Design and implementation of DC-Bus Voltage Control with a Three-Phase Bidirectional Inverter for DC Distribution Systems

R.Haridharan[1], Mr.Rajselvan[2]

***ABSTRACT*—this paper presents dc-bus voltage control with a three-phase bidirectional inverter for dc distribution systems. The bidirectional inverter can fulfill both grid connection and rectification modes with power factor correction. In this paper a dc-bus capacitance and control dc-bus voltage to track a linear relationship between the dc-bus voltage and inverter inductor current. This paper first presents determination of dc-bus capacitor size. The inverter tunes the dc-bus voltage every line cycle, which can reduce the frequency of operation-mode change and current distortion. This approach together can prevent dc-bus voltage from wide variation and improve the availability of the dc distribution systems without increasing dc-bus capacitance. Experimental results measured from a three-phase bidirectional inverter have verified the feasibility of the discussed control approaches.**

Index Terms—Bidirectional inverter, dc distribution system, dc-bus voltage control, grid connection, rectification, MPPT

I. INTRODUCTION

GRID-CONNECTED systems based on an ac-grid or ac-bus configuration at low-voltage distribution side has been widely studied, In an ac-bus system, the maximum power point tracker (MPPT) will draw maximum power from photovoltaic (PV) arrays and inject the power into ac bus or ac grid through an inverter. For a typical offline application, such as electronic ballast, personal computer, or variable speed . Appliance, it usually has a rectifier, a power factor corrector (PFC), and a dc/dc or dc/ac converter to supply the loads. However, this ac system leads to high power conversion loss. Thus, the concept of “dc grid” or “dc distribution” system has been presented recently [1]. It can be calculated that the power conversion efficiency in the ac-bus system is less than that in the dc-bus system about 8%. In addition, the dc-bus system can also save one rectifier and one PFC, saving component cost around 25%. Therefore, the dc distribution system is feasible in renewable energy applications. The dc distribution system requires a dc-bus voltage control to balance the power flow among PV panels, dc loads, and ac grid.

When the overall PV power is higher than the dc load power, the bidirectional inverter needs to sell power to ac grid, which is often defined as grid-connection mode. On the contrary, the inverter will buy power from ac grid, which is a rectification, namely “rectification mode.” Moreover, since in a dc distribution system, the dc-bus voltage is sensitive to step load changes, the control of dc-bus voltage is more critical than that in a grid-connected inverter system [2].In the past studies, the voltage control based on gain scheduling was presented [3]–[5], which uses a droop concept to design proper dc gain .Moreover, some attempts combing the Gain-scheduling with fuzzy control were also discussed [6], [7], which incorporate fuzzy control and adjust dc voltage reference

To balance power flow. Then, other dc-bus voltage controls, such as robust, adaptive, and hybrid control [8]–[10] to enhance system stability were reported.

