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Load sharing of Multiple DFIGs in islanded mode Microgrid.

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Abstract — *Now a day's wind power energy is playing a major role in power industry. Among the different form of variable speed fixed frequency topologies DFIG is most popular form due to its efficiency and ability to allow wide range of speed variation at reduced converter size. When wind power penetration is high, the available generation may be more than needed, especially for wind-powered micro grids working autonomously. Because the maximum peak power tracking algorithm may result in a supply-demand imbalance, an alternative algorithm is needed for load sharing. Here fully distributed control scheme is presented to coordinate the operations of multiple doubly-fed induction generators (DFIGs) in a micro grid. According to the proposed control strategy, each bus in a micro grid has an associated bus agent that may have two function modules. The global information discovery module discovers the total available wind generation and total demand. The load sharing control module calculates the generation reference of a DFIG. By controlling the utilization level of DFIGs to common value, the supply demand balance can be maintained. The generated control references are tracked by coordinating converter controls and pitch angle control. Simulation results with a 5-DFIG micro grid demonstrate the effectiveness of the proposed control scheme.*

Keywords- *Coordination system, distributed control, micro grid, wind power generation.*

I. INTRODUCTION

IN RECENT years, global warming has become the centre of attention due to its negative impact on the environment. However, many studies have been made to reduce the emissions of carbon dioxide (CO2) which is the main reason of greenhouse gases emission. In recent years, environmental and economic concerns have significantly increased the demand for clean and efficient power generation[1]. **R**ECENTLY, interests have been shown in using distributed energy resources (DERs) to achieve low-cost power systems expansion, improve power quality (PQ), and other environmental & economical benefits. To integrate the DERs with the grid, the micro grid concept was introduced. A micro grid is a group of loads and sources in a distribution level that operates either in connection or is islanded from the grid. The size of a micro grid may Range from a typical housing estate, isolated rural communities, to mixed suburban environments, academic or public communities, to commercial areas, industrial sites and trading estates, or municipal regions [2].The grid absence in islanded micro grids introduces many challenges. Wind power is gaining more popularity compared with other types of renewable energy resources. The U.S. Department of Energy expects to derive 20% of its national electrical supply from wind energy by 2030[1]. However, the intermittency of wind power poses new challenges for power system operation and control, especially during times of high penetration. One challenge with the control of a wind-powered micro-grid is setting the generation references of the wind turbine generators under dynamic wind and loading conditions. This is achieved by "load sharing" control, whose objective is to realize supply-demand balance of the micro grid. This process is called "load sharing." The popular maximum peak power tracking (MPPT) algorithm may cause supply-demand imbalance when the maximum wind power is more than required, such as in an autonomous micro grid. To overcome this problem, some DFIGs can be controlled to work at MPPT mode and the rest can evenly share the remaining demand. However, this type of solution is susceptible to inaccuracy in available wind power prediction. Another alternative way is utilizing energy storage devices, such as pumped water, compressed air, or super-capacitors, which can store the excessive power generated according to MPPT[3]. However, limited by current energy storage techniques, it is very expensive to install high-capacity energy storage devices. Even if energy storage is available, its initial installation is usually limited and will run out of energy storage capability easily. All of the methods discussed in [4] have some limitations, such as response speed, range of operation, and maintenance costs. Over the past several years, MAS has been applied widely to load restoration and power system reconfiguration [5], [6]. Recent development in consensus and cooperative control make advanced MAS-based designs possible, such as in [7]. Thus, it is necessary to investigate the control issue when there is insufficient or no energy storage devices in an autonomous microgrid.The main objective of this paper is to implement MAS based distribution solution which is reliable, flexible, less expensive to implement and has the ability to survive single-point failures. The load sharing algorithm aims at maintaining the active power supply-demand balance within an islanded micro grid, which will regulate frequency. To calculate the desired utilization level, the consensus based global information discovery algorithm proposed in [7] is introduced. The algorithm can guarantee convergence for micro grids of any size and topology and can be implemented using simple communication network. To realize generation reference tracking, the deloading strategies for both converter control and pitch angle control of a DFIG are designed and the implementation details are provided. Deloaded generation reference of a DFIG can be tracked by coordinating converter and pitch angle controls. The rest of the paper is organized as follows. Section II introduces the proposed control strategy for load sharing among multiple DFIGs. Section

