

DFIG Based SWECS Operation in Microgrid by Controlling Frequency and Regulating Voltage

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ABSTRACT: This paper focuses on the impact of frequency, voltage regulation, along with active and reactive power capabilities in wind power plants operating parallelly in micro-grids. A micro-grid control model for distributing the load variations in system and wind turbine model with capability to control output power is developed in simulink. The main aim of this control strategy is to maintain the frequency and voltages within safe limits and also to control the active and reactive power from wind power plants when operating in parallel with the grid. A comparison of system voltage and frequency is done to demonstrate the effectiveness of wind power plants in the regulation mode when compared with present wind power plants operating at maximum active power. This study helps to determine the amount of wind power that can be delivered into the system under new controlling mode without compromising on reliability and integrity of the system

KEYWORDS: Standalone Wind Energy Conversion System(SWECS), Doubly Fed Induction Generator (DFIG), Battery Energy Storage System (BESS), Power Quality.

I. INTRODUCTION

Still there are some interior places, where the accessibility to the grid is very difficult. In these places, the usual option for the power generation is the diesel generators (DG). However, most of these islanded or regional communities are rich in natural resources. Therefore, it is advantageous to use renewable energy sources for power generation. Because of its technological development, wind energy is becoming economical as compared to other renewable energy sources [1-4]. In olden days, most of the wind energy conversion systems (WECSs) have been fixed speed WECS. Based on the characteristics of wind turbine, the rotor speed should be variable for extracting maximum power. Even though, these fixed speed WECS are very much simple and reliable in operation, significant amount of power is gone astray [5-7]. Out of many variable speed WECS, Doubly Fed Induction Generator (DFIG) is the most preferred one, because of its less converter rating requirement. Because of its rotor power utilization, power extracted from the DFIG is more for the same machine rating as compared to others. [8-9]. The main challenge in Standalone Wind Energy Conversion System (SWECS) is to maintain voltage and frequency at variable wind speeds and varying loads. In [10-13], voltage and frequency controllers (VFC) for variable speed DFIGs, linear loads are considered rather than non linear loads. These nonlinear loads introduce harmonics in the windings of the stator. These unwanted harmonics create noise, vibrations and losses in the machine. Normally, the residential loads are of nonlinear, dynamic and unbalanced types. Due to the random nature of wind, these existed SWECS are not able to cater the whole demand when the wind speed is low. Even at high wind speeds, these existed technologies are extracting only the power required by the consumers. So these are not working up to their full capacity for extracting maximum power from the wind. So there is a need of some energy storage such as super capacitors, fly wheels and batteries [14-15]. Nowadays, BESSs (Battery Energy Storage Systems) are used in high power applications such as load levelling, power quality, transmission line stability, black start and local VAR control [16-17]. By integrating BESS, if the wind speed is high and the load demand is low, then the extra energy is stored in the battery. In the other way, if the wind speed is low and the load

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Vol. 6, Issue 11, November 2017

demand is high, then the battery is discharged. This feature is termed as power levelling. So by integrating BESS in this DFIG, assured power supply can be achieved irrespective of the wind speed. Mindset.al [18] have also used BESS in conjunction with WECS through a buck-boost DC-DC converter. Goelet.al [19] has connected BESS directly on the DC link of two back toback connected VSCs. But in that voltage and frequency controller, terminal voltage is regulated by controlling the Load Side Converter (LSC). So the stator is not working exactly at unity power factor. Therefore, the power generating capability may be reduced because of the reactive power. In direct current control method, the LSC currents which consist of harmonics and unbalance are considered as reference currents for the controller. However, in an indirect current control, the reference current is the stator current, which is balanced and sinusoidal. This indirect current control increases the tracking capability as compared to direct current control. By using an indirect current control of LSC, the stator currents are made to be balanced depending upon the MPPT condition. As the stator currents are controlled to be the balanced and sinusoidal, the unbalancing and harmonics in the load currents are supplied through LSC only. This is called as load compensation and harmonics elimination.

II. SYSTEM CONFIGURATION

The doubly fed induction generator consists of a wind turbine connected to the rotor shaft of the induction generator through a gear train. The topology used in this scenario uses a converter capable of supplying and receiving power from the rotor to the grid. This converter consists of two separate devices with different functions connected to each other via a DC interconnection link i.e. a dc link capacitor. These two devices are separate converters, one connected to the grid and the other connected to the rotor. The converter connected to the generator controls the real and reactive power output of the wind turbine and the grid connected converter maintains the dc link capacitor voltage at the set point. A wind turbine connected to a double fed induction generator equipped with a grid side and a generator side converter is shown in Figure 1.

