



Introducing a New Method for Tracking and Transmitting Maximum Power of a Wind Power Plant to the Grid During Wind Shortages

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ABSTRACT

The present paper proposes a novel vector control based method to connect a wind plant equipped with a Doubly-Fed Induction Generator to the grid. It also provides separate control capacity of injection power to the grid under wind shortages in addition to optimum performance in normal climatic conditions. The mathematical modeling of converters of the grid and rotor side is presented, which provides such a control tool. The idea of using an energy storage system has been presented to reduce power swings of the wind plant to grid in the dc-link of back-to-back converter of the rotor side. In order to achieve an optimal control system, the strategy of maximum wind power tracking and unit power factor of the wind farm are included in the control system. However, the power exchange strategy with the unit power factor is related to the type of operation of the grid, and reactive injection power can also be controlled when needed. Finally, a simulation of the studied system and the proposed control system in the SIMULINK environment of MATLAB software is presented, which provides a powerful tool for these types of systems. The results obtained from the conducted studies on a sample system demonstrate the efficiency and accuracy of the proposed method.

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1. INTRODUCTION

Worldwide demand for renewable energy is increasing rapidly because of the climate problem, and also because oil resources are limited [1]. Wind energy appears as a clean and good solution to cope with a great part of this energy demand [2-3], but along with the many benefits, including cleanliness and lack of greenhouse emission, the problem of oscillation of wind speed makes the use of these systems a challenge. Because this problem and consequently a swing in output power and also grid frequency reduces the quality of grid parameters, which is undesirable [4-5]. Therefore, the use of control strategies such as maximum power point tracking (MPPT) is required for transmission power control and enhancing the grid power density.

The researches performed in [6-8] have focused on modeling and controlling a wind turbine along with a doubly-fed induction generator (DFIG) and back-to-back converters. The direct connection of the generator to the wind turbine and no need for a gearbox is one of the desirable features of the generator that increase efficiency and reduces costs. The control strategy for transmitted active power control is a vector control method that can be used to obtain maximum power from wind energy in any wind speed and guarantee the power quality of the load side. The optimum speed of the generator is calculated by employing MPPT and is the input to the control system as a reference speed. The generator speed and the axis current of d-q of the generator have been controlled by applying PI controllers at reference values, which allow the generator speed to be set to the optimum value and to obtain the maximum power as the wind speed changes. In this system, the axis current of d has been set to be zero for the unit power factor [9-10]. In the proposed method, a back-to-back converter has been employed to

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conduct the vector control, and one of the advantages of this conventional converter is the absence of a bulk capacitor or inductor. The back-to-back converter can also be used to neutralize the output current of the generator and inject a current with fixed frequency and unit power factor [11]. The ultimate objective of this system is to provide a control strategy to improve the efficiency of variable speed wind turbines, which is done by a back-to-back converter that provides excellent power quality and unit power factor. Validation of models and control designs has been achieved through the system simulation in the SIMULINK environment of MATLAB software.

In [12], a comparative study of fixed and variable speed wind turbines, which include the squirrel cage induction generator, is presented considering all the realistic limitations. The two systems are modeled and simulated using MATLAB. Modeling and control of the brushless doubly-fed induction generator (BDFIG) for wind turbines (WTs) are discussed in [13] by the authors. In the present study, the super-twisting sliding mode direct power control (SSM-DPC) has been applied to optimize the controller parameters of a WT with DFIG. In [14], a new configuration has been proposed for a wind farm connected to the power grid. In this study, the proposed wind energy conversion system (WECS) uses a six-leg matrix converter to control two doubly-fed induction generators. Each of these generators is controlled by rotor currents and has employed an optimal control algorithm of the voltage vector to control the voltage of the rotor terminals. In [15], a model predictive control (MPC) for power control of DFIG is presented using a state-space prediction model. Genetic algorithms (GAs) have shown their potential to find suitable solutions to complex problems. However, GA lacks a mechanism for controlling the constraints in its original form. In this method, the time is proposed to adjust the MPC based on a constrained GA. In [16], considering the diverse range of wind energy conversion systems utilizing DFIGs.

In the present study, the authors use a direct power control method for DFIG control in which the genetic and fuzzy hybrid optimization algorithm has been applied to obtain optimal parameters of fuzzy controllers. The ultimate purpose of this optimization is to reduce power errors to enhance the tracking accuracy. In [17], the authors have proposed a performance study of a variable speed wind turbine based on the doubly-fed induction generator by a matrix converter by employing the maximum power point tracking method to derive the maximum available power. In [18], the objective was to introduce a maximum power point tracking (MPPT) strategy for a wind turbine and investigate its steady-state behavior using MATLAB/SIMULINK. In [19], the modeling, stability, and control analysis of the DFIGs are discussed for

wind turbines (WTs). In the present study, artificial bee colony and imperialist competitive algorithms have been used to optimize the controller parameters of a WT with DFIG. In [20], the main consideration is to evaluate wind speed in a variable speed wind turbine that conducts a simultaneous magnet generator. In this case, intelligent methods are employed to enhance the performance of the control system for maximum wind power tracking. In [21], a new configuration has been proposed for a wind farm connected to the power grid. In this study, the proposed wind energy conversion system (WECS) uses a six-leg matrix converter to control two doubly-fed induction generators. Each of these generators is controlled by rotor currents and has employed an optimal control algorithm of the voltage vector to control the voltage of the rotor terminals. In [22], neuro-fuzzy sliding mode control (NFSMC) as a hybrid control method based on the BDFIG is proposed. In [23], reactive and active power control applied to DFIG for wind turbines using SMC is done.

