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EE564 – Project 3

Wind Turbine Desıgn

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# INTRODUCTION

In this project, a wind turbine generator is designed analytically and the results are verified in the simulation platform using finite element analysis principles. The analytical design of the generator is started with the design of windings and determination of magnetic and electrical loading. Then, the motor dimensions are specified. For that dimensions and excitations, a simulation model is implemented in RMXPRT and more detailed analysis is conducted in 2D Maxwell Solution.

# ANALYTICAL DESIGN

## Motor Dimensions

In Table 1, the design inputs of the wind turbine generator are given. With the given output power and shaft speed, how much torque should be produced by the electrical motor can be calculated.

|  |  |
| --- | --- |
| Output Power | 250 kW |
| Turbine Speed | 24.3 rpm |
| Gear Ratio | 31.2 |
| Rated Speed | 758 rpm |
| Line Voltage | 400 Vrms |
| Frequency | 50 Hz |
| Pole Number | 8 |
| Phase Number | 3 |

Table : Design Inputs

Since the induction motor torque is skew-symmetric around the rated speed, Fig. 1, the induction generator can be considered as in motoring operation with negative rated slip. Therefore, the generator can be designed assuming it is a motor which rotates at 742 rpm and in this project, the design and simulation verifications are done with this realization.

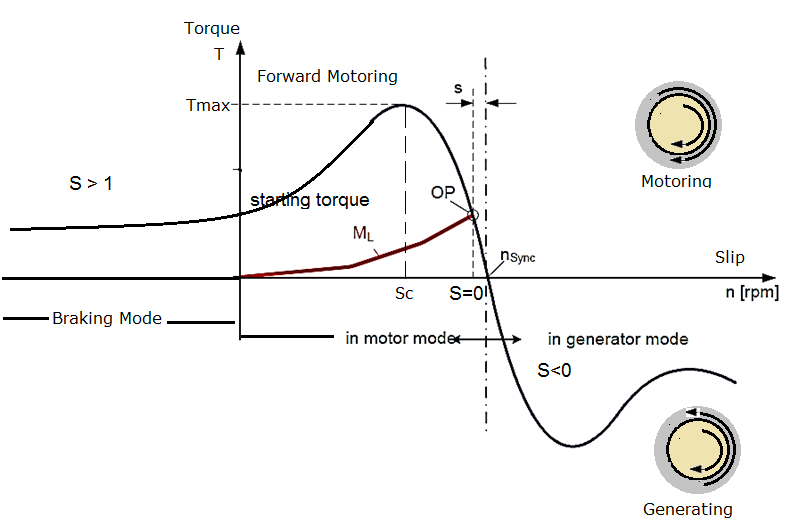


Figure : Torque vs Speed Graph of Induction Machine[[1]](#footnote-1)

As stated earlier the rated torque can be calculated by dividing the output torque by the shaft speed as explained in (1) & (2).

For an induction machine, the magnetic loading (Bpeak) should be in range of 0.7T – 0.9T and the electrical loading in 30kA/m – 65kA/m. Thus, in this design, the magnetic loading is selected as 0.7T & electrical loading is selected as 55kA/m. With these loading rated, the tangential stress is calculated using eqn. (3) where the power factor is taken as 0.85. Then, the volume of the rotor is calculated as in (4) which enables us to reach D2L’, (5).

The aspect ratio, which is the ratio of axial length to the bore diameter, is taken as 0.35, so the shape of the motor is like a pancake. The aim was to increase the magnetic loading. It happens because reducing aspect ratio means reducing DL’ as a result of constant D2L’. Therefore, we obtain smaller pole area, (6), so the magnetic loading increases, for the same flux per pole which is also stays constant due to the same induced voltage. Consequently, the bore diameter is obtained as 632 mm and effective axial length as 221 mm. Moreover, the air-gap is calculated using the eqn. (7). Knowing the air-gap the real axial length can be calculated as in eqn. (8).

## Winding Design

For the winding design, the stator winding is designed for single layer. For different slots per pole per phase, q, values the slot number and slot pitch is calculated accordingly as shown in Table 2.

|  |  |  |
| --- | --- | --- |
| q | Qs | Slot Pitch (mm) |
| 1 | 24 | 82.7 |
| 2 | 48 | 41.4 |
| 3 | 72 | 27.6 |
| 4 | 96 | 20.7 |
| 5 | 120 | 16.5 |
| 6 | 144 | 13.8 |

Table : Slot Numbers and Slot Pitches

Considering the rule of thumb that the slot pitch is between 7 mm and 45 mm, the slot number cannot be 24. Also, for the large power applications the slot pitch is greater. Therefore, the slot number is selected as 48 for this design. The resulting winding diagram is given below.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| A1 | A2 | -C1 | -C2 | B1 | B2 | -A1 | -A2 | C1 | C2 | -B1 | -B2 |

Table : Winding Diagram Over a Pole Pair

For this winding scheme, the MMF is plotted for three different case where the turn number is taken as one and the current peak value is also taken as one. Therefore, to calculate the actual MMF value, just the extension with NI coefficient is enough. The MMF plots of the cases are shown in Figure 2, 3 and 4. In both plots, the MMF is given for 12 slots which covers a pole pair. Thus, the plots just repeat itself for each pole pair.



