HYBRID WIND-SOLAR ENERGY SYSTEM WITH RECTIFIER TECHNOLOGY

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Abstract: Environmentally friendly solutions are becoming more prominent than ever as a result of concern regarding the state of our deteriorating planet. This project presents a new system configuration for a hybrid wind/photovoltaic energy system. This configuration allows the two sources to supply the load separately or simultaneously depending on the availability of the energy sources. The inherent nature of this Cuk-SEPIC fused converter, additional input filters are not necessary to filter out high frequency harmonics. Harmonic content is detrimental for the generator lifespan, heating issues, and efficiency. The fused multi-input rectifier stage also allows Incremental Conductance Maximum Power Point Tracking (MPPT) to be used in solar power systems with direct control method. Contributions are made in several aspects of the whole system, including converter design, system simulation and controller programming. The resultant system is capable of tracking MPPs accurately and rapidly without steady-state oscillation, and also, its dynamic performance is satisfactory. MATLAB and Simulink were employed for simulation. Simulation results indicate the feasibility and improved functionality of the system.

Keywords: Renewable Energy Source, simulation, Solar Energy, short term energy and long term energy, *MPPT - maximum power tracking***.**

I. INTRODUCTION

With increasing concern of global warming and the depletion of fossil fuel reserves, many are looking at sustainable energy solutions to preserve the earth for the future generations. Recently, energy generated from clean, efficient and environmentally friendly sources has become one of the major challenges for engineers and scientists. Other than hydro power, wind and photovoltaic energy holds the most potential to meet our energy demands.

Solar energy systems:

Among all renewable energy sources, solar power systems attract more attention because they provide excellent opportunity to generate electricity while greenhouse emissions are reduced. Solar energy is a unique prospective solution for energy crisis. However, despite all the aforementioned advantages of solar power systems, they do not present desirable efficiency.

The efficiency of solar cell depends on many factors such as temperature, insolation, spectral characteristics of sunlight, dirt, shadow and so on. Changes in insolation on panels due to fast climatic changes such as cloudy weather and increase in ambient temperature can reduce the photovoltaic array output power. Each PV cell produces energy pertaining to its operational and environmental conditions.

In addressing the poor efficiency of PV systems, some methods are proposed, among which is a new concept called “maximum power point tracking”(MPPT). All mppt methods follow the same goal which is maximizing the PV array output power by tracking the maximum power on every operating condition.

Wind energy systems:

With growing concerns about environmental pollution and a possible energy shortage, great efforts have been taken by the government around the world to implement renewable energy systems more essential for sustainable development. Wind energy is one of the most important and promising sources of renewable energy all over the world, mainly because it is considered to be nonpolluting and economically viable. At the same time, there has been a rapid development of related wind turbine technology.

Wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Similarly, solar energy is present throughout the day but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees etc. The common inherent drawback of wind and photovoltaic systems are their intermittent natures that make them unreliable.

This kind of electric power generation usually causes problems in the electrical system it is connected to, because of the lack or scarcity of control on the produced active and reactive power. Wind being seasonal and site specific, grid connected systems or hybrid systems are needed for reliable and continuous power.

The working principle of a wind turbine encompasses two conversion processes, which are carried out by its main components the rotor, which extracts kinetic energy from the wind and converts it into a mechanical torque, and the generating system, which converts this torque into electricity. This general working principle is depicted in Fig.1.1 although this sounds rather straightforward wind turbine is a complex system in which knowledge from the area of aerodynamics, mechanical, civil, electrical and control engineering comes. Currently, three main wind turbines are there in the market. The main difference between the three concepts is the generating systems and the way in which the efficiency of the rotor is limited during high wind speeds.

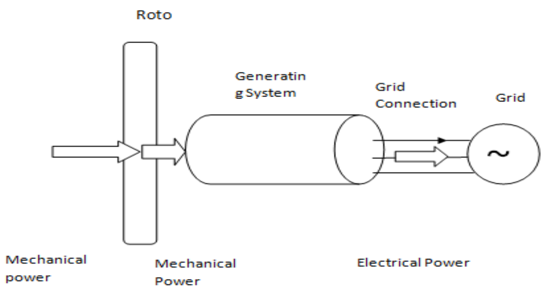


Fig.1 General working principle of wind power generation

As for the generating system, nearly all wind turbines installed at present use either one of the following systems:

1) Squirrel cage induction generator
2) Doubly fed (wound rotor) induction generator
3) Direct drive synchronous generator

The first generating system consists of a conventional, directly grid coupled squirrel cage induction generator. The slip, and hence the rotor speed of a squirrel cage induction generator varies with the amount of power generated. These rotor speed variations are, however, very small, approximately 1 to 2 per cent. Therefore, this wind turbine type is normally referred to as a constant speed or fixed speed turbine. It should be mentioned that squirrel cage induction generators used in wind turbines can often run at two different (but constant) speeds by changing the number of pole pairs of the stator winding.