III describes the control implementation of DFIGs and synchronous generator. Section IV presents the simulation results with a 5-DFIG micro grid. Section V provides discussion and concluding remarks

II. PROPOSED CONTROL STRATEGY

The fully distributed control architecture is illustrated in Fig. 1. The micro grid contains m distributed DFIGs, as well as a reliable conventional generator (CG), as shown in Fig. 1. The CG provides reactive power for voltage regulation and generates additional active power during low wind conditions. A circuit breaker (CB) connects micro grid with the main grid. Each bus in a micro grid has a corresponding bus agent (BA). The MAS based control system is fully distributed in the sense that no hierarchical framework or specialized agent is used to coordinate the operations of the autonomous agents. As illustrated in Fig.1, the communication topology (blue dash line) is the same as the topology of the power network. This type of design can utilize the power line communication techniques

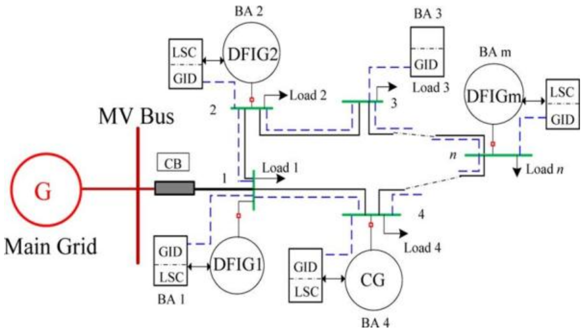

Fig. 1 .Distributed control architecture [1]

A bus agent may have two function modules for global information discovery (GID) and load sharing control (LSC), respectively. The functions of a specific BA are decided by the properties of the corresponding bus. If a bus has no generation capability, such as bus 3 in Fig. 1, then its corresponding BA only has the function of GID. If a bus has generation capability, such as buses 1, 2, 4, and in Fig. 1, the corresponding BA has both functions of GID and LSC. The GID module is responsible for measurement and prediction of local generation/load and information exchange among agents. The LSC module decides the common utilization level with the help of the GID module and sets the active power generation references for the corresponding DFIG. The DFIG receives the generation reference information from the corresponding bus agent and realizes active power reference tracking (deloading) by coordinating the converter and pitch angle controls. Since the distributed solution requires neither a powerful central controller to process the huge amount of data nor a complicated communication network, it is less expensive to implement.

A. Consensus based Active Power Setting

A micro grid can operate in either grid-connected mode or islanded mode. In grid connected mode, the power grid can either absorb surplus power from the micro grid or inject power into the micro grid to compensate for the power shortage. Thus, in grid-connected mode, the supply demand balance is maintained by the power grid and there is no need to use the load sharing algorithm. On the other hand, when a micro grid operates under islanded mode, supply-demand should be balanced within the micro grid to ensure that the system operates autonomously. This requires the DFIGs to coordinate with each other properly. In this paper, only the micro grid under islanded mode is considered. The targeted problem of the fully distributed MAS- based algorithm for active power setting is introduced below.
The total active power demand of a micro grid can be represented using:

$$\boldsymbol{Pd = \sum_{i=1}^{n} Pid + Ploss} \qquad \text{Eq. (1)}$$

where n is the number of buses in the micro grid, Pid is the local net demand calculated based on the local load and generation, and P loss is the active power loss in the micro grid and can be considered as a small percentage of Pd.
The total available wind power generation of the DFIGs can be calculated using:

$$\boldsymbol{P_{wmt} = \sum_{i=1}^{m} Piwm} \qquad \text{Eq. (2)}$$

Where $\boldsymbol{Piwm}$ denotes the predicted maximum wind power generation of the ith DFIG.
If Pd is larger than Pwmt, all DFIGs should be operated under MPPT control. If the reliable supply from the CG or power grid is insufficient to compensate for the difference, non-vital loads can be disconnected until. If Pd is less than Pwmt, a suitable deloading strategy is required to share the demand among DFIGs. This is achieved by controlling the utilization levels of DFIGs, maintaining them at a common value.

