PV and Wind Energy Harvesting System With Multi-Rectifier stage for Grid Application

Cicily Antony T,
PG scholar
Electrical and electronics engineering
Mar Athanasius College of engineering
Kothamangalam, India

Beena M Varghese,
Associate professor
Electrical and electronics engineering
Mar Athanasius College of engineering
Kothamangalam, India

SmithaPaulose
Assistant professor,
Electrical and electronics engineering
Mar Athanasius College of engineering
Kothamangalam, India

***Abstract*—Environmental friendly energy sources such as solar, wind, hydro energy etc…have gained more popularity nowadays, because of their availability, reliability, less cost, no pollution and high efficiency. This paper introduces the combination of two renewable energy sources such as wind and solar, connected to a multi input rectifier stage having a single output. The proposed rectifier stage uses the combination of CUK-SEPIC converter and an inverter is connected its output for ac grid or load applications. The proposed rectifier stage eliminates the need of input filters, reduce harmonics, ripples at the input and output are also less. Different MPPT algorithms are there; among these the most accurate and simplest method called incremental conductance method is utilized here to track maximum power point. The simulation and validation of the scheme is carried out in MATLAB/ SIMULINK. PIC16F877A microcontroller is used, to develop switching pulses for hardware implementation. The experimental set up for multi input rectifier with single inverter at output is developed and its operation is validated and results are verified with the simulation results. The experimental and simulation results obtained are also included in this paper.**

Keywords*—*CUK-SEPIC converter , photovoltaic system , wind turbine, full bridge inverter , incremental conductance algorithm.

I. INTRODUCTION

Renewable energy resources have gained more popularity in power electronics field because of their environmental friendly nature, easy availability, less cost, high efficiency, less pollution etc... With the necessity of electricity, and the depletion of our present energy sources such as coal, charcoal, kerosene etc. lead to make use of renewable energy sources. Different types of renewable energy sources are available. Among them the most popular are solar and wind energy [1]-[3]. Solar energy is a good means because its available in plenty, eco-friendly, does not causes any atmospheric pollution and free of cost. But it has a major drawback that is, its irradiation level gets changes with variation in sun intensity and with the unexpected shadows caused by clouds, birds, trees etc. Wind energy is able to meet high load demand but its presence is unpredictable. The intermittent nature of these two sources makes them inefficient [4]-[7]. Hence to track maximum power output from these sources a maximum power point tracking algorithm is introduced.

Different types of MPPT algorithms are there such as perturb and observe method, incremental conductance method, dP/dV feedback control method, fuzzy logic, neural network, adaptive control method etc… In perturb and observe method it perturbs the operating point and observe the output power[18]. If the direction of perturbation provides a positive change in output power then continue with the same direction and if the direction of perturbation provides a negative change in output power then reverse the direction. If there is no change in output power then it's the maximum power point. The main drawback of this P and O method is that it gets oscillates at maximum power point and it can't work efficiently at fast varying atmospheric conditions. In this paper a simple and efficient MPPT algorithm called incremental conductance method is introduced and it eliminates the drawback of P&O method and can operate at fast varying atmospheric conditions. In incremental conductance method, both instantaneous and incremental values are considered Photovoltaic and wind systems require a power electronics interface to define their operating point at optimal conditions for any load. For that DC/DC and DC/AC converters are widely used. Here the combination of two dc to dc converters is used as rectifier [8]-[16].

The rectifier stage proposed in this method is a combination of CUK and SEPIC converter in which the output inductor of CUK converter is shared by the SEPIC converter. In the proposed multi rectifier stage the output can be either step up or step down by controlling the duty cycle and it's done by MPPT algorithm. At the output of rectifier stage, a full bridge inverter is connected, so that it can be used to drive ac load and grid. The PV and wind applications commonly adopt boosting converters for grid-connected applications due to the requirement of increased voltage to the grid connected inverter operating conditions. The current ripple magnitude is an important factor in the selection of power converters, because high current ripples produce an oscillation around the maximum power point (MPP) that reduces the energy extracted from the PV generator. The paper contains the circuit representation of proposed circuit with an inverter at its output. The MATLAB/SIMULINK model of PV panel with mathematical model of MPPT also represented. The experimental setup utilize PIC16F877A microcontroller to generate switching pulses.

