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Solar-Wind Hybrid Power Generation System

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Abstract : This paper presents Photovoltaic (PV) and Wind Hybrid renewable energy systems with Cuk DC-DC converter, three-phase inverter, and LC filter. Because of emissions-free and abundant in India, Solar and Wind are suitable for hybrid system. The hybrid system, on the other hand is absolutely intermittent and produces a variable output voltage, causing damage to equipment that require a stable supply. MATLAB/Simulink Software was used to model the hybrid system, which includes a Cuk converter, three-phase inverter, and LC filter. All of the blocks, such as the PV model, the wind model, the Cuk converter, the inverter, and the LC filter, are created independently before being merged into a complete DC voltage hybrid system with the principal grid of electricity. In the simulation, different irradiance values and different wind speeds are employed as input parameters. The results show that the hybrid system has higher output voltage generation reliability than a stand-alone system. A hybrid power generating system with a Cuk DC-DC converter, three phase universal bridge based inverter, and LC filter can reduce output voltage fluctuations.

***IndexTerms* - Hybrid, Solar, Wind, MPPT, Cuk DC-DC Converter, Inverter, PMSG.**

I. INTRODUCTION

Energy is the most important aspect in any country's economic progress. The prices of fossil fuels steeply increasing. Renewable energy sources are the best choice in terms of environmental impacts and play a vital role in reducing the consumption of conventional energy sources [1].

A hybrid power system integrates two or more renewable energy sources. A hybrid power system has several advantages over a standalone system in terms of efficiency, cost, and dependability [1].Solar and wind hybrid power systems were used to generate power in this paper. The majority of alternative energy sources manifest as Solar energy. It can be harnessed in two ways: through solar thermal collectors and through solar photovoltaic systems. Heat energy is converted into electrical energy in solar thermal collectors, whereas light energy is converted into electrical energy in solar photovoltaic systems via the Photovoltaic effect. Solar panels have a higher efficiency of approximately 24.5% [9].

Wind is produced as a by product of solar energy. A wind turbine gets converted kinetic energy into mechanical energy, which is then used to power generators. Wind energy employs various generator types, including the doubly-fed induction generator (DFIG), wound rotor induction generator (WRIG), squirrel-cage induction generator (SCIG) and permanent magnet synchronous generator (PMSG). In this paper Permanent magnet synchronous generator (PMSG) was chosen because of its high efficiency, improved power factor control, and compact size[1]. The Solar energy is fed into a Cuk DC-DC converter, which has an output voltage magnitude that is either greater or less than the input voltage magnitude and is connected to a single-phase AC load via an inverter [1],[2]. The P&O MPPT controller is used to maximise power extraction under all conditions. The Wind turbine subsystem is equipped with a PMSG generator and HCS MPPT Controller searches for the maximum power of the wind turbine. Both systems of renewable energy are connected in parallel to the power through a common single-phase AC load. Both Solar and Wind turbine systems have been modelled and simulated using MATLAB/Simulink Software [1],[2].The figure 1 depicts the pictorial representation of Hybrid System.

Figure 1: Pictorial representation of Hybrid System

II. MATHEMATICAL MODELLING OF PV ARRAY

The PV Array block implements a PV module array. The array is made up of strings of modules connected in parallel, with each string made up of modules connected in series. The PV cell is essentially a P-N junction diode; when sunlight with a specific temperature strikes the cell, electrons cross the barrier, causing a short circuit; thus, electrical power is generated and can be used [3],[4],[5].

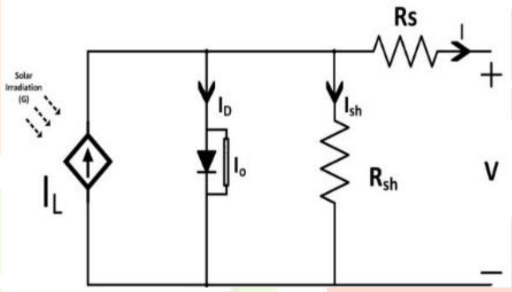

Figure 2: Equivalent Circuit of PV Cell

Figure 2 depicts the solar cell as a dependent current source, with additional series and parallel resistors connected to a diode. It is worth noting that when there is no solar light, the PV cell acts as a load and generates no power. The actual current from the current source (PV cell) is determined by the amount of sunlight that falls on the PV cell (photo-current).