Ku= {Pd/pwmt,1} Eq.(3)

Piw=kuPiwm Eq. (4)

Where Piwm denotes the predicted maximum wind power generation of ith the DFIG.

The global information is discovered iteratively, and the updating rule is formulated as:

Xi (k+1) =Xi(k)+$\sum_{j=1}^{n} aij\,[xj(k) - xi(k)]$ Eq.(5)

Where xi(k) and xj(k) are the information discovered by agents i and j at iteration k respectively, xi(k+1)is the immediate update of si(k) ,aij is the coefficient of the information exchanged between agents i and j, and n is the number of agents participating in information discovery.[1]
We can calculate Ku as per
Ku= Pd/Pwmt Eq. (6)

B. Deloading Strategies for Control Reference Tracking.

1) Rotor Speed Adjustment: When the available wind power exceeds the demand, deloading tracking should be used instead of MPPT. The power extracted from wind can be calculated according to the well-known wind turbine aerodynamic characteristics:

$$P_m = \frac{1}{2} C_p(\lambda,\beta)\rho A v^3{}_w$$ Eq. (7)

- *Pm: Mechanical output power of the turbine (W)*
- *Cp: Performance coefficient of the turbine*
- *P: Air density (kg/m3)*
- *A: Turbine swept area (m2)*
- *Vwind: Wind speed (m/s)*
- *λ:Tip speed ratio of the rotor blade tip speed to wind speed*
- *B:Blade pitch angle (deg)*
- It Can be normalized In the per unit (pu) system

$$P_{m\_pu} = K_p C_{p\_pu} v^3{}_{wind\_pu}$$ Eq. (8)

Performance or power coefficient *Cp* depends on wind speed, the speed of the turbine and the pitch of the blades. The power coefficient of the turbine is given by

$$C_p(\lambda,\beta) = C_1(C_2/\lambda_i\text{-}C_3\beta\text{-}C_4)e^{-cb/\lambda_i}+C_6\lambda$$ Eq.(9)

With

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$ Eq. (10)

Fixing the ratio λ and the pitch blades β to their optimum values, the wind system will provide optimum electrical power.

This ratio λ, called also the tip speed ratio:

$$\lambda = \frac{\Omega.R}{v}$$ Eq.(11)

Where: Ω is the speed of turbine, R the blade radius and

V the wind velocity.

The coefficients c1 to c6 are: c1 = 0.5176, c2 = 116, c3 = 0.4, c4 = 5, c5 = 21 and c6 = 0.0068. The cp-λ characteristics, for different values of the pitch angle β, are illustrated below. The maximum value of cp (cp max = 0.48) is achieved for β = 0 degree and for λ = 8.1. This particular value of λ is defined as the nominal value (λ nom)

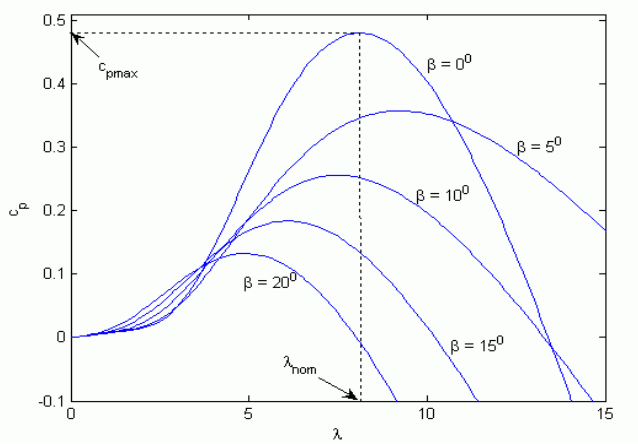

Fig. 2 Power coefficient versus λ and β[2]

According to (7), the generated power can be adjusted by controlling rotor speed wr and/or regulating turbine pitch angle β. Tuning the rotor speed is preferable for two reasons. First, the rotor speed can be altered faster than the pitch angle because it can be controlled through power converters, which respond faster than the blades actuators. Second, tuning the rotor speed can protect the pitch blade from suffering wear and tear [10]. However, when the rotational speed reaches the upper bound, changing the pitch angle becomes the only option

2) Pitch Angle Adjustment*:* Pitch angle control is another method of active power control. It is activated when the rotor speed exceeds the predefined speed threshold. In this paper ,1.3p.u. is used as that threshold. When the rotor speed exceeds this value, the pitch angle control system sets 1.3 p.u as the rotor speed reference in order to protect the generator, which can also shed the extra energy according to the deloading com- mand. For deloading tracking, the electrical power converters (over- speeding) control and the mechanical wind turbine (pitch angle) control need to be coordinated.

