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The Effect of Eccentricity Fault on the Performance of Doubly Fed Induction Generators

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Abstract – Doubly Fed Induction Generators are widely used in wind turbine industry. These generators can be operated in adverse conditions such as environmental conditions and changing loads. Faults have negative effects on the performance of generators. In this study, the effects of eccentricity fault on the performance of generator were examined using the model of Doubly Fed Induction Generator generated via finite elements method. The fault status of the machine was determined using Fast Fourier Transformation at the frequency dimension. Changes in eddy and hysteresis losses were examined depending on the fault status. It was observed as a result of the study that eccentricity fault in this generator causes harmonics in stator voltage thereby decreasing the general performance of the machine.

1. Introduction

Wind energy is one of the important renewable energy sources of recent years that decreases dependency to foreign countries, that is clean and low cost and based on wind which is continuously renewed. Due to these features, interest in wind energy has been increasing. Doubly Fed Induction Generators (DFIG) are among the primary generators which are most frequently used in wind energy systems in recent years. The reasons for preferring these generators are low cost, resistance against damaging effects and stability in

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addition to their ability to generate high amounts of power [1-4]. Faults in DFIGs which are widely used cause repair-maintenance costs as well as production losses [5].

Faults of DFIGs can be classified as electrical and mechanical. Electrical faults consist of stator winding faults, rotor bar breakages, rotor ring breakage and rotor winding faults whereas mechanical faults include eccentricity faults and bearing faults [6-7]. Eccentricity faults occur when the distance between the rotor and stator is not equal and has three different types as static, dynamic and mixed type (static+dynamic) according to the position of the rotor and stator as can be seen in Figure 1. Whereas the rotor rotates on a fixed axis different than that of the stator in static eccentricity faults (SEF), the rotor rotates in continuously changing axes together with the stator in dynamic eccentricity faults. Whereas both SEF and dynamic eccentricity faults occur in mixed type eccentricity faults [8-9].

a)   b)   c)
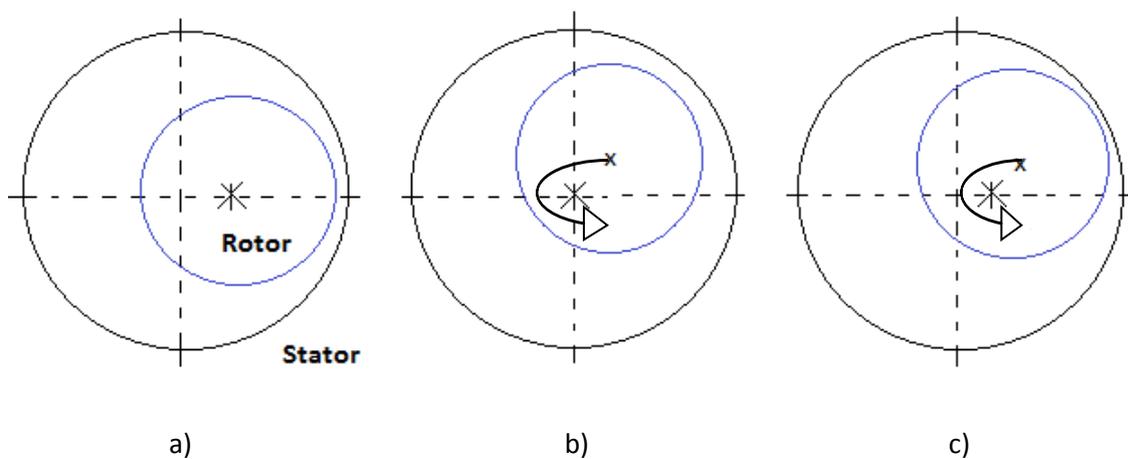
Şekil 1: Different types of eccentricity fault a)Static, b)Dynamic, c)Mixed

The main reasons for SEF faults are; incorrect positioning of the rotor or stator during manufacturing stage, oval stator core, incorrect positioning and wearing of the bearings. Whereas the main reasons of dynamic eccentricity faults are wearing of the bearings, shifting of the shaft, incline of the rotor shaft, mechanical resonance at critical speed, bearing gap and unbalanced loads due to wear in the stator caps.

The air gap distance of the DFIGs used in wind turbine systems is small. Hence, eccentricity fault in these big powerful machines result in important risks such as rotor stator friction. It is important for the prevention of adverse results and for early intervention to detect eccentricity faults in these generators for which even minor eccentricity faults can be dangerous [8-10].

