A SINGLE STAGE HYBRID ELECTRIC POWER GENERATION USING DUAL LEG DC/AC CONVERTER

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Abstract: *In this research article P&O based Maximum Power Point Tracking (MPPT) technique and Sliding Variable Structure Control (SVSC) implemented to control the MPPT battery charger and Dual Leg DC/AC Converter for Hybrid Electric power generation is presented. A fluctuated low dc voltage of photovoltaic array was regulated by MPPT converter and the output of Wind is connected to the DC bus. It is boosted and inverted into a* $220V_{rms}$ *ac voltage at a fundamental frequency in a single stage. Generally the sliding mode control and feedback control techniques were widely used for controlling the output of the converters but it involves more complex control theory. The main objective is to reduce the more power stages for converting dc power in to ac power and synchronizing two different power sources. Hence the proposed control technique is used to keep the constant output voltage with inconsistent loads. Therefore the proposed hybrid electric power generation system has more desirable features such as single power conversion stage and minimum number of switches. The Total Harmonic Distortion (THD) generated by the proposed configuration is quite reasonable. The complete system is modeled using MATLAB/SIMULINK.*

Key words: *MPPT controller, Sliding Variable Structure Control, Single stage power conversion, Total Harmonic Distortion*

1. Introduction

The increasing of energy demand and oil prices, the researchers are moving to other alternate sources like renewable energy sources which are cost effective, pollution free and feasible [4]. The falling of conventional energy sources, increasing of different pollutions and the ever increasing demand of the fossil fuels are motivating the engineering society to involve more investigation in the renewable power generation and the development of alternative energy sources which are less or zero pollution and eco-friendly [9].

Many renewable sources are now well developed as the cost effective solution for many applications. Moreover the solar energy and wind are become one of the most hopeful sources of energy as they are pollution less and fuel free. Beside this, solar energy is easy to adopt with existing power converters [4-6]. Also the single sources are may not be meet the power demand in all days due to the environmental reasons. Therefore hybridization of two sources is essential to meet the load demands and renewable energy resources are an approach to compensate or overcome the demerits of an individual system with the other one [11].

The optimal hybridization strategy depends on the type of two or more combinations of energy resources [2]. There are many hybrid power generation based articles were literature, but all are not adapting to all applications and having some demerits. The integration of various renewable energy sources are should be meet the higher efficiency, low cast, and availability of resources. The limitation of Biogas energy and the collection radius bring a challenge of the consistent and sufficient fuel supply. Therefore the plant scale has to be limited and also having low energy conversion efficiency [1].

Hadi Ghasemi [2] et al, is presented the hybrid power system which combinations of solar and geothermal energy sources. Geothermal power plants are burning fossil fuels for generation the electric power and it do not produce greenhouse gases. So it can be harmful to the atmosphere. Toshiro Hirose and Hirofumi Matsuo are presented standalone hybrid power system which consist of solar and wind. A hybrid power generation using Dual Leg DC/AC Converter which integration of solar and wind energy. Solar power converters are designed by electronic circuits associated to the power inversion, control and conditioning [8] the electric power.

Due to the climate changes, the performance of the solar energy is not able to give constant voltage and low capacity factor [1]. In addition, the integration of energy storage systems and more number of solar cells will lead a higher specific investment of the solar power plant. Hence a Single Stage Hybrid Electric Power Generation Using Dual Leg DC/AC Converter is proposed in this paper which consists of maximum power point tracking (MPPT) solar charger, single power conversion stage as shown in Fig. 1. MPPT [5] controller like P&O algorithm regulates the variable dc output of photovoltaic (PV) modules [1] into a constant DC and it can be stored in battery. Dual leg dc-ac converter converts low PV dc voltage to high ac voltage with a fundamental utility frequency in a single stage that can be fed into the commercial electrical grid or off grid electrical network.

Dual Leg DC/AC Converter is generally boosted and inverted the power in a single stage. Among them, buck-boost inverter, buck inverter, boost-buck inverter and multi level inverter are commonly used in the solar power generation system. The proposed topology shown in Figure1 used in this paper, maintains constant voltage under various irradiation, temperature of the solar photovoltaic cell and various load conditions.

This paper mainly focused on controllers such as MPPT, SVSC and Dual Leg DC/AC Converter and its control topology because of this is due to its boosting and inverting property which is achieved by a single stage. The MPPT based P&O algorithm technique [2, 6 & 10] is implemented for regulating the output voltage of the solar and the SVSC technique was [7] implemented for regulating the output voltage of the Dual Leg DC/AC Converter to meet the single phase ac loads.

