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Research Article

# An Efficient DC-DC converter with Analog MPPT controller for the stand alone Photo Voltaic system

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***Abstract***

*In this research article we have proposed a new hybrid bridge resonant DC-DC converter with analog MPPT controller for the photo voltaic system in stand-alone load. The output of the photo voltaic panel is unregulated DC supply due to the change in weather conditions. The maximum power is tracked with respect to the temperature and irradiance level by using DC-DC converter. The logic truth table based perturbation and observation algorithm is applied for maximum power point tracking (MPPT) purpose. This algorithm is selected due to its ability to withstand against any parameter variation and having high efficiency. The solar cell array powers the steady state energy and the battery compensates the dynamic energy in the system. The aim of the control strategy is to control the hybrid bridge resonant DC-DC converter and bi-direction DC-DC converter to operate in suitable modes according to the condition of solar cell and battery, so as to coordinate the two sources of solar cell and battery supplying power and ensure the system operates with high efficiency and behaviours with good dynamic performance. The output of DC-DC converter is converted to AC voltage by using inverter. The AC output voltage and frequency are regulated. A closed loop voltage control for inverter is done by using unipolar sine wave pulse width modulation (SPWM). The regulated AC voltage is fed to AC standalone loads or grid integration. The overall system is designed, developed and validated by using MATLABSIMULINK.*

**Keywords:** *Hybrid Bridge Resonant DC-DC converter, Photo-voltaic systems, Perturbation and observe, Analog MPPT Controller, Inverter, Bidirectional DC-DC Converter (BDC)*

## 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. 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/ m2. 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. 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

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(P&O) algorithm. 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.

Inverters are static power converters that produce an AC output waveform from a dc power supply. The dc power from resonant converter is fed to inverter to get ac output power. A Bi-Directional DC-DC Converter (BDC) is connected between the resonant Converter and Inverter. BDC is used to store the dynamic energy in battery and supply to load when there is overcast sky or at night. For sinusoidal ac outputs, the magnitude and frequency should be controllable. This is done by comparing a sinusoidal wave of the same frequency as inverter output against triangular carrier frequency wave. This technique called sinusoidal pulse width modulation (SPWM) mainly used because of its simplicity and ease of implementation. The output voltage magnitude is controlled by closed loop control system using PI controller.

A mono crystalline PV system structure in which two PV modules connected in series is considered and it provides an output power of nearly 100 Watts. To address the PV system structure, this paper proposes a new MPPT algorithm, which is based on the improved research on the characteristics of the PV array to track the global MPP even under non-uniform insulation. Battery charging and discharging is done using BDC (Bidirectional converter). BDC is operated in three modes namely; Buck, Boost and Bidirectional. The algorithm was verified with MATLAB-SIMULINK that it can track the real MPP very fast when the temperature changes. The closed loop operation of proposed system is verified with MATLAB simulations including Load and source disturbances.

## 2. Proposed system configuration

The block diagram schematic of the proposed solar energy conversion scheme is shown in Fig 1. It consists of a mono crystalline solar cell array, a battery, hybrid bridge resonant DC-DC converter, bi-directional DC-DC converter (BDC) and single phase Inverter. The solar cell array and battery are connected to the same DC Bus through the hybrid bridge DC-DC Converter and bi-directional DC-DC converter respectively. The system has several advantages: (1) the charging and discharging currents of the battery are only controlled by the BDC and the system structure is simpler. (2) The over-load power is supplied by the battery (3). The energy management can be realized through the control of the UDC and BDC, ensuring the system to work with high efficiency.

The output Power of the hybrid bridge DC- DC converter is varied due to temperature and irradiations. Hence, the Maximum power is tracked and extracted from the PV array and transferred to the stand-alone load through single phase Inverter. The controller generates the gating pulses for the resonant DC-DC converter, BDC and Inverter to extract maximum power, Energy management and to maintain desired ac output voltage and frequency across load terminals.

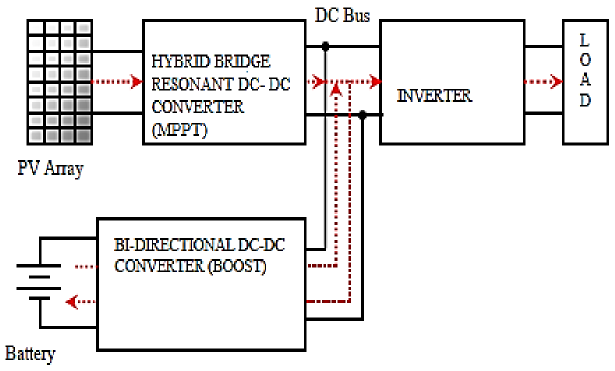



**Fig 1:** Block diagram of proposed system

## 3. Modes of operation

The working situation of the system can be divided into four operation modes based on the value of the voltage of the solar cell array ($V_{PV}$), the voltage of the battery ($V_{Bat}$), and the charging or discharging current of the battery ($I_{Bat}$), which are illustrated in Table 1.