II. Proposed Multi Input Rectifier Topology

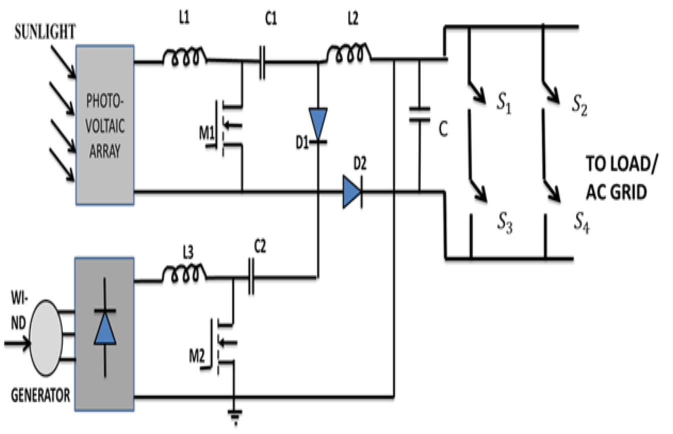

Fig.1 proposed multi input rectifier topology with inverter

Figure 1 show the proposed topology which utilize both solar and wind energy as their input sources. Depending upon the load demand and the availability of the sources, either they can operate separately or simultaneously. Here the input of CUK converter is connected to the photovoltaic array and that of SEPIC converter is supplied from a wind turbine. Photovoltaic panel convert solar energy into direct current using semiconductors that exhibit photovoltaic effect. The photovoltaic panel is formed by connecting a number of solar cells either in series or parallel depending upon the voltage or current requirement. A solar cell is basically a p-n junction device which takes the advantage of photovoltaic effect, which is the ability to convert electromagnetic radiations into electric current. Materials presently used for making photovoltaic module include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulphide [2]. Due to the increased demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years. The equivalent circuit of solar cell contain two resistance such as R_s and R_{sh}. Where R_s is the series resistance which is of very small value and it is offered by the contacts and semiconductor materials of solar cell and R_{sh} is the shunt resistance, due to the impurities near the edges of cells and it is very large value.

In the proposed circuit we utilizes two sources such as wind and solar as input sources and connecting an inverter at its output. That is it uses a DC-DC converter for each sources and DC-AC converter as common for both sources for grid applications. For efficient operation of these sources an efficient DC-DC converter is necessary so that it can extract maximum power from these sources. Low current ripple and high conversion efficiency are also some necessary factor for selecting a suitable DC-DC converter for PV and wind applications. The current ripple magnitude is an additional factor in the selection of power converters for photovoltaic applications because high current ripples are reduced to a great extend with proper selection of high gain converter, and hence its power production and life time increases. The DC-DC converter used in this topology is the combination of CUK and SEPIC converter in which the fusion of these two converters is achieved by sharing the output inductor of CUK converter by the SEPIC converter. Different types of non-isolated DC-DC converters are available. Among these converters the most efficient converters are CUK and SEPIC converter. Because in these converters the energy transfer element is capacitor and inductor is connect at both input and output side which reduce the current ripples at both source and load side when compared to other converters. The other merits of these converters include continuous input and output current, less switching loss and high efficiency eliminates the need of external filtering requirements, small size and less weight, output voltage can be either greater than or less than input voltages. The input and output voltage relation of a CUK converter is

$$\frac{V_0}{V_d} = \frac{D}{1-D} \tag{1}$$

Here, $V_d = V_{PV}$ .By adjusting the duty cycle we can control the output voltage and there by the power. The SEPIC converter is a single ended primary inductance converter is a type of DC-DC converter that provides a positive regulated output voltage from an input voltage. It can operate as a non-inverting step up or step down DC-DC converter. If D_1 is the duty cycle for SEPIC converter, then the input -output voltage relation is,

