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A Preliminary Study of Grid Connected Wind Power System

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***Abstract*—Wind energy is most sought out renewable energy source after solar energy. Wind turbines are operated either in fixed speed or variable speed. As the actual wind speed is variable, variable speed wind turbines (VSWT) is normally used. VSWT provide us with different exciting control strategy. Generally, VSWT employs doubly fed induction generator (DFIG). Market of DFIG based VSWT has grown tremendously. DFIG is connected to grid via back to back converter. Grid connected wind turbines is required to have some standard and quality as imposed by grid codes. Power converter helps in controlling active and reactive power and thereby maintaining power quality as imposed by grid code. Power converters employed in DFIG consists of two converters namely rotor side converter and grid side converter. Both the converters require separate control strategy and have different input variables and goals. The whole wind energy system modelling is done in MATLAB/ Simulink. Enhancement of quality is achieved with the help of grid side filter.**

***Index Terms*—DFIG (doubly fed induction generator), VSWT (variable speed wind turbine), GWEC (Global Wind Energy Council), GSC (grid side converter), RSC (rotor side converter), SG (synchronous generator), VSC (Voltage source converter), MATLAB/ Simulink.**

I. INTRODUCTION

Wind energy systems are one of the fastest growing and promising energy sources. It is abundant, renewable and environmental friendly. It can play its part in preventing energy crisis and climate change. Improvement in research and technology coupled with need for sustainable and clean energy has led to reduction in cost. India has set up an ambitious plan of generating 175 GW by 2022 from renewable sources alone. Wind energy is going to help India achieve that target. According to Global Wind Report 2016 by GWEC (Global Wind Energy Council), India set up a record high 3,612 MW of new installations, bringing the total to 28,700 MW. Over the decade, the wind power penetration has increased significantly in most countries like Denmark (40%), Uruguay (20%), Portugal (20%), Ireland (20%), Spain (20%) and Cyprus (20%). GWEC has projected 800 GW of cumulative installed capacity by the end of 2021 globally. This is an enormous figure compared to around 24 GW in the year 2001.

Components typically associated with wind power system are wind turbine which consists of rotor and its blades, gear box, generator, power converter, protective devices and transformer. Two types of generator systems are employed for wind turbines, namely induction generator (IG), doubly fed induction generator (DFIG) and synchronous generator (SG).[2] [16] Wind turbines are mainly divided into fixed speed wind

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turbines and variable speed wind turbines. The first one, as the name suggests, are the turbines which are operated at apparently fixed speed irrespective of wind speed. In the latter one, maximum efficiency is achieved over a range of wind speed with the help of power converters.

II. Doubly Fed Induction Generator (DFIG)

DFIG is a wound rotor type asynchronous machine. They are invariably used for variable speed wind turbines [1]. Both the stator and rotor winding are fed by AC; therefore they are "Doubly fed". DFIG is normally used for multi-MW wind system. The stator circuit of DFIG is linked to the grid. On the other hand, rotor circuit is connected to three- phase power converter via slip rings. Stator windings usually handle low voltages and rotor windings normally handle medium voltages. As the DFIG is operated with variable wind, they can run below and above their natural synchronous speed (i.e. sub- and super- synchronous modes). When the wind speed increases, so does the rotor speed to maintain optimum tip speed ratio, and the machine starts working super- synchronous operating mode (s<0). As opposed to, when wind speed reduces, the machine works in sub- synchronous operating mode (s>0) [16][17].