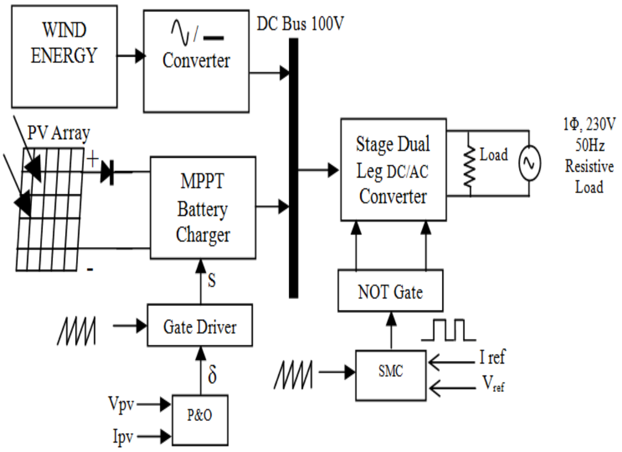

Fig. 1.Block diagram of proposed a Regulated Standalone Solar Power Generation.

2. Single stage power conversion

The proposed Dual Leg DC/AC Converter is consists of two separate bidirectional dc – dc converters which gives dc biased sinusoidal voltage shown in Figure 2. The phase shift of output voltage of each converter is π angle, which will deliver the maximum voltage differentially across the load. Reference node of each converter is commonly connected and load should be connected across the positive node of each converter.

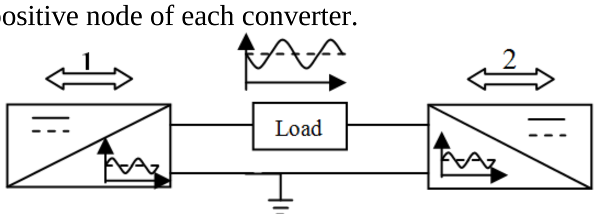

Fig. 2.Basic arrangement of two bidirectional dc-dc converters

The main advantages of this Dual Leg DC/AC Converter converts dc voltage to ac voltage and boost the low level dc to high ac voltage in a single power conversion stage, minimum number of power switches and smooth sine wave of the output voltage without involving filters. The proposed Dual Leg DC/AC Converter boost inverter is shown in Fig 3.

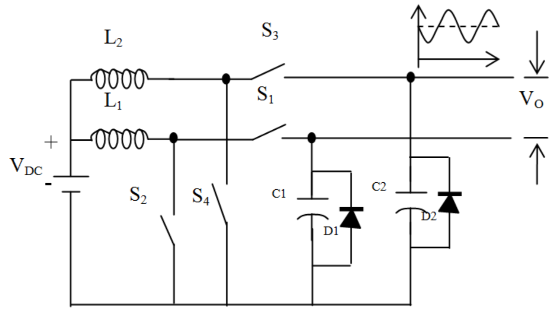

Fig. 3.Circuit description of Dual Leg DC/AC Converter

The operation of dual leg DC/AC converter can be understand by modes of operation as shown in Fig. 3 and each converter operates under two modes such as:

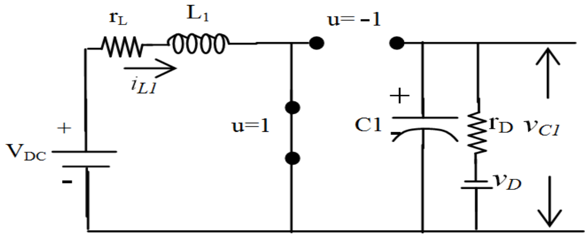

Fig. 4.State modeling of the equivalent circuit of single bidirectional dc-dc converter

Mode 1:

When the power switch S_1 is closed and S_2 is open as in the Figure 4, the current i_{L1} rises quite linearly, capacitor C_1 supplies energy to the output stage and voltage V_{C1} decreases.

Mode 2:

When the power switch S_1 is open and S_2 is closed as in the Figure 4 the supply voltage is V_{DC}, the inductor current i_{L1} flows through capacitor C_1 and the load, the current i_{L1} decreases while capacitor C_1 recharged.

The conduction mode of the converter 1 is given by $\frac{V_{C1}}{V_{DC}} = \frac{1}{1-\delta}$ and the conduction mode of the converter 2 is given by $\frac{V_{C2}}{V_{DC}} = \frac{1}{\delta}$;

Where δ is the duty cycle, V_{C1} is the voltage across the capacitor of the converter-1 and V_{C2} is the voltage across the capacitor of the converter-2, V_s is the input voltage to the boost inverter. Since the two converters are 180^0 out of phase, the output voltage is given by

$$V_0 = V_{C1} - V_{C2} = \frac{V_{DC}}{1-\delta} - \frac{V_{DC}}{\delta} \Rightarrow \frac{V_O}{V_{DC}} = \frac{2\delta - 1}{(1-\delta)\delta}$$

