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Half Bridge Flyback Converter for Photovoltaic (PV) System

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Abstract : This paper presents a comparative analysis of Half Bridge Flyback Converter for photovoltaic (PV) system using Renewable Energy. The proposed converter is the Integration of Half Bridge and FlybackConverter, it provides a compact single-unit solution with maximized energy harvest for photovoltaic (PV) system. The proposed converter consists of High frequency transformer ,which provides a Galvanic isolation , High step up conversion and Zero voltage switching. The proposed converter is simulated in open and closed loop using PI,PID and FUZZY controller. The simulation results are verified experimentally and the output of the proposed converter is free from ripples and has regulated output voltage.
Keywords : Half Bridge Flyback (HBF) Converter, Photovoltaic (PV) system ,Renewable Energy, Galvanic isolation, High step up conversion, Zero voltage switching.

1 Introduction

Solar energy is a primary and renewable source of energy, as the cost of photovoltaic (PV) panels is seen to reduce continuously, PV-based power generation is gaining its popularity for both grid-connected and stand-alone systems [1,2,3–5]. The Stand-alone systems are independent of utility grids and commonly employed for satellites, space stations, Unmanned Aerial Vehicles (UAV) and Domestic applications [6,7,8–10]. These applications require storage elements to accommodate the intermittent generation of solar energy [11,12,13–15]. The conventional converter results in low power conversion efficiency , the power density by weight (PDW) and the power density by volume (PDV) is low [16,17,18–20]. The two-port topology utilizes the Dual active bridges (DAB) [21,22,23–25] and the half or full bridges to support the multiport structure. The conventional converter consists of one PV input port, one bidirectional battery port and an isolated output . However, the conventional converter, is not suitable for a multi-input multi-output (MIMO) system. The conventional converter cannot provide a single-unit solution for interfacing multiple energy sources and common loads [26,27,28–30].The conventional converter used in PV-battery application, results that one converter interfaces the three components of the PV array, battery and loads. However in each energy transfer state, the current passes through at least five inductor windings, especially under high switching frequency conditions, giving rise to power loss, its peak efficiency is less than 90% and its power capability is limited by the transformer design, making it impossible for current sharing. The conventional converter also suffers from the circuit complexity by using Three active full bridges or Half bridges ,which leads to the power loss caused by reactive power circulation. To overcome these problems Half Bridge Flyback (HBF)converter has been proposed.

2. Half bridge Flyback (HBF) Converter

The proposed converter is the Integration of Half Bridge and Flyback Converter, it provides a compact single-unit solution with maximized energy harvest for photovoltaic (PV) system. The proposed converter is illustrated in Figure. 2.1. The main switches S_1 and S_2 transfer the energy from the PV to the load, in either interleaved or synchronous mode. The switches S_3 and S_4 are operated in the interleaved mode to transfer energy from source to load. L_1 and L_2 are two coupled inductors whose primary winding (N_1) is employed as a filter and the secondary windings (N_2) are connected in series to achieve a high output voltage gain. L_{lk} is the leakage inductance of the two coupled inductors and N is the turns ratio from N_2/N_1. C_{S1}, C_{S2}, C_{S3} and C_{S4} are the parasitic capacitors of the main switches S_1, S_2, S_3 and S_4 respectively. The proposed converter achieves zero voltage switching.

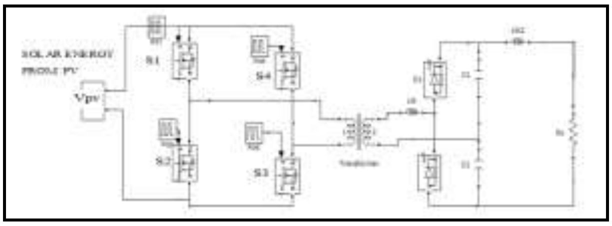

Figure.2.1 Circuit diagram of Half Bridge Flyback (HBF) converter

In particular, the Half Bridge Flyback (HBF) converter has become an attractive topology for various applications owing to their multiple energy source connection, compact structure and low cost.In this topology, a simple power flow management scheme can be used since the control function is centralized. A high-frequency transformer can provide galvanic isolation and flexible voltage conversion ratio. The HBF Converter utilizes the Triple active bridges (TAB) with inherent features of power controllability and ZVS. Their soft-switching performance can be improved if two series-resonant tanks are implemented. An advanced modulation strategy is used , which incorporates a phase shift and a PWM to extend the operating range of ZVS. . Therefore a HBF converter is proposed to integrate a three-port topology in the half bridge and to decompose the multivariable control problem into a series of independent single-loop subsystems. The HBF Converter achieves improved control strategy and to achieve decoupled port control, flexible power flow and high power capability while still making the system simple and cheap.

3. Simulation Results

The Half Bridge Flyback (HBF) Converter is simulated in both open and closed loop system using MATLAB simulink and the results are presented. Scope is connected to display the output voltage.

The following values are found to be a near optimum for the design specifications:

Table 3.1 Simulation Parameters

Parameter	Rating
Input voltage	12V
$C_1= C_2$	220µF
C	1000 µF
$L_{k1}=L_{k2}$	500 µH
Switching Frequency	20kHz
Diode	IN 4007
MOSFET	IRF840
Turns ratio (coupled inductor set)	1:2
R	200Ω

