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On-Off Control Based Maximum Power Point Tracking of Wind Turbine Equipped by DFIG Connected To the Grid

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Abstract: This paper presents An on-off Control method which is based on maximum power point tracking and anticipated to control the rotor side converter of DFIG based wind turbine connected to the grid. The Grid Side Converter is controlled in such a way to assure a smooth DC voltage as well as ensure sinusoidal current on the network. The performance analysis to the new developed DFIG based WT Matlab Simulink model with MPPT based on-off control is assessed with the conventional Matlab Simulink model, which demonstrate the enhanced performance output of newly developed model as compared to the traditional model.

Keywords: DFIG; Wind turbine; MATLAB SIMULINK models.

Abbreviations: DFIG: Doubly Fed Induction Generator, VSC: Voltage Source Converter, WEC: Wind Energy Conversion.

INTRODUCTION

The study of increasingly alternate energy sources, requirements for electric energy is growing very fast. Amongst the available alternative energy sources, wind energy, solar energy, plus fuel cells have strained considerable attention. Supplementary, all of these alternate energy sources are also of renewable nature. Among the mentioned alternate energy sources, wind power generation systems have been the most cost competitive alternative. For the first decade of the 21st century, India emerged as the 2nd leading wind power market in Asia. More than 2,100 MW wind capacity projects were added in the financial year 2010–11. The installed capacity increased from a modest base of 41.3 MW in 1992 to reach 28,700 MW by December 2016. Because the route, as well as the speed of winds, may differ from position to position as well as occasionally, the variable speed wind turbine technology offers inherent advantages over the fixed rate one [1].The DFIG is worn in cycle with the wind turbine to produce electric energy. The DFIG through the use of the two back to Back converters, rotor side and grid side converters can deal with a wide variety of wind speeds by injecting a compensating variable frequency current component in the rotor circuit. Its facilitates both super and subsynchronous operations of DFIG. It is well known that the Induction machine is widely used in industrial application due to its low cost, the simplicity of construction and low maintenance cost. Such type of mechanisms can be used for an electric production wherever the momentum of the prime mover is steady, i.e., just above the synchronous speed. On the other hand, it is a fact that the wind speed varies drastically depending upon the environmental conditions and time of operation. Thus, there is a significant margin of speed variation. Such large margins of speed variation make wound rotor induction machines suitable for generation of wind energy [2]. In addition to its significant speed variation, the wound rotor induction machine offers the additional benefit of bidirectional move of the rotor power which depends on the rotor speed and field speed [3]. The DFIG is fundamentally a wound rotor induction machine capable of operating in super synchronous as well as subsynchronous mode. The compensation of DFIG more than the permanent speed induction generators is enhanced power excellence, concentrated mechanical stress as well as fluctuation and advanced energy capture [4].The operations of DFIG associated with the grid are helped with the help of rotor side and grid side converter. It is the accountability of the inverter connected to the rotor side to provide the necessary complementary frequency to uphold the stator frequency at a constant level, in spite of variations in the mechanical power. The control of DFIG presents a twofold crisis to compensate the speed variations and reactive power. The stability and presentation of the overall setup are to be preserved in the face of model uncertainties, external noise, a variety of the internal machine parameters and speed. The primary question for the research to carry forward is the ways by which the available energy at a given wind velocity can be harnessed to its maximum.

II.AN OVERVIEW OF WIND TURBINES

A wind turbine is a mechanism that converts kinetic energy as of the wind into mechanical energy. If the mechanical energy is used to create electrical energy, the machine may be named a wind generator or wind changer. If the mechanical energy is wont to drive machines, for example to grinding grain or pumping water, the device is predicted a windmill or wind pump. Today's wind turbines are manufactured in a range of vertical and horizontal axis types. Wind turbine system can be categorized by the nature of their operation, i.e., either fixed speed or different speed. For fixed-speed wind turbines, induction generator is straight linked to the grid. For the reason that the speed is approximately set to the grid frequency and most probably not controllable. It is not probable to store the turbulence of the wind in the form of energy rotational. In favor of a variable-speed wind turbine, the generator is controlled by power electronic apparatus, which makes it probable to control the rotor speed. The power variations caused by wind variations can be more or less engrossed through changing the rotor speed, and thus power variation originating from the wind conversion and the drive train can be reduced. Hence, the power quality impact caused by the wind turbine can be improved compared to a fixed-speed turbine.