3. Proposed control scheme for single stage dual leg dc/ac converter

The state space modeling of the state variables i_{L1} and v_{C1} is getting by applying Kirchhoff voltage and current law and to the equivalent circuit of single bidirectional dc-dc converter.

$$\frac{\Delta i_{L1}}{\Delta t} = \frac{v_{DC}}{L_1} - i\,\frac{r_L}{L_1} \qquad (1)$$

$$\frac{\Delta v_{C1}}{\Delta t} = \frac{\Delta v_{C2}}{r_D c_1} - i\,\frac{r_L}{L_1} \qquad (2)$$

$$\frac{v_{DC}}{L_1} - \frac{v_{C1}}{L_1} - i\,\frac{r_L}{L_1} = \frac{\Delta i_{L1}}{\Delta t} \qquad (3)$$

$$\frac{\Delta v_{C1}}{\Delta t} = \frac{i}{c_1} - \frac{v_{C1}}{r_D c_1} + \frac{v_{C2}}{r_D c_1} \qquad (4)$$

The state space model with state variables i_{L1} and V_{C1} from above equations (1), (2), (3) and (4)

$$\begin{bmatrix} \dot{x} \\ \ddot{x} \end{bmatrix} = \begin{bmatrix} \frac{-r_L}{L_1} & \frac{-1}{L_1} \\ \frac{1}{C_1} & \frac{-1}{C_1 r_D} \end{bmatrix} \begin{bmatrix} i_{L1} \\ v_{C1} \end{bmatrix} + \begin{bmatrix} \frac{v_{C1}}{L_1} \\ \frac{-i_1}{C_1} \end{bmatrix} \gamma + \begin{bmatrix} \frac{v_{DC}}{L_1} \\ \frac{v_{C2}}{C_1 r_D} \end{bmatrix}$$

$$\dot{X} = Ax + B\gamma + C$$

Where γ is the status of the switches, $\dot{x}$ and x are the vectors of the state variables (i_{L1}, v_{C1})

$$\gamma = \begin{Bmatrix} 1 \rightarrow S_{W1}\ ON, S_{W2}\ OFF \\ 0 \rightarrow S_{W1}\ OFF, S_{W2}\ ON \end{Bmatrix}$$

The variable structure voltage control equation in the state space expressed by a linear combination of state variable errors ε_1 and ε_2 are gives a good transient response for the output voltage.

$$\gamma(i_1, v_{C1}) = K_1\varepsilon_1 + K_2\varepsilon_2 = 0 \qquad (5)$$

Where coefficients K_1 and K_2 are proper gains

$$\varepsilon_1 = i_1 - i_{1ref} \qquad (6)$$

$$\varepsilon_2 = v_{C1} - v_{c1ref} \qquad (7)$$

By substituting equations (6) and (7) in (5),

$$\gamma(i_1, v_{C1}) = K_1(i_1 - i_{1ref}) + K_2(v_{C1} - v_{C1ref}) \qquad (8)$$

The system response is determined by the circuit parameters and coefficients K_1 and K_2. With proper selection of these coefficients in any operating condition, high robustness, stability and fast response can be achieved.

A sliding variable structure control strategy proposed to control the output of the single stage dual leg dc-ac converter in Fig.6. Sum of the error values of the state variables of the proposed converter with proper gains [14] are given to the hysteresis current controller. There are two bands are formed in the hysteresis current controller which is lower and upper band based on the ripple of the error signals. A continues pulse signal is produced with unequal width by cutting the ripples on the edges of lower and upper bands with the frequency range is up to 400KHz.

The main advantage of this closed loop control method is to keep the output voltage constant barring various transient conditions like abrupt load changes. The voltage across the capacitor (V_{C1}) and inductor current (I_{L1}) of the converter 1 is adjusted separately with the proper gain values of K_1 and K_2 to get the proper duty cycle of the converter-1 and hence as a result we can get a continuous pulse signal with unequal width. This signal controls the power switches of the converter-1 and converter-2 respectively.

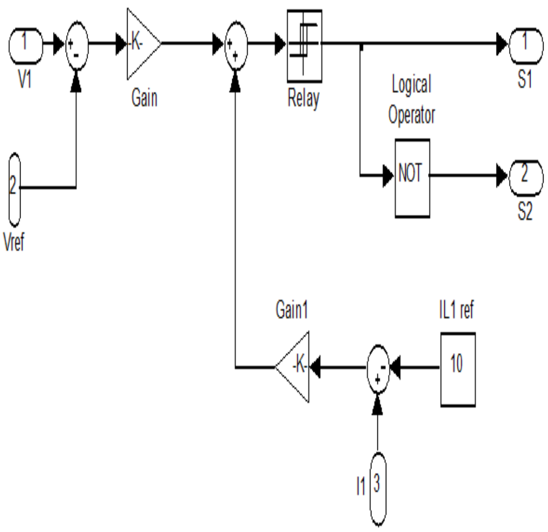

Fig. 5. Proposed sliding variable structure control strategy for single stage dual leg dc-ac converter

4. Simulation model of the proposed system

The design and modeling of Dual Leg DC/AC Converter for Hybrid Electric power generation and control techniques are developed by MATLAB SIMULINK environment as shown in Figure 6.

