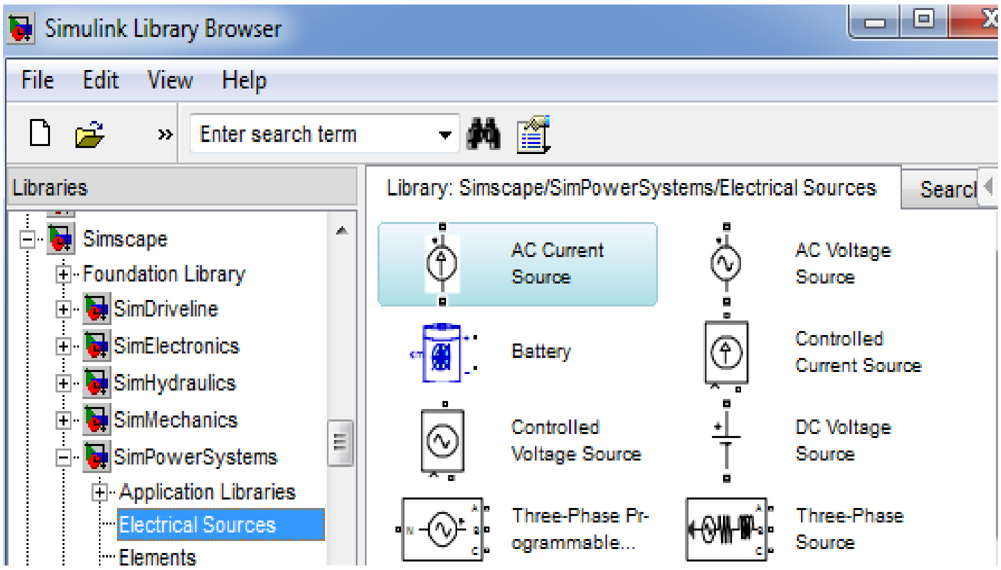
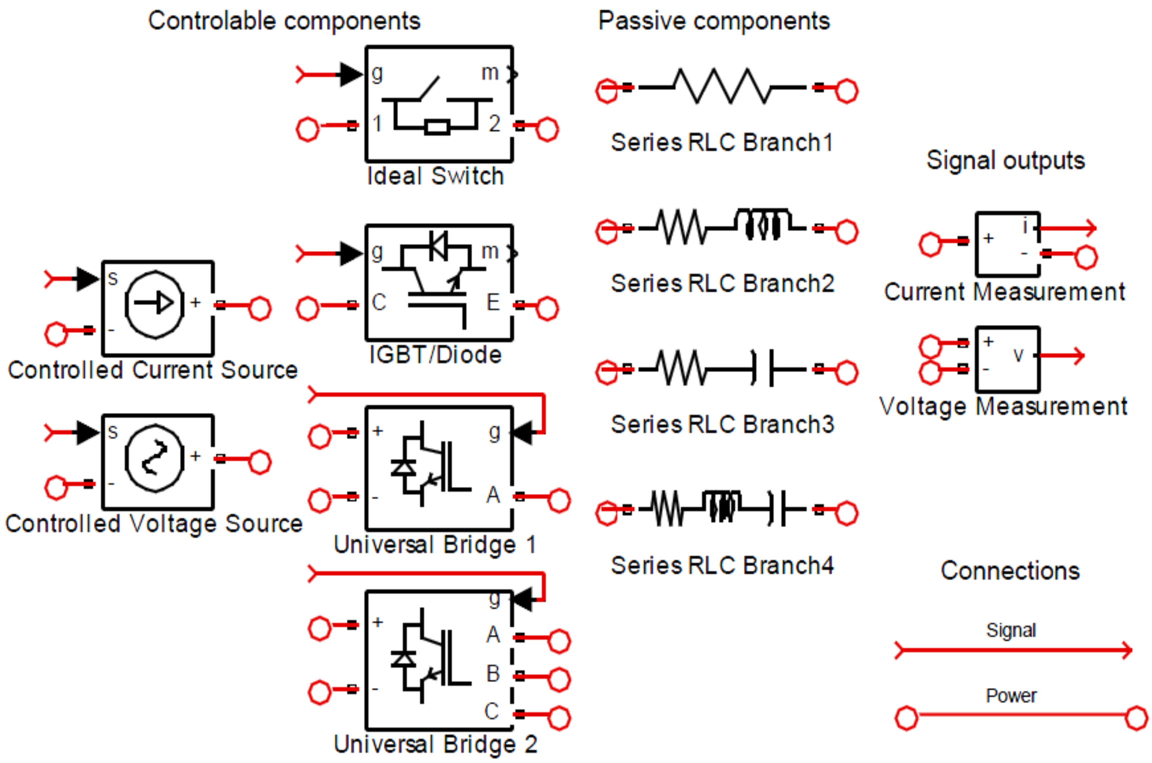


Fig 4.3 : Block Sets of Electrical Sources Used In Sim Power Systems

With Sim power systems,we build a model of a system just as we would assemble a physical system.The component in the model are connected by physical connections that represent ideal conduction paths.This approach describes the physical structure of the system rather that deriving and implementing the equations for the system .From the model ,which closely resembles a schematic,sim power systems automatically constructs the differential algebraic equations (DAEs) that characterize the behavior of the system .These equations are integrated with the rest of the simlink model.

We can use the sensor blocks in simlink power sytems to measure current and voltage in your power network,and then pass these signals into standard simlink blocks.sources blockes enable simulink signals to assign values to the electrical variables current and voltage.sensor and source blocks connect a control algorithms developed in simlink to a powersystem networks.

Simpower systems enables to model custom components by using the fundamental elements incluse in its libraries and by combining these elements with simlink blocks.



Electrical elements: Linear and saturable transformers; arrestors and breakers; and transmission line models.

Electric machinery: Models of synchronous, permanent magnet synchronous, and DC machines; excitation systems; and models of hydraulic and steam turbine-governor systems

Power electronics: Diodes, simplified and complex thyristors, GTOs, switches, IGBT models, and universal bridges that allow selection of standard bridge topologies

Control and measurement: Voltage, current, and impedance measurements; RMS measurements; active and reactive power calculations; timers, multimeters, and Fourier analysis; HVDC control; total harmonic distortion; and abc-to-dq0 and dq0-to-abc transformations

Electrical sources: To implement sinusoidal current source, sinusoidal voltage source, generic battery model, Controlled AC Current and Voltage sources, DC Voltage Source.

To implement three-phase voltage source with programmable time variation of amplitude, phase, frequency, and harmonics, and to implement three-phase source with internal R-L impedance.

Three-phase components: RLC loads and branches; breakers and faults; *pi*-section lines; voltage sources; transformers; synchronous and asynchronous generators; and motors, analyzers, and measurements

Electric Drives and Other Application Libraries

SimPowerSystems provides the following specialized application libraries:

Flexible AC Transmission Systems (FACTS): Phasor models of flexible AC transmission systems

Distributed Resources: Phasor models of wind turbines

Electric Drives: Editable models of electric drives that include detailed descriptions of the motor, converter, and controller for each drive. The Electric Drives library includes permanent magnet, synchronous, and asynchronous (induction) motors. The converters and controllers implement the most common strategies for controlling the speed and torque for these motors, such as direct-torque control and field-oriented control.