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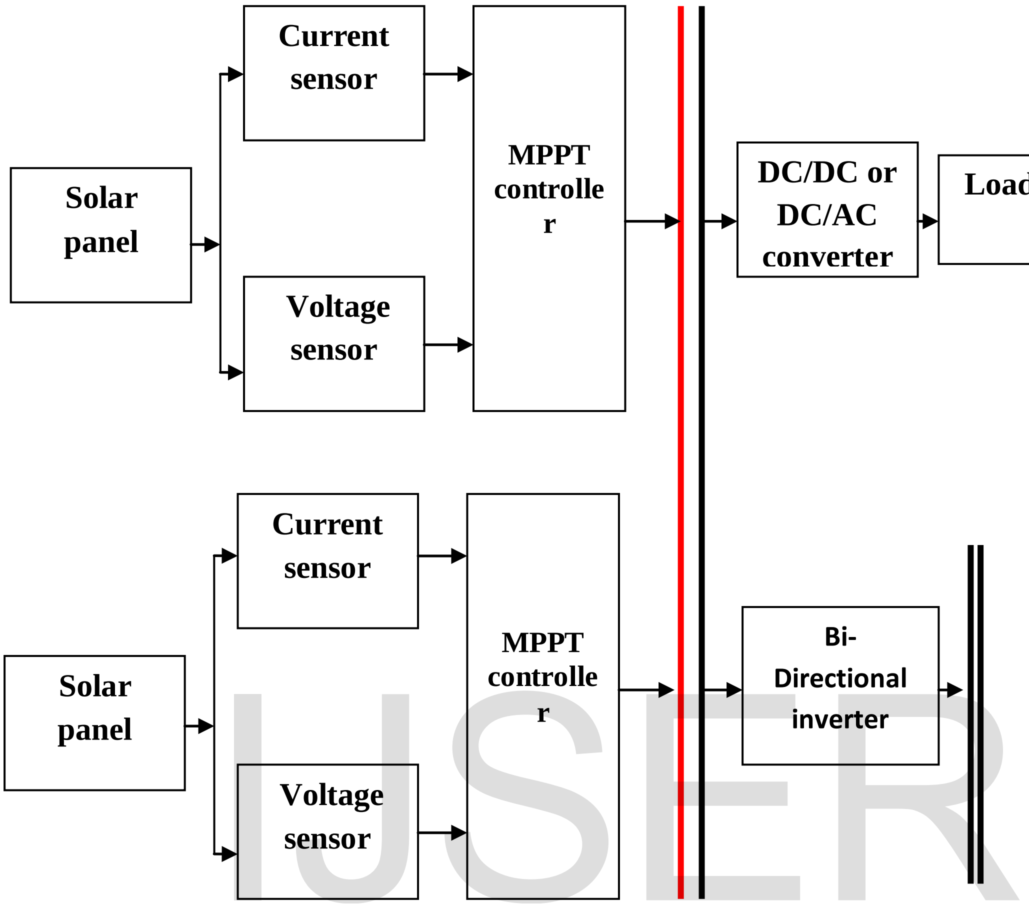


Fig 1. Block diagram

Proposed system:

The fig (1) dc distribution system requires a dc-bus voltage control to balance the power flow among PV panels, dc loads, and ac grid. When the overall PV power is higher than the dc load power, the bidirectional inverter needs to sell power to ac grid, which is often defined as grid-connection mode. On the contrary, the inverter will buy power from ac grid, which is a rectification, namely “rectification mode.” Moreover, since in a dc distribution system, the dc-bus voltage is sensitive to step load changes, the control of dc-bus voltage is more critical than that in a grid-connected inverter system

II SOLAR PANEL:

A solar panel (photovoltaic module or photovoltaic panel) is a packaged, interconnected assembly of solar cells, also known as photovoltaic cells. The fig (2) solar panel can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications.

Because a single solar panel can produce only a limited amount of power, many installations contain several panels. A photovoltaic system typically includes an array of solar panels, an inverter, and sometimes a battery and interconnection wiring.

Fig 2 solar panel

III. THEORY AND CONSTRUCTION:

Solar panels use light energy (photons) from the sun to generate electricity through the photovoltaic effect. The structural (load carrying) member of a module can either be the top layer or the back layer. The majority of modules use wafer-based crystalline silicon cells or thin-film cells based on cadmium telluride or silicon. The conducting wires that take the current off the panels may contain silver, copper or other conductive (but generally not magnetic) transition metals. The cells must be connected electrically to one another and to the rest of the system. Cells must also be protected from mechanical damage and moisture. Most solar panels are rigid, but semi-flexible ones are available, based on thin-film cells. Electrical connections are made in series to achieve a desired output voltage and/or in parallel to provide a desired current capability. Separate diodes may be needed to avoid reverse currents, in case of partial or total shading, and at night. The p-n junctions of mono-crystalline silicon cells may have adequate reverse current characteristics that these are not necessary. Reverse currents waste power and can also lead to overheating of shaded cells. Solar cells become less efficient at higher temperatures and installers try to provide good ventilation behind solar panels.

Some recent solar panel designs include concentrators in which light is focused by lenses or mirrors onto an array of smaller cells. This enables the use of cells with a high cost per unit area (such as gallium arsenide) in a cost-effective way

Depending on construction, photovoltaic panels can produce electricity from a range of frequencies of light, but usually cannot cover the entire solar range (specifically, ultraviolet, infrared and low or diffused light). Hence much of the incident sunlight energy is wasted by solar panels, and they can give far higher efficiencies if illuminated with monochromatic light.

