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CONTROL STRATEGY FOR STAND-ALONE HYBRID WIND-BATTERY SYSTEM

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ABSTRACT

Present energy require intensely depends on the ordinary sources. However, the restricted accessibility and consistent increment in the cost of ordinary sources has moved the center toward renewable sources of energy. Of the accessible option sources of energy, wind energy is thought to be one of the demonstrated advancements. With an aggressive expense for power generation, wind energy conversion system (WECS) is these days conveyed for meeting both network joined and remain solitary burden requests. Be that as it may, twist stream by nature is discontinuous. To guarantee constant supply of force suitable stockpiling innovation is utilized as reinforcement. In this paper, the supportability of a 4-kW half breed of wind and battery system is explored for meeting the necessities of a 3-kW remain solitary dc burden speaking to a base telecom station.

KEYWORDS: **Maximum power point tracking (MPPT), pitch control, state of charge (SoC), wind energy conversion system (WECS).**

INTRODUCTION

Energy is the thought to be the critical data for improvement. The force yield of the SEIG relies on upon the wind stream which by nature is flighty. Both sufficiency and recurrence of the SEIG voltage change with wind speed. At present attributable to the consumption of accessible customary assets and concern in regards to ecological debasement, the renewable sources are being used to meet the perpetually expanding energy request. However, the nature of wind stream is stochastic. Investigation of wind energy conversion system (WECS) and the related controllers are, consequently, turning out to be more huge with every passing day. . The significant point of interest of offbeat machine is that the variable rate operation permits removing most extreme force from WECS and diminishing the torque vacillations. The force yield of the SEIG relies on upon the wind stream which by nature is sporadic. Both sufficiency and recurrence of the SEIG voltage shift with wind speed. Such self-assertively changing voltage when interfaced specifically with the heap can offer ascent to flash and flimsiness at the heap end. Thus, the WECS are incorporated with the heap by force electronic converters to guarantee a directed burden voltage.

HYBRID WIND-BATTERY SYSTEM FOR AN ISOLATED DC LOAD

The proposed mixture system includes a 4-kWWECS and 400 Ah, C/10 lead corrosive battery bank. The system is intended for a 3-kW remain solitary dc load. The design of the whole system alongside the control technique is demonstrated in Fig. 1. The determinations of the WT, SEIG, and battery bank are arranged in the Appendix. The WECS comprises of a 4.2-kW level hub WT, rigging box with an apparatus proportion of 1:8 and a 5.4 hp SEIG as the WTG. since the heap is a stand-alone dc load the stator terminals of the SEIG are associated with a capacitor bank for self-excitation. The air conditioner yield is corrected by three-stage uncontrolled diode rectifier. In any case, there is a requirement for a battery reinforcement to take care of the heap demand amid the time of inaccessibility of adequate wind power. The charge controller is a dc–dc buck converter which decides the charging and releasing rate of the battery. Further, as indicated in Fig. 1, the charging of the battery bank is accomplished by MPPT rationale, while the pitch controller constrains the mechanical and electrical parameters inside of the evaluated quality.

CONTROL STRATEGY FOR STAND-ALONE HYBRID WIND-BATTERY SYSTEM

The wind flow is erratic in nature. Therefore, a WECS is integrated with the load by means of an ac–dc–dc converter to avoid voltage flicker and harmonic generation. The control scheme for a stand-alone hybrid wind-battery system includes the charge controller circuit for battery banks and pitch control logic to ensure WT operation within the rated value. The control logic ensures effective control of the WECS against all possible disturbances.

