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Load Frequency Control of DFIG - Isolated and Grid Connected Mode

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ABSTRACT

Wind energy is one of the extraordinary promising sources of renewable energy due to its clean character, free availability and economic viability. A Doubly Fed Induction Generator (DFIG) feeds power from both the stator and the rotor windings at speeds above synchronous speed of the machine. This paper deals the load frequency control of doubly fed induction generator in isolated mode and grid connected mode. The wind turbine model is obtained using MATLAB/ SIMULINK which consists of DFIG, rotor side rectifier, grid side inverter and grid. This model is controlled by conventional controllerand proposed Load Frequency Control (LFC) method. The results are proven that frequency control gives better results in all the aspects.

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Nomenclature

Pr -power delivered by the rotor
Ps -power delivered by the stator
Tm -Mechanical torque
Tem -electromechanical torque
ωs -angular speed of stator magnetic field
ωr -angular speed of rotor
J -Inertia of the machine
s -slip of the generator
Pm -wind power
P - air density
A - area swept by the rotor blades and,
υ_w - wind velocity
λ - tip speed ratio
β - Pitch angle
ω_t - angular speed of the rotor
R - radius of the rotor blades and
υ_w - wind velocity

1. INTRODUCTION

Wind farms can no longer be considered as a simple energy source or local control of regulation. Now they must operate as power plants, they must be able to provide reactive power, remain connected during systems faults and adapt their control to the needs of the system. A converter system is used to achieve variable wind speed operation which has numerous benefits such as higher energy yield, reduced power fluctuations and improved VAr supply. These large wind turbines are based on either variable wind speed with pitch control using a synchronous generator or a doubly fed induction generator.

Doubly-fed induction generators have two active windings the stator and rotor; both the windings transfer significant power to the electrical system. The major advantage of using doubly fed machine is that the power consumed by the power electronic equipment is (20-30%) of total power supply [1]. The stator winding is connected directly to the grid and the rotor windings are controlled by using power electronic converters.

Juan Dixon in [2] explained about different types of three phase controlled rectifiers and their control using PWM signals. The control method for DC link voltage was also explained. In [3], Balasubramaniam, Babypriya and Rajapalan Anita simulated the DFIG using MATLAB and analyzed various DFIG characteristics. In [5], B.Chitti Babu and K.B.Mohanty presented the complete modeling and simulation of wind turbine driven Doubly Fed Induction Generator that feeds AC power to the utility grid. The AC-DC-AC converters are divided into two components, the rotor side rectifier and the grid side inverter. Both are voltage source converters. The capacitor connected on the dc side acts as the dc voltage source. Rotor side converter is used to control the output power and the voltage measured at the grid terminals. The grid side converter is used to regulate the voltage of the dc bus capacitor by Branislav, Dosijanoski in [6-8]. In [9-10], Mariusz Malinowski presented the mathematical model and operation description of PWM rectifier. Different control strategies for PWM rectifiers were also described.

2. RESEARCH METHOD

The DFIG technology extracts maximum energy from low wind speeds and minimizes mechanical stresses on the turbine. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generator [5].

2.1 Operating principle of DFIG

The stator connected to the ac mains, where as the rotor feeds power via back to back PWM converters. The DC bus capacitor link connects stator and rotor-side converters. To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltage [2]. The slip power flows from rotor to the grid. The speed of the machine can be controlled from either rotor or stator-side converter for all speed ranges. As a result, the machine can be controlled as a generator in both super and sub-synchronous operating modes realizing four quadrant operations. In this project only generation mode is considered. At the synchronous speed, slip power is taken from supply to excite the rotor windings and in this case machine behaves as a synchronous motor. The power delivered by the rotor and the stator are computed as follows [7]:

$$Pr = Tm * \omega r \tag{1}$$

$$Ps = Tem * \omega s \tag{2}$$

For a loss less generator the mechanical equation is

$$J\frac{d\omega}{dt} = Tm - Tem \tag{3}$$

In steady-state at fixed speed for a loss less generator

$$Tm = Tem \tag{4}$$

$$Pm = Pr + Ps \tag{5}$$

$$Pr = (Pm - Ps) = (Tm * \omega r - Tem * \omega s) = -sPs$$

$$Pr = -sPs \tag{6}$$

Where,

$$s = \frac{\omega s - \omega r}{\omega s} \tag{7}$$

Generally the absolute value of slip is much lower than 1 and, consequently, Pr is only a fraction of Ps [8]
- If s>0, Tm is negative, *ωr* is positive thus power is delivered to the grid
- For super synchronous speeds, *Pr* is transmitted to DC bus capacitor and tends to increase the DC voltage

