International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 4 No. 2 Oct. 2013, pp. 456-464

http://www.issr-journals.org/ijias/

An Efficient Analog Maximum Power Point Tracking (MPPT) Regulator for the Parallel Hybrid Photo Voltaic – Diesel and Wind Energy Systems

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ABSTRACT: In this research article we have proposed a new analog MPPT regulator with the high efficiency DC-DC converter for the photo voltaic and high efficient z- source converter for the variable speed wind energy systems. The both renewable energy output power is connected in parallel with the diesel generator and whole system provide the efficient hybrid energy systems to given the electrical power to the external grid. The MPPT regulator provides the control signal for the DC-DC converter and tracks the maximum power from the solar panel. In which here a logic truth table based perturbation and observation (P & O) algorithm used for the maximum power point tracking (MPPT) and hybrid bridge resonant DC-DC converter is giving the constant output voltage equal to the DC bus voltage by changing the proper modes. The parallel configuration is selected for the energy transformation from the solar panel, wind power and diesel systems to the load. The design includes a bidirectional inverter along with a dc-dc converter capable of interfacing a battery bank with the AC bus. The goals of the project included the implementation of two modes of operation: a battery discharge mode where current is being fed into the AC bus and a battery charging mode in which current is pulled from the grid and put into the batteries. A secondary goal of the design was to ensure that the current being injected into AC bus was at or near unity power factor by utilizing a hysteresis current control method.

KEYWORDS: MPPT regulator, P&O algorithm, Hybrid Bridge Resonant, DC-DC converter, Wind energy, Bi-directional Inverter.

1 INTRODUCTION

The demand for energy will continue to increase as long as world population increases and people continue to demand a higher standard of living. The global demand for electric energy has continuously increased over the last few decades. Energy and the environment have become serious concerns in the today's world. As per the Kyoto agreement from the world nations reduce the production of greenhouse gases, the Alternative sources of energy generation have drawn increasing attention in recent years. Among a variety of the renewable energy sources, PV sources are predicted to become the biggest contributors to electricity generation among all renewable energy generation candidates by prediction IMS research in 2040 of 35 GW [10]. Photo voltaic systems are become a promising alternate energy source because it has over advantages such as abundance, pollution free and renewability. Photovoltaic systems are converting the energy of sunlight into electricity by using photo voltaic effect. The sunlight on earth surface at noon is around 1KW/ m^2. Due to the non-linear relationship between the current and voltage of the photo-voltaic cell, it can be observed that there is a unique maximum power point at a particular environment, and this peak power point keeps changing with the solar illumination and ambient temperature.

In recent year's large no. of techniques have been implemented for the maximum power point tracking (MPPT), such as constant voltage tracking (CVT), the incremental conductance (ICT), and hill climbing / perturbation and observation (P & O) algorithm [11]. Here Perturbation and Observation (P&O) method has a simple feedback structure and fewer measured parameters. It operates by periodically perturbing (i.e. incrementing or decreasing) the solar array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. In this manner, the peak power tracker continuously seeks the peak power condition.

For the distributed MPPT application, it requires a MPPT controller to generate a proper reference signal for the DC/DC controller in order to ensure the PV module operating at its maximum power point. A cost-effective analog MPPT controller is proposed to form a single chip controller solution for the distributed MPPT stage. The operation of proposed MPPT controller is based on a logic truth table extracted from the perturbation and observation (P&O) algorithm [6]. The capacitor based storage cell concept is proposed to store the Vpv and Ppv in the last perturbation cycle. The perturbation frequency and step size may be adjusted by the user. MPP is tracked by using DC-DC converters. Much attention has been given to the hybrid bridge DC-DC converter topology. The resonant DC/DC converters, which are good candidates for the distributed MPPT stage application due to their simple structure, soft switching features and high efficiency [5].

