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Maximum Power Point Tracking Controller for Wind Energy Conversion System for Micro-Grid Applications

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ABSTRACT:

A controlled wind generation system for a stand-alone application is presented in this paper. A cascaded step-up/step-down power electronic converters topology is proposed to control the wind power system in the whole wind speed range. For the low wind speed range, the control strategy is aimed to follow the wind turbine's maximal power coefficient by adjusting the generator's rotational speed. For high wind speeds, the system power regulation is also made by controlling the generator speed. This control is made by the DC/DC power electronic converter, which modifies its input voltage, changing the machine voltage and consequently varying the generator's rotor speed. The proposed system is validated by computer simulation. The proposed control system shows a good performance for its application in autonomous wind energy systems.

INTRODUCTION:

In this paper a design of efficient control techniques in variable speed to give continuous Supply to load is implemented. Variable-speed wind turbines have many advantages over fixed-speed generation such as increased energy capture, operation at maximum power point, improved efficiency, and power quality [1]. Their liability of the variable-speed wind turbine can be improved significantly by using a direct- generator. PMSG has received much attention in wind-energy application because of their property of self-excitation, which allows an operation at a high power factor and high efficiency [2]. Optimum power/torque tracking is a popular control strategy, as it helps to achieve optimum wind energy utilization [3]–[4]. The switch-mode rectifier has also been investigated for small-scale variable-speed wind turbine [5], [6].It is very difficult to obtain the maximum voltage level by using PI controller. In order to obtain the maximum output, PWM control can be used. For a stand-alone system, the output voltage of the load side converter has to be controlled in terms of amplitude and frequency. Previous publications related to PMSG-based variable-speed wind turbine are mostly concentrated on grid connected system [6]-[8]. Much attention has not been paid for a stand-alone system. Many countries are affluent in renewable energy resources; however, they are located in remote areas where power grid is not available.

Isolated places or locations where the grid is unavailable are one of the main commercial applications of stand-alone wind turbines. Autonomous variable speed wind energy systems have been studied in the past decades and they have shown a high efficiency and good performance in face of constant speed or non-controlled systems, even in low power range. For wind turbines (WT) of less than 50 kW, particularly in the lowest power range, the permanent magnet synchronous generator (PMSG) is mostly chosen because of its low cost, reduced power losses, simple construction and no external magnetization characteristics. Most of switch-mode electronic power converters, from small DC/DC choppers to large AC/AC three-phase converters, are used to obtain an efficient power transfer from the WT rotor to the electrical system. The system's power level defines the appropriate power electronic converter: choppers for battery chargers and low power DC applications and voltage or current source inverters for the connection to AC power systems. Electrical machine drives are the optimal complement for classic aerodynamic wind turbine control strategies.

The variable speed operation of the electric machine (in indirect grid connection or isolated applications) has shown advantageous for several reasons. Previously studied power structures and control schemes in low power wind energy systems [3-6] are helpful to propose a new topology. In this article, a power electronic conversion system with a diode rectifier and a cascaded DC/DC converter is presented and studied for its application in a stand-alone wind energy system. The cascaded DC/DC converter is composed of a boost converter and a buck converter to optimize the wind turbine operation for all its wind speed range. The proposed topology is well suited for a low power DC system with battery storage.

Along with the electrical generator, the principal electric component of the proposed wind energy system is the proposed DC/DC converter. Controllability of the system voltage allows the machine rotational speed adjustment to obtain the maximal wind turbine available power. A decoupled two-stage control system is designed for proper operation of the wind energy system. The two (boost and buck) converters are controlled independently and operate complementarily. A simple linear control for the system rotation speed gives the voltage reference to a feedforward control of the cascaded converter. Results show that the proposed structure can operate with a good performance in a stand-alone wind energy conversion system for low power generation applications.

SYSTEM DESCRIPTION:

The proposed hybrid system comprises of a WECS and lead acid battery bank. The system is designed for a stand-alone dc load. The layout of the entire system along with the control strategy is shown in Fig. 1. The specifications of the WT, SEIG, and battery bank are tabulated in the Appendix. The WECS consists of a horizontal axis WT, gear box with a gear ratio of 1:8 and a SEIG as the WTG. Since the load is a stand-alone dc load the stator terminals of the SEIG are connected to a capacitor bank for self-excitation. The ac output 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 sufficient wind power. This hybrid wind-battery system requires suitable control logic for interfacing with the load. The uncontrolled 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, regardless 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 limits 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.

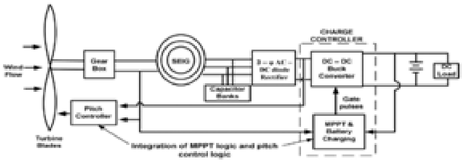

Fig. 1: Layout of hybrid wind–battery system for a stand-alone dc load

Control Strategy:

The implementation of the charge control logic as shown in Fig. 2 is carried out by three nested control loops. The outer most control loop operates the turbine following MPPT logic with battery SoC limit. To implement the MPPT logic, the actual tip speed ratio (TSR) of turbine is compared with the optimum value. The error is tuned 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 command is generated in the intermediate control loop. To design the controller, it is essential to model the response of the battery current (Ib) with respect to the inductor current (IL).

