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An Improved Control Strategy for DC Grid - Based Wind Power Generation System in a Microgrid

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ABSTRACT: This paper presents the design of a dc grid-based wind power generation system that allows flexible operation of multiple parallel - connected wind generators by eliminating the need for voltage and frequency synchronization. An alternative solution to the ac micro grids proposed with a distribution network where the ac outputs of the wind generators (WGs) are rectified to a common voltage at the dc bus. The dc micro grids provides the flexibility to enable the voltage at the dc grid to be controlled for parallel operation of several WGs without the need to synchronize the voltage, frequency and phase, thus allowing the WGs to be turned ON or OFF anytime without causing any disruptions. To increase the controller's robustness against variations in the operating conditions a fuzzy based controller is introduced the fluctuations of the micro grid are controller with the constant regulated power a separate controller is introduced to the wind turbine to maintain the fixed power to mitigate the vartional errors . The proposed scheme is validated with test setup designed in matlab Simulink which illustrates the operational capability of the proposed micro grid when it operates connected to and islanded from the distribution grid, and the results obtained are discussed.

I. INTRODUCTION

In general now a day's renewable energy sources are most popular and vast increasing trend for production of power. Production of power from wind energy is one of the concept and vital role in our state. Wind power using wind turbines (WTs) to reduce the demand on the grid. Usually in wind farms the wind speed is variable one. The variability of wind speed in wind farms directly depends on the environmental and weather conditions. Thus, the generation of power due to wind speed variation and related issues that affect the reliability of electricity supply and power balance in system grid.

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 photovoltaics and fuel cells. Many research works on dc micro grids have been conducted to facilitate the integration of various DERs and energy storage systems. In previous work, a dc micro grid 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. 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 used. However, with the existing architecture, the failure of one converter will result in all four WTs of the same group to be out of service. The research works 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 co-ordination between the DERs and the controllers. A hybrid ac/dc grid architecture that consists of both ac and dc networks connected together by a bidirectional converter is used. Hierarchical control algorithms are incorporated to ensure smooth power transfer between the ac micro grid and the dc

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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.

An alternative solution using a dc grid based distribution network where the ac outputs of the wind generators (WGs) are rectified to a common voltage at the dc grid is used in this work. The most significant advantage of the existing system is that only the voltage at the dc grid has to be controlled for parallel operation of several WGs without the need to synchronize the voltage, frequency and phase, thus allowing the WGs to be turned ON or OFF anytime without causing any disruptions.Many research works on designing the controllers for the control of inverters in a micro grid during grid-connected and islanded operations. A commonly adopted control scheme contains an inner voltage and current loop and an external power loop to regulate the output voltage and the power flow of the inverters. A control scheme uses separate controllers for the inverters during grid-connected and islanded operations is used. Although there are a lot of research works being conducted on the development of primary control strategies for DG units, there are many areas that require further improvement and research attention. These areas include improving the robustness of the controllers to topological and parametric uncertainties, and improving the transient response of the controllers.

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. 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.

II. TITLE WORKS

In the past decade, there has been a significant increase in the research, development, and use of distributed-generation systems [1]. The prospect of generating power from clean energy sources and local power generation near consumers has fundamentally changed the way of thinking with regard to the conventional centralized, large generation-based power systems. Power systems composed of small-scale distributed energy resources, such as wind turbines, fuel cells, photovoltaic, storage devices, etc. can be stand alone and grid connected. Many of these generation sources directly produce either dc or variable frequency/voltage ac outputs and, thus, power-electronics technologies have become the key element of many distributed generation systems [2], [3].Considering a distributed power system with its own small scale generations and loads, a micro grid is formed [4]. Typical examples of micro grids are power systems in an all-electric ship [5], isolated island [6], [7], CERTS micro grid [8], etc. Most of the research conducted so far has concentrated on ac micro grids (e.g., islanding detection and autonomous operation of ac micro grids [7], [9] and power sharing of parallel-connected multiple ac inverters [10], [11]).With the rapid development of power-electronics technology, the wider adoption of renewable energy sources, and the improvement and cost reduction of energy storage systems, multi terminal high-voltage dc grid and low-voltage dc micro grid have been proposed for large-scale wind power integration [12], commercial facilities (e.g., data centers [13], [14], isolated island [15], etc.). The protection of low-voltage dc micro grids was studied in [14] where various protection devices were discussed and different fault detection and grounding methods were investigated. DC voltage control and power sharing in a dc micro grid was investigated considering the dc-side impedance. Different operation modes for dc distribution networks including ac connection fault and islanding have been studied [15].Reduced matrix converter is a convenient topology for offshore wind farm by its potential to reduce the size and weight of the converter, to improve the reliability by removing the electrolytic capacitor, and to increase the efficiency inherent to the less stages of conversion. Moreover, it is a very flexible topology which permits different types of operation with a simpler modulation compared with conventional three phase matrix converter. This paper investigates different modulation strategies applied to reduced matrix converter for offshore wind farms focused on efficiency improvement of the entire convention system. Simulation results using a detailed loss model are presented. Four cases are investigated according to the modulation strategies (space vector modulation and carrier based modulation) and the operation principle (current source converter or voltage source