SimPowerSystems supports the development of complex, self-contained power systems, such as those in automobiles, aircraft, manufacturing plants, and power utility applications. You can combine SimPowerSystems with other MathWorks physical modeling products to model complex interactions in multi-domain physical systems. The block libraries and simulation methods in SimPowerSystems were developed by Hydro-Québec of Montreal.

CONNECTING TO HARDWARE:

- We can connect the Simulink model to hardware for rapid prototyping, hardware-in the-loop (HIL) simulation, and deployment on an embedded system.
- We can connect the Simulink model to hardware for rapid prototyping, hardware-in the-loop (HIL) simulation, and deployment on an embedded system.
- Simulink provides built-in support for prototyping, testing, and running models on low-cost target hardware, including Arduino®, LEGO® MINDSTORMS® NXT, and BeagleBoard .

With Real-Time Windows Target™, we can run Simulink models in real time on Microsoft® Windows® PCs and connect to a range of I/O boards to create and control a real-time system.To run the model in real time on a target computer, we can use xPC Target™ for HIL simulation, rapid control prototyping, and other real-time testing applications. See xPC Target Turnkey for available target computer hardware. Simulink models can be configured and made ready for code generation. By using Simulink with add-on code generation products, you can generate C and C++, HDL, or PLC code directly from your model.

APPLICATIONS:

A number of MathWorks and third-party hardware and software products are available for use with Simulink. For example, Stateflow extends Simulink with a design environment for developing state machines and flow charts. Coupled with Simulink Coder, another product from MathWorks, Simulink can automatically generate C source code for real-time implementation of systems. As the efficiency and flexibility of the code improves, this is becoming more widely adopted for production systems, in addition to being a popular tool for embedded system design work because of its flexibility and capacity for quick iteration. Embedded Coder creates code efficient enough for use in embedded systems.

Target together with x86-based real-time systems provides an environment to simulate and test Simulink and Stateflow models in real-time on the physical system. Embedded Coder also supports specific embedded targets, including Infineon C166, Motorola68HC12, Motorola MPC 555, TI C2000, TI C6000, RenesasV850 and Renesas SuperH. With HDL Coder, also from MathWorks, Simulink and Stateflow can automatically generate synthesizable VHDL and Verilog.

Simulink Verification and Validation enables systematic verification and validation of models through modeling style checking, requirements traceability and model coverage analysis. Simulink Design Verifier uses formal methods to identify design errors like integer overflow, division by zero and dead logic, and generates test case scenarios for model checking within the Simulink environment. The systematic testing tool TPT offers one way to perform formal test- verification and validation process to stimulate Simulink models but also during the development phase where the developer generates inputs to test the system. By the substitution of the Constant and Signal generator blocks of Simulink the stimulation becomes reproducible.

Sim Events adds a library of graphical building blocks for modeling queuing systems to the Simulink environment. It also adds an event-based simulation engine to the time-based simulation engine in Simulink.

CHAPTER-5

RESULTS AND ANALYSIS

5.1 INVERSE WATKINS JOHNSON TOPOLOGY:

SBI is a single-stage power converter derived from Inverse Watkins Johnson (IWJ) Topology. This topology exhibits properties similar to that of a Z-source inverter (ZSI) with lower number of passive components and more active components. This section presents a review of the approach used to derive the SBI from IWJ topology. A detailed comparison of SBI with a traditional two-stage dc-to-ac conversion system is
also given in this section.

5.2 DERIVATION OF SBI FROM IWJ TOPOLOGY:

The schematic of IWJ converter [26] is shown in Fig 5.1 and its equivalent circuits in $D{\cdot}TS$ and $(1 - D){\cdot}TS$ intervals of a switching cycle TS are shown in Fig. 5.2 and 5.3 respectively. As shown in Fig 5.2, during $D{\cdot}TS$ interval, the two switches of the converter are in position 1, and inductor L is connected between the input and the output. Similarly, during $(1 - D){\cdot}TS$ interval, the switches are in position 0 and the inductor is connected between the output and the ground, as shown in Fig 5.3 Interchanging the $D{\cdot}TS$ (position1), and $(1 - D){\cdot}TS$ (position 0) intervals of IWJ converter leads to Fig. 4(d). This configuration is named as the complementary IWJ (CIWJ) topology in. Note that this interchange has no impact on the states of the converter. However, as far as implementation is concerned, this will imply that the controlled switch and diode of CIWJ and IWJ are interchanged.

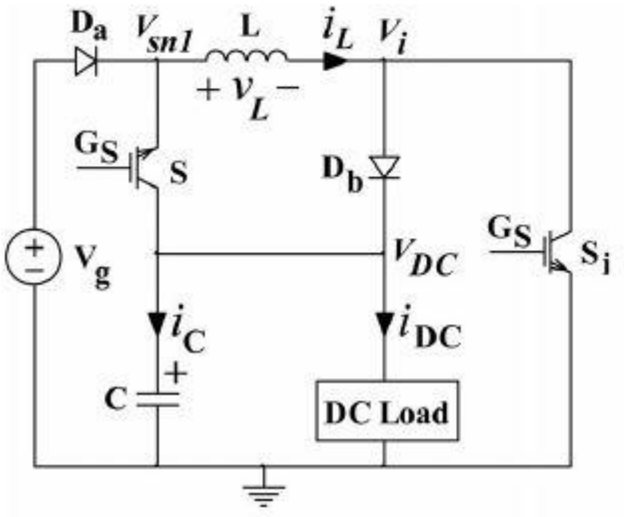


Fig 5.1 : Realization of CIWJ topology using power semiconductor devices.

Fig. 5.1 shows the realization of CIWJ topology using power semiconductor devices .The output of this converter is a dc voltage *V*DC. In order to convert this dc voltage to an ac voltage, one has to use a VSI. This VSI may be directly connected at the output node *V*DC of CIWJ topology [shown in Fig. 5.2 which becomes a cascaded connection of a dc–dc converter and a regular VSI. But this combination cannot overcome the general limitations of a traditional VSI.

- Dead-time is necessary to prevent the damage of the switches in the event of shoot-through in inverter phase legs,
- Complex dead-time compensation technologies should be used to compensate the waveform distortion caused by dead-time.