Wind energy has the biggest share in the renewable energy sector. Over the past 20 years, grid connected wind capacity has more than doubled and the cost of power generated from wind energy based systems has reduced to one-sixth of the corresponding value in the early 1980s. The important features associated with a wind energy conversion system are Available wind energy, Type of wind turbine employed, Type of electric generator and power electronic circuitry employed for interfacing with the grid [14]. In this research article we are focusing on the induction generator coupled with the variable speed turbine fed with the z-source converter to get the maximum output from the wind energy and this whole system is connected in parallel with the photo voltaic and diesel system for the optimizing and efficient hybrid energy system [13].

In the bi- directional inverter the design was specified to use the same hardware in two modes of operation and thus have bidirectional power flow functionality. The discharge mode was specified as the process of extracting energy from the battery bank and using it to supplement the AC bus. This was accomplished by boosting the battery bank voltage to the necessary level and then converting it to ac with the proper frequency and phase needed in order to inject current into the AC bus [2]. This mode required a way to synchronize the inverter output current with the AC bus voltage in order to ensure a near unity power factor and thus minimize reactive power. Alternatively, the charge mode of operation utilizes the AC bus to recharge the battery bank and store energy. This is accomplished by rectifying the AC bus voltage and regulating the amount of current flowing into the batteries.

In this parallel configuration allows all energy sources to supply the load separately at low or medium load demand. The supplying peak loads from combined sources by synchronizing the inverter with the alternator output waveform. The capability to synchronize the inverter with diesel generator and the wind power allows greater flexibility to optimize the operation of the system [1].

2 PROPOSED SYSTEM CONFIGURATION

The block diagram of the proposed system is shown in figure1. It consists of PV array, MPPT regulator, hybrid bridge resonant converter, bi-directional inverter, wind power, diesel generator and battery. The main advantage of this systems are (1) the system load can be met in an optimal way (2) the diesel generator efficiency and maintenance can be maximized (3) a reduction in rated capacities of the device also meet peak loads. The MPPT regulator is achieve to track the maximum power from the solar array and given the control signal to the resonant DC- DC converter. The hybrid bridge resonant DC-DC converter having the maximum efficiency when the conversion takes place (wide range input voltage into constant output voltage) and given the constant output voltage to the DC bus. This DC bus voltage is ideal for the input of the battery bank and also the bi- directional inverter. For the production of power from the wind energy the double fed induction generator with the z-source inverter is used. The output of the z- source inverter is relate with constant alternating voltage and frequency related with the AC bus. Diesel generator is need only when the battery backup is dry and there is no power from the solar array (during night) and no power from the wind(very low wind session) in the medium load conditions which is directly connected to the load also the peak load conditions it will share the load by synchronizing. In this system seek to reduce the number of cycles and the depth-of-discharge for the battery bank, run the diesel generator in its most efficient operating range, maximize the utilization of the renewable resource, and ensure high reliability of the system.

For most efficient operation the generated power is supplied directly to the load from all energy sources which reduce the cycling of the battery bank. The high capacity sealed lead- acid battery is selected for the battery bank which is having the less maintenance and long life time.

3 MODES OF OPERATION

The design process of hybrid energy systems requires the selection of the most suitable combination of energy sources, power-conditioning devices, and energy-storage system, together with the implementation of an efficient energy dispatch strategy. For most suitable operations hybrid energy system controller set to operate in the difference mode. The modes are described as follows