Inverter is used to generate the power *Pgc* in order to keep the DC voltage constant. In steady-state, for a lossless AC/DC/AC converter *Pgc* is equal to *Pr*. The frequency of rotor induced voltage is equal to the product of the grid frequency and the absolute value of the slip as in Eqn. 2.6. Rectifier and Inverter have the capability for generating or absorbing reactive power and could be used to control the reactive power or the voltage at the grid terminals [1].

2. 2. Load Frequency Control

The usual practice of generating PWM pulses is by comparing the DC voltage obtained from rotor side rectifier with a reference voltage. These PWM pulses are used to trigger the switches of inverter. The block diagram of such a controller scheme is shown in Figure . .3.In this work, the grid frequency is considered as a feedback to the frequency control method. The frequency regulator block consists of PLL, comparator and PI controller. PLL is used to convert three phase grid voltage into a proportional frequency and this frequency is given to the comparator. The comparator compares the load side and reference frequencies. PI controller performs a control action based on the error produced by the comparator. This output is the Idgc_ref that is same as that in the conventional control system. The currents I_d and I_q are fed to a current regulator that generates the required Vgc. PWM generator uses this control voltage Vgc to generate pulses for the control of the grid side inverter. Grid frequency control is essential to ensure stable and reliable operation of the system. The block diagram of frequency control is as shown in Figure 2. Figure 3 indicates the block diagram of grid frequency based control of grid side inverter.

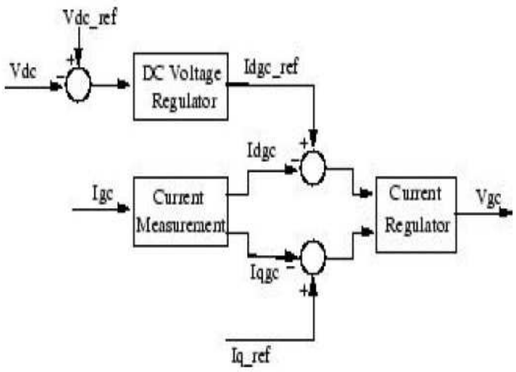


Figure 2. Conventional controllers for grid side inverter

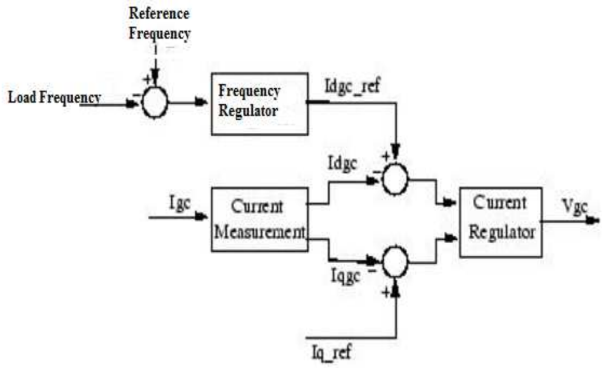


Figure 3. Grid frequency based control of grid side inverter

2.3. Modeling of wind turbine

Wind turbine is intended towards conversion of the kinetic energy inherent in the wind due to its motion into useful mechanical energy that can be used to generate electrical energy. The inherent power of the wind in the form of kinetic energy can be expressed by the following equation:

$$Pw = 0.5 * \rho * A * \vartheta_\omega^3 \quad (8)$$

Now the power extracted by the mechanical turbine is only a portion of the available kinetic energy of the wind. The performance of power coefficient C_p in a turbine is expressed as the ratio of power developed by the turbine to the power of the wind which is expressed as follows [10]

$$Cp = Pm \div Pw \quad (9)$$

Alternatively,

$$Pm = Cp * Pw \quad (10)$$

Thus the net mechanical power developed by the turbine is given by the equation

$$Pm = 0.5 * \rho * Cp * A * \vartheta_\omega^3 \quad (11)$$

The expression for *Cp* (λ, β) used in the modeling of wind turbine is as given below,

$$Cp\ (\lambda, \beta)\ =\ 0.22 * (\frac{116}{\lambda 1}\ -\ 0.4\beta\ -\ 5) * e^{\frac{12.5}{\lambda 1}} \tag{12}$$