A. Charge Controller For The Battery Bank

This segment talks about in detail the advancement of charge controller circuit for a 400 Ah, C/10 battery bank utilizing a dc–dc buck converter as a part of MATLAB/SIMULINK stage. By and large, the batteries are charged at C/20, C/10, or C/5 rates relying upon the maker's detail where C determines the Ah rating of battery banks. Along these lines, the battery bank system considered in the configuration can be charged at 20, 40, or 80 A. Yet, in this paper, C/10 rate (i.e., 40 A) for battery charging is picked. Be that as it may, the current needed for charging the battery bank relies on upon the battery SoC. A common battery for the most part charges at a steady current (CC), i.e., C/10 rate mode till battery SoC achieves a certain level (90%–98%). This is alluded to as CC method of battery charging. The CC mode charges the battery as quick as could reasonably be expected. Past this SoC, the battery is charged at a consistent voltage (CV) which is meant as CV method of battery charging so as to keep up the battery terminal volt

B. Control Strategy

This segment talks about in detail the advancement of charge controller circuit for a 400 Ah, C/10 battery bank utilizing a dc–dc buck converter as a part of MATLAB/SIMULINK stage. By and large, the batteries are charged at C/20, C/10, or C/5 rates relying upon the maker's detail where C determines the Ah rating of battery banks. Along these lines, the battery bank system considered in the configuration can be charged at 20, 40, or 80 A. Yet, in this paper, C/10 rate (i.e., 40 A) for battery charging is picked. Be that as it may, the current needed for charging the battery bank relies on upon the battery SoC. A common battery for the most part charges at a steady current (CC), i.e., C/10 rate mode till battery SoC achieves a certain level (90%–98%). This is alluded to as CC method of battery charging. The CC mode charges the battery as quick as could reasonably be expected. Past this SoC, the battery is charged at a consistent voltage (CV) which is meant as CV method of battery charging so as to keep up the battery terminal volt

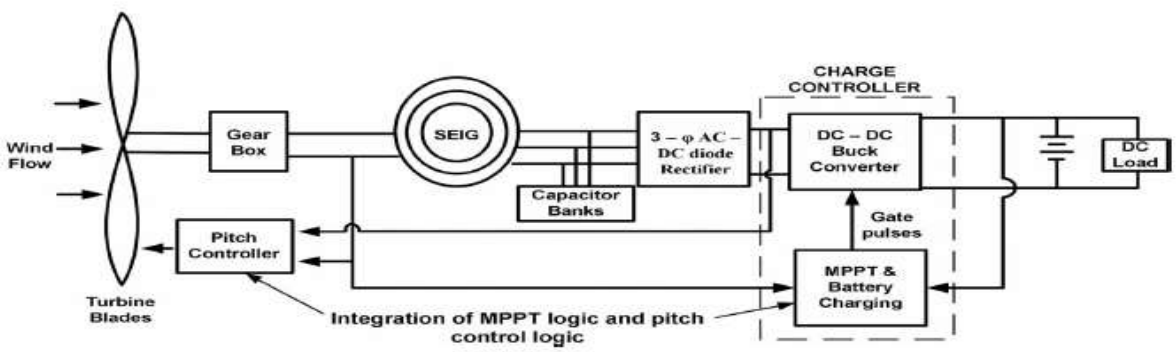


Fig. 1. *Layout of hybrid wind–battery system for a stand-alone dc load.*

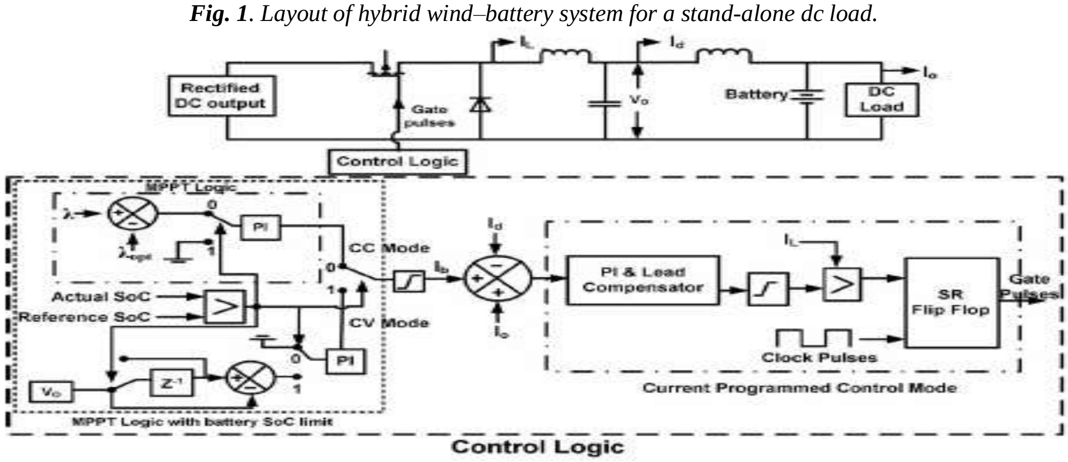


Fig. 2. Block schematic of the charge controller circuit for battery.

