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Control and Operation of A DC Grid Based on Wind Power Generation System in a Micro Grid



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Introduction

Poultry farming is the raising of domesticated birds such as chickens and ducks for the purpose of farming meat or eggs for food. To ensure that the poultries remain productive, the poultry farms in Singapore are required to be maintained at a comfortable temperature. Cooling fans, with power ratings of tens of kilowatts, are usually installed to regulate the temperature in the farms. Besides cooling the farms, the wind energy produced by the cooling fans can be harnessed using wind turbines (WTs) to reduce the farms' demand on the grid. The Singapore government is actively promoting this new concept of harvesting wind energy from electric ventilation fans in poultry farms which has been implemented in many countries around the world. The major difference between the situation in poultry farms and common wind farms is in the wind speed variability. The variability of wind speed in wind farms directly depends on the environmental and weather conditions while the wind speed in poultry farms is generally stable as it is generated by constant-speed ventilation fans.

Thus, the generation intermittency issues that affect the reliability of electricity supply and power balance are not prevalent in poultry farm wind energy systems. In recent years, the research attention on dc grids has been resurging due to technological advancements in power electronics and energy storage devices, and increase in the variety of dc loads and the penetration of dc distributed energy resources (DERs) such as solar photovoltaic's and fuel cells. Many research works on dc microgrids have been conducted to facilitate the integration of various DERs and energy storage systems.

In a dc microgram based wind farm architecture in which each wind energy conversion unit consisting of a matrix converter, a high frequency transformer and a single-phase ac/dc converter is proposed. However, the proposed architecture increases the system complexity as three stages of conversion are required. In a dc micro grid based wind farm architecture in which the WTs are clustered into groups of four with each group connected to a converter is proposed. However, with the proposed architecture, the failure of one converter will result in all four WTs of the same group to be out of service. The research works conducted in are focused on the development of different distributed control strategies to coordinate the operation of various DERs and energy storage systems in dc micro grids. These research works aim to overcome the challenge of achieving a decentralized control operation using only local variables.

However, the DERs in dc micro grids are strongly coupled to each other and there must be a minimum level of coordination between the DERs and the controllers. In a hybrid ac/dc grid architecture that consists of both ac and dc networks connected together by a bidirectional converter is proposed. Hierarchical control algorithms are incorporated to ensure smooth power transfer between the ac micro grid and the dc micro grid under various operating conditions. However, failure of the bidirectional converter will result in the isolation of the dc micro grid from the ac micro grid.

To increase the controller's robustness against variations in the operating conditions when the micro grid operates in the grid-connected or islanded mode of operation as well as its capability to handle constraints, a model-based model predictive control (MPC) design is proposed in this paper for controlling the inverters. As the micro grid is required to operate stably in different operating conditions, the deployment of MPC for the control of the inverters offers better transient response with respect to the changes in the operating conditions and ensures a more robust micro grid operation. There are some research works on the implementation of MPC for the control of inverters. In a finite control set MPC scheme which allows for the control of different converters without the need of additional modulation techniques or internal cascade control loops is presented but the research work does not consider parallel operation of power converters.

In an investigation on the usefulness of the MPC in the control of parallel-connected inverters is conducted. The research work is, however, focused mainly on the control of inverters for uninterruptible power supplies in standalone operation. The MPC algorithm will operate the inverters close to their operating limits to achieve a more superior performance as compared to other control methods which are usually conservative in handling constraints. In this paper, the inverters are controlled to track periodic current and voltage references and the control signals have a limited operating range. Under such operating condition, the MPC algorithm is operating close to its operating limits where the constraints will be triggered repetitively. In conventional practices, the control signals are clipped to stay within the constraints, thus the system will operate at the sub-optimal point.

DISTRIBUTED GENERATION AND MICROGRID OVERVIEW OF DISTRIBUTION SYSTEM

A part of power system which distributes the electrical power for local use is known as "Distribution system". It lies between the substation fed by the transmission system and the consumer meters.

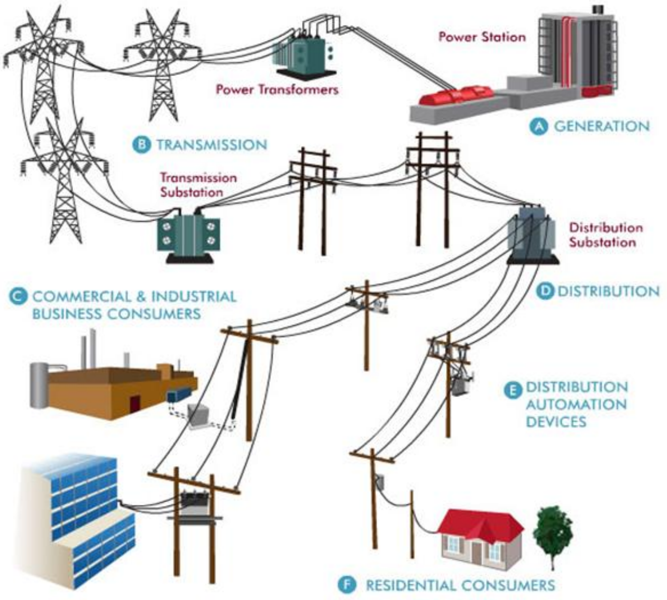

Fig.2.1 Simple model of Electrical Distribution system

Typical diagram of distribution system is shown in fig.2.1 the transmission system is distinctly different from the distribution system.

Distributed generation takes place on two-levels: the local level and the end-point level. Local level power generation plants often include renewable energy technologies that are site specific, such as solar systems (photovoltaic and combustion), fuel cells and wind turbines.

INTRODUCTION TO DISTIBUTION SYSTEM

The portion of the power network between a secondary substation and consumers is known as distribution system. The distribution system can be classified into primary and secondary system. Some large consumers are given high voltage supply from the receiving end substations or secondary substation. The area served by a secondary substation can be subdivided into a number of sub- areas. Each sub area has its primary and secondary distribution system. The primary distribution system consists of main feeders and laterals.

The main feeder runs from the low voltage bus of the secondary substation and acts as the main source of supply to sub-feeders, laterals or direct connected distribution transformers. The lateral is supplied by the main feeder and extends through the load area with connection to distribution transformers. The distribution transformers are located at convenient places in the load area. They may be located in specially constructed enclosures or may be pole mounted. The distribution transformers for a large multi storied building may be located within the building itself. At the distribution transformer the voltage is stepped down to 400V and power is fed into the secondary distribution systems.