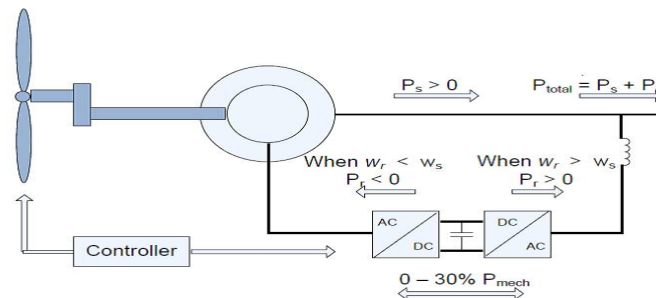


Figure 1 Double fed induction generator schematic

In this DFIG based SWECS, the loads are connected to stator windings of the DFIG. RSC is connected to rotor terminals and LSC is connected to the stator or the load with inductors. For supplying guaranteed power to the consumers, a BESS is connected in the DC link of back to back connected converters. In this system, a wound rotor induction machine is coupled to the DC machine. The wind turbine characteristics are emulated using DC machine and Type-A chopper.

2.1 Generator Side Converter Control

The variations in stator flux are negligible hence are assumed to be constant. Also it is assumed that there would not be any occurrence of saturation. Because of its small presence the stator resistance is considered as zero. To make the calculation simpler it is assumed that the stator flux is along the d axis in the d-q frame. Therefore,

$$\varphi_q = 0$$

$$\frac{d}{dt} \varphi_{d=0}$$

From the above equation it can be deduced that

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$$V_d = 0$$

$$V_q = -\omega \varphi_d$$

The power output from the stator can be written as:

$$S_s = V_s * I_s$$

$$P_s = \frac{3}{2} (V_d * I_d + V_q * I_q) = \frac{3}{2} (V_q * I_q)$$

$$Q_s = \frac{3}{2} (V_d * I_q - V_q * I_d) = -\frac{3}{2} (V_q * I_d)$$

From these equations it is evident that the active power delivered at the stator terminals can be controlled by the I_q component and the reactive power can be controlled by the I_d component assuming constant stator flux. Therefore, to control the DFIG output, a control scheme may be applied to vary the I_d and I_q values to achieve the required power output set point.

2.2 Grid Side Converter Control

The main purpose of the grid side converter is to maintain a constant dc link voltage. To maintain this dc link voltage, the converter takes power from the grid and generates a dc current which keeps the capacitor in the dc link charged. This charged capacitor maintains a constant voltage at the terminals of the generator side converter. The control signal for the grid side converter is the pre-determined voltage set point.

2.3 Capability of Doubly Fed Induction Generator

Active and reactive power capability information of a machine is essential in analyzing the stability of the machine. The capability of any machine depends on its physical construction and materials used. For a DFIG machine, the active power output is limited by the prime mover capability. Similarly, reactive power output is limited by the maximum current and heating limits of the armature and the field coil. These physical limitations guide the capability of the machine. The capability of a DFIG presents similarities to the conventional synchronous generator capability. The active power varies with the wind speed and the slip is assumed to be constant here.

III. MODELLING

3.1 Synchronous Generator Modelling

The synchronous generator model consists of three parts, the synchronous machine model, and the governor model with hydraulic turbine, and the excitation system. A governor model takes the frequency change as an input and changes the servomotor output to provide adequate mechanical power to offset the frequency change from the reference. This model produces available mechanical power as an output which is then fed to the synchronous machine. The excitation system produces the required field voltage for the synchronous machine to maintain the commanded generator terminal voltage. The synchronous machine model takes available mechanical power and required field voltage as an input from the governor and excitation system models, and produces the required current and line-to-line voltage.