3.1 Open Loop Sysem

3.1.1 Conventional Boost Converter

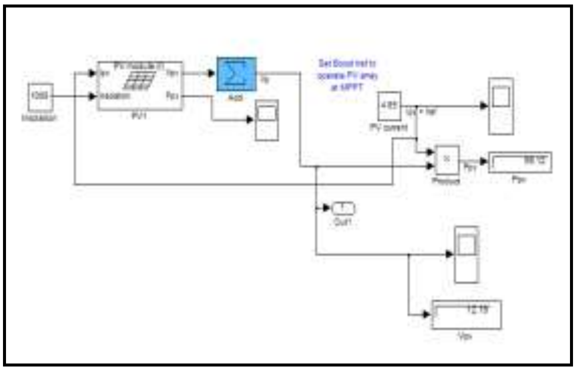

Figure.3.1 Solar model

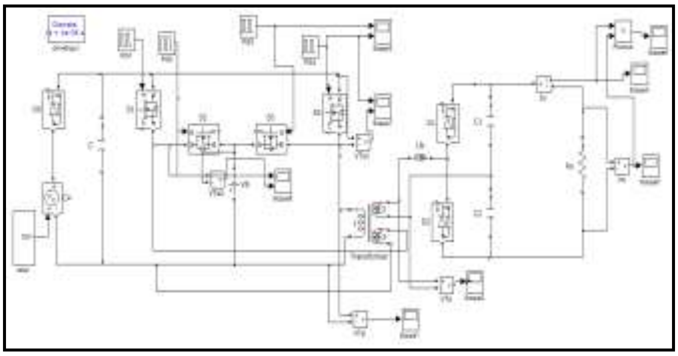

Figure.3.2 Simulated diagram of Conventional circuit

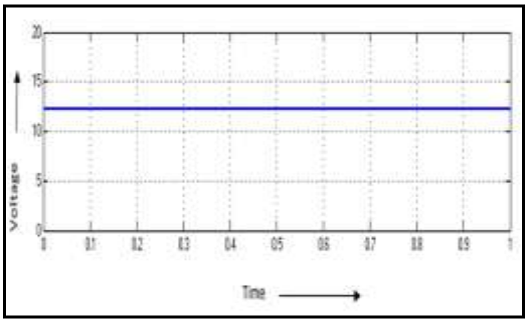

Figure.3.3 Output Voltage from Solar System

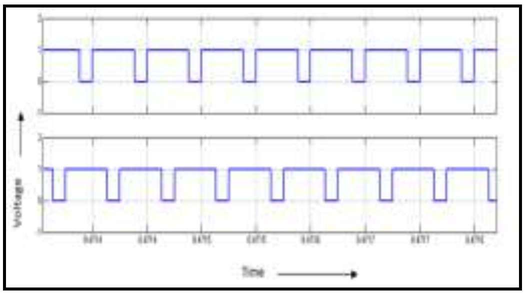

Figure.3.4 Switching Pulse for S_3 & S_4

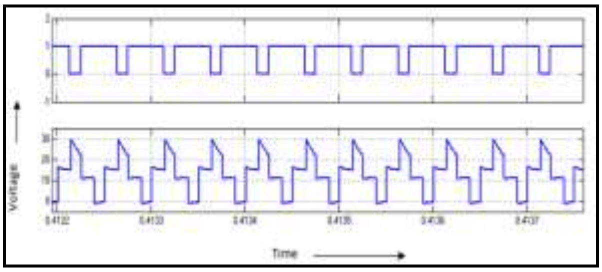

Figure.3.5 Switching Pulse for S_4&V_{ds}

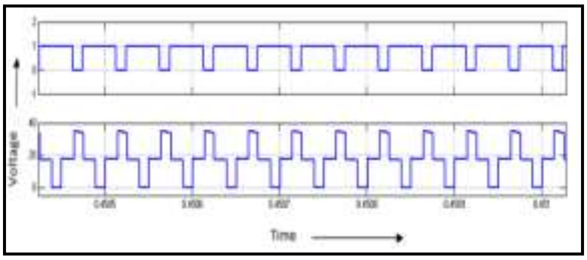

Figure.3.6 Switching Pulse for S_2&V_{ds}

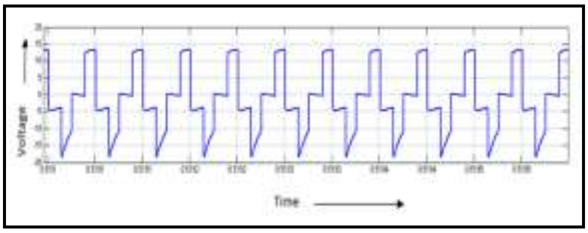

Figure.3.7 Transformer Primary Voltage

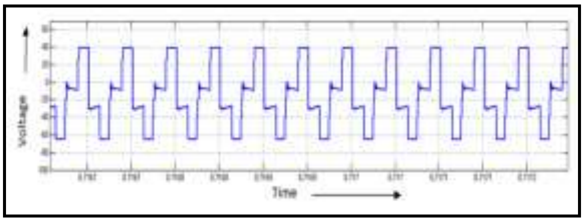

Figure.3.8 Transformer Secondary Voltage

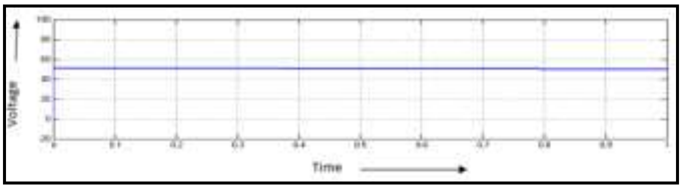

Figure.3.9 Output Voltage

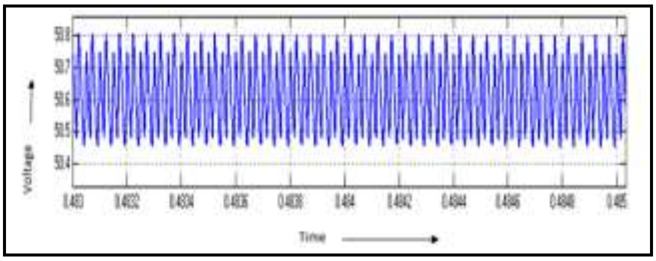

Figure.3.10 Output Ripple Voltage

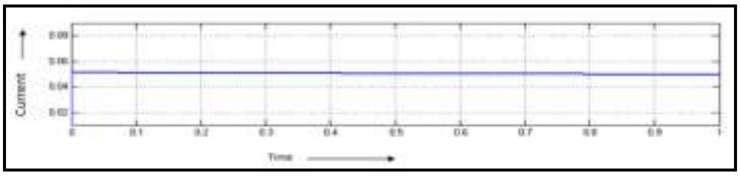

Figure. 3.11 Output Current

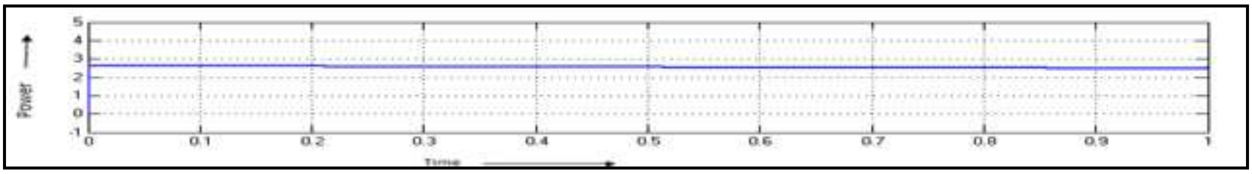

Figure. 3.12 Output power

3.1.2 Half bridge Flyback converter with LC filter

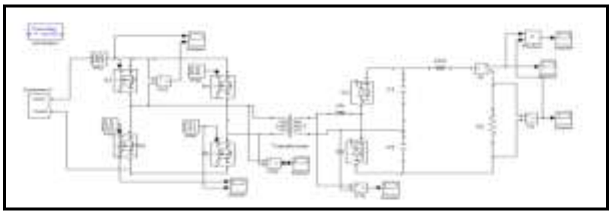

Figure. 3.13 Simulated diagram of HBF converter with LC filter

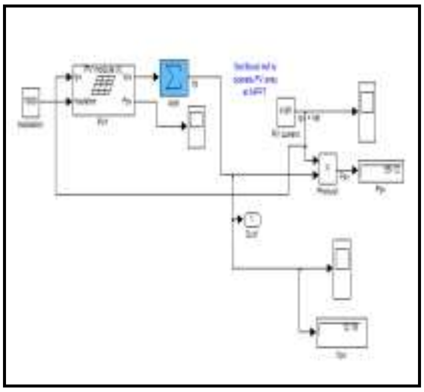

Figure3.14 Solar model

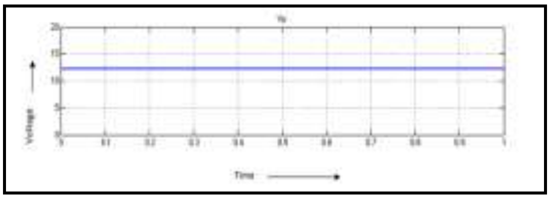

Figure3.15 Solar output Voltage

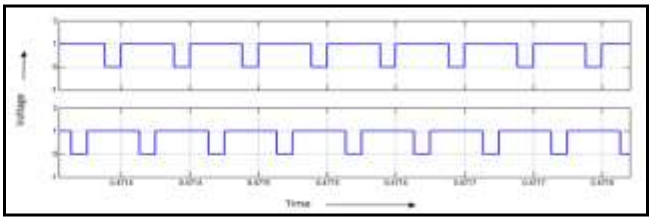

Figure.3.16 Switching Pulse for S_3& S_4

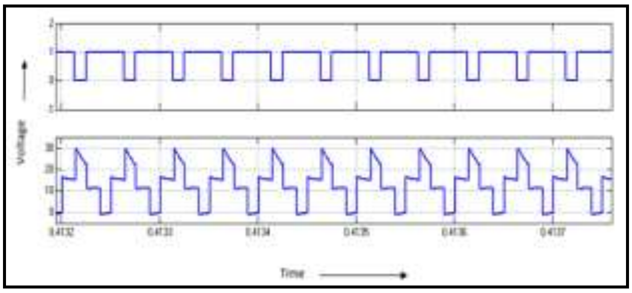