A squirrel cage induction generator always consumes reactive power. In most cases, this is undesirable, particularly in case of large turbines and weak grids. Therefore, the reactive power consumption of the squirrel cage induction generator is nearly always partly or fully compensated by capacitors in order to achieve a power factor close to one.

Wind power generation versus conventional power generation:

As can be concluded from the above, there are principal differences between wind power on one hand and conventional generation on the other:

- In wind turbines, generating systems different from the synchronous generator used in conventional power plants are applied.
- The prime mover of wind turbines, i.e., the wind, cannot be controlled, and fluctuates randomly. Up to this moment, the generated power of wind turbines is completely determined by the wind speed and not controlled any further.

An additional difference is that the typical size of wind turbines is much lower than that of a conventional power plant. These differences between conventional and wind power generation are reflected in a different interaction with the power system. Also a distinction is made between local and system wide impacts of wind power.

Local impacts of wind power are impacts that occur in the (electrical) vicinity of a wind turbine or Wind Park that can be attributed to a specific turbine or park, i.e., of which the cause can be localized. These effects occur at each turbine or park, independently of the overall wind power penetration level in the system as a whole. When the wind power penetration level in the whole system is increased, the local effects occur in the vicinity of each turbine or park, but when the (electrical) distance is large enough, adding wind power on one location does not affect the local impacts of wind power elsewhere. Only adding turbines locally increase the local impacts. Further, the local impacts differ for the three main wind turbine types.

System wide impacts, on the other hand, are impacts of which the cause cannot be localized. They are a consequence of the application of wind power that can, however, not be attributed to individual turbines or parks. Nevertheless, they are strongly related to the penetration level in the system as a whole. However, in opposition to the local effects, the level of geographical spreading of the wind turbines and the applied wind turbine type are less important.

II. WIND AND SOLAR ENERGY SYSTEM

Due to the increasing concern about the environment and the depletion of natural resources such as fossil fuels, much research is now focused on obtaining new environmentally friendly sources of power. To preserve our planet for the future generations, natural renewable sources are being closely studied and harvested for our energy needs. Wind energy is environmentally friendly, inexhaustible, safe, and capable of supplying substantial amounts of power. However, due to wind’s erratic nature, intelligent control strategies must be implemented to harvest as much potential wind energy as possible while it is available. Because of its advantages, erratic nature, and recent technological advancements in wind turbine aerodynamics and power electronic interfaces, wind energy is considered to be an excellent supplementary energy source. Research to extract the maximum power out of wind energy is an essential part of making wind energy much more viable and attractive.

Among all renewable energy sources, solar power systems also attract more attention because they provide excellent opportunity to generate electricity while greenhouse emissions are reduced. It is also gratifying to lose reliance on conventional electricity generated by burning coal and natural gas. Regarding the endless aspect of solar energy, it is worth saying that solar energy is a unique prospective solution for energy crisis. However, despite all the aforementioned advantages of solar power systems, they do not present desirable efficiency.

***Photovoltaic module and MPPT**:*

The basic structural unit of a solar module is the PV cells. A solar cell converts energy in the photons of sunlight into electricity by means of the photoelectric phenomenon found in certain types of semiconductor materials such as silicon and selenium. A single solar cell can only produce a small amount of power. To increase the output power of a system, solar cells are generally connected in series or parallel to form PV modules. PV module characteristics indicate an exponential and nonlinear relation between the output current and voltage of a PV module. The main equation for the output current of a module is

$$I_o = n_p I_{ph} - n_p I_{rs}\left[\exp\left(k_o \frac{v}{n_s}\right) - 1\right]$$

where I_o is the PV array output current, V is the PV output voltage,
I_{ph} is the cell photocurrent that is proportional to solar irradiation, I_{rs} is the cell reverse saturation current that mainly depends on temperature, K_o is a constant, *ns* represents the number of PV cells connected in series, and n_p represents the number of such strings connected in parallel.

