Artificial Intelligence Technique Based Wind Power Generation System in a Micro Grid

Duba Revathi [1], Dr Midhunchakkaravarthy[2]
Research Scholar, Lincoln University College, Malaysia[1]
drevathi@lincoln.edu.my

Dean, Faculty of Computer Science and Multimedia[2]
Lincoln University College, Malaysia
midhun@lincoln.edu.my

Abstract-
This paper presents the design of a dc grid-based wind power generation system. The proposed system allows flexible operation of multiple parallel-connected wind generators by eliminating the need for voltage and frequency synchronization. A model predictive control algorithm that offers better transient response with respect to the changes in the operating conditions is proposed for the control of the inverters. An Artificial Intelligence(AI) Technique based Fuzzy controller is used in this project to regulate the dc micro grid. The design concept is verified through various test scenarios to demonstrate 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.
***Index Terms*—Wind power generation, dc grid, energy management, model predictive control, Artificial Intelligence(AI) Technique, fuzzy logic controller.**

I.INTRODUCTION

In our pursuit of sustainable energy sources, wind power has emerged as a beacon of hope, symbolizing our ability to harness the natural forces around us. Wind energy, derived from the kinetic energy of moving air masses, holds immense promise in meeting our growing electricity demands while mitigating environmental impacts.

The concept of utilizing wind for energy dates back centuries, from the humble windmills of old to today's sleek wind turbines that adorn landscapes around the globe. What sets wind energy apart is its renewable nature—unlike fossil fuels, wind is an abundant resource that won't run out.

In this exploration of wind energy, we delve into the workings of wind turbines, the advantages they offer, and the challenges we face in integrating this clean power source into our energy mix. From wind-swept plains to offshore installations buffeted by ocean breezes, wind energy is transforming how we envision the future of electricity generation

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). Distributed energy resources (DERs) are electricity-producing resources or controllable loads that are directly connected to a local distribution system or connected to a host facility within the local distribution system. DERs can include solar panels, combined heat and power plants, electricity storage, small natural gas-fuelled generators, electric vehicles and controllable loads, such as HVAC systems and electric water heaters. These resources are typically smaller in scale than the traditional generation facilities that serve most of the existing demands.

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. 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 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.

II.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 paper 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 micro grid 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 $P_{wt,opt}$ as follows:

$$P_{wt,opt} = k_{opt}\,(\omega_{r,opt})^3 \qquad 2.1$$

$$k_{opt} = \frac{1}{2} C_{p,opt} \rho A \left[R/\lambda_{opt} \right]^3 \qquad 2.2$$

$$\omega_{r,opt} = \lambda_{opt} v/R \qquad 2.3$$

where k_{opt} is the optimized constant, $\omega_{r,opt}$ is the WT speed for optimum power generation, $C_{p,opt}$ is the optimum power coefficient of the turbine, ρ is the air density, A is the area swept by the rotor blades, λ_{opt} is the optimum tip speed ratio, v is the wind speed and R is the radius of the blade. 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 according to [24], 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 micro grid 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

$$SOC_{min} < SOC \leq SOC_{max} \quad 2.4$$

III. 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 [27]–[29].During islanded operation where the CBs disconnect the micro grid from the distribution grid, the WTs and the SB are only available sources to supply the load demand. The SB can supply for the deficit in real power to maintain the power balance of the micro grid as follows:

$$P_{wt} + P_{sb} = P_{loss} + P_l \quad 2.5$$

where P_{wt} is the real power generated by the WTs, P_{sb} is the real power supplied by SB which is subjected to the constraint of the SB maximum power $P_{sb,max}$ that can be delivered during discharging and is given by

$$P_{sb} \leq P_{sb,max} \quad 2.6$$

P_{loss} is the system loss, and $P_l$is the real power that is supplied to the loads.