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converter). Losses in the clamp circuit are also calculated. Results show that current source operation with space vector modulation presents minimum losses. This operation is suitable for series connection of offshore wind farms which has been reported as the most efficient alternative from the grid losses point of view.

This paper presents a "distributed high-voltage dc (HVDC) converter" for offshore wind farms. The proposed converter topology allows series interconnection of wind turbines with the need of neither ac transformer nor offshore platform at the sending end. Each wind turbine is equipped with a 5-MW permanent-magnet synchronous generator and an ac–dc–dc converter. The converter topology is a diode rectifier (ac–dc) cascaded with a single-switch step-down converter (dc–dc). The dc–dc stage allows the current to flow at all times in the dc link while simultaneously regulating generator torque. The inverter station, located onshore, is a thyristor-based converter that performs dc link current regulation. It also regulates the HVDC link voltage through supervisory inverter controls. A complete wind farm is simulated using the PSCAD/EMTDC software package. The 150-MW wind farm is modelled using six units of 25 MW with a rated dc link voltage of 125 kV at 1.2 kA. The simulation demonstrates the stable operation of the proposed configuration where each turbine is able to independently perform peak power tracking.

Droop control is the basic control method for load current sharing in dc micro grid applications. The conventional dc droop control method is realized by linearly reducing the dc output voltage as the output current increases. This method has two limitations. First, with the consideration of line resistance in a droop-controlled dc micro grid, since the output voltage of each converter cannot be exactly the same, the output current sharing accuracy is degraded. Second, the dc-bus voltage deviation increases with the load due to the droop action. In this paper, in order to improve the performance of the dc micro grid operation, a low-bandwidth communication (LBC)-based improved droop control method is proposed. In contrast with the conventional approach, the control system does not require a centralized secondary controller. Instead, it uses local controllers and the LBC network to exchange information between converter units. The droop controller is employed to achieve independent operation and the average voltage and current controllers are used in each converter to simultaneously enhance the current sharing accuracy and restore the dc bus voltage. All of the controllers are realized locally, and the LBC system is only used for changing the values of the dc voltage and cur-rent. Hence, a decentralized control scheme is accomplished. The simulation test based on MATLAB/Simulink and the experimental validation based on a 2 × 2.2 kW prototype were implemented to demonstrate the proposed approach.

In an islanded ac micro grid with distributed energy storage system (ESS), photovoltaic (PV) generation, and loads, a coordinated active power regulation is required to ensure efficient utilization of renewable energy, while keeping the ESS from over-charge and over discharge conditions. In this study, an autonomous active power control strategy is proposed for ac-islanded micro-grids in order to achieve power management in a de centralized manner. The proposed control algorithm is based on frequency bus-signaling of ESS and uses only local measurements for power distribution among micro grid elements. Moreover, this study also presents a hierarchical control structure for ac micro grids that is able to integrate the ESS, PV systems, and loads. Hereby, basic power management function is realized locally in primary level, while strict frequency regulation can be achieved by using additional secondary controller. Finally, real-time simulation results under various state of charge (SoC) and irradiance conditions are presented in order to prove the validity of the proposed approach.