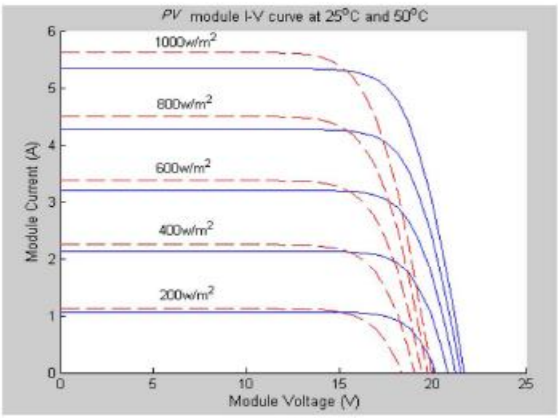
$$I_{Ph} = [I_{scr} + k_i(T - T_r)]\frac{S}{100}$$

where
I_{scr} cell short-circuit current at reference temperature and radiation;
k_I short-circuit current temperature coefficient;
T_r cell reference temperature;
S solar irradiation in milliwatts per square centimeter.

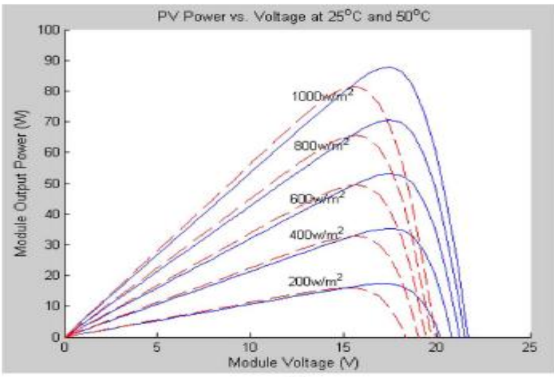
Moreover, the cell reverse saturation current is computed from

$$I_{rs} = I_{rr}[\frac{T}{T_r}]^3 \exp\left(\frac{qE_G}{kA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right)$$

where
T_r cell reference temperature;
I_{rr} reverse saturation at T_r;
E_G band-gap energy of the semiconductor used in the cell.



(a)



(b)

Fig. 2 Maximum power with varying weather conditions (a) *I–V* curves. (b) *P–V* curves.

The resultant curves are shown in Fig. 3.10 (a) and (b). It shows the effect of varying weather conditions on MPP location at *I–V* and *P–V* curves. Fig.3.11 shows the current-versus-voltage curve of a PV module. It gives an idea about the significant points on each *I–V* curve: open-circuit voltage, short-circuit current, and the operating point where the module performs the maximum power (MPP). This point is related to a voltage and a current that are V_{mpp} and I_{mpp}, respectively, and is highly dependent on solar irradiation and ambient temperature.

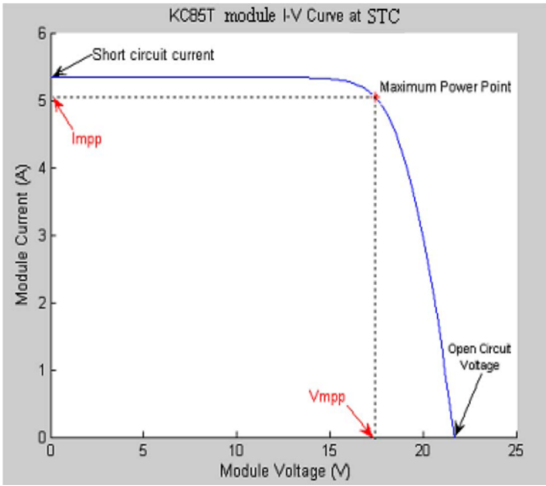


Fig. 3 Current-versus-voltage curve of a PV module

In Fig.3.10, it is clear that the MPP is located at the knee of the *I–V* curve, where the resistance is equal to the negative of differential resistance

$$\frac{V}{I} = -\frac{V}{I}$$

This is following the general rule used in the P&O method,
in which the slope of the PV curve at the MPP is equal to zero

$$\frac{dP}{dV} = 0$$

Above Equation can be rewritten as follows:

$$\frac{dP}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV}$$

$$\frac{dP}{dV} = I + V\frac{dI}{dV}$$

and hence

$$I + V\frac{dI}{dV} = 0$$

which is the basic idea of the IncCond algorithm. One noteworthy point to mention is that (12) or (13) rarely occurs in practical implementation, and a small error is usually permitted. The size of this permissible error (*e*) determines the sensitivity of the system. This error is selected with respect to the swap between steady-state oscillations and risk of fluctuating at a similar operating point. It is suggested to choose a small and positive digit.
Thus, the above equation can be rewritten as

$$I + V\frac{dI}{dV} = e$$

In this project, the value of "*e*" was chosen as 0.002 on the basis of the trial-and-error procedure. According to the MPPT algorithm, the duty cycle (*D*) is calculated. This is the desired duty cycle that the PV module must operate on the next step. Setting a new duty cycle in the system is repeated according to the sampling time.