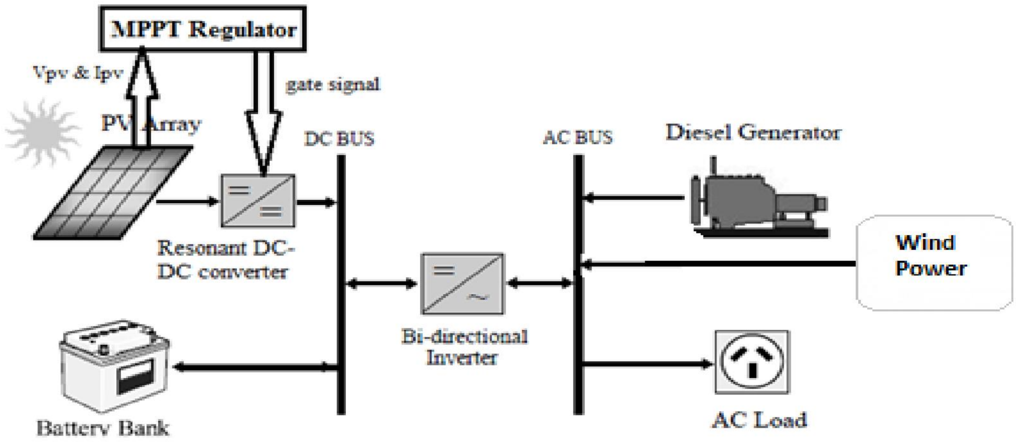


Fig. 1. Block diagram for parallel configuration of hybrid systems

Mode (I)
The base load, which is typically experienced at night and during the early morning hours, is supplied by wind power or energy stored in the batteries. Photovoltaic power is not available and the diesel generator is not started.
Mode (II)
PV power is supplemented by stored energy to meet the medium load demand.
Mode (III)
Excess energy is available from the PV generator, which is stored in the battery. The medium load demand is supplied from the PV generator and from the wind power.
Mode (IV)
The diesel generator is started and operated at its nominal power to meet the high evening load. Excess energy available from the diesel generator is used to recharge the batteries.
Mode (V)
The diesel generator power is insufficient to meet the peak load demand. Additional power is supplied from the batteries by synchronizing the inverter ac output voltage with the alternator waveform.
Mode (VI)
The diesel generator power exceeds the load demand, but it is kept operational until the batteries are recharged to a high state-of-charge level.

4 MPPT REGULATOR

At present many MPPT methods have been developed and they implemented digitally either in a microcontroller (MCU) or field programmable gate array (FPGA). The tracking performance of the MPP using digital controller is high. However the potential benefit of the analog solution is in MPPT can be integrated with DC/DC controller to form a single chip “MPPT Regulator” shown in figure 2.

The most desirable approach for universal analog MPPT is the P&O method. Moreover, for the target PV applications, the P&O method is capable of obtaining a satisfactory tracking result. However, there is an implementation problem with this method dealing with how to implement the algorithm with simple circuits and how to store the value of Vpv and Ppv in last perturbation cycle. This is a challenge for analog MPPTs.

In this research, a truth table is extracted from the P&O algorithm. Based on this table, the analog MPPT controller may only need to use several logic gates to realize the tracking algorithm. Meanwhile, the concept of a capacitor based storage cell is proposed to save the value of Vpv and Ppv in the last perturbation cycle. The minimum voltage step of perturbation may be set by the combination of amplitude of charge (discharge) current and the time duration of charge (discharge) action. Normally 0.5% of the open circuit voltage is selected [6].

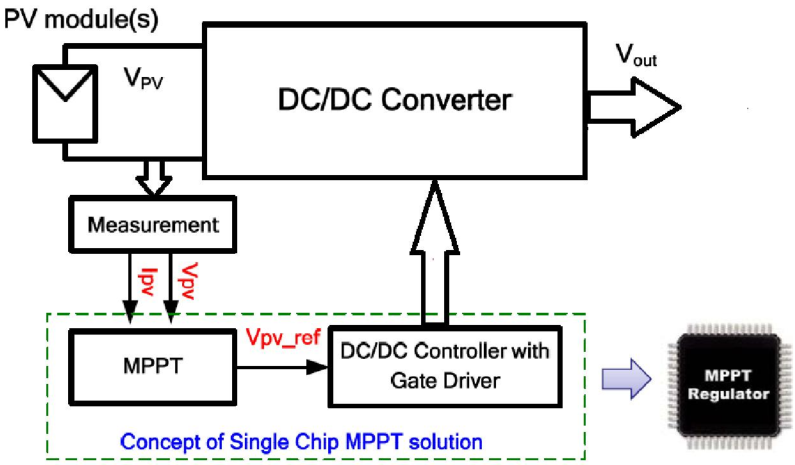


Fig. 2. MPPT Regulator

The analog MPPT controller has two input signals: PV panel voltage Vpv, panel current Ipv. The output signal from MPPT controller is a reference signal for DC/DC controller and its value will keep updating once MPPT starts running.