$$\frac{V_0}{V_d} = \frac{D_1}{1-D_1} \tag{2}$$

In SEPIC converter, the input source is wind, hence $V_d = V_w$. The proposed system contains two inputs and a single output with an inverter. The inverter used here is a full bridge inverter. The system can operated in number of modes such as either both switches M_1 and M_2 of each converters and S_1S_3 or S_2S_4 of inverter is operating or only any one of the converter switch say either M_1 or M_2 and any pairs of inverter switches are operating or both converter switches are off and inverter switches are operating. In inverter no two switches of same leg can operate. To track maximum power from each sources a maximum power point algorithm is used. There are different types of MPPT algorithms are there such as perturb and observe method, incremental conductance method, fuzzy logic, neural network etc. The most commonly used method is perturb and observe method in which it perturbs the operating point and observes the output power. The main drawback of this method is that it oscillates at operating point and it can't work properly for fast varying atmospheric conditions. Here an incremental conductance algorithm is use because it can work at fast varying atmospheric condition. A simple Block diagram representation of proposed system is shown in figure.2.

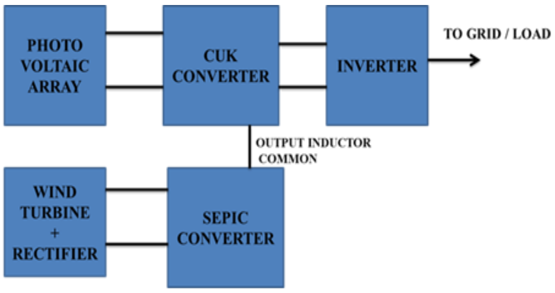

Fig.2 block diagram representation of proposed system

III. MPPT Control of Proposed System

Wind energy and solar energy are two effective means to generate electricity, because it does not causes any atmospheric pollution and never results in the emission of greenhouse gases; hence it attracts more attention to solve the energy crisis. Even if these sources are attractive, their intermittent natures make them in effective. That is, solar energy is available in plenty and free of cost but its irradiation level changes with sun intensity and unpredictable shadows [16]. The wind energy is capable of providing better power output but its presence is unpredictable. These drawbacks restrict the system to operate properly. For efficient operation of these sources an efficient DC-DC converter and an MPPT algorithm is needed. Different types of MPPT algorithms are there such as perturb and observe method, dP/dV method,, incremental conductance method, fuzzy logic, adaptive control method, neural network etc..[2]-[4] Among these method the most common and simplest methods are perturb & observe method and incremental conductance method. These methods are called hill climb search method. In P and O method, it perturbs the operating point and observes the output. If the direction of perturbation provides a positive change in power, then assumed direction of perturbation is correct and continue in the same direction, else reverse the direction of perturbation[15]. The main drawback of this method is that it gets oscillates at its maximum power point and it can't respond to fast varying atmospheric conditions. In incremental conductance method both incremental and instantaneous values are considered. It's an advanced form of dP/dV method. In incremental conductance method the slope of P-V curve is zero at maximum power point and it is increasing on left of MPP and decreasing on its right half [18] as shown in figure 3.

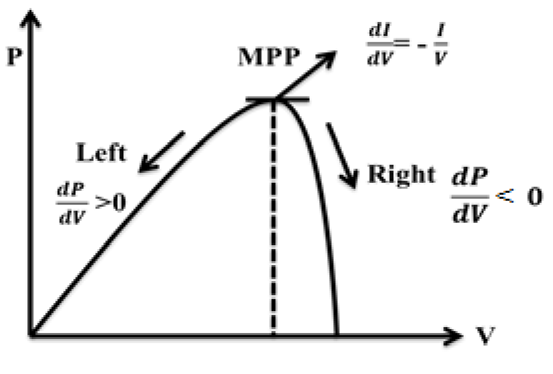

Fig .3 .incremental conductance method

Incremental conductance method without PI controller is used in this paper and it is implemented using mathematical expressions. In incremental conductance method the change in voltage and current is determined and the error is calculated. If there is no change in voltage and current, then it will continue with the same operating point as the maximum power point and if there is any change in voltage and current then calculate rate of change of current and voltage and check whether $\frac{dI}{dV}$ is greater than or less than $-\frac{I}{V}$. If it is greater than zero then operating point is at left of maximum power point else it's on the right half depending upon the duty cycle is adjusted and the maximum power point is tracked. Incremental conductance with PI controller can also use but it increases the complexity and cost. The figure 3 can also represented using mathematical expression as follows.

