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DESIGN OF PI CONTROLLER FOR INTERLEAVED - FLYBACK WITH ACTIVE CLAMPING CIRCUIT FOR A HYBRID OF SOLAR AND FUEL CELL ENERGY

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ABSTRACT

This paper proposes a design of PI controller for a interleaved – flyback with active clamping circuit. The hybrid renewable energy system comprising solar photovoltaic (PV) and fuel cell (FC) for continuous power supply to the load. As solar energy source is intermittent in nature because of the variations in irradiation and temperature, the fuel cell is added to the system for ensuring continuous power flow. The transformer of interleaved-flyback converter used for the isolation purpose. The proposed system incorporates the auxiliary switch and clamp capacitor are used in the flyback converter to recycle the energy stored in the transformer leakage in order to minimize the spike voltage across the two main switches. Therefore the voltage stress of main switch can be reduced. Thus this paper presents an efficient scheme of power generation from solar and fuel cell system for stand-alone applications.

Keywords—PV, MPPT, Fuel cell, Hybrid System, interleaved Flyback Converter, Active Clamp.

1. INTRODUCTION

In recent years, renewable energy sources such as solar, fuel cell, wind, tidal, biomass and so on have been focused by a growing environmental awareness to global warming. The photovoltaic system converts sunlight into electricity. The basic device of photovoltaic system is the photovoltaic cell. Cell may be grouped to form panels or modules. The panel can be grouped to form large photovoltaic arrays. In solar panel several cells connected in series or parallel. Cells connected in parallel increase the current and cells connected in series provide greater output voltage.

The modeling and circuit based simulation of photovoltaic array is proposed in [1]. Maximum power point tracking (MPPT) is desirable to achieve maximum power point output at minimum cost under various operating conditions. However, the maximum power point varies with solar irradiance. The perturb and observe (P&O) algorithm is also known as the “hill climbing” method is very commonly used because of its simplicity in algorithm and ease of implementation. They operate by periodically perturbing (i.e incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. If the power is increasing, the perturbation will continue in the same direction in the next cycle otherwise perturbation direction will be reversed. A solution to the problem faced by the P&O MPPT algorithm is proposed in [2-5]. The results showed that in the design of efficient MPPT regulators the easiness and flexibility of P&O MPPT control technique can be exploited by optimizing it according to the specific system’s dynamic characteristics.

Developments and applications of the fuel-cell power generation system become one of the most effective solution to compensate the fossil-fuel energy shortage and to protect the global environment because the fuel cell is a clean and renewable energy source with high efficiency, high reliability, and easy modularization performance.

Nowadays, thanks to recent improvements in fuel cells (FC) technology, hydrogen is most promising energy to reach on environment friendly distributed electrical energy production. Since, fuel cells are highly efficient, require less maintenance, and operate silently, they are ideal in distributed power generation applications in both grid- connected and off grid-connected or stand alone configurations [6,7]. A fuel cell is the stationary power generator. The fuel cell chosen for this type of application must provide competitive, reliable, and quality power without emitting pollutants such as oxides of nitrogen, carbon and sulphur. It must respond quickly to changes in load and have low maintenance requirements as well as a long cell life. Design and implementation of fuel cell is present in [8-12].

A system that brings together two or more sources of energy is called a hybrid system. The main advantage of hybrid system is the continuous power supply. The power supply is optimized. The load can get the peak power all the time. Even, absence of anyone supply which will not affect the circuit operation. Hybrid of solar energy and fuel cell energy which, is free of cost, clean and pollution free system.

The flyback converter transformer used to achieve circuit isolation, boosting the input voltage and energy storage. The switch in the flyback converter operated at hard switching. Therefore the voltage and current stress of switch suffered from the transformer leakage inductance is very high. The auxiliary switch and clamping capacitor are used in the flyback converter to recycle the energy stored in the transformer leakage in order to reduce the spike voltage at the primary side. Therefore the voltage stress of the main switch reduced. Analysis and design of active clamp circuit presented in [13-16].

2. PROPOSED SYSTEM

The proposed system has a PV panel and fuel cell hybrid system connected to a interleaved-flyback converter with active clamping circuit. The interleaved flyback converter (ILFC) which is the DC-DC converter used to boost the output voltage and minimizing the hybrid system current ripple. The main switch of the interleaved-flyback converter controlled using PI controller through the MPPT technique that helps to obtain maximum power from the solar panel.