The voltage produced by the PV cell will be affected by an open circuit voltage across the diode and it is [3],[4],[5].

$$V = \frac{NKT}{Q} ln \frac{I_L - I_0}{I_0} + 1 \quad (1)$$

Where
V= PV Cell Open circuited Voltage
N stands for the diode constant 1.50
Boltzmann constant K = $(1.381x\ 10^{-23}\ JK^{-1})$
T = Temperature in kelvin
Q stands for "elementary charge" $(1.602\ x\ 10^{-19}$ Coulomb)
I_o = Maximum current of a diode (A)
The Current generated by light (Radiation) is

$$I_L = \left(\frac{G}{G_{ref}}\right) * (I_{L\,Ref} + \alpha I_{Sc}(T_c - T_{c\,ref})) \quad (2)$$

Where
G = Irradiation instantaneous (W/m^2)
G_{ref}= Standard irradiation =1000 W/m^2
I_{LRef} denotes a reference. Under normal circumstances, photoelectric current 0.15 A
Instant temperature is T_c.
T_{cref} stands Model temp at 298.0 K
αI_{SC} stands SC current temp co-efficient (A/K)=0.0065 AK^{-1}
I_L = Current Generated by the Light = I_{ph} (A)
Reverse saturation current is

$$I_0 = I_{or}\left(\frac{T_c}{T_{cref}}\right)^3 e^{\frac{Q*E_g}{(K*N)*\left[\left(\frac{T_c}{T_{cref}}\right)-\left(\frac{1}{T_c}\right)\right]}} \quad (3)$$

$$I_{or} = \frac{I_{scn}}{e^{\frac{V_{ocn}}{N*V_m}}} \quad (4)$$

Where
I_o = Current Capacity in Reverse
I_{or} = Current Capacity
Eg is the band gap of a silicon diode, which is 1.10 eV.
Current SC ($I_{sh} = I_L$)
Under SC circumstances, the maximum current generated by a cell: Volt = 0.00 V

$$I_{sh} = (I_L - I_0) * \left(e^{\frac{eV}{KT}} - 1\right) A \quad (5)$$

III. MODELLING OF CUK DC-DC CONVERTER

Due to the intermittent nature of the Solar power the output voltage from the solar panel is often less and varies with load, it should be stepped up (or) stepped down and stabilized by a DC-DC converter. The Cuk converter is under the category of Buck – Boost converter. The polarity of Cuk converter's output voltage will be opposite to that of polarity of input voltage[2],[10],[11].
Cuk converters have several benefits over Buck and Boost converters. Since continuous flow of input current from Cuk converter, it is capable of generating ripple free output current. It's output voltage is either greater or lesser than the input voltage value [2],[10],[11].The figure 3 represents the basic structure of a Cuk Converter Topology.

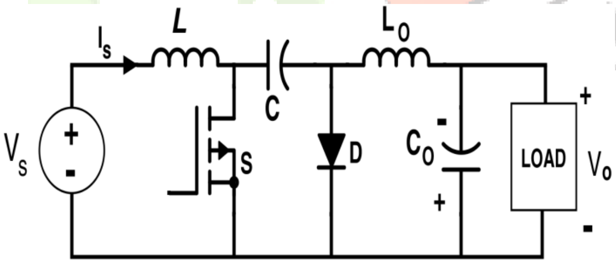

Figure 3: Cuk DC-DC converter

The Cuk converter contains two inductors, two capacitors, one diode, and one switch. The input side looks like the boost converter and output side looks like buck converter in a disconnected inverting manner connected by one capacitor between them.
The input voltage source (V_s) and output voltage source (V_o) are converted into current sources by the two inductors L_1 and L_2. An inductor can be presumed of as a current source on a short time scale as it maintains a constant current. If the capacitor were connected directly to the voltage source, the current would be limited only by the parasitic resistance, resulting in considerable energy loss[2],[10],[11].
The capacitor C_1 is indeed the primary means of storing and transferring energy from the input to the output in the Cuk converter topology. The theoretical transfer function of the Cuk converter, assuming a constant voltage across C is

$$\frac{Vout}{Vin} = -\frac{D}{1-D} \quad (5)$$

where D is the duty cycle.