Maximum power point tracking:

Maximum power point tracking is used to extract maximum power from the sun when it is available. When a source is unavailable or insufficient in meeting the load demands, the other energy source can compensate for the difference. Several hybrid wind/pv power systems with MPPT control have been proposed and discussed. Here an alternative multi-input rectifier structure is proposed for hybrid wind/solar energy systems. The proposed design is a fusion of cuk and sepic converters. The features of the proposed topology are:

1) the inherent nature of these two converters eliminates the need for separate input filters for photovoltaic conversion
2) it can support step up or step down operation for each renewable source
3) MPPT can be realized for each source
4) Individual and simultaneous operation is supported

There is a large number of algorithms that are able to track MPPs. Some of them are simple, such as those based on voltage and current feedback, and some are more complicated, such as perturbation and observation(p&O) algorithm. There is one more algorithm named incremental conductance algorithm method which has several advantages compared to the p&o. They also vary in complexity, sensor requirement, ability to detect multiple local maxima, and their applications.

On the other hand, some MPPTs are more rapid and accurate and, thus, more impressive, which need special design and familiarity with specific subjects such as fuzzy logic or neural network methods. MPPT fuzzy logic controllers have good performance under varying atmospheric conditions and exhibit better performance than the P&O control method; however, the main disadvantage of this method is that its effectiveness is highly dependent on the technical knowledge of the engineer in computing the error and coming up with the rule-based table. It is greatly dependent on how a designer arranges the system that requires skill and experience.

A similar disadvantage of the neural network method comes with its reliance on the characteristics of the PV array that change with time, implying that the neural network has to be periodically trained to guarantee accurate MPPs. The Incremental Conductance method is the one which overrides over the aforementioned drawbacks. In this method, the array terminal voltage is always adjusted according to the MPP voltage. It is based on the incremental and instantaneous conductance of the PV module.

III. PRINCIPLE AND OPERATION OF HYBRID WIND-SOLAR ENERGY SYSTEM

With increasing concern of global warming and the depletion of fossil fuel reserves, many are looking at sustainable energy solutions to preserve the earth for the future generations. Other than hydro power, wind and photovoltaic energy holds the most potential to meet our energy demands. Alone, wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Similarly, solar energy is present throughout the day but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. The common inherent drawback of wind and photovoltaic systems are their intermittent natures that make them unreliable.

However, by combining these two intermittent sources and by incorporating maximum power point tracking (MPPT) algorithms, the system's power transfer efficiency and reliability can be improved significantly.When a source is unavailable or insufficient in meeting the load demands, the other energy source can compensate for the difference. Several hybrid wind/PV power systems with MPPT control have been proposed and discussed. In this project, an alternative multi-input rectifier structure is proposed for hybrid wind/solar energy systems. The proposed design is a fusion of the Cuk and SEPIC converters.

The features of the proposed topology are:
1) the inherent nature of these two converters eliminates the need for separate input filters for PFC
2) it can support step up/down operations for each renewable source
3) MPPT can be realized for each source
4) individual and simultaneous operation is supported.
The circuit operating principles will be discussed in this chapter.

IV. SIMULINK OF THE HYBRID WIND-SOLAR ENERGY SYSTEM

In this chapter the simulink model diagrams are discussed. At first the simulink model of wind energy system is proposed and then the solar energy system. And finally the simulink model of hybrid wind solar energy system is shown and the topology is discussed further.

Simulink model of wind energy system:

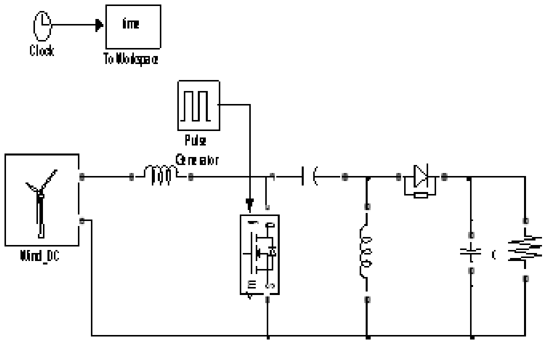


Fig.4 simulink model of wind energy system

Fig.4 illustrates the case when only the wind source is available. In this case, diode *D*2 turns on and the the proposed circuit becomes a SEPIC converter. The power coefficient (Cp) is a nonlinear function that represents the efficiency of the wind turbine to convert wind energy into mechanical energy. It is dependent on two variables, the tip speed ratio (TSR) and the pitch angle. The TSR, λ, refers to a ratio of the turbine angular speed over the wind speed.

