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THESIS TITLE: MODELLING, ANALYSIS AND IMPLEMENTATION OF A SWITCHED ELUCTANCE MACHINE BASED WIND ENERGY CONVERSION SYSTEM

ABSTRACT

Electricity generation from renewables has become a hot topic of research in the last couple of decades since renewable energy sources are visualized as one of the powerful means to fight global warming and climate change. Electrical power generation from wind energy has seen considerable growth in the last twenty years. Both off-shore and on-shore wind energy conversion system (WECS) configurations have gained equal importance. The major electrical components involved with WECS, such as generators and power converters, have gone through several important transformations in their structural and control aspects. Conventionally doubly fed induction generators (DFIGs) have been in use for generating hundreds of kilowatts of power from wind due to their lower cost, which can be attributed to their capability to function with partial rated power converters. However, DFIGs are not as rugged as the squirrel cage induction generators. In this regard, permanent magnet synchronous generators (PMSGs) with full-rated converters could work extremely efficiently and reliably as wind power generators, especially at MWs of power levels. But, the presence of a permanent magnet in the rotor makes PMSGs really expensive and heavy. For small-scale WECS like the ones installed on the roof-top, some of the special electrical machines such as switched reluctance machines (SRMs) and permanent magnet brushless DC machines (PMBLDCMs) can be employed. This thesis explores the possibility of using an SRM for a small-scale wind power generating system.

SRM has several advantages like high torque to inertia ratio, better reliability, maintenance-free operation and rugged rotor structure devoid of permanent magnets and windings. It is also more cost effective than a PMSG. One of the major problems associated with the SRM is the ripples present in its output power. When an SRM based WECS has to be implemented, it would be desirable to model the entire system in a simulation tool and verify its successful working through simulation studies. For this purpose, it is essential to develop an accurate model for the SRM. Due to its non-linear magnetic behaviour, modelling an SRM is a formidable task. An attempt has been made in this thesis to develop two different models for a 1-hp 8/6 SRM by making use of the

experimentally obtained flux linkage characteristics, for different phase currents and rotor positions. One is a linear model wherein the inductance is represented by mathematical equations depending upon the rotor position and phase currents. The other one is a nonlinear model where the flux linkage is represented by making use of look-up tables and/or a polynomial function consisting of rotor position and phase current. These developed models have been validated by simulating the motoring and generating modes of operation and comparing the performances obtained with the actual experimental results. The results are found to match well with each other which verifies that the models developed represent the machine reasonably accurately.

A small-scale WECS based on an SRM can be used advantageously to generate electricity to cater to the needs of remote areas where grid connectivity is completely absent or unreliable. If the machine can work in self-excited mode, that would be highly beneficial. Finding an appropriate value of capacitance for the self-excited operation of an SRM over a wide range of wind-speeds has been taken up as the second task in this research work. It is shown that by choosing the capacitor value judiciously, and by providing a small voltage initially across the capacitor, voltage is built-up properly in the phase winding of the switched reluctance generator (SRG). The functioning of SRG in self-excited mode has been demonstrated for a wide range of wind speeds in simulation studies as well as in the experimental setup.

Harvesting maximum power from a roof-top WECS (as per the wind speed) is extremely important as these systems are designed for meagre power ratings and also to make a household electrically self-sufficient. Maximum power point tracking (MPPT) control for the SRG is done through an outer power control loop and an inner current control loop. Current control is accomplished by choosing the firing angles for the devices in the asymmetric half bridge converter (AHBC) suitably. Two different optimization techniques, namely, particle swarm optimization technique and gravitational search algorithm are used to arrive at the optimum combination of firing angles to extract maximum power from the SRG at different wind speeds. These optimization techniques are capable of finding appropriate combinations of firing angles even without having prior knowledge of SRM's geometrical parameters like rotor and stator pole widths, interpolar space width, length of the air gap, etc. Modelling and simulation of these optimization algorithms applied to an SRG based WECS have been carried out in the Simulink/MATLAB environment. Finally, in the experimental setup, MPPT has been achieved for varying wind speed conditions by making use of these turn-on and turn-off angles for the AHBC devices.

Due to varying values of wind velocity, the DC output voltage from an SRG based WECS does not remain constant. A DC-DC converter is used at the output of the SRG to regulate its output voltage before feeding it to the loads/ DC microgrid. Non-isolated topologies are preferred over isolated and interleaved configurations, as the focus here is on low cost and a compact system. A SEPIC (Single ended primary inductor converter) is used to regulate the output voltage of the SRG before tying it up to a 48 V DC bus to which a battery energy storage system and loads of a DC home are connected. The entire system has been modelled and simulated and found to perform satisfactorily. A laboratory prototype consisting of a self-excited SRG driven by a DC motor (emulating a wind turbine), an AHBC, a SEPIC to regulate the DC voltage, along with a battery energy storage system (BESS) and loads, has been developed and its performance has been studied at different prime-mover speeds. It is found that the voltage output from the SRG is regulated to 48 V under varying wind speeds and simultaneously, maximum power extraction is accomplished. When the load demand exceeds the generation, BESS makes up for the short-fall. When the wind speed is higher and the load demand is lower, BESS makes use of the excess generated power to replenish its charge.

To summarize, a self-excited SRG based wind energy conversion system has been designed, modelled, analyzed, simulated and implemented in hardware to deliver a regulated DC voltage of 48 V magnitude to a small microgrid consisting of a BESS and various loads, at varying wind velocity conditions.