III. CONTROL IMPLEMENTATION

To implement the control strategy outlined above, the DFIG units in a micro grid must be well controlled, which presents a challenge. This section explains how the proposed control strategy is implemented through the controls of DFIGs and the synchronous generator (SG).

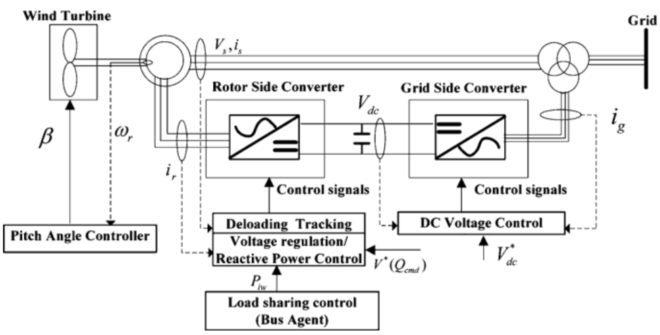

Fig.3 control of DFIG under deloading mode.[1]

A. Control of DFIGS

Once the references for active power generation have been decided, the control reference can be tracked by control- ling the DFIG. In this way, the overall system's active power supply-demand balance can be maintained, and the operation of multiple DFIGs can be coordinated. In addition to active power, reactive power and the voltages of the terminal bus and dc-link voltage also must be controlled. As illustrated in Fig. 3, the control of a DFIG has three modules for electrically controlling the two converters and mechanically controlling the pitch angle.The active power is controlled through the rotor side converter (RSC). The reactive power injection can be obtained and adjusted by controlling the RSC, the grid side converter (GSC),or both. For the voltage control, the rotor-side converter is preferred. Thus, RSC is selected in this paper to control both active power and reactive power, and GSC is used only to stabilize the dc-link voltage. More information about the three control components is provided below.

1) RSC Control*:* In this paper, the DFIG is controlled by back-to-back converters. With the decoupled control method, the rotor-side converter (RSC) controls both the active and reactive power of the DFIG. The active power is controlled by adjusting the d -axis rotor current idr , while the reactive power is controlled by adjusting the q -axis rotor current iqr, as shown in Fig. 4.The slight active power imbalance can be compensated by a PI controller taking frequency deviation (Δf) as input. The deviation between the active power output of DFIG Pw and the reference value pw* forms the error signal that is processed by a PI controller to produce the rotor current idr*reference. Through another PI controller, the difference between rotor current idr and reference value idr* is used to produce rotor voltage vdr* . There are two modes for reactive power control, the voltage and reactive power regulation modes. Both modes regulate q -axis rotor current iqr. . In voltage regulation mode, iqr is controlled to reduce voltage fluctuation. For reactive power regulation, the difference between the reactive command Qcmd and the reactive power output Qw forms rotor current reference iqr* through a PI controller. In voltage control mode iqr can be divided into magnetizing component iqr and terminal voltage control component. The magnetizing component compensates for the no-load reactive power absorbed by the DFIG, and the voltage control component is controlled in response to voltage fluctuations.

