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Integrated DC-DC Converter for Multi-Renewable Sources

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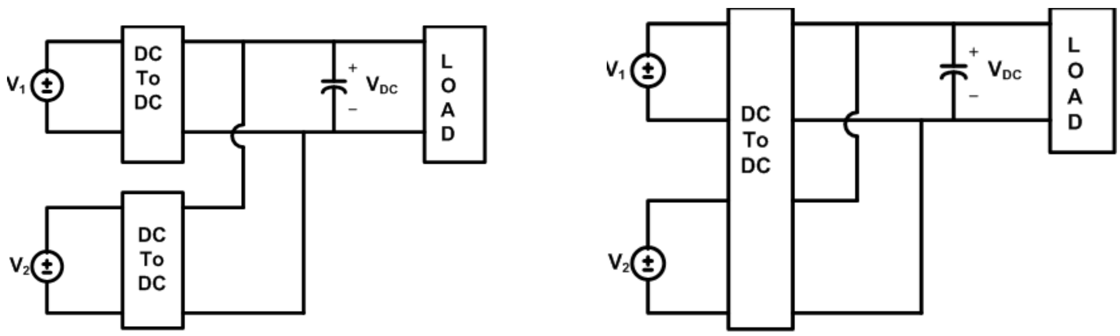
Abstract:- The renewable generations are growing rapidly as they exhibit solutions to many concern to the human development. They are primarily interfaced to the power system network through the DC-DC converter topology to interface the multiple generations of renewable resources to grid through a common DC bus. This single integral converter is used for two energy sources viz.wind-wind, solar-solar or solar –wind type of combinations .This reduces the number of DC-DC converters required for individual sources with independent controllers. The maximum power control on each individual is executed by adopting the common MPPT algorithm using golden search method. The converter under different operating condition indicates the effectiveness of this DC-DC converter. The simulation results are presented by using MATLAB/SIMULINK and its hardware implementation using dSPACE is given.

Keywords: **-** DC-DC converters, Golden search technique, MPPT, PV generation, wind energy generation.

I. INTRODUCTION

The sources of conventional energy on the verge of extinction on the other hand the energy demand is continuously increasing. Extensive research has been done on alternative energy sources. Solar energy and wind energy which are free and abundant has proven to be a challenging source of energy. The photovoltaic power and wind power are complementary since sunny days are usually calm while cloudy days have often strong winds. Since solar energy and wind energy are inconsistent source of energy, for continuous supply of power hybrid system is more reliable than individual source of energy. Hybrid systems can be off –grid systems or grid connected systems. In off grid systems energy produced is used to charge batteries via charge controllers. However, use of battery is not eco-friendly because of its chemical pollution, bulky size; limited life cycle .Cost is also one of the limitation. Nowadays the solar and wind energy are utilized by directly connecting them to grid .In grid connected hybrid system battery backup can be avoided as well as it provides efficient and maximum utilization of power and can be used for distributed power generating systems

Generally two DC voltage sources are connected to two independent dc-dc converters to obtain two stable and equivalent output voltages, which are then connected to the DC bus .Fig.1(a) shows the block diagram of the two voltage source power system with two individual dc-dc converters. In order to simplify the system and reduce the cost, a double-input DC-DC converter is used in this paper as shown in fig.1 (b).



a) With two individual dc-dc converters b) Single integrated converter

Fig.1. Interface of DC-DC Converter

The proposed topology consists of double input dc-dc converter, H-Bridge dc-ac inverter the output of which is connected to the grid. The PV array and the wind turbine output voltage act as the input dc voltage sources. A new MPPT algorithm Golden Section Search algorithm has been introduced. The MPPT algorithm in combination with the PWM technique is used to operate switches S_1 and S_2 to draw maximum power from both the sources. SPWM technique is used to operate the switches S_3-S_6.Detailed operating principle of the proposed multi-input renewable converter has been introduced further. The advantages of the proposed topology are :1)a single DC-DC converter reduces cost,complexity,size,2)a single MPPT controller increases the efficiency and reduces the cost as well,3)the golden search algorithm has same number of converging iterations irrespective of the operating conditions,4)both the sources can deliver power to the grid individually as well as simultaneously.