Figure.3.17 Switching pulse S_4 &V_{Ds}

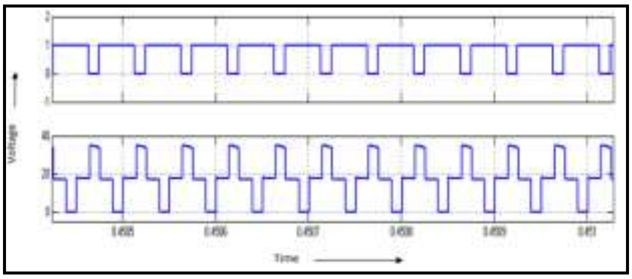

Figure.3.18 Switching pulse S_2&V_{Ds}

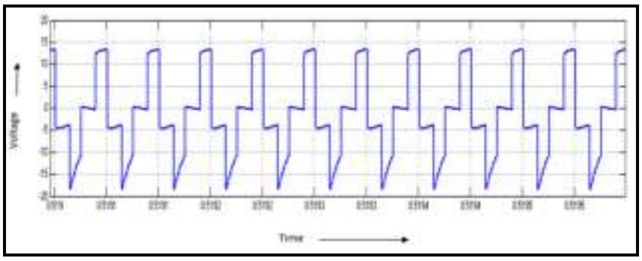

Figure.3.19 Transformer Primary voltage

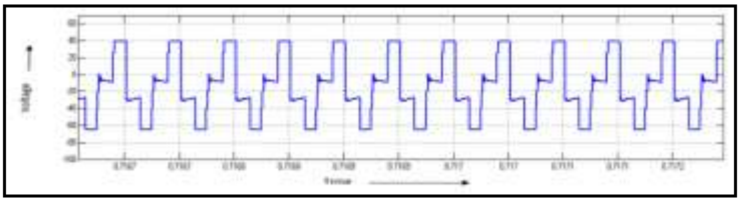

Figure.3.20 Transformer Secondary voltage

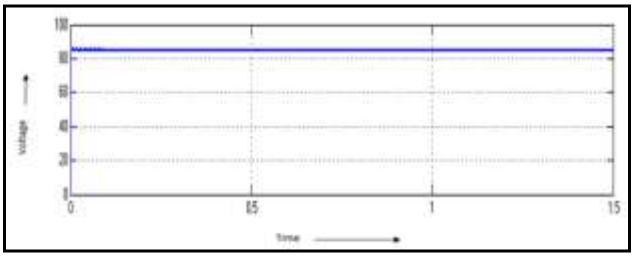

Figure.3.21 Output Voltage

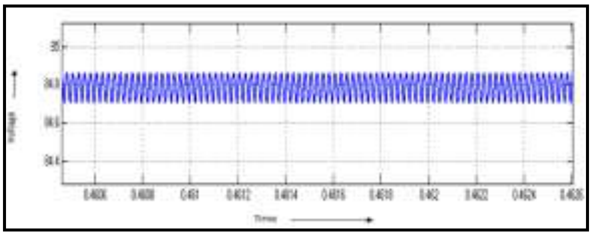

Figure.3.22 Output Ripple Voltage

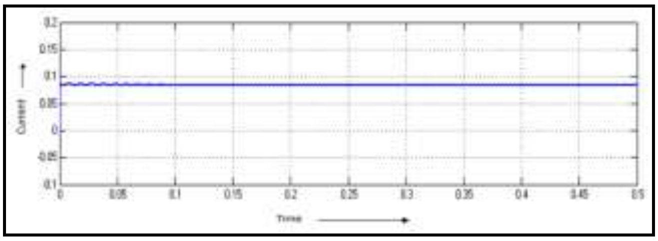

Figure.3.23 Output current

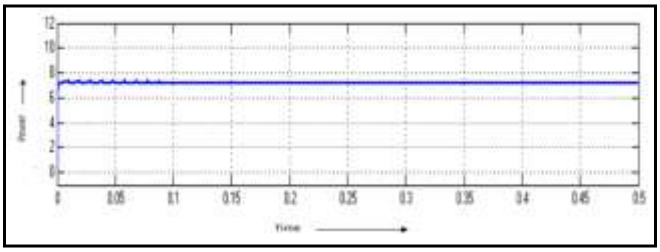

Figure.3.24 Output power

3.1.3 Half bridge Flyback converter with Pi Filter

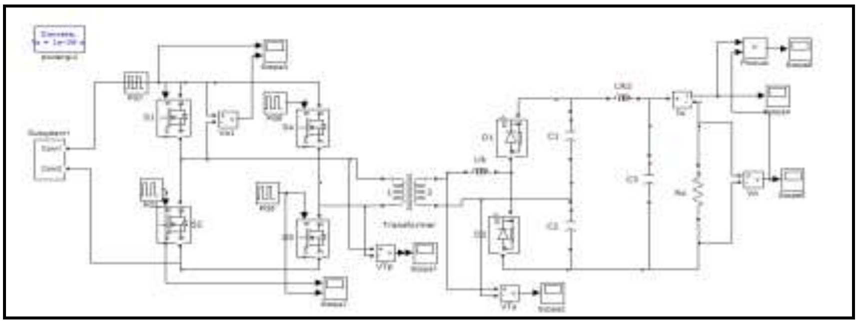

Figure.3.25 Simulated diagram of Half bridge flyback converter with Pi filter

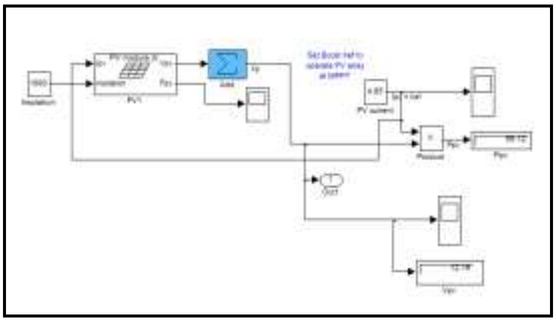

Figure.3.26 Solar Model

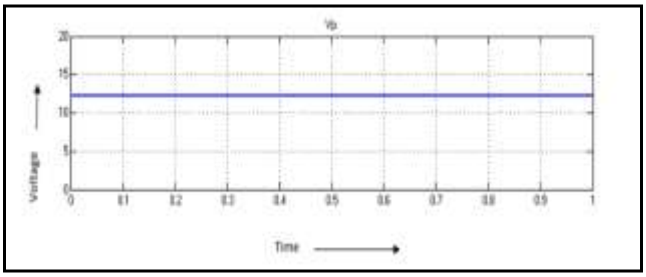

Figure.3.27 Solar output Voltage

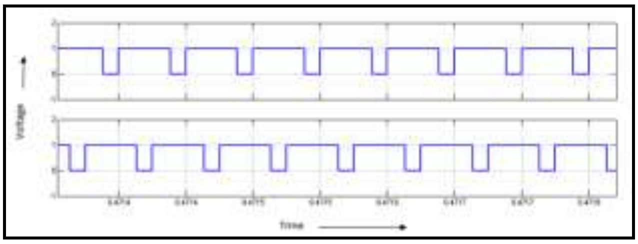

Figure.3.28 Switching Pulse for S_3& S_4

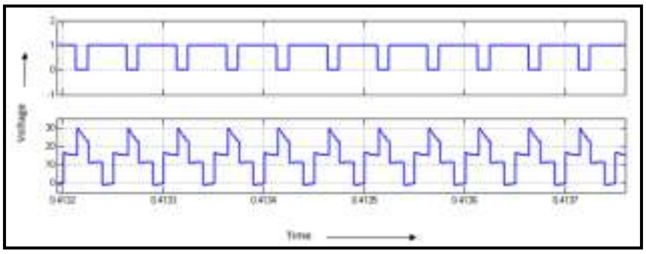

Figure.3.29 Switching pulse S_4 &V_{Ds}

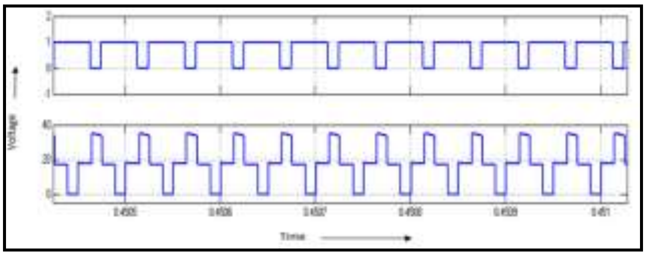

Figure.3.30 Switching pulse S_2&V_{Ds}

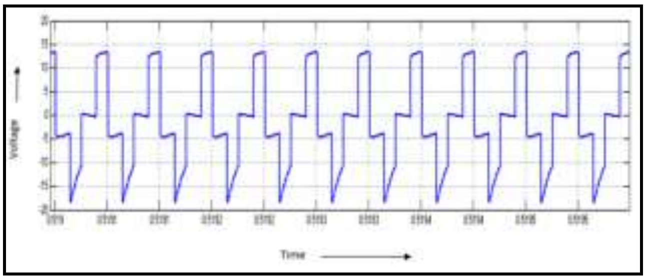

Figure.3.31 Transformer Primary voltage

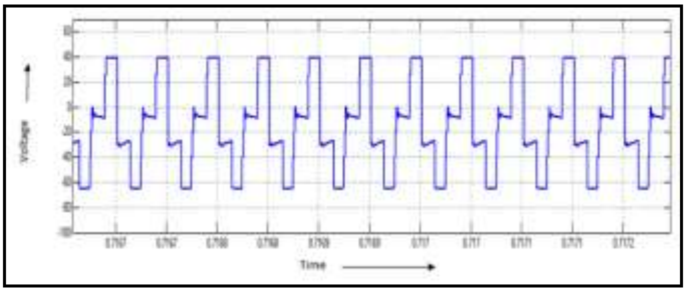

Figure.3.32 Transformer Secondary voltage

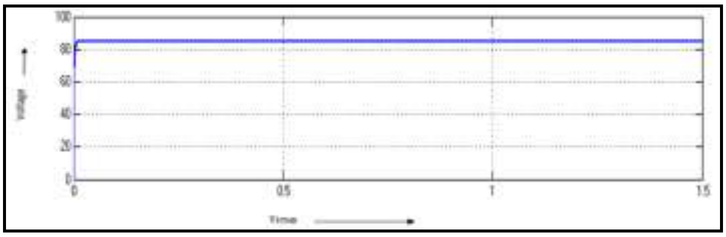

Figure.3.33 Output Voltage

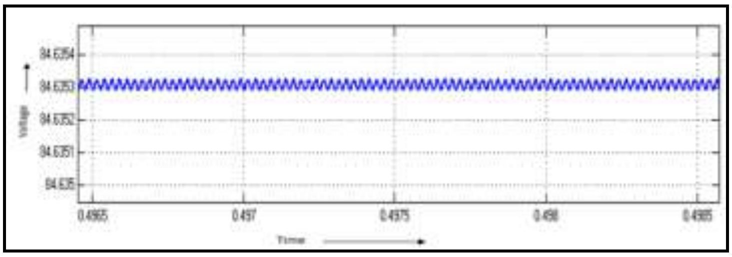