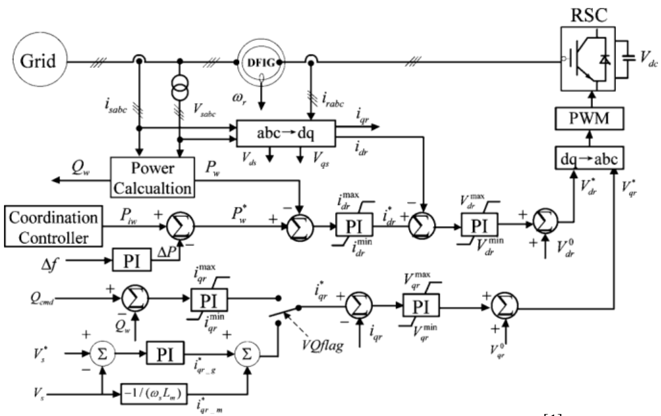

Fig. 4. Control of the rotor side converter.[1]

2) GSC Control*:* Fig. 5 shows the overall control scheme of the GSC. The dc-link voltage is controlled by regulating the d-axis grid side current id _ g c , which can regulate the active power that the dc link exchanges with the grid to maintain the dc voltage.

3) Pitch Angle Control*:* The pitch angle controller used in this paper is depicted in Fig. 6. it consists of the PI Controller and the pitch angle actuator.The threshold speed is set to1.3 p.u, and the βmax is set to zero. The maximum pitch angle change rate is limited by (dβ/dt) max and (dβ/dt)min,which is set to 8/s.

B. Control of the Synchronous Generator

In this paper, a synchronous generator (SG) is used to illus- trate the control of the conventional generators. To maximize the energy efficiency, the SG is controlled only to generate reactive power for voltage regulation when the wind energy is sufficient. When the wind energy is insufficient, the SG should also gen- erate active power to compensate for the active power shortage. The control logic of the SG is shown in Fig. 7. In order to model the ramp rate of the SG, a rate limiter is added in the control loop, as in Fig. 7. The governor system is mainly a PI controller.

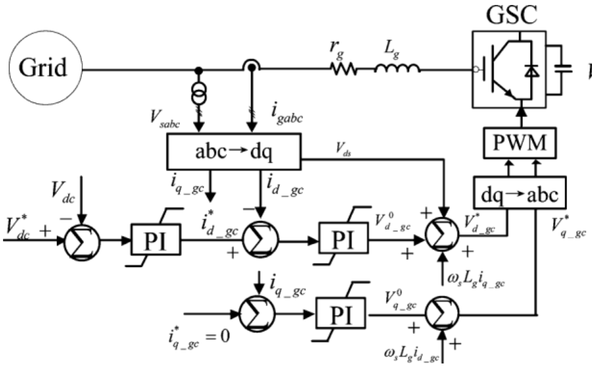

Fig. 5. Control of the grid side converter.[1]

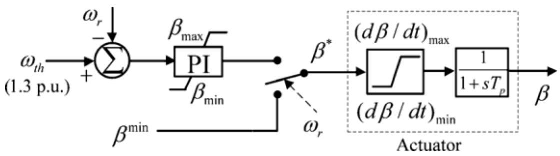

Fig. 6. Scheme of pitch angle control.[1]

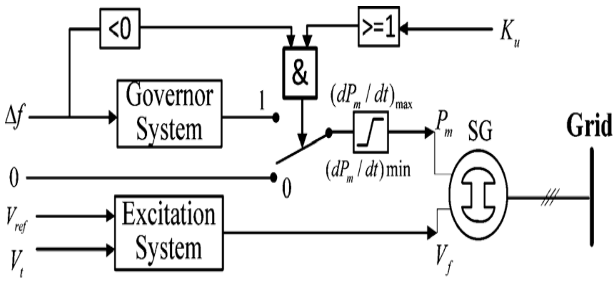

Fig. 7. Control of the synchronous generator[1]

IV. SIMULATION STUDIES

The proposed cooperative control method is tested with a 6-bus micro grid system, as shown in Fig. 8. During simulation studies, both MAS and microgrid are implemented using Simulink and the Simpowersystems toolbox. The micro grid contains six loads, five DFIGs, and one SG. DFIGs 1, 2, and4 are controlled in var regulation mode, and DFIGs 3 and 5are controlled in voltage regulation mode, as introduced in Section II. The active power output of the SG is maintained at zero,