III. CONTROLLER DESIGN

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

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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. This results in inferior performance and increases the steady-state loss. MPC, on the contrary, tends to make the closed-loop system operate near its limits and hence produces far better performance. MPC has also been receiving increased research attention for its applications in energy management of micro grids because it is a multi-input, multi-output control method and allows for the implementation of control actions that predict future events such as variations in power generation by intermittent DERs, energy prices and load demands. In these research works, the management of energy is formulated into different multi-objective optimization problems and different MPC strategies are proposed to solve these optimization problems. The scope of this paper is however focused on the application of MPC for the control of inverters.

A. SYSTEM DESCRIPTION AND WORKING

3.1.1 System Description

The overall configuration of the proposed dc grid based wind power generation system is shown in Fig. 3.

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 paper because it does not require a dc excitation system that will increase the design complexity of the control hardware.

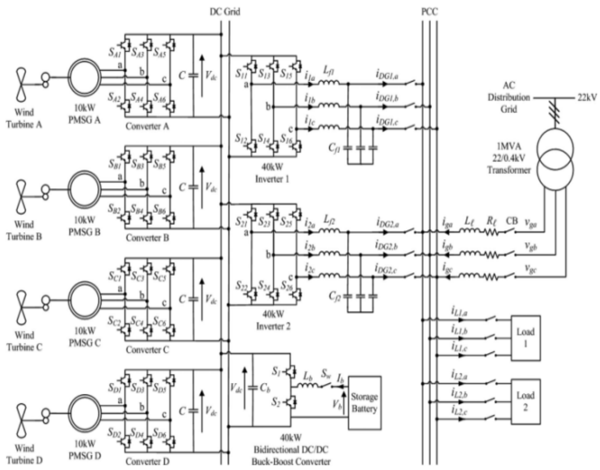

Fig. 1 Overall configuration of the proposed dc grid based wind power generation system in a micro grid

The depletion of fossil fuel resources, growing power demand and environment changes force to investment in renewable energy resources, such as solar, wind, biomass, and cell fuel. Among them, wind is one of the most promising one. A total of 282.5 GW wind power capacity have been installed all over the world by the end of 2012. Wind energy is especially important to Japan because it is an island country with very limited resource. After the devastating Fukushima nuclear accident in 2011, Japanese government changed its energy policy and increased the priority to renewable energies. Limited by its available land, wind farm along its coastline has attracted a large number of attentions. In fact, shortly after the nuclear disaster, research institutions, which are supported by the government and private companies, started to build experimental wind farm. However, the increasing penetration of grid-connected wind energy causes a problem: unstable output of wind turbines may greatly deteriorate the quality of grid power. Wind kinetic energy is converted to electrical energy using wind turbines. As the environment is turbulent and almost unpredictable, the quality of the output power largely depends on the control and management of the wind turbines. How to maintain a stable output and also achieve a reasonably high efficiency is an important issue.

Even the most efficient wind turbine cannot capture 100% power of the wind. Since the output power is a function of the wind speed and the tip-ratio speed, the wind turbine should run at the tip-speed ratio even the wind speed changes to extract as much power as possible from wind. Fig. 2. shows typical wind generation curves for three different types of wind turbines.

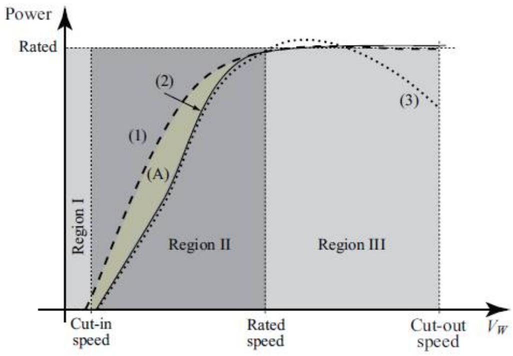

Fig. 2 Output power characteristic of three types of wind turbines: (1) variable-speed wind turbine, (2) pitch-controlled constant-speed wind turbine, and (3) stall-controlled constant-speed wind turbine.