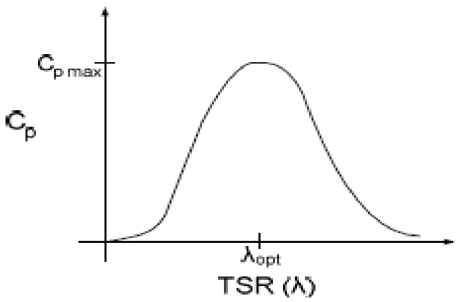


Fig.5 Power Coefficient Curve for a typical wind turbine

The pitch angle, β, refers to the angle in which the turbine blades are aligned with respect to its longitudinal axis. Fig.5 and Fig 6 are illustrations of a power coefficient curve and power curve for a typical fixed pitch (β =0) horizontal axis wind turbine. It can be seen from Fig.5 and 6 that the power curves for each wind speed have a shape similar to that of the power coefficient curve. Because the TSR is a ratio between the turbine rotational speed and the wind speed, it follows that each wind speed would have a different corresponding optimal rotational speed that gives the optimal TSR.

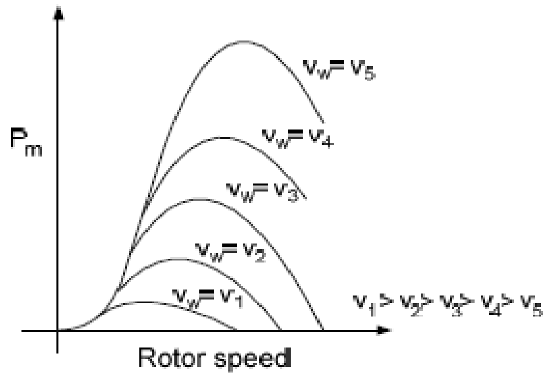


Fig.6 Power Curves for a typical wind turbine

For each turbine there is an optimal TSR value that corresponds to a maximum value of the power coefficient (Cp,max) and therefore the maximum power. Therefore by controlling rotational speed, (by means of adjusting the electrical loading of the turbine generator) maximum power can be obtained for different wind speeds.

Simulink model of solar energy system:

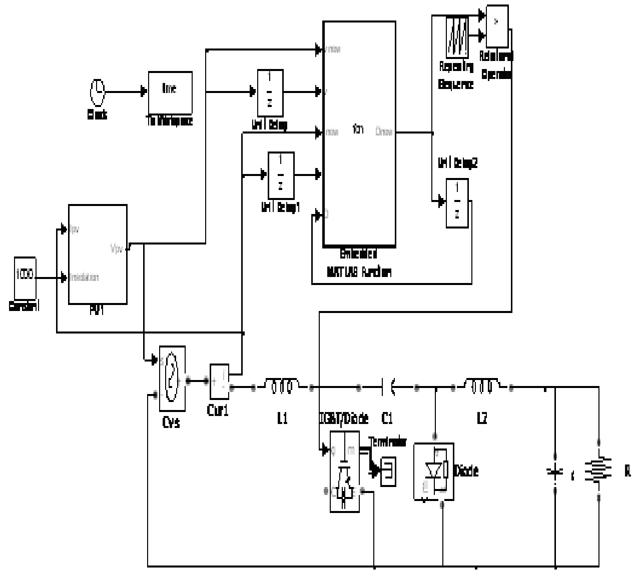


Fig.7 simulink model of solar energy system

This is the simulink model diagram of solar energy system. It is also known as cuk operation mode. The pv panel is connected to the cuk converter fed with incremental conductance algorithm. Both Cuk and buck–boost converters provide the opportunity to have either higher or lower output voltage compared with the input voltage. Although the buck–boost configuration is cheaper than the Cuk one, some disadvantages, such as discontinuous input current, high peak currents in power components, and poor transient response, make it less efficient.

On the other hand, the Cuk converter has low switching losses and the highest efficiency among no isolated dc–dc converters. It can also provide a better output-current characteristic due to the inductor on the output stage. Thus, the Cuk configuration is a proper converter to be employed in designing the MPPT.

The PV array is operating around an open-circuit voltage before connecting the PV to the load through the MPPT circuit. When the PV is connected to the MPPT circuit, it does not operate at the mentioned voltage anymore, and the voltage drops to a new point instantly. This new operating voltage depends on the impedance of the load. In order to move the new operating point to the MPP, the control rules of Incremental Conductance within the direct control loop will assume the function. Solar modules are usually connected together to attain high output power. There are two general types of connecting modules: series and parallel. The type of connection totally depends on the application where large current or voltage is required.