II. RENEWABLE GENERATING SOURCES AND MAXIMUM POINT TRACKING

1) Photovoltaic Array

When large numbers of solar cells are connected in series or parallel it forms a solar array. Each solar cell is formed by a p-n junction semiconductor, which produces current by photovoltaic effect. An equivalent model of a PV cell is shown in Fig.2 below.

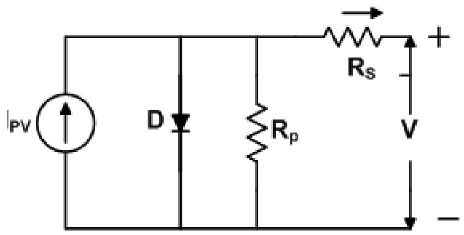


Figure2. Equivalent Circuit of solar cell

The PV output current is given by [3] equation below

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

Where, I_{pv} is light generated current at nominal condition (usually 25°C and 1000 W/m^2), I_o is the diode saturation current, V is array output voltage, R_s is series resistance associated with connecting the active portion of the cell, R_p is parallel leakage resistance and V_t is thermal voltage of array,a is ideality factor of diode (1 to 1.5) The I-V characteristics of solar cell is non-linear and varies with irradiance and temperature. For a given irradiance and temperature, maximum power is supplied by the PV cell at a particular operating point ,this point is termed as Maximum Power Point (MPP).Output power characteristics as function of irradiance in fig.3.

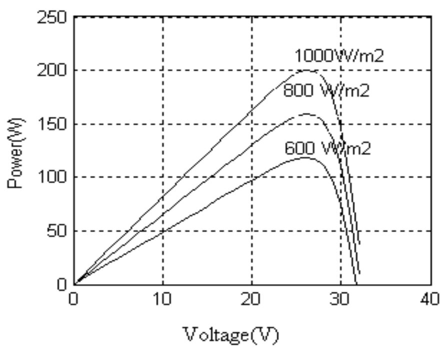


Fig.3. P-V characteristics as a function of irradiance

These operating charactristic is obtained using irradiation and temperature as input with online computation programme developed to update the data of power. From the figure it can be observed that this Maximum Power Point (MPP) varies with irradiance and temperature. Therefore Maximum Power Point Tracking (MPPT) techniques are needed for extracting the maximum power from the PV systems. This maximum power extraction is implemented using golden section search rule having distinct advantages over the conventional methods. This is presented in next section.

2)Wind Turbine

A permanent magnet synchronous turbine has comparatively higher efficiency and is more reliable having wide use in wind generation.

The power available in the wind is given by

$P_{wind} = (1/2)\ \rho\ A\ V^3$ (2)

Where A is are swept by the rotor blades (m^2), ρ is air density (kg/m^3) and V is wind velocity (m/s).

The power P_b extracted by the blades is given by

$P_b = (1/2)\ \rho\ AV^3\ C_p$ (3)

C_p is the power coefficient of the wind system is ratio of power extracted by the rotor to the power available in the wind stream. C_p is nothing but the efficiency of the rotor.

$Cp = P_e / [(1/2)\rho AV^3]$ =Power extracted by rotor / Power available in wind (4)

The Tip speed ratio λ is the ratio of speed of blade tip to free stream wind speed V

$\lambda = \omega R/V$=Speed of blade/ Free stream wind speed (5)

C_p can be expressed in terms of λ

$C_p = (1/2)(1+\lambda)(1-\lambda^2)$ (6)

For maximum power transfer $dC_p/d\lambda$ should be equal to zero

Thus λ =1/3 i.e. .blade efficiency is maximum when it slow down the wind to 1/3[rd] of its undisturbed upstream velocity. Thus it can be seen that maximum power transfer depends on λ .The change in output voltage of wind generator leads to change in λ thus by controlling the output of the generator maximum power flow can be ensured.