3.2 Wind Power Plant Modelling

Wind power plants are designed to extract power as demanded from the command signal. To be aware of the wind capacity at all time, its tracking characteristics should be known as shown in Figure 2. The power is tracked with a pre-defined power-speed characteristic, namely tracking characteristics. The tracking characteristic is defined by four points: A, B, C and D. In this paper, the wind turbines are assumed to have coinciding C and D points. Until the speed of point A, the wind power is zero. Between points A and B, the tracking characteristic is a straight line. Between points B and C/D, the tracking characteristic is the locus of the maximum power of the turbine (maxima of the turbine

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Vol. 6, Issue 11, November 2017

power vs turbine speed curves). Beyond point D, the reference power is a constant equal to one per unit (1 pu).

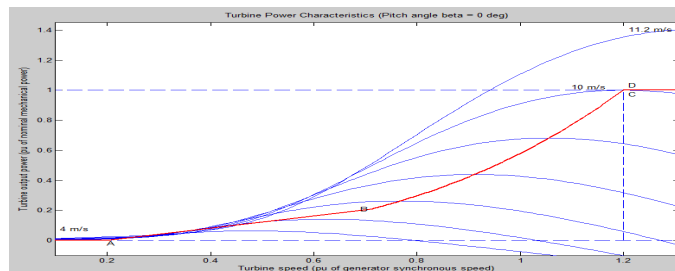


Figure 2 Wind turbine power characteristics

3.3 Wind Turbine Modelling

A Simulink model is developed as shown in figure below.

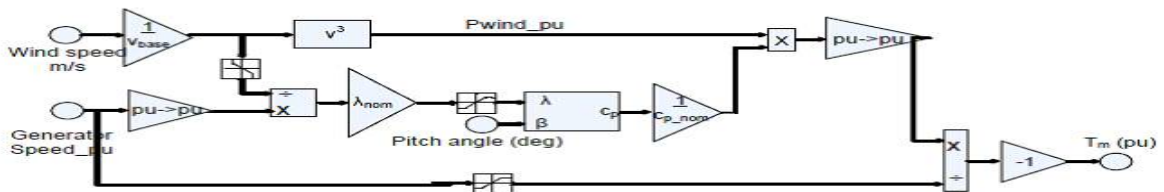


Figure 3 Simulink wind turbine model

3.4 DFIG modelling

The Doubly Fed Induction Generator is modelled as an asynchronous machine with the commanded d-q axis voltage as one of the input with the a-b-c phase terminal voltage and the torque produced by the wind turbine as the other two inputs.

The model outputs all the a-b-c and d-q axis voltage and current quantities of stator and rotor as an output.

3.5 Grid Side Converter Modelling

The grid side converter is used to regulate the voltage of the DC bus capacitor. The control system for the grid side converter is displayed below in Figure 4(i). The d-axis (for d-q transformation) of the rotating reference frame is aligned with the positive sequence of the terminal voltage.

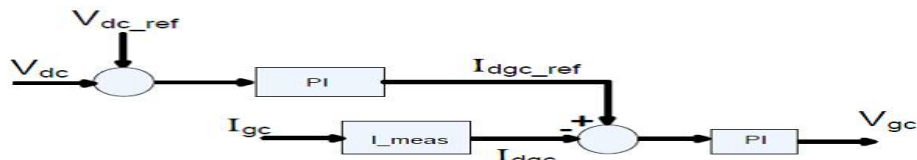


Figure 4(i) Grid side controller

This controller consists of a measurement system to measure the d-axis and q-axis components of AC currents to be controlled, and the DC link capacitor voltage. This controller also includes an outer and inner regulation loop to regulate the DC voltage and the current. The outer loop generates d-axis reference current I_{dgc_ref} through a DC voltage regulator, in phase with terminal voltage to control the active power flow. This outer loop output is given to the inner loop as an input. The inner loop controls the converter voltage V_{gc} by comparing the reference current from the outer loop with the measured d-axis current I_{dgc} from the grid side through a current regulator for a specified q-axis reference current. The logic and the implementation in Simulink is shown in Figure 5(ii).

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Vol. 6, Issue 11, November 2017

$$ids^* = -(Lm/Ls) * iqr.$$

For achieving unity power factor operation at stator, iqs^* is made zero. Reference stator currents (isa^* , isb^* and isc^*) are calculated from the direct and quadrature axis reference currents (ids^* , iqs^*). Sensed stator currents (isa , isb and isc) are compared with the reference stator currents (isa^* , isb^* and isc^*) and the current error is passed through the PI controller for estimating the modulating signals. These modulating signals are compared with the fixed frequency PWM for switch LSC.

