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A Novel Hybrid Wind Energy Control Scheme for a Rural Based Telecom Station

Chandana.N
M.Tech (Power Electronics)
Department of EEE
Kuppam Engineering College,
Kuppam, Chittoor,
Andhra Pradesh.

V.Sekhar, ME, (Ph.D), LMISTE, LMSESI, AMIE.,
Associate Professor
Department of EEE
Kuppam Engineering College,
Kuppam, Chittoor.

Dr. Venugopal.N, Ph.D, M.E, B.E
HoD
Department of EEE
Kuppam Engineering College,
Kuppam, Chittoor,
Andhra Pradesh.

Abstract:

In present Cellular network operators are always seeking to improve the rural network demand, this makes the potential customers in remote rural areas. However, because of load demand, non-renewable energy resources (fossil fuel) pose major challenges to cellular network operators. The specific power supply needs for remote based telecom stations (RBTSs) such as economical, highly efficient and reliable which can be satisfied by taking advantage of the technological advances in renewable sources. In order to ensure continuous supply of power suitable storage technology is used as backup by effective control logic.

In this paper, the sustainability of a 4-kW hybrid of wind and battery system is investigated for meeting the requirements of a 3-kW remote based telecom stations by integration of MPPT logic and pitch control logic. A charge controller for battery bank based on turbine maximum power point tracking and battery state of charge is developed to ensure controlled charging and discharging of battery. The mechanical safety of the RBTSs is assured by means of pitch control logic. The Battery SOC and pitch control schemes are integrated and the efficacy is validated by testing it with various load and wind profiles in MATLAB/SIMULNIK. Finally we are going to find the wind turbine and battery parameters under the influence of gradual variation, step variation and arbitrary variation of wind speed.

Index Terms— ***Maximum power point tracking PI base error accuracy, turbine pitch control logic, Battery storage capacity, rural based telecom stations (RBTSs).***

INTRODUCTION

Energy is the considered to be the pivotal input for development. At present owing to the depletion of available conventional resources and concern regarding environmental degradation, the renewable sources are being utilized to meet the ever increasing energy demand. Due to a relatively low-cost of electricity production wind energy is considered tube one of the potential sources of clean energy for the future. But the nature of wind flow is stochastic. So rigorous testing into be carried out in laboratory to develop efficient control strategy for wind energy conversion system (WECS). The study owes and the associated controllers are, thus, becoming more and more significant with each passing day. Nowadays, many stand-alone loads are powered by renewable source of energy.

With this renewed interest in wind technology for stand-alone applications, a great deal of research is being carried out for choosing a suitable generator for stand-alone WECS. A detailed comparison between asynchronous and synchronous generators for wind farm application is made. The major advantage of asynchronous machine is that the variable speed operation allows extracting maximum power from WECS and reducing the torque fluctuation. Induction generator with a lower unit cost, inherent robustness, and operational simplicity is considered as the most viable option as wind turbine generator (WTG) for off grid applications. However, the induction generator

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requires capacitor banks for excitation at isolated locations. The excitation phenomenon of self-excited induction generator (SEIG) is explained. The power output of the SEIG depends on the wind flow which by nature is erratic. Both amplitude and frequency of the SEIG voltage vary with wind speed. Such arbitrarily varying voltage when interfaced directly with the load can give rise to flicker and instability at the load end.

Wind power:

Wind is abundant almost in any part of the world. Its existence in nature caused by uneven heating on the surface of the earth as well as the earth's rotation means that the wind resources will always be available. The conventional ways of generating electricity using non renewable resources such as coal, natural gas, oil and so on, have great impacts on the environment as it contributes vast quantities of carbon dioxide to the earth's atmosphere which in turn will cause the temperature of the earth's surface to increase, known as the green house effect. Hence, with the advances in science and technology, ways of generating electricity using renewable energy resources such as the wind are developed. Nowadays, the cost of wind power that is connected to the grid is as cheap as the cost of generating electricity using coal and oil. Thus, the increasing popularity of green electricity means the demand of electricity produced by using non renewable energy is also increased accordingly.

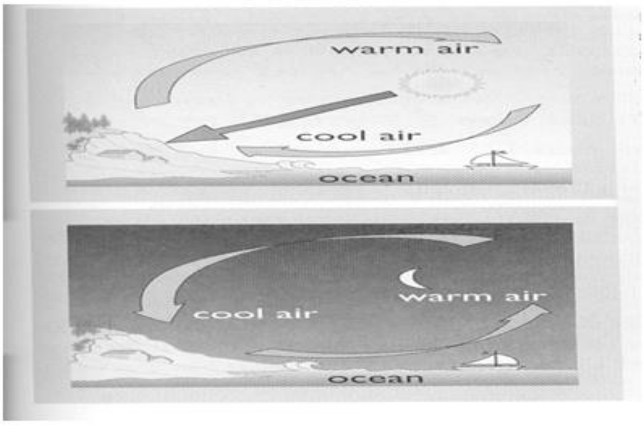

Fig: Formation of wind due to differential heating of land and sea

Features of wind power systems:

There are some distinctive energy end use features of wind power systems

i. Most wind power sites are in remote rural, island or marine areas. Energy requirements in such places are distinctive and do not require the high electrical power.

ii. A power system with mixed quality supplies can be a good match with total energy end use i.e. the supply of cheap variable voltage power for heating and expensive fixed voltage electricity for lights and motors.

iii. Rural grid systems are likely to be weak (low voltage 33 KV). Interfacing a Wind Energy Conversion System (WECS) in weak grids is difficult and detrimental to the workers' safety.

iv. There are always periods without wind. Thus, WECS must be linked energy storage or parallel generating system if supplies are to be maintained.