Table 1. Truth Table extracted from P&O algorithm

Present Perturbation	Change in power	Next perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

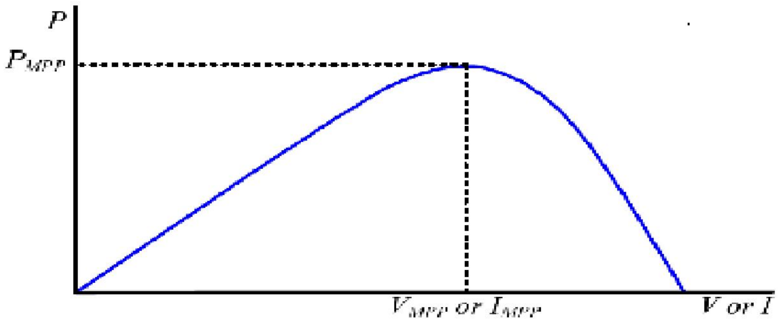
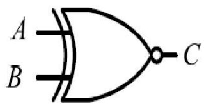


Fig. 3. Typical P-V curve of a PV panel

When operating on the left side of the MPP, incrementing the panel voltage will increase the power; whereas operating on the right side of MPP, incrementing the panel voltage will decrease the power. By continuously injecting perturbation onto the panel voltage or current and observing the variation of output power, the MPP may be reached when following the algorithm summarized in Table 1.



A	B	C
1	1	1
1	0	0
0	1	0
0	0	1

Fig. 4. Symbol and Truth Table of EXOR gate

In Table, "positive" is defined as logic "1" and "negative" is defined as logic "0", a truth table may be derived which implies that the algorithm may be implemented by simple logic circuitry. Moreover, if we take "perturbation" and the "change in power" as two inputs and the "next perturbation" as output, the logic relationship between the inputs and output matches that of an XNOR gate shown in figure4, As a result, with the derived truth table, the P&O algorithm may be implemented around an XNOR gate with some other logic circuitry [6].

5 HYBRID BRIDGE RESONANT DC-DC CONVERTER

The main challenge for the front end DC-DC converter in the photo voltaic system is to achieve the wide input voltage range with the high efficiency. The circuit diagram of hybrid bridge resonant DC-DC converter and their parameters are shown in figure 5. The Hybrid bridge resonant DC-DC converter is achieving the wide input voltage range with high efficiency by operating with the two modes of operation. In this converter a threshold voltage is defined as the half of the maximum open circuit voltage in panel. When the converter input voltage is above the threshold voltage (Vin > Vth), the converter is acts as a half-bridge converter. In half bridge mode the switches S_1 ans S_2 are conducting to achieve the mode and get the proper DC gain with high efficiency and when the input voltage of the converter is less than the threshold voltage (Vin < Vth), the converter acts as a full bridge converter. In full bridge mode all the four switches S_1, S_2, S_3, and S_4 are conducting to achieve the mode. In this mode we know the DC gain is doubled in full bridge, so we may get the proper high gain and good efficiency. Here the pulse signal for the switches S_1 and S_4 are identical and S_2 and S_3 are the same. A special gate logic generator is designed to the safe mode transition by generating proper gate drive signals [5].