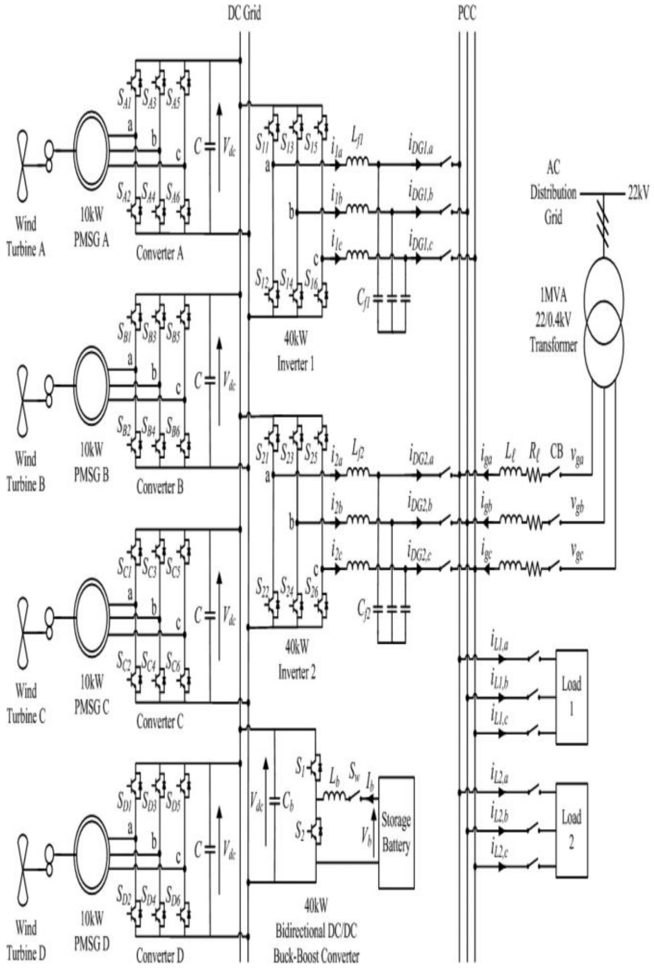

Fig. 2.1 Overall configuration of the proposed dc grid based wind power generation system in a micro grid.

IV 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 ($V^*dc-Vdc$) at the dc grid, which is then fed into a proportional integral controller to generate a current reference i^*_d for i_d to track. To eliminate the presence of high frequency switching ripples at the dc grid, Vdc is first passed through a first-order LPF.

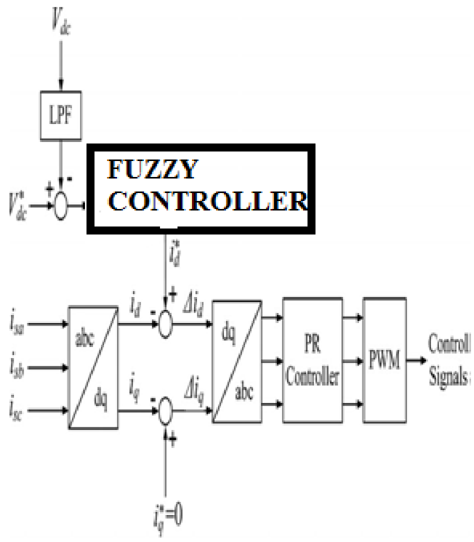

Fig 4.1 Configuration of the proposed controller for the ac/dc converter.

The current iqis controlled to be zero so that the PMSG only delivers real power. The current errors Δidand Δiqare then converted into the abcframe and fed into a proportional resonant(PR) controller to generate the required control signals using pulse-width modulation.

Fuzzy set theory is an extension of classical set theory where elements have varying degrees of membership. Fuzzy logic uses the whole interval between 0 and 1 to describe human reasoning. In FLC the input variables are mapped by sets of membership functions and these are called as "FUZZY SETS".

Fuzzy set comprises from a membership function which could be defines by parameters. The value between 0 and 1 reveals a degree of membership to the fuzzy set. The process of converting the crisp input to a fuzzy value is called as "fuzzificaton." The output of the Fuzzier module is interfaced with the rules. The basic operation of FLC is constructed from fuzzy control rules utilizing the values of fuzzy sets in general for the error and the change of error and control action. Basic fuzzy module is shown in fig.4.2 The results are combined to give a crisp output controlling the output variable and this process is called as "DEFUZZIFICATION."

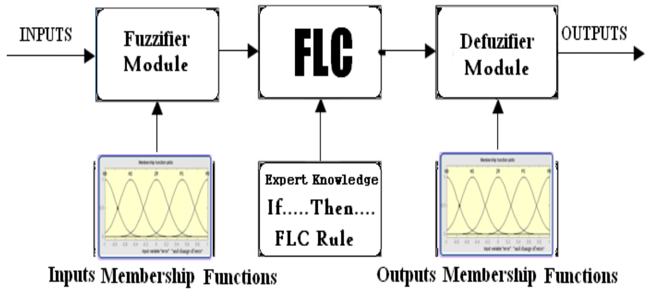

Fig.4.2: Block diagram fuzzy logic Controller.