In Region I, wind turbine stops because the wind speed is lower than the cut-in wind speed, which is the required minimum wind speed. The value of the cut-in wind speed may be different for different types of wind turbines. In Region II, it is clear from (1) that ω should be adjusted according to $V_W$to track the maximum power curve. This is possible for a variable-speed wind turbine, but it is impossible for a constant-speed one. So, a variable-speed wind turbine produces more power [Area (A) in Figure 4.1] than a constant-speed one under the same condition. In Region III, when wind speed is higher than the rated speed, the output power is limited to a constant value for the safety reason. And when the wind speed is higher than the cut- out wind speed, which is the maximum allowable speed, the wind turbine is disconnected from grid to avoid possible fatal physical damage.

Variable-speed wind turbines, which are equipped with complex electronic system, have high aerodynamic efficiency. However, the increased investment may make them uneconomic. On the other hand, constant – speed wind turbines with induction generator are widely installed for their simple structure, low price and robustness.

Stall control was mainly used in early constant-speed wind turbines. The control system is simple and reliable because the structure of the rotors is simple and does not have any moving components. However, Curve (3) in Fig. 2 shows that a big drop occurs in the electrical power at high wind speed. A pitch-controlled constant-speed wind turbine, which ensures a constant power output when wind speed is higher than the rated speed [Curve (2) in Fig. 2] was introduced to solve this problem. In this study, we consider a pitch-controlled constant-speed wind turbine with a 275 kW induction generator.

Torque generated by wind turbine planes changes with the fluctuations in the wind speed, and it causes the change in the rotational speed of the rotor. The objective of pitch angle control is to ensure that the rotor maintains a constant speed. In previous research, several control methods have been proposed for pitch-controlled wind turbines. Kanabaretal. analyzed the stability problem of constant-speed wind turbine generators [5]. Leithead gave an extensive investigation in the control of active pitch regulation of a constant-speed wind turbine, and also compared the results of the use of PI controller and the classical Nyquist-Bode loop shaping method. Connor designed an LQG controller for a constant-speed horizontal wind turbine mentioned.

3.1.2 Plant Modelling

A linear approximate model of the plant is derived in this section by linearizing the plant at a specific operating point. The state-space representation of the linear model is used to design the control system. The general structure of a

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pitch-controlled wind turbine system is shown in Figure 3.3. It includes aerodynamic, the drivetrain, an induction generator, a pitch controller, and the pitch actuator.

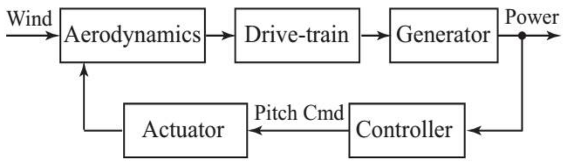

Fig. 3 Structure of a pitch-controlled wind turbine system

IV. RESULTS AND DISCUSSION

A dc micro grid based wind turbine scheme for a grid connected is designed , the proposed 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 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 designed in the mat lab Simulink.

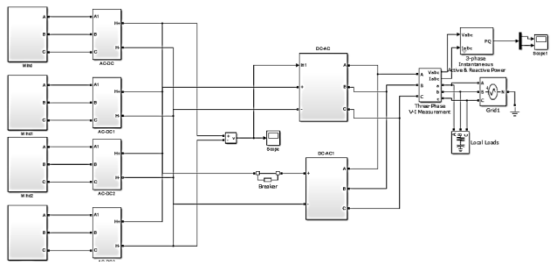

Fig. 4 Design of the wind turbine system with the wind generators and ac-dc converter and the grid tie inverter.

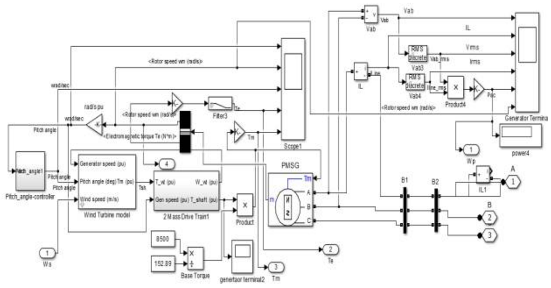

Fig.5 Design of the PMSG based wind turbine system for a range of 10 KW

In order to regulate the wind power under the vibrational speed the wind turbine is controlled to maintain the power output, and grid is connected this is done to mitigate the stabilization errors. A fuzzy based controller is used to reduce the grid connected system, the fuzzy controller stabilizes the voltage of the grid which maintain the active power.

