Chapter 8

Conclusion and Future Scope

8.1 Conclusion

Electrification of remote areas is one of the prime focuses of world organizations. It is essential owing to the untapped potential of people residing in those places. Excess to electrical power to remote areas has shown marked improvement in the performance of education, health, irrigation, productivity, communication, and microenterprises. Renewable energy-based off-grid power generation is the best solution for remote area electrification applications owing to its low infrastructure cost, no carbon-di-oxide emission, and local availability of the energy resources.

Wind energy is one of the prominent sources of renewable energy in the world. However, a dedicated off-grid wind energy conversion system (WECS) for remote area electrification has not been proposed yet. In this thesis, a dedicated off-grid WECS has been proposed. The proposed system is to be installed at the roof-top of residential buildings and thus termed as rooftop WECS (RWECS). The proposed system is capable of canceling high intermittency of wind energy at building rooftops as well as maintains voltage regulation at variable load.

The proposed system consists of a vertical-axis wind turbine, a dual-stator axial-flux permanent magnet synchronous machine as a wind generator, an uncontrolled rectifier, and an inverter operating at constant modulation indexes. The components of the system have been selected to simplify the structure and incur low maintenance costs that are desirable features of a remote area located power plant.

The principle of operation of the proposed system is based upon balancing generator-load power under transient wind conditions. The power balancing is achieved by regulating generator power as per load demand. The generator power is regulated by the field-weakening of the generator. The field-weakening in the generator is achieved by mechanical shift of one of the stator with respect to the other stator in angular direction. Here, the wind turbine extracts variable power from wind energy as per the demanded load. This creates reserve power capacity in the system, similar to an energy storage device in a solar energy conversion system.

The above hypothesis is tested on an experimental hardware setup based on the proposed RWECS. The experimentations have been performed to test the effect of mechanical field-weakening on the performance of the wind generator, the effectiveness of the proposed system in variable wind and variable load demand conditions, and the fault-ride-through capability of the system. The results validate the ability of the system to absorb the input and output intermittency and maintain the generator-load power balance.

Further, the proposed RWECS has been hybridized with a rooftop solar energy conversion system to compensate for the intermittency of wind energy. A suitable hybridization technique has been proposed that uses a minimum number of active components to simplify the system and reduce the maintenance cost of the system. The role of the solar energy conversion system in supporting the wind energy conversion system has been validated by experimentations. The results show the effective operation of the proposed hybrid rooftop solar-wind energy conversion system under variable wind conditions supplying constant loads.

The proposed hybrid rooftop solar-wind energy conversion system is a dedicated electrical power system for remote are electrification applications.

The limitations of the proposed scheme are :

1. The proposed system is for low/medium wind speed applications owing to the use of a vertical-axis wind turbine and an axial-flux PM generator. The rating of the system may be increased by employing horizontal-axis wind turbine and using dual-stator radial-flux PMSG. However, the new system would lose the simplicity of the proposed system.

2. The MFW of PMSG method in the proposed system is used for bucking the generator voltage. The boosting of generator voltage at low wind speed may be done by using transformer at the load-end.

3. The use of an uncontrolled rectifier at generator-end injects low-order harmonic current in the generator. However, filters may be used to filter out low-order harmonics.

4. The mechanical field-weakening technique injects low-order harmonics in the non-sinusoidal generator topologies. Therefore, it is recommended to use sinusoidal generator topologies.

5. The non-MPPT operation of the system decreases the efficiency of the system. However, MPPT operation may be implemented, given that an energy storing device is present in the system. However, the energy storage device increases the cost of the overall system.

8.2 Future Scope

In the present work, a dedicated wind energy conversion system for remote area applications has been designed. However, in the urban city, the roof-top area is quite large in comparison to a remote area, and therefore, higher installed capacity is possible when the proposed system is installed at roof-tops of urban buildings. The urban city is enabled with a grid. Therefore, the first work that could start from the study conducted in this thesis is to test the performance of the system when it interacts with the grid. In remote areas, the power balance was created by extracting wind power just equal to the load demand. In urban areas, the wind system works at MPPT, and extra wind power is injected into the grid. The field-weakening of the generator would then regulate the output power at wind speeds above rated speed.