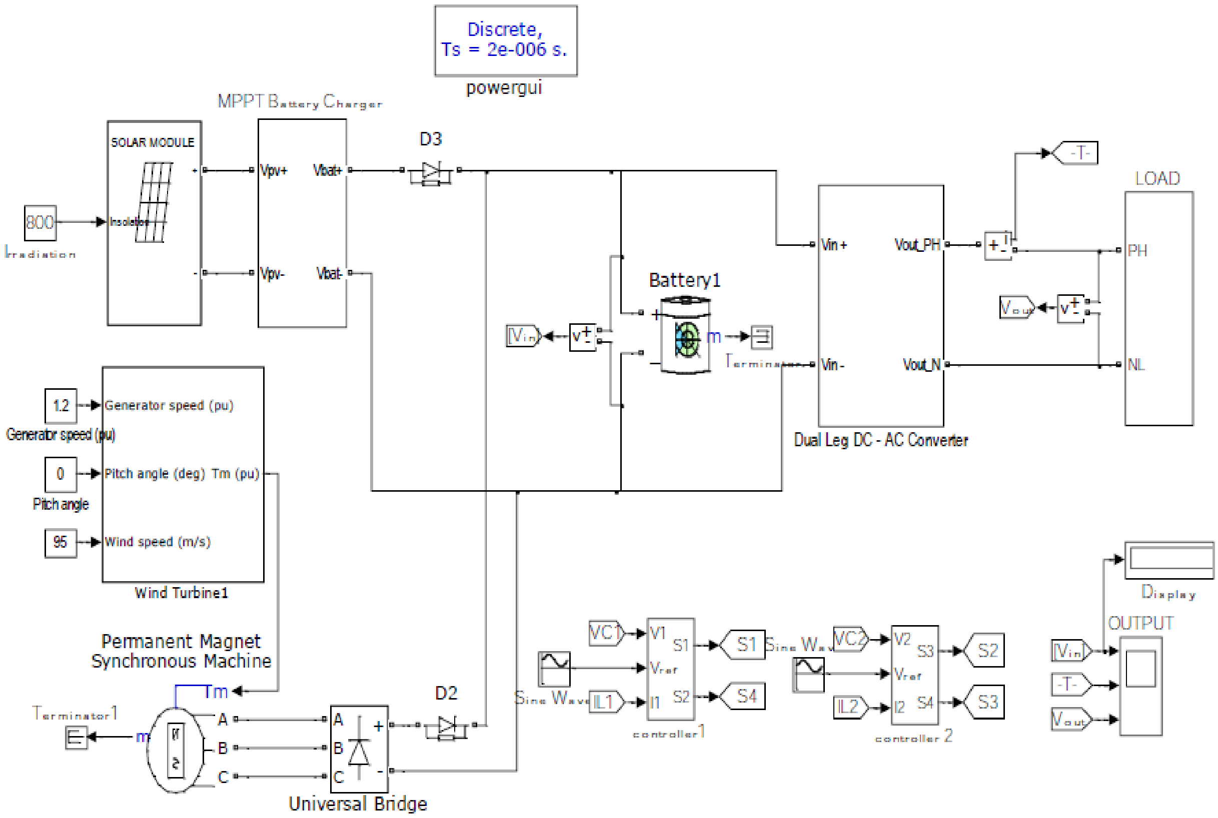

Fig.6. Simulink model of proposed single stage hybrid electric power generation using dual leg dc-ac converter by SVSC technique

Assumption of power switches, capacitor voltage and inductors current with internal resistance r_L are ideal. The parameters are: Vs = 100V, $V_O = 300\sin\omega t$ ($215V_{RMS}$), L1, L2 = 750µH each, C 1, C2 = 20µF each f_{SW} = 400KHz (Variable).