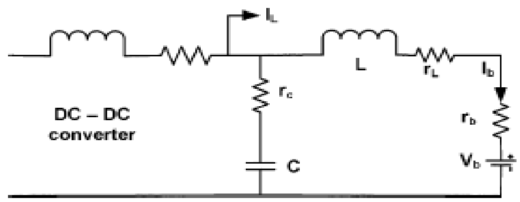
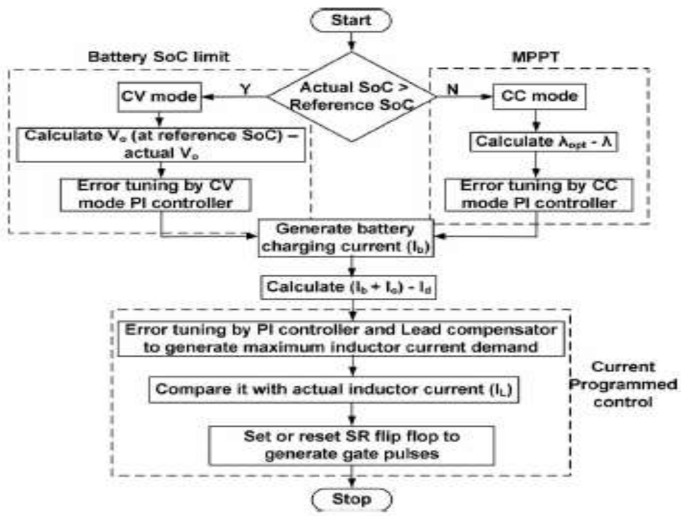


Fig. 3. Circuit representation of buck converter output.

As shown in Fig. 3, the battery is assumed to be a CV source with a small internal resistance (*rb*). The effective series resistances (ESR) of the capacitor (*rc*) and the inductor (*rL*) are also considered. The ESR of the capacitor and the inductor is taken to be 1mΩ each. The battery internal resistance is 10 mΩ. For regulating the peak-to-peak (p–p) ripple of battery current and converter output voltage within 2% of the rated value the L and C are calculated



***Flow chart of the charge controller circuit for battery*.**

to be 10 mH and 5 mF, respectively. For controlling the battery current the actual converter output current (*Id*) is compared with the reference (*Ib* + *Ia*) and the error is processed by a cascade of a PI and a lead compensator. The PI controller is modeled as an inverted zero. To maintain the phase margin of the open-loop system the frequency of this zero is 50 times lower than the crossover frequency. To improve the phase margin of the battery charging current control loop (i.e., (1) along with the PI controller) a lead compensator is connected in cascade with the PI controller as shown in Fig. 2. The zero and pole of the lead compensator are designed to have a positive phase margin and to restrict the crossover frequency to about 14% of the switching frequency. The bode plot of the PI controller along with the lead compensator and the loop gain of the battery current control loop are shown in Fig. 4(a) and (b). As shown in Fig. 4, the phase margin is 34.2◦ at 130 Hz. The output of the lead compensator determines inductor current reference for the dc–dc converter. In order to prevent over loading the turbine (and its consequent stalling) the lead compensator output is first passed through an adjustable current limiter. The lower limit is set to zero and the upper limit is varied according to the maximum power available at a given wind speed. The output of this limiter is used as the reference for the current controller in the dc–dc converter. Finally, in the inner most loop the actual inductor current is made to track the reference using peak current mode control. The compensated output of the intermediate loop is compared with the instantaneous inductor current of the buck converter.