Simulink model of hybrid wind solar energy system:

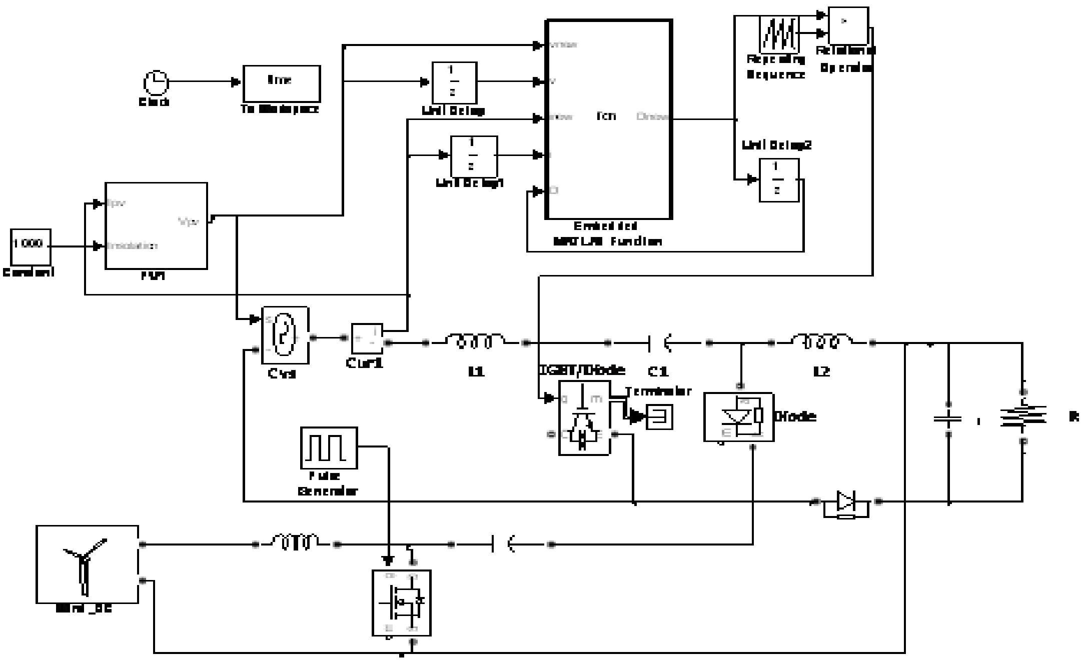


Fig.8 simulink model of hybrid wind solar energy system

A simulink diagram of the proposed rectifier stage of a hybrid energy system is shown in Fig.8, where one of the inputs is PV array fed with incremental conductance algorithm and the other input is a wind generator. The fusion of the two converters is achieved by reconfiguring the two existing diodes from each converter and the shared utilization of the Cuk output inductor by the SEPIC converter.

This configuration allows each converter to operate normally individually in the event that one source is unavailable. When only the wind source is available, diode *D*1 turns off and diode *D*2 turns on; the proposed circuit becomes a SEPIC converter. On the other hand, if only the PV source is available, then *D*2 turns off and *D*1 will always be on and the circuit becomes a Cuk converter. In both cases, both converters have step-up/down capability, which provide more design flexibility in the system if duty ratio control is utilized to perform MPPT control.

V. RESULTS

Detailed simulation studies are carried out on MATLAB/ Simulink platform to verify the operating behavior of the proposed scheme. All the simulations are done in SIMULINK. On the basis of simulation results we can conclude that the proposed multi-input rectifier stage can support individual as well as simultaneous operation.

Simulation results when only solar energy is present:

The waveforms illustrates the system where only the pv source is supplying power to the load.It is also known as CUK converter mode since the cuk converter is used for pv operation.