$$E = \frac{dI}{dV} + \frac{I}{V} \tag{3}$$

$$\frac{dI}{dV} = -\frac{I}{V} \text{ (At maximum power point)} \tag{4}$$

The mathematical model of incremental conductance method and the PV panel is formed using the following equations [17].

Photo current,

$$I_{ph} = [I_{scr} + K_i(T - 298)] * \frac{\lambda}{1000} \tag{5}$$

Reverse saturation current,

$$I_{rs} = \frac{I_{scr}}{[\exp(\frac{qV_{oc}}{N_S KAT}) - 1]} \tag{6}$$

Saturation current,

$$I_0 = I_{rs}[\frac{T}{T_r}]^3 \exp[\frac{qE_{go}}{BK}\{\frac{1}{T_r} - \frac{1}{T}\}] \tag{7}$$

Output current of PV module,

$$I_{PV} = N_p * I_{ph} - N_P * I_0[\exp\{\frac{q*(V_{PV} + I_{PV}R_S)}{N_S AKT}\} - 1]$$

(10)

Where,

N_p = number of cells connected in parallel and here it's taken as 1

N_S = number of cells connected in series and it is chosen as 36

A= ideality factor = 1.6

K, Boltzmann constant = $1.3805 * 10^{-23} J/K$

T=module operating temperature

T_r = reference temperature=298K

I_{scr} =2.55A, module short circuit current

Illumination, $\lambda = 1000 W/m^2$

IV. SIMULATION RESULTS

The proposed multi rectifier stage with wind and solar as input source and an inverter at its output for grid application is simulated in MATLAB 2010a version. In simulation model instead of wind turbine, three phase source with a diode bridge rectifier is used. The output of rectifier is connected to a SEPIC converter and input of CUK converter is connected to the PV module modeled using mathematical expressions 5 to 8. The incremental conductance algorithm is modeled using expressions 3 and 4 and it controls the proposed system to track maximum power from these sources. The simulation is done for an input voltage of 148V and obtained an output voltage of 230V. The solar panel is developed with 36 cells connected in series and it provides an output voltage of around 38V and the wind system provides a voltage of 110V [17].