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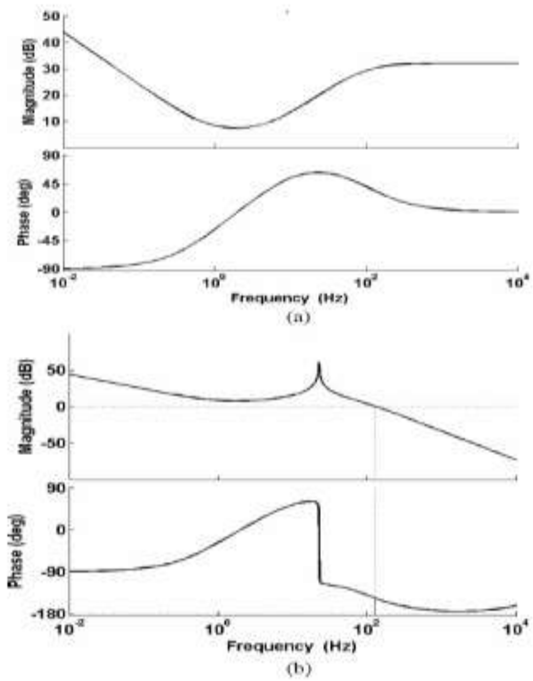


Fig. 4. Bode plot of (a) PI controller in cascade with lead compensator. (b) Loop gain of the battery current control loop.

The output of the comparator is applied to an SR flip flop to produce the gate pulses for the dc–dc buck converter. The frequency of the clock pulses is 2 kHz. The frequency of the gate pulse is equal to the clock pulse frequency. This method of generating gate pulses for the converter is known as the current programmed control technique. The advantage of this method is that it does not allow the inductor current to go beyond the rated limit. This in turn protects the buck converter switch and inductor from over current situation.

MODES OF BATTERY CHARGING

A. CC Mode of Battery Charging

In CC mode, the battery charging current interest is resolved from the MPPT rationale. MPPT is actualized by looking at the genuine and ideal TSR (λopt). The lapse is tuned by a PI controller to produce the battery charging present according to the wind speed. In this mode, the converter yield voltage ascends with time while the MPPT rationale tries to exchange however much power as could reasonably be expected to charge the batteries. The real battery charging current that can be accomplished does not stay steady but rather changes with accessible wind pace subject to a most extreme of C/10 rating of the battery. The battery charging current summon has least breaking point of zero. In the event that the wind velocity is lacking to supply the heap even with zero battery charging current the inductor current reference is solidified at that specific quality and the offset load current is supplied by the battery

B. CV Mode of Battery Charging

In the CC mode, the battery voltage and SoC rise fast with time. However, the charge controller should not overcharge the batteries to avoid gasification of electrolyte. As a result, once the battery SoC becomes equal to the reference SoC the controller must switch over from CC mode to CV mode. In CV mode, the battery charging voltage is determined from the buck converter output voltage (V_o). The value of the converter voltage when the battery SoC reaches 98% is set as the reference value and is compared with the actual converter output voltage. The error in the voltage is then controlled by a cascaded arrangement of PI controller and lead compensator to generate the inductor current reference. It is then compared with the actual inductor current by a logical comparator to generate gate pulses in a similar way as described in Section A. In this mode, the converter output voltage is maintained at a constant value by the controller action. So, in CV mode the battery voltage and SoC rise very slowly with time as compared to CC mode. The battery charging current slowly decreases with time, since the potential difference between the buck converter output and battery terminal gradually reduces. Thus, in CC mode the buck converter output current is regulated while the output voltage keeps on increasing with time. Thus, in CC mode much of the available power from primary source is injected into