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A. Primary observation of the DFIG Based Wind Turbine

The mechanical power which is produced by a wind turbine is proportional to the cube of the wind speed, i.e., $Pm \infty v^3$. Here P_m is the mechanical power of the wind, as well as v, is the velocity of the wind speed. The maximum power which is received through the revolving speed of the wind turbine defer from different wind speeds. For this reason, the operation of variable speed is necessary to maximize the energy. Two fundamental concepts exist for variable speed turbines. The first ideas are an electric generator with a converter connected to the stator windings along with the grid network which is shown in Figure 1(a). For the rated power of the wind turbine, the converter is to be designed. A generator is a synchronous machine which is frequently a permanent magnet. On behalf of the direct drive concept, a wind turbine using a DFIG has a converter associated to the rotor windings of the wound rotor induction machine, which is shown in Figure 1(b). This type of generator can be defined as a fraction (~30%) of the rated power. But the system ensures competent power conversion appropriate to variable rotor speed, which adjusts automatically by prevailing wind speeds [5]. The primary benefit of doubly-fed induction generators, while used in wind turbines, is that they permit the amplitude as well as the frequency of their output voltages to be maintained at a constant value, despite what the speed of the wind blowing on the wind turbine rotor is. As doubly-fed induction generators frankly associated with the AC power network and stay at the back coordinated at all times with AC power network. Further compensation includes the capability to control the power factor (e.g., to uphold the power factor at unity) while keeping the power electronics devices in the wind turbine at a moderate size. In the subsynchronous operating mode, the stator of the DFIG supplies power to the grid. In the super-synchronous operating mode, both stator output power and the rotor slip power are fed into the grid. A variable speed wind turbine with full-size converter along with doubly fed induction generator is exposed in Figure 1. However, the converter has to be intended for the rated power of the turbine. This problem can be taken care of by using the DFIG, which has a converter connected to the rotor winding of the wound rotor induction machine (Figure 1(b)). Rated power has been reduced to (25% - 35%) in the case of DFIG. The main components of the wind turbine are given as follows.

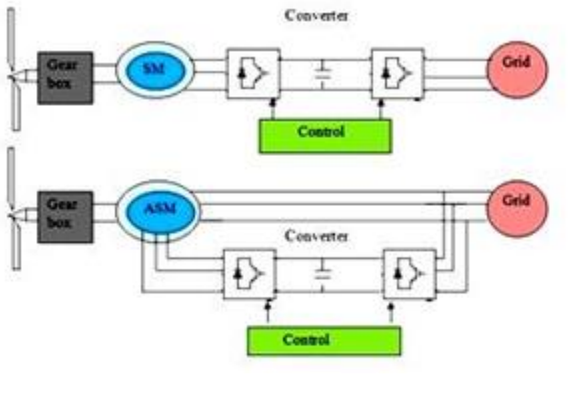

Fig. 1. Variable speed wind turbines (a) with full-size converter (b) with a DFIG[3]

(i) Drive Train along with Aerodynamics:

The drivetrain has a turbine, gearbox, shafts and other mechanical components of the wind turbine; a multi-mass (in general two mass) model to be used for dynamic studies of wind turbines through DFIG [6]. A simplify aerodynamic model is sufficient when the speed and pitch angle changes on the aerodynamic power during the grid faults. For stability investigation, the drive train system has to be approximated by the at least a two mass-spring as well as damper model while the system response to massive disturbance [7]. There is a flexible shaft during the turbine, and generator masses are associated.

(ii)Pitch Angle Control System:

The "Pitch Control" is a technique to mechanically regulate the blade pitch angle to change the curve of the power coefficient to the turbine [8]. PI control is used to realize the pitch angle, in servomechanism model using time control $T_{servo,}$ accounts for the realistic response in the pitch angle control System. For the period of the grid faults how quick the aerodynamic power can be reduced to stop more speed is determined by the velocity of altering limit.

B.Modeling of the Wind Turbine

Here wind turbine model is discussed for optimal operations of the wind turbine at different wind speeds [9,18]. It has to operate at its maximum power coefficient ($C_{Poptimum}$=0.3-0.5), *i.e.,* at a constant tip speed ratio, proposed for operation approximately it's maximum power coefficient.
The aerodynamic power generated by a wind turbine is given as follows.

$$C_p = \frac{P_{windturbine}}{P_{air}}$$

$$P_m = \frac{1}{2}\rho A_r v^3 C_p\left(\lambda, \beta\right)$$

A=Swept area of the blades (=πR^2),

□ □ Tip ratio speed, *v* = wind velocity

□$_T$ □ rotating speed of the rotor, □ = Pitch angle,
R= Radius of the area covered through the blades
C_p = wind turbine energy coefficient.