The auxiliary switches in the interleaved-flyback converter controlled through the PI controller. The interleaved-flyback converter which produce the output of DC power. The single phase full bridge inverter used convert the DC power to the AC power. LC filter are used to reduce the harmonics in the output of AC power. Finally the AC output power supplied to the RL load for the off grid or stand alone application. The combination of proportional and integral terms is important to increase the speed of the response. Using the PI controller for comparing the reference and output value then produce the error signal. PI controller reduce the overshoot of error signal and bring that into steady state level. The block diagram of the proposed system is shown in figure 1.

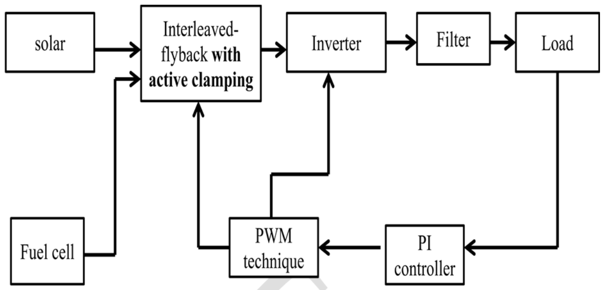

Figure. 1 Block Diagram of proposed system

3. DESCRIPTION OF THE HYBRID SYSTEM

In this section, the dynamic simulation model is described for the proposed photovoltaic and fuel cell hybrid generation system. The hybrid power system which, includes the solar panel and fuel cell system. In the proposed system solar panel is designed based upon the equations they are given below

$$I = I_{pv,cell} - I_{o,cell}\,[\exp(qv/akT) - 1] \qquad (1)$$

$$I = I_{pv} - I_o\,[\exp((V+R_sI)/V_{ta}) - 1] - (V+R_sI)/R_p \qquad (2)$$

Where Ipv and I_0 are the photovoltaic and saturation currents of the array and Vt = NsKT/q is the thermal voltage of the array with Ns cells connected in series.

$$I_{pv} = (I_{pv,n} + K_I \triangle T)\,(G/G_n) \qquad (3)$$

Where Ipv,n [A] is the light generated current at the nominal condition.

$$I_0 = (I_{sc,n} + K_I \triangle T)/\exp((V_{oc,n} + K_v \triangle T)/aV_t) - 1 \qquad (4)$$

From the above equation (1), (2), (3), and (4) the solar panel is designed. Which, is given below

