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Research Article

UTILIZING HIGH STEP UP DC-DC BOOST CONVERTER WITH INTERLEAVED FLY BACK BOOST CONVERTER TOPOLOGY AND MAXIMUM POWER POINT TRACKING METHOD (MPPT) ALGORITHM FOR OPTIMAL HARVESTING OF SOLAR RADIATION

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Abstract

PV generation is one of the fast-growing renewable power generation system; it helps to meet the ever-growing power demand. Among the various PV generation techniques available, the micro inverter system which finds its application in roof top systems is rated as one of the best option for maximum energy harvest from each solar panel. Poor harvesting of solar energy due to shading has been identified as a major setback for PV-based renewable power generation systems. Hence, this paper presents a simulation of a 46kVA micro-inverter utilizing a high step-up dc-dc boost converter with Interleaved Fly back boost converter topology and a Maximum power point tracking method (MPPT) algorithm for optimal harvesting of solar radiation. Solar panels, DC-DC converter, DC-AC inverter, and LC filter make up the Micro Inverter architecture. The solar cell provides electricity to a DC-DC converter, which increases the input DC voltage to the inverter's desired rated input voltage. A pi filter is used between the converter and inverter circuits to eliminate ripple.

Keywords: Micro Inverter, Maximum Power Point Tracking, Dual Stage Inverter, PWM, MPPT Algorithm.

INTRODUCTION

The world demand for electric energy is constantly on the rise and conventional energy sources are gradually diminishing and are even closer than ever to being depleted. Conventional energy sources are the natural resources used for energy generation which are present in a limited quantity. They are also known as non-renewable energy resources as once they've been depleted, they can't be generated back at the rate which can sustain the consumption rate unless they are left to replenish over a long period of time. The need for alternative energy sources has become indispensable and solar energy is particular due to its pollution free nature which is its major advantage. Renewable or green energy is therefore being developed an increased speed recently, especially solar energy. One of various methods to harvest the solar energy is using the photovoltaic (PV) modules, which absorb the sun's photonic energy and transfer it to electricity with a p-n junction. In comparison to other kinds of renewable energy systems, there is no moving part in a solar system, which means that the solar systems may last for a long time with minimum maintenance. In PV systems, inverters are used for converting Direct Current (DC) from a solar panel to Alternating Current (AC) to connect directly to the utility grid. Solar panels (photovoltaic panels) produce direct current and to connect these panels to the electricity grid of a home(s) or for industrial use, we should have an AC output at the certain required voltage level and frequency. The conversion from DC to AC is essentially carried out by means of a DC to AC inverter.

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The output of the solar panels is not constant or continuous and is related to the sunlight intensity and ambient temperature. This indicates a growing need for the development of reliable and resilient inverter systems. Enhancing the robustness and performance of PV systems will aid and support the continued penetration of solar energy into the electricity grid and will lead to the overall success of the industry

LITERATURE REVIEW

On the work done on a grid system by (Vokas, Gazis, Katsimardou, & Kaldelis, 2013) is to research on the study of micro inverter technology to discover what the result will bring up if the inverter is placed on each photovoltaic module and to get the output of the two inverter technologies. In the work of (Tahir *et al.,* 2022), distribution and thermal stresses is proposed which occurs in semiconductor devices of micro inverters and likewise, the performance of the micro inverter evaluated on the basis of conduction and switching losses in basic micro inverters. In the work of (Bezerra *et al.,* 2017), the author present the development of a single – phase inverter with high efficiency and high power density to be applied on photovoltaic panel's applications. Unlike the previous study (Saeedinia *et al.,* 2022) proposes a rated power of 300W and an appropriate control strategy for photovoltaic system and the designed was based on two – stage topology. The author (S.Subramaniam, B.Akash, R.Vignesh, & R.Mahalakshmi, 2019) focus on the operational performances of two kinds of configuration of solar modules. A configuration of a DC module and an AC module, the precious study of (Mohd, 2011) the architecture of micro – inverter which allows each module to be independent, standalone and a quantitative analysis of micro-inverters' performance.