The secondary distribution system consists of distributors which are laid along the road sides. The service connections top consumers are tapped off from the distributors. The main feeders, laterals and distributors may consist of overhead lines or cables or both. The distributors are 3 phase, 4 wire circuits, the neutral wire being necessary to supply the single phase loads.

The following is a list of those of potential interest to electric utilities. The main part of distribution system includes.

- Receiving substation
- Sub- transmission lines
- Distribution substation located nearer to the load centre
- Secondary circuits on the LV side of the distribution transformer.
- Service mains

Where the later draws power from the single source and transmits it to individual loads, the transmission system not only handles the largest blocks of power but also the system.

The distribution system is categorized into the sub-divisions:

- Primary distribution system
- Secondary distribution system

The fig.2.2 shows that simple model of electrical distribution system and also it shows the primary and secondary distribution system.

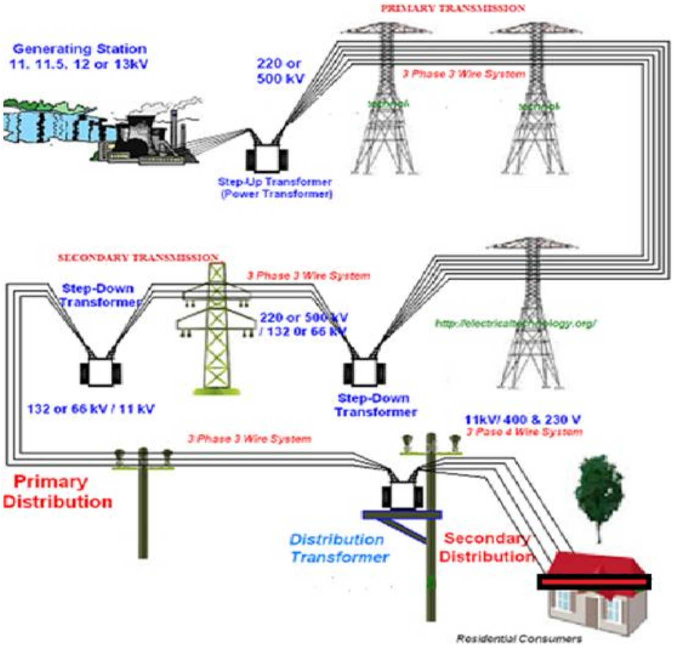

Fig.2.2 Model of electrical primary and secondary distribution system

DISTRIBUTED GENERATION AS A VIABLE ALTERNATIVE

Traditionally, electrical power generation and distribution are purely a state owned utility. However, in order to keep up with the growing demand, many states and provinces in North America are deregulating the electrical energy system. This trend is not without its own challenges. For example, how is an independent power producer (IPP) able to enter the market

Recent innovations in power electronics such as fast switching, high voltage Insulated Gate Bipolar Transistors (IGBT) and developments in power generation technologies have made DG a considerable alternative to either delaying infrastructure upgrades or as additional cogeneration support. Though the cost per KW-hr is still higher than basic power grid distribution costs, (4.36rupees/Kw-hr for gas turbines and as high as 31.13rupees/KW-hr for PV). The trend to completely deregulate the North American electric power grid along with the increasing trend in the cost of fossil fuels has resulted in the consideration of DG as a viable opportunity. Currently, BC Hydro, Canada's third largest utility has more than 50 Distributed Generator stations ranging from 0.07 MVA to 34 MVA. In the distributed system has various alternative source which always available in the nature of the system. Although the distributed system is not reliable there are renewable to system.

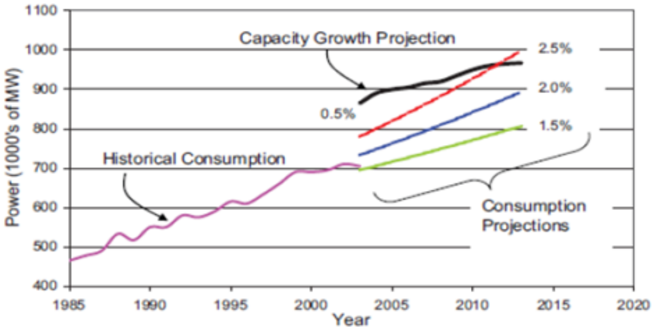

Fig.2.3 2006 United States Projected Summer Generation and Capacity

The fig 2.3 shows the 2006 United States projected summer generation and the capacity of the distribution generation system.

TYPES OF DISTRIBUTED GENERATION

Distributed Generators can be broken into three basic classes: induction, synchronous and asynchronous. Induction generators require external excitation (VARs) and start up much like a regular induction motor. They are less costly than synchronous machines and are typically less than 500 KVA. Induction machines are most commonly used in wind power applications. Alternatively, synchronous generators require a DC excitation field and need to synchronize with the utility before connection. Synchronous machines are most commonly used with internal combustion machines, gas turbines, and small hydro dams. These plants tend to be smaller and less centralized than the traditional model plants. They also are frequently more energy and cost efficient and more reliable. Some of these DG technologies offer high efficiency, resulting in low fuel costs, but emit a fair amount of pollutants (CO and NO); others are environmentally clean but are not currently cost-effective. Still others are well suited for peaking applications but lack durability for continuous output. With so much to consider, it is often difficult for decision makers to determine which technology is best suited to meet their specific energy needs.

Technology	Typical Cap	Utility Interface
Photovoltaic	10va To 5000va	Inverter
Wind	10va To 500kva	Induction And Syncronous Generators Inverters
Geothermal	100va To Several Mva	Syncronous Generator
Micro Hydro	100va To Several Mva	Induction Or Syncronous Generator
Reciprocating Engine	1000va To Several Mva	Induction Or Sycronous Generator
Comubtion Turbine	1000va To Several Mva	Syncronous Generator
Combined Cycle	1000va To Several Mva	Sycronous Generator
Micro Turbines	10 Kva To Several Mva	Inverter
Fuel Cells	10 Kva To Several Mva	Inverter

Table.2.1 Types of DG and Typical Capacities

DISTRIBUTION SYSTEM WITH MULTIPLE DGS

Distributed or dispersed generation may be defined as generating resources other than central generating stations that is placed close to load being served, usually at customer site. It serves as an alternative to or enhancement of the traditional electric power system.