Power from the Wind:

Kinetic energy from the wind is used to turn the generator inside the wind turbine to produce electricity. There are several factors that contribute to the efficiency of the wind turbine in extracting the power from the wind. Firstly, the wind speed is one of the important factors in determining how much power can be extracted from the wind. This is because the power produced from the wind turbine is a function of the cubed of the wind speed. Thus, the wind speed if doubled, the power produced will be increased by eight times the original power. Then, location of the wind farm plays an important role in order for the wind turbine to extract the most available power form the wind.

The next important factor of the wind turbine is the rotor blade. The rotor blades length of the wind turbine is one of the important aspects of the wind turbine since the power produced from the wind is also proportional to the swept area of the rotor blades i.e. the square of the diameter of the swept area.

The relationship between the powers produced by the wind source and the velocity of the wind and the rotor blades swept diameter is shown below.

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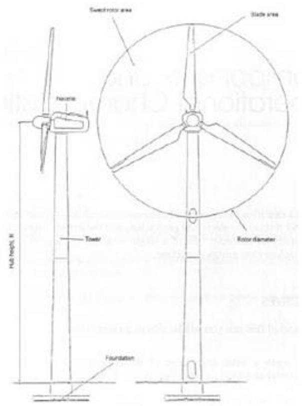
$$P_{wind} = \frac{\pi}{8} d D^2 v_{wind}^3$$

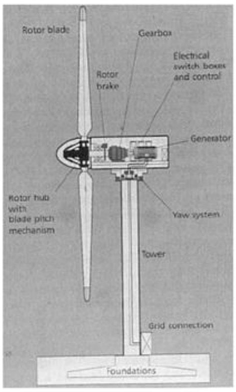
Wind Turbines:

There are two types of wind turbine in relation to their rotor settings. They are:

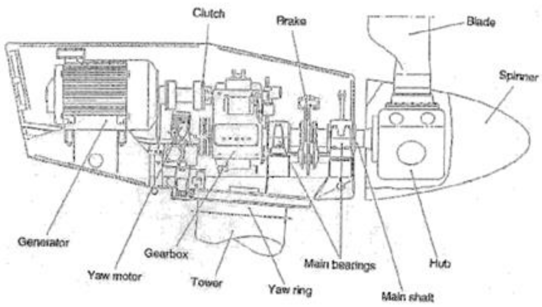
- Horizontal-axis rotors, and
- Vertical-axis rotors.



(a)



(b)



(c)

Figs: (a) Main Components of Horizontal-axis Wind Turbine (b) Cross-section of a Typical Grid-connected Wind Turbine (c) Cross-section of a Nacelle in A Grid-connected Wind Turbine

Tower:

It is the most expensive element of the wind turbine system. The lattice or tubular types of towers are constructed with steel or concrete. Cheaper and smaller towers may be supported by guy wires. The major components such as rotor brake, gearbox, electrical switch boxes, controller, and generator are fixed on to or inside nacelle, which can rotate or yaw according to wind direction, are mounted on the tower. The tower should be designed to withstand gravity and wind loads. The tower has to be supported on a strong foundation in the ground. The design should consider the resonant frequencies of the tower do not coincide with induced frequencies from the rotor and methods to damp out if any. If the natural frequency of the tower lies above the blade passing frequency, it is called stiff tower and if below is called soft tower.

Rotor:

The aerodynamic forces acting on a wind turbine rotor is explained by aerofoil theory. When the Aero foil moves in a flow, a pressure distribution is established around the symmetric aerofoil as shown in the fig. a reference line from which measurements are made on an aerofoil section is referred to as chord line and the length is known as chord.

Rotor speed:

Low speed and high-speed propeller are the two types of rotors. A large design tip speed ratio would require a long, slender blade having high aspect ratio. A low design tip speed would require a short, flat blade. The low speed rotor runs with high torque and the high-speed rotor runs with low torque. The wind energy converters of the same size have essentially the same power output, as the power output depends on rotor area. The low speed rotor has curved metal plates. The number of blades, weight, and difficulty of balancing the blades makes the rotors to be typically small.