METHODOLOGY

The operation of the Micro Inverter designed is based on two power stages which are the DC/DC power conversion stage and the DC/AC power inversion stage as shown in Fig 1. The first stage which is the DC/DC power conversion stage takes supply from the solar panel. The DC supply from the solar panel is not always constant but the output from the DC/DC power stage has to be a constant DC output this is achieved by the control unit which alters the duty cycle of operation to keep the output voltage constant. To ensure maximum power is tracked from the panel under varying irradiance and temperature levels, the maximum power point tracking (MPPT) algorithms have been incorporated to control the switching pattern of the converter. The second stage of the Micro Inverter is the DC/AC conversion where the output DC voltage from the DC/DC conversion is inverted to AC with the use of MOSFET and a high frequency transformer. The switching is controlled using the pulse width modulation techniques. These techniques have the advantages of low total harmonic distortion outputs and effectiveness. The output AC voltage from the DC to AC conversion is then filtered and connected to the utility grid. The output from each stage is fed as input to voltage and current sensing units for further processing by the control unit. The control unit is responsible for sensing and feedback in the Micro Inverter circuitry.

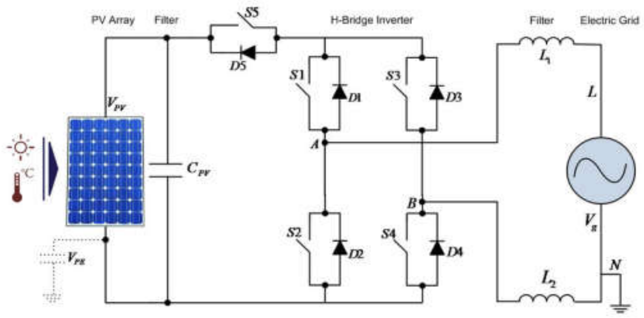

Fig. 1. Micro Inverter block diagram (Zeb *et al.,* 2018)

PV Module

Solar panel has a significant role in designing a Micro Inverter. PV array consists of a number of solar cells in series parallel combination to generate rated voltage and current. A solar cell is a device having non-linear PN junction properties. In this work, mono crystalline photovoltaic cell LG360Q1C-A5 was used for the Micro Inverter architecture. The manufacturer specifications are as follows:

a) Open circuit voltage, V_{oc} of 42.7 V
b) Voltage at maximum power V_{mpp} of 36.5 V
c) Short circuit current I_{sc} of 10.79 A
d) Current at maximum power point I_{mpp} of 9.87 A
e) Maximum power of 360 W

For this 46kVA Micro Inverter architecture, 16 Micro Inverter units are synchronized to obtain the output. Each unit utilizes 8 of the above stated panel connected in parallel to obtain maximum power. Since the panels are connected in parallel, the output current from the PV module increases to 78.96 Amps and the voltage remains the same at 36.5 Volts. This output is then fed into the DC/DC conversion stage of each of the 16 Micro Inverter units.

DC/DC power conversion stage

The Boost converter increases the DC voltage level and Buck converter decreases the DC voltage level. It consists of one inductor, one switch (mosfet) and one diode basically. One capacitor is connected across the load end to maintain constant load voltage. The DC output voltage of the converter is controlled by the switching and duty ratio. For this work, the Boost converter was used in the DC-DC conversion stage to step-up the PV module output voltage. The equation for the output voltage of a Boost converter is given by:

$$Vo = \frac{Vs}{1-k} \quad (1)$$

Where;

$V_s = V_{mp}$ = Maximum power voltage of the solar panel = 36.5 volts; V_o= Output voltage from the DC/DC converter and k = Duty cycle of the switching pulse

When the Mosfet (IRHM7360SE) is on, a closed path of current is formed and the inductor stores energy during the period T_{on}. When the Mosfet is off, the inductor releases some of its stored charges back into the circuit, and since inductor current cannot die instantaneously, it thus flows through the diode and the load for the period T_{off}. The polarity of the induced emf in the inductor is reversed as the current decreases. As a result, the source voltage Vs is exceeded by the load voltage Vo. The step up converter acts in this fashion and the stored energy in the inductor is released to the load. This way, the input voltage from the PV module is stepped up to 240V DC (High DC) and a proportional current drop occurs as the output current from the DC to DC stage drops to about 12A.