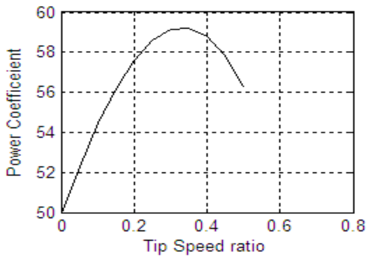


Fig. 4.Power coefficient variation with tip speed ratio

C) MPPT Algorithm-A Golden Section Search

There are various algorithms for MPPT such as Constant Voltage (CV) [5]-[6], Open Circuit Voltage [5], Short Circuit Current [4][6], Perturb and Observe (P&O) [5][6], incremental Conductance(IC) [5] and temperature method [5]. The performances of these methods are more signal noise sensitive and iterative process depends on the derivative. A Golden Section Search (GSS) is presented [1] for this application is having current as a search variable. In this paper a Golden Section Search technique is proposed with voltage as a search variable and gives faster response with minimum iterations irrespective of the irradiance and temperature.

The golden section search is technique for finding extremum (minimum or maximum) by successive narrowing the range of values inside which extremum is known to exist. Suppose we have to find maximum functional value of f(x) subject to $a \leq x \leq b$. Now, two points x_1 and x_2 are selected in the interval [a b] as shown in fig.5 and function f(x) is evaluated at these points. The points x_1 and x_2 are such selected each point subdivides interval into two parts such that

Length of whole line / Length of larger fraction = Length of larger fraction/Length of smaller fraction

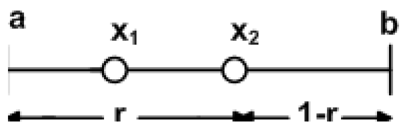


Fig.5. Division of interval

Now $f(x_1)$ and $f(x_2)$ are evaluated at x_1 and x_2:

a) If $f(x_2) > f(x_1)$, then in the range$[x_1, x_2]$ the function is increasing. Therefore we know that function value is greater than $f(x_1)$. Thus the maximum is in the range of $[x_1, b]$.

b) If $f(x_1) > f(x_2)$, then in range $[x_1\ x_2]$ the function is decreasing. Thus the maximum is in the range $[a, x_2]$.

c) If $f(x_1) = f(x_2)$,then maximum must lie in the range $[x_1\ x_2]$, since points x_1 and x_2 have to be on either side of maximum. This method has definite convergence in a very small number of iterations.

III. PROPOSED CONVERTER-INVERTER SCHEME

1) Integrated Grid Connected Converter

A hybrid grid connected application typically consists of five main components as shown in fig.6:1) the source of energy i.e. PV array /Wind turbine, 2) a dc-dc converter that converts dc voltage to desired level, 3) an inverter that converts the dc voltage to single phase or three phase ac voltage, 4) a controller that controls the converter operation, 5) a filter that absorbs the harmonic generated by the system [7].