Rotor alignment:

The alignment of turbine blades with the direction of wind is made by upwind or downwind rotors. Upwind rotors face the wind in front of the vertical tower and have the advantage of somewhat avoiding the wind shade effect from the presence of the tower. Upwind rotors need a yaw mechanism to keep the rotor axis aligned with the direction of the wind. Downwind rotors are placed on the lee side of the tower. A great disadvantage in this design is the fluctuations in the wind power due to the rotor passing through the wind shade of the tower which gives rise to more fatigue loads. Downwind rotors can be built without a yaw mechanism, if the rotor and nacelle can be designed in such a way that the nacelle will follow the wind passively.

Generator:

Electricity is an excellent energy vector to transmit the high quality mechanical power of a wind turbine. Generator is usually 95% efficient and transmission losses should be less than 10%. The frequency and voltage of transmission need not be standardized, since the end user requirements vary. There are already many designs of wind/ electricity systems including a wide range of generators. The distinctive features of wind/electricity generating systems are:

(i) Wind turbine efficiency is greatest if rotational frequency varies to maintain constant tip speed ratio, yet electricity generation is most efficient at constant or near constant frequency.

(ii) Mechanical control of turbine to maintain constant frequency increases complexity and expense. An alternative method, usually cheaper and more efficient is to vary the electrical load on the turbine to control the rotational frequency.

(iii) The optimum rotational frequency of a turbine in a particular wind speed decreases with increase in radius in order to maintain constant tip speed ratio. Thus, only small turbines of less than 2 m radius can be coupled directly to generators. Larger machines require a gearbox to increase the generator drive frequency.

(iv) Gearboxes are relatively expensive and heavy. They require maintenance and can be noisy. To overcome this problem, generators with a large number of poles are being manufactured to operate at lower frequency.

(v) The turbine can be coupled with the generator to provide an indirect drive through a mechanical accumulator (weight lifted by hydraulic pressure) or chemical storage (battery). Thus, generator control is independent of turbine operation.

The generators used with wind machines are
i) Synchronous AC generator
ii) Induction AC generator and
iii) Variable speed generator

Yaw system:

It turns the nacelle according to the actuator engaging on a gear ring at the top of the tower. Yaw control is the arrangement in which the entire rotor is rotated horizontally or yawed out of the wind. During normal operation of the system, the wind direction should be perpendicular to the swept area of the rotor. The yaw drive is controlled by a slow closed- loop control system. The yaw drive is operated by a wind vane, which is usually mounted on the top of the nacelle sensing the relative wind direction, and the wind turbine controller. In some designs, the nacelle is yawed to attain reduction in power during high winds.

Control systems:

A wind turbine power plant operates in a range of two characteristic wind speed values referred to as Cut in wind speed and Cut out wind speed . The turbine starts to produce power at Cut in wind speed usually between 4 and 5 m/s. Below this speed, the turbine does not generate power. The turbine is stopped at Cut out wind speed usually at 25 m/s to reduce load and prevent damage to blades. They are designed to yield maximum power at wind speeds that lies usually between 12 and 15 m/s. It would not be economical to design turbines at strong winds, as they are too rare. However, in case of stronger winds, it is necessary to waste part of the excess energy to avoid damage on the wind turbine. Thus, the wind turbine needs some sort of automatic control for the protection and operation of wind turbine. The functional capabilities of the control system are required for:

1. Controlling the automatic startup
2. Altering the blade pitch mechanism
3. Shutting down when needed in the normal and abnormal condition
4. Obtaining information on the status of operation, wind speed, direction and power production for monitoring purpose.

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Induction generator:

An induction generator is a type of electrical generator that is mechanically and electrically similar to a polyphase induction motor. Induction generators produce electrical power when their shaft is rotated faster than the synchronous frequency of the equivalent induction motor. Induction generators are often used in wind turbines and some micro hydro installations due to their ability to produce useful power at varying rotor speeds. Induction generators are mechanically and electrically simpler than other generator types. They are also more rugged, requiring no brushes or commutators.

Induction generators are not self-exciting, meaning they require an external supply to produce a rotating magnetic flux. The external supply can be supplied from the electrical grid or from the generator itself, once it starts producing power. The rotating magnetic flux from the stator induces currents in the rotor, which also produces a magnetic field. If the rotor turns slower than the rate of the rotating flux, the machine acts like an induction motor. If the rotor is turned faster, it acts like a generator, producing power at the synchronous frequency.

Induction Machine Analysis

The following figure shows the torque vs speed characteristic of typical squirrel cage induction machine.