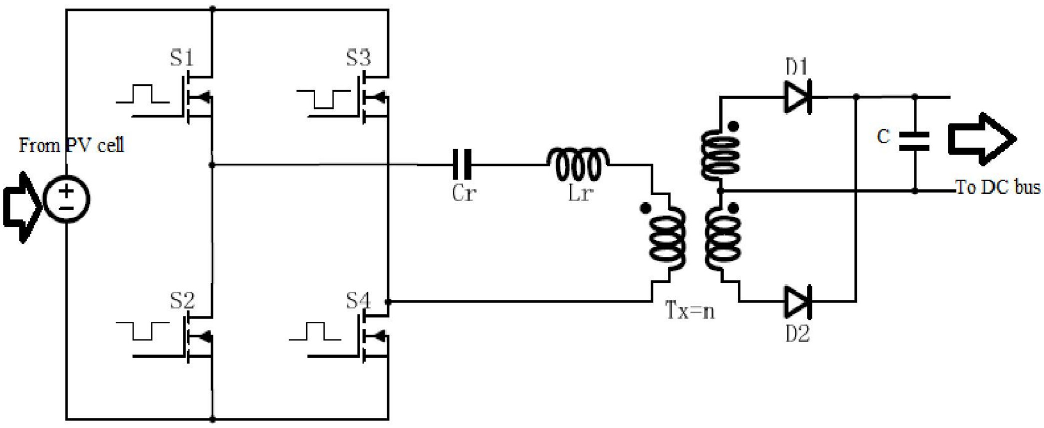


Fig. 5. Circuit diagram of Hybrid Bridge DC- DC converter

When designing the proposed DC/DC converter, it is important to choose a proper threshold voltage Vth. The basic rule for selecting Vth is that the converter's efficiency may be optimized throughout the whole input voltage range. Ideally, Vth should be the voltage at which the converter may have identical efficiency no matter in which mode it operates. For practical design, the half of the highest V_{OC} (happens in cold weather) of PV panel can be chosen as Vth for initial evaluation. Then design the resonant converter parameters with input range of 1/2 V_{OC}~V_{OC} and optimize efficiency at point Vnom, where Vnom is equal to V_{MPP}. The power loss should be analyzed for converter operating in both FB mode and HB mode with

Vin =Vth. In this condition, suppose η1 represents efficiency in HB mode and η2 is efficiency in FB mode. If η1>η2, Vth should decrease; otherwise, Vth increases. An optimal point can be obtained for Vth after several iterations.

Hybrid Bridge resonant DC-DC converter operates in either full bridge mode or half bridge mode based on the input voltage. Say the dc bus voltage 50 volt and the open circuit voltage is 36. So that threshold voltage is 18volts. When the input voltage is below the 18 volt it will operate as full bridge mode and above the 18volts it may operate as half bridge mode In variable speed wind turbines, power electronic circuitry partially or completely decouples the rotor mechanical frequency from the grid electrical frequency, enabling the variable speed operation. The type of electric generator employed and the grid conditions dictate the requirements of the power electronic interface. The electrical generator popularly employed for partially variable speed wind energy conversion systems are doubly-fed induction-generators. In this method where the rotor circuit is controlled by the power converter system via the slip rings and the stator circuit is connected to the grid. This method is advantageous as the power converter has to handle a fraction ~ 25% - 50 % of the total power of the system. The power converter system employs a rotor side ac-dc converter, a dc link capacitor, and a dc-ac inverter connected to the grid. The power converter enables vector control of the field which facilitates active/reactive power control.

6 Z- SOURCE BASED VARIABLE SPEED WIND ENERGY SYSTEMS

The variable speed turbine can generate electricity from winds with speeds ranging from 9 to 65 miles per hour. In conjunction with the variable speed feature, this wide operating envelope increases the turbine's energy capture by 10 to 15 percent or more over a comparably sized constant speed turbine, The variable speed turbine's rotor can turn faster as wind speed increases, storing some of the wind's energy as kinetic energy, which generates additional electricity when released. The rotor side converter controls the speed and torque of the rotor and the stator side convertor maintains a constant voltage across the dc link capacitor, irrespective of the magnitude of the rotor power. This method is more efficient than the fixed speed system; however it does not reflect the possible optimal efficiency. By employing a full scale ac-ac converter system the wind turbine can be completely decoupled from the grid, enabling a wider range of optimal operation. The variable frequency ac from the turbine is fed to the three phase ac-dc-ac converter. The generator side ac-dc converter is controlled to obtain a predetermined value at the terminal of the dc link capacitor [12]. The dc voltage is then inverted using a six-switch dc-ac inverter. Inversion is inherently buck operation hence the turbine side ac-dc converter has to ensure sufficient voltage level is obtained in order to integrate with the grid. If additional boosting of the voltage is required, an additional dc-dc boost converter can to be employed. This increases the overall cost and complexity. To overcome the shortcomings a Z-source inverter based conversion system can be employed.