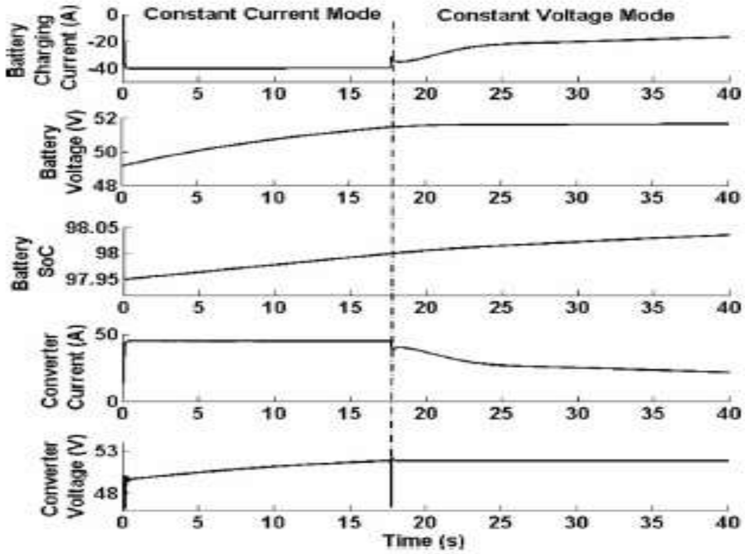


Fig. 5. Battery charging modes at a constant wind speed of 10 m/s.

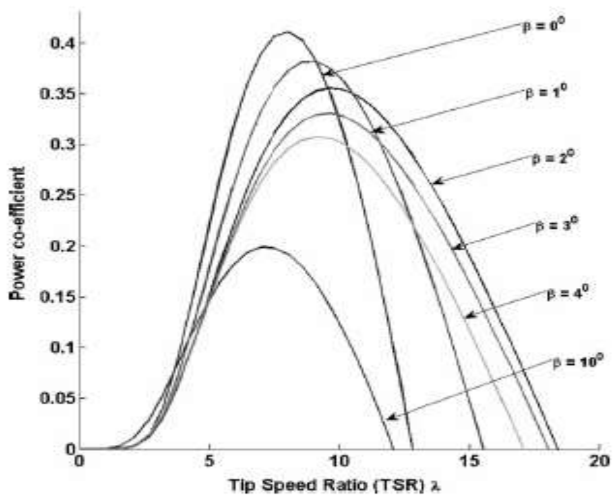


Fig. 6. Cp −λ characteristics of the WT for different pitch angles

the battery whereas in CV mode the battery is charged slowly to avoid gasification and heating issue.

C. Pitch Control Mechanism

The WT power output is proportional to the cube of wind velocity. Generally the cut-off wind speed of a modern WT is much higher compared to the rated wind speed. If the WT is allowed to operate over the entire range of wind speed without implementation of any control mechanism, the angular speed of the shaft exceeds its rated value which may lead to damage of the blades. So, it is very much essential to control the speed and power at wind speeds above the rated wind speed. Such a mechanism is referred to as the pitch control of WT. The power coefficient (Cp) versus TSR (λ) characteristics of the WT considered in this study for different pitch angles are shown in Fig. 6. As examined from the characteristics, at a pitch angle of zero degree the value of Cp is maxima. But the optimum value of power coefficient reduces with increase in pitch angle. This happens

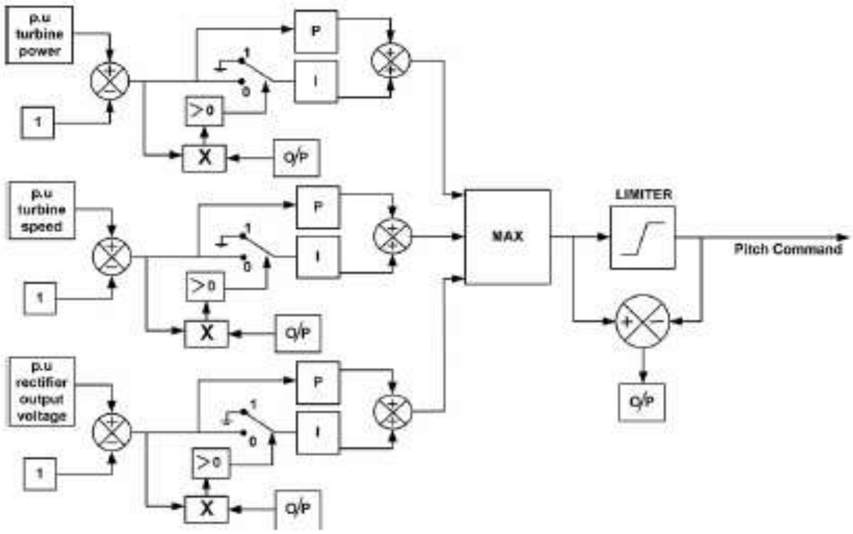


Fig. 7. Pitch control scheme for a stand-alone WECS.