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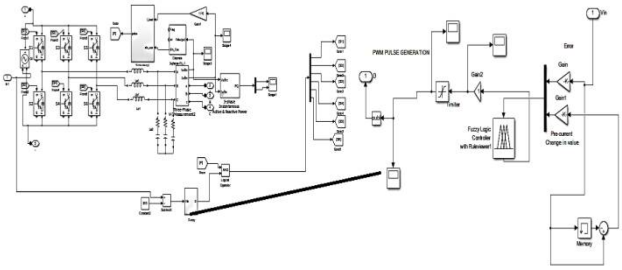

Fig. 6 Implementation of the fuzzy controller

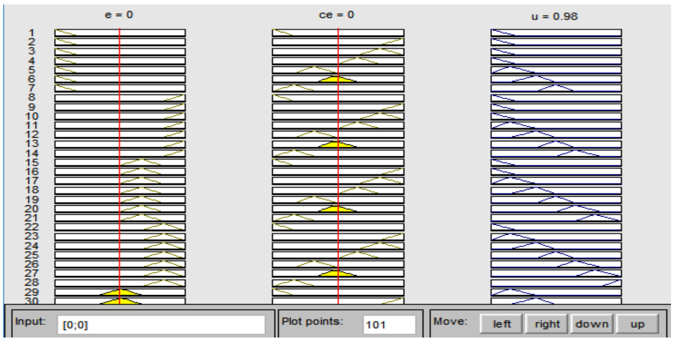

Fig. 7 Fuzzy rule set for the grid voltage regulator

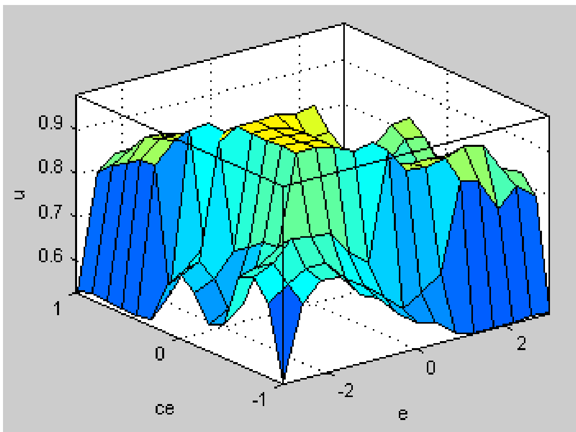

Fig. 8 Fuzzy surface for interpreting error and change of error

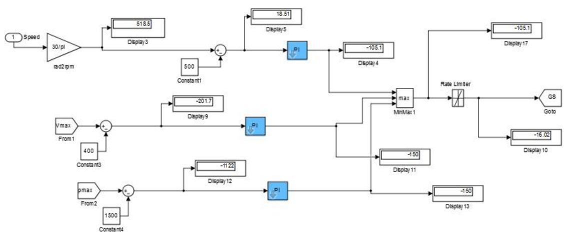

Fig. 9 Controller for the wind turbine to main the constant power, the turbine is maintained with the regulated power despite of the line variations

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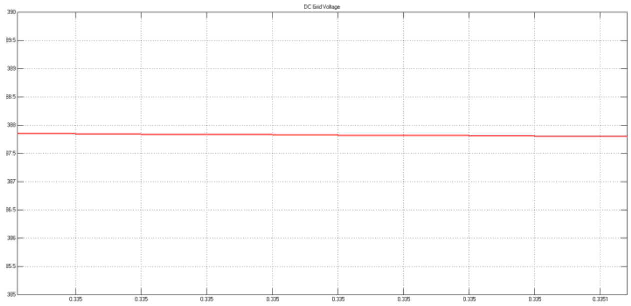
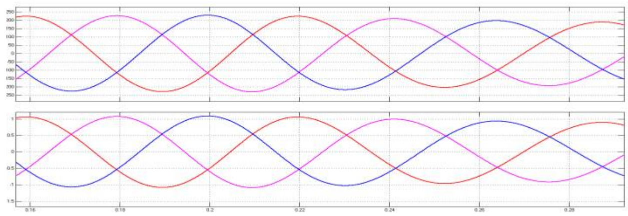
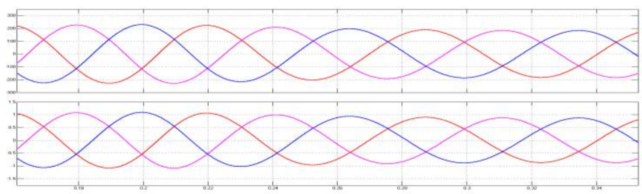