III. AN GENERAL IDEA OF THE DFIG OPERATING PRINCIPLE

The overview and operating principle of DFIG discussed in this section is also mentioned in [10, 18]. The structural diagram of DFIG with converters is shown in Figure 2. The AC/DC/AC converter comprises two components: the rotor side converter C_{rotor} as well as network area converter C_{grid}. These converters are voltage source converters that utilize forced commutation power electronic devices (IGBTS) to synthesize AC voltage from DC voltage source. A capacitor connected to DC side acts as a DC voltage source. The generator slip rings are linked to the rotor side converter,

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which shares a DC link with the grid side converter in a so-called back-to-back configuration. The wind power captured by the turbine is converted into electric power by the IG and is transferred to the network using stator as well as rotor windings. The control system affords the pitch angle command, along with the voltage commands for C_{rotor} as well as C_{grid} to control the power of the wind turbine, DC bus voltage plus reactive power or voltage at grid terminals. [11]. When the rotor speed is higher than the rotating magnetic field from the stator, the stator induces a high current in the rotor. The quicker the rotor rotates, the extra power will be transfer as an electromagnetic force to the stator, furthermore, in turn, converted to electricity that is feed to the electric network. The velocity of the asynchronous generator will differ with rotating force functional to it. Its dissimilarity from synchronous speed in percent is called generator's slip. With rotor winding short-circuited, the generator at full load is only a small percentage. Using the DFIG, slip control provides the rotor plus grid side converters. At high rotor speeds, the slip power is recovered and delivered to the network, resultant in high overall system efficiency. If the rotor speed range is determined, the ratings of the frequency converters will be small equated with the generator rating, which helps in reducing converter losses and the system cost [12].Because the mechanical torque functional to the rotor is constructive for power production and since the rotation speed of the magnetic flux in the air gap of the generator is definite in addition to constant for an invariable frequency network voltage, the sign of the rotor electric power output is a function of the slip sign. C_{rotor}, as well as Cgrid, have the capability of generating or absorbing reactive power can be employed intended for controlling the reactive power or the grid terminal voltage. The pitch angle is controlled to limit the generator output power to its standard value in support of high wind speeds. The grid provides the necessary reactive power to the generator.

IV.MPPT CONTROLLER

Maximum power point tracking is an efficient method of extracting generated power from the generating systems used by grid-connected inverters, solar battery chargers, and wind energy conversion system. Wind energy is dependent on weather, topology, and environment. It is essential to choose the best place where the quality of air can produce more electricity. Then it is difficult to wind turbine to provide 60% of power wind speed. Wind energy conversion system also has other losses like mechanical friction as well as low generator`s efficiency. So the amount of power output from WECS depends on the tracked wind power. Therefore, a maximum power point tracking control is required [13].

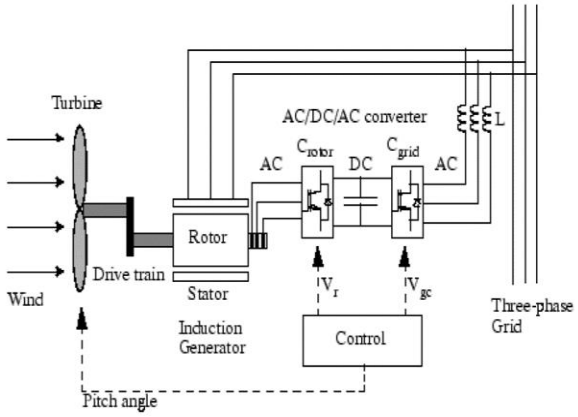

Fig. 2.Basic diagram of Doubly Fed Induction generator with converters [18]

V. ON-OFF CONTROL

Several research works have been presented with different power/voltage control of the DFIG based wind energy conversion system associated to the grid with battery storage. These control diagrams are usually based on vector control notion with conventional PI controllers due to their simplicity and easy implementation [14] [15]. Fuzzy logic and adaptive fuzzy controllers have also been used in the power/voltage control loop [16]. The Classical controllers for wind energy conversion systems (WECS) can be developed for more effective strategies based on intelligent control technique. On-Off control is a robust control scheme aiming at captured power maximization of DFIG-based WECS connected to the grid with battery storage. This technique superposes the tracking of the optimal torque value [17].The control objective can be formulated as an optimization problem, in which an objective function is maximized or minimized, to extract the maximum power from the wind energy. There is a specific complexity concerning the On-Off control, concerning the description of a switched constituent (following the sign of the tip speed ratio error) with guaranteed properties of attractiveness and stability. An on-off Control method based maximum power point tracking is planned to manage the rotor side converter of wind turbine equipped with doubly fed induction generator connected to the grid.