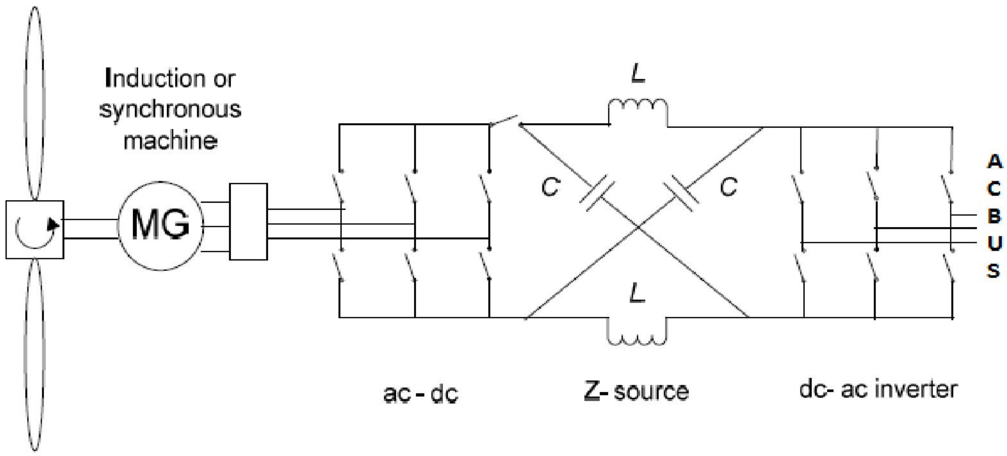


Fig. 6. Z-source based variable speed wind energy systems

Z-source inverter is a relatively new topology and has the following advantages over the conventional voltage source/current source inverters are Buck-boost ability, Inherent short circuit protection due to Z-source configuration, Improved EMI as dead bands are not required Z-source inverter based wind power conversion systems are relatively new, however researches are investigating its applicability [13]. A Z-source converter based wind energy system has been studied and presented in Figure 6 shows a Z-source based wind energy conversion system.

7 BI – DIRECTIONAL INVERTER

As discussed earlier in this bi- directional inverter to use the same hardware in two modes of operation and thus have bidirectional power flow functionality. The block diagram of bi-directional inverter with the energy management is show in figure 7. An H-Bridge inverter connected in series with a bidirectional dc-dc converter. In the discharge mode, the bidirectional buck/boost converter is used to boost the battery voltage to a level higher than the output of the transformer so that current will be allowed to flow from the batteries into the AC bus [2]. The inverter is used to chop up the DC voltage from the batteries into an unfiltered ac voltage. The chopped ac voltage is then passed through an output filter in order to smooth out the current waveform passing into the AC bus. The current is finally passed through a step-up transformer which provides isolation while stepping the voltage up to direct interface with the AC bus.

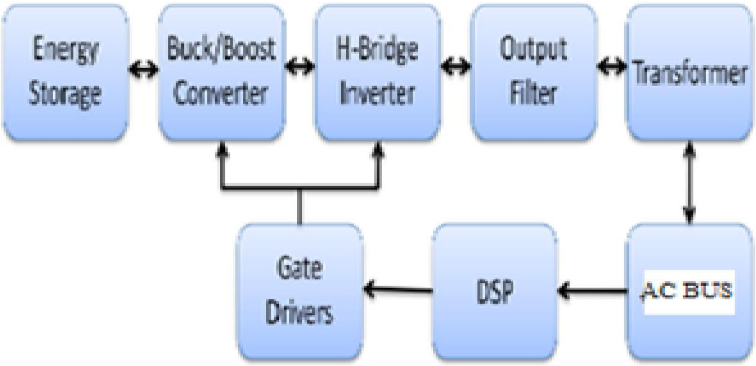


Fig. 7. Bi- directional Inverter block diagram

Since the voltage waveform is determined by the AC bus, the inverter will be of the current controlled type. A hysteresis control method was selected for this system because of its ease of implementation. This method works by setting a band around a reference signal and turning on and off switches according to when the current crosses the band boundary. Additionally, the boost converter was controlled by using a proportional-integral (PI) control strategy.