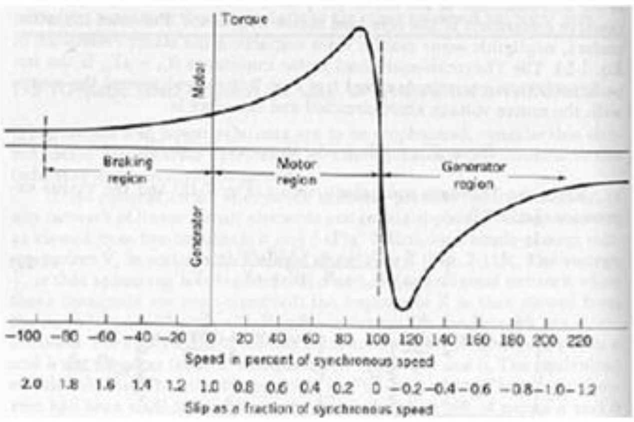
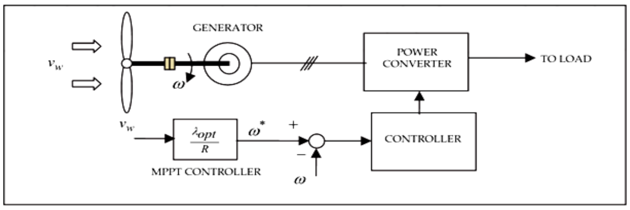


Fig: Torque vs. Speed Characteristics of Squirrel-cage Induction Generator

Maximum power point tracking control

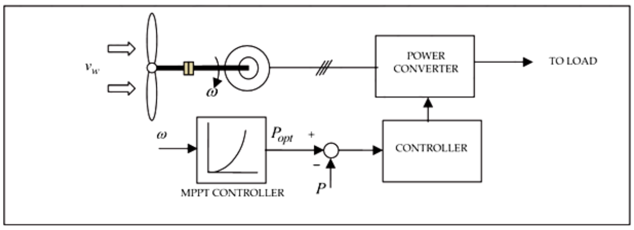
Wind generation system has been attracting wide attention as a renewable energy source due to depleting fossil fuel reserves and environmental concerns as a direct consequence of using fossil fuel and nuclear energy sources. Wind energy, even though abundant, varies continually as wind speed changes throughout the day. Amount of power output from a WECS depends upon the accuracy with which the peak power points are tracked by the MPPT controller of the WECS control system irrespective of the type of generator used.

The maximum power extraction algorithms researched so far can classified into three main control methods, namely tip speed ratio (TSR) control, power signal feedback (PSF) control and hill-climb search (HCS) control.



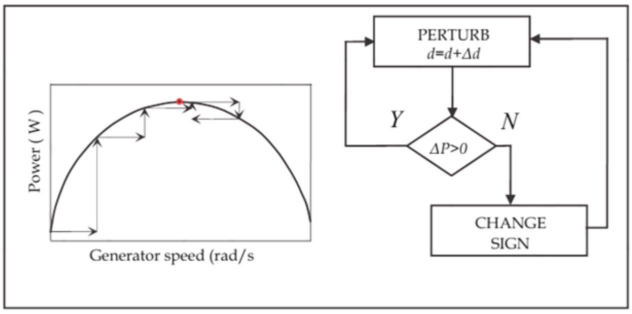
Tip speed ratio control of WECS.

In PSF control, it is required to have the knowledge of the wind turbines maximum power curve, and track this curve through its control mechanisms. The maximum power curves need to be obtained via simulations or off-line experiment on individual wind turbines. In this method, reference power is generated either using a recorded maximum power curve or using the mechanical power equation of the wind turbine where wind speed or the rotor speed is used as the input. Fig. 3 shows the block diagram of a WECS with PSF controller for maximum power extraction.

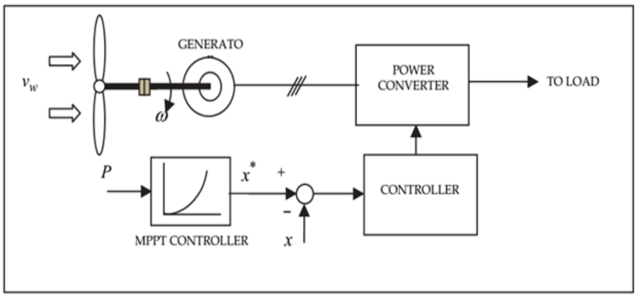


Power signal feedback control.

The HCS control algorithm continuously searches for the peak power of the wind turbine. It can overcome some of the common problems normally associated with the other two methods. The tracking algorithm, depending upon the location of the operating point and relation between the changes in power and speed, computes the desired optimum signal in order to drive the system to the point of maximum power. Fig shows the principle of HCS control and shows a WECS with HCS controller for tracking maximum power points.



HCS Control Principle.



WECS with hill climb search control.

MPPT control methods for PMSG based WECS

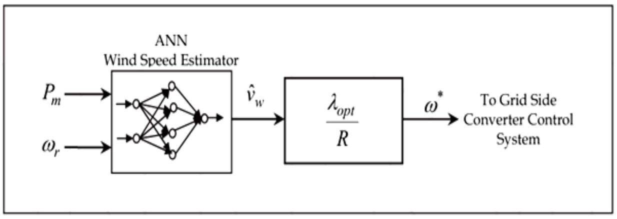
Permanent Magnet Synchronous Generator is favored more and more in developing new designs because of higher efficiency, high power density, availability of high-energy permanent magnet material at reasonable price, and possibility of smaller turbine diameter in direct drive applications. Presently, a lot of research efforts are directed towards designing of WECS which is reliable, having low wear and tear, compact, efficient, having low noise and maintenance cost; such a WECS is realizable in the form of a direct drive PMSG wind energy conversion system.