The commonly used distributed resources are wind power, photo voltaic, hydro power. The fig.2.4 shows the single line diagram of the distribution system with multiple DGs.

Small localized power sources, commonly known as "Distributed Generation" (DG), have become a popular alternative to bulk electric power generation. There are many reasons for the growing popularity of DG; however, on top of DG tending to be more renewable.

DG can serve as a cost effective alternative to major system upgrades for peak shaving or enhancing load capacity margins. Additionally, if the needed generation facilities could be constructed to meet the growing demand, the entire distribution and transmission system would also require upgrading to handle the additional loading.

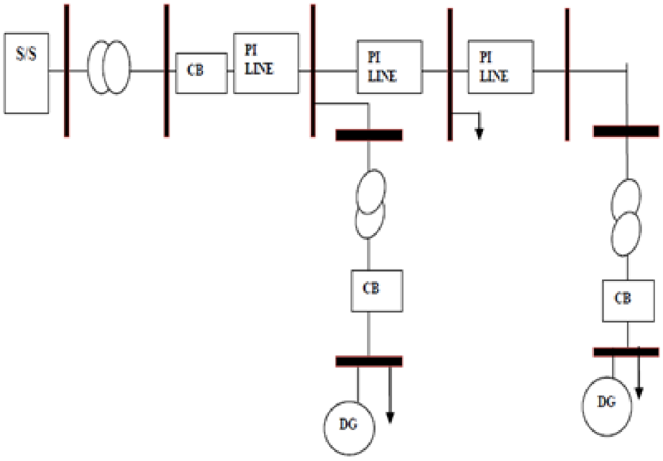

Fig.2.4 Single line diagram of Distributed system with multiple DGs

Therefore, constructing additional power sources and upgrading the transmission system will take significant cost and time, both of which may not be achievable.

Advantages of distributed generations

DG resources can be located at numerous locations within a utility's service area. This aspect of DG equipment provides a utility tremendous flexibility to match generation resources to system needs.

- Improved Reliability - DG facilities can improve grid reliability by placing additional generation capacity closer to the load, thereby minimizing impacts from transmission and distribution (T&D) system disturbances, and reducing peak-period congestion on the local grid.
- Improved Security - The utility can be served by a local delivery point. This significantly decreases the vulnerability to interrupted service from imported electricity supplies due to natural disasters, supplier deficiencies or interruptions, or acts of terrorism.
- Reduced Loading of T&D Equipment - By locating generating units on the low-voltage bus of existing distribution substations, DG will reduce loadingson substation power transformers during peak hours, thereby extending the useful life of this equipment and deferring planned substation upgrades.
- Reduces the necessity to build new transmission and distribution lines or upgrade existing ones.
- Reduce transmission and distribution line losses.
- Improve power quality and voltage profile of the system.

TECHNICAL CHALLENGES FACING DISTRIBUTED GENERATION

Distributed Generation (DG) is not without problems. DG faces a series of integration challenges, but one of the more significant overall problems is that the electrical distribution and transmission infrastructure has been designed in a configuration where few high power generation stations that are often distant from the their consumers, ”push” electrical power onto the many smaller consumers.

DG systems are often smaller systems that are that are locally integrated into the low voltage distribution system. Which conflicts with the existing power network design paradigm. An example of a similar radial system is with a large city’s water distribution where one very large pipe of water slowly becomes narrower and narrower until it reaches the customer’s tap at a low flow and low pressure.

What would happen if one of the consumers had water well and started pumping water into the system. Adding DG to the existing electric power distribution system can lead to a reduction of protection reliability, system stability and quality of the power to the customers. More specifically, the technical challenges that the installation of distributed generation faces have been reviewed in various studies where the findings of the various studies are discussed.

Depending on the amount of DG connected and the strength of the utility power system, the issues can become substantial problems. Of the challenges with DG

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the problem of protection against unplanned islanding is a significant one.

MICROGRID

A micro-grid is a network consisting of distributed generator and storage devices used to supply loads. A distributed generator (DG) in a micro-grid is usually a renewable source, such as combined heat and power (CHP), photovoltaic (PV), wind turbine, or small-scale diesel generator. DGs are usually located near the loads, so that line losses in a micro-grid are relatively low. A micro-grid can work with a host grid connection or in islanded mode. When grid connected, DGs supports the main grid during peak demand. However, if there is a disturbance in the main grid, a micro-grid can supply the load without the support of the main grid. Moreover, a micro-grid can be reconnected when the fault in the main grid is removed. Furthermore, as in any technology, micro-grid technology faces many challenges. Many considerations should be taken into account, such as the control strategies based on of the voltage, current, frequency, power, and network protection.

Need for a micro grid

A micro-grid is used for many reasons. It is a new paradigm that can meet the increase in the world’s electrical demand. It can also increase energy efficiency and reduce carbon emission, because the DGs commonly use renewable sources or a small-scale back-up diesel generator. By using a micro-grid, the critical loads will be ensured to be supplied all the time. Economically, extending the main grid is expensive, so a micro-grid can be used to supply the load instead. Moreover, the main grid is supported by DGs; therefore, overall power quality and reliability will improve. Also, by using a micro-grid, the main grid generators will supply less power. Having a generator of the main grid that runs with less fossil fuels is beneficial. Another economic reason is that the DGs are located near the load, and thus line losses are kept to a minimum. A micro-grid can be used to supply energy to remote areas or in places where the host grid is both inefficient and difficult to install. For example, in some areas, the load demand is so low that the load can be supplied entirely by small-scale DGs. Therefore, a micro-grid is the suitable choice for supplying the load demand. Moreover, some areas have harsh geographic features, making the main grid difficult to connect. Using a micro-grid is the best solution to provide power to these areas. In summary, the most important issues that make the micro-grid technology important are:

- Load demand has increased worldwide.
- Micro-grids use renewable sources, so they have less impact on the environment.
- Extending the main grid is not only costly but also difficult.
- A micro-grid can supply critical loads even if it is disconnected from the main grid.