V 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 [32], [33]. To derive the control algorithm for the inverters, the state-space equations are transformed into augmented state-space equations by defining the incremental variables in the following format:

$\Delta\xi(k)=\xi(k)-\xi(k-1)$ where ξ represents each variable in the inverter model, such as v_{DG}, i_{DG}, $i$and u as shown in Fig.By defining the incremental variables, the augmented state space model for the inverter model operating in the CCM during grid-connected operation can be expressed as follows:

Xg(k + 1) = Ag augXg(k) + Bg1 augVg(k) + Bg2 augUg(k) 4.18

Yg(k) = Cg augXg(k) 4.19

where

$$Ag\ \text{aug} = \begin{bmatrix} 1-\frac{R}{Lf}\text{Ts} & 0 \\ 1-\frac{R}{Lf}\text{Ts} & 0 \end{bmatrix},$$

$$Bg1\ \text{aug} = \begin{bmatrix} 0 & 0 & -\frac{Ts}{Lf} \\ -\frac{Cf}{Ts} & \frac{Cf}{Ts} & -\frac{Ts}{Lf} \end{bmatrix},$$

$$Bg2\ \text{aug} = \begin{bmatrix} \frac{Vdc}{Lf}Ts & -\frac{Vdc}{Lf}Ts \\ \frac{Vdc}{Lf}Ts & -\frac{Vdc}{Lf}Ts \end{bmatrix},$$

Cg aug = [0 1]

Xg(k) =[Δi(k) i_{DG}(k)]^{T}is the state vector; Vg (k) = [Δv_{DG}(k + 2) Δv_{DG}(k + 1) Δv_{DG}(k)]^{T}is the exogenous input; Ug(k) = Δug(k) is the control signal; and Yg(k) =i_{DG}(k) is the output.

Similarly, the augmented state-space model for the inverter model operating in the VCM during islanded operation can be expressed as follows:

$$Xi(k+1) = Ai\ \text{aug}Xi(k) + Bi\ \text{aug}Ui(k) \qquad 4.20$$

$$Yi(k) = Ci\ \text{aug}Xi(k) \qquad 4.21$$

here

$$A_{i\_aug} = \begin{bmatrix} 1-\frac{R}{L_f}T_s & -\frac{T_s}{L_f} & 0 & 0 \\ \frac{T_s}{L_f} & 1 & -\frac{T_s}{L_f} & 0 \\ 0 & 0 & 1 & 0 \\ \frac{T_s}{L_f} & 1 & \frac{T_s}{L_f} & 1 \end{bmatrix},$$

$$B_{i\_aug} = \begin{bmatrix} \frac{V_{dc}}{L_f}T_s \\ 0 \\ 0 \\ 0 \end{bmatrix},$$

C_{i_aug} = [0 0 0 1]

Xi(k) =[Δi(k) Δv_{DG}(k) Δi_{DG}(k) v_{DG}(k)]^{T}is the state vector; Ui(k) = Δui(k) is the control signal; and Yi(k) = v_{DG}(k) is the output.

For the control of the two augmented models in the CCM and the VCM, the following cost function is solved using quadratic programming in the proposed MPC algorithm [33]:

$$J = (Rs-Yj)T(Rs-Yj) + UTjQUj \qquad 4.22$$

subject to the constraint

$$-1 \le uj(k) \le 1 \qquad 4.23$$

where *Rs*is the set-point matrix, *Q* is the tuning matrix for the desired closed-loop performance, *Yj*is the output of either the augmented model in the CCM or VCM (i.e., *Yg*or *Yi*) , *Uj*is the control signal of either the augmented model in the CCM or VCM (i.e., *Ug*or *Ui*). The first part of the cost function is to compare the output of the augmented model *Yj*with the reference *Rs*and to ensure that the output tracks the reference with minimum error. The second part of the cost function is to calculate the weighted factor of the control signal and to ensure that the control signal generated by the MPC algorithm is within the constraints. The quadratic programming will ensure that the optimal solution for the control signal deviation Δ*u*is achieved while minimizing the cost function *J*. After the control signal *u* is generated by the MPC algorithm, it will be applied to the dc/ac inverter .