A. Controller Design

This approach supposes that the WECS reacts sufficiently fast to the variation of the low-frequency wind speed; this happens in the case of low-power WECS. Thus, for ensuring the optimal energy conversion, it is sufficient to feed the electrical generator with the torque control value corresponding to the steady-state operating point placed on the ORC. To this end, an on-off-controller-based structure can be used to zero the difference $\sigma = \lambda_{opt} - \lambda$, where λ is given by the low-frequency component of the wind speed, *v:* [17]

$$\lambda = \frac{\omega_r R}{v}$$

B. Rotor side converter based On-Off control:

For ensuring the maximum power point tracking an On-Off supposes that the WECS reacts sufficiently fast to the variation of wind speed (see Fig. 3). An On-Off controller can be used to zero the difference between the optimal tip speed ratio and the actual tip speed ratio σ [19]:

$$\sigma = \lambda_{opt} - \lambda$$

The on-off objective is to make the difference between the optimal tip speed ration and the exact tip speed ratio as small as possible with regulating the rotor speed according to the wind speed.

The control law u has two components:

$T_{emref} = u^{eq} + u^{n}$

Where the equivalents control u^{eq} as defined:

$$u^{eq} = 0.5\pi \rho R^3 \frac{C_p(\lambda_{opt})}{i\lambda_{opt}} v_s^2 = A v_s^2$$

With: $A = 0.5\pi \rho R^3 \dfrac{C_p(\lambda_{opt})}{i\lambda_{opt}}$ and i is the gearbox ratio, u^n is an alternate, high-frequency component, which switches between two values, $-\alpha$ and $+\alpha$, $\alpha>0$:

$u^n = \alpha \,\mathrm{sign}\,(\sigma)$

Component u^{eq} makes the system operated at the optimal point, whereas u^n has the role of stabilizing the system behavior around this point, once reached. The control law associated with the diagram in Fig.3 provides the steady state torque reference. The control input has, in this case, a large spectrum; the zero-order sample-and-hold (S&H in Fig.3) has been introduced to limit the loop switching frequency. If this frequency is too large, the control loop becomes inefficient. The zero order S&H element is approximated as a first order low-pass filter with a time constant $T_{S\&H} = T_s/2$, where T_s is the sampling period of the S&H. In Fig.3 the nonlinear part consists of an On-Off relay (“sign” block).The control of the rotor side converter is illustrated in Fig.3; the reference i_{qref} is derived from the high-speed shaft Ω_h and measured wind speed v by tuning the On-Off controller based maximum power point tracking (MPPT). Thus, by adding a PI regulator in the loop control of the d-axis and q-axis rotor currents is realized, as shown inFig.3 [19].

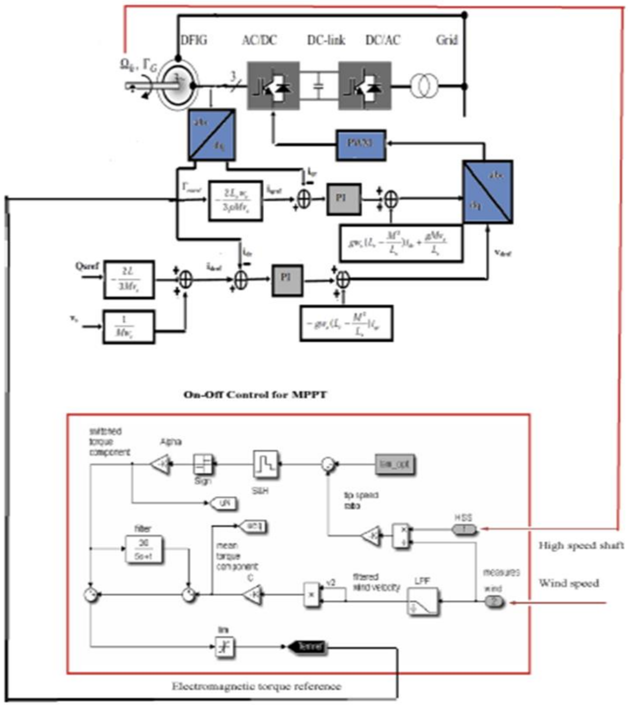

Fig.3.Rotor side converter based on-off control scheme [19]