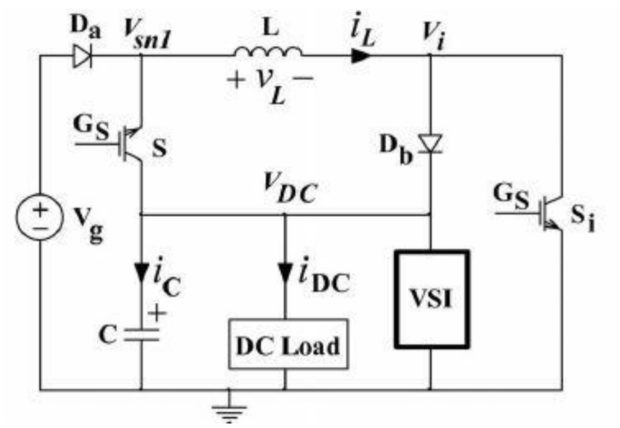


Fig 5.2 : Connection of a VSI across the dc output node *V*DC of CIWJ topology.

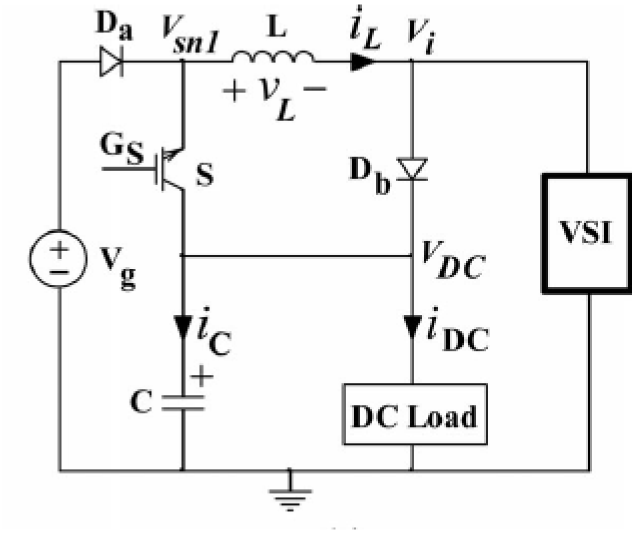


Fig 5.3 : Connection of a VSI across the switching terminal Vi of the CIWJ topology (switch Si can be realized by using the shoot-through state of the VSI).

Fig. 5.3 shows another possible connection of the VSI, in which the inverter bridge is connected across the switch node Vi of the CIWJ topology. Note that this combination requires only controlled switch S apart from the inverter bridge. The switch Si of CIWJ topology can be realized by utilizing the shoot-through state of the inverter bridge. Also, similar to the cascaded connection shown in Fig. 5.2 this circuit can also supply a dc load (at the output of CIWJ) and an ac load (at the output of the inverter bridge) simultaneously from a single dc voltage source Vg . The circuit of Fig. 5.3 is named as SBI topology. Note that it is not a direct cascade connection of CIWJ topology and VSI, as the inverter bridge is connected at a switch node of CIWJ converter but not at its output terminal. When compared to the cascaded connection shown in Fig. 5.2.

5.3 ADVANTAGES OF SBI:

- In the event of shoot-through in any phase leg of the inverter bridge, the diode Db is reverse-biased and capacitor C is disconnected from the inverter bridge. Now, the current through the circuit is limited by the inductor L. So, similar to ZSI, shoot-through does not damage the switches of the SBI also.

- As the SBI allows shoot-through, no dead-time is needed to protect the converter. Also this circuit exhibits better EMI noise immunity compared to a traditional VSI.
- Since dead-time is not required, there is no need of extra dead-time compensation technologies to compensate the waveform distortion caused by dead-time..

Note that a ZSI also exhibits similar advantages of SBI mentioned above. But the SBI achieves these properties with lower number of passive components and more active components compared to ZSI. This is because the impedance network of ZSI uses two inductors, two capacitors, and a diode apart from the inverter bridge, while the SBI requires only one inductor, one capacitor, a controlled switch, and two diodes. The Reduction in number of passive components leads to the reduced size of the power converter stage. Also ZSI requires passive components with high consistency, which is not the case with SBI. Another major advantage of SBI when compared to ZSI is that it can supply both dc and ac loads simultaneously from a single dc voltage source, as shown in Fig 5.3 However, the limitation of SBI is that its peak inverter input voltage is only $(1-D)$ times that of ZSI, where D is the shoot-through duty ratio of the inverter bridge. A more detailed quantitative comparison of SBI and ZSI give below.

5.4 COMPARISON OF SBI WITH TRADITIONAL TWO –STAGE DC – AC CONVERSION SYSTEM:

In the previous section, it is shown that the SBI is a single input, two-output (one dc output and one ac output) power converter derived from IWJ converter and a VSI. Similar to the traditional two-stage dc-to-ac conversion system shown in Fig. 6, the SBI can also generate an ac output voltage that is either greater or less than the input dc voltage. However, the SBI has certain advantages and limitations when compared to the two stage conversion system shown in Fig 5.4 which are discussed below.

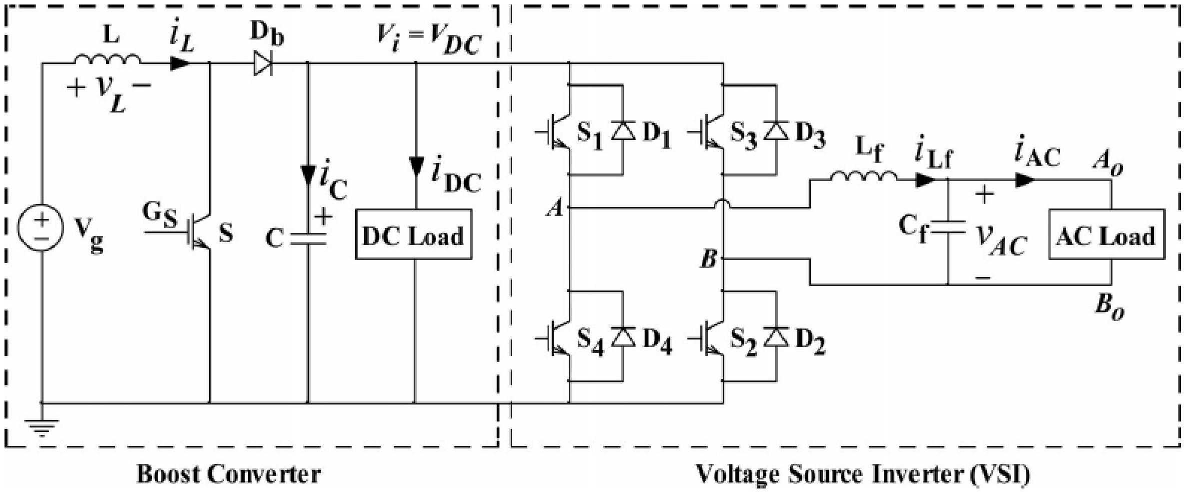


Fig 5.4 : Traditional two-stage dc-to-ac conversion system Boost converter cascaded with a VSI**.**

- **Dead-Time Requirement:** A shoot-through event in the inverter bridge of the two-stage conversion system damages the power converter stage, as well as the dc loads connected to the dc bus of the nan grid. So a dead-time circuit is necessary to minimize the occurrence of shoot-through events in this system. Moreover, to compensate the waveform distortion caused by dead-time, one has to use the complex dead-time compensation technologies.This is not the case with SBI, as it allows shoot-through in the inverter phase legs. So the use of SBI eliminates the need for a dead-time circuit as well as the requirement of dead-time compensation technologies.