**Table 1**: conditions for mode operation

| Mode I | Mode II | Mode III | Mode IV |
|---|---|---|---|
| $V_{bat\_min} < V_{bat} < V_{bat\_max}$ | $V_{pv} > V_{PV\_min}$ | $V_{bat\_min} < V_{bat} < V_{bat\_max}$ | $V_{bat} \le V_{bat\_max}$ |
| $V_{pv} > V_{PV\_min}$ | $I_{bat} \ge I_{bat\_max}$ | $V_{pv} \le V_{pv\_min}$ | $Vpv \le V_{pv\_min}$ |
| $I_{bat} < I_{bat\_max}$ | $V_{bat} \ge V_{bat\_max}$ | $I_{bat} < 0$ | $Vpv > V_{pv\_min}$ |
| | | $V_{bat} \ge V_{bat\_max}$ | $I_{bat} \ge I_{bat\_max}$ |

*Mode-I*

The hybrid bridge resonance DC-DC converter works in Maximum Power Point Tracking (MPPT) mode and the BDC in Boost mode in mode I, where the DC Bus voltage and reverse inductor current of the BDC is controlled to get a stable voltage for DC Bus. When solar cell cannot provide enough energy to power load (Ppv<Po), the shortage will be complemented by battery via the BDC; and when solar cell can provide more power than load needed (Ppv>Po), solar cell powers load and residual power charges battery synchronously. So battery can work between charging and discharging state freely, and the difference between charging and discharging state is the reverse power flow direction.

*Mode-II*

Mode II starts when VBat reaches over-charged-point voltage or IBat reaches the maximum charge current during mode I, then the operation mode of BDC must change from Boost to Buck mode, which control VBat and inductor current of BDC to charge the battery, meanwhile the operation mode of resonant Converter must also change from MPPT to CV mode immediately, which control the DC Bus voltage.

*Mode-III*

When VPV_min in the case of overcast sky or at night, the output power of solar cell is zero (Ppv=0), then the resonant DC-DC Converter stops working and only the BDC works in Boost mode to regulate the DC Bus voltage to be stable to power the load.

*Mode-IV*

Due to continuous raining days during operation mode III, the battery may come into over-discharge state for continuously supplying power to load. When VBat_min reaches over-discharged-point voltage, the BDC immediately stop working to protect the battery, and the whole system stops.

*3.1 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 fig2. 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 S1 ans S2 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 S1, S2, S3, and S4 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 S1 and S4 are identical and S2 and S3 are the same. A special gate logic generator is designed to the safe mode transition by generating proper gate drive signals.

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 VOC (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 VOC~VOC and optimize efficiency at point Vnom, where Vnom is equal to VMPP. 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 500 volt and the open circuit voltage is 360. So that threshold voltage is 180volts. When the input voltage is below the 180 volt it will operate as full bridge mode and above the 180volts it may operate as half bridge mode

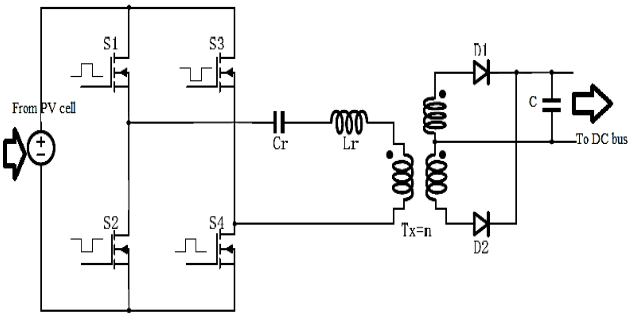



**Fig 2**: Circuit diagram of Hybrid Bridge DC- DC converter

*3.2 Analog MPPT Controller*

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 fig 3.

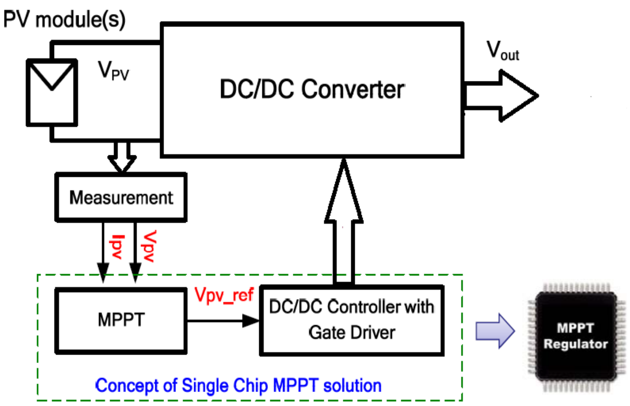



**Fig 3:** MPPT Regulator

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.