Figure : MMF plot for Ia = 1 and Ib = Ic = -0.5



Figure : MMF plot for Ib = 1 and Ia = Ic = -0.5



Figure : MMF plot for Ic = 1 and Ib = Ic = -0.5

Furthermore, the pitch factor, the distribution factor and the resulting winding factor are calculated as in eqns. (9), (10), (11) and given in Table 4. The coil span is 180 degrees whereas the slot angle is 30 degrees.

|  |  |  |  |
| --- | --- | --- | --- |
| Harmonic Order | Pitch Factor | Distribution Factor | Winding Factor |
| 1 | 1 | 0.9659 | 0.9659 |
| 3 | -1 | 0.7071 | -0.7071 |
| 5 | 1 | 0.2588 | 0.2588 |
| 7 | -1 | -0.2588 | 0.2588 |
| 9 | 1 | -0.7071 | -0.7071 |
| 11 | -1 | -0.9659 | 0.9659 |

Table : Winding Factors

Here, even though the winding factors for the harmonics are observed in very high amount in the line-to-line voltages they will not be that much high. As shown in eqn. (12), the magnetic harmonics in the air gap have different magnitudes. Since, the higher order harmonics have lower magnitudes, they will not be seen in induced emf. That expectation is verified with 2D FEA results as given in Figure 5 and Figure 6.