MICROGRID STRUCTURE AND COMPONENTS

The fig.2.5 shows the structure of a micro-grid. This structure is based on renewable energy sources. The main grid is connected to the micro-grid at the point of a common coupling. Each micro-grid has a different structure (number of the DGs and types of DGs), depending on the load demand. A micro-grid is designed to be able to supply its critical load. Therefore, DGs should insure to be enough to supply the load as if the main grid is disconnected. The micro-grid consists of micro sources, power electronic converters, distributed storage devices, local loads, and the point of common coupling (PCC).

The grid voltage is reduced by using either a transformer or an electronic converter to a medium voltage that is similar to the voltage produced from the DG

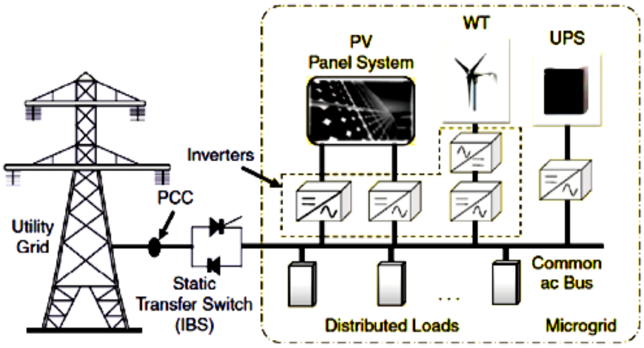

Fig.2.5 Micro-grid Structure based on renewable energy sources

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The components of the micro-grid are as follows.

- Micro source
- Power electronics converters
- Various loads on micro grid
- Storage devices
- Control system

MICRO-GRID OPERATION

A micro-grid being a plug and play power unit does have different operational modes. More specifically, a micro-grid that is an integral part of a bulk grid system can only have the following modes of operation:

Grid Connection Mode

The grid connection mode is the normal operation status of the micro-grid. In this mode, the load is supplied by both the grid and the micro-grid.

The voltage of the grid is determined by the PCC. The voltage of the grid should be in the same phase as the voltage generated by the DG.

Therefore, in the grid connection mode, the voltage and frequency of the DG are controlled by the grid voltage and frequency.

Islanded Mode

When the grid experiences a fault or disturbance, the main grid is disconnected from the micro-grid by the PCC switch. In this situation, the micro-grid loads are supplied only by the DGs.

Thus, the voltage amplitude and frequency are regulated by the DGs, and the DGs are responsible for the stability of the system by providing nominal voltage and frequency for the micro-grid.

Voltage and frequency management

The primary purpose is to balance the system against losses disturbances so that the desired frequency and power interchange is maintained that is why, voltage and frequency inner loops must be adjusted and regulated as reference within acceptable limits

Supply and demand balancing

When the system is importing from the grid before islanding, the resulting frequency is smaller than the main frequency, been possible that one of the units reaches maximum power in autonomous operation.

Besides, the droop characteristic slope tries to switch in vertical as soon as the maximum power limit has been reached and the operating point moves downward vertically as load increases..

Power quality

Power quality must synthesize quality of supply and quality of consumption using sustainable development as transporting of renewable energy, embedded generation, using high requirements on quality and reliability by industrial, commercial and domestic loads/costumers avoiding variations as harmonic distortion or sudden events as interruptions or even voltage dips.

After the primary control is applied in islanded mode, a small deviation in the voltagee and frequency can be observed in the micro-grid.

This deviation must be removed to ensure the full and stable operation of the micro-grid in islanded mode. DGs are responsible for the stability of the system by providing nominal voltage.

Transition between grid connection and islanded mode

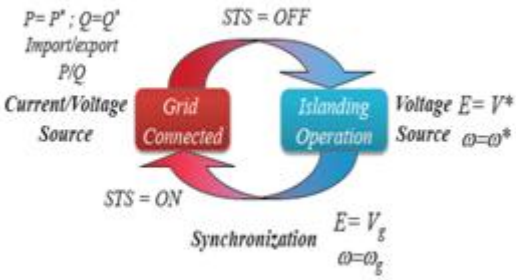

Fig.2.6 Transition between grid connection and islanded mode

The third type of operation mode of a micro-grid is the transition between grid connection and islanded mode 0shown in fig.2.6.

In this situation, the voltage amplitude and frequency should be controlled to be within the acceptable limits to ensure the safe transition from one mode to another. At this stage, the static switch adjusts the power reference to the desired value. After the primary control is applied in islanded mode, a small deviation in the voltage and frequency can be observed in the micro-grid. This deviation must be removed to ensure the full and stable operation of the micro-grid in islanded mode.

WIND ENERGY CONVERSION SYSTEMS

WIND TURBINE TECHNOLOGY

The wind turbine is the first and foremost element of wind power systems. There are two main types of wind turbines, the horizontal-axis and vertical-axis turbines.

Horizontal-axis Turbines

Horizontal-axis turbines (see Figure 3.1) are primarily composed of a tower and a nacelle mounted on top of tower. The generator and gearbox are normally located in the nacelle. It has a high wind energy conversion efficiency, self-starting capability, and access to stronger winds due to its elevation from the tower. Its disadvantages, on the other hand, include high installation cost, the need of a strong tower to support the nacelle and rotor blade, and longer cables to connect the top of the tower to the ground.

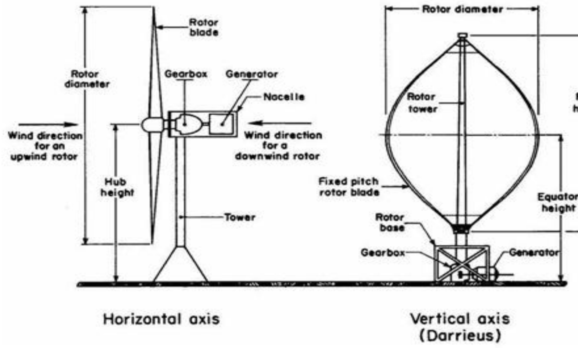

Figure 3.1: illustration of a horizontal axis and a vertical axis wind turbine.

Vertical-axis Turbines

A vertical axis turbines' spin axis is perpendicular to the ground (See Figure 3.1). The wind turbine is vertically mounted, and its generator and gearbox is located at its base. Compared to horizontal-axis turbines, it has reduced installation cost, and maintenance is easier, because of the ground level gear box and generator installation. Another advantage of the vertical axis turbine is that its operation is independent of wind direction. The blades and its attachments in vertical axis turbines are also lower in cost and more rugged during operation. However, one major drawback of the vertical wind turbine is that it has low wind energy conversion efficiency and there are limited options for speed regulation in high winds. Its efficiency is around half of the efficiency of horizontal axis wind turbines. Vertical axis turbines also have high torque fluctuations with each revolution, and are not self-starting. Mainly due to efficiency issue, horizontal wind turbines are primarily used. Consequently, the wind turbine considered in this thesis is a horizontal axis turbine.