The benefit of the charge mode lies in the fact that it only adds one additional switch to those required for the discharge mode. The charge mode utilizes the freewheeling diodes on the inverter as a bridge rectifier while the dc-dc converter regulates the amount of current that is allowed to flow into the batteries. This aspect of the design was the easiest to implement since it only requires the modulation of a single switch and does not require any special phase locking considerations. This mode was considered a secondary goal to some extent for this reason. The battery charging was accomplished through a simple trickle charge method.

Hall Effect sensors and voltage level shifting circuits are measuring the current and voltage respectively. The bi-directional inverter operation is controlled by the DSP TMS320F2808.

The boost converter utilized a PI controller to regulate the increased voltage to a desired level. The H-bridge inverter used a hysteresis control to chop up the boosted voltage and regulate the current flowing into the AC bus. The PI control was initialized whenever the battery bank is connected and a voltage greater than required voltage was sensed by the DSP.

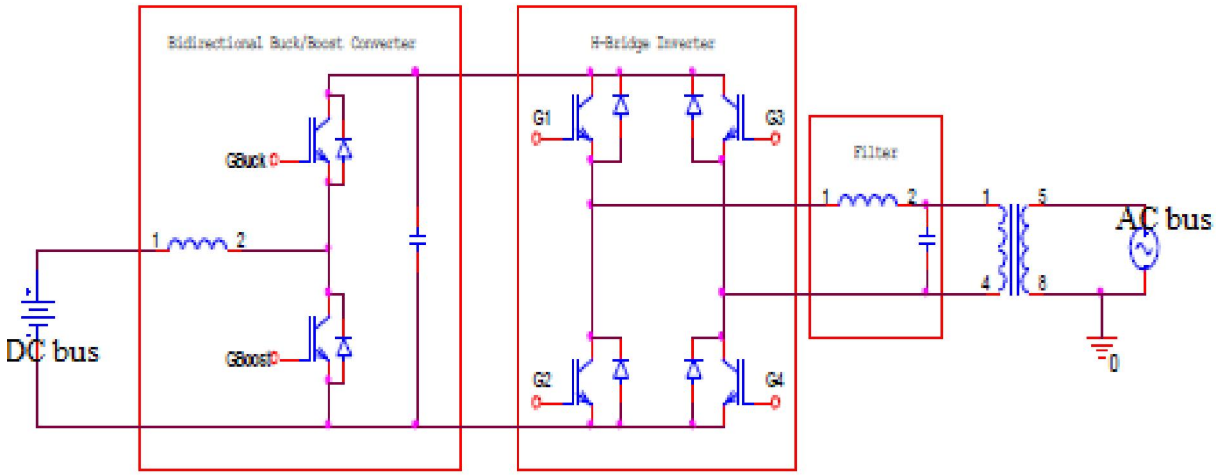


Fig. 8. Circuit diagram of Bi- directional Inverter

The hysteresis control begins whenever the boost voltage becomes greater than the transformer input voltage. The system was designed to continue running until stopped manually by disconnecting the battery bank and AC bus.

8 CONCLUSION

In this research, a simple MPPT analog regulator based on a Logic truth table perturbation and observation is presented to deliver the highest possible power to the DC converter from the solar arrays. The hybrid bridge resonant DC/DC converters are given the excellent performance, low noise for solar energy systems and give the efficiency of 98 %. The Z-source based variable speed wind energy systems are giving maximum output from the wind energy and the advantage of short circuit protection and improved EMI as dead bands. The Bi-directional inverter is works based on the mode of operation with the hysteresis loop control method. High capacity sealed lead acid battery is use for the battery bank for the long life, low maintenance operation. Parallel configuration gives the system load can be met in an optimal way and gives the full efficiency operation.

ACKNOWLEDGEMENT

The Authors express their gratitude to J. Raja Simmon for partially supporting this work and the authorities of SJUIT lecturers and friends for their constant support in completing this work.

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