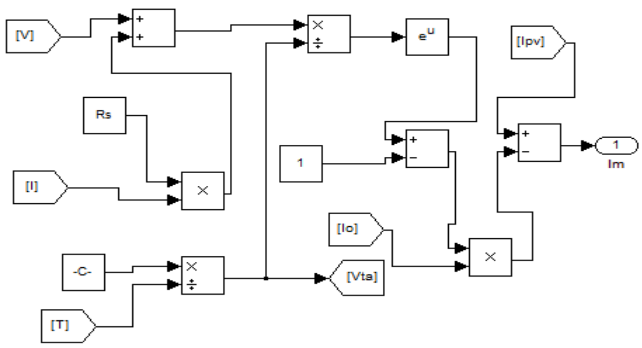

Figure. 2 Equation for Im

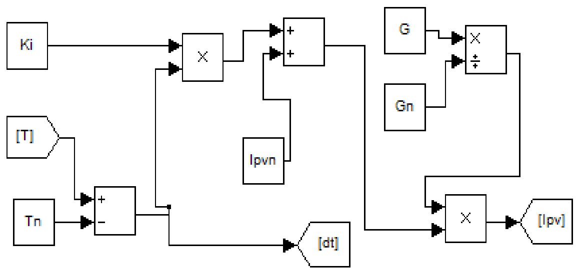

Figure. 3 Equation for Ipv

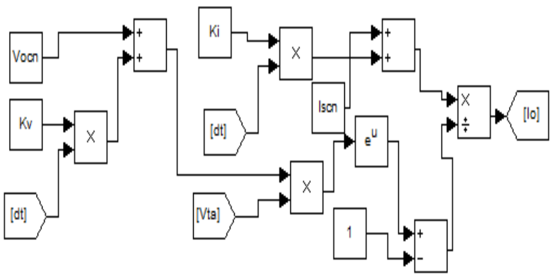

Figure. 4 Equation for I0

From the fig 2, 3, 4 I0 is the output current, Voc,n is the nominal open circuit voltage, Isc,n is the nominal short circuit current, Kv is the temperature coefficient, Ipv is the light generated current, T, Tn is the nominal and actual temperature coefficient, Im is the maximum current and Rs, Rp is the series and parallel connected resistance. The major principle of MPPT is to extract the maximum available power from PV module by making them operate at the most efficient voltage (maximum power point).

The Fig. 5 which shows the hybrid method of the solar panel and fuel cell energy generation system.

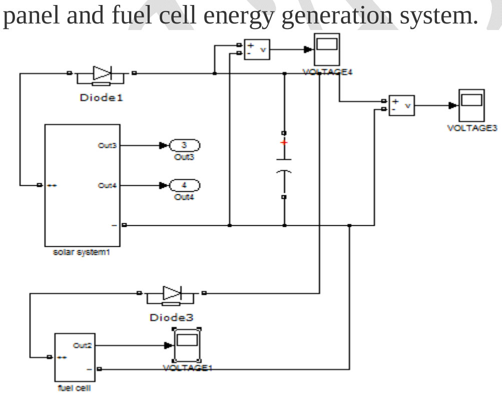

Figure. 5 Simulation diagram of Hybrid system

In this hybrid power system, the fuel cell is used to produce power if the load power exceeds that produced from the PV system. It can also function as an emergency generator, if the PV system fails. An electrolyzer converts electricity into chemical energy which produces hydrogen which can be stored in pressure tanks and used for fuel cell. The main advantage of hybrid system is the continuous power supply. The power supply is optimized. The load can get the peak power all the time. The main advantage of hybrid system is the continuous power supply. The power supply is optimized. The load can get the peak power all the time.

4. INTERLEAVED – FLYBACK CONVERTER

This paper proposes the interleaved-flyback converter with active clamp circuit. Flyback converter is nothing but the combination of switch and capacitor. Interleaved converter is the parallel connection of same circuit at the "n" number of times. Which, for improving the system efficiency. The interleaved-flyback converter which, has the two main switches Sm1 and Sm2. The interleaved-flyback converter without active clamp switch operated as the hard switching. The active clamp circuit which, has the auxiliary switch and clamp capacitor.

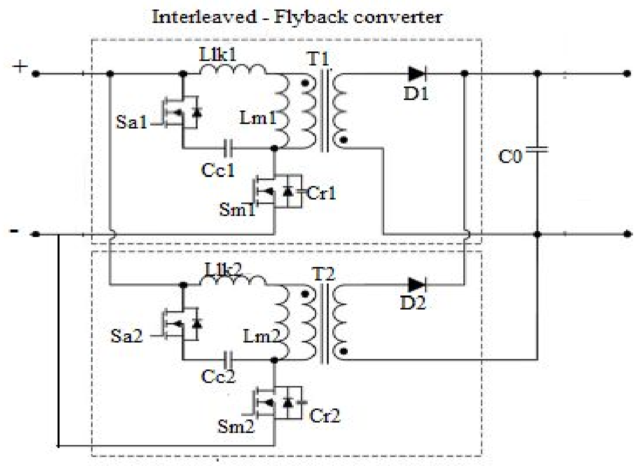

Figure. 6 Interleaved-flyback with active clamp circuit

The fig. 6 shows interleaved-flyback converter with active clamp circuit which has the two auxiliary switches Sa1, Sa2 two main switches Sm1, Sm2 and the two clamp capacitors Cc1 and Cc2.

A. Operation of ILFC Converter

The interleaved flyback converter which has the main Switches Sm1, Sm2 auxiliary switches Sa1, Sa2 resonant capacitor Cr1, Cr2 auxiliary diodes Da1 and Da2. The active clamp circuit including the auxiliary switches Sa1,Sa2 and clamp capacitor Cclamp, is added in parallel to primary side of the flyback transformerTr1,Tr2 to recycle leakage energy and achieving soft switching for the main switches Sm1,Sm2.