Figure.3.34 Output Ripple Voltage

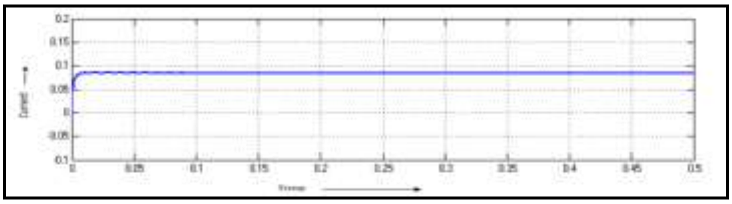

Figure. 3.35 Output Current

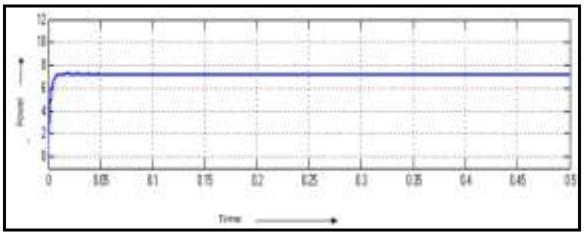

Figure.3.36 Output Power

3.1.4 Half bridge Flyback converter with using Motor load

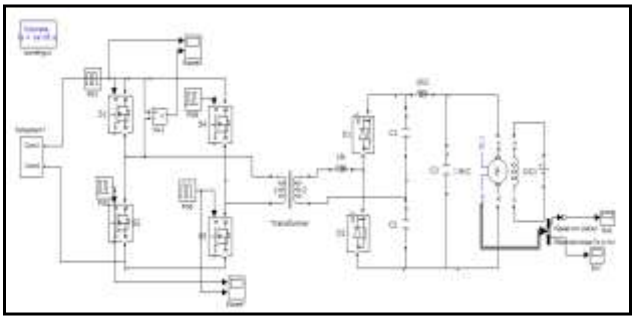

Figure.3.37 Simulated diagram of HBF Converter with Motor load

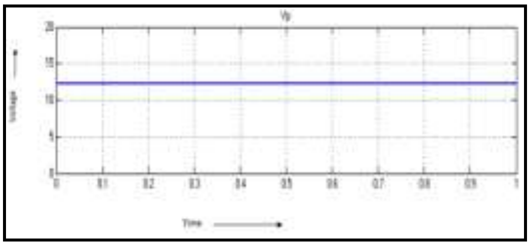

Figure.3.38 Output voltage from solar system

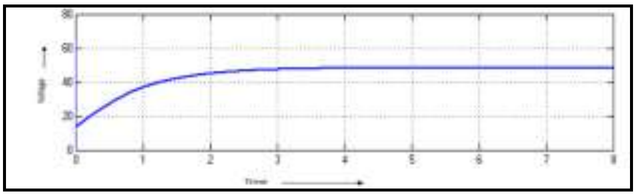

Figure.3.39 Output voltage of HBF Converter using Motor load

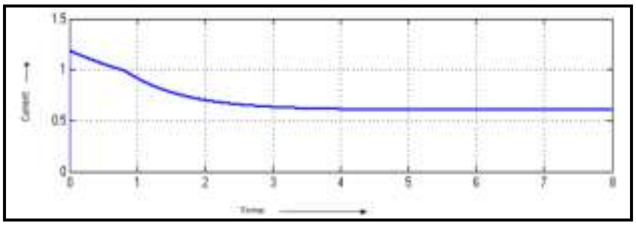

Figure.3.40 Output current of HBF Converter using Motor load

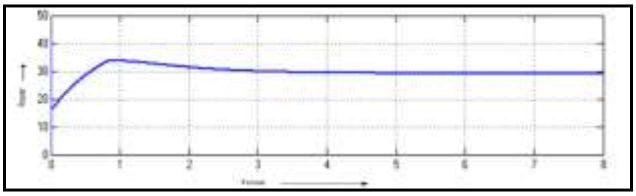

Figure.3.41 Output power of HBF Converter using Motor load

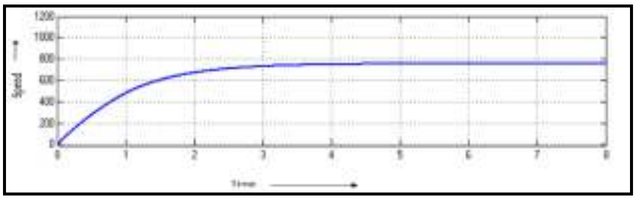

Figure.3.42 Motor speed of HBF Converter using Motor load

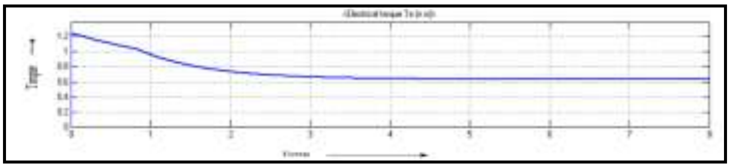

Figure.3.43 Torque of HBF Converter using Motor load

3.1.5 Half bridge Flyback converter with Disturbance

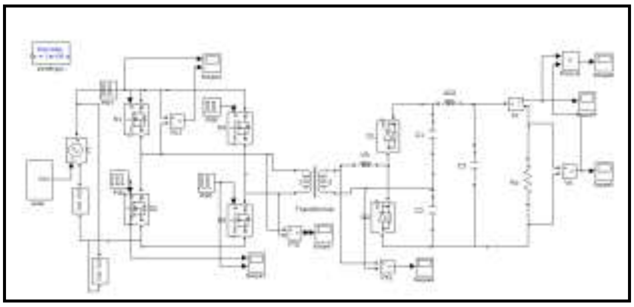

Figure.3.44 Simulated diagram of HBF Converter with Disturbance

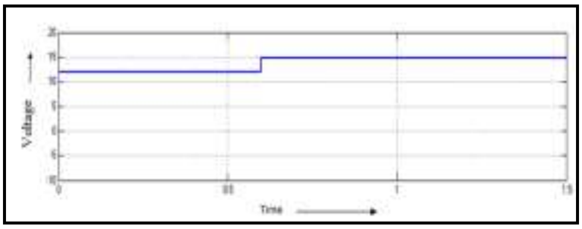

Figure.3.45 Input voltage of HBF Converter with Disturbance

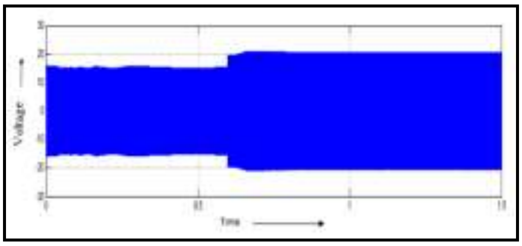

Figure.3.46 Transformer primary voltage of HBF Converter with Disturbance

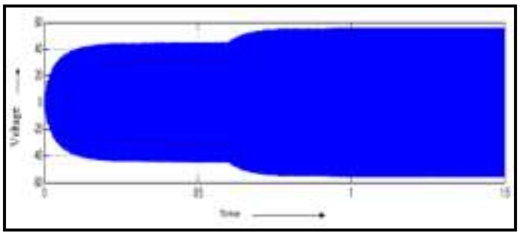

Figure 3.47 Transformer secondary voltage of HBF Converter with Disturbance