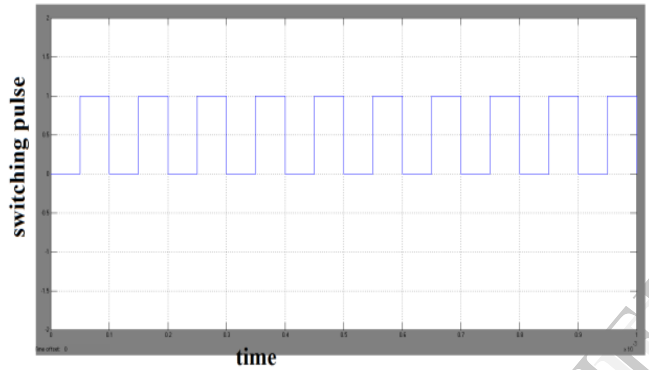

fig.4switching pulses for converter switches

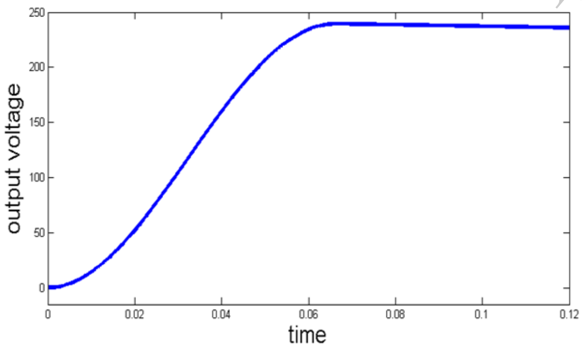

Fig.5 output voltage of dc-dc converter

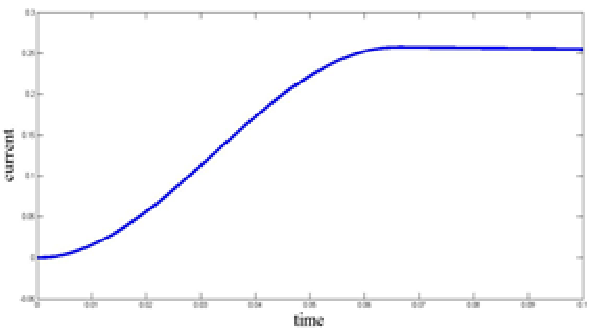

Fig 6. Output current waveform of dc-dc converter

The total harmonic distortion in the inverter output voltage of proposed system is very small and its amplitude is around 0.88. Figure5 and 6 shows the dc – dc converter output voltage and current waveform. The total harmonic distortion waveform is shown in fig.8 and the inverter output voltage for an irradiation of 1000 is shown in fig 7. Fig.4 shows the switching pulses developed in MATLAB using incremental conductance algorithm and by adjusting its duty cycle the maximum power point can be attained. The switching pulses for inverter are developed with a switching frequency of 50 Hz and 50% duty cycle. The simulation of proposed system is done with a converter switching frequency of 1 kHz