because with increase in blade pitch the lift coefficient reduces which results in decreasing the value of *Cp* [15]. So, the pitch control mechanism controls the power output by reducing the power coefficient at higher wind speeds. Below the rated wind speed the blade pitch is maintained at zero degree to obtain maximum power. The pitch controller increases the blade pitch as the WT parameters exceed the rated value. The reduction in the value of *Cp* by pitching compensates for the increase in WT power output under the influence of higher wind speeds. Apart from regulating the WT parameters, it is also essential to control the output voltage of the ac–dc rectifier to avoid overvoltage condition in the WECS. Hence, the pitch controller ensures that with desirable pitch command, the WT parameters and the rectifier output dc voltage are regulated within their respective maximum allowable limits to ensure safe operation of the WECS.

D. Pitch Control Scheme

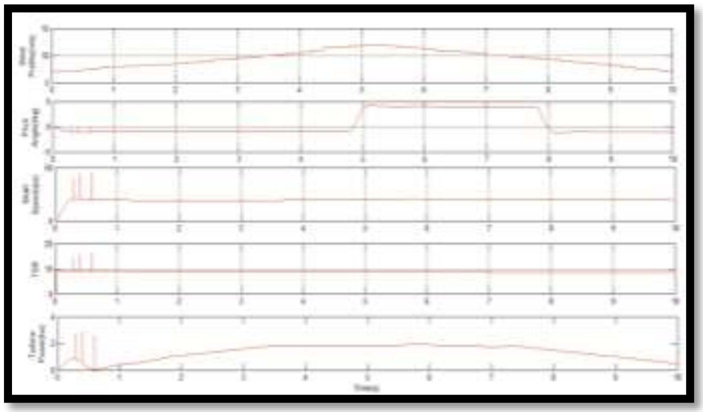
The pitch control scheme is shown in Fig. 7. As seen the p.u. value of each input is compared with 1 to calculate the error. The errors are tuned by PI controller. The "MAX" block chooses the maximum output from each PI controller which is then passed on to a limiter to generate the pitch command for the WT. The actual pitch command is compared with the limited value. The lower limit of the pitch command is set at zero. There arises an error when the actual pitch command goes above or below the specified limit. This is multiplied with the error obtained from each of the comparator. The product is compared with zero to determine the switching logic for integrator. This technique is carried out to avoid integrator saturation. The pitch controller changes the pitch command owing to variation in turbine rotation speed, power, and output voltage of rectifier, which ensures safe operation of the WECS.

RESULTS AND DISCUSSION

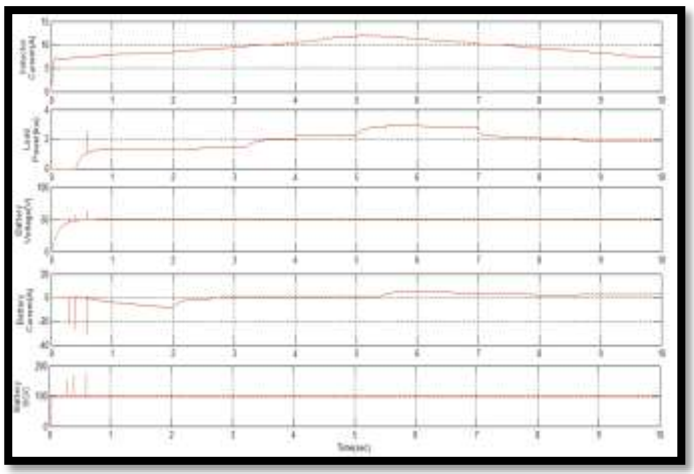
A WECS needs to be efficient to ensure continuous power flow to the load. The effectiveness can be achieved by integrating the hybrid wind-battery system with suitable control logic. This includes the charge control logic and the pitch control logic. The charge controller regulates the charging and discharging 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 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. 9.1(a) is applied to the WT. The wind speed gradually rises from 2 to 5 m/s in 5 s and then falls to 5 m/s in the next 5 s. The WT parameters and the current profile of the converter, load and the battery are observed in Fig. 9.1 (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 from1.5 to 4m/s is shown in Fig. 9.2(a) while the arbitrary variation in wind speed from 1 to 9 m/s is highlighted in Fig 9.3(a).