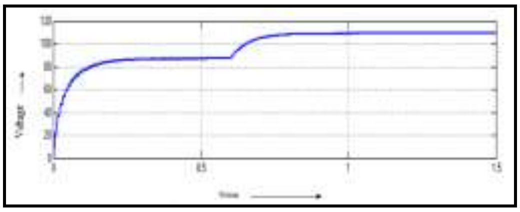

Figure.3.48 Output voltage of HBF Converter with Disturbance

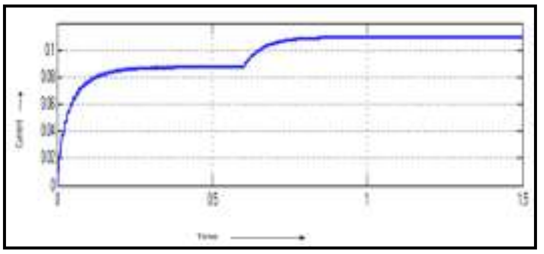

Figure.3.49 Output current of HBF Converter with Disturbance

Table 3.2: Comparison between Conventional Boost converter and Half bridge Flyback (HBF) converter

Parameters	**Conventional Boost converter**	**Half bridge Flyback converter**
Input Voltage	12V	12V
Transformer Primary Voltage	12V	12V
Transformer Secondary Voltage	40V	40V
Output Voltage	52V	85V
Ripple Voltage	0.3V	0.001V
Output Current	0.05A	0.08A
Output Power	2.8W	7W

Table 3.3 : Comparison between Half bridge Flyback (HBF) converter with LC and Pi filter

Parameters	**HBF converter with LC filter**	**HBF converter with Pi filter**
Input Voltage	12V	35V
Output Voltage	85V	85V
Ripple Voltage	0.3V	0.001V
Output Current	0.08A	0.08A
Output Power	7W	7W

Table 3.4: Comparison Between Half Bridge Flyback (HBF) Converter With Resistive And Motor Load

Parameters	**HBF converter with resistive load**	**HBF converter with motor load**
Input Voltage	12V	12V
Output Voltage	85V	50V
Output Current	0.08A	0.7A
Output Power	7 W	30W

Table 3.5: Comparison between Half bridge Flyback (HBF) converter with and without Disturbance

Parameters	**HBF converter without disturbance**	**HBF converter with disturbance**
Input Voltage	12V	15V
T.P.V	12V	20V
T.S.V	40V	58V
Output Voltage	85V	110V
Output Current	0.08A	0.11A
Output Power	7W	9W