5. Simulation Results

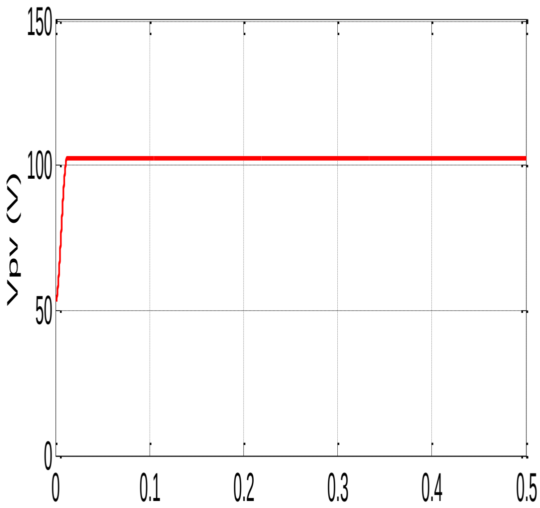

Fig. 7. PV panel voltage

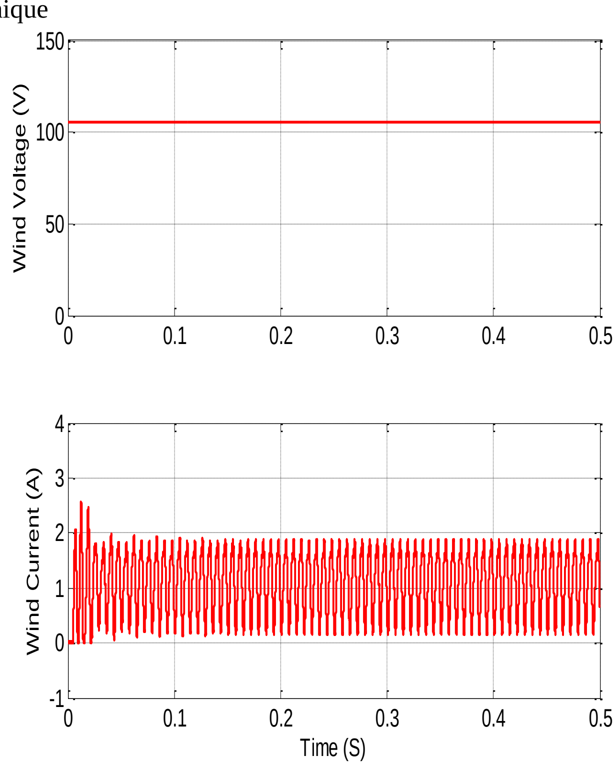

Fig. 8. Wind panel voltage and current

Solar power and wind energy sources are designed for charging the 96 volts rated battery. Bothe energy sources are input of the battery.

Fig.7 shows the output of the solar panel and it maintained 100 volts and Fig.8 shows the wind energy output and it delivers 104 volts and maintained 1.9 amps with the initial peak of 2.5 amps for charging a battery.

These outputs are clearly shows that the input sources are not oscillates due to the inconsistent loads.

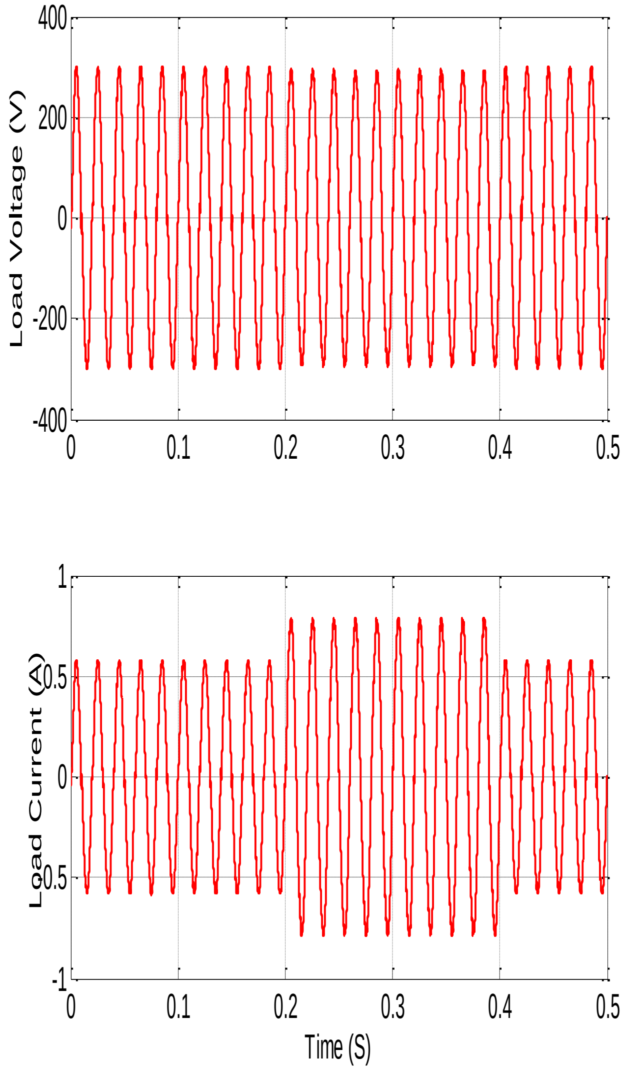

Fig. 9. Load voltage and load current of the single stage dual leg dc-ac converter V_O=215V_{rms}.