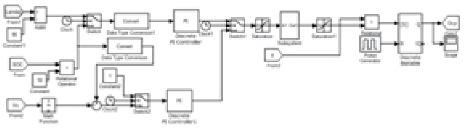

Figure 2: control strategy for converter

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 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, 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 loops the actual inductor current is made to track the reference using peak current mode control [21]. The compensated output of the intermediate loop iscompared with the instantaneous inductor current of the buckconverter. The output of the comparator is applied to an SR flipflop-to produce the gate pulses for the dc–dc buck converter. Thefrequency of the clock pulses is 2 kHz. The frequency of thegate pulse is equal to the clock pulse frequency. This method ofgenerating gate pulses for the converter is known as the currentprogrammed control technique. The advantage of this methodis that it does not allow the inductor current to go beyond therated limit. This in turn protects the buck converter switch andinductor from over current situation.

Pitch Control Strategy:

The pitch control scheme is shown in Fig. 3. 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.

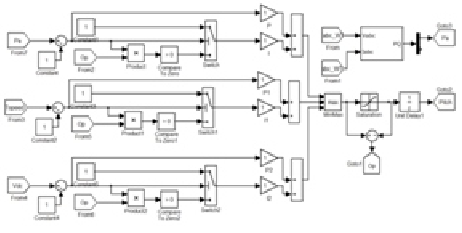

Fig 3: pitch angle controller

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.

BATTERY USAGE:

In CC mode, the battery charging current demand is determined from the MPPT logic. MPPT is implemented by comparing the actual and optimum TSR (λopt). 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 rating of the battery. The battery charging current command 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.

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 [14]. 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 (Vo). 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 valueby the controller action. So, in CV mode the battery voltageand SoC rise very slowly with time as compared to CC mode.The battery charging current slowly decreases with time, sincethe potential difference between the buck converter output andbattery terminal gradually reduces.

SIMULATION RESULTS:

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.

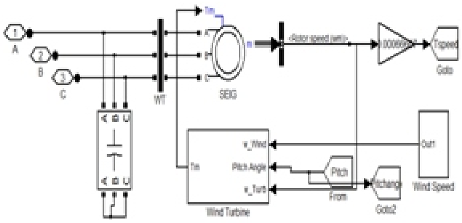

Fig 4: simulation design of WECS

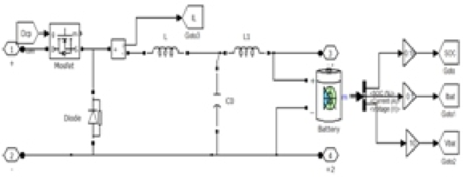

Fig 5: DC/DC converter with battery

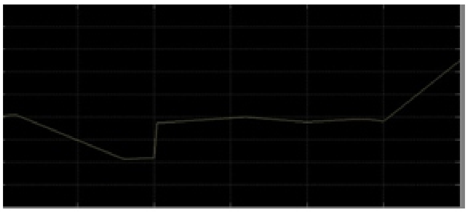

Fig 6: battery current.

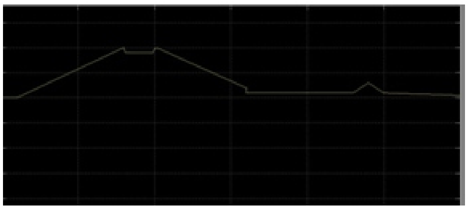

Fig 7: battery voltage

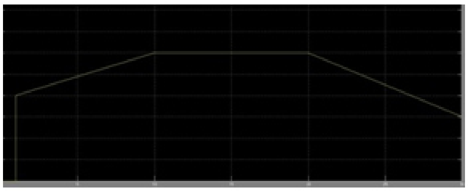

Fig 8: load current

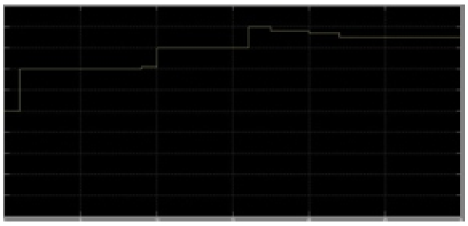

Fig 9: load power

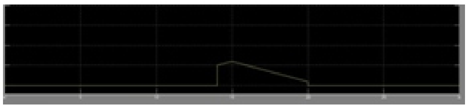

Fig 10: pitch angle

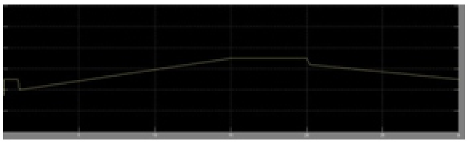

Fig 11: shaft speed

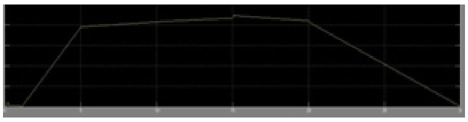

Fig 12: turbine power

CONCLUSION:

An electronic power conversion system composed of a diode bridge rectifier and a cascade DC/DC converter is presented and studied for its application in a stand-alone wind generation system. The proposed system is validated by computer simulation. The combination of a generator's speed feed-back control with an open-loop feed-forward converter's voltage control has shown a good performance for the autonomous wind energy system.

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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