3.2 Closed Loop System

3.2.1 Half bridgeFlyback converter using Pi Controller

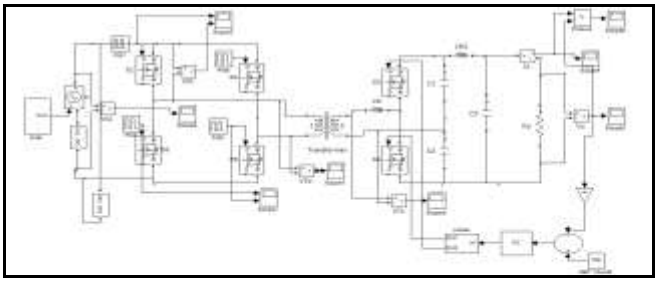

Figure.3.50 Simulated diagram of HBF Converter with PI controller

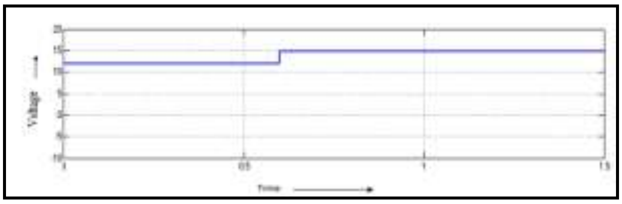

Figure.3.51 Input voltage of HBF Converter with PI controller

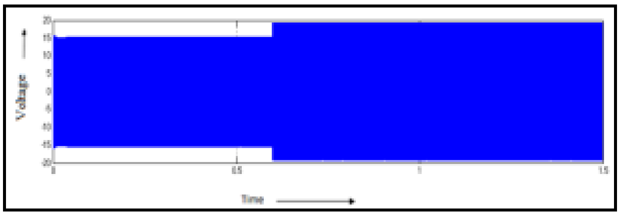

Figure.3.52 Transformer primary voltage of HBF Converter with PI controller

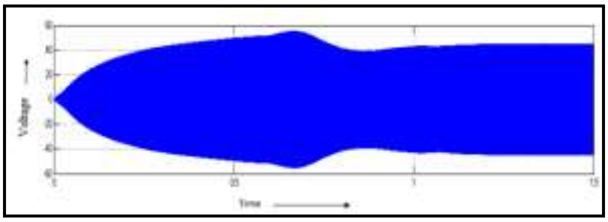

Figure.3.53 Transformer secondary voltage of HBF Converter with PI controller

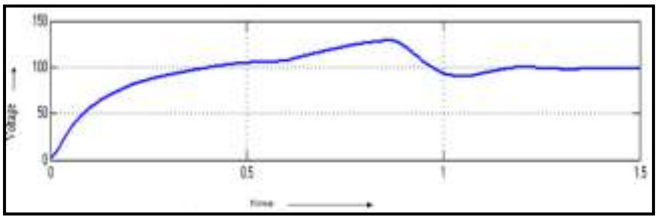

Figure.3.54 Output voltage of HBF Converter with PI controller

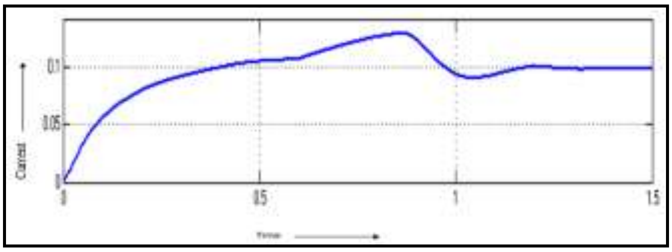

Figure.3.55 Output current of HBF Converter with PI controller

3.2.2 Half bridge Flyback converter using PID controller

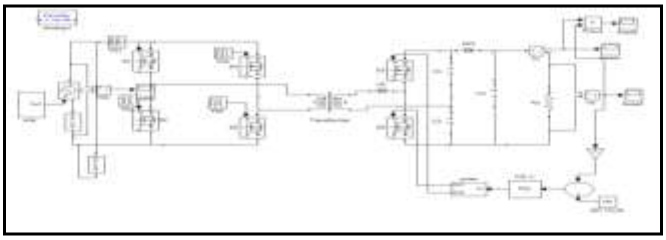

Figure.3.56 Simulated diagram of HBF Converter with PID controller

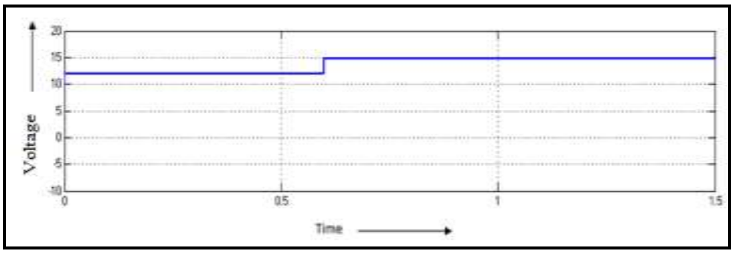

Figure.3.57 Input voltage of HBF Converter with PID controller

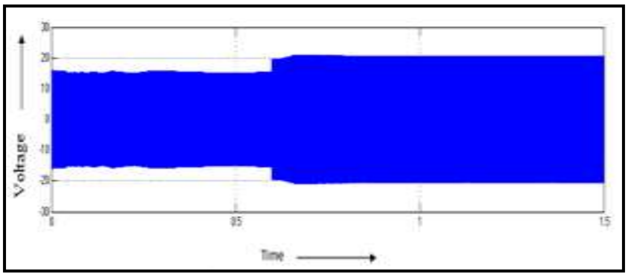

Figure.3.58 Transformer primary voltage of HBF Converter with PID controller

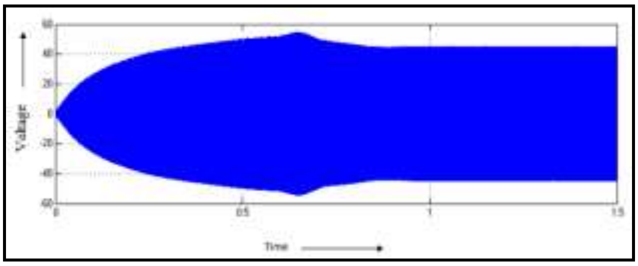

Figure.3.59 Transformer secondary voltage of HBF Converter with PID controller

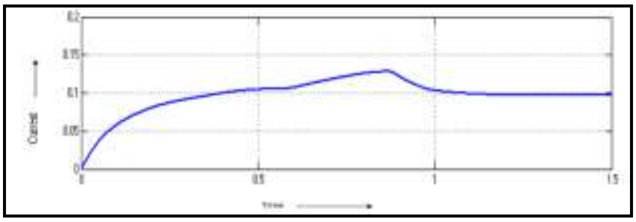

Figure.3.60 Output current of HBF Converter with PID controller

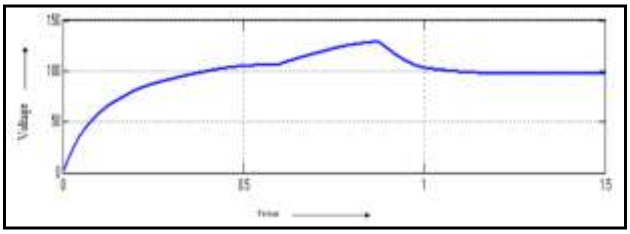

Figure.3.61 Output voltage of HBF Converter with PID controller

3.2.3 Half bridge Flyback converter using FUZZY controller

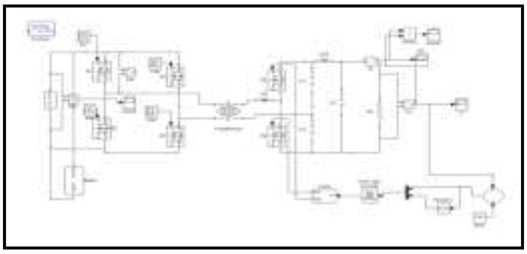