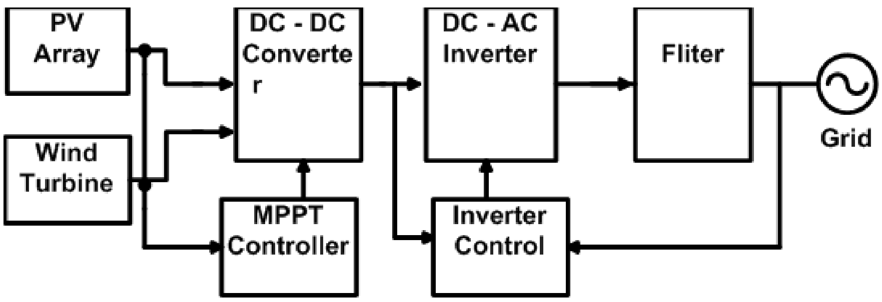


Fig.6. Block diagram of Hybrid System

2) Multi-Input DC-DC Converter

The schematic diagram of the proposed multi-input converter is shown in Fig.7. It consists of two input voltage sources V_{pv} and V_{wind} .When both the sources are acting independently they represent buck and buck boost converter respectively. The switching frequency of switch S_1 & S_2 can be different but due to interference and filter design it is operated at same switching frequency. The switch S_1 & S_2 are operated with turn –on instant and same turn –off instant Depending on the duty cycle of the switches S_1 and S_2 ,there are four different operating modes[3].The modes of operation are tabulated in Table 1 below.

TABLE1. MODES OF OPERATION

Modes of Operation	S_1	S_2	D_1	D_2
1	On	Off	Off	On
2	Off	On	On	Off
3	Off	Off	On	On
4	On	On	Off	Off

The diodes D_1 and D_2 act as freewheeling diodes. The relation between input and output voltage can be derived by inductor volt-sec balance equation. When S_1 has longer conduction period with respect to S_2 then sequence of mode of operation is Mode1,Mode 4,Mode3 while, if S_2 has longer conduction period than S_1 then it is Mode2,Mode 4,Mode 3.Applying the volt -second balance theorem the following equations are obtained.

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When $d_1>d_2$

$(V_{pv}-V_{DC})(d_1-d_2)T_s+(V_{pv}+V_{wind})d_2T_s+(-V_{DC})(1-d_1)T_s=0$ (7)

d_1 is duty cycle of switch S_1 ,d_2 is duty cycle of switch S_2

V_{DC} is output dc voltage

On solving above equation (7) we get,

$V_{dc}=[d1/(1-d2)]V_{pv}+[d2/(1-d2)]V_{wind}$ (8)

When $d_2>d_1$

$(V_{wind})(d_2-d_1)T_s+(V_{pv}+V_{wind})(d_1)T_s+(-V_{DC})(1-d_2)=0$ (9)

On solving above equation (9) we get,

$V_{dc}=[d1/(1-d2)]V_{pv}+[d2/(1-d2)]V_{wind}$ (10)

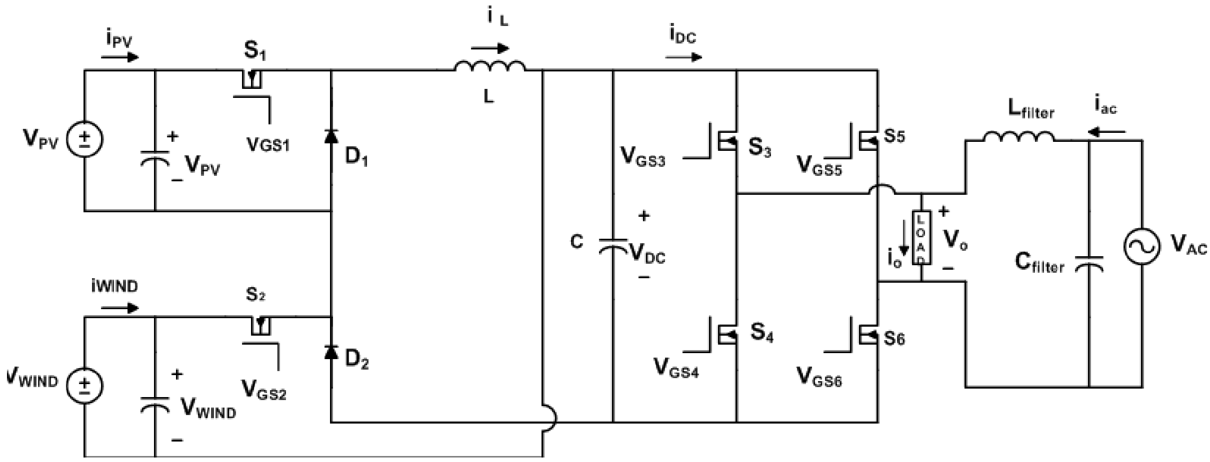


Fig.7 Schematic Diagram of proposed Multi-Input Converter

Thus it can be observed that equation (8) and (10) are similar which implies that switches S_1 and S_2 can be operated independently. Similarly the a relationship between the input current and voltage can be obtained [3].