III. Back to Back Converters

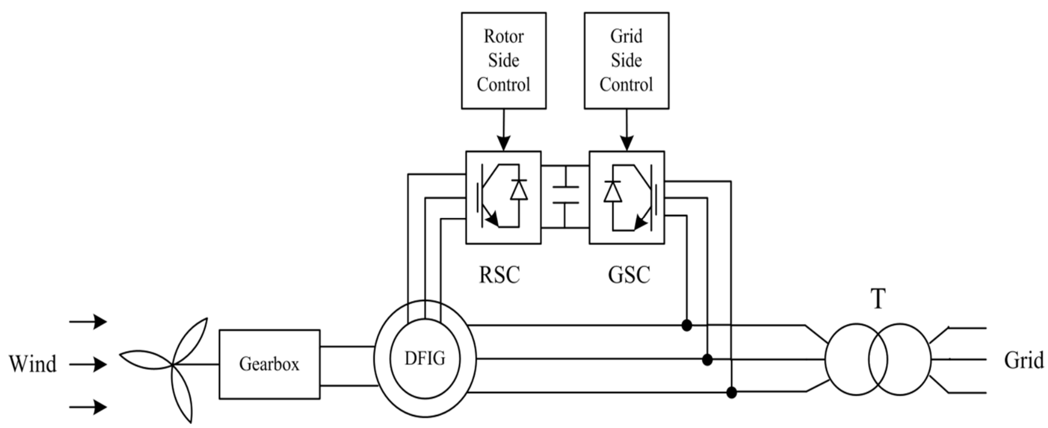

Figure 1. DFIG employing RSC and GSC converters

DFIG based wind power system consists of two power converters [13][14] as shown in figure 1. These converters are called Rotor side converter (RSC) because it is connected to the rotor and Grid side converter (GSC) because it is connected to the grid. These converters are connected "back to back". These power converters connected to the DFIG, handles fraction of total power (i.e. around 30%). Due to this fact, the size and the cost of converter reduce. These back to back converters may be constructed from voltage source converters to new age multi-level converters. A DC link capacitor is placed between the two converters for voltage variations (ripple) reduction. GSC sends active power to grid and its value is determined by the state of DC link voltage. If voltage of DC link capacitor increases, then more power can be exported and vice versa. When VSC (Voltage source converter) is used, current ripples and *dv/dt* arises. Additional use of filters can effectively try to eliminate them. GSC should control DC link bus voltage notwithstanding of the magnitude and direction of rotor power. Additionally, it helps in controlling the active and reactive power exchanges between rotor and grid. As it is connected to grid, it works at grid frequency. A LR filter is used to connect GSC with the grid. GSC and RSC consist of bidirectional switches [4][5][11].

The aim of RSC control technique is to supervise the torque generated. This is achieved by optimally aligning the position of rotor flux generated by rotor currents to that of the position of stator flux. The control strategy of RSC consists of 2 loops. The first one consists of i_{dr}^* for controlling the reactive power. The latter one involves i_{qr}^* for speed and hence torque control. Similarly, GSC also consists of two loops for its control strategy. The first one employs i_{dg}^* *for* limiting DC link voltage and consequently active power control, the second one consists of i_{qg}^* for controlling reactive power. Meanwhile the purpose of RSC is to control the torque or speed of the DFIG. Furthermore, it is used to regulate the power factor (p.f.) at stator terminals.[8]

After dq transformation, rotor voltage equations [8] are given by

$$v_{rd} = R_r i_{rd} + \sigma L_r \frac{di_{rd}}{dt} - \omega_{slip} \sigma L_r i_{rq} \qquad (1)$$

$$v_{rq} = R_r i_{rq} + \sigma L_r \frac{di_{rq}}{dt} + \omega_{slip} \left(L_o i_{ms} + \sigma L_r i_{rd} \right) \qquad (2)$$

Where, $\sigma = 1 - \frac{L_m^2}{L_s L_r}$, as leakage factor

$L_o = \frac{L_m^2}{L_s}$, as equivalent inductance

ω_{slip}, slip angular frequency

The Electromagnetic torque, T_e is given by

$$T_e = -\frac{3}{2} p L_o i_{ms} i_{rq} \qquad (3)$$

Simulink model diagram developed is shown in figure 2. Here, two IGBT based VSC are connected back to back as GSC and RSC. A capacitor is connected between the two power converters. A LR grid filter is also added for harmonic reduction. Rotor angle, rotor speed and electromagnetic torque are measured from the measurement terminal of the asynchronous machine model in MATLAB/ Simulink. Pulses are given both for GSC and RSC for required performance. A grid is modelled as a three phase source. Desired torque is provided to the asynchronous machine model using the step function. Voltage and current measurement blocks are used when necessary.