Data of many signals such as voltage, flux, torque, speed etc. are used for detecting faults in electrical machines. Analysis of motor current signals is the most frequently used. The main reasons for these are that this current holds data related with motor faults and that they can be simply acquired from the motor via simple sensors. In general, certain frequency components of the fault current spectrum are monitored for the analysis of the motor current signals. This method is also used in detecting many different electrical faults such as eccentricity fault, rotor bar breakage fault, short circuit fault in stator windings in addition to mechanical faults. [11-12] Analysis of the motor current signals has been preferred for fault detection in this study.

Signal processing plays an important role in determining the properties of the faults carried by the signals. Signal processing methods can be classified under three main headings

which are time dimension, frequency dimension and frequency-time dimension analyses. These signal processing methods provide different success results in fault detection based on fault property and signal characteristic. Whereas analyses carried out in time dimension and frequency dimension are suited more for linear signals, especially the signal-frequency dimension yields more successful results for non-linear signals [13].

Fast Fourier Transformation (FFT) is the most frequently used transformation in the frequency dimension (FFT) [8-10]. FFT is used frequently for the detection of mechanical and electrical faults. This method reveals the frequencies in equation (1) related with the eccentricity of the air gap in specific side bands of the source in the current spectrum [14]:

$$f_{ecc} = \left((kN_r \pm n_d \frac{(1-s)}{p} \pm v \right) f \tag{1}$$

Here, s is the shift, k is a positive integer, Nr is the number of slots, p is the number of dipoles for $Nr=0$ at SEF state and $nd=1,2,…$ at the dynamic eccentricity state, f is the mains frequency and $v=1, 3, 5,…$ is the stator time harmonics series.

In this study, stator phase current and the voltages induced at the stator acquired via the model obtained using finite elements method (FEM) for the working and SEF fault states of DFIG were processed via FFT after which the fault effect depending on different air gap distances were examined comparatively.

2. Modeling of DFIG by using FEM

FEM enables the most accurate modeling of the properties related with the faulty and working states in machine state monitoring and fault detection. Hence, it is frequently used in recent years.

Maxwell equalities provide an opportunity for solving electromagnetic problems in transient analysis [15].

The relationship between E denoting the electrical field intensity and J denoting the current density is given in equation (2).

$$J = \sigma E \tag{2}$$

If the induced area is expressed, it is defined as such:

$$\nabla xE = -\nabla xA \tag{3}$$

A used in this equality is equivalent to the negative rotational of the magnetic vector potential. Electrical field expression in two-dimensional problems is defined as in equality (4).

$$E = -(Ax\nabla V) \tag{4}$$

And if this expression is placed in equality (5), we get:

$$J = -\sigma A - \sigma \nabla V \tag{5}$$

The current density expression can be defined as in equation (6) depending on magnetic vector potential and voltage gradient.

$$\nabla x(\frac{1}{\mu(B)}\nabla xA) = = -\sigma A - \sigma \nabla V + J_{kaynak} \tag{6}$$

The term μ denotes the magnetic permeability of the environment, whereas ∇V represents the gradient of the voltage value in the region outside of the conducting material in two-dimensional magnetic field problems. The amplitude and phase angle values of A are calculated as such.

Flux, current, voltage, magnetic field, power, energy and speed values of the generator over a period of time can be acquired at specific time intervals in transient analysis using the Maxwell equalities given above [16].

In order to analyze this generator via FEM, it should be modeled in the closest possible way to the actual system and operated in accordance with actual parameters [8]. The label values of the DFIG used for the modeling in this study have been given in Table 1.

Table 1: Parameters of the modeled DFIG

| AC Phase Generator		Stator Outside Diameter 120 mm
Frequency	50 Hz	Rotor Outside Diameter 180 mm
Rated Voltage	220 V	Stator Size 65 mm
Output Power	0.55 kW	Stator Number of Slots 24
Rated Voltage	1500 d/d	Rotor Number of Slots 30
Number of Poles	4	