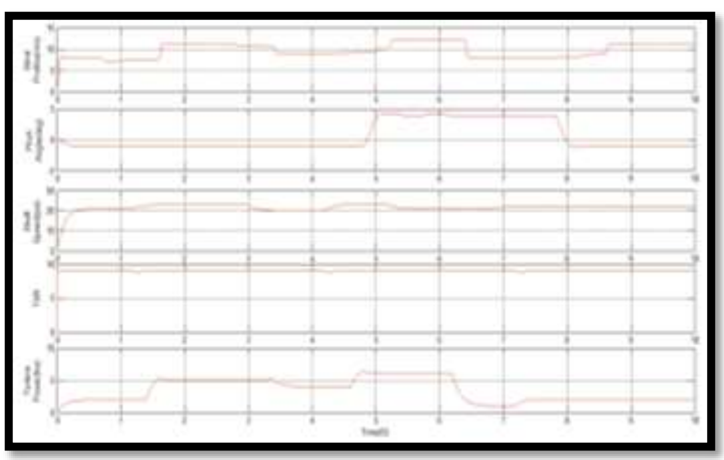


(a)

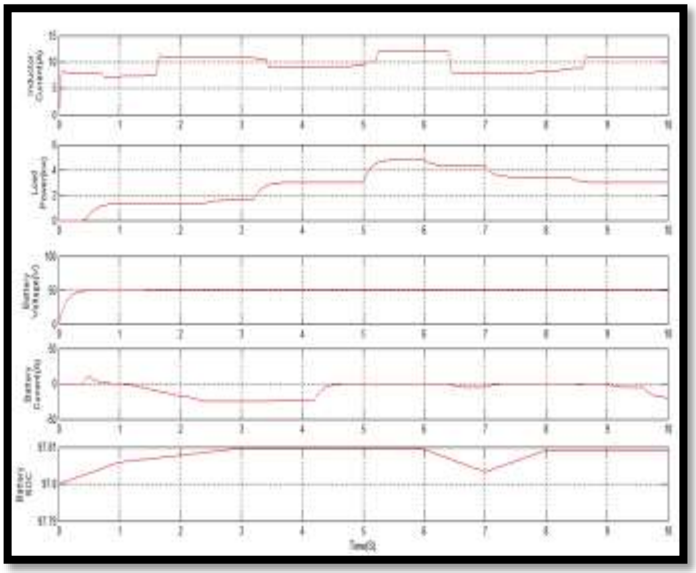


(b)

Fig.8. *(a) WT and (b) battery parameters under the influence of gradual variation of wind speed.*

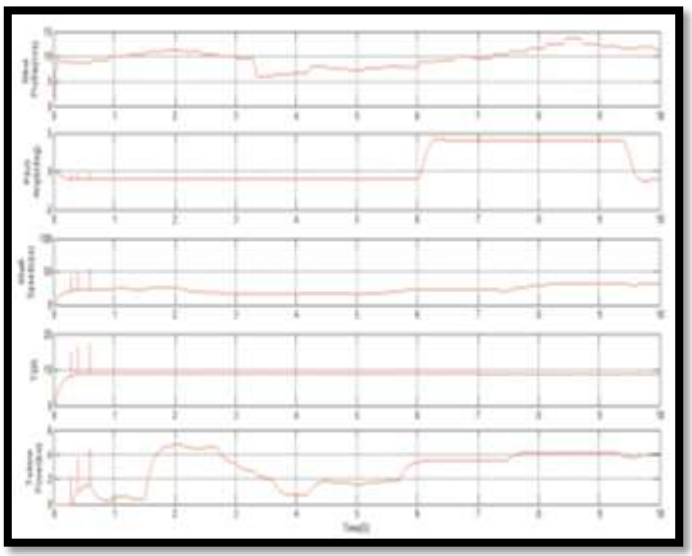


(a)