V. NEED FOR FREQUENCY CONTROL IN DFIG

Frequency control in a power system is done to maintain a sufficient harmony balance between the consumed and generated active powers, so that the frequency remains within acceptable limits around the nominal frequency. With constantly changing power demand, frequency control becomes an important task for a power system. Generally, the changing system load is predictable and units are committed and dispatched based on the forecasted load levels. Therefore, under normal operating conditions, the balancing of energy is achieved by adjusting the generator active power set-points. Signals to generators for such adjustments are either issued by the system operator or automatically generated and issued by automatic generation control (AGC). In the event of a load change or any unexpected event like loss of generation, an imbalance of load occurs in the system which causes frequency excursions. Every power system tries to fight the frequency excursion by releasing the stored kinetic energy in the form of system inertia. In every system, with increase in the load, the kinetic energy is released and reduction of the load results in absorption of the kinetic energy which tries to maintain the nominal frequency of the system. This inherent system inertial response due to the masses of the connected generators and the load is not sufficient to return the system frequency to its nominal value. Hence frequency control is normal operation of the grid as suggested by CERTS is shown in Figure 7. In an islanded system, these frequency guidelines are a bit relaxed giving normal frequency operation of ± 1.2 Hz required to support the stable and secure operation of the power system. In large interconnected power systems, the power imbalances created due to the loss of single component are small when compared to the total system size. In addition, the inertia of the system also contributes towards restricting the rate of frequency change. Thus the frequency deviations are small in large systems.

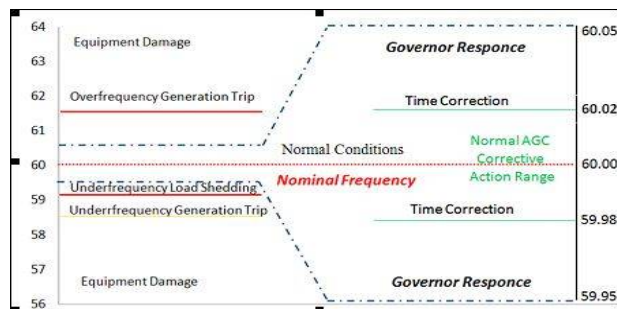


Figure 7. Frequency relaxation limits

VI. SIMULATION RESULTS

The one line diagram of the micro grid system used is shown in Figure 8. In this paper, the micro grid test system is small and isolated but has three synchronous generators and two wind power plants. All the generators are assigned 1% droop which makes sure the full operation of governors for a frequency deviation of 0.6 Hz and equal participation from all of the generators.

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Vol. 6, Issue 11, November 2017

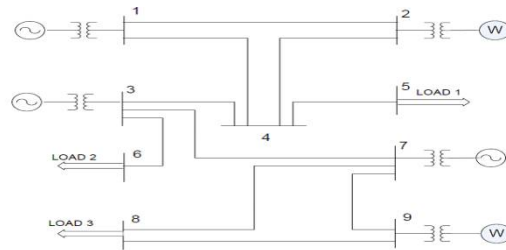


Figure 8. One line diagram for the test system

A micro grid model is developed in Simulink as shown in Figure 9 based on the one line diagram of Figure 8. This model is developed as a phasor model to expedite the simulation process. In phasor simulation, changes in magnitude and phases are calculated instead of solving complex differential equations. This type of simulation saves computational time that is required to solve the differential Equations.