During the first interval the current will flow through the main switch Sm1, leakage inductance, transformer T2 and diode D2 remaining will be off condition. At the time of second interval the direction of current flow is main switch Sm1, inductance and resonant capacitor Cr2. During the third interval switch Sm1, inductance, transformer T2, diode D2 and auxiliary switch Sa1 are on condition. During the fourth time the current flow through the resonant capacitors Cr1, Cr2, transformer T2, diode D2 and inductances. In the fifth interval the conduction elements are auxiliary diode Da1, main switch diode, clamp capacitor Cc1 and inductances. During the sixth interval transformer T1, diode D1, inductances and main switch Sm2 are on condition remaining will be off states.

At the time of seventh interval the conduction elements are resonant capacitor Cr1, inductances and main switch Sm2. During the time of eight interval auxiliary switch Sa1, clamp capacitor Cc1, transformer T1, diode D1 inductances and main switch Sm2 are all present state. At the time of ninth interval transformer T1, diode D1, resonant capacitor Cr1, inductances and resonant capacitor Cr2 are all on condition. At the time of final state the current will flow through the inductances, auxiliary diode Da2, transformer T2, clamp capacitor Cc2 and diode D2.

B. Gate Pulse Generation

The gating pulse for the main switch (Sm1, Sm2) of interleaved flyback converter are generated using P&O MPPT technique. *Perturbation and observation* is the most commonly used algorithm in MPPT algorithms because of its simplicity. Perturbation and Observation can track the Maximum Power Point (MPP) all the time, irrespective of the atmospheric conditions, type of PV panel, and even aging, by processing actual values of PV voltage and current.

They operate by periodically perturbing (i.e. incrementing or decrementing) the array termed voltage and comparing the PV output power with that of the previous perturbation cycle. If the power is increasing, the perturbation will continue in the same direction in the next cycle, otherwise the perturbation direction will be reversed. This means the array terminal voltage is perturbed every MPPT cycle.

C. Interleaved-flyback converter control strategy

The interleaved-flyback converter also known as the DC-DC converter which has the four switches. Such as two main switches Sm1, Sm2 and two auxiliary switches Sa1, Sa2.

The four switches of ILFC controlled through the PI regulators. PI controller is the proportional and integral controller. PI controller is the combination of proportional and integral controller. The PI controller used to increase the speed of the response. Using the PI controller for comparing the reference and output value then produce the error signal. And the PI controller reduce the overshoot of error signal and bring that into steady state level.

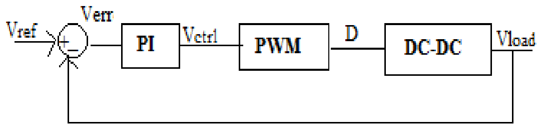

Figure. 7 PI controller control

The actual voltage and reference voltage both are given to the difference block that produce the difference which is called the error. This error is given to the PI controller which error signal is split into two separate paths one is directly amplified, and the other is amplified and then integrated. The amplified error signal and the integrated error signal are then recombined at the output via a simple addition operation. The integrator is included to drive the steady-state error of the system to zero. The output of PI controller is given to the PWM pulse generator which produces the gate pulse for the four switches of interleaved-flyback converter. To avoid the switching loss of ILFC switches the auxiliary switches of Sa1, Sa2 conduction is very short time period.

D. DC-AC control Strategy

In the proposed system single phase full bridge inverter is used to convert the DC power in to AC power. Here, the output of interleaved –flyback converter is the DC power. So, this inverter used to convert the DC-AC power and then supplied to the AC loads. The single phase full bridge inverter which has the four switches S1, S2, S3 and S4. These four switches are controlled using two PI regulators.

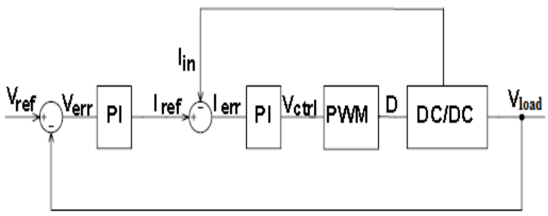

Figure. 8 Inverter Control Loop Block Diagram

The fig. 8 shows the closed loop control of the single phase full bridge inverter. In this two PI controller method both the voltage and current taken as the reference. The current control is necessary to prevent the hybrid system output current to exceed its maximum. The error signal is produced after the comparison of reference voltage and actual voltage which is given to the PI controller. The reference current is generated by means of the PI in the voltage loop and compared to the average input current. The current PI error is used by the PWM modulator to generate the gate signal.