Therefore another design concept is to split the light into different wavelength ranges and direct the beams onto different cells tuned to those ranges. This has been projected to be capable of raising efficiency by 50%. The use of infrared photovoltaic cells has also been proposed to increase efficiencies, and perhaps produce power at night. Currently the best achieved sunlight conversion rate (solar panel efficiency) is around 21% in commercial product, typically lower than the efficiencies of their cells in isolation. The Energy Density of a solar panel is the efficiency described in terms of peak power output per unit of surface area, commonly expressed in units of Watts per square foot (W/ft2).

IV. MODELING A PV CELL

The fig (3) use of equivalent electric circuits makes it possible to model characteristics of a PV cell. The method used here is implemented in MATLAB programs for simulations. The same modeling technique is also applicable for modeling a PV module. There are two key parameters frequently used to characterize a PV cell. Shorting together the terminals of the cell, the photon generated current will follow out of the cell as a short circuit current (Isc). Thus, Iph = Isc, when there is no connection to the PV cell (open-circuit), the photon generated current is shunted internally by the intrinsic p-n junction diode. This gives the open circuit voltage (Voc). The PV module or cell manufacturers usually provide the values of these parameters in their datasheets.

The simplest model of a PV cell equivalent circuit consists of an ideal current source in parallel with an ideal diode. The current source represents the current generated by photons (often denoted as Iph or IL), and its output is constant under constant temperature and constant incident radiation of light.

The PV panel is usually represented by the single exponential model or the double exponential model. The single exponential model is shown in fig.

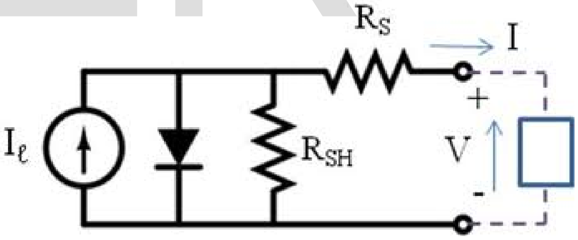


Fig 3 Modeling a Pv Cell

MPPT:

MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array. Over the past decades many methods to find the MPP have been developed and published. These techniques differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, correct tracking when irradiation and/or temperature change, hardware needed for the implementation or popularity, among others.

Among these techniques, the P&O and the Is an algorithms are the most common. These techniques have the advantage of an easy implementation but they also have drawbacks, as will be shown later. Other techniques based on different principles are

Fuzzy logic control, neural network, fractional open circuit voltage or short circuit current, current sweep, etc. Most of these methods yield a local maximum and some, like the fractional open circuit voltage or short circuit current, give an approximated MPP, not the exact one. In normal conditions the V-P curve has only one maximum, so it is not a problem. However, if the PV array is partially shaded, there are multiple maxima in these curves

.

Perturb and observe:

The P&O algorithm is also called “hill-climbing”, but both names refer to the same Algorithm depending on how it is implemented. Hill-climbing involves a perturbation on the duty cycle of the power converter and P&O a perturbation in the operating voltage of the DC link between the PV array and the power converter. In the case of the Hill-climbing, perturbing the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and the power converter, so both names refer to the same technique. In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be. As can be seen in Figure(4),(5), on the left of the MPP incrementing the voltage increases the power whereas on the right decrementing the voltage increases the power. If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm is implemented. The process is repeated until the MPP is reached.

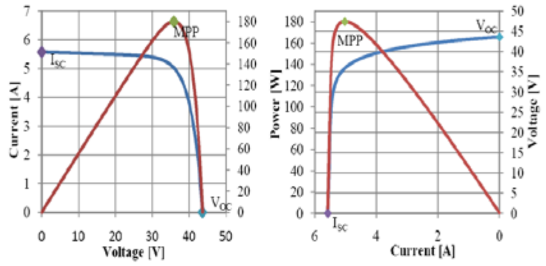


Fig 4 characteristics curve

Then the operating point oscillates around the MPP. This problem is common also to the InCond method, as was mention earlier. A scheme of the algorithm is shown in Figure