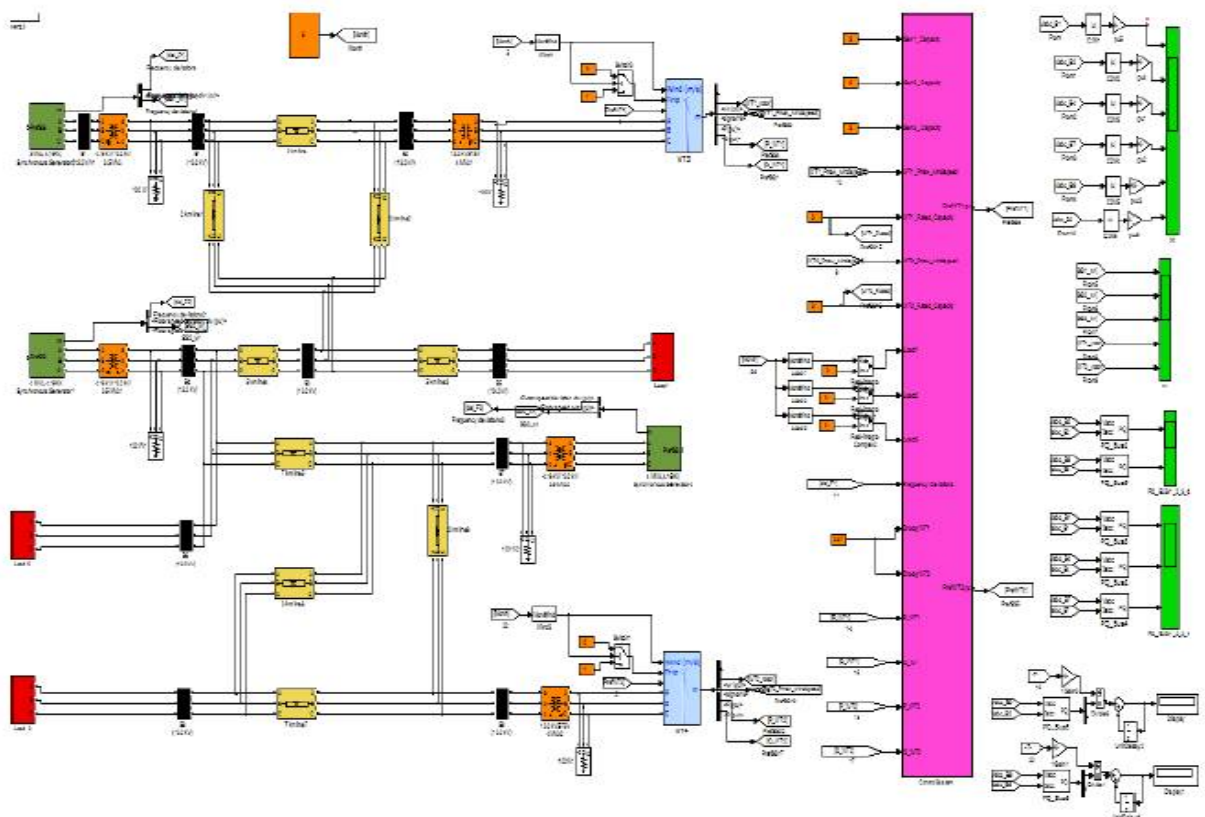


Figure 9. Micro grid test system implemented in Simulink

The dark green coloured blocks in the system represents the synchronous generators. The components in light blue represent the wind power plants and the red coloured components are the three loads in the system. The black blocks represent bus bars which actually are used to measure the voltage and current at that particular location. The orange blocks and the light yellow blocks represent transformers and transmission lines respectively. The pink coloured blocks are the micro grid control system for wind power plants and the light green blocks are for recording the output. The Micro grid test subsystem implemented in Simulink is shown in Figure 10.

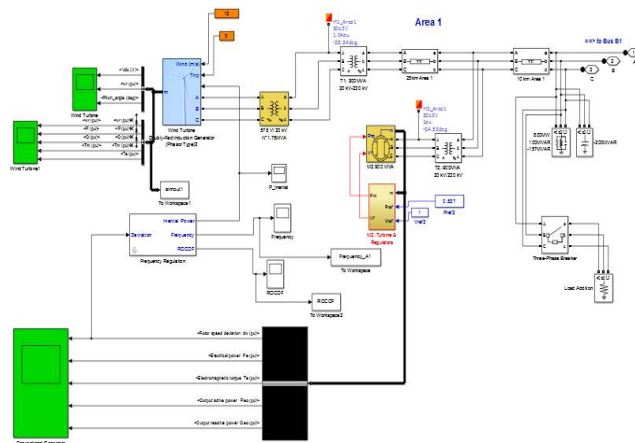


Figure 10. Micro grid test subsystem implemented in Simulink Figure 11. Wind turbine1