TYPES OF WIND ENERGY CONVERSION SYSTEMS (WECS)

There are two main types of WECSs, the fixed speed WECS and variable-speed WECS. The rotor speed of a fixed-speed WECS, also known as the Danish concept, is fixed to a particular speed. The other type is the variable-speed WECS where the rotor is allowed to rotate freely. The variable-speed WECS uses power maximization techniques and algorithms to extract as much power as possible from the wind.

Fixed Speed Wind Energy Conversion Systems

As the name suggests, fixed speed wind energy systems operate at a constant speed. The fixed speed WECS configuration is also known as the "Danish concept" as it is widely used and developed in Denmark. Normally, induction (or asynchronous) generators are used in fixed speed WECSs because of its inherent insensitivity to changes in torque. The rotational speed of an induction machine varies with the force applied to it, but in practice, the difference between its speed at peak power and at idle mode (at synchronous speed) is very small.

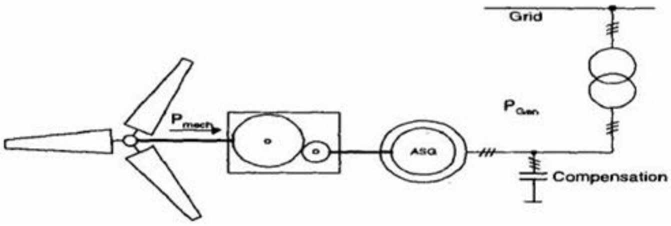

Figure 3.2: A typical fixed speed wind turbine configuration.

The fixed speed wind systems have the generator stator directly coupled to the grid (see Figure 3.2).

Consequentially, the system is characterized by stiff power train dynamics that only allow small variations in the rotor speed around the synchronous speed. Due to the mechanical characteristics of the induction generator and its insensitivity to changes in torque, the rotor speed is fixed at a particular speed dictated by the grid frequency, regardless of the wind speed. The construction and performance of fixed-speed wind turbines are dependent on the turbine's mechanical characteristic. Squirrel-cage induction generators (SCIG) are typically used in fixed speed systems. The system in Figure 3.2 transforms wind energy into electrical energy by using a squirrel cage induction machine directly connected to a three-phase power grid. The rotor of the wind turbine is coupled to the generator shaft with a fixed ratio gearbox. With respect to variable speed wind turbines, fixed speed turbines are well established, simple, robust, reliable, cheaper, and maintenance-free. But because the system is fixed at a particular speed, variation in wind speed will cause the turbine to generate highly fluctuating output power to the grid. These load variations require a stiff power grid to enable stable operation and the mechanical design must be robust enough to absorb high mechanical stresses. Also, since the turbine rotates at a fixed speed, maximum wind energy conversion efficiency can be only achieved at one particular wind speed. This is because for each wind speed, there is a particular rotor speed that will produce the TSR that gives the maximum Cp value. As observed from the relationship described by (1) and illustrated by Figures, the maximum Cp value corresponds to the maximum mechanical power. Since fixed speed systems do not allow significant variations in rotor speed, these systems are incapable of achieving the various rotor speeds that result in the maximum Cp value under varying wind conditions.

Variable Speed Wind Turbine Systems

In variable speed wind turbine systems, the turbine is not directly connected to the utility grid. Instead, a power electronic interface is placed between the generator and the grid to provide decoupling and control of the system. Thus, the turbine is allowed to rotate at any speed over a wide range of wind speeds. It has been discussed earlier that each wind speed has a corresponding optimal rotor speed for maximum power. With the added control feature of variable speed systems, they are capable of achieving maximum aerodynamic efficiency. By using control algorithms and/or mechanical control schemes (i.e. pitch controlled, etc), the turbine can programmed to extract maximum power from any wind speed by adjusting its operating point to achieve the TSR for maximum power capture. The mechanical stresses on the wind turbine are reduced since gusts of wind can be absorbed (i.e. energy is stored in the mechanical inertia of the turbine and thus reduces torque pulsations).

Another advantage of this system is that the power quality can be improved by the reduction of power pulsations due to its elasticity. The disadvantages of the variable speed system include the additional cost of power converters and the complexity of the control algorithms. In this thesis, an adaptive maximum power point tracking control algorithm is developed for variable speed energy systems to achieve maximum efficiency under fluctuating wind conditions.

MODELING OF A VARIABLE SPEED WIND TURBINE WITH PMSG

Full Scale Wind Turbines (FSWT) are the state-of-the-art type wind turbines that the generator is completely decoupled from the grid with two back-to-back converters and whole power is transferred through these controlled converters. One converter is used on the generator side and the other one is used on the grid side. FSWTs can employ both induction (asynchronous) and synchronous type generators, where synchronous generators can be separately excited (conventional) or permanent magnet type. Generally multi-pole permanent magnet synchronous generators are employed, which removes the need for a gearbox between wind turbine rotor and generator. Since this type of wind turbines has many advantages like mechanical reliability, better efficiency, reduced risk of possible drive-train oscillations, this thesis will deal with PMSG type FSWTs.

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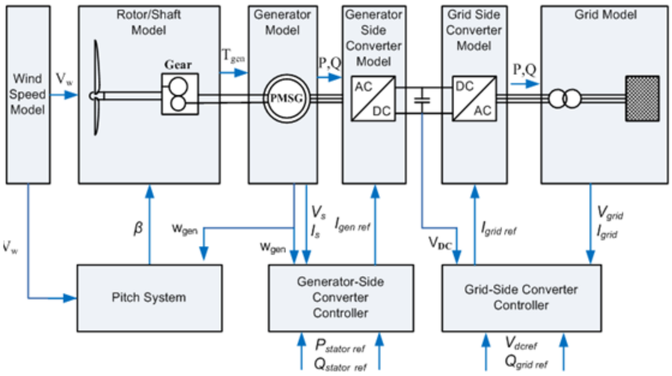

Figure 3.11 Block Diagram of PMSG Type Wind Turbine

Figure 3.11 depicts the general block diagram of a VSWT with PMSG. As seen, the model of a VSWT equipped with PMSG is very similar to that of a VSWT with a DFIG. Wind speed model, rotor (aerodynamic) model and pitch model are identical to those in DFIG type wind turbine model.