The proposed dc-ac converter is designed for 100Watts and it is tested under the variables loads such as 40W, 60W and 100W as shown in Fig. 9.

The Fig. 9 shows the load currents are varying according to the load variations, 60watts load maintained from 0sec to 0.2 sec and suddenly load is increased to 100w at 0.2 sec and it can be fall down to 40watts in 0.4 sec.

But output voltage of the single stage dual leg dc-ac converter is maintained a constant voltage of 215V_{RMS} with the fundamental frequency of 50Hz.

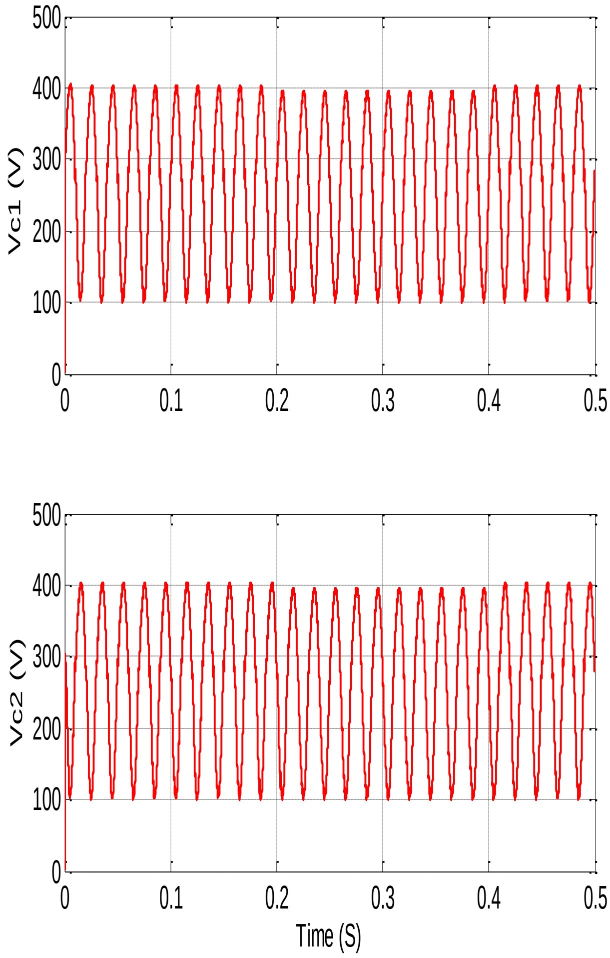

Fig. 10. Capacitor voltage of the each capacitor V_{C1}&VC2 = 400Vm in Volts

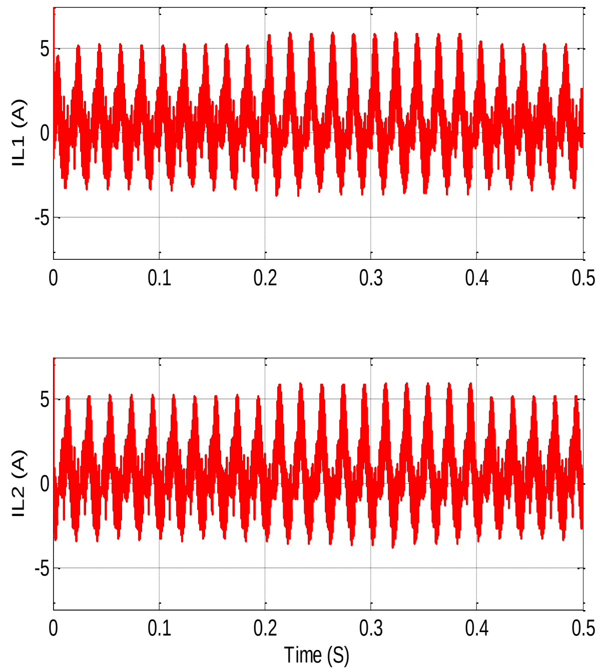

Fig. 11. Inductor current of the each inductor I_{L1}& I_{L2} = 6A

Fig. 10 & 11 shows the voltage across the capacitors V_{C1} & V_{C2} and current flows in the inductors I_{L1} & I_{L2} of the dual leg dc-ac converter. The phase angle of V_{C1} & V_{C2} is 180^0 out of phase with dc biased sinusoidal pattern. There are no surge current flows initially in the inductors. Hence sliding variable structure control technique is controlled both capacitor voltage and curre