IV. PERTURB AND OBSERVE (P&O) MPPT ALGORITHM IN SOLAR PV SYSTEM

Maximum power point tracking (MPPT) is a technique commonly used with wind turbines and photovoltaic (PV) solar systems to maximise power extraction under all conditions. To achieve maximum power, MPPT techniques are used to generate the firing pulses to the DC – DC converter[3]. The MPPT algorithm is based on the fact that the derivative of the output power (P) with respect to the panel voltage (V) is equal to zero at the maximum power point. In the P&O method, the module voltage is perturbed on a regular basis, and the corresponding output power is compared to those of the previous perturbing cycle. The algorithm constantly adjusts the electrical operating point by measuring the operating voltage and current of the PV panel and observing the change in power transfer. The perturbation is done by changing the voltage stepwise in a specific direction and observing the power change.

If the change is positive, it is fairly obvious that the MPPT has moved the PV panel's operating point closer to the MPP. Thus the voltage is continued perturbed in the same direction. If the change is negative, the operating point has become less optimal, and the direction of the perturbation must be changed [3],[5].The figure 4 represents the flow chart for P&O MPPT algorithm.

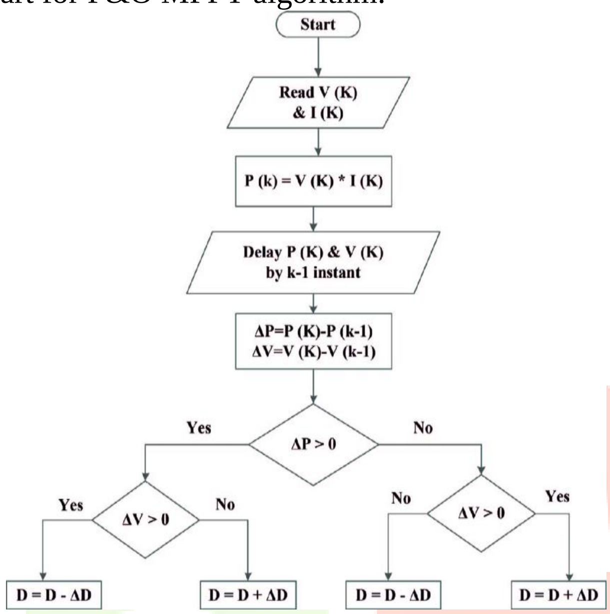

Figure 4: Flow chart for P&O MPPT algorithm

V. PERMANENT MAGNET SYNCHRONOUS MOTOR BASED WIND ENERGY CONVERSION SYSTEMS

Wind energy is one of the fastest growing renewable energy sources, and it flourished in many countries each year. Wind energy is the fastest growing renewable energy source. When air is in motion, its kinetic energy can be converted into mechanical energy, which is then used to energise electrical power generators[7],[12],[13].The mechanical power provided by the wind turbine is expressed by

$$P_w = ½ \rho \pi r^3 V_w^3 C_p \qquad (6)$$

Where ρ = air density=1.225 kg/m^3

r = blade radius in m

V_w = wind velocity in m/s

C_p = power coefficient

Wind energy employs various generator types, including the squirrel-cage induction generator(SCIG), doubly-fed induction generator (DFIG), wound rotor induction generator (WRIG), and permanent magnet synchronous generator (PMSG). Among the classes of wind generators, Permanent magnet synchronous generator (PMSG) is the most popular in full-variable speed wind energy conversion systems (WECS) due to its high-power density and reliability, no need for excitation and gearbox, improved power factor control, compact size and low rotor losses and high efficiency [12],[13].