One of the most important issues in the operation of wind turbines equipped with DFIG is that wind energy is of an unpredictable and non-uniform nature. This causes a number of destructive effects, including oscillating power generation and non-uniform power injection into the grid. Therefore, the idea of using the energy storage system (BESS) in the dc-link of back-to-back converter of the rotor side has been used in this paper. In fact, by utilizing energy-saving batteries in the dc-link of two-way back-to-back converters, the ability to store and release energy is created under different powers of wind turbine.

The contents of this paper are organized as follows: the 2th Chapter presents the Modeling. The 3th Chapter presents the structure of generator control. The 4th Chapter presents the control strategy of power stabilization during wind shortages. The 5th, 6th Chapters are simulation results and conclusion, respectively.

2. MODELING

2.1. Wind Turbine Modeling The output power of the wind turbine is a nonlinear function which is dependent on wind speed; thus, the amount of output power of a wind turbine follows the Equation (1) as the following:

$$P_m = 0.5\rho AC_p(\lambda, \beta)V^3 \quad (1)$$

Moreover, the ratios of the linear velocity at the tip of the blade to the wind speed (λ) is defined as follows:

$$\lambda = \frac{\omega R}{V} \quad (2)$$

where, ρ is the density of the wind (kg/m^3), A is the area swept by the turbine blades (m^2), V is the wind

speed (m/s), (R) is the turbine blades radius (m), ω is the rotational speed (rad/s), and C_p is the performance coefficient of the wind turbine. There are many empirical relationships for $C_p(\lambda, \beta)$. The relationship applied in the paper is as follows [9]:

$$C_p(\lambda, \beta) = C_1 \left(\frac{C_2}{\lambda_i} - C_3\beta - C_4 \right) e^{-\left(\frac{C_5}{\lambda_i}\right)} + C_6\lambda \quad (3)$$

where

$$\frac{1}{\lambda_i} = \left[\frac{1}{(\lambda + C_7\beta)} \right] - \left[\frac{C_8}{(\beta^3 + 1)} \right] \text{ and } \beta = 0 \quad (4)$$

Figure 1 indicates the simulation of Equation (3) using different values for β . The value of the performance factor C_p is a function of the blade tip speed ratio λ and the blade angle β that reaches its maximum value in a particular λ named λ_{opt} . Hence, λ must be maintained in the value λ_{opt} using the optimal speed of the turbine rotor to obtain maximum energy from the wind. This optimal speed is obtained by applying Equation (2) and is defined by Equation (5):

$$\omega_{opt} = \frac{\lambda_{opt} V}{R} \quad (5)$$

In the MPPT region, where the wind power is less than rated power, and since the angle of the blade is constant ($\beta = 0$), the value C_p is only a function of λ and reaches its maximum value ($C_{p-max} = 0.48$) in ($\lambda_{opt} = 8.1$) according to Figure 2. Thus, we use MPPT control to control the performance factor at its maximum value.

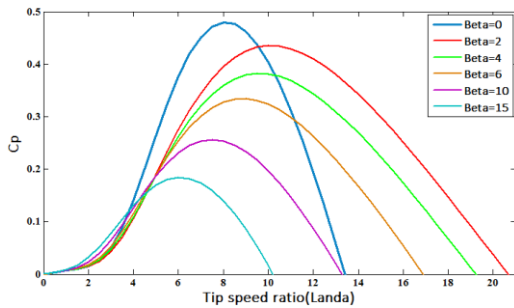


Figure 1. Performance factor diagram for different values of β

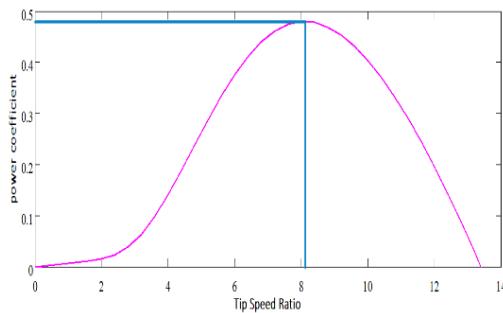


Figure 2. Performance factor diagram for β

2. 2. MPPT Control The purpose of the MPPT strategy is to obtain the maximum power from wind energy, which includes tracking the power curves indicated in Figure 3 and presented by Equation (6). The optimal power can be defined by Equation (6) by applying Equation (1).

$$P_{opt} = 0.5\rho AC_{p-max}(\lambda_{opt})V^3 \quad (6)$$

At each wind speed, the speed controller controls the rotor speed to the optimum value according to the Equation (5), and therefore the electrical power of the generator will be controlled. Hence, λ can be maintained in λ_{opt} by adjusting ω_r in different wind speeds and the optimum value, and thus the maximum power available for the wind turbine can be achieved. Equation (7) and Equation (8) demonstrate the relationship between the maximum powers P_{MPPT} and its corresponding torque T_{MPPT} at the optimum speed of the generator. Figure 3 indicates the power-speed curves of the wind turbine, and also the curve of the maximum power using the Equation (7) is illustrated in red color, which shows the points that are expected from a system with MPPT to work in which points.

$$P_{MPPT} = K \omega_{opt}^3 \quad (7)$$

$$T_{MPPT} = K \omega_{opt}^2 \quad (8)$$

3. GENERATOR CONTROL AND MODELING

Generator voltage equations in the d-q rotating reference frame are defined using the Equations (9) – (10):

$$V_{gq} = -R_g i_q - PL_q i_q + \omega_e L_d i_d + \omega_e \lambda_m \quad (9)$$

$$V_{gd} = -R_g i_d - PL_d i_d - \omega_e L_q i_q \quad (10)$$

where V_{gd} and V_{gq} are the voltages of the generator on the d-q axes and i_d and i_q are the currents of the generator on the d-q axes. Also, L_d and L_q are the inductances of the generator on the d-q axes, R_g is the