Tip speed ratio control

A wind speed estimation based TSR control is proposed in [3] in order to track the peak power points. The wind speed is estimated using neural networks, and further, using the estimated wind speed and knowledge of optimal TSR, the optimal rotor speed command is computed. The generated optimal speed command is applied to the speed control loop of the WECS control system.

The PI controller controls the actual rotor speed to the desired value by varying the switching ratio of the PWM inverter. The control target of the inverter is the output power delivered to the load. This WECS uses the power converter configuration shown in Fig. 6 (a). The block diagram of the ANN-based MPPT controller module is shown in Fig. 7. The inputs to the ANN are the rotor speed brand mechanical power Pm. The Pmis obtained using the relation.

$$P_m = \omega_r \left(J \frac{d\omega_r}{dt} \right) + P_e$$



ANN-based MPPT control module of turbine rotor speed.

RESULTS AND DISCUSSIONS:

A WECS needs to be efficient to ensure continuous power flow to the load. The effectiveness can be achieved by integrating the hybrid wind-battery system with suitable control logic. This includes the charge control logic and the pitch control logic. The charge controller regulates the charging and discharging rate of the battery bank while the pitch controller controls the WT action during high wind speed conditions or in case of a power mismatch. Both the control strategy are integrated with the hybrid system and simulated with various wind profiles to validate the efficacy of

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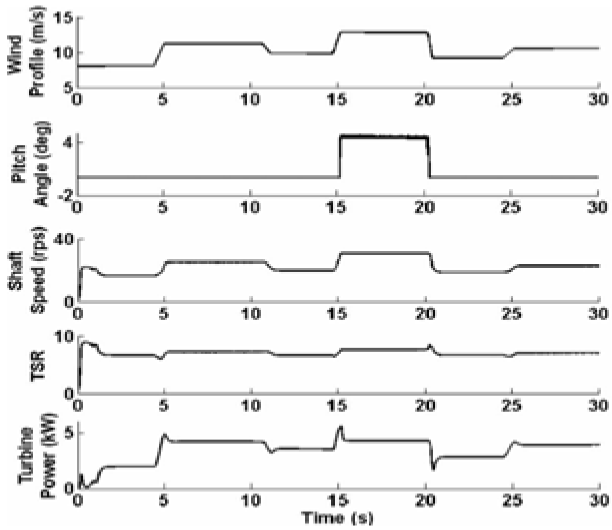
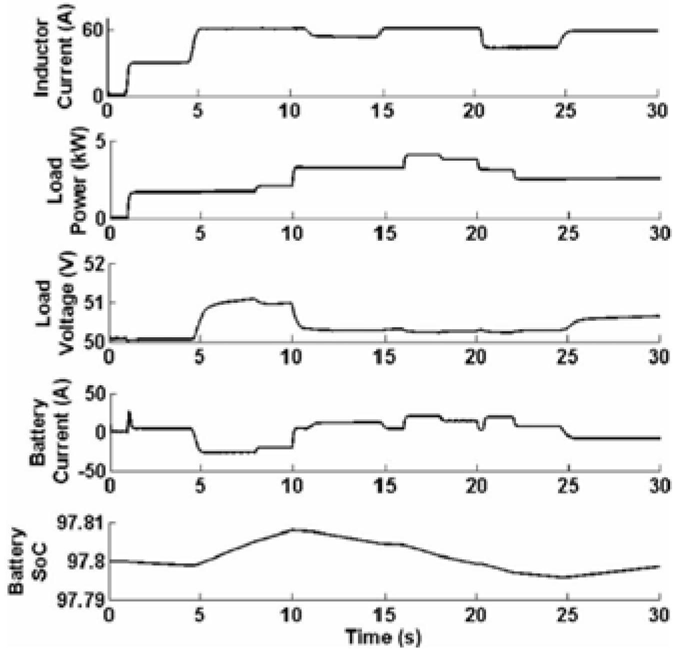
the system. The system is connected to a load profile varying in steps from 0 to 4 kW. The WT parameters like shaft speed, TSR, blade pitch and output power are analyzed with variation in wind speed conditions. The current profile of the converter, load, and the battery are also monitored with the wind profile. To ensure uninterrupted power flow, load demand is given more priority over battery charging. The WT and battery parameters are observed for the following wind profiles.

1) Gradual rise and fall in wind speed.
2) Step variation in wind speed.
3) Arbitrary variation in wind speed.

A gradual rise and fall in wind speed as shown in Fig. 8(a)is applied to the WT. The wind speed gradually rises from 8 to12 m/s in 15 s and then falls to 8 m/s in the next 15 s. The WT parameters and the current profile of the converter, load and the battery are observed in Fig. 8(a) and (b). Further the efficacy of the complete control scheme is validated with a step variation in wind profile and an arbitrary varying wind speed. The variation of the wind profile in step from 8 to 12 m/s is shown in Fig. 9(a)while the arbitrary variation in wind speed from 6 to 14 m/s is highlighted in Fig 10(a). The response of WT parameter and the current profiles with respect to step variations and arbitrary variations are shown in Figs. 9 and 10, respectively. The results also demonstrate the change in battery SoC for all possible wind profiles.