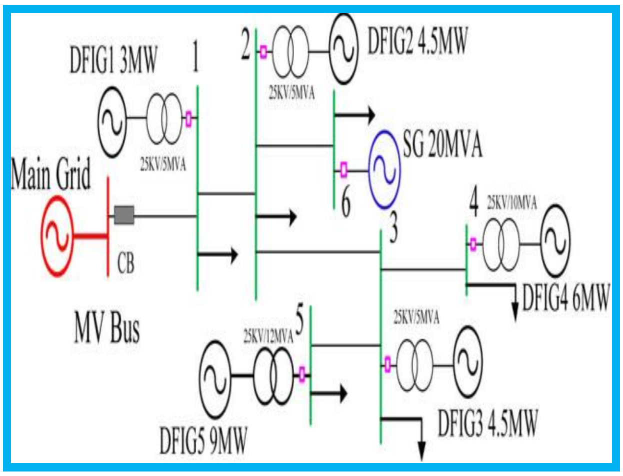

Fig.8 Confugaration of 6 bus micro grid.

When the wind power is sufficient, When the wind power is insufficient, the SG is controlled to increase the output for regulating the frequency. The ramp-up and ramp-down rates of the SG are both set to 0.02 p.u./s.In this section, Simulation of 6 bus micro grid is done. in future MAS topology will be apply and the control scheme will be tested under two operating conditions, i.e., constant winds and loads, and variable winds and loads. The first operating condition, while unrealistic,is easier to understand due to its simplicity.

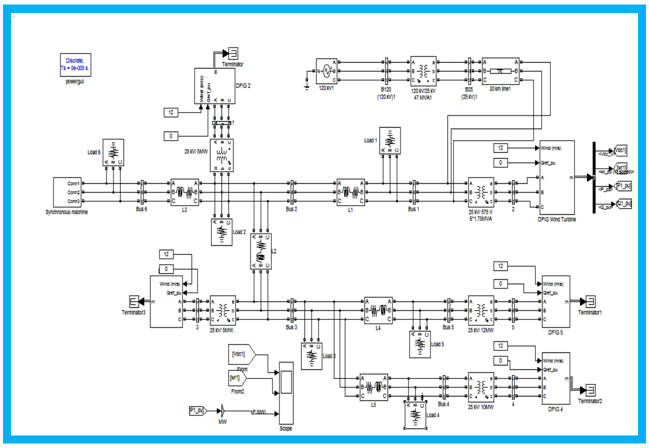

Fig.9 MATLAB/Simulink model of 6 BUS micro grid

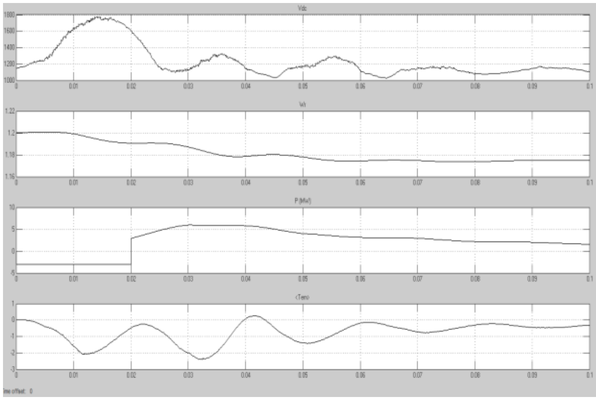

Fig.10 Simulation Wave forms of Vdc(V),Wr,(Rotorspeed)(pu)&P(ActivepowerDFIG1)(MW),Tem(electro magnetic torque)