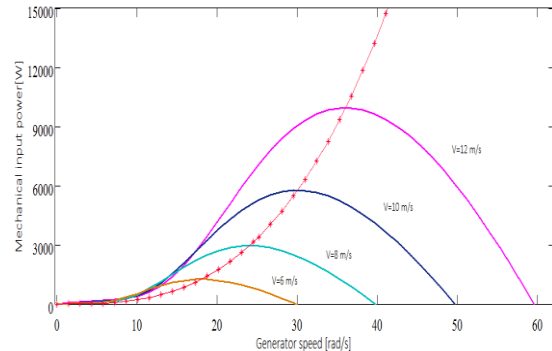


Figure 3. Power-speed wind turbine curves

stator resistance, ω_e implies to the electrical rotating speed of generator and λ_m is the magnetic flux. Figure 4 shows the equivalent circuit of the generator on the axes d and q, and also the electromagnetic torque is defined by Equation (11):

$$T_e = \frac{3}{2} P [\lambda_m i_q - (L_d - L_q) i_d i_q] \quad (11)$$

where P is the number of pole pairs. The axis d is aligned with the magnetic flux using field oriented control (FOC), and since it is considered to be $i_d = 0$, the electromagnetic torque can be rewritten as Equation (12). The axis current of q can be applied for the generator speed control using the reference speed obtained from the MPPT implementation, and the axis current of d is maintained at zero, as mentioned earlier.

$$T_e = \frac{3}{2} P i_q \lambda_m \quad (12)$$

4. CONTROL STRATEGY OF POWER STABILIZATION DURING WIND SHORTAGES

4. 1. Proposed Control System Figure 5 shows the diagram of the proposed control system for the grid-side converter (GSC) and rotor-side converter (RSC). As shown in the diagram, the outer loop control comprises the active and reactive power control system and the inner loop control comprises the converter current control system. The unique features of this control system are separate control of all the active parameters such as speed, active power, torque and reactive parameters such as voltage, reactive power, power factor and so on. When the rotor circuit power is allowed to flow in two directions, the control system will be able to cover a wide range of rotor speeds including sub-synchronous and super-synchronous speeds.

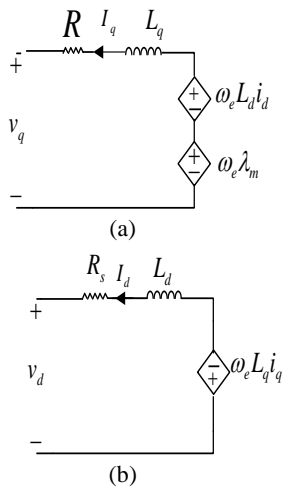


Figure 4. (a) Equivalent circuit of the axis q of generator (b) Equivalent circuit of the axis d of generator

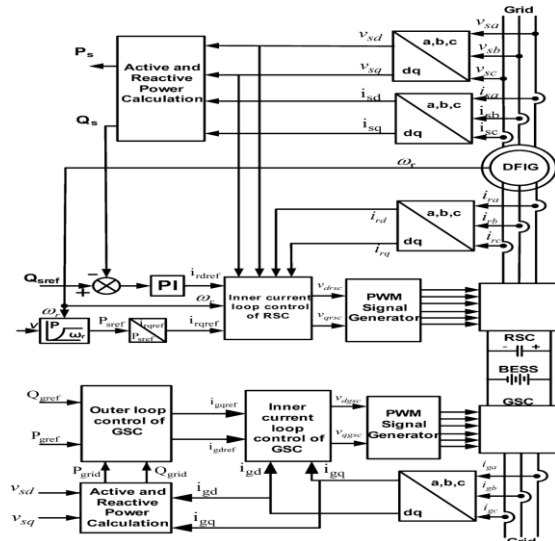


Figure 5. The proposed control diagram of RSC and GSC circuits in DFIG system equipped with BESS

The distinctive feature of this method is the implementation of the power control loop in the outer loop of the GSC control. The active power required by the network is always determined by a specified value, which simulates the reference amount of power demanded by the network. By comparing the reference active power and the actual active power injected into the grid, which is obtained by the instantaneous voltage and terminal current signals converted into the d-q rotating machine, the value of the active power injection error is obtained. This error value is compensated by passing a proportional-integral (PI) controller and the output of this PI controller will generate the reference value of the q-axis converter current.

4. 2. BESS Modeling The modeling of energy storage in dc-link back-to-back converters is discussed in this section. The use of the BESS for wind turbines that their production is unpredictable is very important and useful. Applying these energy storages will always provide a definite and controllable amount of active and reactive power to the grid. However, the most essential issue is the definition of the level of the BESS that has a significant impact on the technical performance and cost of the system. The maximum surface of the BESS is determined by the curve in Figure 6 [24]. In fact, the geographic information is required to determine this level of storage. This level of storage is determined by the maximum distance of the instantaneous power of wind relative to the average power. The amount of total energy in dc-link back-to-back converters is obtained from the Equations (13) to (14) [24]:

$$E_b = \sum_{i=1}^n (P_{mi}) * t_i \quad (13)$$

$$P_{mi} = P_{inst} - P_{ave} \quad (14)$$

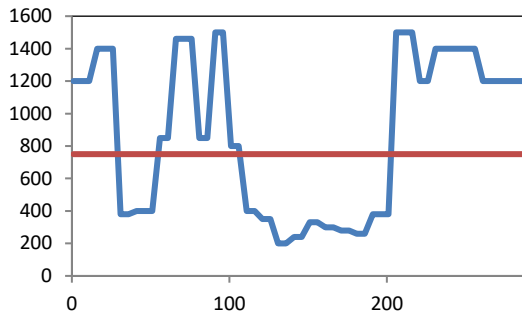


Figure 6. The characteristic of instantaneous output power and its average value for one day with a 5-minute step [24]

where P_{mi} is the instantaneous power in each 5-minute interval. t_i is also the time of each 5-minute interval. The unit of E_b is kWh, and the unit of P_{mi} is kW. The average power (P_{ave}) can sometimes be extracted and counted for annual or monthly intervals. Figure 6 illustrates the issue that the BESS must be able to store or release the difference between P_{ave} and P_{gen} . Consequently, it is assumed that the wind power conditions are similar to Figure 6 for the 5-minute intervals at the location of the site [24]. The design of the BESS is based on the injection power control of the grid in such a way as to dampen the swing of Figure 6 on a daily period and always inject the required power to the grid with a specified range.