5. SIMULATION OF PROPOSED SYSTEM

The simulation of the proposed system with auxiliary switches and clamping capacitor is shown in figure 9. It combines the simulation of solar panel, fuel cell system, MPPT, hybrid of solar system and fuel cell system, interleaved-flyback converter and single phase full bridge inverter.

The solar panel and fuel cell block is wrapped in a subsystem whose voltage outputs are obtained. The output voltage of the hybrid system is connected to the interleaved-flyback converter. The output current and voltage of solar panel is connected to the MPPT block that generates gating signals for the two main switches Sm1and Sm2 of the interleaved-flyback converter. The interleaved-flyback converter boosts the input voltage and provides the soft switching to the two main switches.

The output of ILFC is connected to the single phase full bridge inverter. The inverter which converts the DC power to the AC power. The output of inverter that feeds an R-L load. The actual current from the inverter is measured using current measurement block and voltage is measured using voltage measurement block.

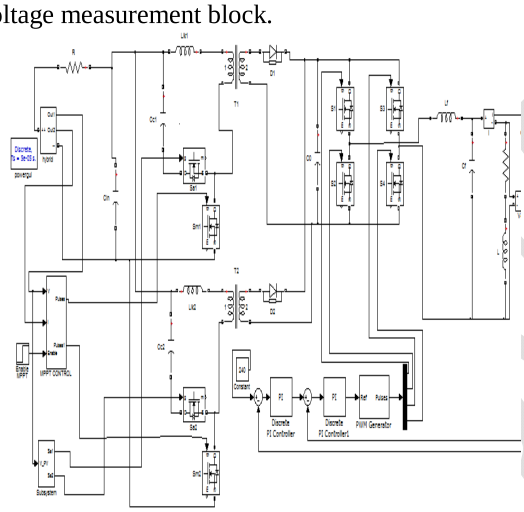

Figure. 9 Simulation of Proposed System

6. SIMULATION RESULTS

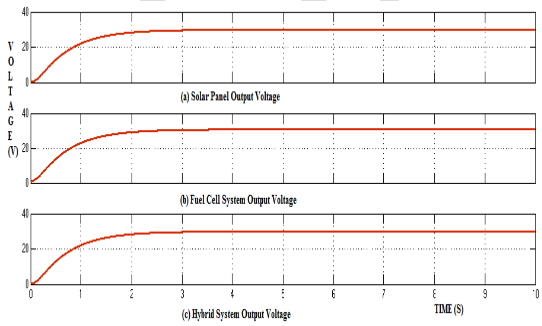

Figure. 10 Solar Panel, Fuel Cell and Hybrid System Output

The fig. 10(a) shows the output voltage of solar panel about 29.5V, (b) shows the output voltage of fuel cell system about 30.5V and (c) shows the output voltage of the hybrid system about 30V which is given to the input of interleaved-flyback converter.

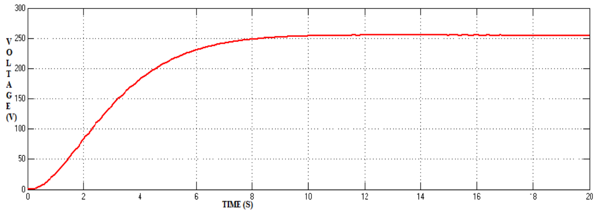

Figure. 11 Output of ILFC

The fig. 11shows the output voltage of the interleaved-flyback converter. The ILFC which produce the DC output power about 250V. The flyback converter transformer used to achieve circuit isolation, boosting the input voltage and energy storage. The switch in the flyback converter operated at hard switching.

Therefore the voltage and current stress of switch suffered from the transformer leakage inductance is very high. The auxiliary switch and clamping capacitor are used in the flyback converter to recycle the energy stored in the transformer leakage in order to reduce the spike voltage at the primary side. Therefore the voltage stress of the main switch reduced.