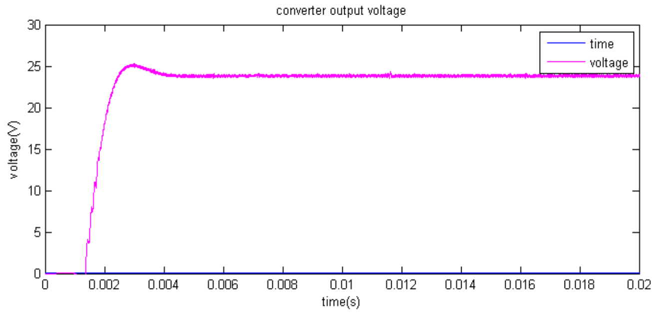


Fig.9 converter output voltage when only pv is active

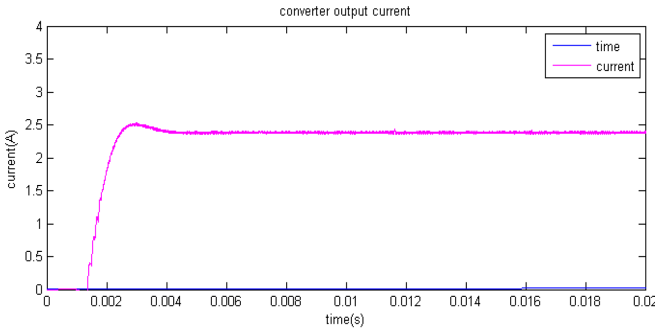


Fig.10 converter output current when only pv is active

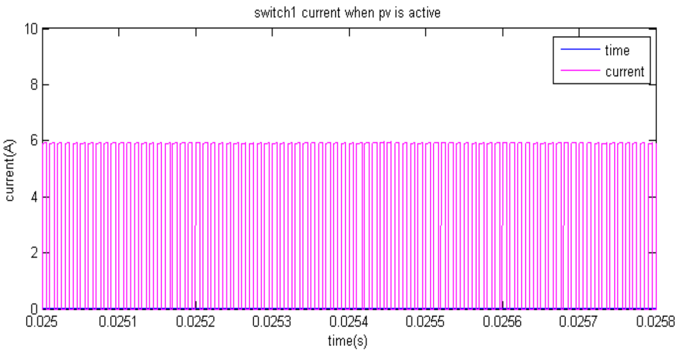


Fig.11 switch 1 current when only pv is active

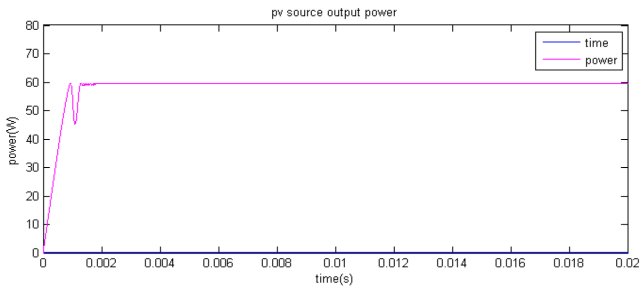


Fig.12 output power when pv is active

Simulation results when only wind energy is present:

The waveform illustrates the system where only the wind energy is supplying power to the load. It is also known as SEPIC converter mode since the sepic converter is used for wind operation.