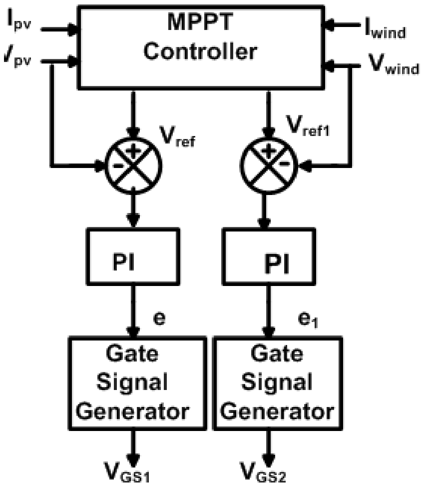
$I_{pv}=[d1/(1-d2)]Io$ (11)

$I_{wind}=[d2(1-d2)]Io$ (12)

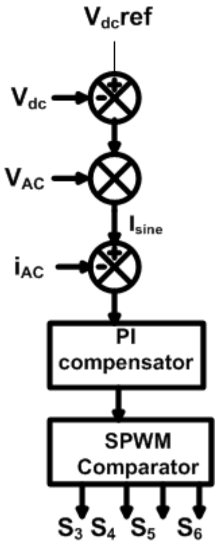
Therefore the control of each power source is possible by controlling the duty cycle of d_1 and d_2.

3) Control Algorithm

The block diagram of the proposed control topology is shown in fig.8(a) and (b). For switching of the dc-dc converter switches S_1 and S_2 the array voltage V_{pv} and the wind generator voltage V_{wind} are sensed and fed as an input to the MPPT controller. The MPPT controller generates the reference voltage corresponding to the maximum power point, this reference signal is compared with the array and wind generator output and is error is processed through a PI controller .The error signal obtained is used to gate signals for switch S_1 and S_2. The Inverter switching is controlled through Sinusoidal Pulse Width Modulation Technique (SPWM).The reference sinusoidal signal is generated from the grid voltage By controlling the modulation index the reactive power flow through the system can be controlled, while by controlling the phase shift between the inverter output voltage and grid voltage the active power flow through the system can be controlled. The dc bus voltage is regulated by the adjusting the amplitude of ac output current.



(a)



(b)

Figure8. Block Diagram of Control Topology

IV. DSPACE IMPLEMENTATION

The dSPACE is system based on the DS1104 R&D Controller Board. The DS1104 is specifically designed for the development of high-speed multivariable digital controllers and real-time simulations in various fields. It is a complete real-time control system based on a 603 PowerPC floating-point processor running at 250 MHz. For advanced I/O purposes, the board includes a slave-DSP subsystem based on the TMS320F240 DSP microcontroller. The switching pulses for the dc to dc converter are obtained using dSPACE. The schematic representation of the complete system is shown in Fig 9.