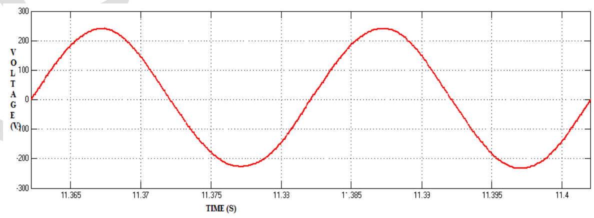

Figure. 12 Output Voltage across Load

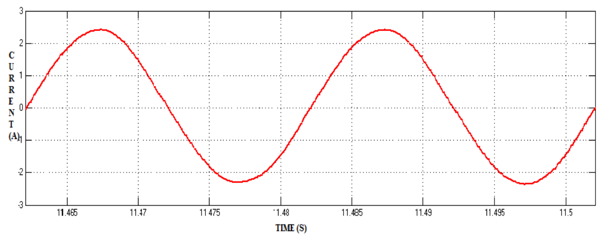

Figure. 13 Output Current across Load

The fig. 12 and 13 shows the output voltage and current across the load about 230V and 2.3A respectively. Here, LC filter is used to reduce harmonics in the output waveform. The output voltage and current both are taken as account. The difference between actual voltage and reference voltage is given to the PI controller. The PI controller produce the error signal which is act as the reference current and compared with the actual current that produce the difference which feeds to the another PI controller. The output of PI controller is given to the PWM generator which, produce the gate pulse.

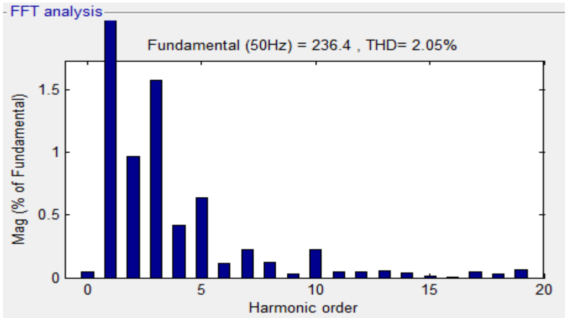

Figure. 14(a) THD Analysis of Output Voltage

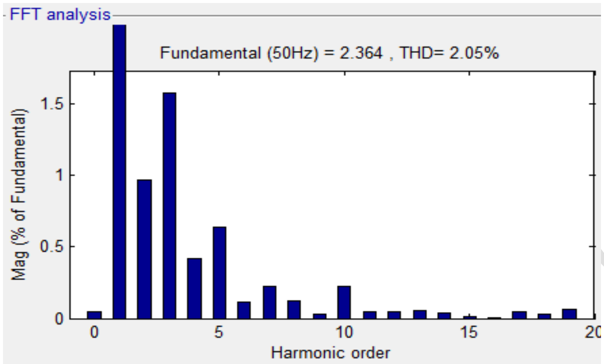

Figure. 14(b) THD Analysis of Output Current

The fig. 14(a) and 14(b) shows the THD analysis of output voltage and current waveform. The THD of iout and Vout are 2.05%, measured by MATLAB.The analysis was done for one cycle and with 50 Hz frequency. Total harmonics distortion is defined as the total amount of harmonics measured in the waveform.

7. CONCLUSION

This paper presents the design of PI controller for interleaved-flyback converter with active clamping for a hybrid of solar and fuel cell system. The main advantage of hybrid system is the continuous power supply. The power supply is optimized. The load can get the peak power all the time. Even, absence of anyone supply which will not affect the circuit operation. Hybrid of solar energy and fuel cell energy which, is free of cost, clean and pollution free system. By the use of MPPT technique**,** maximum power is obtained from the solar panel thereby increasing the efficiency of the solar panel.

The interleaved-flyback converter which has the auxiliary switch and clamping capacitor are used in the flyback converter to recycle the energy stored in the transformer leakage in order to reduce the spike voltage at the primary side. Therefore the voltage stress of the main switch reduced. From the FFT analysis the percentage of harmonics present in the wave form is 2.05%. Thus this project presents an efficient hybrid (Solar panel and Fuel Cell) system for standalone applications.

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