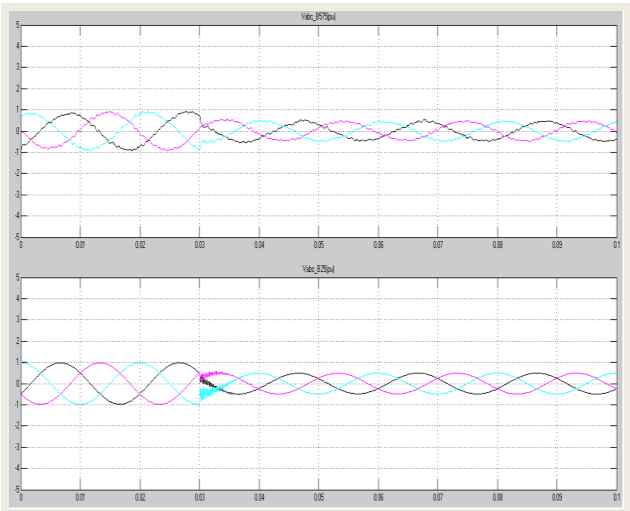

Fig.11 Simulation Wave forms of Vabc _B575(pu),Vabc _B25(pu) to DFIG1

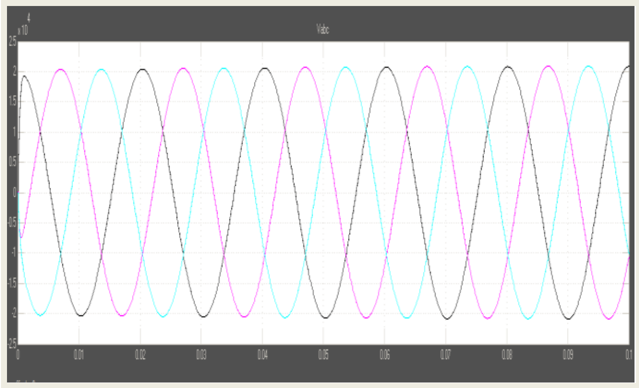

Fig. 12 Simulation wave form of Vabc(V) of S.M

V. CONCLUSION AND DISCUSSION

This paper presented a fully distributed algorithm for coordinating multiple DFIGs in micro grids. Due to the distributed property, the solution is stable, reliable, adaptive, scalable, and cost efficient. Simulation studies have demonstrated the effectiveness of the proposed solutions. Suitable algorithms can be adopted to realize load sharing control for different types of renewable energy resources. Thus, the proposed algorithm can be applied widely to various micro grids consisting of different types of distributed energy resource units. The load sharing algorithm aims at maintaining the active power supply-demand balance within an islanded micro grid, which will regulate frequency. To compensate the inaccuracies that cause power imbalance, PI controls with frequency deviation as input are introduced. According to the simulation results, it can be seen that the proposed controller is effective and the control performance is satisfactory. Just like other existing solutions, the control scheme has certain requirements on operating conditions, such as the SG is able to compensate the generation deficiency of the DFIGs and the deloading strategies can regulate the DFIG's output to a desired value in a timely manner. Under certain extreme operating conditions, such as gust wind, the proposed control strategy might have trouble in reducing the generation of a DFIG to a desired value or responding fast enough. For these extreme situations, other control options, such as shedding load(s) or disconnecting DFIG from the microgrid, can be adopted.

VI. APPENDIX

Below are the parameters of the 6-bus microgrid

1) Data of synchroneouse machine:
SB=20MVA,H=3s, Damp=0.01p.u,xd=1.81p.u,xq=1.76p.u, xd'=0.23 p.u,xd"=0.25p.u,T'd0=6s, T"d0=0.03s,T"q0=0.3371 s,T"d0=0.0295s.
The control parameters of the RSC controller are:
The active power regulator: KP=1, ki=100
The current regulator (d -axis): kp=0.03, ki=8
The reactive power regulator: kp=1, ki=100
The voltage regulator: kp=20, ki=5
The current regulator (q -axis): kp=0.03, ki=8
The control parameters of the GSC controller are:
The voltage regulator: kp=100, ki=20
The current regulator (d -axis): KP=0.03, ki=8
The current regulator (q –axis): KP=0.03, ki=8
The control parameters of the pitch angle controller are:
Kp=100,ki=5, the maximum rotor speed is 1.3 p.u., Bmax=45 degrees, Bmin=0 degrees, the rate limiter is 8 degree/s,and actuator time constant Tp is 0.1

Table 1: Data of 5 DFIGS.

SPECIFIATION	DFIG 1	DFIG 2 &3	DFIG4	DFIG5
PB(MW)	3	4.5	6	9
VB	575 V	575	575	575
Rsp.u	0.00706	0.00686	0.00641	0.00745
Lsp.u	3.28	2.98	2.88	2.67
Rr	0.005	0.0046	0.0045	0.0055
Lr	3.52	3.01	2.62	2.44
Lm	3	2.85	2.40	2.05
H	1.5 s	1.75	2.55	3
P. p.u	0.7865	0.7865	0.7865	0.7865
Wm/s	12	12	12	12

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