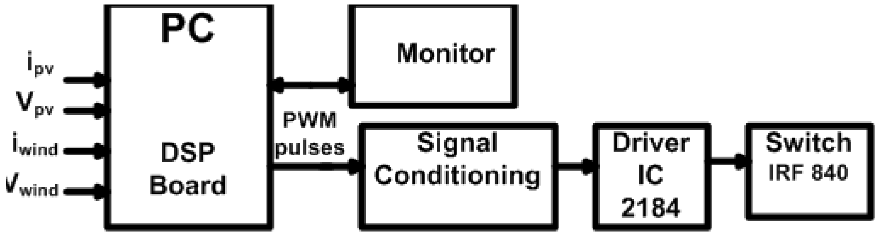


Fig.9. Schematic representation of complete System

V. SYSTEM PERFORMANCE

To evaluate system performance the proposed topology has been simulated in MATLAB/SIMULINK. Fig.10 shows the gate pulses for switch S_1 and S_2.Duty cycle of switch S_1 is greater than that of S_2. In Table.2 simulation parameters are listed.

TABLE 2. SIMULATION PARAMETERS

Grid	230V,50Hz
Vpv	400V
Vwind	200V
Vdc	415V
$F_s$of dc-dcconverter	2Khz
C	100µF

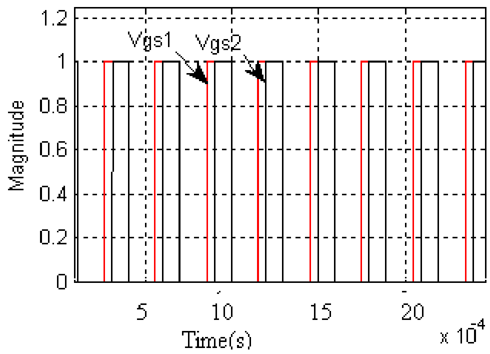
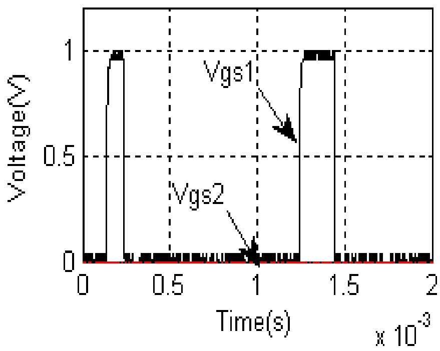
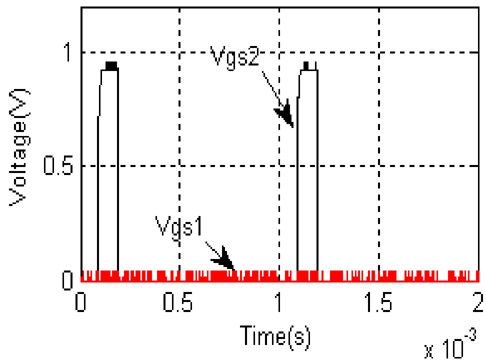


Fig.10. Gate pulses of switch S_1 and S_2

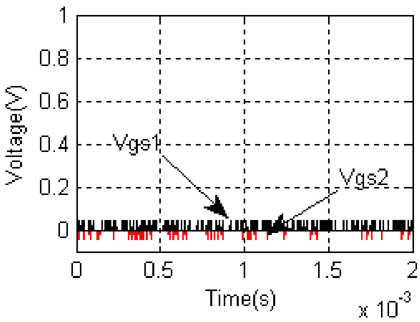
Fig.11 shows the various modes of operation which are obtained using dSPACE. From fig.10 and 11 it can seen that the dSPACE waveforms are similar to the simulated waveforms.



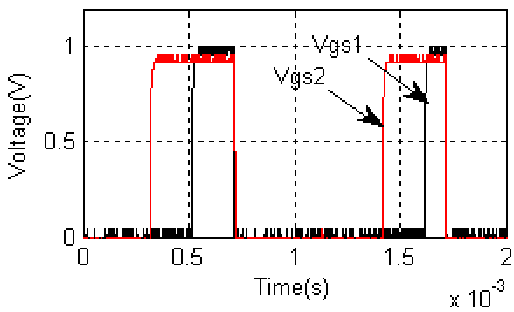
(a) Mode 1



(b) Mode 2



(c) Mode 3



(d) Mode 4

Figure 11 Modes of operation

Fig.12 shows waveforms of input currents and inductor current ,since switch S_1 and S_2 have different duty ratios inductor current have different charging slopes.Fig.13 shows input voltage waveforms and dc bus voltage ,dc bus voltage remains almost constant.