- **Reliability and EMI Noise Immunity:** Even with a dead time circuit, the probability of a shoot-through event cannot be eliminated completely because an EMI noise can also cause shoot-through in the inverter phase legs.With the use of SBI, the shoot-through event does not damage the switches of the power converter. So, SBI exhibits better EMI noise immunity and hence has better reliability compared to the two-stage conversion system.

- **Extreme Duty Cycle Operation:** At the extreme duty ratio operation (e.g., for $D \geq 0.75$) of a conventional boost converter, the inductor L is charged over a longer time duration in the switching cycle, and very small time interval is left to discharge the inductor through the output diode *Db*..So this diode should sustain a short pulse width current with relatively high amplitude. Also, this causes severe diode reverse recovery current and increases the EMI noise levels in the converter. This also imposes a limit on the switching frequency of the boost converter and thus increases the size of the passive components used in the two-stage conversion system shown in Fig 5.4.In case of SBI, the maximum shoot-through duty ratio is always limited to 0.5 for a positive dc bus voltage. So, even when the converter operates at the point of maximum conversion ratio, the conduction time of the diodes *Da*, *Db* of SBI is approximately equal to 50% of the switching time period, which alleviates the problems due to extreme duty ratio operation of a boost converter. So, SBI can operate at relatively higher switching frequencies compared to the traditional two stage conversion system. This also decreases the size of passive components used in the power converter.

- **Voltage Stress of Switching Devices:** The Table shown below compares the voltage stress of the semiconductor devices used in the SBI and the two-stage conversion system shown in Fig 5.4 From this table, it can be observed that the switch "*S*" has less voltage stress ($V_{DC} - V_g$) in case of SBI. For all other devices, the voltage stress is same for both SBI and the two-stage conversion system.

Converter	Voltage stress across the device				
	S	S_1, S_2, S_3, S_4	D_a	D_b	D_1, D_2, D_3, D_4
SBI (Fig. 3)	$V_{DC} - V_g$	V_{DC}	$V_g - V_{DC}$	V_{DC}	V_{DC}
Two-stage conversion system (Fig. 6)	V_{DC}	V_{DC}	-	V_{DC}	V_{DC}

Fig 5.5 : Voltage Stress Comparison Of SBI and Two Stage Conversion System

Maximum Conversion Ratio : The maximum conversion ratio (VDC/Vg) of a practical boost converter cannot exceed 3.0 (approximately), due to the effects of various non idealities such as DCR/ESR of the passive components, on-state voltage drops of the semiconductor devices, etc. This value may slightly vary depending on the actual values of non ideal elements present in the converter. Similarly, the rms ac output voltage $V_{ac}(rms)$of a single-phase inverter using sinusoidal PWM cannot exceed times the dc link voltage (VDC) in the linear modulation range ($0 < M < 1$), for a low distortion sine wave output. So the maximum overall rms ac-to-dc conversion ratio of two-stage conversion system shown in Fig 5.4 is approximately 2.12. This value may still decrease if the effects of non idealities in VSI are taken into consideration. The rms ac-to-dc conversion ratio of the two-stage conversion ratio may be increased slightly by using semiconductor devices with very low forward voltage drops and passive components with very low ESR/DCR. This enhances the overall cost of the power converter stage. Another way to increase the conversion ratio of the two-stage conversion system is to use high step up dc-to-dc converters or the converters with transformer coupled inductor . These converters require additional semiconductor devices and passive components which increase the size as well as cost of the power converter stage. In this paper, it is shown experimentally in Section V that the maximum rms ac-to-dc conversion ratio of the SBI is 2 which is comparable to that of a two-stage conversion system. Also, as explained above, SBI has no diode reverse recovery problems with extreme duty ratio operation. So this conversion ratio is possible even at high switching frequency and with better reliability and EMI noise immunity. Note that, in this paper, the SBI has been tested with only one PWM control technique proposed in where the maximum value of modulation index (M) is limited by the shoot-through duty ratio (D). However, as the operation of SBI is similar to ZSI, it is possible to extend maximum boost control and maximum constant boost control techniques of ZSI to SBI. This may help SBI to achieve higher conversion ratios compared to the two-stage conversion system, without increasing the number of devices.

- **Number of Control Variables:** Similar to a two-stage conversion system, the SBI also has two control variables: Shoot through duty ratio (D) and the modulation index (M).The dc bus voltage VDC is controlled by D, while ac output voltage of the converter is controlled by M. However, similar to ZSI. The value one of these two control variables decides the upper limit of the second control variable of SBI. The mathematical relation between D and M depends on the control technique used. Note that, as mentioned above, it is possible to extend most of the PWM control techniques of ZSI to control the SBI also.

- **Number of Devices:** As shown in Fig 3.6 the SBI requires five active switches, six diodes, two inductors, and two capacitors for its realization. The two-stage conversion system shown in Fig. 6 uses only one diode (Da) less compared to the SBI. However, in a dc nan grid, the input comes from a renewable energy source, e.g., solar panel or fuel cell, which should always be associated with a series diode to block the reverse power flow.So the diode Da of SBI can be a part of the renewable energy source which eliminates the need for an external diode. Thus, the number of devices in both converters is same.

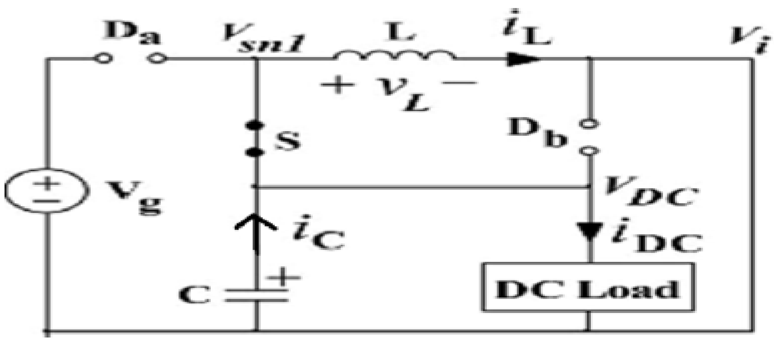


Fig 5.6 : Equivalent circuit of SBI in *D·TS* interval.