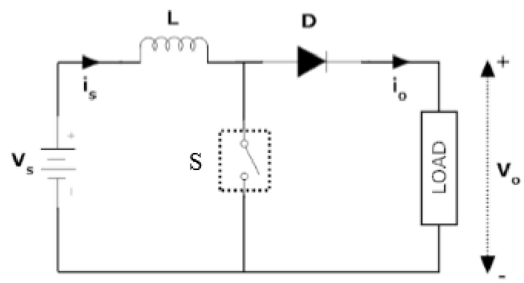

Fig. 2. Boost Converter Circuit (Garanayak & Behera, 2015)

DC/AC power inversion stage

The inverter used in the design of the DC/AC stage is called an H-Bridge inverter [Fig. 3] as the switches are configured to look like an 'H' with the output being connected to the filter which then connects to the grid/load. In order for the system to generate AC voltage, first switches S1 and S4 are trigged to close. This allows a voltage to be applied to the load and current flows through to the load. At a certain period of time, switches S1 and S4 are re-opened. Thus the voltage is removed and current stops flowing. At this time, switches S2 and S3 are then closed. Therefore the voltage polarity across the load changes and current flows in the opposite direction. This occurs until another point in time, at this time S2 and S3 are reopened, while S1 and S4 are re-closed and the process continues. In an ideal case i.e. when ideal switches are used which exhibit no internal resistance, the voltage applied to the load is equal that of the source such that the output of the DC/AC power inversion stage is a current of 12A and voltage of 240V AC for each Micro Inverter unit. However, due to power dissipation and losses to components in the power stages, the output power of the DC/AC inversion stage is about 80% of the actual input power from the DC/DC conversion stage. Hence, the output from the DC/AC stage after filtering is rated 220V, 10.5A for each Micro Inverter unit.

Maximum Power Point Tracking

The irradiance of the sun incident on the PV panel tends to change throughout the day. But there occurs peak in the PV graph. In order to obtain maximum efficiency, the panel has to be operated at this peak value. By employing suitable algorithms, the converter is given gate pulses to operate with maximum power. The converter used in this circuit is a boost converter. The switching of this converter was controlled using the MPPT algorithm. The converter contains a 674H inductor on the input side, a 50F capacitor on the output side, and a 500uF capacitor on the input side. This converter is made to operate with a duty cycle of 85%. To operate the PV system at the peak of the PV graph, MPPT algorithms are used. By operating it that way, the problems due to load mismatch can also be avoided apart from increasing the efficiency.

Control Unit

In order to control the boost converter and provide a constant output voltage under fluctuating input conditions, a feedback control system is needed. Output voltage can be maintained by regulating the duty cycle applied to the switches/mosfet in the circuit. This method is used to maintain a consistent voltage output across the DC capacitor and H-bridge for the inverter. The control unit used was the MEGA 2560 microcontroller. The MEGA 2560 control unit has 54 digital I/O pins and 16 analog I/O pins. The microcontroller sends control pulses through a crystal oscillator, which provides appropriate clock pulses to control the switching of the Mosfet in each stage. Each Micro Inverter architecture is designed such that the output from each stage is fed back into the control unit to ensure that each stage is giving out the required output. The output from the PV module and the high voltage DC output from the DC/DC conversion stage are fed through voltage divider units so as to drop the value of the voltages to one below 5V which is the maximum voltage that can be read by the microcontroller unit. The high voltage AC output is feedback through a bridge rectifier so as to drop the voltage and also convert to a DC value that can be fed into the microcontroller unit.

Synchronization and Grid Connection

The Micro Inverter units are connected in parallel to provide system redundancy and high reliability, which is important for critical load demand. A natural problem for parallel-connected inverters is how the load is shared among them. The aim is to implement a crucial automatic synchronization across the 16 inverter units with regards to frequency, phase and voltage to keep the inverters running independent of each other yet achieving an output that is well synchronized with one another. Grid synchronization and connection of the 16 Micro Inverter units is achieved by matching the frequency, phase and voltage of each Micro Inverter unit to that at the grid level. This function is carried out by the grid Microcontroller MEGA 2560. The grid microcontroller receives signal from the final output of each Micro Inverter unit and senses signals from the grid, it then compares the output from each Micro Inverter with the required grid level. Micro Inverter units with output levels similar to that of the grid are connected and those with different outputs are disconnected until they match the grid level. When a Micro Inverter unit has an output (frequency and voltage) similar to that at the required grid level, the grid microcontroller send a control signal to the transistor at the output to switch the relays on and so the unit is connected to the grid and if otherwise, the grid microcontroller sends a control signal to the transistor to switch the relays off to disconnect the unit from the grid if the synchronizing parameters differ from the required grid parameters.