FLC determined by the set of linguistic rules. The mathematical modeling is not required in fuzzy controller due to the conversion of numerical variable into linguistic variables. FLC consists of three part: a. Fuzzification, b. Interference engine, c. Defuzzification. The fuzzy controller is characterized as; For each input and output there are seven fuzzy sets. For simplicity a membership functions is Triangular. Fuzzification is using continuous universe of discourse. Implication is using Mamdani's "min" operator. Defuzzification is using the "height" method.

VI.SIMULATION RESULTS

TEST CASE : CONNECTION OF AC/DC CONVERTER DURINGGRID-CONNECTED OPERATION:

The most significant advantage of the proposed dc grid based wind power generation system is that it facilitates the connection of any PMSGs to the micro grid without the need to synchronize their voltage and frequency. This capability is demonstrated in this case study.

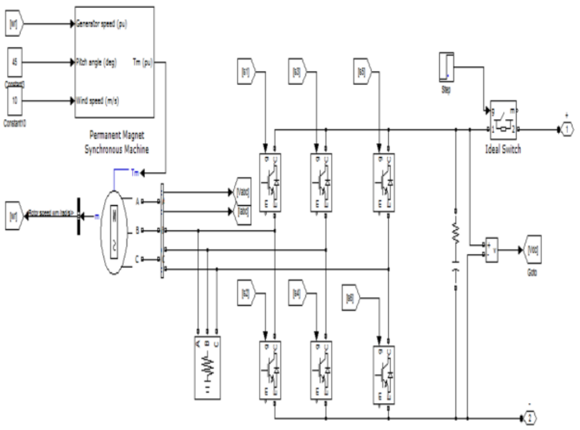

Fig. 6.1 INTRODUCTION OF STEP INPUT RISE AFTER T=0.2 SEC TO AC/DC CONVERTER CONTROL CIRCUIT OF PMSG-A

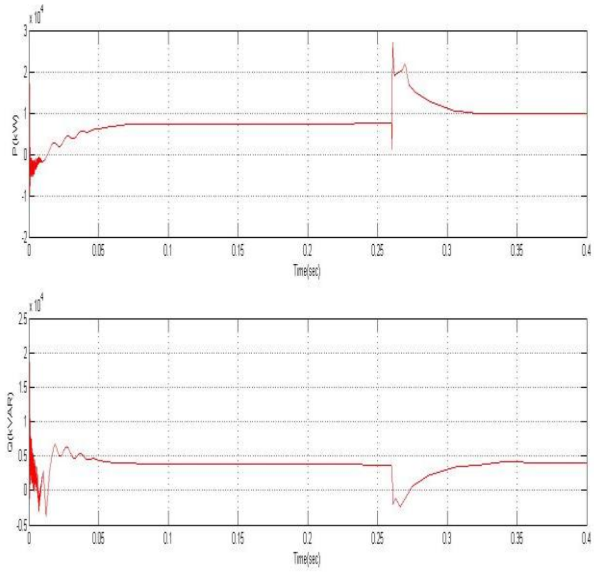

Fig.6.2 REAL (TOP) AND REACTIVE (BOTTOM) POWER DELIVERED BY INVERTER 1.

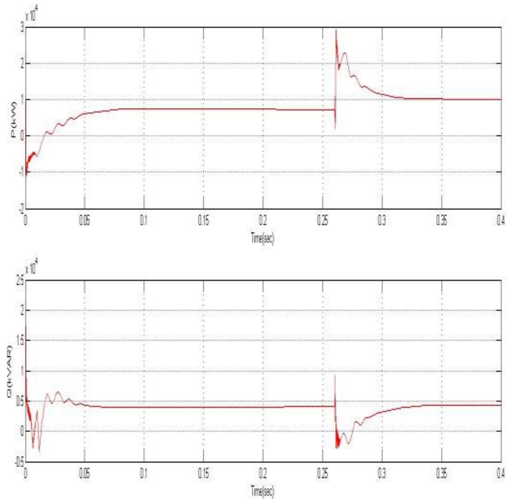

Fig.6.3 REAL (TOP) AND REACTIVE (BOTTOM) POWER DELIVERED BY INVERTER 2.