SYSTEM DESCRIPTION AND MODELING

A. SYSTEM DESCRIPTION

The overall configuration of the proposed dc grid based wind power generation system for the poultry farm is shown in Fig. 4.1. The system can operate either connected to or islanded from the distribution grid and consists of four 10 kW permanent magnet synchronous generators (PMSGs) which are driven by the variable speed WTs. The PMSG is considered in this project because it does not require a dc excitation system that will increase the design complexity of the control hardware. The three-phase output of each PMSG is connected to a three-phase converter (i.e., converters A, B, C and D), which operates as a rectifier to regulate the dc output voltage of each PMSG to the desired level at the dc grid. The aggregated power at the dc grid is inverted by two inverters (i.e., inverters 1 and 2) with each rated at 40 kW. Instead of using individual inverter at the output of each WG, the use of two inverters between the dc grid and the ac grid is proposed. This architecture minimizes the need to synchronize the frequency, voltage and phase, reduces the need for multiple inverters at the generation side, and provides the flexibility for the plug and play connection of WGs to the dc grid. The availability of the dc grid will also enable the supply of power to dc loads more efficiently by reducing another ac/dc conversion. The coordination of the converters and inverters is achieved through a centralized energy management system (EMS). The EMS controls and monitors the power dispatch by each WG and the load power consumption in the microgrid through a centralized server. To prevent excessive circulating currents between the inverters, the inverter output voltages of inverters 1 and 2 are regulated to the same voltage. Through the EMS, the output voltages of inverters 1 and 2 are continuously monitored to ensure that the inverters maintain the same output voltages. The centralized EMS is also responsible for other aspects of power management such as load forecasting, unit commitment, economic dispatch and optimum power flow.

Important information such as field measurements from smart meters, transformer tap positions and circuit breaker status are all sent to the centralized server for processing through wireline/wireless communication. During normal operation, the two inverters will share the maximum output from the PMSGs (i.e., each inverter shares 20 kW). The maximum power generated by each WT is estimated from the optimal wind power Pwt,opt as follows

$$P_{wt,opt} = K_{opt}(W_{r,opt})^3$$

$$K_{opt} = \frac{1}{2} C_{p,opt} \rho A \left(\frac{R}{\lambda_{opt}}\right)^3$$

$$W_{r,opt} = \frac{\lambda_{opt} V}{R}$$

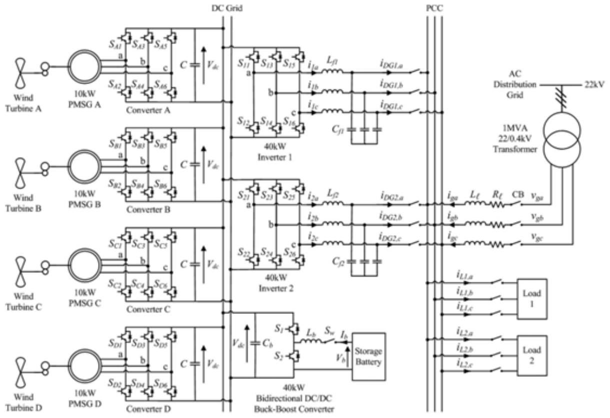

Fig. 4.1. Overall configuration of the proposed dc grid based wind power generation system in a microgrid.

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When one inverter fails to operate or is under maintenance, the other inverter can handle the maximum power output of 40 kW from the PMSGs. Thus the proposed topology offers increased reliability and ensures continuous operation of the wind power generation system when either inverter 1 or inverter 2 is disconnected from operation. An 80 Ah storage battery (SB), which is sized is connected to the dc grid through a 40 kW bidirectional dc/dc buck-boost converter to facilitate the charging and discharging operations when the microgrid operates connected to or islanded from the grid. The energy constraints of the SB in the proposed dc grid are determined based on the system-on-a-chip (SOC) limits given by

$$\mathrm{SOC} < SOC \leq \mathrm{SOC}_{\max}$$

B. SYSTEM OPERATION

When the micro grid is operating connected to the distribution grid, the WTs in the micro grid are responsible for providing local power support to the loads, thus reducing the burden of power delivered from the grid. The SB can be controlled to achieve different demand side management functions such as peak shaving and valley filling depending on the time-of-use of electricity and SOC of the SB. During islanded operation where the CBs disconnect the microgrid from the distribution grid, the WTs and the SB are only available sources to supply the load demand.

C. AC/DC CONVERTER MODELING

Fig. 4.2 shows the power circuit consisting of a PMSG which is connected to an ac/dc voltage source converter. The PMSG is modeled as a balanced three-phase ac voltage source esa, esb, esc with series resistanceRs and inductanceLs.

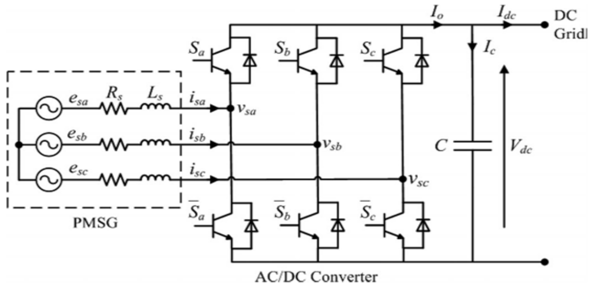

Fig. 4.2. Power circuit of a PMSG connected to an ac/dc voltage source converter

D. DC/AC Inverter Modeling

The two 40 kW three-phase dc/ac inverters which connect the dc grid to the point of common coupling (PCC) are identical, and the single-phase representation of the three-phase dc/ac inverter is shown in Fig. 4.3.