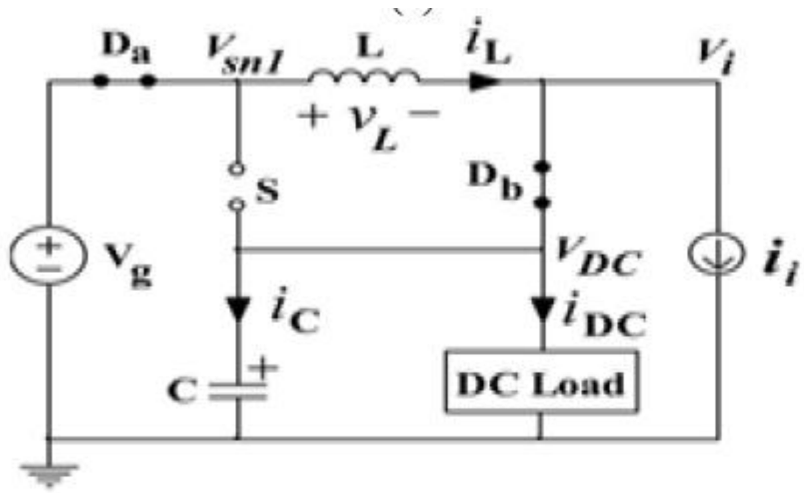


Fig 5.7 : Equivalent circuit of SBI in (1 – *D*)·*TS*

5.5 PWM CONTROL OF SBI:

The circuit diagram of SBI supplying both dc and ac loads is shown in Fig. 3. Fig. 7(a) and (b) shows the equivalent circuits of SBI during the shoot-through interval *D·TS* and non-shoot through interval (1 – *D*).*TS* of the inverter bridge, respectively. As shown in Fig. 7(a), during *D·TS* interval, the inverter is in shoot-through zero state and switch *S* is turned ON. The diodes *Da* and *Db* are reverse biased as *V*DC > *Vg* .In this interval, capacitor *C* charges the inductor *L* through switch *S* and the inverter bridge. So, the inductor current equals the capacitor discharging current minus the dc load current. During (1 – *D*) ·*TS* interval, the inverter is in non-shoot through state and the switch *S* is turned OFF. The inverter bridge is represented by a current source in this interval as shown in the equivalent circuit of Fig 5.7 .Now, the voltage source *Vg* and inductor *L* together supply power to the dc load, inverter, and the capacitor through diodes *Da* and *Db* . The inductor current in this interval equals the capacitor charging current added to the inverter input current and the dc load current. Note that the inductor current is assumed to be sufficient enough for the continuous conduction of the diodes *Da* , *Db* for the entire interval (1 – *D*)·*TS* . Fig 5.8 shows the steady-state waveforms of the converter operation for one switching cycle *TS* with respect to the gate control signal *GS* of switch *S*

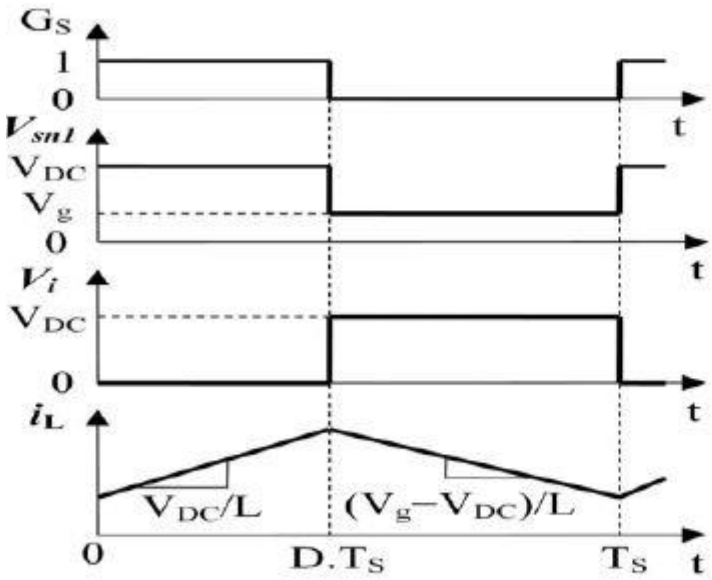


Fig 5.8 : Steady-state waveforms.

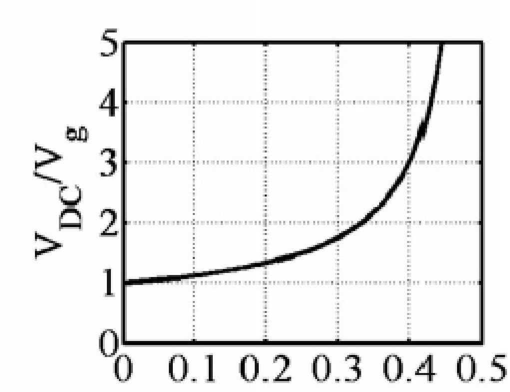


Fig 5.9 : Transfer (dc–dc) characteristics of SBI.

The SBI utilizes the shoot-through interval of the H-bridge to invoke the boost operation. So, the traditional PWM techniques of VSI have to be modified to incorporate the shoot-through state, so that they are suitable for SBI. In a PWM scheme for SBI is developed based on the traditional sine-triangle PWM with unipolar voltage switching This technique has been illustrated in Fig. 8 during positive and negative half cycles of the sinusoidal modulation signal $V_m(t)$

As shown in Fig. 8(b) and (d), during positive half cycle of $V_m(t)$ ($V_m(t) > 0$), the gate control signals *GS* 1 and *GS* 2 are generated by comparing the sinusoidal modulation signals $V_m(t)$, and $-V_m(t)$ with a high-frequency triangular carrier $V_{tri}(t)$ of amplitude Vp . The frequency f_s of the carrier signal is chosen such that f_o . Therefore, $V_m(t)$, is assumed to be nearly constant in Fig 5.10 The signals ST1 and ST2 are generated by comparing $V_{tri}(t)$ with two constant voltages V_{ST} and -V_{ST}, respectively. The purpose of these two signals is to insert the required shoot-through interval *D·TS* in the PWM signals of the inverter bridge. Now the gate control signals for switches *S*3 , *S*4 , and *S* can be obtained using the logical expressions given as follows:

*GS*3 =*GS*2+ST1 ; *GS*4 =*GS*1 +ST2 ; *GS* = ST1 +ST2 .

Similarly, as shown in Fig 5.12 and 5.13 during negative half cycle of $V_m(t)$, ($V_m(t)$, < 0), the gate control signals *GS*3 and *GS*4 are generated by comparing the modulation signals $-V_m(t)$,, and $V_m(t)$, with the triangular carrier $V_{tri}(t)$. The shoot-through signals ST1 and ST2 are generated in the same manner as in the positive half cycle. The gate control signals for switches *S*1 , *S*2 , and *S* can be obtained using the logical expressions given as follows:

*GS*1 =*GS*4+ST1 ; *GS*2 =*GS*3 +ST2 ; *GS* = ST1 +ST2 .

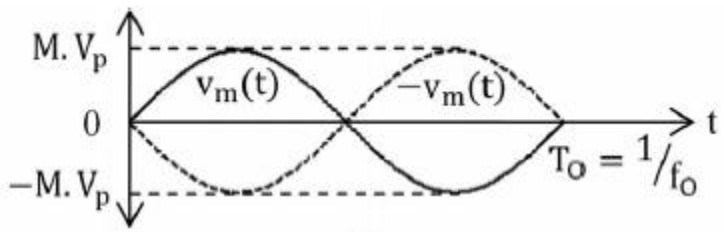


Fig 5.10 : Sinusoidal Modulation Signals vm (t) and –vm (t).

