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Pitch Control Scheme for a Continuous Wind Energy Conversion System

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Abstract

Effective utilization of power is more important than generation of power because power scarcity is the major problem at present in India. Renewable energy systems are becoming popular for remote area power generation applications due to advances in renewable energy technologies and shortage of fossil propellant staple. It works as an unremitting power source that is able to feed a certain minimum amount of power into the load under all conditions. With a competitive cost for electricity begetting, wind energy conversion system (WECS) is nowadays deployed for meeting both grid-connected and stand-alone load solicitation. In this paper, the most inbuilt of a 4-kW hybrid of wind and battery system is investigated for meeting the requirements of a 3-kW stand-alone dc load representing a base trans receiver. A charge controller for battery bank based on turbine maximum power point tracking and battery state of charge is developed to ensure controlled accumulator battery. The mechanical safety of the WECS is assured by means of pitch control system. Both the control schemes are unified and the efficacy is validated by testing it with various load and wind profiles in MATLAB/SIMULNIK.

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

Introduction

Energy is the considered to be the pivotal input for chrysalis. 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 [1]. Due to a comparably low cost of electricity production [2] wind energy is considered to be one of the potential sources of clean energy for the future [3]. But the nature of wind flow is stochastic. So proper testing is to be carried out in laboratory to develop efficient control strategy for wind energy conversion system (WECS). The research of WECS and the unite controllers are, thus, becoming more and more cogent 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 utilization, a great deal of research is being carried out for choosing a suitable generator for stand-alone WECS. A detailed weighing between asynchronous and synchronous generators for wind farm application is made in [4]. The favour of battery energy storage for an isolated WECS is discussed in [10]. With battery energy storage it is possible to capture maximum power [11] from the handy wind. A weighing of several maximum power point tracking (MPPT) algorithms for small wind turbine (WT) is carried out in [12] and [13]. In order to clipping maximum power form WECS the turbine needs to be operated at optimal angular speed [13]. However, [11] do not take into account the limit on maximum allowable battery charging current nor do they protect against battery overcharging. In order to observe the charging limitation of a battery a charge controller is required. Such a charge control scheme for battery charging for a stand-alone WECS using MPPT is explained in [14]. However, in this paper also the maximum battery charging current is unlimited. The discontinuous battery charging current causes harmonic heating of the battery. The terminal voltage instead of state of charge (SoC) is used for changeover from current mode to voltage mode. Also the MPPT implementation is highly parameter dependant and will be affected by variation of these parameters with operating conditions. Moreover the wind speed exceeds its rated value, the WT power and speed needs to be regulated for ensuring mechanical and electrical safety [15].This is negotiated by changing the pitch angel to the enforced value [16]. Several pitch control techniques are explained in [17]–[19].

Hybrid Wind-Battery System For An Isolated Dc Load

The proposed hybrid system comprises of a 4-kW WECS and 400 Ah, C/10 lead acid battery bank. The system is designed for a 3-kW stand-alone dc load. The layout of the entire system along with the control strategy is shown in Fig. 1. The WECS subsist of a 4.2-kW horizontal axis WT, gear box with a gear ratio of 1:8 and a 5.4 hp SEIG as the WTG. Considering the load is a stand-alone dc load the stator terminals of the SEIG are connected to a capacitor bank for self-excitation. The produced ac is rectified by three-phase uncontrolled diode rectifier. However, there is a need for a battery backup to meet the load demand during the period of unavailability of tolerable wind power. This combination wind-battery system requires suitable control logic for interfacing with the load. The unconstrained dc output of the rectifier is applied to the charge controller circuit of the battery. The charge controller is a dc–dc buck converter which determines the charging and discharging rate of the battery. The battery bank connected to the system can either act as a source or load depending on whether it is charging or discharging. However, lax of this the battery ensures that the load terminal voltage is regulated. Further, as shown in Fig. 1, the charging of the battery bank is achieved by MPPT logic, while the pitch controller restraint the mechanical and electrical parameters within the rated value. The integrated action of the battery charge and pitch controller ensures reliable operation of the stand-alone WECS.

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 section discusses in detail the development of charge controller circuit for a 400 Ah, C/10 battery bank using a dc–dc buck converter in MATLAB/SIMULINK platform. Generally, the batteries are charged at C/20, C/10, or C/5 rates depending on the manufacturer’s specification where C specifies the Ah rating of battery banks. So, the battery bank system considered in the design can be charged at 20, 40, or 80 A. But, in this paper, C/10 rate (i.e., 40 A) for battery charging is chosen. However, the current required for charging the battery bank depends on the battery SoC. A typical battery generally charges at a constant current (CC), i.e., C/10 rate mode till battery SoC reaches a certain level (90%–98%). This is referred to as CC mode of battery charging. The CC mode charges the battery as fast as possible. Beyond this SoC, the battery is charged at a constant voltage (CV) which is denoted as CV mode of battery charging in order to maintain the battery terminal voltage.