$$\frac{v}{v_0} = \left(\frac{h}{h_0}\right)^n \quad (15)$$

where the v is the new wind speed at height h . In this paper the coefficient n is considered to be 0.13 and wind speed at height of 20 meters above ground level is measured².

At this point, the authors are seeking to determine the battery capacity. The minimum dc-link voltage is extracted from the following Equation (16):

$$V_{dc} = \frac{N_2}{N_1} \sqrt{\frac{2}{3}} V_{line} \quad (16)$$

where V_{dc} is the minimum voltage required for the dc-link and the batteries, $\frac{N_2}{N_1}$ is the transformer turns ratio of the grid side and the V_{line} is the line rms voltage of the grid side. Now considering this voltage level, the number of series batteries can be extracted from the following Equation (17):

$$N_{series} = \frac{V_{dc}}{V_b} \quad (17)$$

where V_b is the voltage of each battery. On the other hand, the number of parallel batteries can be calculated from the following Equation (18):

$$N_{parallel} = \frac{E_b * 1000}{V_{dc} * P_b * MDOD} \quad (18)$$

where P_b is the capacity of each battery in terms of (Ah) and MDOD is the maximum capacity of battery discharge.

5. SIMULATION RESULTS

5.1. Parameters Required for the Studied System

In this section, a wind farm equipped with DFIG with the vector control system is simulated by the BESS system in the dc-link back-to-back converter to reduce the swing of injection power to the grid and increase the productivity of the grid. In this regard, the parameters of the wind turbine system are given in Table 1. The optimal turbine constants for extracting the maximum power of wind for transmission to the grid are also indicated in Table 2.

According to Equation (3), the power coefficient $C_p(\lambda, \beta)$ plays a significant role in the realization of MPPT. Also, the output power of the turbine is highly dependent on the coefficients expressed in Equation (3). It should be noted that the coefficients of the parameter C_p applied in the paper are shown in Table 2.

The Thevenin's equivalent model of the battery is shown in Figure 7.

The design and modeling details of this part of the system were discussed in the previous section, along with its characteristic equations. Therefore, the battery unit with the capacity of kWh is implemented in MATLAB software. In this case, the required capacity of the battery bank is obtained from Equation (19).

TABLE 1. Wind turbine parameters

Parameters	Quantity
Rated power [MW]	1.5
Minimum operating wind speed[m/s]	4
Maximum operating wind speed[m/s]	16
Rated wind speed[m/s]	10
Number of blades	3
Rotor diameter[m]	82
Swept region[m ²]	5281

TABLE 2. Coefficients of the parameter C_p [9]

Parameters	Value	Parameters	Value
C_1	0.5176	C_6	0.0068
C_2	116	C_7	0.08
C_3	0.4	C_8	0.035
C_4	5		
C_5	21		

² <http://www.imd.gov.in/section/nhac/aws/aws.htm>

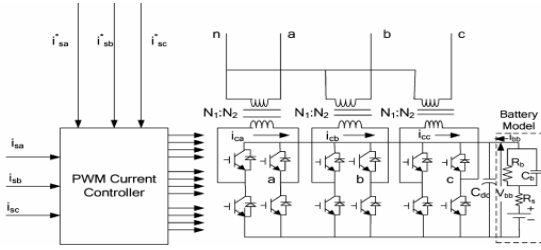


Figure 7. Thevenin's equivalent circuit of a battery-based model at the dc-link of the controller

$$C_b = \frac{(KWh) \cdot 3600 \cdot 10^3}{0.5(V_{ocmax}^2 - V_{ocmin}^2)} \quad (19)$$

where V_{ocmin} and V_{ocmax} are the minimum and maximum open-circuit voltage of the battery under fully discharged and charged conditions. Also, in the Thevenin's model of the implemented battery, R_s is the equivalent resistance (internal+external) of parallel/series combination of a battery, which has a small amount. Also the parallel circuit of R_b and C_b is used to describe the stored energy and voltage during charging or discharging. Also, the general characteristics of the battery bank are given in Table 3.

Also, the studied DFIG characteristics have been entirely presented in Table 4. The electrical system, including turbines, batteries, generator, rotor side converter (RSC) and grid side converter (GSC), power grid, transformer, etc. have been implemented in SimPower environment of MATLAB software. The problem is solved with the od23 software in a discrete time. The results of the analysis and simulation will be presented and analyzed in the next section.