λ_1 is given by the expression

$$\lambda 1\ =\ (\frac{1}{(\lambda + 0.08\beta)}\ - \frac{0.035}{\beta^3 + 1}) \tag{13}$$

The tip speed ratio (λ) is a function of wind speed, angular speed of the rotor and radius of the rotor blades and is expressed as below:

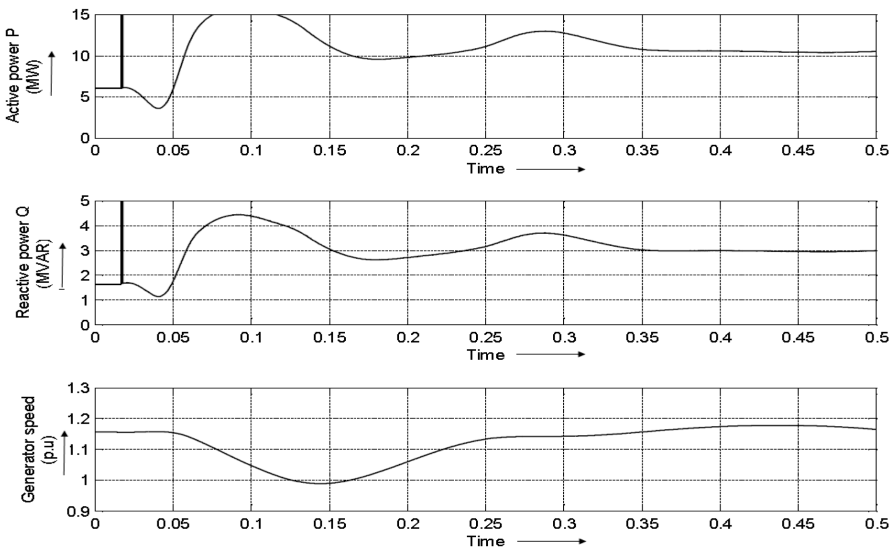
$$\lambda\ =\ \frac{(\omega t * R)}{v_w} \tag{14}$$

3. RESULTS AND ANALYSIS

The inputs to the wind turbine are wind speed, pitch angle and the speed of the rotor. The tip speed ratio lambda (λ) is calculated by using the equation (4.7). The value of lambda obtained is used to compute the power co-efficient (Cp) which is a function of pitch angle beta (β) and tip speed ratio lambda (λ) as in the equation (4.5) the net power generated by the turbine is computed using the equation (4.4) and this is divided by the angular speed of the rotor to obtain the mechanical torque output which drives the doubly fed induction machine. For this turbine the cut-in speed and the cut-off speed is 5 m/s and 25 m/s respectively. The rated speed is 11 m/s. The system under consideration demonstrates simulation of a 6X1.5 MW wind farm consisting of a 9 MW Doubly-Fed Induction Generator. The generator exports power to a 120 kV grid through a 30 km transmission line operating at a voltage of 25kV. The voltage at generator terminals is 575 V. The system is feeding the load and system parameters are observed for varying conditions. The models of: DFIG in isolated mode with conventional and frequency control and DFIG in grid connected mode with conventional and frequency control were developed.

3.1 DFIG in isolated mode

The wind turbine driven DFIG is isolated from the grid by the use of a circuit breaker. The circuit breaker operation is such that when wind speed is insufficient, the circuit breaker isolates the DFIG from the grid to avoid motoring mode and when sufficient power is delivered by the wind turbine for local loads, grid integration can be considered and circuit breaker is closed. Figure .4 indicates the results obtained with the conventional control system and Figure 7 indicates the results obtained with the use of frequency control. The following parameters are considered for comparing the results: a) Active power b) Reactive power c) Generator speed d) Terminal voltage e) Load current f) DC link voltage and g) Frequency deviation