B. Control Strategy

The implementation of the charge control logic carried out by control loops. To implement the MPPT logic, the certain tip speed ratio (TSR) of turbine is compared with the optimum value. The error is attune by a PI controller to generate the battery current demand as long as the battery SoC is below the CC mode limit. Beyond this point, the SoC control logic tries to maintain constant battery charging voltage. This in turn reduces the battery current demand and thus prevents the battery bank from overcharging. The buck converter inductor current canon is generated in the intermediate control loop.

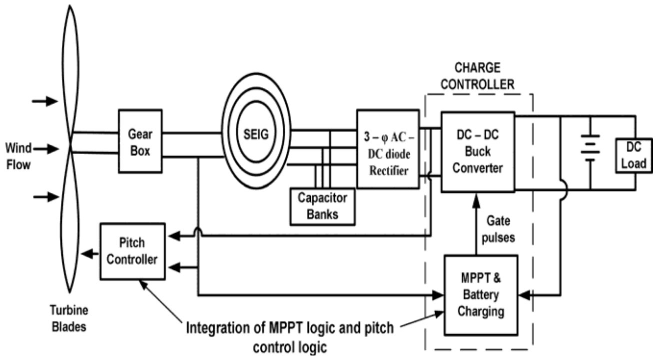

Figure 1: Layout of hybrid wind–battery system for a stand-alone dc load

Modes of Battery Charging

A. *CC Mode of Battery Charging*

In CC mode, the battery charging current demand is determined from the MPPT logic. MPPT is implemented by comparing the actual and optimum TSR (λ_{opt}). The error is tuned by a PI controller to generate the battery charging current as per the wind speed. In this mode, the converter output voltage rises with time while the MPPT logic tries to transfer as much power as possible to charge the batteries. The actual battery charging current that can be achieved does not remain constant but varies with available wind speed subject to a maximum of C/10 rat- ing of the battery. The battery charging current mandate has a minimum limit of zero. In case the wind speed is insufficient to supply the load even with zero battery charging current the inductor current reference is frozen at that particular value and the balance load current is supplied by the battery.

B. CV Mode of Battery Charging

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.

C. Pitch Control Mechanism

The pitch control scheme, 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 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 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.

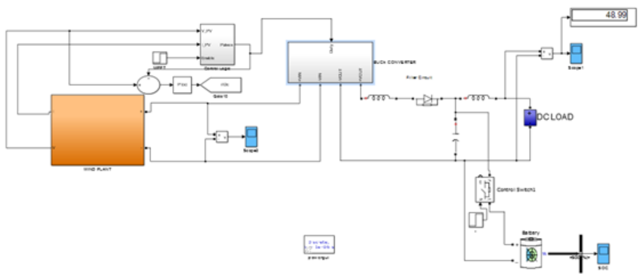

Figure 2: Simulation Diagram

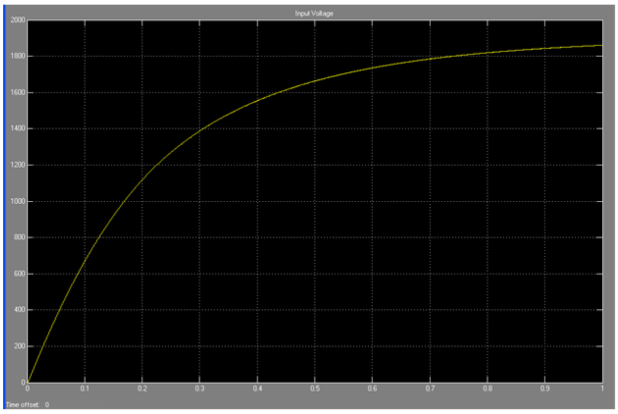

Figure 3: Input Voltage

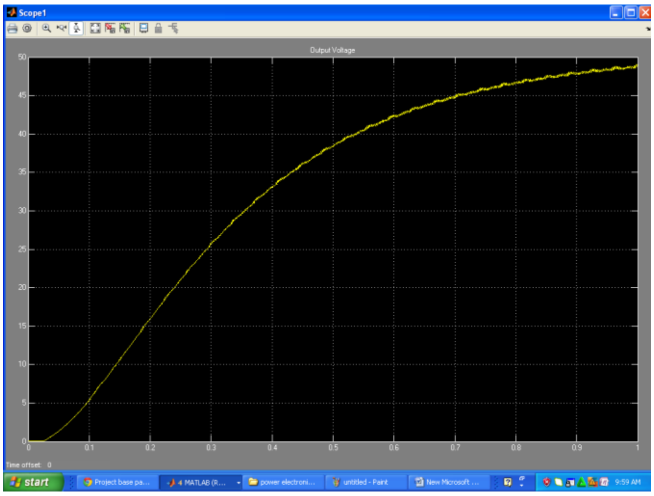

Figure 4: Output Voltage

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, suit- able 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 cur- rent 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. Be- sides controlling the WT characteristics, the pitch control logic guarantees that the rectifier voltage does not lead to an over- voltage situation. The hybrid wind-battery system along with its control logic is developed in MATLAB/SIMULINK and is tested with various wind profiles.

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