The Micro Inverter is connected to the grid microcontrollers which constantly sample/measure the frequency on the grid and use this information to drive the input of the control unit such that its clock output can be advanced or retarded until the micro inverter frequency matches the frequency on the grid. Once frequency synchronization is achieved, the micro inverter will close a contactor to the grid. In the event that there is a frequency or voltage mismatch beyond allowable pre-determined tolerance value, the grid Microcontroller should open the contactor to effectively disconnect the Micro Inverter output from the grid for system protection. Additionally, once connected to the grid, the Micro Inverter units would go to sleep or at least the output stage of the Micro Inverter would sleep while the load on the system is less than the sum of output of the entire Micro Inverter system. The advantage of this architecture is the system being completely built of multiple units/modules which are expandable/contractible as well as robust/resilient such that if anyone or perhaps two units were to fail the system would continue to function but at a reduced capacity.

RESULTS AND DISCUSSION

The result for this Project is presented for each output stage which are:

Panel DC output; DC-DC converter stage DC output; DC-AC Converter stage AC output without filter and DC-AC Converter stage AC output after filter.

Panel DC output

The simulation result of the panel used is shown in Fig 4. The waveform shows the output of the solar panel being fed into the DC-DC conversion stage. The result shows that the output from the solar panel is about 36.5volts when operating in clear sky condition.

DC-DC converter stage DC output

Simulation results of the DC-DC Converter controlled by the PWM signal from the Microcontroller is shown in Fig 5. In the DC-DC Converter stage, the microcontroller is used to generate a PWM signal driven by a variable duty cycle.

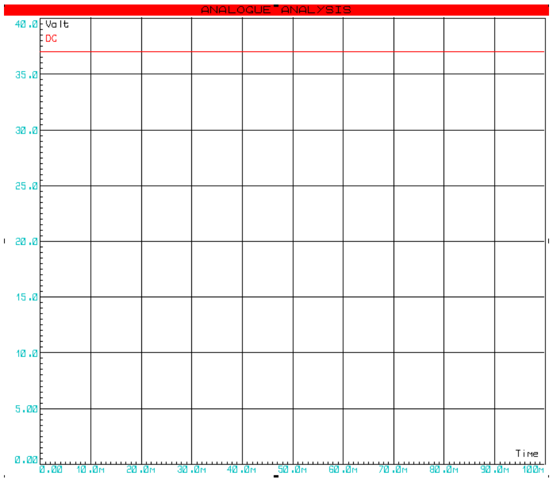

Fig. 4. Solar panel output

Afterward, the switch (MOSFET) in the DC- DC conversion stage is controlled by this PWM signal in order to obtain the same waveform as the reference signal at the output. This PWM signal takes it source from pin 46 of the microcontroller [PD3/TXD1/INT3]. The waveform in the result of the DC-DC conversion stage shows that the output of the solar panel had been boosted up to 240volt DC.

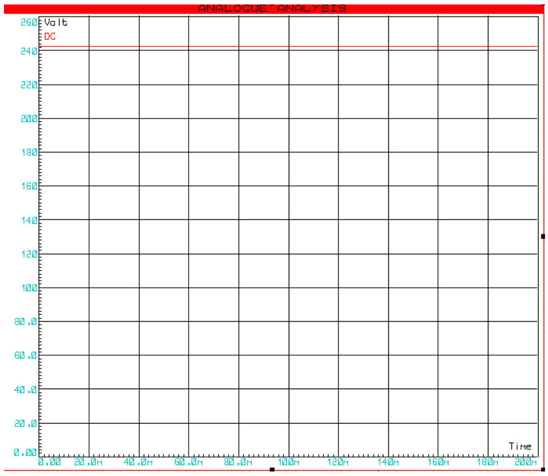

Fig. 5. DC-DC conversion stage output

DC-AC Converter stage AC output without filter

The waveform in Fig 6 shows the output of the h-bridge before filtering. The waveform has amplitude of 290V peak to peak which shows the required grid level has not been attained due to noise and distortions in the output.