(a)



(b)

Fig.9. (a) WT and (b) battery parameters under the influence of step variation of wind speed.

From Figs 8–10, it is observed, that when the wind speed is below the rated value (10 m/s) the MPPT scheme regulates the TSR of WT at its optimum value irrespective of the variation in wind profile. Thus maximum power is extracted from WECS at all wind speeds to meet the load requirement and charge the battery bank. But, the wind power is not always sufficient to meet the load demand and charge the battery in CC mode. In such situations the system first meets the load requirement and charges the battery bank at a reduced rate. Moreover, when the wind power is not adequate as per the load demand, the battery discharges to meet the deficit. The battery Sock increases during charging but decreases while discharging. However, the charge controller ensures that the battery current during charging or discharging never exceeds 40 A. The pitch angle of WT is maintained at zero deg at wind speed below 10 m/s. But the pitch controller is activated as the wind speeds exceeds its rated limit. The increase in the pitch angle limits the power and speed output within the safe limits of WT operation. The response of WT and

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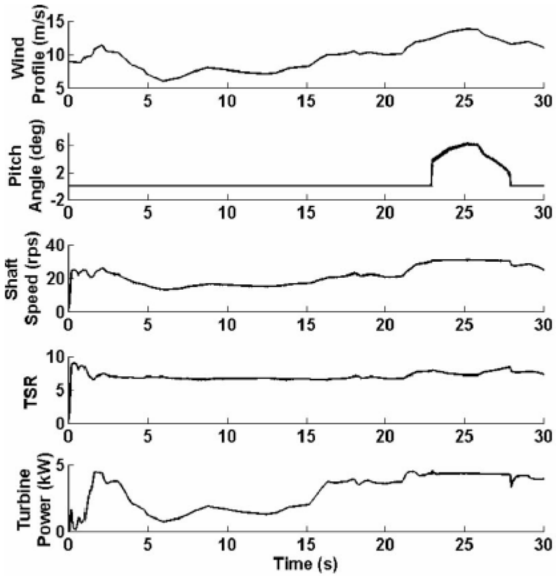
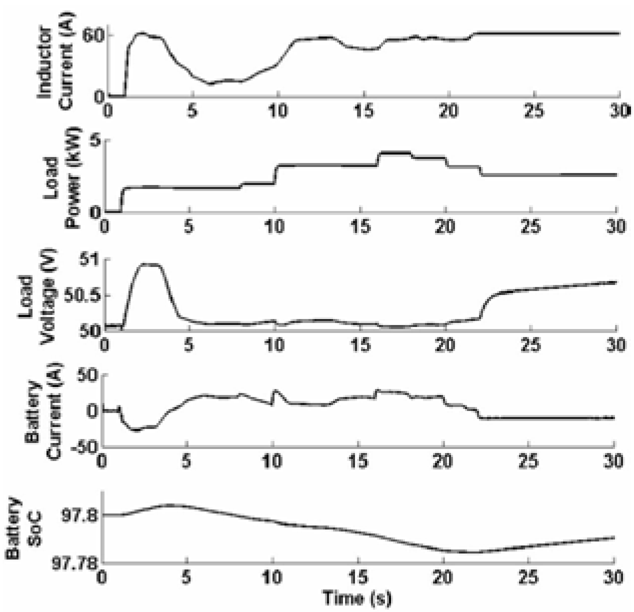
currents for all possible variations in wind profile indeed prove the efficacy of the proposed control logic for the hybrid wind–battery system.



(a)

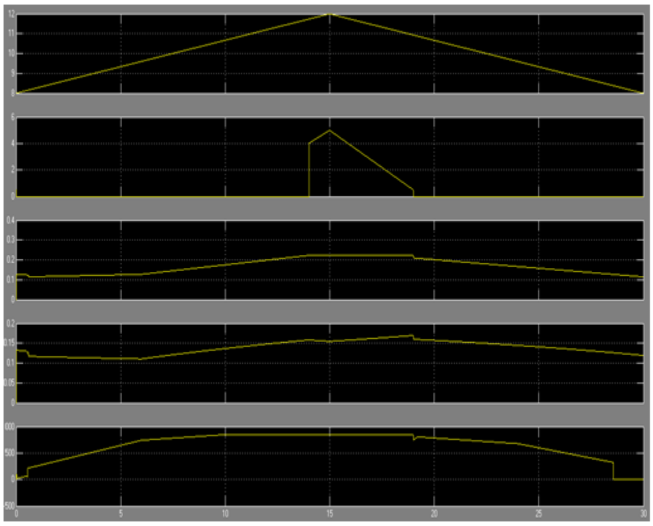


(b)

Fig. 10. (a) WT and (b) battery parameters under the influence of arbitrary variation of wind speed.