VI. HILL CLIMBING SEARCH (HCS) MPPT ALGORITHM IN WECS

The output power of a Wind Energy Conversion System is decided by the accuracy with which the peak power points are tracked by the WECS control system's MPPT controller. There are three types of maximum power point algorithms: tip speed ratio control (TSR), power signal feedback control (PSF), and hill-climb search control (HCS). The rotational speed of the generator is regulated in the TSR control method in order to keep the TSR at an optimum value where its power extracted is maximum[6],[[7],[14],[15]. Wind speed and turbine speed must always be measured or estimated, in addition to determining the optimum TSR of the turbine to extract the most power.The PSF control has entailed insights of the wind turbine's maximum power curve, as well as the tracking of this curve through its control mechanisms. In this method, reference power is generated using a recorded maximum power curve or the mechanical power equation of the wind turbine, with wind speed or rotor speed as an input parameter.
The HCS control algorithm is continuously striving for the maximum power of the wind turbine. It is primarily determined by the location of the operating point and the relationship between changes in power and speed, and it calculates the desired optimum signal in order to reach the maximum power point [14],[15],[16]. The HCS MPPT algorithm is implemented by distributing a control variable in some step-size increments and observing the changes in the objective function until the slope goes to zero[15],[16].The figure 5 represents the Flow chart for HCS MPPT algorithm

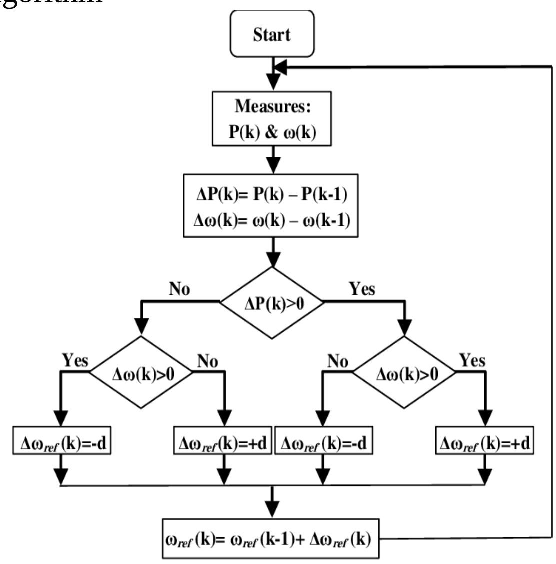

Figure 5: Flowchart for HCS MPPT algorithm

VII.THREE-PHASE INVERTER AND FILTER

Three-phase PWM inverter is used to convert DC power into three-phase AC power and to reduce the lower order harmonics. Higher-order harmonics can be easily filtered by using the LC filter.

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VIII.SIMULATION MODEL OF PV ARRAY

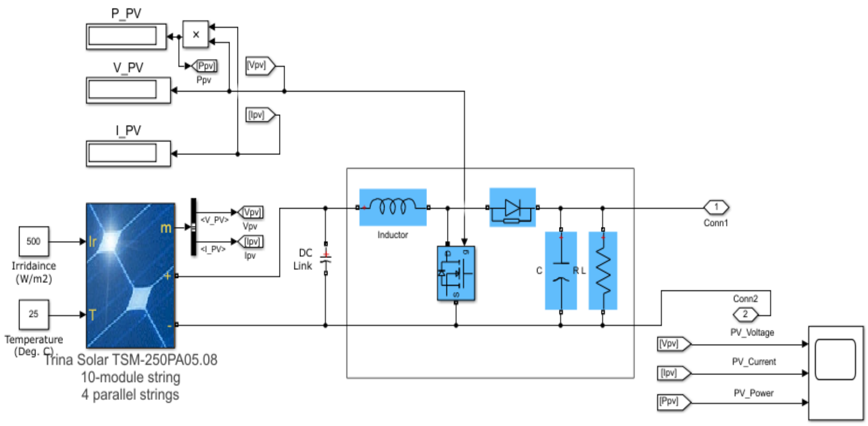

Figure 6: Simulation Model of PV array

The maximum power is calculated from the voltage and current. The output curves are shown through the scope block with respect to the time.