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.

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 2.

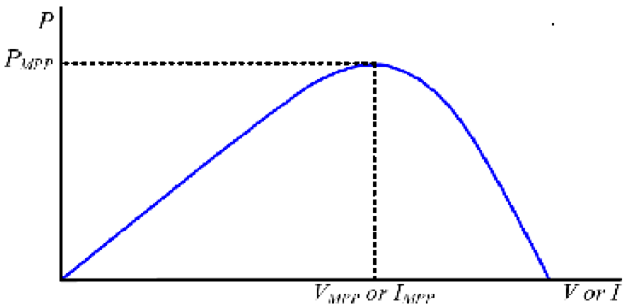
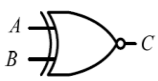



**Fig: 4** Typical P-V curve of a PV panel

**Table 2**: 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 |




| A | B | C |
|---|---|---|
| 1 | 1 | 1 |
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | 1 |

**Fig 5**: 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 fig 5, As a result, with the derived truth table, the P&O algorithm may be implemented around an XNOR gate with some other logic circuitry.

*3.3 Bidirectional DC-DC Converters*

A bidirectional DC-DC converter shows in fig 6 which allows transfer the power between two DC sources becomes an important theme of power electronic converters. When power flows to one direction the converter works in buck mode, on the other hand, when the power flows to the other direction the converter works in boost mode. When there is excess energy in PV array, BDC works in buck mode and the Battery will be in charging mode but when there is cloudy or at nights, BDC works in boost mode and then battery supplies power to load. This can be achieved by controlling the duty cycle. LCL configuration is used to effectively damp out the ripples in the Battery current. Possible modes of operation of BDC are; Buck mode, Boost mode, Bidirectional mode.

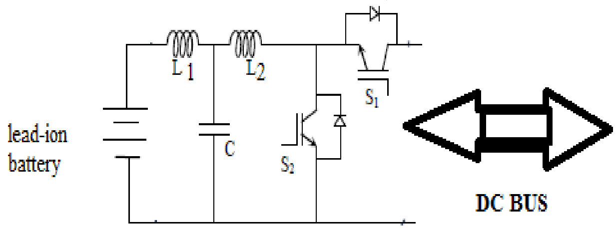



**Fig 6**: Bi-directional DC- DC converter

*3.4 PWM Converter*

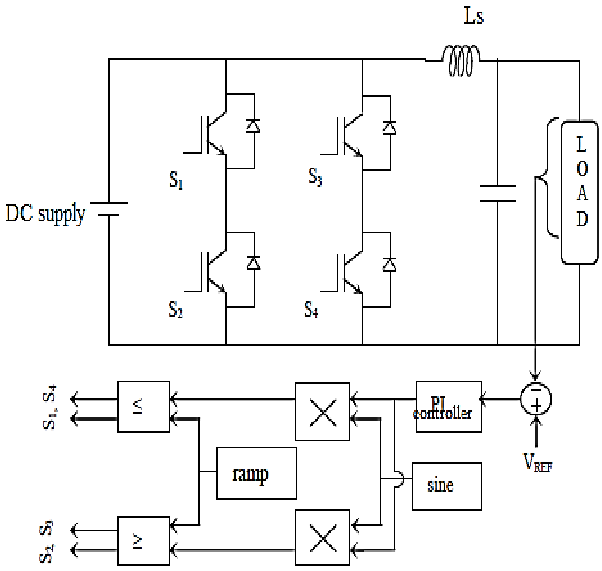



**Fig 7:** closed loop control of PWM inverter

The block diagram of closed loop operation of single phase inverter is shown in Fig 7. Output voltage of inverter is controlled by using PI controller. Sine wave pulse width modulation (SPWM) is used to control the four switches of inverter.

## 4. 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 %. BDC is operated in suitable modes according to the conditions of PV panel and battery. The BDC can operate in three modes: buck, boost and shutdown illustrated using simulation results. At the same time, output results of inverter with SPWM control strategy have better voltage control and simulation results of system demonstrate that the PV system has the fast and effective response under changing irradiance levels. So the PV generation system based P&O MPPT method, BDC and SPWM control for single-phase voltage source PWM inverter is feasible and effective.

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