It can be observed from Fig. 8 that, during positive half cycle of $V_m(t)$,the shoot-through signals ST1, ST2 are logically added to *GS*2 , *GS*1 , respectively, while in negative half cycle of $V_m(t)$,, these signals are logically added to *GS*4 , GS3, respectively. This takes care that all four switches of the inverter bridge equally participate in generating the shoot-through interval. Note that with this PWMcontrol technique, the shoot-through state of the inverter bridge will have no effect on the harmonic spectrum of the inverter's output voltage V_{AB}, if the sum of shoot-through duty ratio (*D*) and the modulation index (*M*) is less than or equal to unity.

$M+D \leq 1$

The maximum ac-to-dc conversion ratio of SBI that can be achieved with this PWM control technique. However, as the operation of SBI is similar to that of a ZSI, it is possible to extend maximum boost control and maximum constant boost control techniques of ZSI to SBI.With these techniques, the sum of *M* and *D* of SBI can be more than unity. Thus, the SBI can achieve higher ac-to-dc conversion ratios with these control techniques.

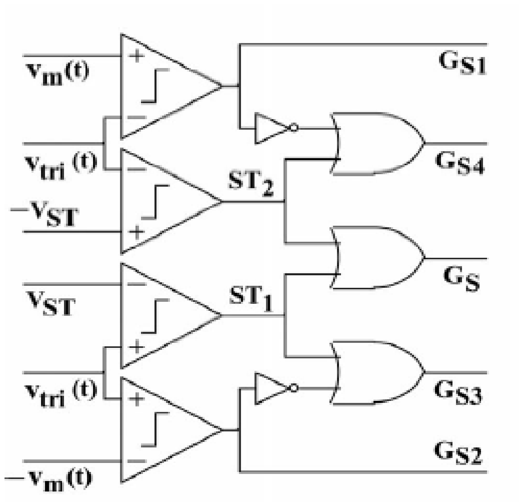


Fig 5.11 : Schematic of the PWM control circuit when vm (t) > 0.

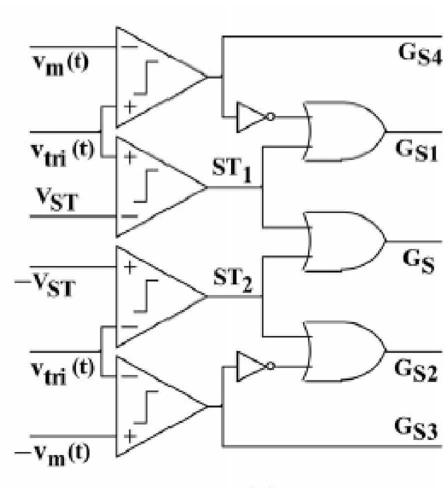


Fig 5.12 : Schematic of the PWM control circuit when vm (t) < 0.

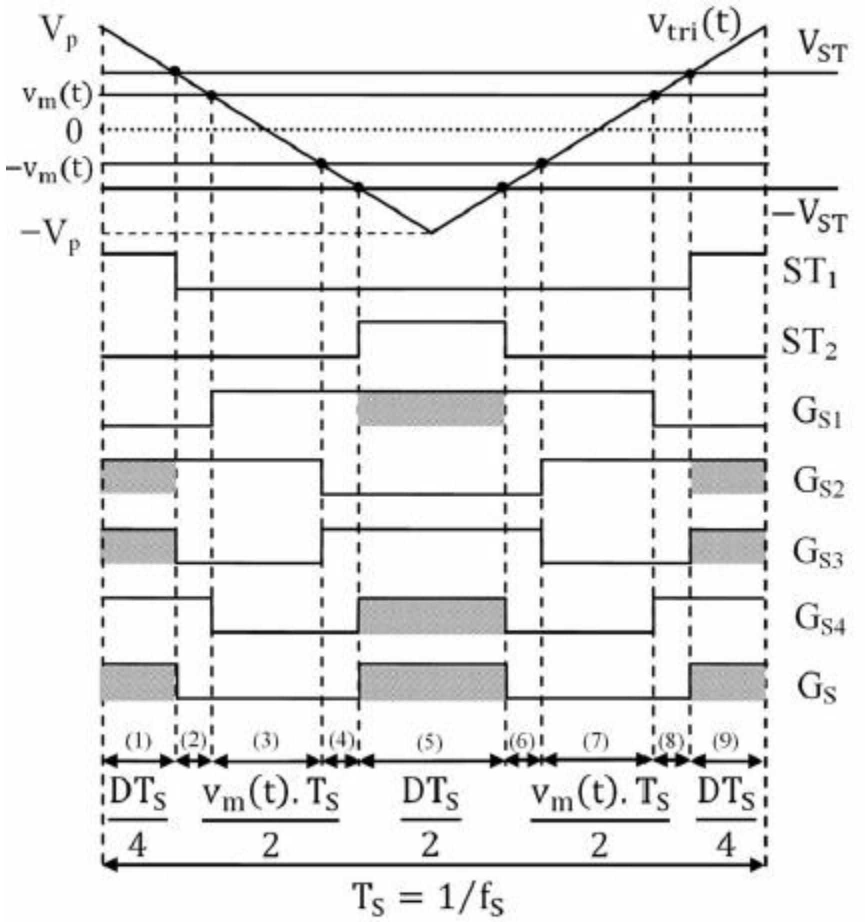


Fig 5.13 : Generation of gate control signals for SBI when vm (t) > 0.

Parameter/Component	Attributes
Input Voltage (V_g)	48 V
Fundamental frequency (f_O)	50 Hz
Switching frequency (f_S)	10 kHz
Inductor (L)	850 μH
Capacitor (C)	1000 μF
Output Filter Inductor (L_f)	1.0 mH
Output Filter Capacitor (C_f)	10 μF
AC Load (Resistive)	210 Ω, 250 W
DC Load (Resistive)	70 Ω, 250 W

Fig 5.14 : Parameters Used For Experiments.

5.6 SIMULATION OF THE PROPOSED SBI BASED DC NANOGRID :

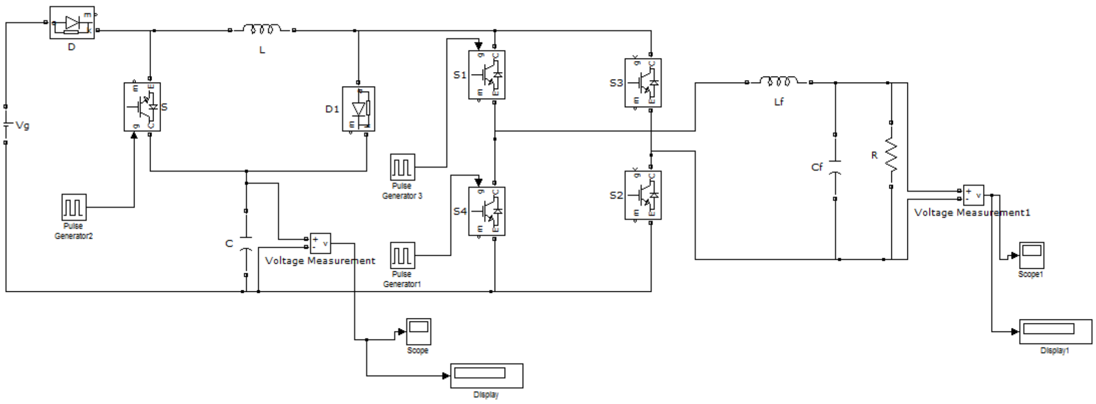


Fig 5.15 : Simulation Diagram of the Proposed Open loop SBI based DC Nanogrid.