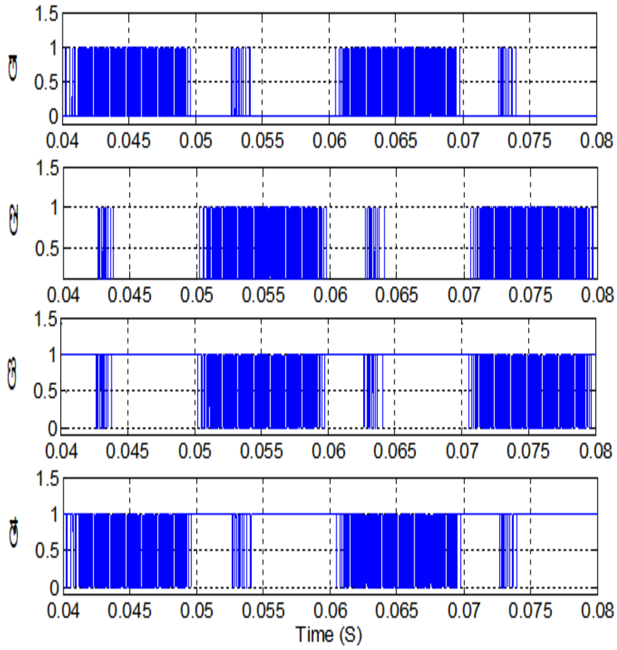

Fig. 12. Gate pulse different duty cycle for power switches of the proposed converter.

Table 1. Output voltage of the single stage dual leg dc-ac converter with SVSC technique under various loads and corresponding Total Harmonic Distortion.

Sl. No.	Load in watts	Peak output V_o In volts	THD
1	40	300	3.43
2	60	300	3.62
3	100	300	4.08

Table 1 shows the output voltage of the Single Stage Dual Leg DC/AC Converter with inconsistent loads. Loads are varying suddenly in 0.2 and 0.4 seconds respectively. The Total Harmonic Distortion (THD) is appeared in the allowable value for both load current and voltage. Also the system is maintained a constant voltage.

6. Experimental analysis

The prototype setup of the Dual Leg DC/AC Converter has been designed with the solid state devices as shown in the Fig. 13 with SVSC technique based control topology. The power switching device IGBT is used in the simulation modelling since it is preferable for high voltage and high current applications.

But in the prototype construction MOSFET has been implemented instead of IGBT to get more accuracy of the results in low ratings. Dual Leg DC/AC Converter is fabricated with IRFZ840 MOSFET and get gate pulse through PIC16F1936 controller by MOSFET driver IRS2110. The control programme is burn into the PIC chip through MPLAB with HITECH compiler and loaded using Programmer PICKIT-3

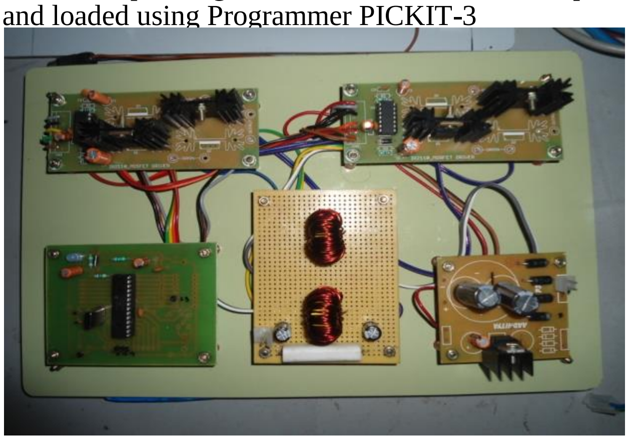

Fig. 13. Prototype model of Dual Leg DC/AC Converter

6. Experimental results

The performance of the proposed SVSC controller for Dual Leg DC/AC Converter is verified by the 10watt resistive load prototype model and results are illustrated as shown in the figures. Fig. 14 shows the input voltage of the converter as 6v dc supply. Input supply given through the 6v battery. This low voltage can be boosted and inverted to desired ac voltage level in a single stage. The voltage across the capacitors Vc_1 & Vc_2 are shown in fig. 15 & fig. 16.. It illustrates both voltages are having 180^0 phase shifted with each other as same as the result of simulation.