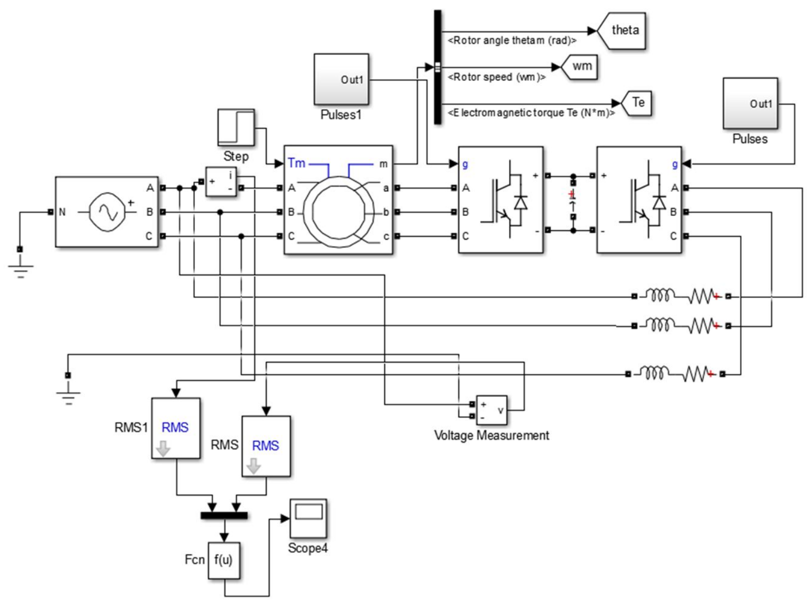

Figure 2. Simulink Model of wind power system

IV. Results and Discussion

The whole system is simulated in MATLAB/ Simulink for results. Simulation time for the model is set for 1 second. Results generated are discussed below. In figure 3, angular speed starts from the synchronous speed and then decrease according to wind speed, which is set to 9 m/sec. As the wind speed is constant, angular speed is also approaching steady state.

As speed is decreasing very fast i.e. for 0 to 0.2 seconds, it is producing fluctuation in torque as shown in figure 4. As we are operating induction machine in generating mode, *Tem* is negative, as seen in the figure 4. As the speed approaches steady value, torque produced is also becoming steady with less and less fluctuations.

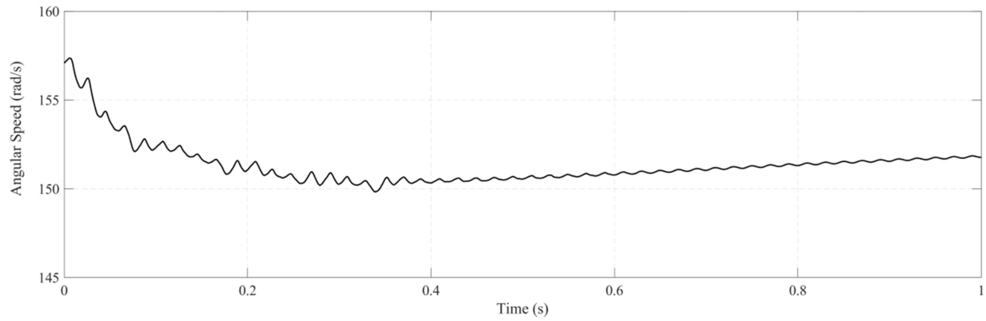

Figure 3. Angular Speed in rad/sec

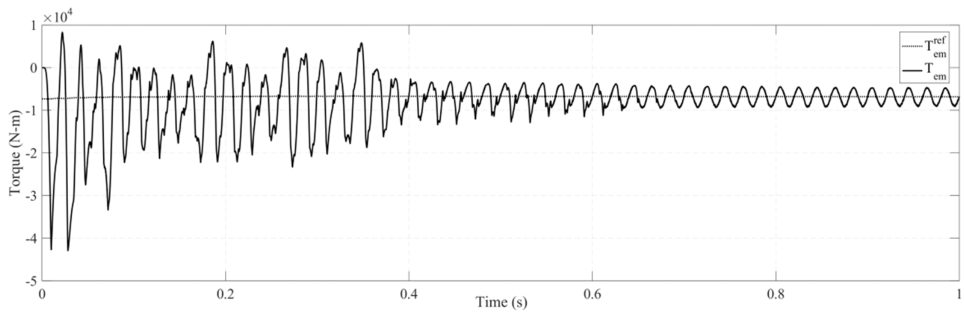

Figure 4. Electromagnetic Torque in N-m

DC bus voltage is set to 1000 Volts, as shown in the figure 5. It reaches steady state value around 0.4 seconds.