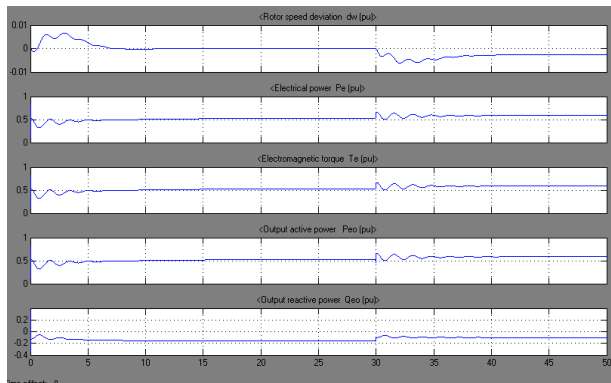
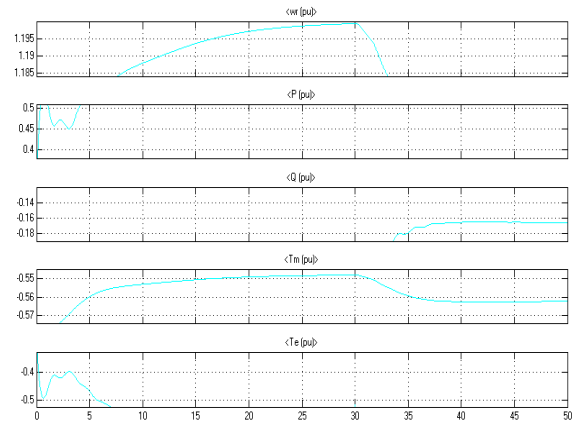


Figure 12. Conventional generator

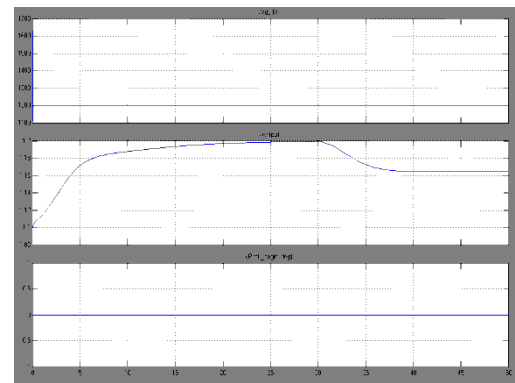


Figure 13. Wind turbine

VII. CONCLUSION

In this paper a novel control scheme for frequency control in wind power plants connected in a micro-grid environment is proposed. This control scheme enables wind power plants to participate in frequency regulation, utilizing its untapped potential/capability to provide variable active power assuming there is adequate amount of wind speed available. This control strategy eliminates the gap between using sag control for synchronous generators and the droop controller for wind power plants. To test this control methodology for implementation in the real world, a test system was modelled in MATLAB and Simulink. This test system resembled a small autonomous grid, isolated from the inheritance grid. The generation mix for the micro grid model consisted of three conventional synchronous generators and two wind power plants, adding up to a total capacity of 15 MW. The three loads connected to this system were modelled to accommodate hourly load changes for a day. The total amount of time set for the simulation of the whole test system was based on accommodating around 15 seconds of response time for each load change. To accommodate the determination of hourly load data, the system was setup to utilize hourly wind data for the wind turbines. This micro grid system was then subjected to 12 day worth of load and wind speed data from two cities. The data for each day was selected so as to represent each month of a year. The simulation study was done for numerous scenarios which included variation of the generation mix configuration from 10% to 50 % wind power to identify the effects of high

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Vol. 6, Issue 11, November 2017

penetration of wind power in a micro-grid. These scenarios also included testing of the micro grid system with and without the proposed control strategy for comparison. Observations made from this study revealed the effectiveness of the control methodology to smooth out the frequency and voltage fluctuations appearing in the isolated system. A reliable generation mix configuration of conventional and wind power generation for the two cities was also deduced which was observed to be in respect to the overall wind capacity in that location throughout the year. This control methodology and the system can be easily modified and scaled to specific requirements and can be used to study integration effects of other renewable or non-conventional energy sources. The next step can be the development of a methodology for assessing and controlling a micro grid equipped with all kinds of non-conventional energy sources like rooftop or community solar photovoltaic plants, fuel cells, internal combustion engine generators, micro-turbines, battery energy storage systems, and plug-in hybrid electric vehicles. These non-conventional energy sources have the potential to support a micro grid in need of active and reactive power sources. Inclusion of these energy sources into the micro-grid would definitely help to strengthen its reliability. Lastly, this structure can be used as a building block for an interconnected pool of micro grids to study its effect on the reliability and flexibility of grid operations.

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