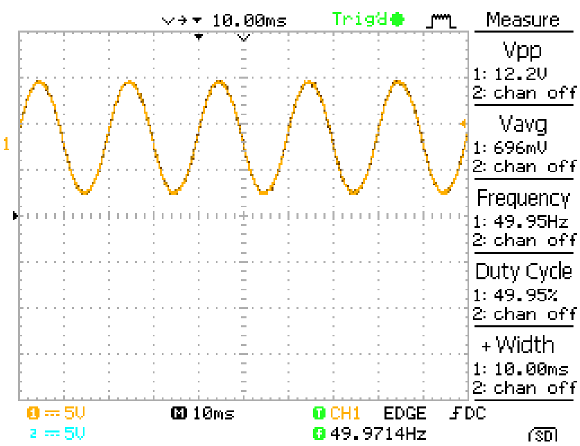

Fig.15. Voltage across capacitors Vc_1

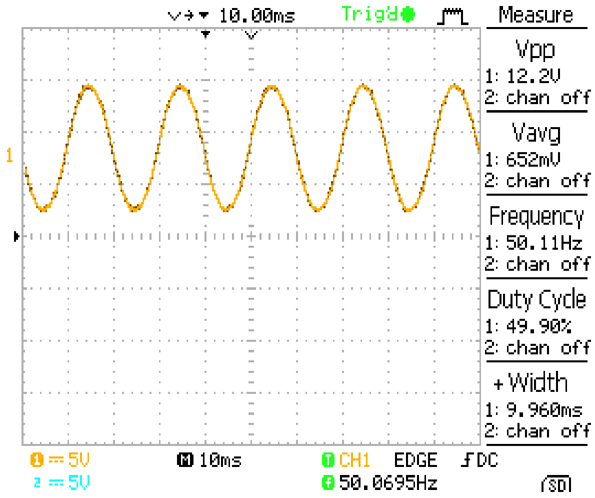

Fig.16. Voltage across capacitors V_{C2}.

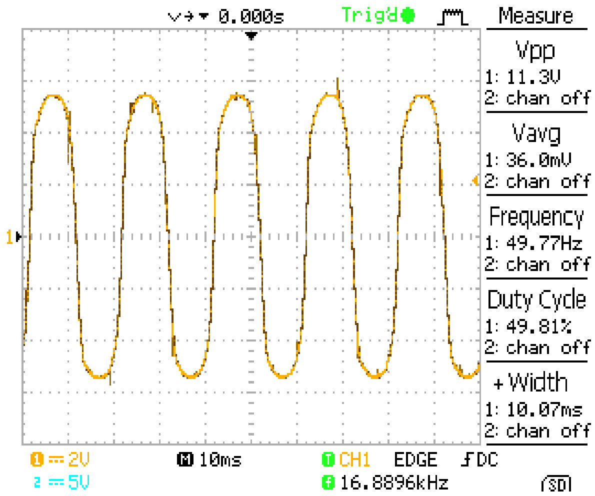

Fig.17 Output voltage of the Dual Leg DC/AC converter

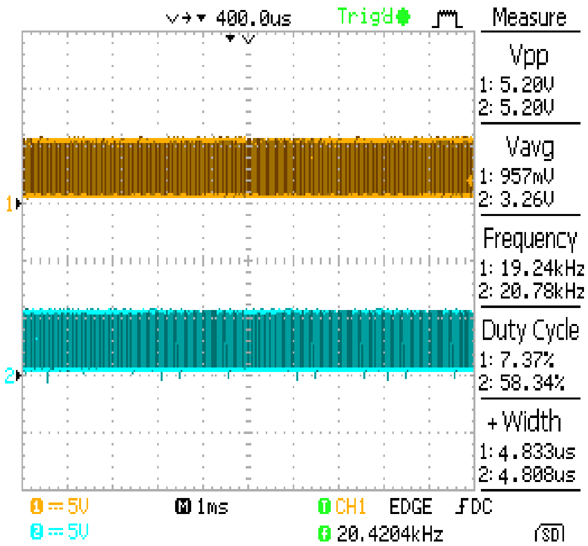

Fig. 18. Gate signal for Power Switches

The prototype model gives the RMS output voltage value of the dual leg dc/ac converter as 11.3 volts with the input voltage of 6volts as shown in fig. 17. The maximum instantaneous voltages are appear across the capacitors V_{C1} and V_{C2} are 12.2 volts. The fig 18 shows a continuous pulse with 20KHz for controlling the power switches in the converter.

8. Conclusion

The model of a Single Stage Hybrid Power Generation Using Dual Leg DC/AC Converter has been developed in Simulink environment and it can be analysed with various load conditions. The system maintains nearly constant output voltage with inconsistent loads. Solar and wind energy is synchronized through DC bus and connected the battery. The MPPT controller regulates the output of the solar panel and maintained constant voltage for charging the battery. In a conventional hybrid power generation, two or more power conversion are required for boosting and inverting low dc voltage into required ac voltage, but in this case there is no need of two power stages required for conversion of dc power in to ac power. This topology is a simple concept and it regulates the output of the Single Stage Leg DC/AC Converter by generating the appropriate duty cycle corresponding various load and satisfies the grid parameters. The proposed converter shows feasibility, effectiveness and operational simplicity. The low cost due to the minimum number of power devices used to execute the above scheme is an additional merit and also it satisfies the single phase ac load parameters without using two or more power conversion stages and the results are verified with the prototype setup results.

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