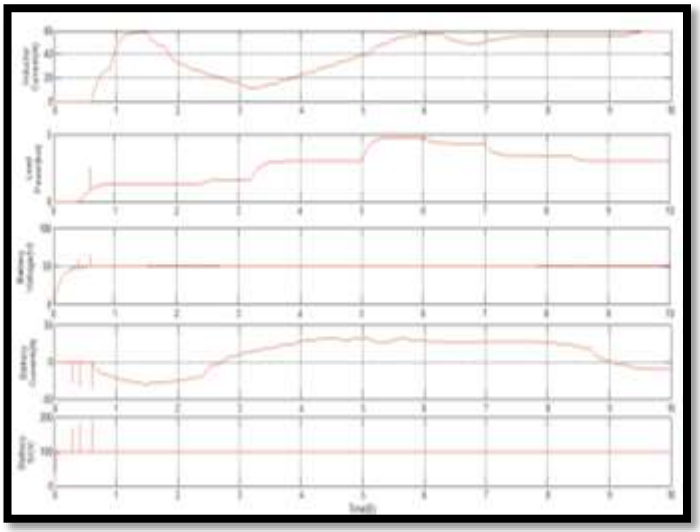
(b)

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



(a)

The response of WT parameter and the current profiles with respect to step variations and arbitrary variations are shown in Figs. 9.2 and 9.3, respectively.The results also demonstrate the change in battery SOC for all possible wind profiles. From Figs 9.1–9.3, 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 mod**e.**



(b)

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

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

TABLES:

I. WIND TURBINE SYSTEM

Table 1.1 *wind turbine specifications*

Parameters	Value(units)
Rated power	4000W
Radius	2.3m
Cut-in wind speed	4 m/s
Rated wind speed	10 m/s
Inertia co-efficient	7 kgm²
Optimum Tip speed ratio	7
Optimum power co-efficient	0.41

II.BATTERY SPECIFICATIONS

Table 1.3 *Battery specifications*

Parameters	Value(units)
Ampere hour rating	400 Ah
Nominal voltage	48 V
Fully charged voltage(No load)	55.2 V
Charging rate	C/10

III. SQUIRREL CAGE INDUCTION MACHINE

***Table 1.2** Squirrel Cage Induction Machine specifications*

Parameters	Value(units)
Rated power	5.4hp
Stator resistance	2.6Ω
Stator leakage inductance	4mH
Mutual inductance	20mH
Rotor resistance	2Ω
Rotor leakage inductance	4mH
Excitation capacitance connected in Δ	15µF

CONCLUSION

The force accessible from a WECS is exceptionally inconsistent in nature. Along these lines, a WECS can't guarantee continuous force stream to the heap. Keeping in mind the end goal to meet the heap necessity at all occasions, suitable capacity gadget is required. Consequently, in this paper, a half and half wind-battery system is decided to supply the craved burden power. To alleviate the irregular attributes of wind stream the WECS is interfaced with the heap by suitable controllers. The control rationale actualized in the half and half set up incorporates the charge control of battery bank utilizing MPPT and pitch control of the WT for guaranteeing electrical and mechanical security. The charge controller tracks the greatest force accessible to charge the battery bank in a controlled way. Further it additionally verifies that the batteries release current is likewise inside of the C/10 breaking point. The current modified control system innately shields the buck converter from over current circumstance. Be that as it may, on occasion because of MPPT control the source force may be all the more when contrasted with the battery and burden request. Amid the force confuse conditions, the pitch activity can manage the pitch point to decrease the WT yield control as per the aggregate interest.

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