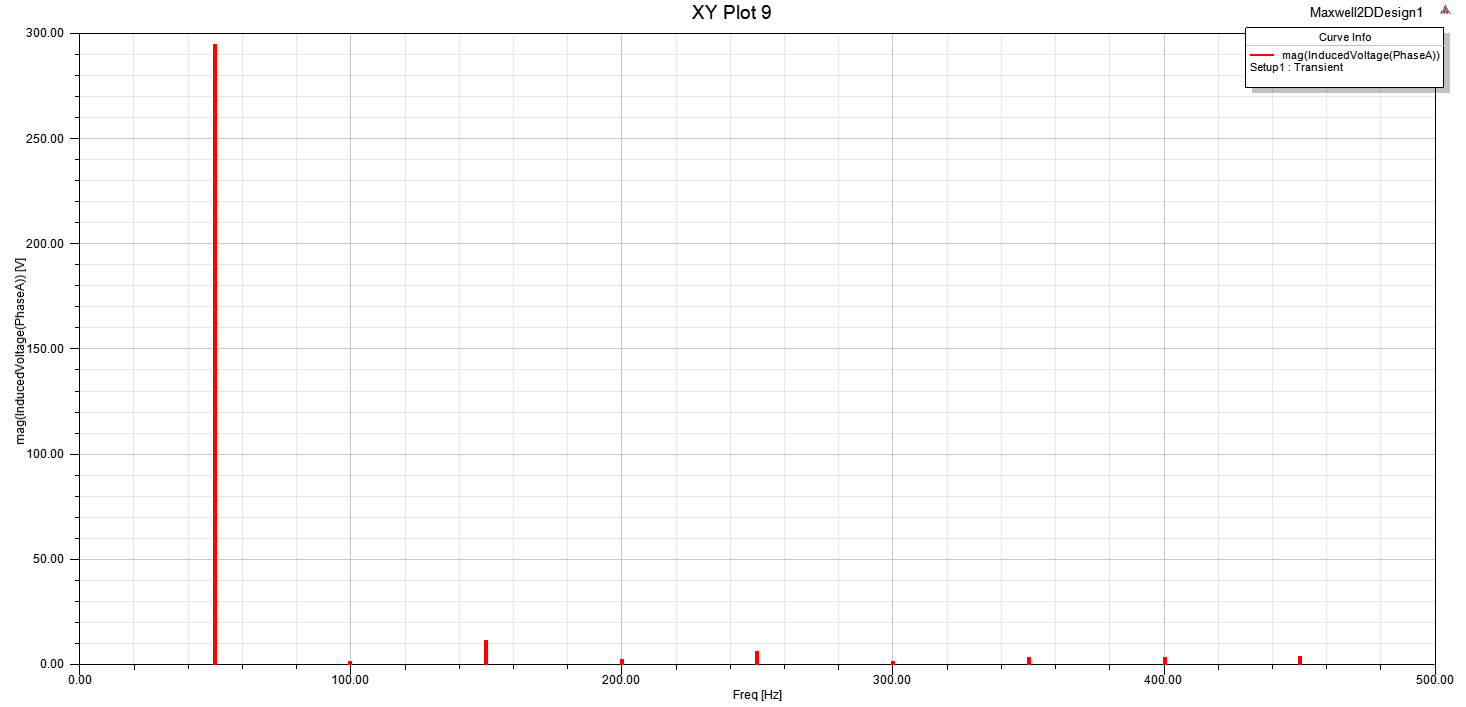


Figure : FFT Result for Phase Induced Voltage

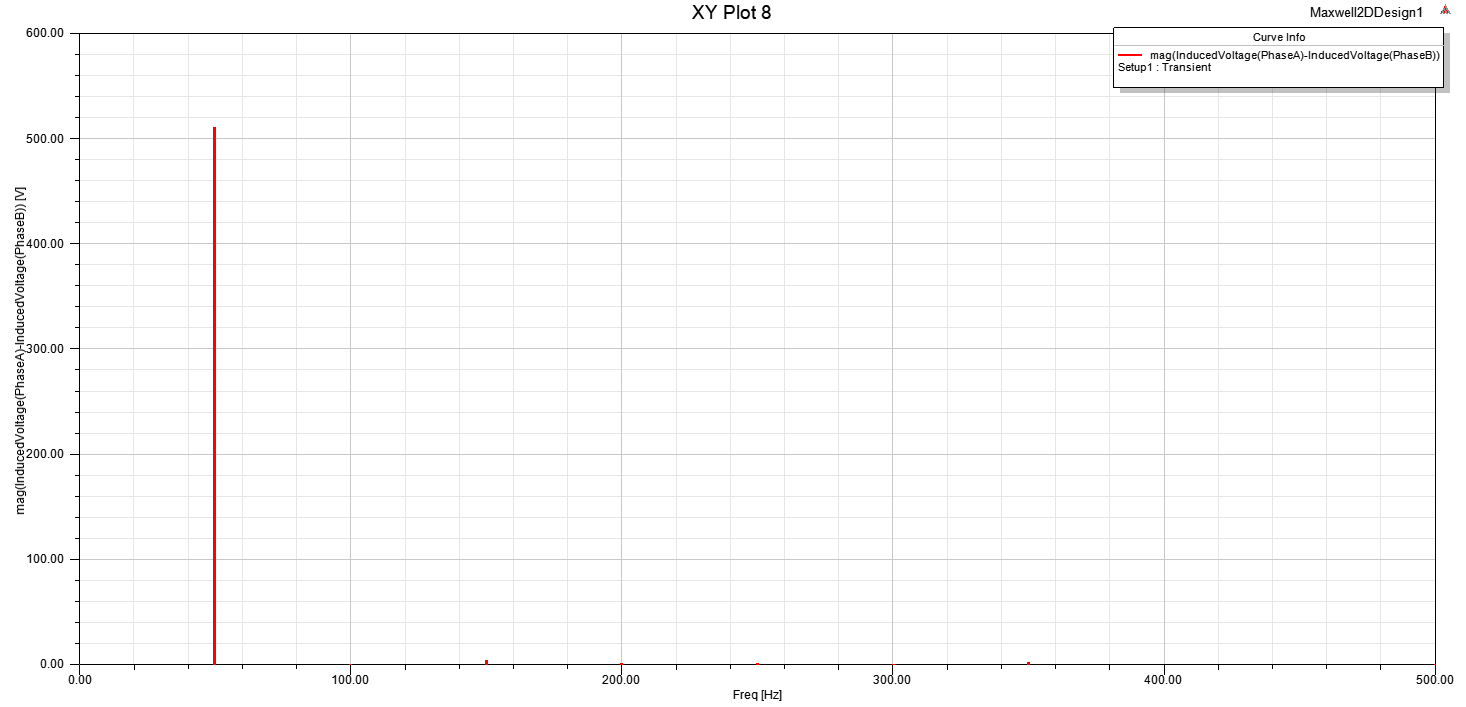


Figure : FFT Result for Line to Line Induced Voltage

Now, since the slot number is decided, it is possible to calculate series turn number in a slot. For this purpose, the flux per pole is calculated using the eqn. (13). Then, the series turn number in a phase is calculated with eqn. (14) and finally, the series conductor number per a slot is calculated in eqn. (15).

Cable Length !

1. http://www.automationbasic.com/2018/01/torque-speed-characteristics-of.html [↑](#footnote-ref-1)