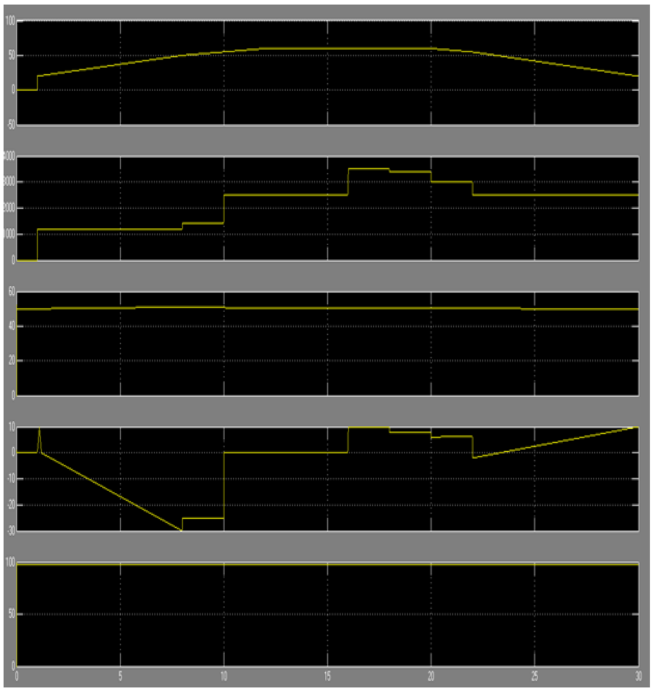
Simulation Results:

Wind turbine parameters under the influence of gradual variation of wind speed



The wind turbine parameters are Wind profile (m/s), Pitch angle (deg), Shaft speed (rps), Turbine power (kw) are taken on Y-axis and time taken on X-axis in secs

Battery parameters under the influence of gradual variation of wind speed



The battery parameters are Inductor current (A), Load power (kw), Battery voltage (v), Battery current (A),Battery SOC are taken as Y-axis and time in secs are taken as X-axis

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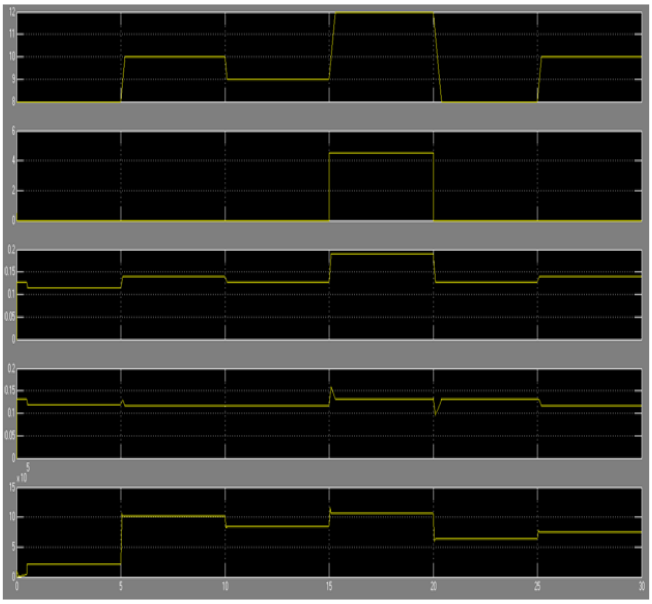
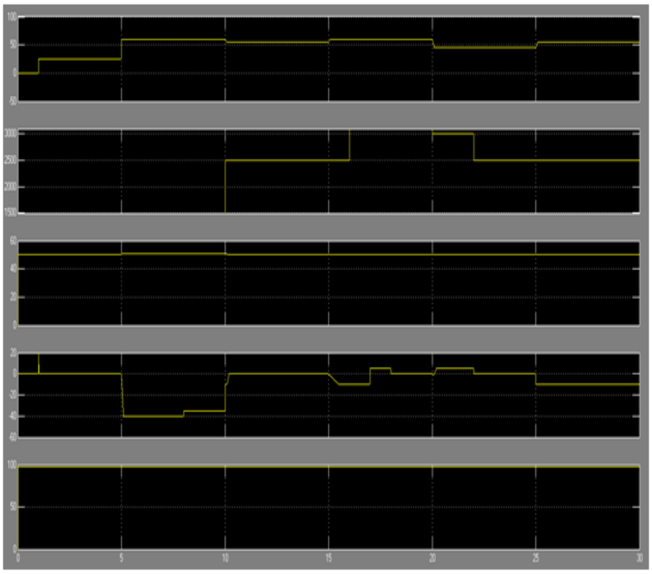
Wind turbine parameters under the influence of step variation of wind speed