The micro grid operates connected to the grid and PMSG A is disconnected from the dc grid for $0 \leq t < 0.2$ s as shown in Fig. 6.1. The real power generated from each of the remaining three PMSGs is maintained at 5.5 kW and their aggregated real power of 16.5 kW at the dc grid is converted by inverters 1 and 2 into 14 kW of real power and 8 kVAR of reactive power. As shown in Figs. 6.3 and 6.4, each inverter delivers real and reactive power of 7 kW and 4 kVAR to the loads respectively. The rest of the real and reactive power demand of the loads is supplied by the grid as shown in Fig.6.8. It can be seen from Fig. 6.8 that the grid delivers 46 kW of real power and 4 kVAR of reactive powerto the loads.

At t = 0.2 s, PMSG A which generates real power of 5.5 kW is connected to the dc grid. This causes a sudden power surge at the dc grid and results in a voltage rise at t = 0.2 s as shown in the voltage waveform of Fig. At t = 0.26 s, the EMS increases the real delivered by each inverter to 10 kW while the reactive power supplied by each inverter remains unchanged at 4 kVAR as shown in Figs. 6.3and 6.4. This causes a momentarily dip in the dc grid voltage at t = 0.26 s as observed in Fig. 6.5 which is then restored back to its nominal voltage of 500 Vfor $0.26 \leq t < 0.4$ s.

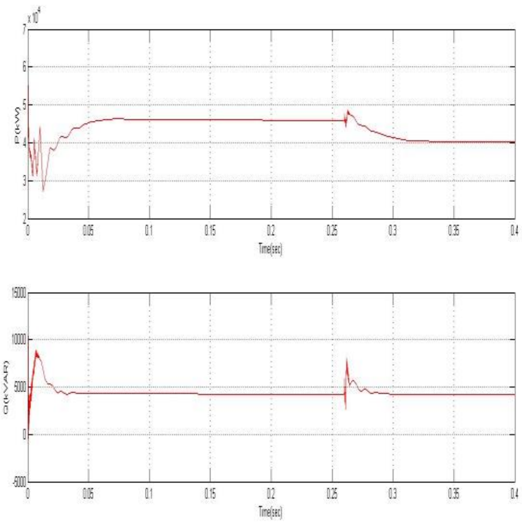

Fig. 6.4 REAL (TOP) AND REACTIVE (BOTTOM) POWER DELIVERED BY THE GRID.

The grid also simultaneously decreases its supply to 40 kW of real power for $0.26 \leq t < 0.4$ s while its reactive power remains constant at 4 kVAR as shown in Fig. 6.6.

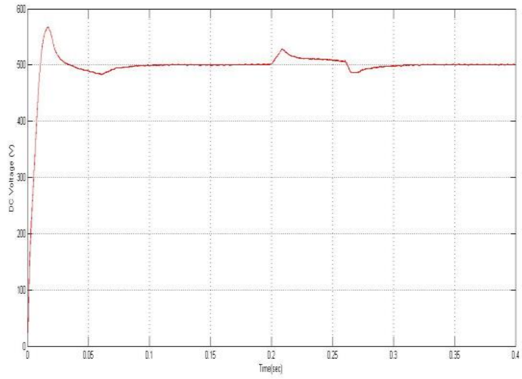

Fig.6.5. DC GRID VOLTAGE.

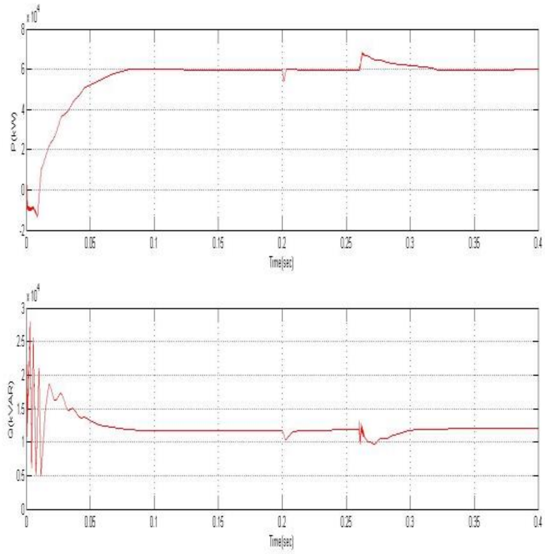

Fig. 6.6. REAL (TOP) AND REACTIVE (BOTTOM) POWER CONSUMED BY THE LOADS.

CONCLUSION

In this project, the design of a dc grid based wind power generation system in a micro grid that enables parallel operation of Several WGs has been 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 AI based fuzzy controller design concept is able to offer increased flexibility and reliability to the operation of the micro grid.

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