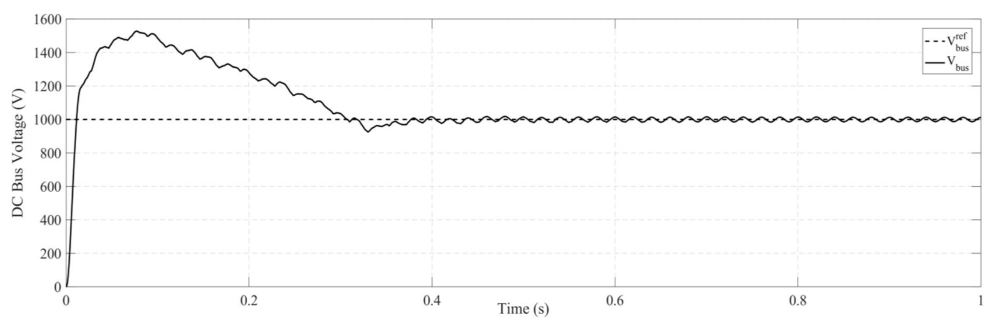

Figure 5. DC Bus Voltage in Volts (V)

Stator current settles around 0.4 sec and has a frequency of 50 Hz, as shown in figure 6. All the three phases are shown with different markings.

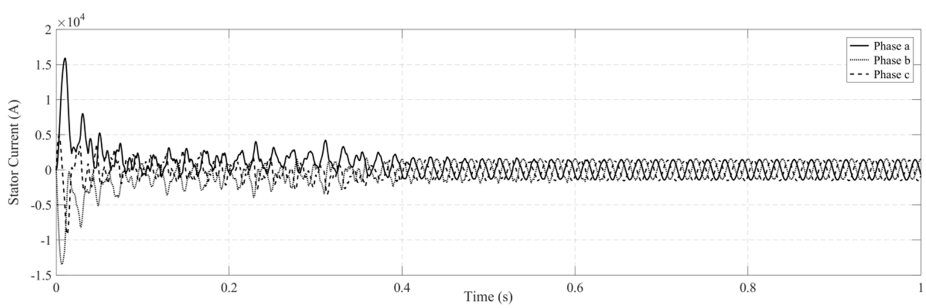

Figure 6. Stator Current in Amperes (A)

Rotor current also settles around 0.4 sec as shown in figure 7. All the three phases are shown with different markings.

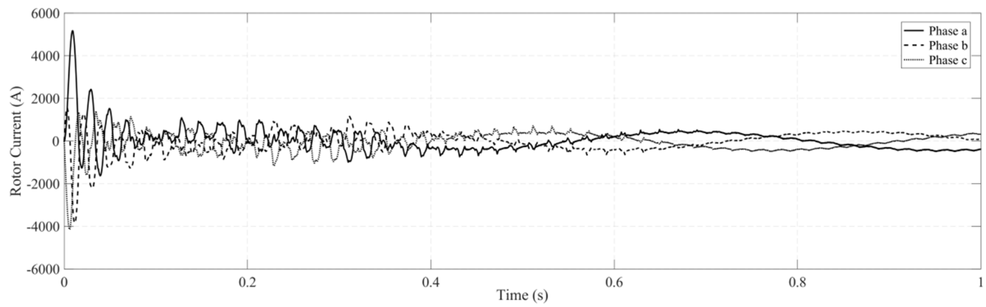

Figure 7. Rotor Current in Amperes (A)

q- Axis rotor current, I_{qr} is related to mode of operation, + when generator operation, - when motor operation. It changes accordingly with the torque and speed. As speed increases so does the I_{qr} increases. In the figure 8, it is around 1750 A.

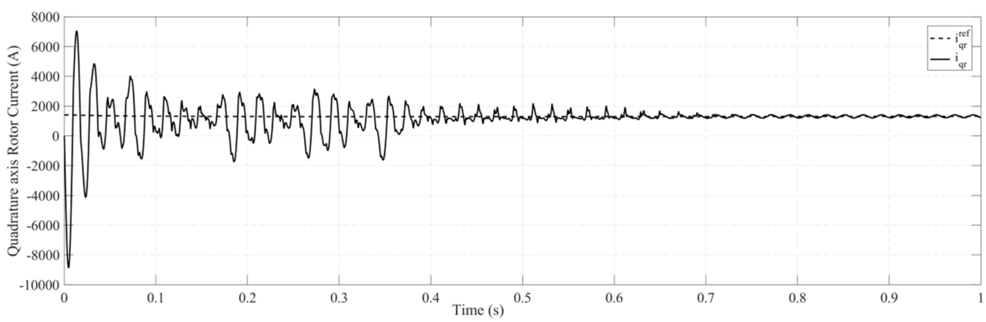

Figure 8. q- Axis rotor current in Amperes (A)