5. 2. Parameters Required for the Studied System

One of the most critical issues in the operation and control of DFIG wind turbines connected to the grid is the changes in wind speed and its direct impact on the output power to the grid. The wind turbines rotate at different speeds due to the natural nature of the wind. This variable speed results in a change in mechanical torque applying on the axis, and eventually, an alteration in electrical power converted and transmitted to the grid. For operation the grid, it is desired to transmit the definite and controllable active and reactive power to the grid, and the changes in wind speed disrupt

TABLE 3. Battery parameters

Parameters	Quantity
Rated voltage of the battery (V_b) [V]	1200
Internal resistance (R_b) [Ω]	10000
Internal capacity (C_b) [F]	675000
battery Series resistor (R_s) [Ω]	0.00094

TABLE 4. DFIG parameters

Parameters	Quantity
Rated power[MW]	0.75
Nominal frequency[Hz]	50
The nominal voltage of the stator[V]	575
Rotor distant relative to the stator	0.38
Number of poles	4
Stator resistance[pu]	0.00706
Rotor resistance[pu]	0.005
Stator leakage inductance[pu]	0.171
Rotor leakage inductance[pu]	0.156
Magnetizing inductance[pu]	2.9
Constant inertia of the generator[s]	5.04

the mentioned demand. The vector control, which is one of the most precise methods of controlling all types of electrical machines, is converted to non-time-varying and controllable signals by converting in a synchronous reference form of time-varying differential equations. In these conditions that the time dependency has disappeared, the scenario of this article will be easily implemented through the proposed control algorithm. It can be referred that the main innovation of the present paper is to stabilize the injection unit of wind power into the grid under varying weather conditions. It means that this wind unit always delivers specified and fixed power to the grid with the change in wind speed. This controlling method is an innovation of the present article since it is capable of stabilizing the output and transmitted power to the grid in a certain amount. It should be noted that an energy storage system and a low pass filter at the connection point of the back-to-back converter are required to apply this tool. The block diagram structure of this system is demonstrated in Figure 8.

In Figure 8, V_{abc} is three-phase voltage of stator, I_{grid} is the grid current, I_{GSC} is the current converter of grid side, I_{RSC} is the converter current of rotor side, I_{ST}

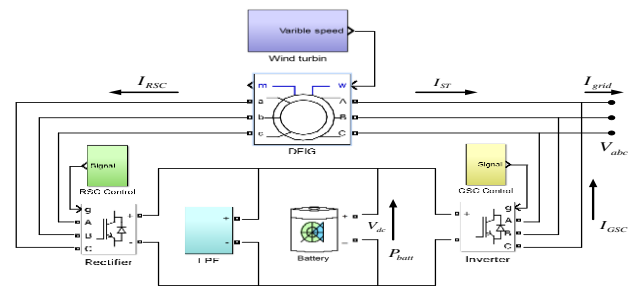


Figure 8. Block diagram of DFIG with a proposed control mechanism

is the stator current, ω_r is the angular speed of rotor, V_{dc} is dc-link voltage, P is the power injected to grid, Q is the reactive power injected to grid, and P_{batt} is the battery power. In this paper, the reference value of reactive power is set to be zero to maintain the system performance in unit power factor and transmission of maximum wind power to the grid. In this section, the system performance will be examined in three different modes to analyze the behavior of the system. These three modes will include investigating the behavior of the system at sub-synchronous speed, super-synchronous speed, and synchronous speed of the system, in which conditions, the objective is to achieve a fixed and specified rate of transmission power to the grid under these three different wind speeds. In all three cases of this simulation, the delivery power of DFIG is stabilized at the nominal value of 0.75 MW.

In this paper, it is assumed that within 0.3 seconds, the wind speed changes in three values of 0.8, 1.2, and 1 p.u, respectively. In these conditions, Figure 9 shows the voltage applied to the balanced three-phase system, which is stabilized at the value of 1 p.u.

This figure also indicates that the output voltage of the wind farm is always imposed by the grid and since the power factor of the wind farm is set to unit value, no reactive power is transmitted between the plant and the grid, and the voltage is always stabilized in the amount of 1 p.u in both cases.

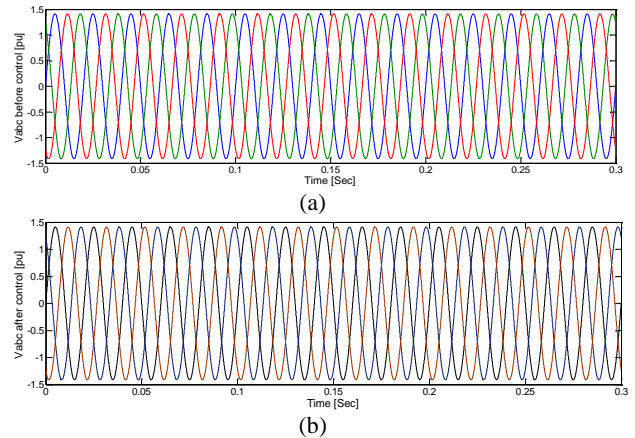


Figure 9. DFIG balanced three-phase voltage at wind speeds of 0.8, 1.2 and 1 p.u: a) Before control and b) After control

Figure 10 indicated the current delivery to the grid. As shown in Figure 9, the voltage is at the value of 1 p.u in both cases, and also, the power factor of the plant is at the unit value. Since the system is not equipped with the control mechanism of wind shortages in the a) before control, an uncontrollable current is consequently injected into the grid regarding wind power. However, in the b) after control, due to the use of an intelligent control system, the current is always constant and controllable due to changes in wind speed.