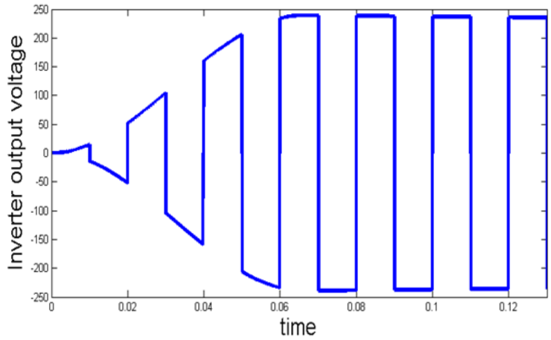

Fig.7 inverter output voltage waveform

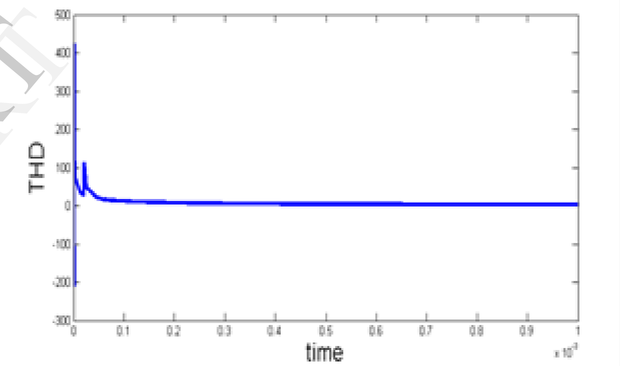

Fig.8 total harmonic distortion waveform

V. EXPERIMENTAL SETUP

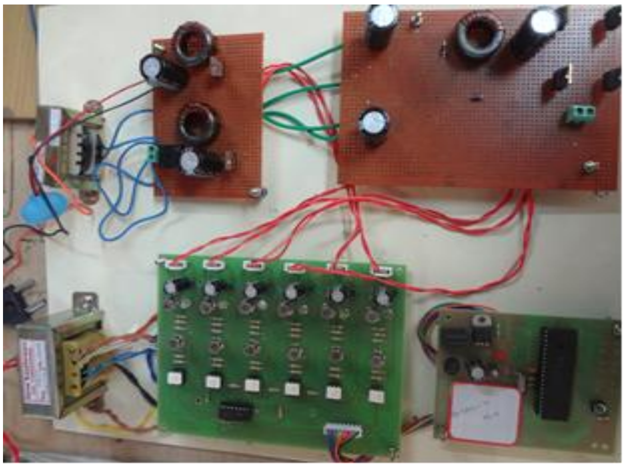

Fig .9 experimental setup of proposed system

The experimental setup of proposed hybrid wind solar energy system with inverter at its output is shown in figure 9. In experiment, a 9V battery is used instead of solar panel and a 230/12V transformer with rectifier is used for wind energy. In order to turn on the switches, switching pulses are required and it is developed using PIC 16F877A microcontroller. The pulses obtained from the microcontroller are around 5V, which is not enough to turn on the switch. Hence a driver circuit is used to boost the voltage triggering signal to 9V to 20V. The proposed circuit consists of six switches that are, 2 switches for the dc to dc converter used in proposed circuit and remaining four switches for inverter circuit. The six switching pulses are generated by the microcontroller and it requires six driver circuits. The driver circuit is again supplied from a separate source of 230V/12V, 7 tapping transformer and it contains an opt coupler at its input section to provide isolation and it prevents the MOSFET from damages. The switches used for experiment are IRF840 MOSFET and the opt coupler used is MCT2E.The driver circuit forms the most important part of the hardware unit, because it gives the triggering pulse to the switches in the proper sequence. The output voltage wave form obtained at the inverter end and the pulses generated for switches are shown in fig.10 and 11. In the experimental setup from an input voltage of 21V (9+12) , an output voltage of around 37V is obtained. The proposed system can provide both step up and step down operation depending upon the duty cycle. Here the system is designed for step up operation and a constant input is provided. In practical case the irradiation of solar is changing continuously hence the system output voltage also varies. Hence to implement the system the battery can be replaced by a voltage source.

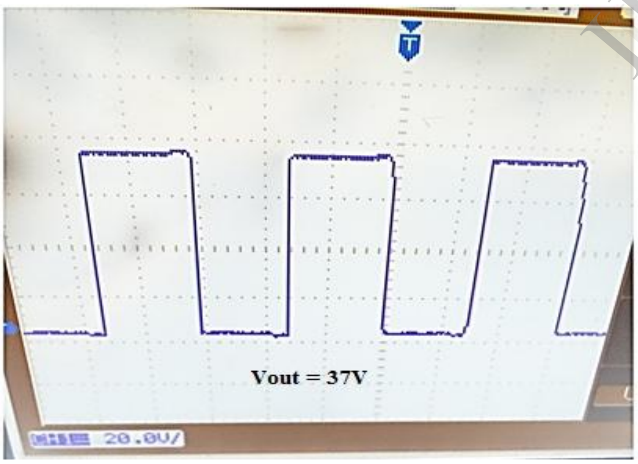

Fig.10. inverter output voltage

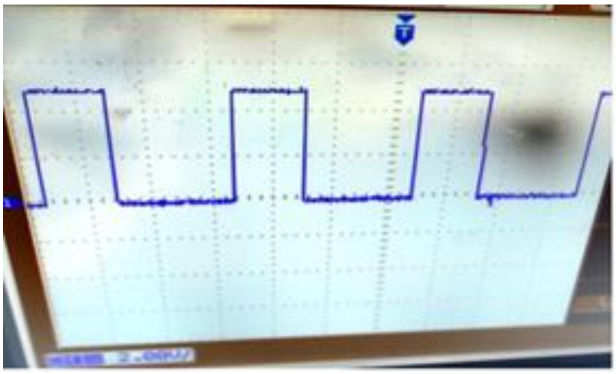

Fig.11 switching pulses for DC-DC converter

VI. CONCLUSION

A multi rectifier system using PV and wind as input and an inverter at its output is designed and analyzed. The simulation and experimental setup of proposed system is conducted and the experimental results are verified with the simulation results. The multi rectifier stage used in this system is the fusion of CUK and SEPIC converter by taking the output inductor as common for both converters which reduce the complexity and increase reliability of the system. The inverter connected at the output terminal convert the DC voltage at output of muti rectifier stage into ac and enables the system for ac grid applications. To track maximum power from these resources an incremental conductance MPPT algorithm is used, which reduces the complexity and avoids the oscillation at operating point and respond with fast varying atmospheric conditions.

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