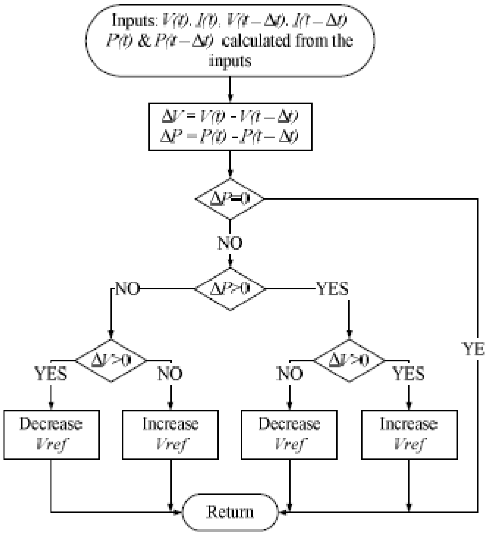
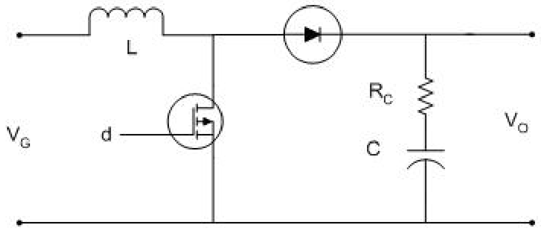


Fig 5 P&O algorithm

DC-DC converter:

The fig (6),(7) boost converter is capable of producing a dc output voltage greater in magnitude than the dc input voltage.

fig 6 boost converter



When the transistor Q1 is on the current in inductor L, rises linearly and at this

Time capacitor C, supplies the load current, and it is partially discharged. During the second interval when transistor Q1 is off, the diode D1, is on and the inductor L, supplies

The load and, additionally, recharges the capacitor C. The steady state inductor current and voltage waveform is shown in figure.

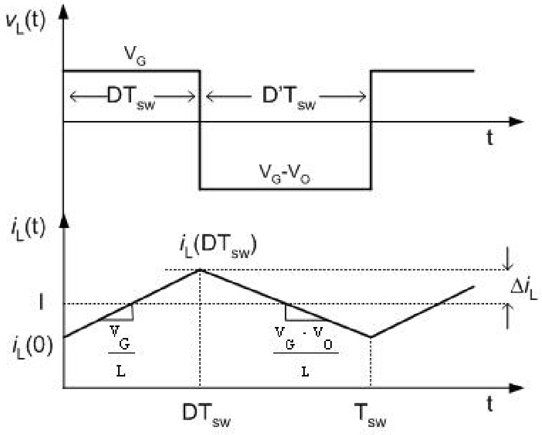


Fig 7 performance curve

Using the inductor volt balance principle to get the steady state output voltage equation

Yields Since the converter output voltage is greater than the input voltage, the input Current which is also the inductor current is greater than output current. In practice the inductor current flowing through, semiconductors Q1 and D1, the inductor winding resistance becomes very large and with the result being that component non-idealities may lead to large power loss. As the duty cycle approaches one, the inductor current becomes very large and these component non idealities lead to large power losses. Consequently, the efficiency of the boost converter decreases rapidly at high duty cycles.

$$V_G . T_{ON} + (V_G - V_O).T_{OFF} = 0$$

$$\frac{V_O}{V_G} = \frac{T_{SW}}{T_{OFF}} = \frac{1}{1-D}$$

Voltage Source Inverters:

The fig(8) main objective of static power converters is to produce an ac output waveform from a dc power supply. These are the types of waveforms required in adjustable speed drives (ASDs), uninterruptible power supplies (UPS), static var compensators, active filters, flexible ac transmission systems (FACTS), and voltage compensators, which are only a few applications. For sinusoidal ac outputs, the magnitude, frequency, and phase should be controllable.

According to the type of ac output waveform, these topologies can be considered as voltage source inverters (VSIs), where the independently controlled ac output is a voltage waveform. These structures are the most widely used because they naturally behave as voltage sources as required by many industrial applications, such as adjustable speed drives (ASDs), which are the most popular application of inverters. Similarly, these topologies can be found as current source inverters (CSIs), where the independently controlled ac output is a current waveform. These structures are still widely used in medium-voltage industrial applications, where high-quality voltage waveforms are required. Static power converters, specifically inverters, are constructed from power switches and the ac output waveforms are therefore made up of discrete values. This leads to the generation of waveforms that feature fast transitions rather than smooth ones. For instance, the ac output voltage produced by the VSI of a standard ASD is a three-level waveform (Fig. 1c). Although this waveform is not sinusoidal as expected (Fig. 1b), its fundamental component behaves as such. This behavior should be ensured by a modulating technique that controls the amount of time and the sequence used to switch the power valves on and off. The modulating techniques most used are the carrier-based technique (e.g., sinusoidal pulse width modulation, SPWM), the space-vector (SV) technique, and the selective-harmonic-elimination (SHE) technique.

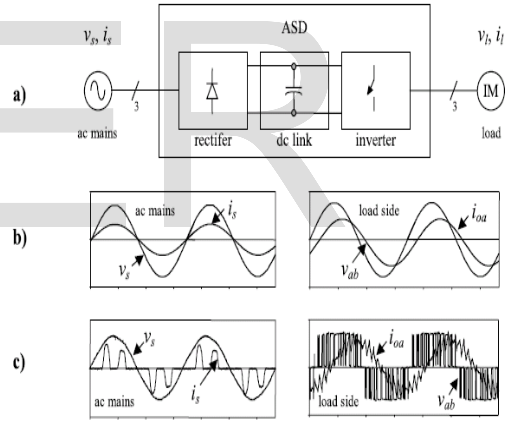
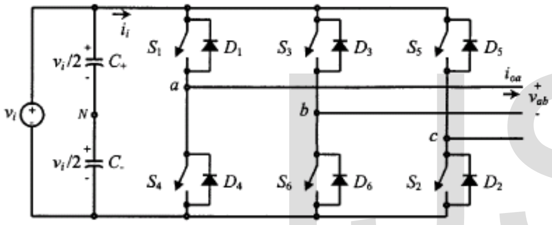


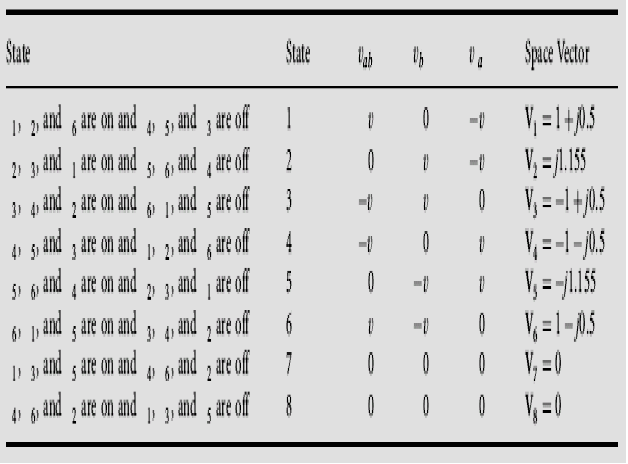
Fig 8. Voltage Source Inverters:

Three Phase Voltage Source Inverters:

Single-phase VSIs cover low-range power applications and three-phase VSIs cover the medium- to high-power applications. The fig(9) main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable. Although most of the applications require sinusoidal voltage waveforms (e.g., ASDs, UPSs, FACTS, VAR compensators), arbitrary voltages are also required in some emerging applications (e.g., active filters, voltage compensators). The standard three-phase VSI topology is shown in Fig. 4 and the eight valid switch states are given in Table 3. As in single-phase VSIs, the switches of any leg of the inverter (S1 and S4, S3 and S6, or S5 and S2) cannot be switched on simultaneously because this would result in a short circuit across the dc link voltage supply. Similarly, in order to avoid undefined states in the VSI, and thus undefined ac output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity. Of the eight valid states, two of them produce zero ac line voltages. In this case, the ac line currents freewheel through either the upper or lower components. The remaining states produce non-zero ac output voltages. In order to generate a given voltage waveform, the inverter moves from one state to another. Thus the resulting ac output line voltages consist of discrete values of voltages that are VI, 0, and -VI for the topology shown in Fig. The selection of the states in order to generate the given waveform is done by the modulating technique that should ensure the use of only the valid states.



Fig(9) Three Phase Voltage Source Inverters:



State	State	v_{ab}	v_b	v_a	Space Vector
$_1$, $_2$, and $_6$ are on and $_4$, $_5$, and $_3$ are off	1	v	0	$-v$	$V_1 = 1 + j0.5$
$_2$, $_3$, and $_1$ are on and $_5$, $_6$, and $_4$ are off	2	0	v	$-v$	$V_2 = j1.155$
$_3$, $_4$, and $_2$ are on and $_6$, $_1$, and $_5$ are off	3	$-v$	v	0	$V_3 = -1 + j0.5$
$_4$, $_5$, and $_3$ are on and $_1$, $_2$, and $_6$ are off	4	$-v$	0	v	$V_4 = -1 - j0.5$
$_5$, $_6$, and $_4$ are on and $_2$, $_3$, and $_1$ are off	5	0	$-v$	v	$V_5 = -j1.155$
$_6$, $_1$, and $_5$ are on and $_3$, $_4$, and $_2$ are off	6	v	$-v$	0	$V_6 = 1 - j0.5$
$_1$, $_3$, and $_5$ are on and $_4$, $_6$, and $_2$ are off	7	0	0	0	$V_7 = 0$
$_4$, $_6$, and $_2$ are on and $_1$, $_3$, and $_5$ are off	8	0	0	0	$V_8 = 0$

Circuit diagram:

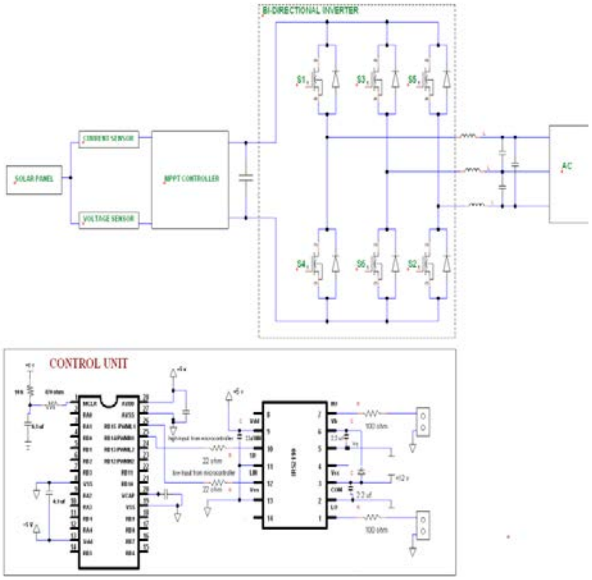


Fig 10 circuit diagram

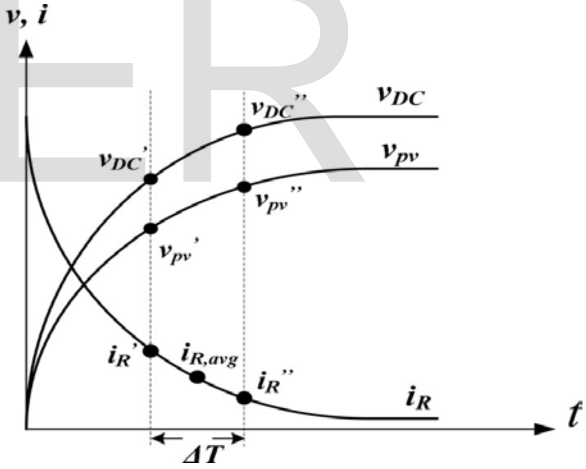


Fig 11 performance curve

A diagram of the discussed three-phase bidirectional inverter is shown in Fig (10),(11).. It can fit to both delta-connected and Y connected ac grid. In the designed prototype, *Rennes's* microchip *RX*62*T* is adopted for realizing the system controller, which has 1.65 MIPS and includes floating-point calculation and division. By considering wide inductance variation, the inverter can be operated stably, especially in high-current applications. Additionally, the system requires dc-bus voltage control schemes for balancing power flow. It includes linear power management scheme, one line-cycle regulation approach, and one-sixth line cycle regulation approach. A stability analysis is presented to support the proposed regulation approaches.

V. MATLAB-SIMULATION

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

SIMPOWER SYSTEMS LIBRARIES

The libraries contain models of typical power equipment such as transformers, lines, machines, and power electronics. The capabilities of Sim Power Systems for modeling a typical electrical system are illustrated in demonstration files. And for users who want to refresh their knowledge of power system theory, there are also self-learning case studies. The Sim Power Systems main library, power lib, organizes its blocks into libraries according to their behavior. The power library window displays the block library icons and names. Double-click a library icon to open the library and access the blocks. The main Sim Power Systems power library window also contains the Powergui block that opens a graphical user interface for the steady-state analysis of electrical circuits. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modeling library. Since Simulink uses MATLAB as its computational engine, designers can also use MATLAB toolboxes and Simulink block sets. Sim Power Systems and Sim Mechanics share a special Physical Modeling block and connection line interface.

SIMULATION CIRCUIT DIAGRAM

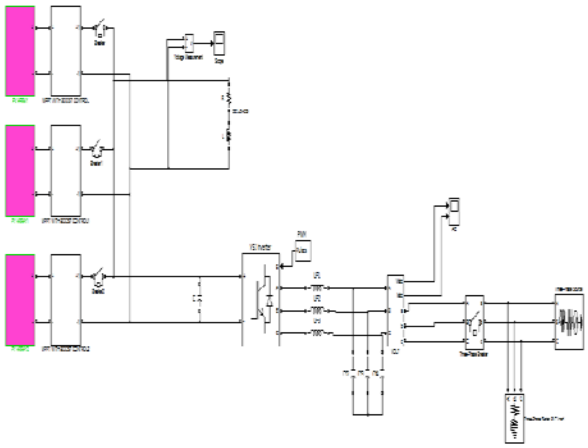


Fig 12 SIMULATION CIRCUIT DIAGRAM

MPPT with boost converter:

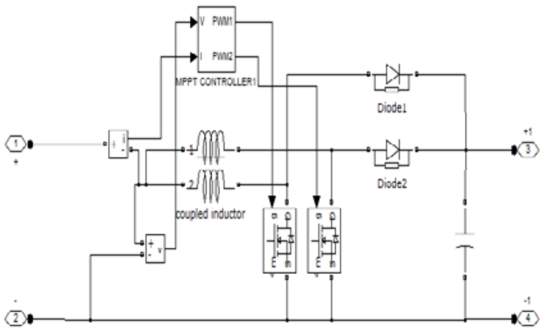


Fig 13 **.** MPPT with boost converter:

Dc bus voltage:

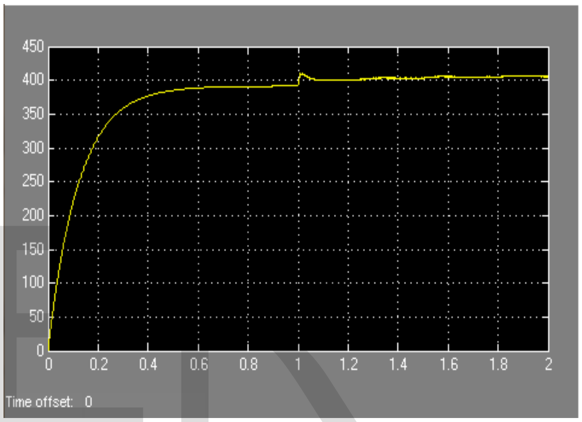


Fig 14 DC bus voltage

VI. Conclusion:

A dc-bus voltage control for three-phase bidirectional inverters in dc distribution systems has been presented. The linear power management scheme including both grid-connection and rectification modes have been described in detail. In the paper, the one line-cycle regulation approach based on the linear power management scheme has been proposed for tuning current command cycle by cycle to regulate the dc-bus voltage according to the load line. For an abrupt voltage change, the one-sixth line cycle regulation approach has been also proposed to prevent over/under dc-bus voltage fault, ensuring system availability.Since both of the approaches are dependent on the parameter of dc-bus capacitance, a determination of capacitor size and a capacitance estimation method have been discussed according to the aspects of dc-bus voltage ripple and energy-storage capability.

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