q-Axis grid current , I_{qg} is responsible for Q_g^{ref}. As Q_g^{ref} , is set to zero, *Iqg* is also zero mostly, as shown in figure 9. Initial fluctuation in the circuit, produces a transient in the I_{qg} which dies out on rapidly.

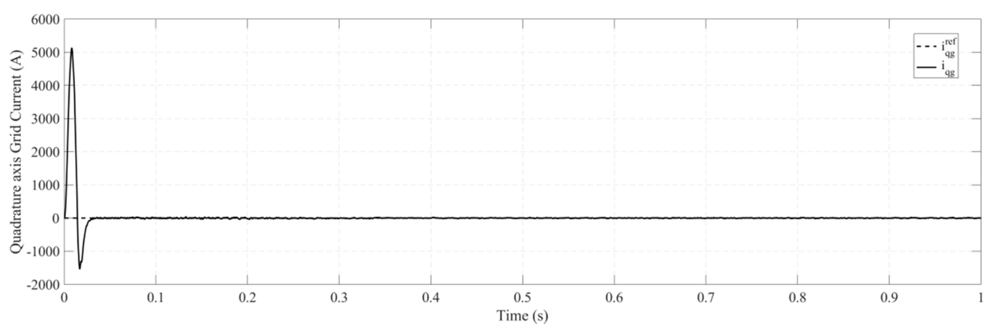

Figure 9. q-Axis grid current in Amperes (A)

The grid side current is shown in the figure 10. All the three phases are shown with different markings.
We have deliberately set d-Axis rotor current, I_{dr} reference to zero, according to our assumption that stator is providing all the reactive power as shown in figure 11.
As we have already stated, d-Axis grid current, I_{dg} is used to control DC link voltage (V_{bus}) control. As V_{bus} settles (figure 5), so does the I_{dg} as shown in figure 12.
Figure 13 shows the stator voltage characteristic. All the three phases are shown with different markings. Figure is deliberately shown only for 0.2 seconds, so that all the phases can be seen clearly. Stator voltage has a peak waveform of 550 volts.

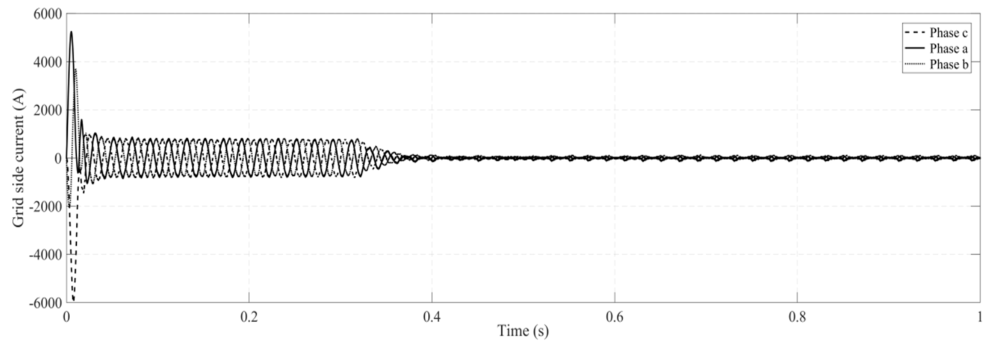

Figure 10. Grid side current in Amperes (A)