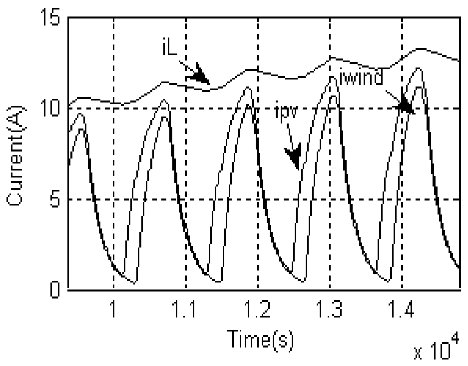


Fig.12. Input current and inductor current waveforms

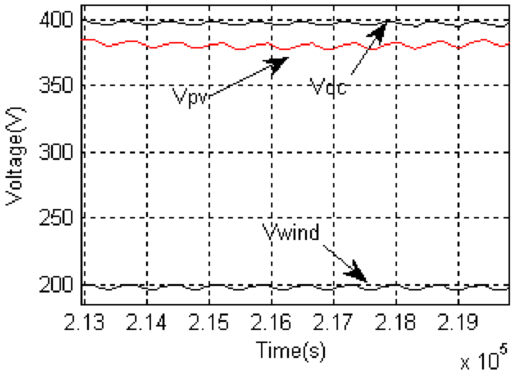


Fig. 13.Input Voltage and DC Voltage Waveforms

From Fig.14 and 15 it can be seen that inverter output voltage is greater than grid voltage that is why the current i_{AC} is negative indicating power is fed to the grid by the converter.

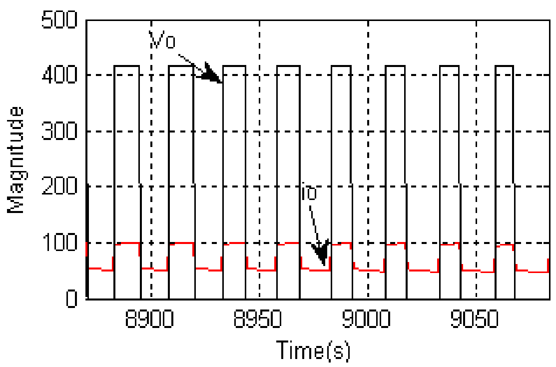


Fig. 14. Load output Voltage and Current waveforms

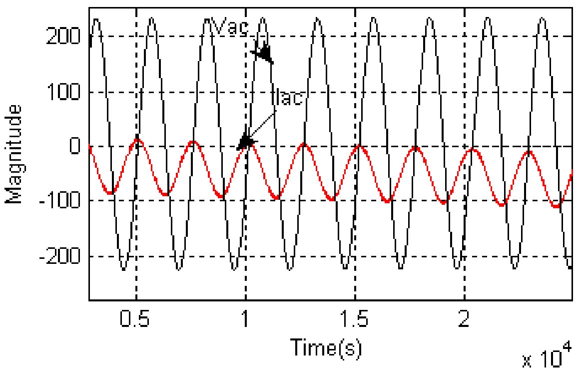


Fig. 15. Grid Voltage and Current waveforms

VI. CONCLUSION

Integrated DC-DC converter for multi-renewable sources is proposed in this paper. A single integral converter for two sources reduces the complexity, size and cost of the system. The proposed Golden Search algorithm is more efficient and has a fast convergence with respect to the other conventional MPPT techniques. It is been observed that the convergence efficiency is high irrespective of the continuously changing operating conditions. This has fast response and also guaranteed convergence. It is also more robust and less noise sensitive.Few experimental results were shown using dSPACE.

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