C: Inverter and direct bus voltage control:

The direct bus voltage is given by the following equation [19].

$$V_{dc} = \int \frac{1}{c} I_c \, dt$$

With: $I_c = I_{dc} - I_n$

With V_{dc} and I_{dc} are the direct bus voltage and current respectively and I_n is the three-phase currents supplied to the grid. The control scheme of the direct bus voltage is presented in Fig. 4. The grid-side converter is wont to regulate the voltage of the DC bus capacitor. For the grid-side controller, the d-axis of the rotating reference frame used for d-q transformation is aligned with the positive sequence of the grid voltage. This controller consists of measuring the d-q components of AC currents to be controlled as well as the DC voltage. Elsewhere the DC/DC buck-boost bidirectional converter controlled voltage source. This converter maintains constant dc-link voltage as a reference value during discharge/charge current from/to batteries bank. [19]

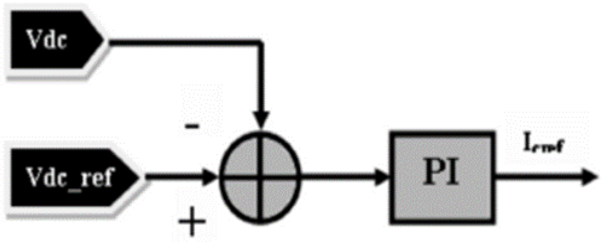

Fig. 4: Direct bus control scheme [19]

The output of the DC voltage regulator is the current reference I_{dgc_ref} for the current regulator. The current corrector controls the magnitude and phase of the voltage generated by the converter C_{grid} (V_{gc}). The grid side controller is presented in Fig. 5.

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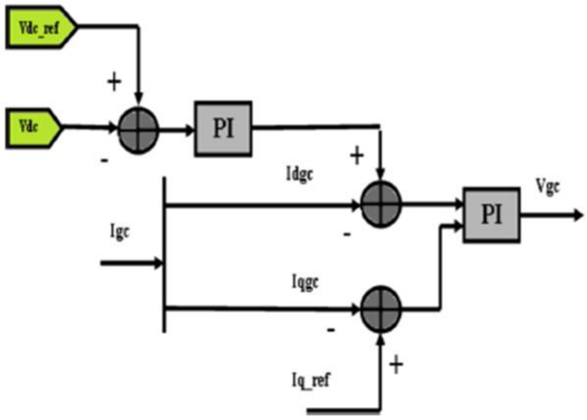

Fig. 5: Grid side control scheme [19]

VI. SIMULATION AND RESPONSE OF THE DFIG SYSTEM

Figure 6 represents the detailed doubly fed induction generator Matlab diagram and voltage (Pu) at DFIG terminals presented in Figure 7. Furthermore, Figure 8 shows the active power delivered. The reactive power requirement of the DFIG is presented in Figure 9. DC link voltage (Pu) at the conventional link capacitor of DFIG is presented in Figure 10.