Figure.3.62 Simulated diagram of HBF Converter with FUZZY controller

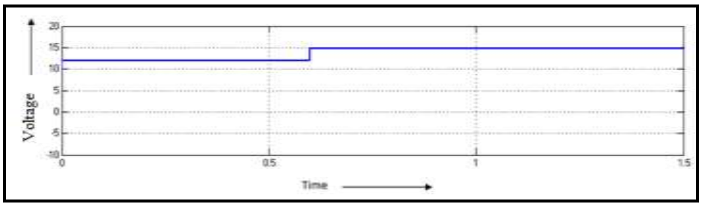

Figure.3.63 Input voltage of HBF Converter with FUZZY controller

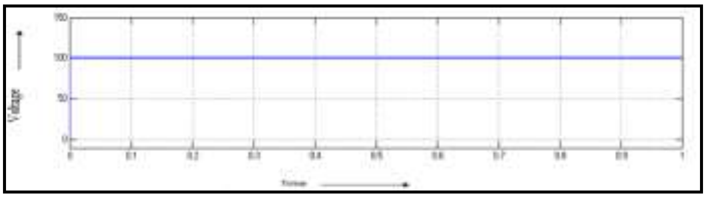

Figure.3.64 Output voltage of HBF Converter with FUZZY controller

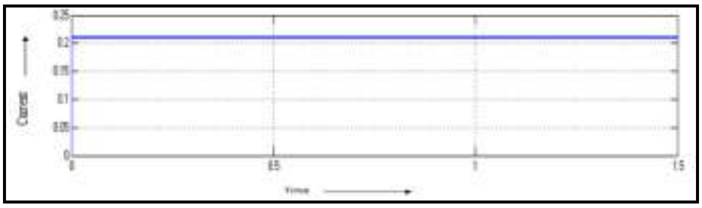

Figure. 3.65 Output current of HBF Converter with FUZZY controller

Table 3.6 Closed loop comparison of different controllers

Parameters	HBF with PI controller	HBF with PID controller	HBF with FUZZY controller
Input Voltage	15V	15V	15V
Output Voltage	100V	100V	100V
Output Current	0.1A	0.1A	0.22A
Delay Time(t_d)	0.1s	0.1s	0.1s
Rise Time (t_r)	0.22s	0.19s	0.009s
Peak Time (t_p)	0.73s	0.62s	0
Settling Time (t_s)	1.3s	1.0s	0
Peak Voltage(Vp)	10V	7V	0
Steady state Error(Ess)	1.6	0.9	0.006

4 Hardware Results

Half Bridge Flyback (HBF) converter is developed and tested in the laboratory. The proposed converter is the Integration of Half Bridge and FlybackConverter, it provides a compact single-unit solution with maximized energy harvest for photovoltaic (PV) system. It consists of two stages , boosting the voltage generated from the solar cell through high frequency transformer is done in the first stage and then the output voltage is given to Pi filter in the second stage. In HBF converter the first stage consists of High-frequency transformer T_r and four MOSFET switches . In the second stage Diode rectifier is used, the voltage doubler circuit consists of Pi filter where the capacitors C_1, C_2 and C_3 , leakage inductors L_{lk1} and L_{lk2} and Motor load.