3. Modeling of the Fault

It may be preferred to use the model at ¼ or ½ ratios in order to decrease the duration of the analysis carried out for many faults other than eccentricity fault. However, in case eccentricity fault occurs, the distribution of the unbalanced air gap will also be divided when the model is divided as such and thus the analyses will not yield proper results. That is why, the full model given in Figure 2 was used in this study for the analyses.
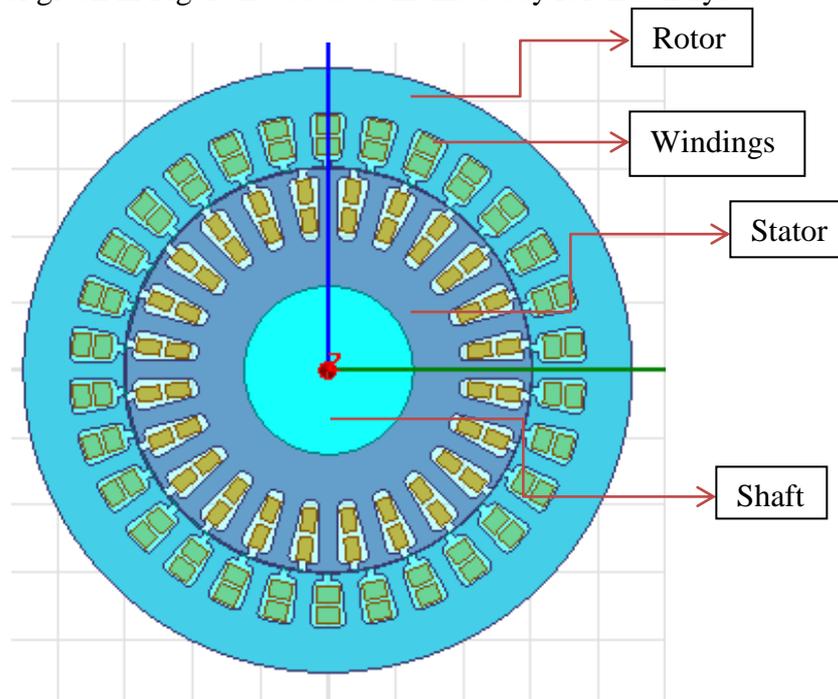
*Şekil 2*: Doubly Fed Induction Generator Model the FEM

The air gap between the stator and rotor for the operating generator is 0.5mm. SEF fault was modeled via ANSYS Maxwell at three different ratios taking into consideration the 0.5 mm air gap size of the generator. The first fault level was eccentricity 1 (EK1) generated with a 20% eccentricity, the second (EK2) with 30% and the third (EK3) with an eccentricity of 40%. The rotor windings of the modeled generator were excited via the input currents which can be seen in Figure 3.
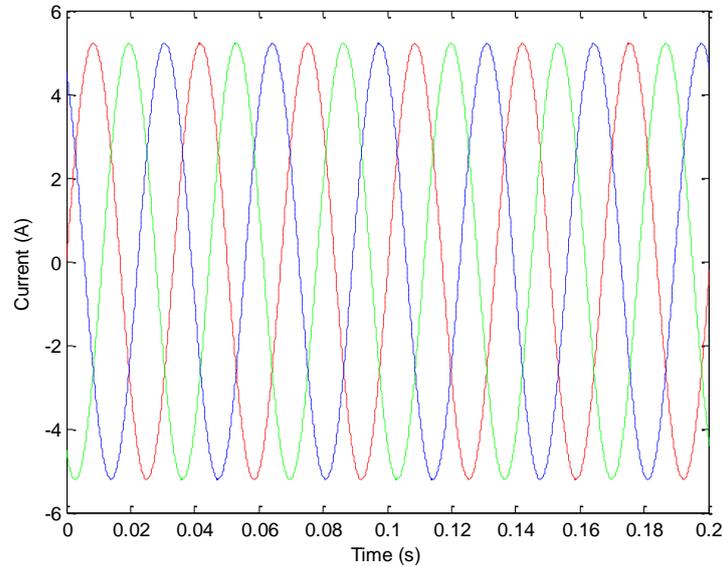

Şekil 3:Generator input currents

The simulation time of the generated models was taken as 2.5 seconds and the step time was taken as 0.0001 seconds for the analyses. The date recorded in the Matlab environment was 25.000 long.