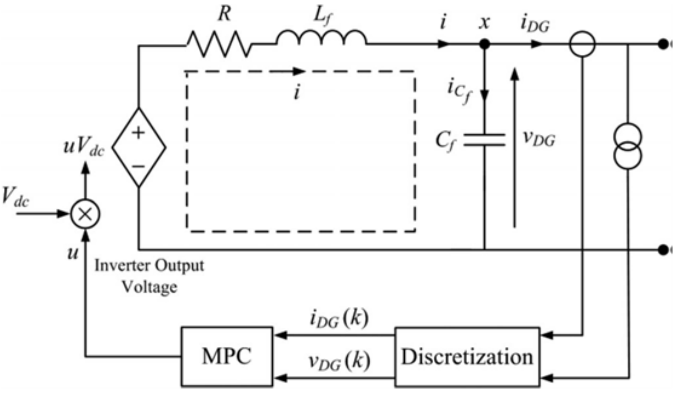

Fig. 4.3. Single-phase representation of the three-phase dc/ac inverter.

During grid-connected operation, the inverters are connected to the distribution grid and are operated in the current control mode (CCM) because the magnitude and the frequency of the output voltage are tied to the grid voltage. In this project, the grid is set as a large power system, which means that the grid voltage is a stable three-phase sinusoidal voltage. Hence, when operating in the CCM, a three-phase sinusoidal signal can be used directly as the exogenous input. During islanded operation, the inverters will be operated in the voltage control mode (VCM). The voltage of the PCC will be maintained by the inverters when the microgrid is islanded from the grid.

E. CONTROL DESIGN FOR THE AC/DC CONVERTER

Fig. 4.4 shows the configuration of the proposed controller for each ac/dc voltage source converter which is employed to maintain the dc output voltage Vdc of each converter and compensate for any variation in Vdc due to any power imbalance in the dc grid. The power imbalance will induce a voltage error at the dc grid, which is then fed into a proportional integral controller to generate a current reference i*d for id to track. To eliminate the presence of high frequency switching ripples at the dc grid, Vdc is first passed through a first-order LPF. The current iq is controlled to be zero so that the PMSG only delivers real power. The current errors Δid and Δiq are then converted into the abc frame and fed into a proportional resonant (PR) controller to generate the required control signals using pulse-width modulation.

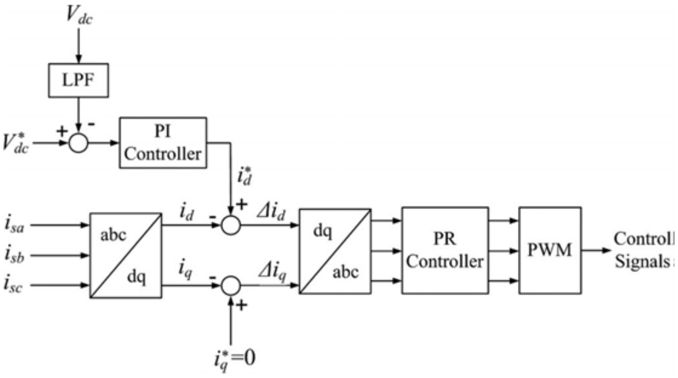

Fig. 4.4. Configuration of the proposed controller for the ac/dc converter.

F. CONTROL DESIGN FOR THE DC/AC INVERTER

In order for the micro grid to operate in both grid-connected and islanded modes of operation, a model-based controller using MPC is proposed for the control of the inverters. MPC is a model-based controller and adopts a receding horizon approach in which the optimization algorithm will compute a sequence of control actions to minimize the selected objectives for the whole control horizon, but only execute the first control action for the inverter. At the next time step, the optimization process is repeated based on new measurements over a shifted prediction horizon. By doing so, MPC can make the output track the reference at the next step, as well as plan and correct its control signals along the control process. This will guarantee a better transient response compared to conventional PID/PR controllers.

SIMULATION RESULTS

The simulation model of the proposed dc grid based wind power generation system shown in Fig. 4.1 is implemented in MATLAB/Simulink. The effectiveness of the proposed design concept is evaluated under different operating conditions when the micro grid is operating in the grid-connected or islanded mode of operation.

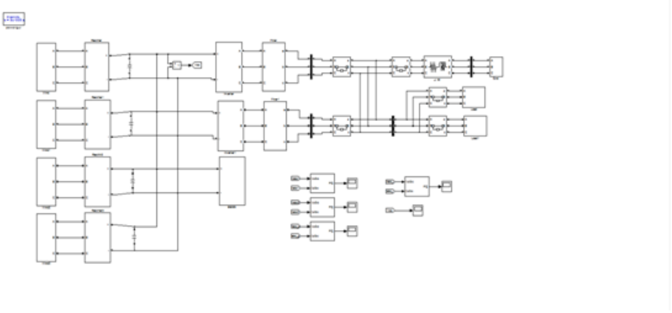

Fig:5.1- simulation diagram of a Failure of One Inverter During Grid-Connected Operationt

The system parameters are given in Table I. The impedances of the distribution line are obtained from [34].In practical implementations, the values of the converter and inverter loss resistance are not precisely known. Therefore, these values have been coarsely estimated.

A. TEST CASE 1: FAILURE OF ONE INVERTER DURING

Grid-Connected Operation When the micro grid is operating in the grid-connected mode of operation, the proposed wind power generation system will supply power to meet part of the load demand. Under normal operating condition, the total power generated by the PMSG sat the dc grid is converted by inverters 1 and 2 which will share the total power supplied to the loads.

When one of the inverters fails to operate and needs to be disconnected from the dc grid, the other inverter is required to handle all the power generated by the PMSGs. In this test case, an analysis on the micro grid operation when one of the inverters is disconnected from operation is conducted. With each PMSG generating about 5.5 kW of real power, the total power generated by the four PMSGs is about 22 kW which is converted by inverters 1 and 2 into 20 kW and 8 kVAr of real and reactive power respectively. Figs. 5.2 and 5.3 show the waveforms of the real and reactive power delivered by inverters 1 and2 for $0 \leq t < 0.4$ s respectively. For $0 \leq t < 0.2$ s, both inverters1 and 2 are in operation and each inverter delivers about 10kW of real power and 4 kVAr