The pulses required for the MOSFET are generated by using a ATMEL microcontroller 89C2051.These pulses are amplified by using a driver amplifier. The driver amplifier is connected between the Optocoupler and MOSFET gate. The gate pulses are given to the MOSFET of the Half Bridge Flyback (HBF) converter. ADC0808 is used for interfacing analog circuit and comparator circuit. To isolate power circuit and control circuit Optocoupler is used.8051 microcontroller has two 16-bit timer/counter registers namely timer 1 and timer 2. Both can be conFigureured to operate either as timers or event counters in the proposed converter. The high frequency transformer provides Galvanic isolation and flexible voltage conversion ratio.

Table 4.1 Hardware Parameters

Parameter	Rating
Input voltage	12V
C_1= C_2	220µF
C_3	1000 µF
L_{k1}=L_{k2}	500 µH
Switching Frequency	50kHz
Diode	IN 4007
MOSFET	IRF840
Turns ratio (coupled inductor set)	1:2
R	200Ω
Regulator	LM7805,LM7812,5-24V
Driver IC	IR2110,+500V or +600V
Crystal Oscillator	230/15V,500mA,50Hz

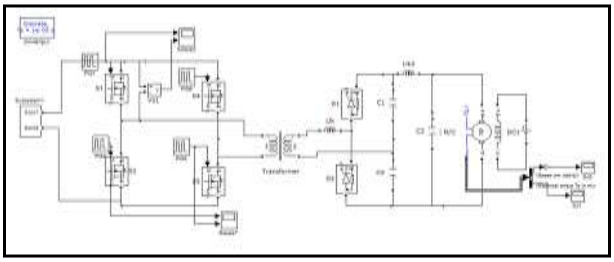

Figure. 4.1 Half Bridge Flyback (HBF) converter with Motor load

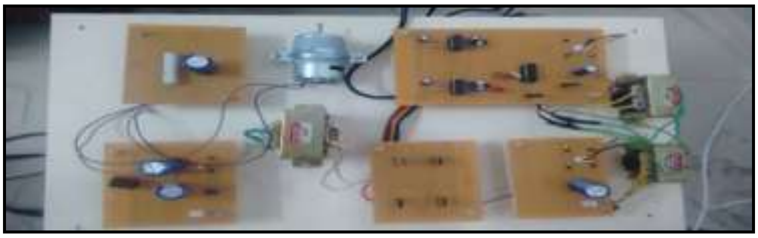

Figure. 4.2 Hardware Layout of HBF Converter with Motor load

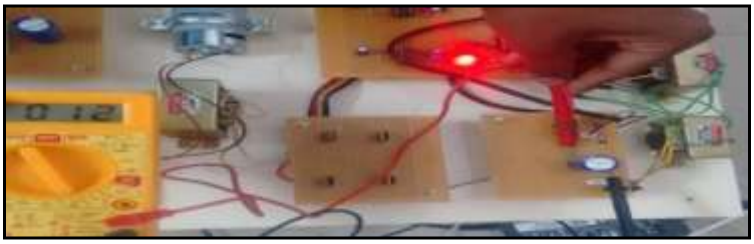

Figure.4.3 Input Voltage of HBF Converter with Motor load

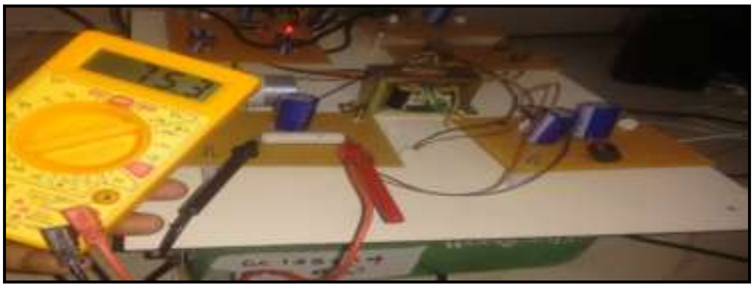

Figure.4.4 Output Voltage of HBF Converter with Motor load

Figure.4.5 Driving Pulse Output of HBF Converter with Motor load

Figure: 4.6 Transformer Primary Voltage of HBF Converter with Motor load

Figure. 4.7 Transformer Secondary Voltage of HBF Converter with Motor load

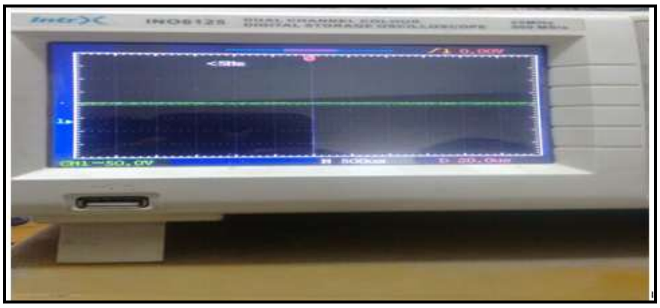

Figure. 4.8 Solar Output Voltage

Figure. 4.9 Output DC Voltage of HBF Converter with Motor load

5. Conclusion

In this paper, a Half Bridge Flyback (HBF) converter is simulated in open and closed loop by using matlabsimulink. By using High frequency transformer , filter capacitor and voltage doubler circuit, the proposed converter achieves Galvanic isolation and flexible voltage conversion ratio.

The proposed converter achieves high step-up capability for power conversion systems including the PV array, the battery storage and the Isolated load consumption. From the open loop system the Half Bridge Flyback (HBF) converter with Pi filter gives the better output with less ripple voltage. In closed loop system the comparison is done by using PI,PID and FUZZY controller. The Fuzzy controller results in negligible Rise time, Peak time, Settling time and Delay time .The steady state error is also less by using FUZZY controller. The performance of the proposed converter with FUZZY controller is found better instead of PID Controller.

From the simulation and experimental results, the output voltage and PV voltage is controlled independently by the phase angle shift and PWM respectively. The decoupled control approach is developed and it achieves the regulation of output voltage and PV voltage which is used for MPPT of stand-alone PV systems. The Half bridge Flyback converter is prototyped and tested to verify the effectiveness of the proposed converter topology and control scheme. The developed technology is capable of achieving high conversion ratio and multiple operating modes .

Finally, the Solar cell as input voltage source is integrated into a prototype converter was implemented and sucessfully verified. The advantages of the proposed converter are small size and cost effective. Thus, the Half Bridge Flyback (HBF) converter is valuable and potential ,which is suitable for Photovoltaic (PV) system.

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