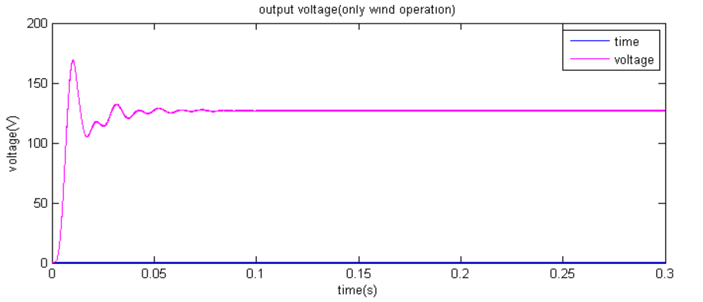


Fig.13 converter output voltage when only wind is active

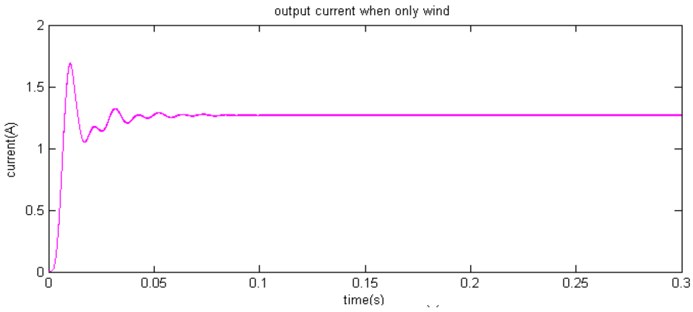


Fig.14 converter output current when only wind is active

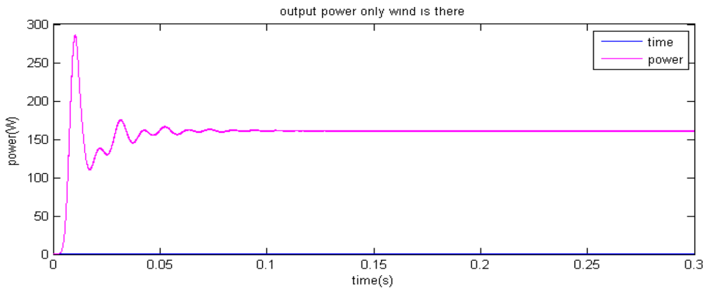


Fig.15 output power when only wind is active

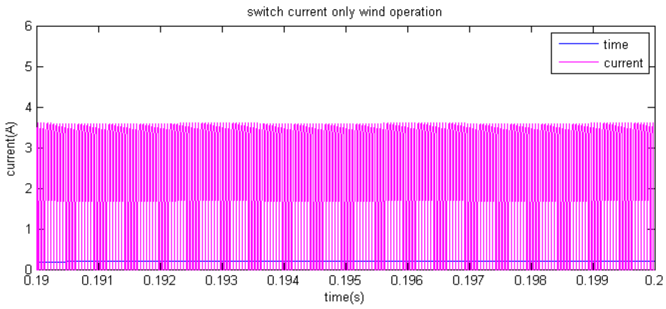


Fig.16 switch 2 current when only wind is active

Simulation results when both wind and solar energy is present:

Figure illustrates the simultaneous operation of the two sources i.e pv and wind. This is known as CUK-SEPIC fusion mode. The diagram of the closed-loop system designed in MATLAB and Simulink is shown which includes the PV module electrical circuit, the Cuk converter, and the MPPT algorithm. The converter components are chosen according to the values. The PV module is modeled using electrical characteristics to provide the output current and voltage of the PV module. The provided current and voltage are fed to the converter and the controller simultaneously. The PI control loop is eliminated, and the duty cycle is adjusted directly in the algorithm. To compensate the lack of PI controller in the proposed system, a small marginal error of 0.002 is allowed.

The output voltage, output current, output power and the switching currents of the system are provided.

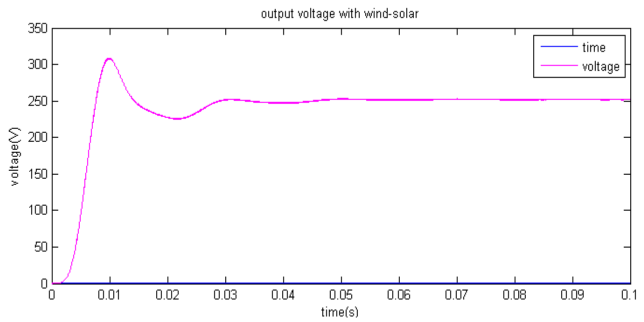


Fig.17 output voltage when both wind and pv is active

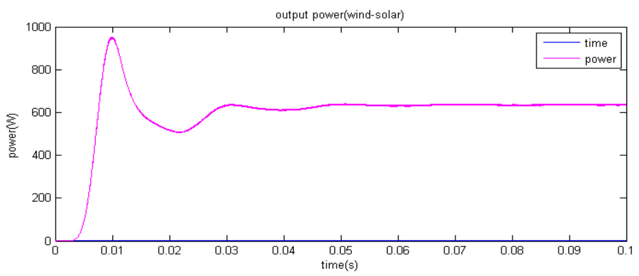


Fig.18 output power when both wind and pv is active

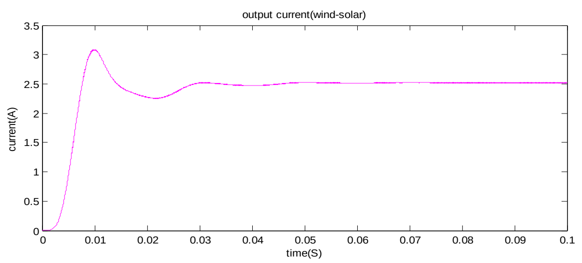


Fig.19 output current when both wind and pv is active

VI. CONCLUSION:

In this project, a new multi-input cuk-sepic converter for hybrid wind and solar energy has been presented. Here a fixed-step-size Incremental Conductance MPPT with direct control method was employed, and the necessity of another control loop was eliminated. The proposed system was simulated and the functionality of the suggested control concept was proven. From the results acquired during the simulations it was confirmed that, with a well-designed system including a proper converter and selecting an efficient and proven algorithm, the implementation of MPPT is simple and can be easily constructed to achieve an acceptable efficiency level of the PV modules. The results also indicate that the proposed control system is capable of tracking the PV array maximum power and thus improves the efficiency of the system and reduces low power loss and system cost. Hence by combining the PV and wind sources and by incorporating MPPT algorithm, the systems power transfer efficiency and reliability is improved significantly.

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AUTHOR'S BIOGRAPHIES

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