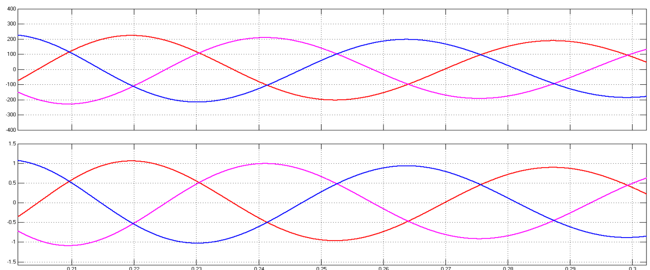
Fig.10 Stabilized grid voltage control of the dc bus.



A. Generated voltage and current of generator -A



B. Generated voltage and current of generator –B



C. Generated voltage and current of generator –C

Fig. 11 Generated voltage and current of the controller scheme which maintain the even voltage and the current ration of the generators are maintained at the same level.

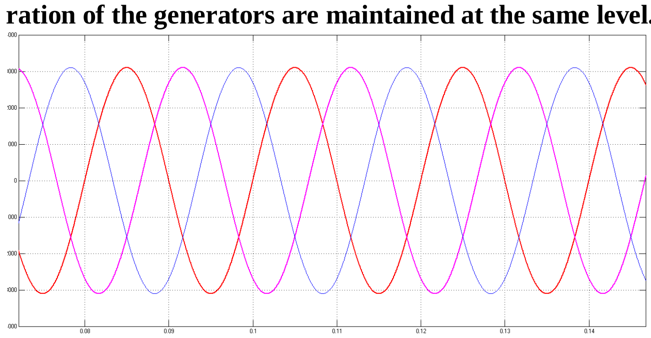


Fig. 12 Generated voltage and current of the converter

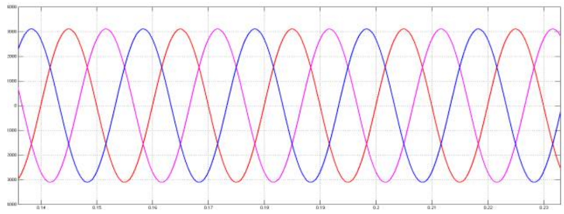


Fig.13 Generated voltage and current of the converter with the inverter -2

In reference to the graphs 5.18 and 5.17 the voltages of the inverter are presented which is equal at the conditions to ensure the balance of the line. In graph voltage in Y axis and time in X axis.

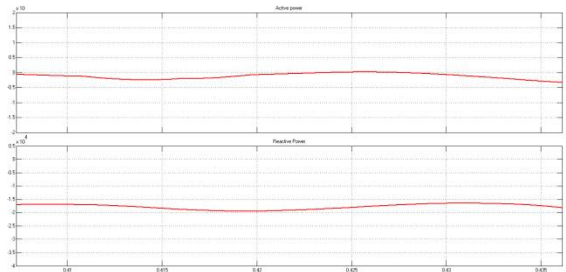


Fig.14 Active and reactive power to the grid connected scheme under the line balance conditions

V. CONCLUSION

In this work a design of a dc grid based wind power generation system in a micro grid that enables parallel operation of several WGs is presented. As compared to conventional wind power generation systems, the proposed micro grid architecture eliminates the need for voltage and frequency synchronization, thus allowing the WGs to be switched on or off with minimal disturbances to the micro grid operation. The design concept has been verified through various test scenarios to demonstrate the operational capability of the proposed micro grid and the simulation results has shown that the proposed design concept is able to offer increased flexibility. More over the wind disturbances are eliminated to maintain the balance across the inverters which the constant power control and the fuzzy control ensures the reliability to the operation of the micro grid

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