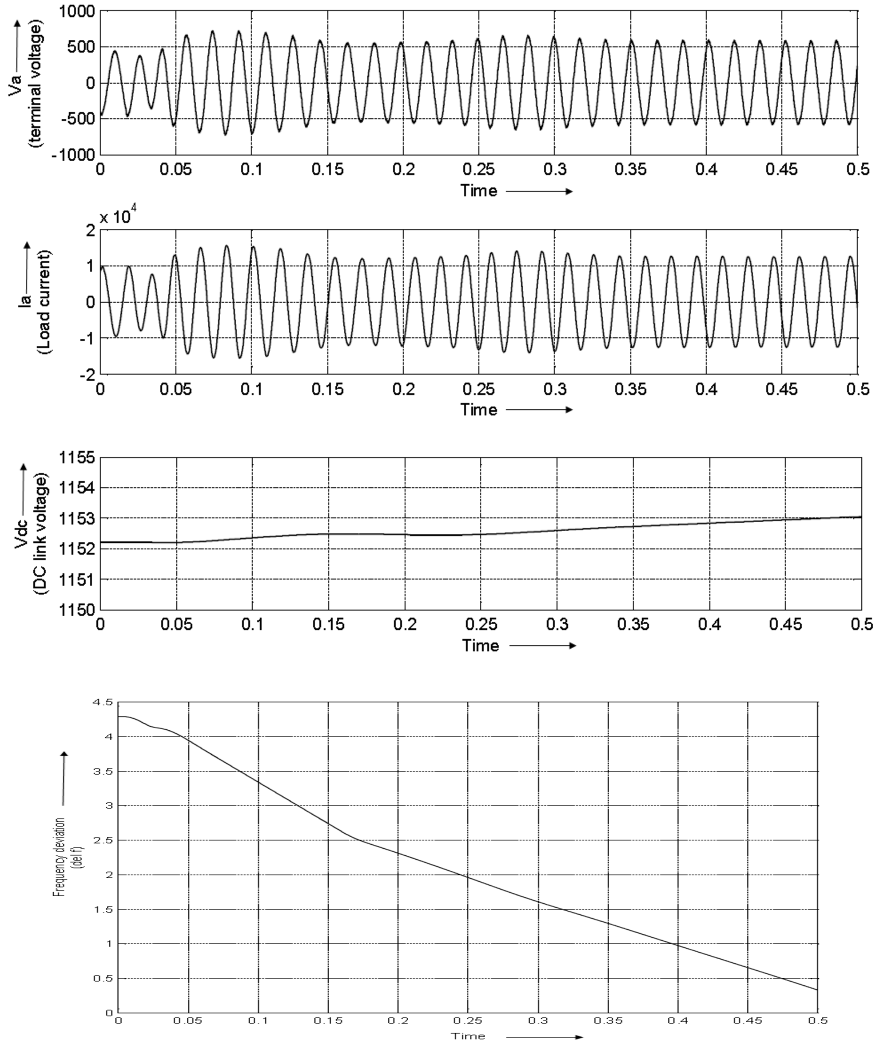
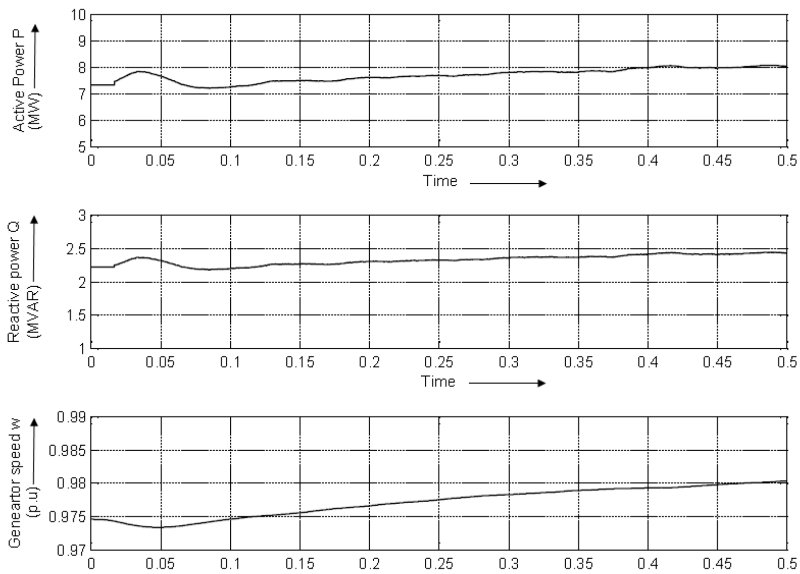