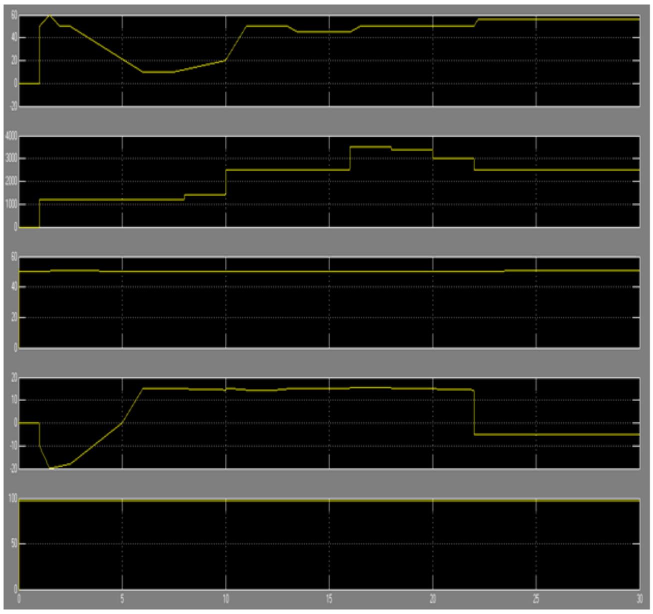
The wind turbine parameters are Wind profile (m/s), Pitch angle (deg), Shaft speed (rps), Turbine power (kw) are taken on Y-axis and time taken on X-axis in secs

Battery parameters under the influence of step variation of wind speed



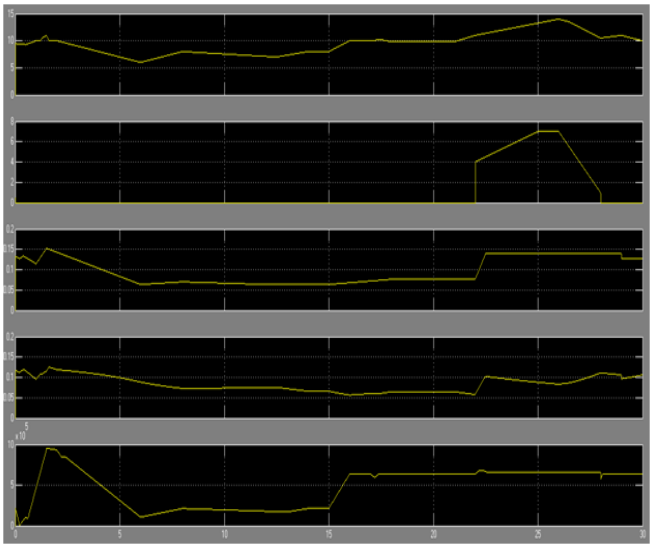
The battery parameters are Inductor current (A), Load power (kw), Battery voltage (v), Battery current (A),Battery SOC are taken as Y-axis and time in secs are taken as X-axis

Battery parameters under the influence of arbitrary variation of wind speed



The battery parameters are Inductor current (A), Load power (kw), Battery voltage (v), Battery current (A), Battery SOC are taken as Y-axis and time in secs are taken as X-axis

Wind turbine parameters under the influence of arbitrary variation of wind speed



The wind turbine parameters are Wind profile (m/s), Pitch angle (deg), Shaft speed (rps), Turbine power (kw) are taken on Y-axis and time taken on X-axis in secs

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CONCLUSION

The power available from a WECS is very unreliable in nature. So, a WECS cannot ensure uninterrupted power flow to the load. In order to meet the load requirement at all instances, suitable storage device is needed. Therefore, in this paper, a hybrid wind-battery system is chosen to supply the desired load power. To mitigate the random characteristics of wind flow the WECS is interfaced with the load by suitable controllers. The control logic implemented in the hybrid set up includes the charge control of battery bank using MPPT and pitch control of the WT for assuring electrical and mechanical safety. The charge controller tracks the maximum power available to charge the battery bank in a controlled manner. Further it also makes sure that the batteries discharge current is also within the C/10 limit. The current programmed control technique inherently protects the buck converter from over current situation. However, at times due to MPPT control the source power may be more as compared to the battery and load demand.

During the power mismatch conditions, the pitch action can regulate the pitch angle to reduce the WT output power in accordance with the total demand. Besides controlling the WT characteristics, the pitch control logic guarantees that the rectifier voltage does not lead to an overvoltage situation. The hybrid wind-battery system along with its control logic is developed in MATLAB/SIMULINK and is tested with various wind profiles. The outcome of the simulation experiments validates the improved performance of the system.

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Author Details

Chandana.N
M.Tech (Power Electronics)
Department of EEE
Kuppam Engineering College,
Kuppam, Chittoor,
Andhra Pradesh.

V.Sekhar, ME, (Ph.D), LMISTE, LMSESI, AMIE.,
Associate Professor
Department of EEE
Kuppam Engineering College,
Kuppam, Chittoor.

Venugopal.N
Ph.D from Dr. MGR University, Chennai. He obtained both B.E. and M.E. Degree from Bangalore University respectively. He has 17 years of teaching experience. His research area is Digital Image Processing & Video separation. Currently working as an HoD of EEE Department & Director of R & D in Kuppam Engineering College, Kuppam, and Chittoor Dist. Andhra Pradesh. His research area of interest includes Power Electronics, Power Systems, Renewable Energy Sources and Embedded Systems.