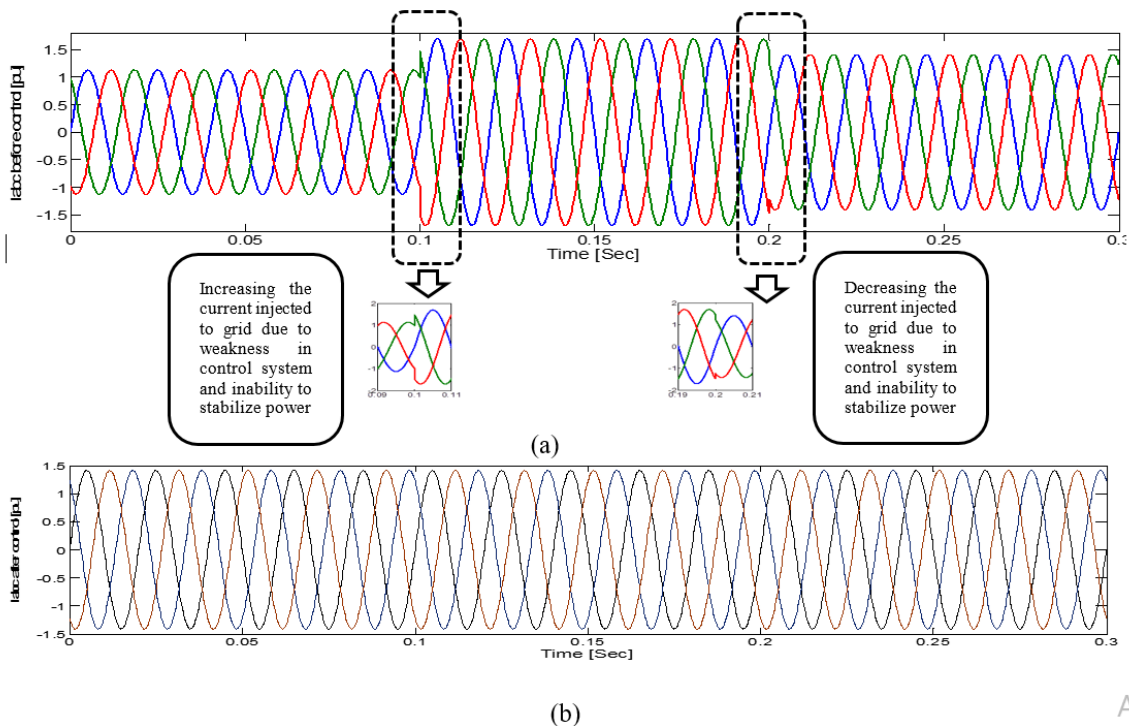


Figure 10. Three-phase current injected to grid at wind speeds of 0.8, 1.2 and 1 p.u: a) Before control and b) After control

Also, in Figure 11, the grid side converter (GSC) current is considered in two controlled and uncontrolled cases. As indicated in the a) before control, there is always a constant power exchange between the converter and the grid due to voltage stabilization, and no other exchange occurs at this point due to the absence of the BESS. However, as shown in the b) after control, which relates to the system equipped with control in wind shortages conditions, with respect to the wind speed, the grid side converter power exchange changes with the grid. Here, at 0 to 0.1 seconds when the wind speed is 0.8 p.u (sub-synchronous), the power stored in the BESS is injected into the grid, and at 0.1 to 0.2 seconds when the wind speed reaches 1.2 pu, the surplus generated power is stored through this converter in the BESS. In the following, a normal power exchange between the grid and the converter is performed due to the reaching speed to 1 p.u. Also, a stator current of the generator is indicated in Figure 12, which naturally behaves similarly in both control states. The power fluctuations in the injected power stator of the generator through the BESS will result in a constant and uniform value that will eventually be transmitted to the grid.

In the following, the angular speed of the DFIG rotor has been indicated for both cases in Figure 13.

As shown in Figure 13, the generator is located in three sub-synchronous, synchronous, and super-synchronous operating areas.

In Figure 14, the voltage rectifier of the back-to-back converter is demonstrated for both cases.

As shown in Figure 14, the dc-link voltage will be controllable and stabilized due to voltage stabilization in the generator terminal.

As mentioned earlier, since in both cases, the nature of the control system is based on the unit power factor (power factor=1), in Figure 15 the exchange reactive power between the power plant and the grid is shown.

As shown in Figure 15, no reactive power is exchanged between the grid and the power plant.

However, the main innovation of this article is indicated in Figure 16.

As can be seen from Figure 16 (a), if the system is not equipped with a control structure in wind shortages, the power injected to the network will change by changing the wind speed, which is not desirable. If the vector control system is equipped with a correction mechanism in wind shortages, the power is injected into the grid in a controlled and stabilized, in which the significant role is played by the BESS according to Figure 16 (b).

According to the Figures presented under different wind speeds in this section, the system which is equipped with FOC and BESS control algorithms will be able to supply transmitted power to the grid at 0.75 MW continuously. According to the Figure17, If the wind speed drops below the nominal value, the energy stored in BESS stabilizes the grid power, and if the wind speed increases to values higher than the nominal value, with the BESS charge will meet this requirement.