Figure 4-a shows the flux density distributed evenly to all the poles of a four-pole operating generator. However, magnetic field distribution gets uneven in case an SEF fault ensues and concentrates on the region where the eccentricity fault is located. The unbalanced flux density distribution generated on the poles of the four pole generator for which the fault model has been provided is shown clearly in Figure 4-b.


a)

b)
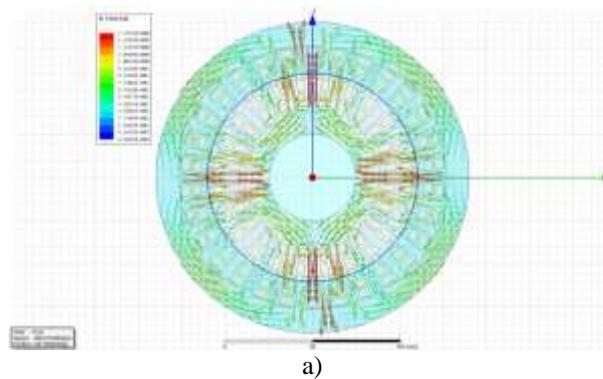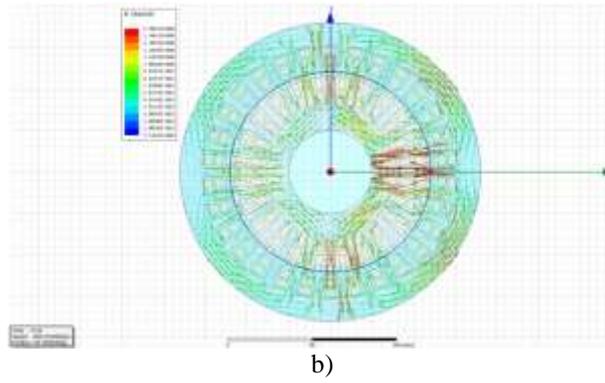
Şekil 4*:* Flux Density Distribution, a) Healty, b) Faulty

Eccentricity fault reveals additional frequency components in the stator phase current signals and the signals of the voltage induced at the stator. These revealed additional frequency components are observed as distortion in current and voltage signals. The distortions in the signals increase with increasing level of eccentricity.

Figure 5 shows distortions in the stator current and Figure 6 distortions in the additional frequency components of the voltage data induced at the stator.
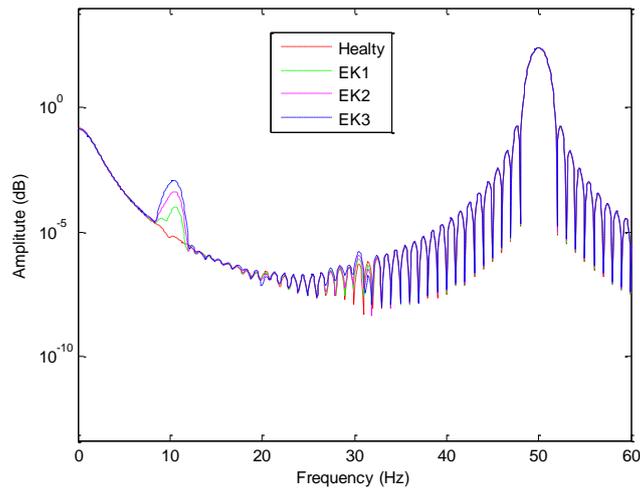

Şekil 5: Spectrum of Generator stator current
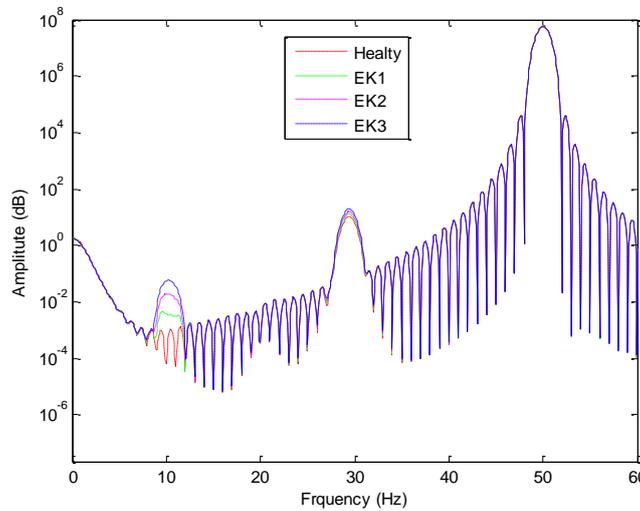
Şekil 6: Spectrum of the voltage induced at the stator

SEF fault state at 10 Hz and 30 Hz frequencies can be clearly distinguished from the operating state in the stator current spectrum given in Figure 5. Whereas the operating state at 10Hz frequency is at a value of 6.634e-006dB; harmonic levels generated at EK1 7.987e-005dB, EK2 0.0004181dB and Ek3 0.001224dB values.