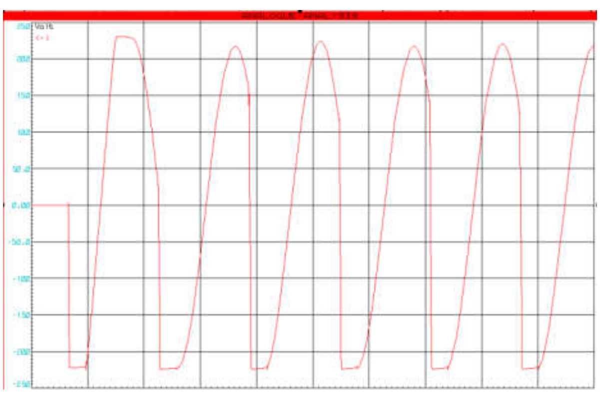

Fig. 6. Simulation result of the DC-AC Converter stage without filtering

DC-AC Converter stage AC output after filter

The Sinusoidal AC output of the microcontroller after passing through the LCL filter is shown by the waveform in Fig 7, with amplitude of 311V peak to peak.

$$Vo = \sqrt{2}Vrms$$

Where V_o is Peak to Peak voltage and V_{rms} is Output Voltage.

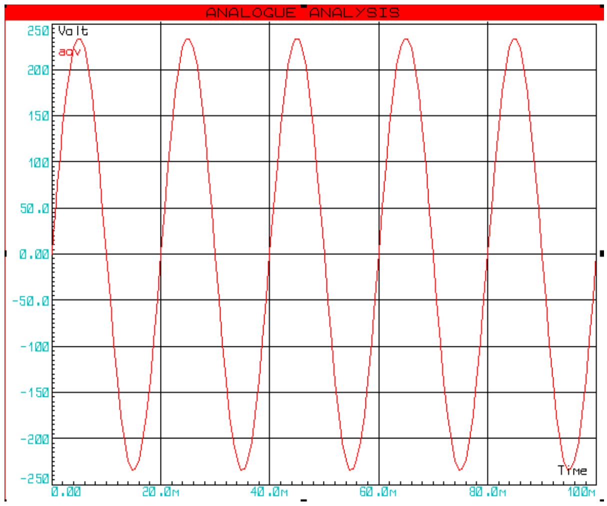

Fig. 7. DC-AC Inversion stage after filtering

The shape of the obtained signals points out the validity of the developed model of this Micro Inverter topology. At this step of development and for off-grid applications, this Micro Inverter can be straightforwardly implemented, as it is, between the PV panel and the AC load. The output from the Micro Inverter is compared with the current voltage at the grid by the grid microcontroller before its output is connected to the grid. This is required to ensure that the output voltage from the Micro Inverter is similar to the grid voltage. The grid microcontroller also serves an important purpose of sensing and feedback to each Micro Inverter to ensure their output voltages are at grid level before they are connected to the grid.

Conclusion

Among the numerous micro-inverter topologies, the dual stage inverter structure is selected in this thesis. In dual-stage inverters, the DC voltage rising circuit and DC/AC voltage inverting circuit are decoupled, while the MPPT function is separated as well. Thus the circuit design and controller design are much simpler compared with single stage inverter. Compared with three stage inverters, the dual stage inverters have a better power efficiency and fewer components for less energy processing stages. From the point of view of the efficiency of the photovoltaic system, it is important to use a MPPT algorithm in the boost stage

Future work

Suggestions for future work in the project include:Construction of a prototype of the proposed system to observe its dynamic behavior and the study of other MPPT techniques, including measurement of incident radiation and study of power gain. The Implementation of the circuit in a three-phase system and Implementation of modern techniques applied to the switching of MOSFETs of DC-DC and DC-AC converters.

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