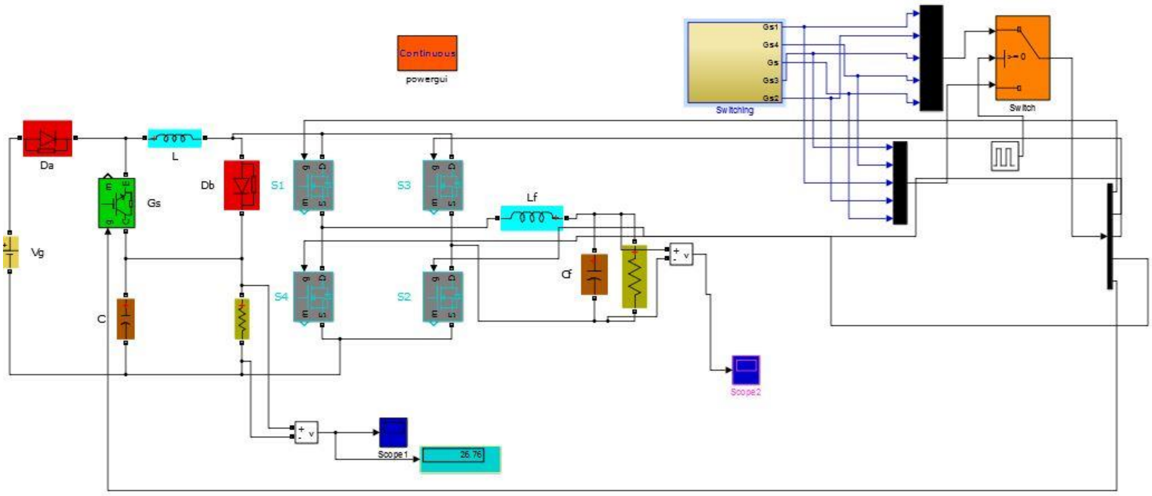


Fig 5.16 : Simulation Diagram of the Proposed Close loop SBI based DC Nanogrid

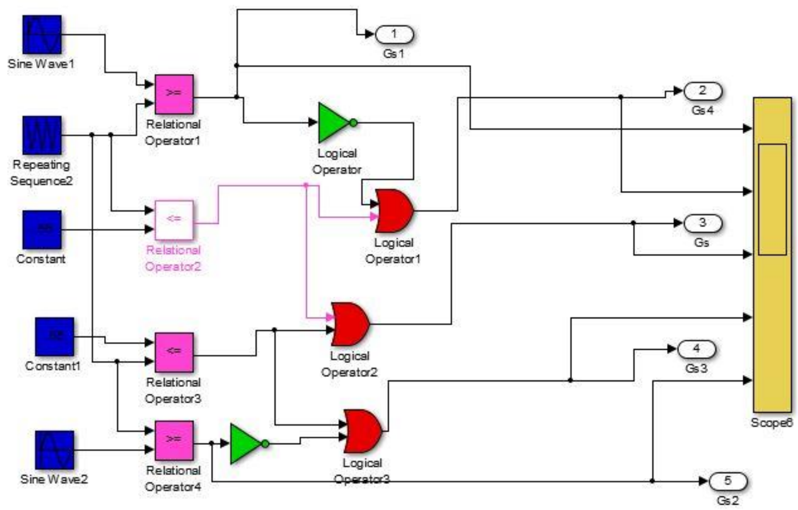


Fig 5.17 : Simulation of Subsystem of Proposed SBI based DC Nanogrid

Pulse width modulation is used to reduce the harmonics and improve the efficiency. The simulation results are shown in fig 7. The input dc voltage from the PV cell and the gating signals of five switches of SBI is shown in fig 5.18 Also the AC and DC output load voltages are shown in fig 5.20 and 5.19 respectively. The output voltage is boosted as compared with the input DC, with the help of the switched Boost Inverter configuration**.**