SEF fault state at 10 Hz and 30 Hz frequencies can be clearly distinguished in Figure 6 from the operating state in the current spectrum induced at the stator. Whereas the operating state is at a value of 0.001dB at 10Hz frequency; harmonic levels generated at EK1 0.003dB, EK2 0.01dB and EK3 0.5dB values.

It can be clearly observed in the current and voltage spectrums that the distortions in the signals vary according to increasing number of faults.

Eddy and hysteresis loss data were collected for the faulty states of the modeled generator in order to examine how SEF changes power loss, after which the graphs shown in Figure 7 were acquired in Matlab environment.
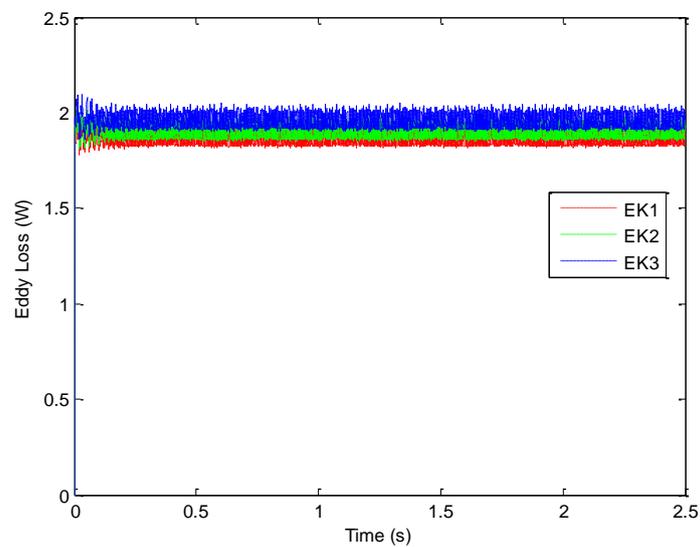
a)
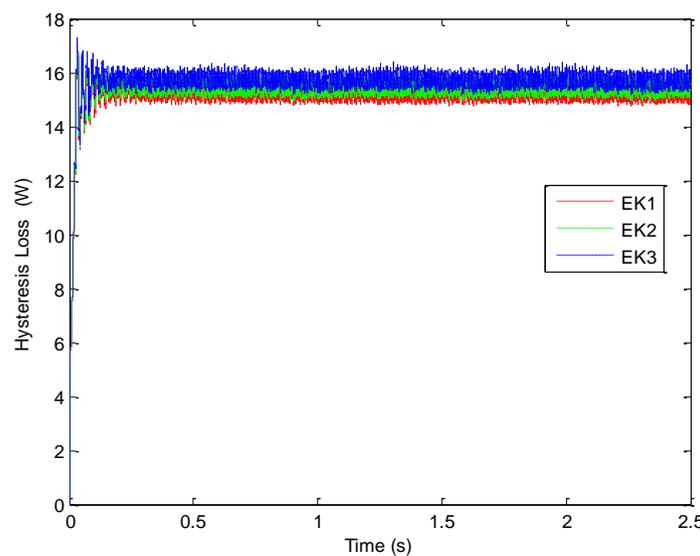
b)

Şekil 7: Power Loss, a)Eddy and b)Hysteresis

It can be clearly seen in the eddy loss graph in Figure 7 a) that energy loss has increased over the time axis depending on the increase in the SEF fault level. On average, EK1 caused a loss of 1.7W, EK2 caused a loss of 1.8W, whereas EK3 caused a loss of 2W.

It can be clearly seen in the hysteresis loss graph in Figure 7 b) that energy loss has increased over the time axis depending on the increase in the SEF fault level. On average, EK1 caused a loss of 15 W, EK2 caused a loss of 15.5 W, whereas EK3 caused a loss of 16 W.

It has clearly been shown that power loss increases with increasing number of faults.

4. Conclusion

In this study, the effect of SEF fault on performance of DFIG modeled via FEM was examined. The stator current and stator induced voltage signals for the SEF fault states were processed in MATLAB via FFT. