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Simulation Modeling On Micro Solar Inverter And Pi Controller Based Induction Drive

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Abstract- This proposed work intends to design, simulate and investigate a photovoltaic powered micro inverter to feed an induction motor. The micro inverter proposed here, can be used for boosting up the small output voltage from photovoltaic panel. The proposed system under study consists of a PV panel, micro inverter and an induction motor. The micro inverter includes a high step up converter and a three phase inverter. The high step up dc- dc converter is provided with a Maximum Power Point Tracker (MPPT) system which automatically varies duty cycle in order to generate the required voltage to achieve maximum power. Three phase voltage source inverter is used to convert DC voltage to AC voltage. An induction motor is connected at the output of this system and a PI controller is used to control the speed of the motor. Matlab software is used to simulate and to investigate the behavior of the proposed system.

Keywords: Solar Micro Inverter, PI Controller, MPPT,Induction Drive

1. INTRODUCTION

The global population growth is increases in every year. Every year addition of human to this earth is increases. So we have to increase the energy sources required to support them. One option is to increase the generation of currently used energy sources and other is to explore new renewable energy sources. Many renewable energy sources have emerged as feasible solution and each one of them has their own positive and negative attributes.

Solar energy is the most low cost, competition free, universal source of energy as sun shines throughout. This energy can be converted into useful electrical energy using photovoltaic technology. The steady state reduction of price per peak watt and simplicity with which the installed power can be increased by adding panels are attractive features of PV technology [4]. A solar inverter or Photo voltaic inverter converts the variable direct current output of a photo voltaic solar panel into a utility frequency alternating current that can be fed into a commercial electrical grid or used by local off grid electrical network[1][20]. It is a critical component in a photovoltaic system.

Mainly two types of solar inverters are used - micro inverter and string inverter. Solar micro inverter is an inverter integrated into each solar panel module. The inverter converts the output from each solar panel to alternating current. They are designed to allow parallel connection of multiple units connected in parallel. The main advantage to micro-inverters is their ability to maintain a robust and consistent flow of power even with shade on one or more of the panels. A “string” of modules in a micro-inverter array is in parallel rather than series as with a conventional inverter. Because the micro-inverters service an individual module, the power performance and the overall health of each module can be tracked and monitored in real time [8]. Monitoring the array with conventional string inverters consist of checking the aggregate output of each string of modules for performance. If there is a single module in a string that is malfunctioning, the installer would need to go on the roof and find the single module that is affecting the string and ultimately the total output of the array [15]. With Micro-inverters, a bad module can be detected virtually instantaneously and the best part, identified remotely. String inverters respond to the least efficient module in a string. For instance if a particular module is slightly more resistive, say 5%

more resistive than the rest of the modules in a string the entire string will perform 5% less efficiently. Variations in modules have no effect on the ultimate output of the array since modules with micro-inverters are independent contributors to the power output. Different types and different manufacturers' modules can be used in a "string" of Micro-inverters. The cost of a micro-inverter system is approximately the same as a string inverter. The difference is in the time it takes to install. The micro-inverter installation is about one to one and a half days shorter than the string inverter installation. Shorter time means more overall profit.

The output voltage of micro inverter is very low. A high step up dc-dc converter is required for converting low output voltage from PV panel to high voltage [2] [3] [19]. The efficiency of conventional boost converter is restricted by duty ratio for higher output voltage. Theoretically, when duty ratio is closed to unity, the voltage gain will be infinity. However, the reverse-recovery loss of the output diode and switching losses are large; the equivalent series resistance of capacitors and parasitic resistances of inductor also constrained the voltage gain and efficiency [9]. In [11] the limitation of conventional boost converter is discussed. Different types of boost converter are also discussed in that paper. These converters are classified on the basis of boosting level, cost and efficiency. Coupled inductor technique is used for high voltage gain [17]. Leakage inductor causes voltage spike on switch and reduces the efficiency.

In the proposed system a micro inverter is used to provide electricity from photo voltaic module. The Module Inverter structure is a two-stage system. The first stage is a high step-up high-efficiency DC-DC converter with maximum power point tracking control. The DC-DC converter raises the input low voltage to a high voltage level. The maximum power point tracking is used to extract maximum power from the photo voltaic module. The second stage is a full-bridge inverter. The DC-AC inverter transforms DC voltage from the first stage into sinusoidal voltage waveform. In maximum power point tracking algorithm which uses hill climb method; the method senses the output voltage and current of the solar panel to determine the duty cycle of the DC converter to be increased or decreased. The system can be used to drive an induction motor. IGBT used as the switching device because on state voltage drop is low compared to MOFET, and hence IGBT can be used for high power application. The Proportional Integral (PI) controller is used to control speed of an induction motor[21]-26].

II BLOCK DIAGRAM DESCRIPTION

In the fig1 the Induction motor is controlled by the micro inverter, where the switching pulse to the inverter is controlled by the PI controller & MPPT set maximum power point .The block diagram consist of DC supply, High step up DC- DC converter, inverter, an Induction motor, MPPT, PWM generator and a PI controller.

As we know current global energy crisis is very high, so we have to go with renewable energy. In the block diagram used a PV cell as DC input source. Photovoltaic (PV) solar energy is one of the green energy sources which can play an important role in reducing greenhouse gas emissions, and global warming, among various renewable energy sources. [4]PV cell convert solar radiation to direct current electricity using semiconductor devices that exhibit the photovoltaic effect. The solar cell works in three steps:

1. Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.
2. Electrons (negatively charged) are knocked loose from their atoms, causing an electric potential difference. Current starts flowing through the material to cancel the potential and this electricity is captured. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.
3. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.

The efficiency of a solar cell may be broken down into reflectance efficiency, thermodynamic efficiency, charge carrier separation efficiency and conductive efficiency. The overall efficiency is the product of each of these individual efficiencies. A solar cell usually has a voltage dependent efficiency curve, temperature coefficients, and shadow angles [15].Due to the difficulty in measuring these parameters directly, other parameters are measured instead: thermodynamic efficiency, quantum efficiency, integrated quantum efficiency, V_{OC} ratio, and fill factor. Reflectance losses are a portion of the quantum efficiency under "external quantum efficiency". This PV cell provides required amount of dc supply to the DC -DC converter.

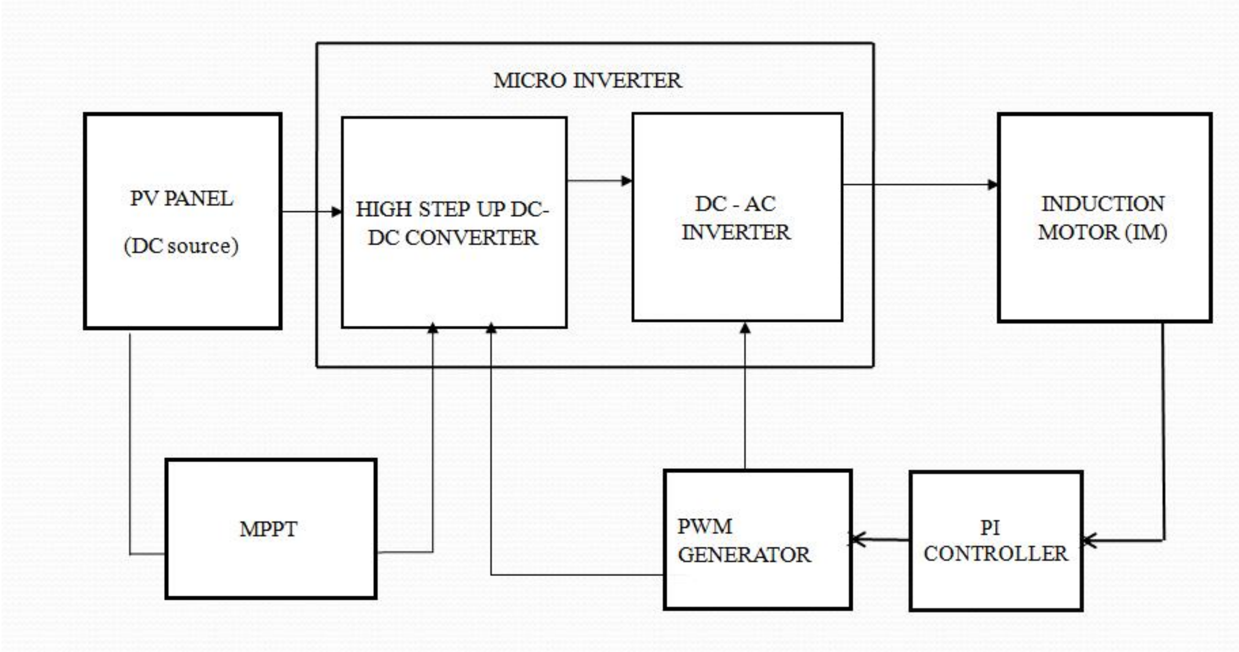

Fig1.Block Diagram of speed control of induction motor using photovoltaic micro inverter and PI controller

High step up DC- DC Converter: A step-up converter is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. [3]Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple. Power for the converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. The output voltage has the same polarity as the input voltage [17] [19].

Inverters: A solar inverter, or PV inverter, converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. It is a critical component in a photovoltaic system, allowing the use of ordinary commercial appliances.

In string inverter, panels are connected in series to produce an array. The power then runs to an inverter, which converts it into standard AC voltage.[20]The main problem with the "string inverter" approach is the string of panel acts as if it were a single larger panel with a max current rating equivalent to the poorest performer in the string. If a panel is shaded its output drops dramatically, affecting the output of the string, even if the other panels are not shaded. Even slight changes in orientation can cause output loss in this fashion.[8] Additionally, the efficiency of a panel's output is strongly affected by the load the inverter places on it. The same issues that cause output to vary from panel to panel, affect the proper load that the MPPT system should apply. If a single panel operates at a different point, a string inverter can only see the overall change, and moves the MPPT point to match. This results in not just losses from the shadowed panel, but the other panels too. Another issue, though minor, is that string inverters are available in a limited selection of power ratings. This means that a given array normally up sizes the inverter to the next-largest model over the rating of the panel array. Other challenges associated with centralized inverters include the space required to locate the device, as well as heat dissipation requirements. Large central inverters are typically actively cooled. Cooling fans make noise, so location of the inverter relative to offices and occupied areas must be considered [15].

Micro-inverters produce grid-matching power directly at the back of the panel. Arrays of panels are connected in parallel to each other, and then to the grid. This has the major advantage that a single failing panel or inverter cannot take the entire string offline. Combined with the lower power and heat loads, and improved MTBF, some suggest that overall array reliability of a micro-inverter-based system is significantly greater than a string inverter-based one. [4]Additionally, when faults occur, they are identifiable to a single point, as opposed to an entire string. This not only makes fault isolation easier, but unmasks minor problems that might not otherwise become visible – a single underperforming panel may not affect a long string's output enough to be noticed. Being small amounts of shading, debris or snow lines on any one solar panel, or even a complete panel failure, does not disproportionately reduce the output of the entire array. Each micro-inverter harvests optimum power by performing maximum power point tracking for its connected panel. They are also simple to design and stock, as there is normally only a single model of inverter that can be used with any size array and a wide variety of panels..

Induction motor: An electric motor converts electrical energy into a mechanical energy which is then supplied to different types of loads. Ac motors operate on an ac supply, and they are classified into synchronous, single phase and 3 phase induction, and special purpose motors. Out of all types, 3 phase induction motors are most widely used for industrial applications mainly because they do not require a starting device. A three phase induction motor derives its name from the fact that the rotor current is induced by the magnetic field, instead of electrical connections. The operating principle of a 3 phase induction motor is based on the production of rotating magnetic field. The stator of an induction motor consists of a number of overlapping windings offset by an electrical angle of 120°. When the primary winding or stator is connected to a three phase alternating current supply, it establishes a rotating magnetic field which rotates at a synchronous speed. The direction of rotation of the motor depends on the phase sequence of supply lines, and the order in which these lines are connected to the stator. Thus interchanging the connection of any two primary terminals to the supply will reverse the direction of rotation. The number of poles and the frequency of the applied voltage determine the synchronous speed of rotation in the motor's stator. Motors are commonly configured to have 2, 4, 6 or 8 poles. The synchronous speed is the rotation rate of the stator's rotating field. An induction motor therefore does not require mechanical commutation, separate-excitation or self-excitation for all or part of the energy transferred from stator to rotor, as in universal, DC and large synchronous motors. An induction motor's rotor can be either wound type or squirrel-cage type [10].

Three-phase squirrel-cage induction motors are widely used in industrial drives because they are rugged, reliable and economical. Single-phase induction motors are used extensively for smaller loads, such as household appliances like fans. Although traditionally used in fixed-speed service, induction motors are increasingly being used with variable-frequency drives(VFDs) in variable-speed service. VFDs offer especially important energy savings opportunities for existing and prospective induction motors in variable-torque centrifugal fan, pump and compressor load applications. Squirrel cage induction motors are very widely used in both fixed-speed and VFD application [12].

Maximum power point tracking (MPPT): Maximum power point tracking (MPPT) is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels, though optical power transmission systems can benefit from similar technology. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve [5] [14] . It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors. Solar cell I-V curves where a line intersects the knee of the curves where the maximum power point is located. Photovoltaic cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor, abbreviated *FF*, is a parameter which characterizes the non-linear electrical behavior of the solar cell. Fill factor is defined as the ratio of the maximum power from the solar cell to the product of

Open Circuit Voltage and Short-Circuit Current. For any given set of operational conditions, cells have a single operating point where the values of the current and Voltage of the cell result in a maximum power output. The power P is product of voltage and current [13]. A photovoltaic cell, for the majority of its useful curve, acts as a constant current source. However, at a photovoltaic cell's MPP region, its curve has an approximately inverse exponential relationship between current and voltage. The "knee" of the curve corresponds to the maximum power point (MPP) [7]. Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell. Different algorithms used for extracting maximum power from a solar cell [6]. Some of the important factors to consider when choosing a technique to perform MPPT are sensors used, ability of an algorithm to detect multiple maxima, costs, and convergence speed [16]. For a large-scale application, the number of sensors use can affect its complexity and accuracy. Often, It's require to use more sensors, for more precise MPPT .The number and type of sensors required depend largely on MPPT technique. The variation in irradiance level at different points on a solar panel's surface will lead to multiple local maxima in one system. The efficiency and complexity of an algorithm determine if the true maximum power point or a local maximum power point is calculated. In the latter case, the maximum electrical power is not extracted from the solar panel. The number of sensors as well as the type of hardware use to monitor and control the electrical tracking system affects the cost of implementing it. For a high-performance MPPT system, the time taken to converge to the required operating voltage or current should be low.

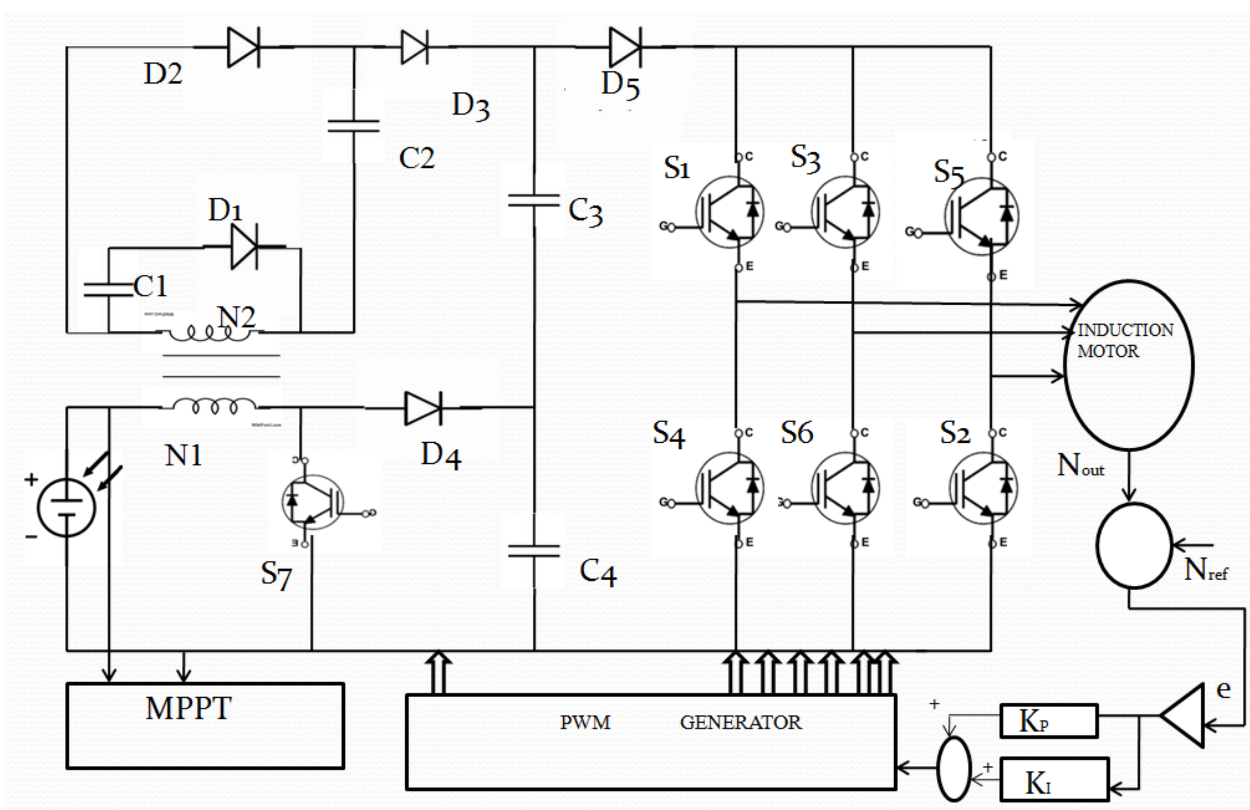

Fig2 Circuit diagram of speed control of induction motor using photovoltaic micro inverter and PI controller

PI controller: A PI controller is used to control the speed of an induction motor. The input of the controller is speed of the motor .Then the speed error is compared with the reference speed and the output of the PI controller is used to control the inverter switches, i.e. as depends on the output of PI controller the gate pulse to the inverter switches are produced. PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller.

III CIRCUIT DIAGRAM DESCRIPTION

The Module Inverter structure is a two-stage system. In fig2 the first stage is a high step-up high-efficiency DC-DC converter with maximum power point tracking control. The DC-DC converter raises the input low voltage to a high voltage level. The maximum power point tracking is used to extract maximum power from the photo voltaic module. The second stage is a full-bridge inverter. The DC-AC inverter transforms DC voltage from the first stage into sinusoidal voltage waveform. In maximum power point tracking algorithm which uses hill climb method. The system can be used to drive an induction motor. The Proportional Integral (PI) controller is used to control speed of an induction motor.

High step up dc-dc converter

A high step up DC-DC converter is used. It is a DC-DC converter structure with coupled inductor and two pairs of switched capacitor circuits. The converter includes an active switch S_7, diodes D_1-D_4, capacitors C1- C4, and a coupled inductor. It uses coupled inductor and switched capacitor to achieve high step-up voltage ratio. The equivalent circuit model of coupled inductor includes magnetizing inductor, leakage inductor and an ideal transformer. To simplify the analysis, following assumptions are made: 1) all circuit components are ideal except coupled inductor. 2) The value of capacitors C_1, C_2, C_3, and C_4 are large enough, so the voltage V_{C1}, V_{C2} , V_{C3} and V_{C4} can be considered as constant value. 3) The turn ratio n of dual winding coupled inductor is equal to N_2/N_1. 4) The magnetizing inductance Lm is large enough, so the circuit is operated in continuous condition mode. The operating modes are described as follows.

Mode I: In this mode, switch S_7 is turned on, only diode D_3 is conducted. The magnetizing inductance L_m and primary leakage inductance L_{k1} are storing energy from V_{in}; meanwhile V_{in} is also transferred through coupled inductor to secondary winding N_2 and be in series with Switched capacitor C_1 and C_2. Switched capacitors start to discharge their energy to capacitor C_3 and load. This mode ends when switch S_7 is turned off.

Mode II: This mode starts when S_7 is turned off. Diode D_3 is off. During this mode, the L_m is changed from storing to releasing energy; switched capacitors are also changed from discharging to charging status. Diodes D_1, D_2 and D_4 are conducted. The leakage energy charge capacitor C4 through diode D_4

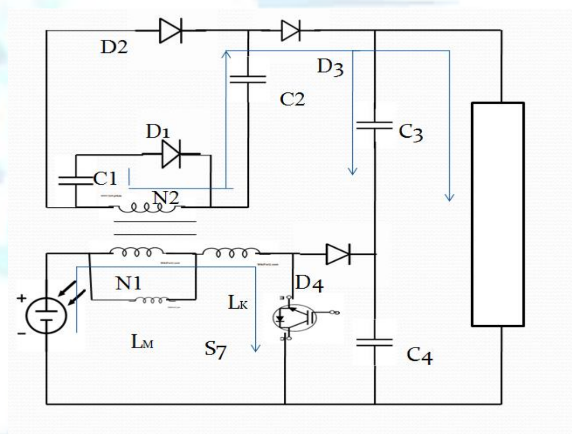

Fig 3 mode I operation of dc-dc converter

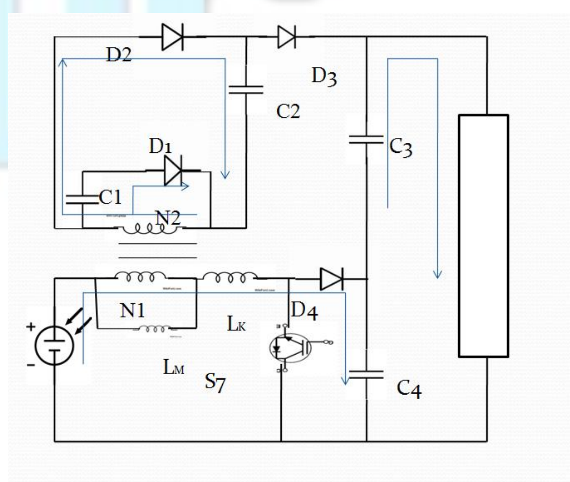

Fig 4 mode II operation of dc-dc converter

The magnetizing inductor Lm is delivering its energy through coupled inductor to charge capacitor C_1 and C_2. The mode ends when leakage current i_{LK1} decreased to zero.

Mode III: During the interval, The Lm is constantly releasing its energy to switched capacitors. The S_7, D_3, and D_4 are off; diodes D_1 and D_2 are conducted. The magnetizing current is decreasing because the magnetizing inductance energy charges capacitor C_1 and C_2 continuously through the coupled inductor. The energy stored in capacitor C_3 and C_4 are constantly discharged to the load. This mode ends when switch S_7 is turned on at the beginning of the next switching period

The voltage across capacitor C3 and C4 can be shown as in equation (1) and (2)

$$V_{c4} = \frac{1}{1-D} V_{in} \qquad (1)$$

$$V_{c3} = \frac{n(1+D)}{1-D} V_{in} \qquad (2)$$

The output voltage V_O is the sum of V_{C3} and V_{C4}. The voltage gain ratio M can be written as:

$$M = \frac{V_o}{V_{in}} = \frac{1+(1+D)n}{1-D} \qquad (3)$$

The boundary normalized magnetizing inductor time constant τ_{LmB} can be derived as:

$$\tau_{LmB} = \frac{D(1-D)^2}{2(1+2n)(1+n+Dn)} \qquad (4)$$

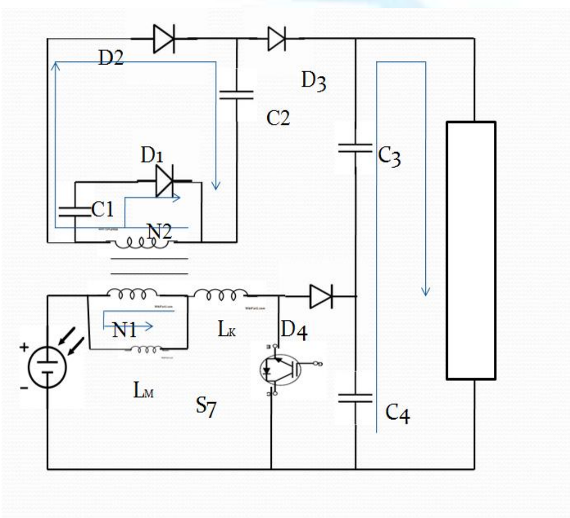

Fig 5mode III operation of dc-dc converter

DC-AC Inverter

The DC-AC inverter consists of a full bridge inverter comprises of six switches. DC to AC inverter transforms a dc power source to a high voltage ac source. Inverters are used for many applications, as in situations where low voltage dc sources such as batteries or solar panels must be converted so that devices can run off of ac power. One example of such a situation would be converting electrical power from a car battery to run a laptop or television. This method, in which low voltage dc power is inverted, is completed in two steps:

1. The conversion of the low voltage dc power to a high voltage dc power
2. The conversion of the high dc source to an ac waveform using pulse width modulation (PWM).

In electronic power converters and motors, PWM is used extensively as a means of powering alternating current (ac) devices with an available direct current (DC) sources or for advanced DC/AC conversion. PI controller is used to control the speed of an induction motor. The output of PI controller is used to produce pulse from PWM generator. Turn on and turns off of switches are controlled by these pulses. Variation of duty cycle in the PWM signal to provide a DC voltage across the load in a specific pattern will appear to the load as an AC signal, or can control the speed of the motors that would otherwise run only at full speed or off.

Maximum power point tracking (MPPT)

Maximum power point tracking (MPPT) is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels, though optical power transmission systems can benefit from similar technology. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors. The maximum power point tracking algorithm used in this paper is a hill climbing method. In this method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. This is called the perturb and observe method and is most common, although this method can result in oscillations of power output It is referred to as a hill climbing method, because it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted. Hill climbing methods that can find the local maximum of the power curve for the operating condition of the array, and so provide a true maximum power point.

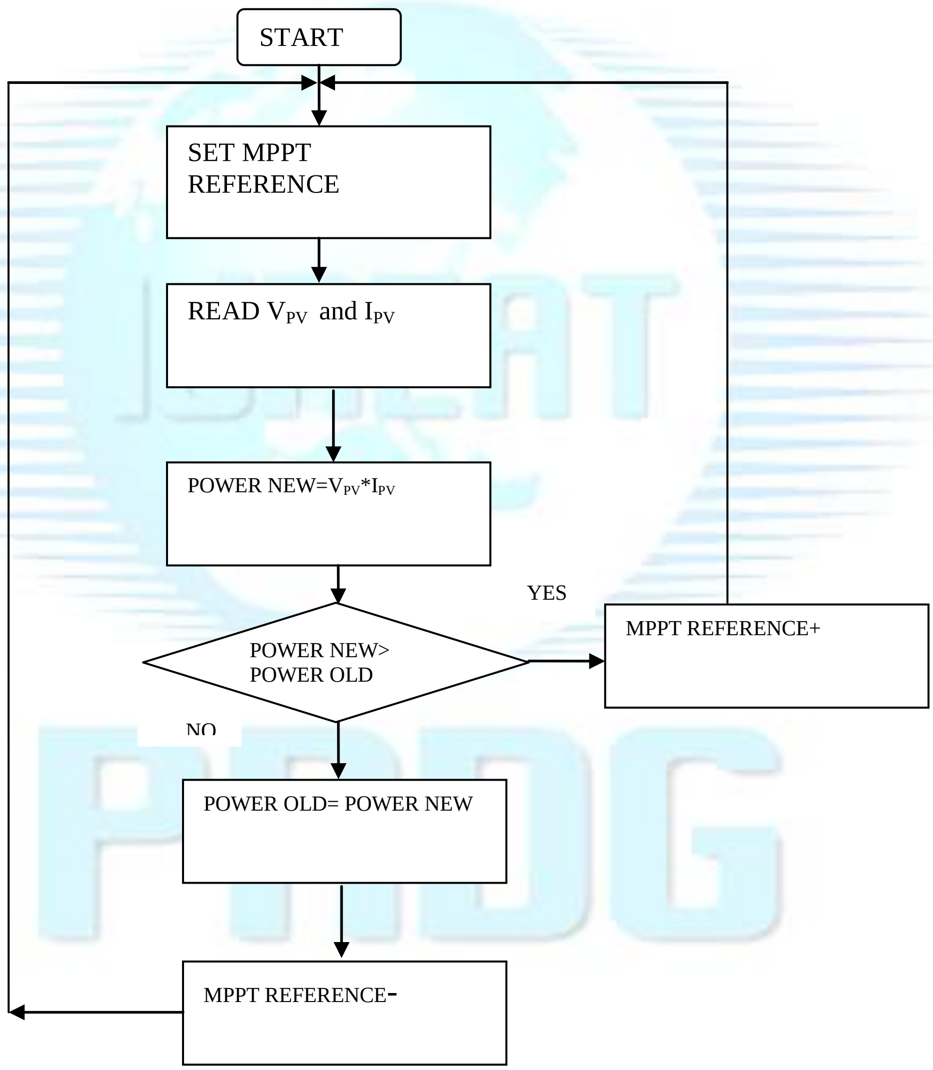

Fig 6 MPPT – Perturb and Observe Flow Chart

IV SIMULATION RESULTS

Circuit specifications are described as follows
Input voltage of dc-dc converter 12.7v
Output voltage of dc-dc converter 300v
Speed range of induction motor 800-1200rpm
Simulated circuit diagram of speed control of induction motor using photovoltaic micro inverter and PI controller is shown in fig 7
Power from PV panel is 4000W which is shown in fig8. The input voltage and output voltage waveforms of dc –dc converter is shown in fig 9 and fig10 respectively. Gate pulses to IGBT are shown in fig11.
Output voltage and current of dc-ac inverter is shown in fig 12 and fig 13 respectively
Electromagnetic torque and speed of an induction motor is shown in fig 14 and 15 respectively.

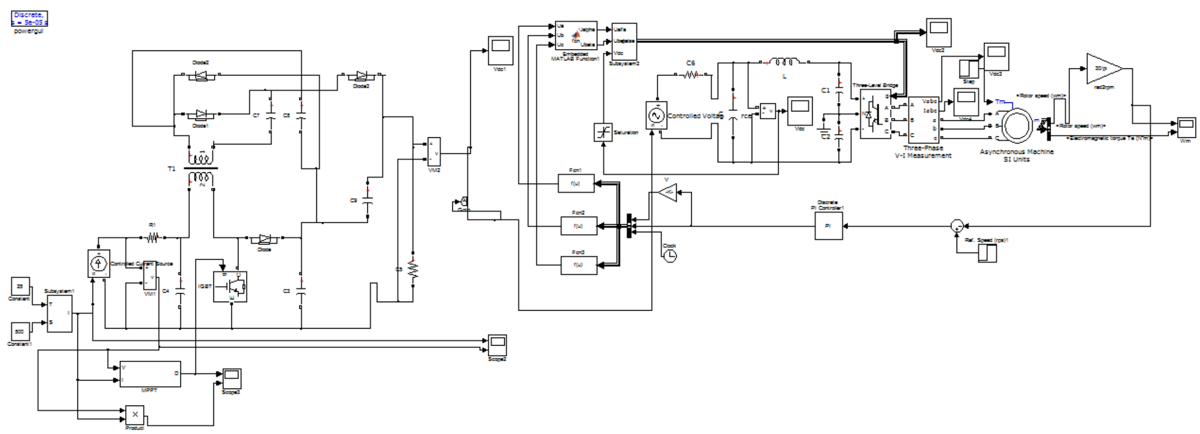

Fig7speed control of induction motor using photovoltaic micro inverter and PI controller

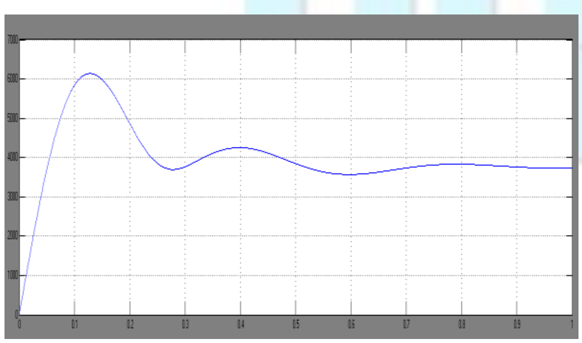

Fig8 Power from pv panel

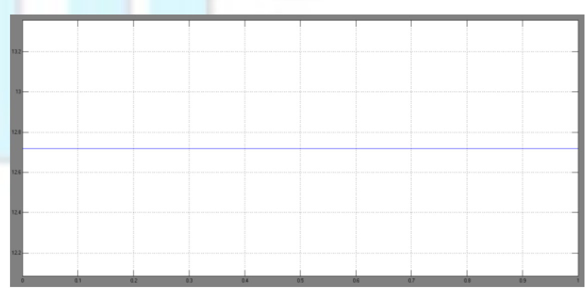

Fig9 Input voltage to dc-dc converter

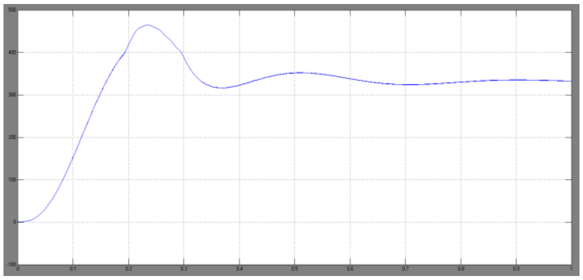

Fig10 Output voltage of dc-dc converter

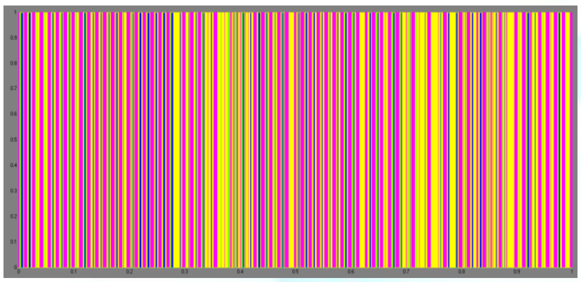

Fig11 gate pulses to IGBT

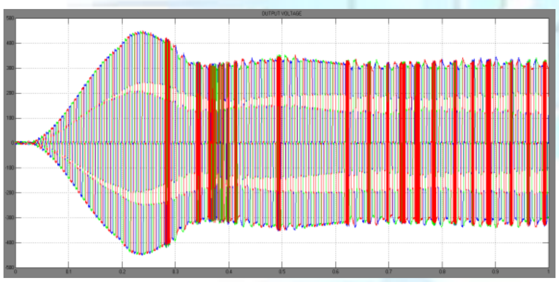

Fig12 Output voltage waveform of inverter

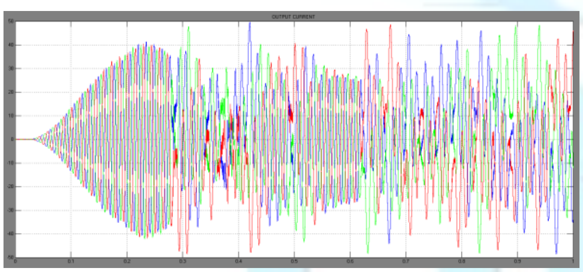

Fig13Output current waveform of inverter

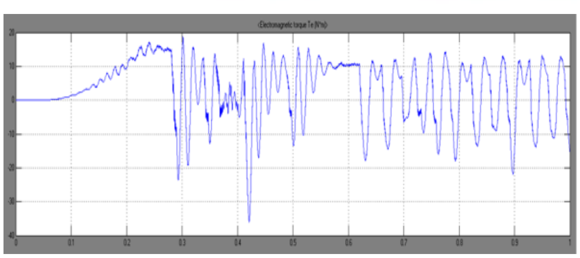

Fig14 Electromagnetic torque of an induction motor

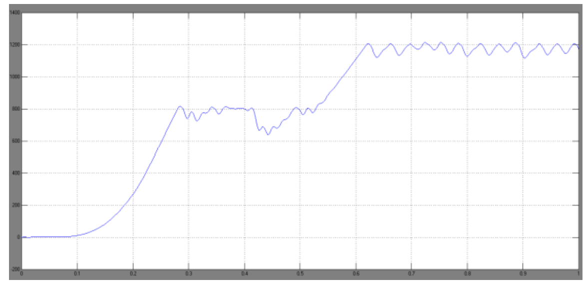

Fig15 Speed of an induction motor

V. CONCLUSION

This work has evaluated the strategy for utilization of PV panel for an induction motor. The Photo Voltaic powered three phase induction motor drive system is successfully designed, modeled and simulated using MATLAB SIMULINK.. The simulation of three phase induction motor using Photo Voltaic as input is presented. A PV micro inverter has been designed, implemented and verified in this paper. The major difference between conventional PV inverter and the proposed micro inverter is the ability to raise the input voltage. The proposed micro inverter can efficiently raises the input voltage to the level that can be used to drive a motor. It also embedded with MPPT which is designed for harvesting maximum solar power from the PV module. The speed of the motor is controlled through a proportional integral (PI) controller.

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