In this thesis, the field-weakening of the generator has been achieved by mechanically shifting one of the stators with respect to the other in real-time to control the generator output voltage at varying wind speed and load. This technique may be used for applications that use a multiphase radial/axial-flux PMSG generator with dual stators. In place of real-time-shifting of the stator, the stator may be shifted and fixed based on the seasonal variations in the average wind speed to regulate the generator output voltage and smooth power generation throughout the year. The same field-weakening technology can also be used in the speed control drive of the dual-stator axial-flux PM motors in electric vehicle applications. The mechanical way of field-weakening saves the sensitive magnet from demagnetization and is simple to operate. However, the external actuator used to shift one of the stators consume power. This reduces the efficiency of the system. Thus, innovative techniques of implementing the MFW of the generator that consumes less power may be another future scope of the presented work in this thesis.

Although field-weakening can be done in an axial-flux machine by controlling air-gap when in operation, however, such a method is not mechanically feasible due to strong force of attraction between NdFeB magnets of the rotating disk and stationary stator iron cores. On the other hand, Electrical field-weakening requires additional controlled field-windings along with the NdFeB magnets on rotor/stator, though it will be devoid of the simple disk construction having permanent magnets. The electrical control of voltages such as Electrical field-weakening, control of DC-grid voltage / Inverter, and control of wind turbine speed by using controlled rectifiers need to be studied, however, these were beyond the scope of present work.

Furthermore, the objective of the design in the present thesis is to simplify the overall structure and reduce the maintenance cost of the off-grid system. The simplification has been achieved by replacing the controlled rectifier in a back-to-back AC-AC power converter by an uncontrolled rectifier, regulating the DC-Link voltage by mechanical field-weakening of the system, and operating the inverter at constant modulation indexes. The same components plus using a vertical-axis wind turbine and a permanent magnet synchronous generator reduces the maintenance cost of the system. However, one of the most critical works related to designing a stand-alone power plant is evaluating the final cost of the plant, also termed as the Levelized Cost of Energy. In other words, the final affordability of the system should be tested by comparing the Levelized Cost of Energy (LCOE) of the proposed system with the popular systems such as single-stator radial/axial-flux PMSG with a controlled rectifier and a variable DC-link voltage.

A work that could be conducted inline to the present thesis is to improve the performance of the system at the gust of wind conditions. The strategy is based upon the dual-stator configuration of the DSAF PMSG. When wind speed increases instantaneously, the rotor speed may be regulated by working one of the stators as a motor. Power is injected into the stator winding. The motoring torque thus, generated in the generator, is opposite to the electromagnetic torque of the generator.

Similarly, the same concept may be used at low wind speed conditions. The motoring power may be injected to support the electromagnetic torque of the generator. The strategy imparts an inherent characteristic to the DSAF PMSG to be hybridized with other sources of energy.

Further, the generator output voltage at low wind speed could be regulated by the use of the DSAF PMSG with multiple parallel paths. In the generator, a provision may be given to change winding's number of parallel paths. At low wind speed number of parallel paths would be decreased to enable an increased number of coils per phase and thus increased output voltage. This would come at the cost of decreased output current rating, and thus load shedding is to be a preferred choice in the proposed stand-alone generation system. Load shedding seems logical if we consider the input power decreases with decreasing wind speed.

In the present thesis, a cost-effective strategy has been implemented to hybridize the roof-top wind energy conversion system with the roof-top solar energy conversion system. The solar energy complimented the wind energy system during fast transients in wind speed. In the study, the DC-link voltage has been maintained constant. However, for regions rich in solar and wind energy, may want to use solar energy for feeding load demand as well. The load share management between solar and wind can be controlled by creating a small variation in the DC-link voltage reference value. Separate studies need to be conducted to analyze the pros and cons of the strategy.

In the present thesis, a wind turbine emulator has been used. The tests conducted need to be repeated for a real wind turbine coupled to a DSAF PMSG to see the actual effect of mechanical field-weakening of the generator upon the actual wind variations. The results are expected to improve, given that the wind transients in the study conducted are stepped in nature.