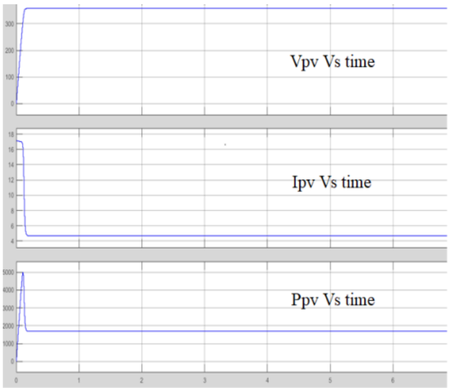

Figure 7: Outputs curves for the PV array

IX.SIMULATION MODEL OF WIND TURBINE GENERATOR

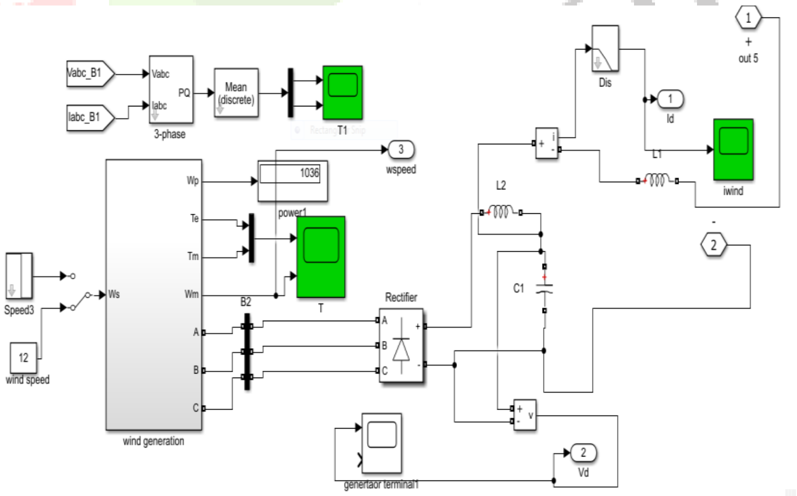

Figure 8: Simulation Model of Wind System

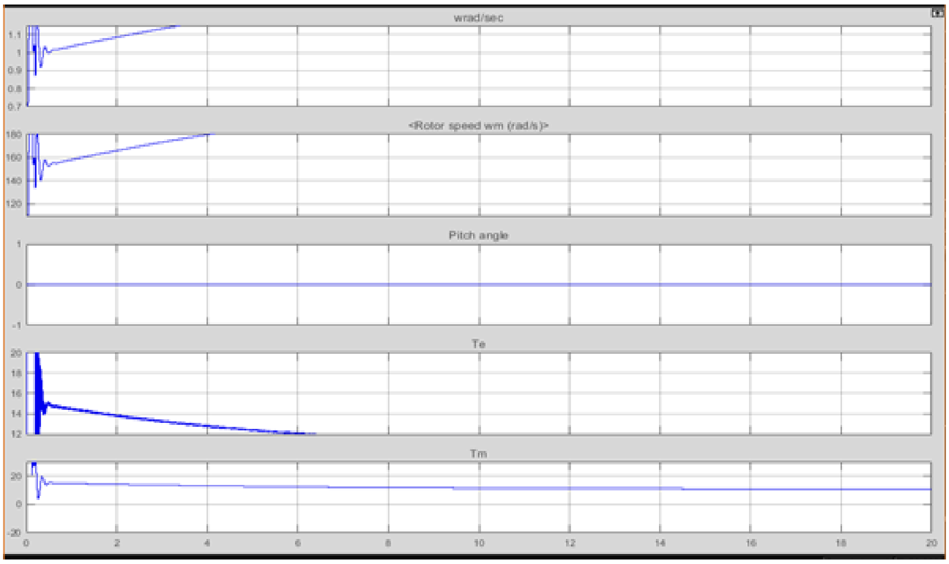

Figure.9: Outputs curves of Wind system

X. INTEGRATED SOLAR-WIND SYSTEM MODEL IN MATLAB/SIUMLINK

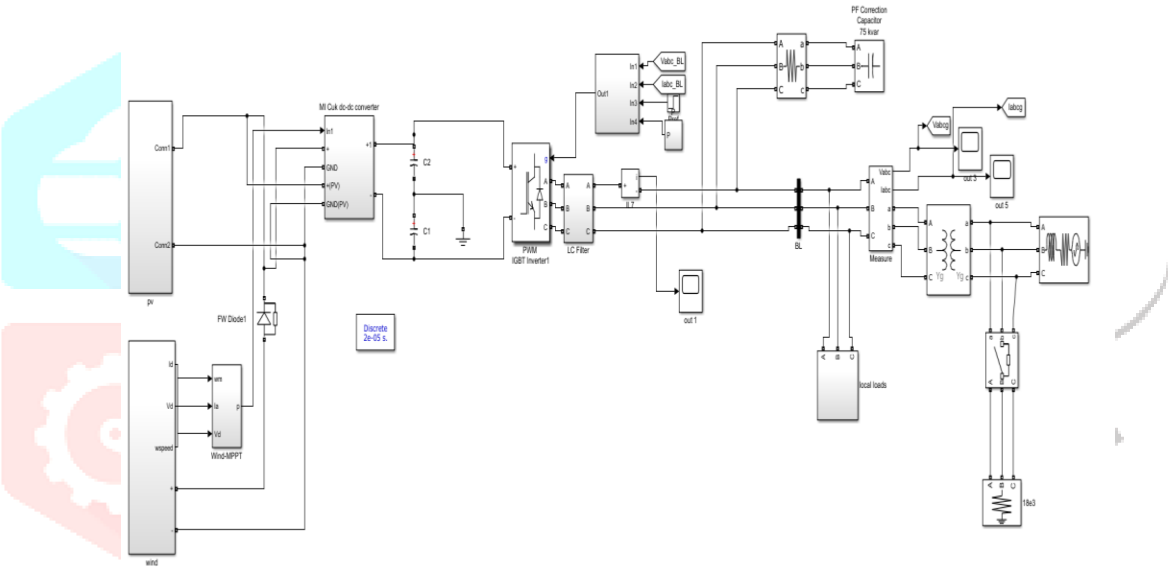

Figure 10: Integrated solar-wind system model in MATLAB/Simulink

The simulation model of the PV array, Wind System is integrated with the wind MPPT controller and is given to the three-phase source through three-phase inverter and filter.

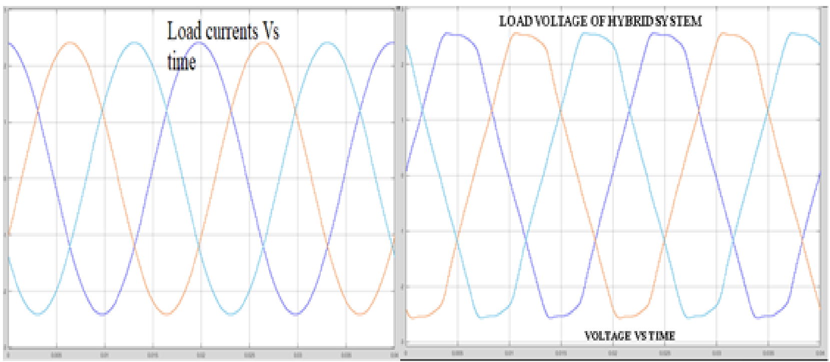

Figure 11: Load currents and Voltages for the Hybrid System

XI. CONCLUSION

Solar-Wind Hybrid power generation system is the best way to generate more power since the load current and load voltage of the hybrid power system is increased when compared to a single source. The power generated by the hybrid system was almost equal to the sum of the power generated by the Solar and the Wind systems. Cuk DC-DC converter acted as the voltage regulator to control the intermittent behaviour of Solar-Wind Hybrid System. P&O MPPT controller in solar and HCS MPPT controller in Wind were applied to maximize power extraction under all conditions. The wind turbine subsystem is outfitted with a PMSG generator because of its higher efficiency and compactness. Thee-phase PWM inverter mitigate the voltage fluctuations and lower order harmonics were suppressed by the LC filter and has given to three-phase AC load.

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