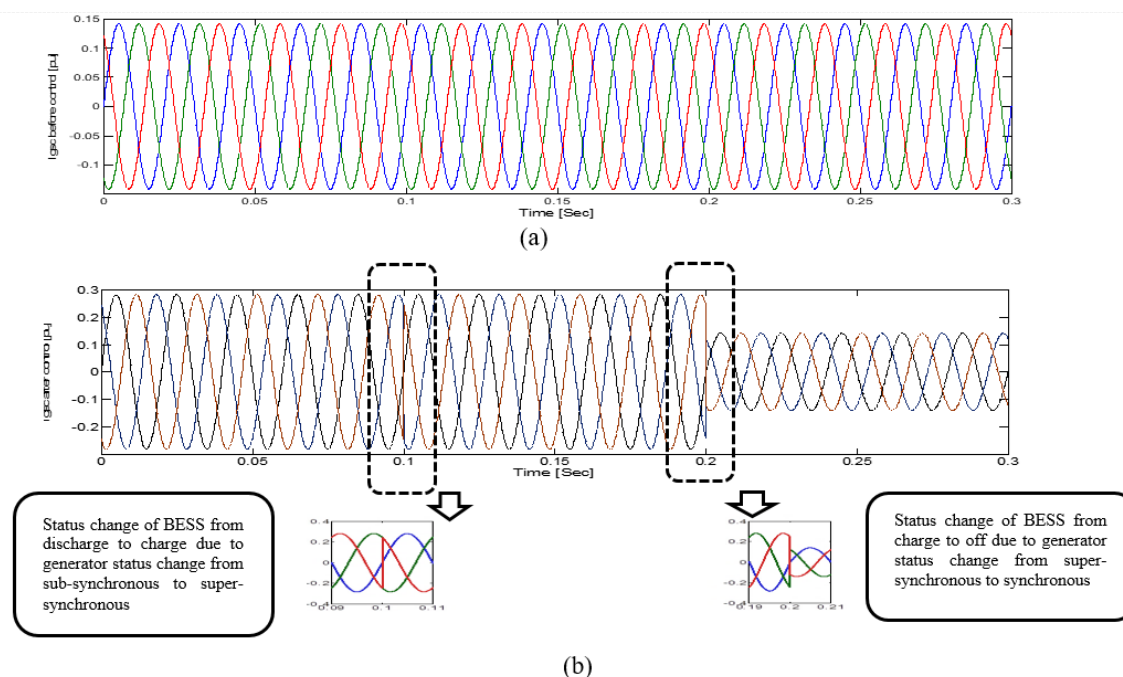
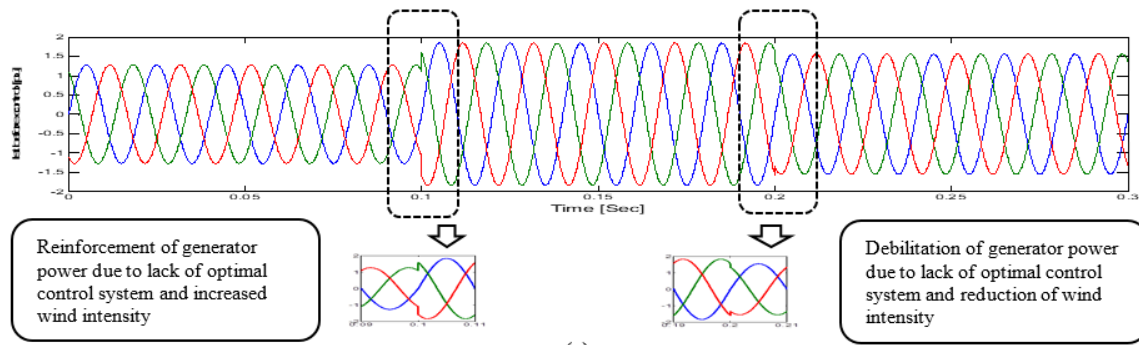
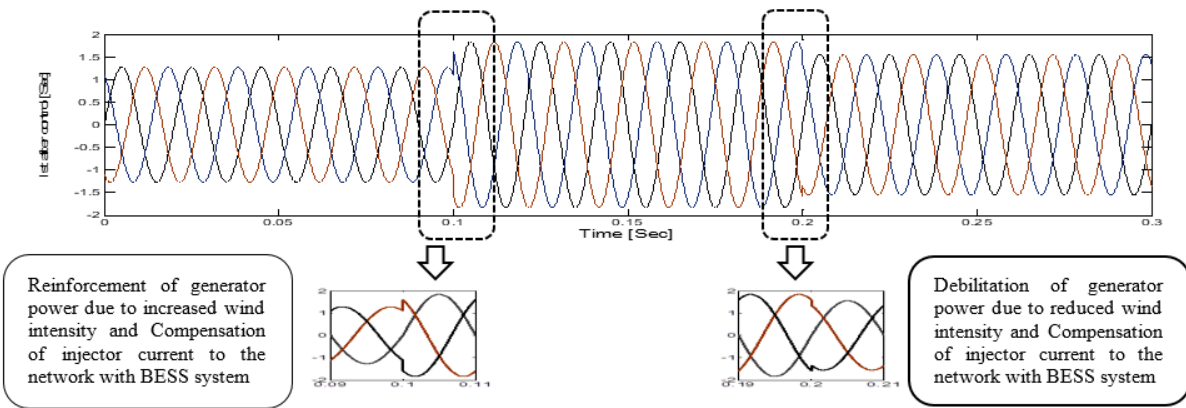


Figure 11. Balanced three-phase current of grid side converter at wind speeds of 0.8, 1.2 and 1 p.u: a) Before control and b) After control



(a)



(b)

Figure 12. Balanced three-phase current of DFIG stator at wind speeds of 0.8, 1.2 and 1 p.u: a) Before control and b) After control