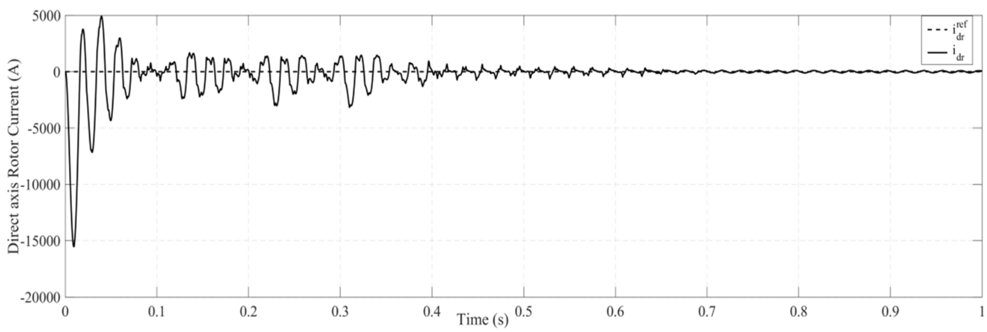

Figure 11. d-Axis rotor current in Amperes (A)

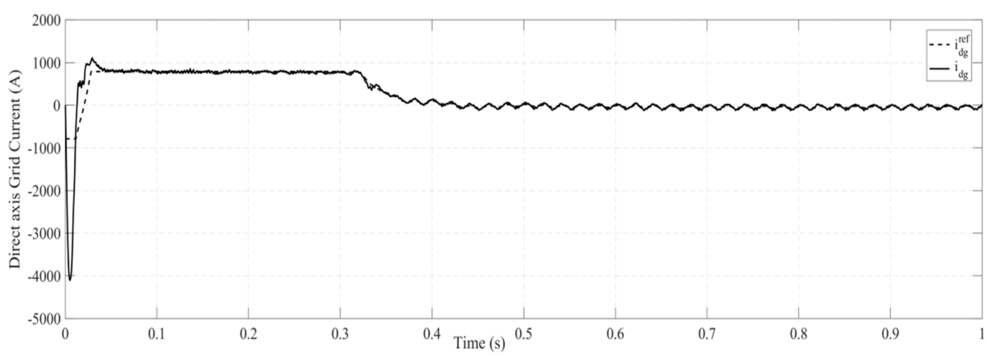

Figure 12. d-Axis grid current in Amperes (A)

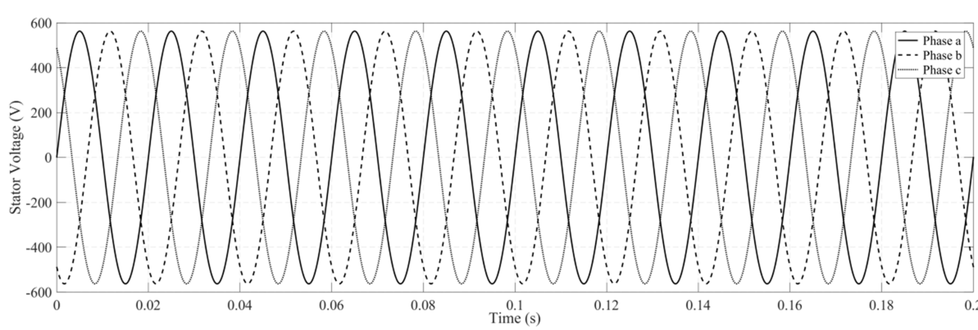

Figure 13. Stator voltage in Volts (V)

V. Conclusion

Paper simulates preliminary type of GSC and RSC control system, for its application in grid connected DFIG based wind power system. With the help of the said control system, active and reactive powers are managed. For reduction of the annoying harmonics, grid side filter is used. The following devices can be used with the DFIG for improvement of power quality and protection.

1. LCL Filter: This type of filter can be incorporated in simulation study. LCL filters reduces the size of inductor [18]. Also, this filter can be used for harmonic elimination.
2. Protective devices: There are many protective devices associated with DFIG. To name a few may include braking systems, crowbar, and series dynamic resistor. These devices improve the system performance during voltage dips [6][7][9] and can improve fault ride through capability.
3. FACTS devices: These devices are routinely associated with power quality [10][12][15]. Introduction of these in the system will definitely improve system response. These devices improve the system performance during voltage swells and can improve high voltage ride through capability.
4. Fuzzy Controllers: Implementation of fuzzy controllers instead of PI [3].

Appendix

System Parameters used for simulations are: Wind Speed = 9 m/s, Grid Frequency = 50 Hz, Rated Power = 2 MW, Rated Speed = 1500 rpm, Rated Stator Voltage = 690 V, Rated Stator Current = 1670 A, Rated Torque = 12732 Nm, DC Bus Voltage = 1000 V, Switching Frequency = 5 kHz.

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