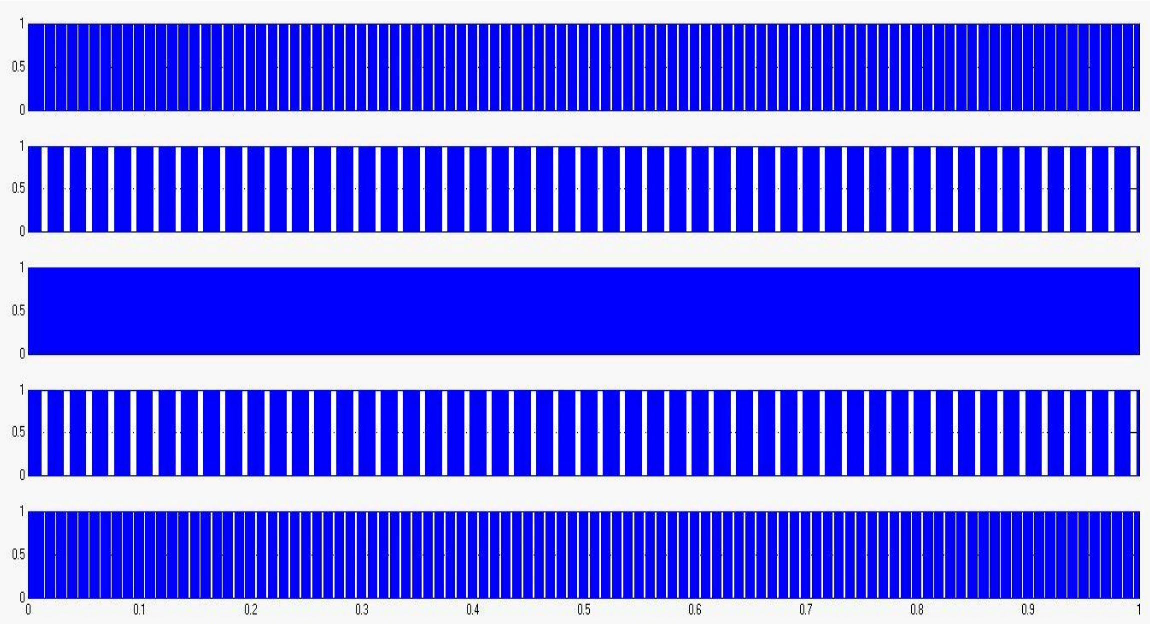


Fig 5.18 : Gattings Signals Of SBI Switches

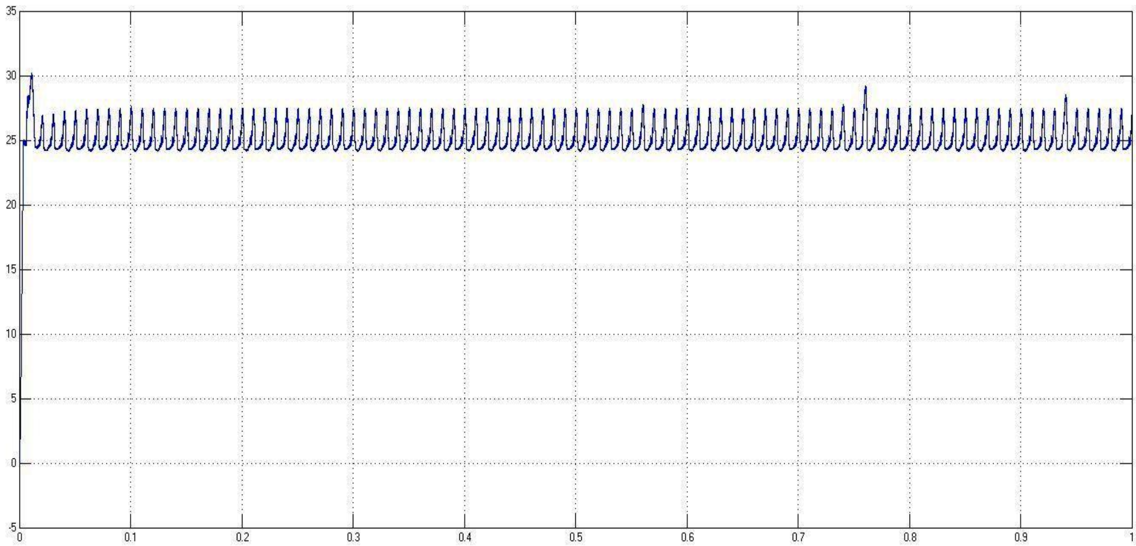


Fig 5.19 : Output DC voltage of the proposed SBI based DC nanogrid

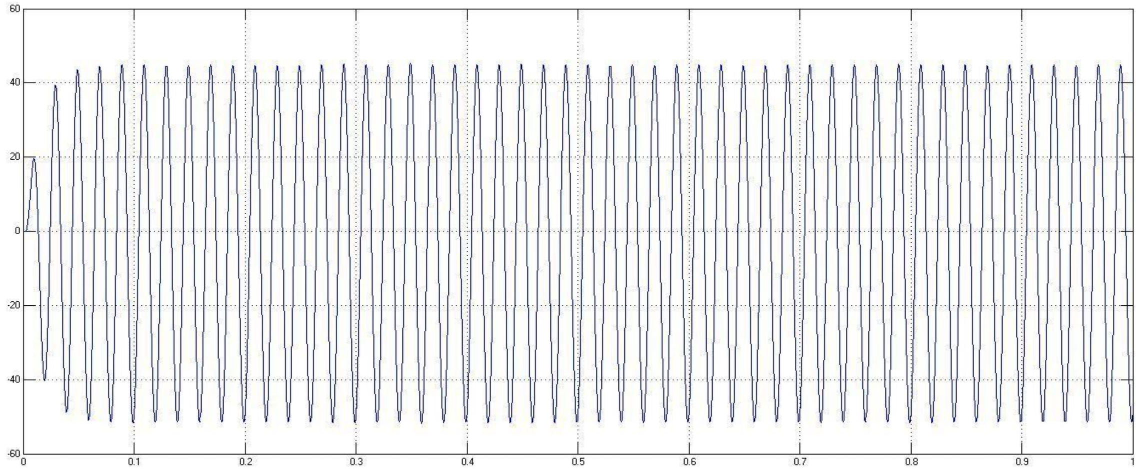


Fig 5.20 : Output AC voltage of the proposed SBI based DC nanogrid

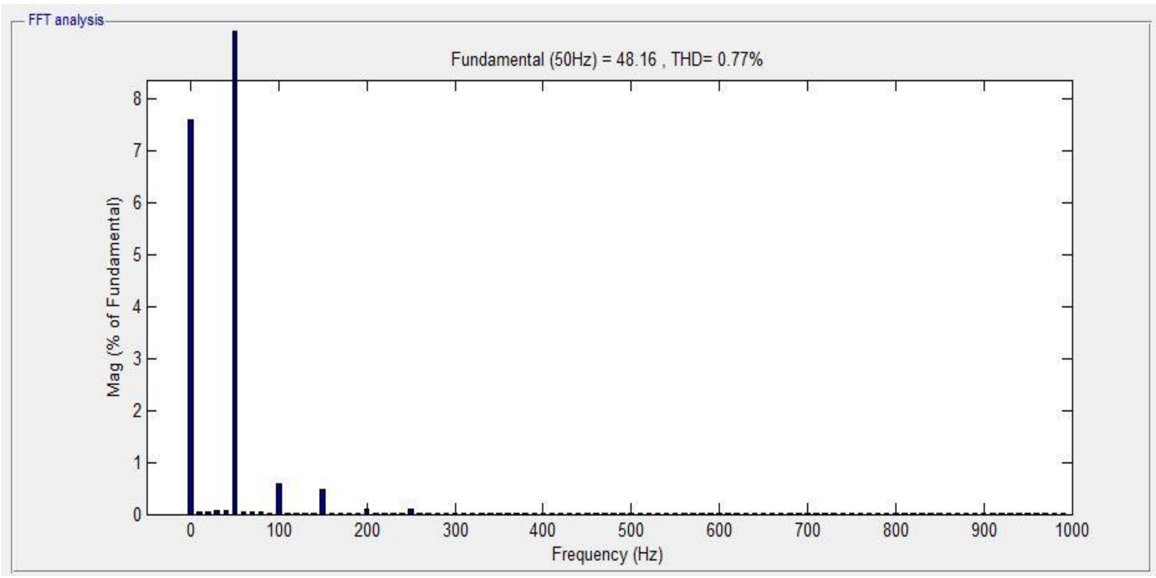


Fig 5.21 : THD of the Proposed SBI Based DC Nanogrid

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CONCLUSION:

Switched boost inverter (SBI) can produce an ac output voltage which is either greater or less than that of the dc input voltage. This also exhibits better Electro Magnetic Interference (EMI) noise immunity as compared to the VSI, which enables compact design of the power converter. It allows the shoot through switching state for boosting the input voltage and, compensates the dead time effect which causes the serious output voltage waveform distortion and avoids the risk of damaging the inverter switches. Therefore this circuit eliminates dead time circuit and complex dead time compensation technologies and thereby reduces the size and cost as compared to two stage DC to AC conversion system. It can supply both ac and dc loads simultaneously from a single dc input source. These features cannot be obtained in the traditional inverters and they are more advantageous for DC nanogrid applications.