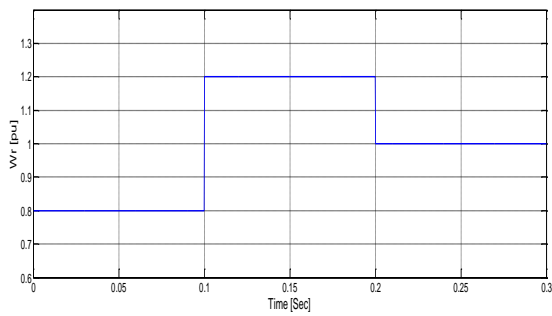


Figure 13. Angular speed of rotor in both cases

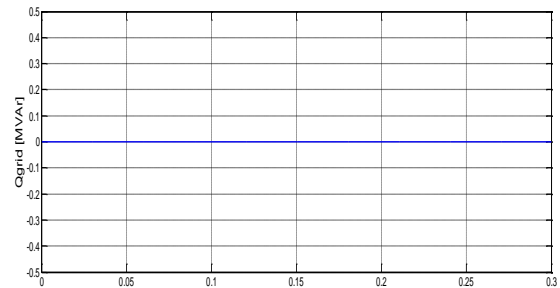


Figure 15. Reactive power transmitted to the grid in both states

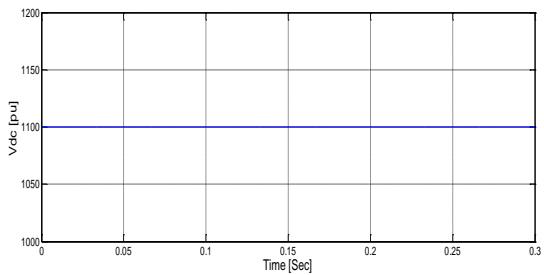
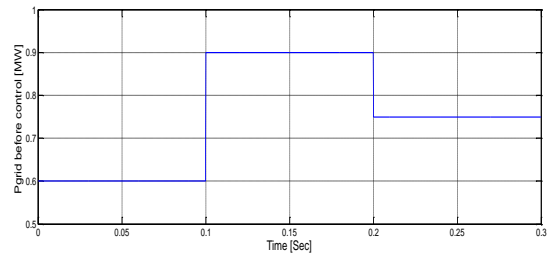


Figure 14. Voltage rectifier for both cases



(a)

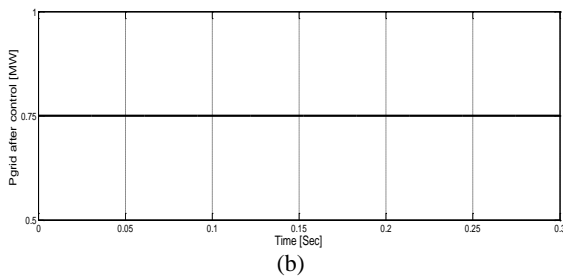


Figure 16. Transmitted active power to the grid at wind speeds of 0.8, 1.2 and 1 p.u: a) Before control and b) After control

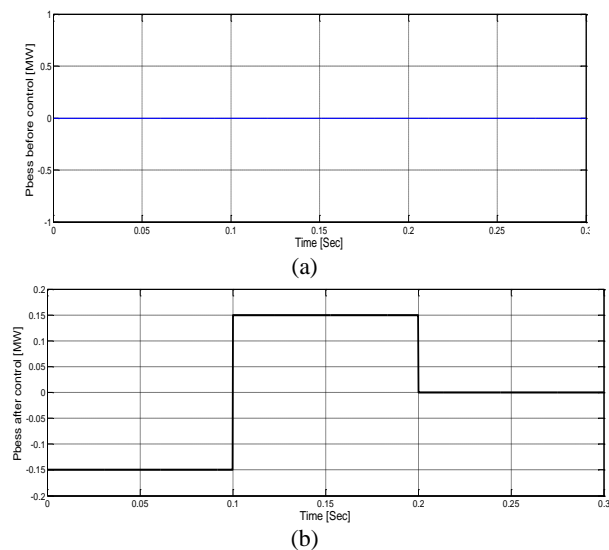


Figure 17. Generation and consumption power of the BESS at wind speeds of 0.8, 1.2 and 1 p.u: a) Before control and b) After control

6. CONCLUSION

The present paper introduces a new method for connecting a wind power plant unit equipped with a DFIG to the grid. This method, which is based on a robust vector control, generates a separate control capacity of injection power to the grid under wind shortages in addition to optimal performance in normal climatic conditions. In the proposed method, energy storage (acid lithium battery) has been applied in the dc-link of rotor side back-to-back converters to enhance the power swing of the wind turbines as well as to improve the performance of the grid. Also, in this study, the strategy of maximum wind power tracking and unit power factor of the plant has been included in the control system to achieve an optimal control system. In this state, the vector control system is equipped with the correction mechanism in wind shortages, which allows the power to be injected into the grid in a controlled and stabilized manner, i.e.,

when the wind speed is lower than the nominal value, the stored energy in BESS stabilizes the grid power, and when the wind speed is higher than the nominal value, BESS charge will meet this requirement. Also, under varying wind speeds, the system which is equipped with FOC and BESS control algorithms will be able to continuously supply the transmission power of 0.75 MW to the grid. The proposed model for network power setting during wind shortages was implemented and simulated using MATLAB software. The results show the efficiency of the proposed method in the network power setting.

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Persian Abstract

چکیده

این مقاله یک روش مبتنی بر کنترل برداری جدید را برای اتصال یک نیروگاه بادی مجهز به ژنراتور القایی دوسو تغذیه به شبکه ارائه می نماید. این روش علاوه بر عملکرد بهینه در شرایط نرمال آب و هوایی، قابلیت کنترل تفکیک شده توان تزریقی به شبکه در شرایط کمبود باد را نیز ایجاد می نماید. مدل سازی ریاضی مبدل های سمت شبکه و روتور که چنین ابزار کنترلی را فراهم می آورند، ارائه شده است. برای کاهش نوسانات توانی واحد بادی به شبکه در لینک dc مبدل های پشت به پشت سمت روتور ایده بهره گیری از یک ذخیره ساز انرژی ارائه شده است. به منظور دستیابی به سیستم کنترلی بهینه، استراتژی ردیابی حداکثر توان باد و ضریب قدرت واحد نیروگاه در سیستم کنترلی گنجانده شده است. البته استراتژی تبادل توان با ضریب قدرت واحد به نوع بهره برداری از شبکه مربوط بوده و در مواقع نیاز می توان توان راکتیو تزریقی را نیز کنترل نمود. در انتها، شبیه سازی سیستم مورد مطالعه و سیستم کنترلی پیشنهادی در فضای SIMULINK نرم افزار MATLAB که ابزار قدرتمندی را برای این نوع سیستم ها ایجاد می نماید، ارائه می گردد. از طریق این نتایج ایده نوین این مقاله و صحت عملکرد سیستم پیشنهادی تایید می شود.
