Abstract

Remote area electrification is one of the major responsibilities of world organizations. There are still 300 million homes inhabited by 1.6 billion people who do not have a stable electric power supply. Off-grid power systems have tremendous potential to electrify remote area locations. Many off-grid projects are running all over the world, supplying power to remote areas. The off-grid projects running across the world cater to 90 percent of the population through solar-based systems. Other renewable energies, such as wind energy, have huge potential to contribute to the cause. However, a dedicated off-grid wind-based system that can cater to the need of remote area electrification has not been proposed yet. This work is an effort to create a dedicated off-grid wind energy-based system for remote areas where the wind profile is descent through-out the year.

Wind Energy Conversion System (WECS) in off-grid/weak-grid mode prefers variable-speed Permanent Magnet Synchronous Generator (PMSG) over constant-speed Induction Generator. In PMSG-based WECS, a full-power converter is preferably used owing to its full control over real power and reactive power flow in the system. Moreover, a generator-side controlled rectifier is essential for speed control of the generator and extract maximum power point tracking (MPPT) from the wind energy. However, the increased number of switches, complex control circuitry, and switching losses in the controlled rectifier increases the cost and jeopardizes the reliability of the system. Moreover, an MPPT technique in an off-grid power system requires an Energy Storage Device (ESD) to save energy at the time of low demand. An ESD increases the cost and maintenance of the system, which is unsuitable for remote area located plants and therefore is avoided in the proposed system. This thesis considers the advantages and disadvantages of using the full-power converter with a controlled rectifier and proposes to use the full-power converter but with an uncontrolled rectifier.

There are two types of dynamics that occur in the system. The first is DC-link voltage dynamics that depends on the power balance between power generated by the generator and load demand. The second dynamics is generator-turbine rotor speed dynamics that depends upon the power balance between power extracted from wind energy by wind turbine and the power generated by the generator. This thesis proposes to regulate the generator power as per the load demand. The generator power has been regulated by mechanical field weakening of the generator. Thus, power balance is maintained at the load-side. The generator power regulation deregulates the generator-turbine speed. The rotor-speed adjusts itself to extract power from wind energy equal to generator power. Subsequently, turbine-side power balance is also achieved. Here, the wind turbine extracts variable power from wind energy. The technique also creates a power reserve in the system, which compensates for the absence of an ESD in the system. The absence of an ESD is even more compensated by hybridizing the proposed system with a solar energy conversion system. A wind-solar hybrid plant improves the reliability of the system owing to the complementary nature of wind and solar energy.

In the present work, a dual-stator axial-flux permanent magnet synchronous generator has been used as a wind generator owing to its higher torque to inertia ratio, magnet usability index, energy density and efficiency. Moreover, the dual-stator configuration of the machine provides an easy method of achieving field-weakening in the machine. The field-weakening in the machine is achieved by shifting one of the stators with respect to others and connecting windings on each stator in series.

The proposed technique is verified by performing experiments on a proof-of-concept hardware setup. There are five types of experimentation performed on the hardware setup which are as following

1. Effect of the Mechanical Field-Weakening (MFW) technique on the performance of the wind generator

2. Effectiveness of the proposed Roof-top Wind Energy Conversion System (RWECS) under variable wind conditions and supplying constant load

3. Effectiveness of the proposed RWECS under constant wind and supplying variable load

4. Low-Voltage-Ride-Through (LVRT) capability of the proposed system

5. Performance evaluation of a rooftop hybrid wind-solar energy conversion system

The results verify the power quality improvement of the proposed system under variable input wind conditions and supplying varying load. The generator acts as a buffer between the input and output variations, and extracts only demanded load from wind. Also, the results show that a generator with sinusoidal back-EMF characteristic is the most appropriate, best suited in MFW based voltage regulations. The LVRT capability of the proposed system is also tested to assess its capability of remaining connected to the grid at the time of grid-faults and supply necessary active and reactive power needs of the grid. Finally, a hybrid wind-solar system is tested. The results show the capability of the proposed technique in cancelling the intermittency in the wind speed and supplying power to a variable load.