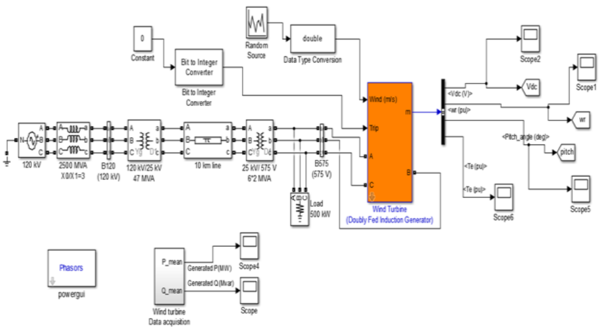

Fig. 6.Detailed DFIG wind turbine diagram

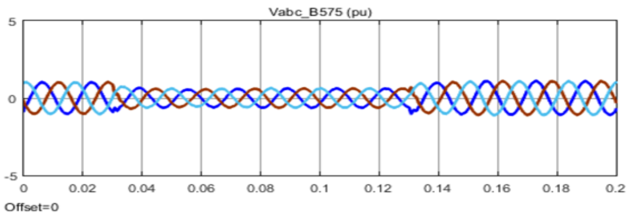

Fig. 7.Voltages at the DFIG terminals

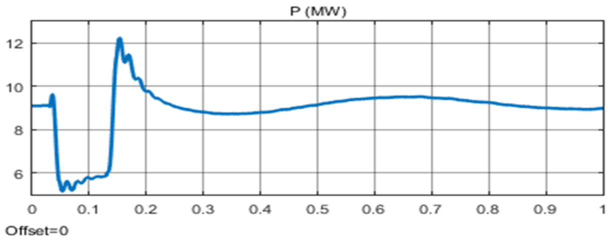

Fig. 8(a).Active power delivered

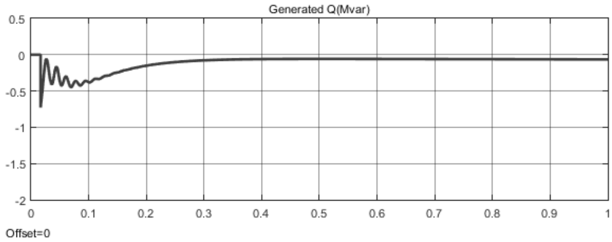

Fig.8 (b). Active Power P Vs. time from Conventional model

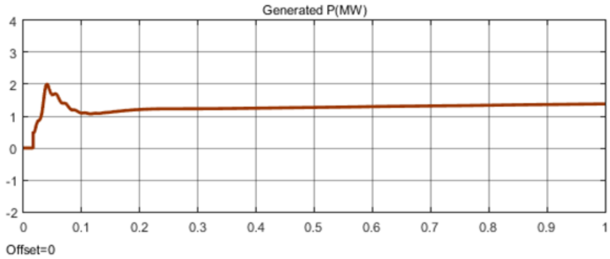

Fig. 9(a).Reactive power requirement of the DFIG

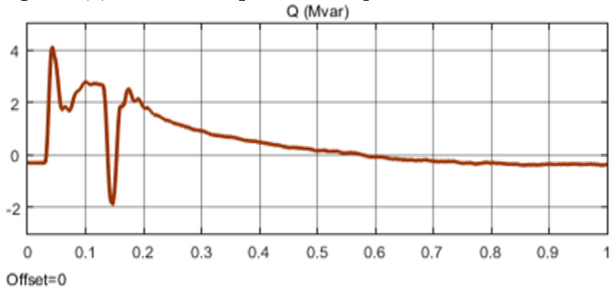

Fig. 9(b): Reactive Power Q v/s time from conventional model

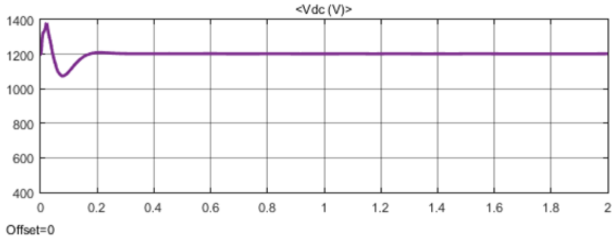

Fig.10 (a). DC link voltage

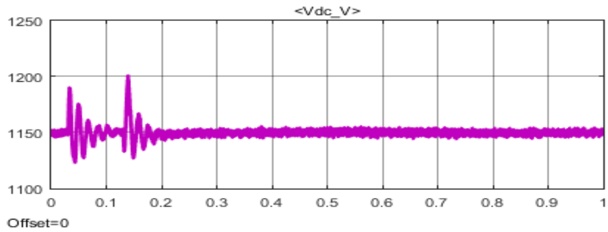

Fig.10 (b). DC bus link voltage Vs. time from conventional model

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Appendix: *Simulation Data*

Table 1: DFIG parameters

Parameters	Values
Power	1.5 MW
Stator resistance R_s	0.023 Ω
Rotor resistance R_r	0.016 Ω
Stator phase inductance L_s	0.18 H
Rotor phase inductance L_r	0.16 H
Generator inertia J	0.0685 kg m^2
Friction factor f	0.01 N ms

VII.CONCLUSION

The concept of MPPT has been proposed here to achieve the goal of tracking maximum power at a given wind velocity. To accomplish the MPPT from the wind system, the MPPT block in coordination with the rotor control block acts to maintain the torque to the value that is optimum for extracting the maximum power output from it. The energy conversion device which is used in wind turbine systems is Doubly Fed Induction Generator. Therefore, a doubly fed induction generator was modeled as an energy conversion device. The modeling included the verification of developed model with that of the generator present in the library of the MATLAB/ Simulink. The results were better than of the model in the MATLAB library. Further to achieve a double-fed induction generator the modeled generator was incorporated with rotor side converters and controllers. The results obtained showed that the system could perform well at average wind speeds while the results were inconsistent with that of expected values at lower and higher wind speeds.

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