Figure 4. Results obtained from isolated mode using conventional method



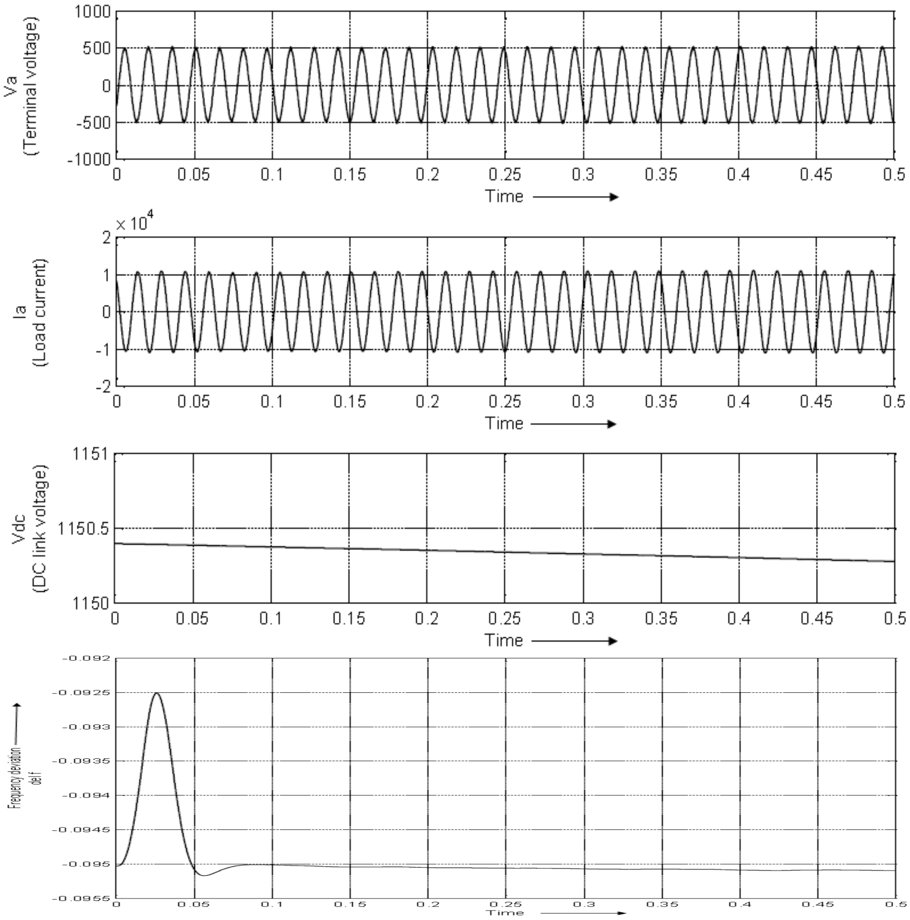
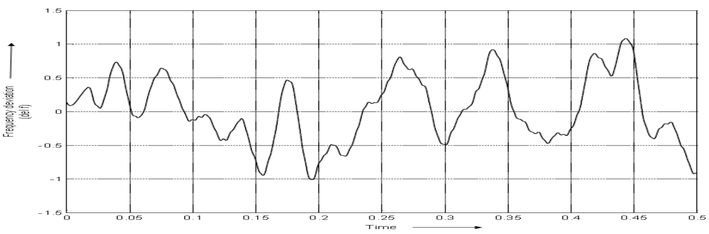


Figure 5. Results obtained from isolated mode using frequency control method

From Figure 4 and 5 upon comparison, it is noticed that significant improvements have been achieved by the use of frequency control. The implementation of frequency control has proven advantageous in the above mentioned parameters. The terminal voltage obtained is a better sinusoid with lesser harmonic content as compared to conventional method as in Figure 4 and 5 The DC link voltage is seen more regulated with the use of frequency control as compared to that of conventional control the direct result of this is the effect on terminal voltage and load current as in Figure 4 and 5.