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of reactive power to the loads. The remaining real and reactive power that is demanded by the loads is supplied by the grid which is shown in Fig. 7. It can be seen from Fig. 7 that the grid delivers 40 kW of real power and 4 kVAr of reactive power to the loads for 0 ≤ t < 0.2 s. The total real and reactive power supplied to the loads is about 60kW and 12 kVAr as shown in the power waveforms of Fig5.5..The unsteady measurements observed in the power waveforms for 0 ≤ t < 0.08 s are because the controller requires a period of about four cycles to track the power references during the initialization period. As compared to conventional control strategies, it can be observed that the proposed MPC algorithm is able to quickly track and settle to the power reference. This is attributed to the optimization of the inverters through the Model-based MPC control. Essentially, model-based control schemes are able to take into account the system parameters such that the overall performance can be optimized. At t = 0.2 s, inverter 1 fails to operate and is disconnected from the micro grid, resulting in a loss of 10 kW of real power and 4 kVAr of reactive power supplied to the loads. As shown in Fig. 5.2, the real and reactive power supplied by inverter 1 is decreased to zero in about half a cycle after inverter 1 is disconnected. This undelivered power causes a sudden power surge in the dc grid which corresponds to a voltage rise at t = 0.2 s as shown in Fig. 5.6. To ensure that the load demand is met, the grid automatically increases its real and reactive power generation to50 kW and 8 kVAr respectively at t = 0.2 s, as shown in Fig. 7.At t = 0.26 s, the EMS of the micro grid increases the reference real and reactive power supplied by inverter 2 to 20 kW and8 kVAr respectively. A delay of three cycles is introduced to cater for the response time of the EMS to the loss of inverter1. As shown in Fig. 5.3, inverter 2 manages to increase its real and reactive power supplied to the loads to 20 kW and 8 kVAr for 0.26 ≤ t < 0.4 s. At the same time, the grid decreases its real and reactive power back to 40 kW and 4 kVAr as shown in Fig. 5.5 respectively.

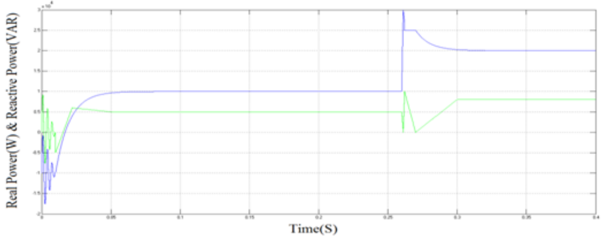

Fig:5.2- Real (top) and reactive (bottom) power delivered by inverter 1.

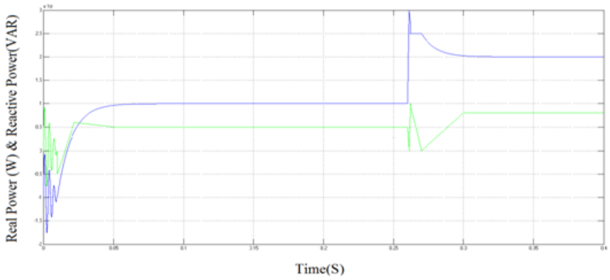

Fig:5.3 Real (top) and reactive (bottom) power delivered by inverter 2.

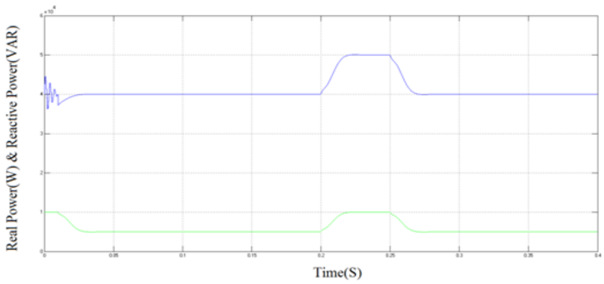

Fig:5.4- Real (top) and reactive (bottom) power delivered by the grid.

The power balance in the micro grid is restored after three cycles from t = 0.26 s. It is observed from Fig. 5.6 that the voltage at the dc grid corresponds to a voltage dip at t = 0.26 s due to the increase in power drawn by inverter 2 and then returns to its nominal value of 500 V for 0.26 ≤ t < 0.4 s. As observed in Fig. 5.5, at t = 0.26 s, the changes in power delivered by inverter 2 and the grid also cause a transient in the load power.

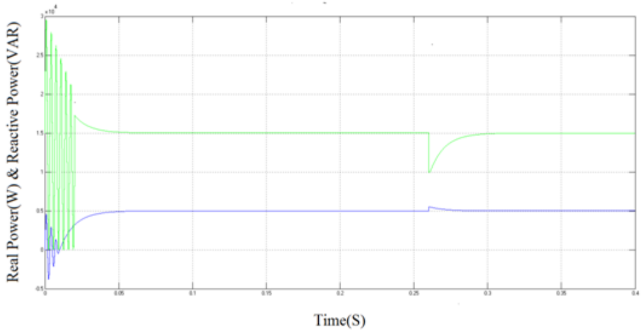

Fig:5.5- Real (top) and reactive (bottom) power consumed by the loads.

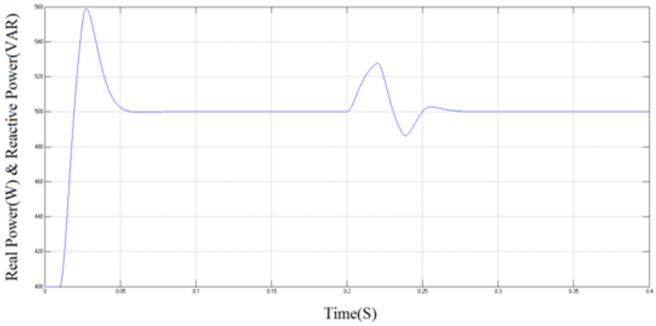

Fig:5.6- DC grid voltage.

CONCLUSION

In this project, the design of a dc grid based wind power generation system in a Micrigrid that enables parallel operation of several WGs in a poultry farm has been presented. As compared to conventional wind power generation systems, the proposed Micrigrid architecture eliminates the need for voltage and frequency synchronization, thus allowing the WGs to be switched on or off with minimal disturbances to the Micrigrid operation. The design concept has been verified through various test scenarios to demonstrate the operational capability of the proposed Micrigrid and the simulation results has shown that the proposed design concept is able to offer increased flexibility and reliability to the operation of the Micrigrid. However, the proposed control design still requires further experimental validation because measurement errors due to inaccuracies of the voltage and current sensors, and modeling errors due to variations in actual system parameters such as distribution line and transformer impedances will affect the performance of the controller in practical implementation. In addition, MPC relies on the accuracy of model establishment; hence further research on improving the controller robustness to modeling inaccuracy is required. The simulation results obtained and the analysis performed in this project serve as a basis for the design of a dc grid based wind power generation system in a micro grid.

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