3.2 DFIG in grid connected mode

The DFIG is connected to the grid when it is in generating mode and is sufficiently meeting grid requirements. The results obtained are shown in Figure 6 and 7. For grid connected mode the parameters considered are Frequency deviation, Generator speed, Terminal voltage Load current and DC link voltage. The active power and reactive power are not included because of grid connected mode. The DC link voltage obtained from both the control methods is similar; hence the obtained terminal voltage and load current are not having significant difference. However, from Figure .6 and 7, it can be concluded that the introduction of frequency control is maintaining the frequency deviation within the grid standards.



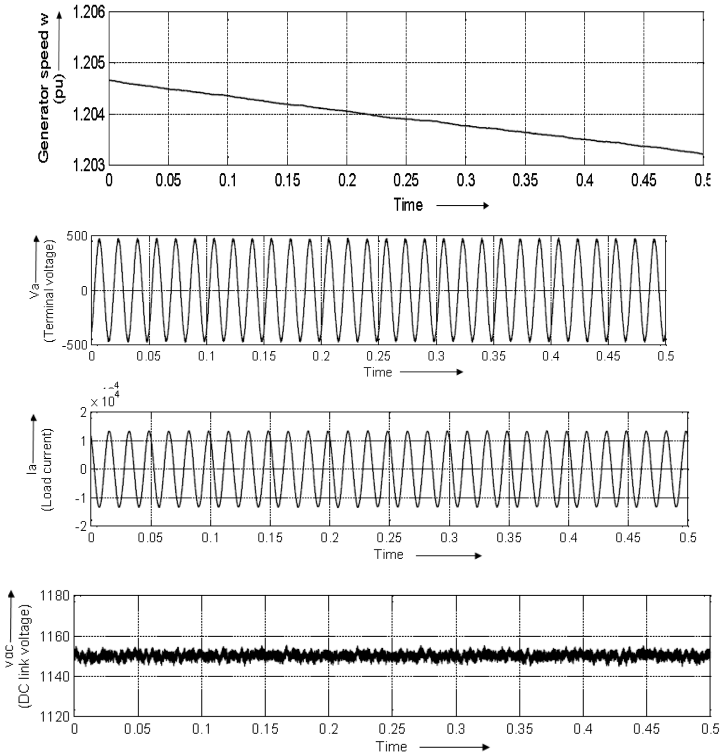


Figure 6. Results obtained from grid connected mode using conventional method

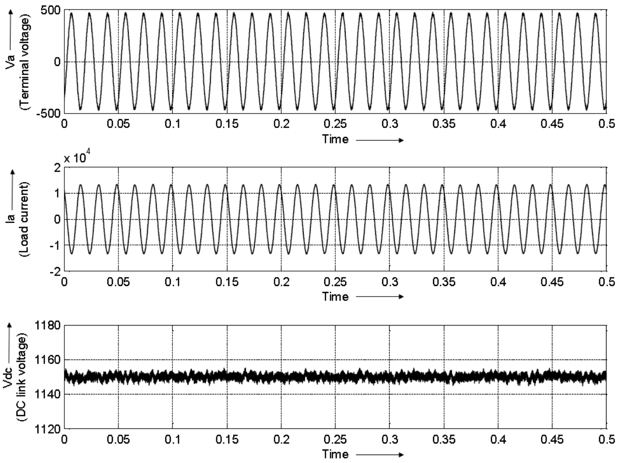


Figure 7. Results obtained from grid connected mode using frequency control method

4. CONCLUSION

This paper presents the study of a doubly fed induction generator integrated to the utility grid. The modeling of wind turbine, DFIG, rotor side rectifier, grid side inverter and grid are done using SIMULINK. In isolated mode of operation, the application of frequency control has yielded positive results. The generator is able to maintain the frequency requirements of the various loads connected across its terminals. When speed of the machine is in the sub synchronous conditions, i.e. at low wind speeds, it is advisable to disconnect the machine from the grid to avoid motoring mode. The frequency control in grid connected mode has also yielded positive results in all cases. In cases where the DC link voltage might tend to fluctuate, the proposed frequency control method is giving better results. From the results obtained, it can be concluded that the proposed frequency control method maintains the frequency deviation within the grid standards compared to the conventional controller.

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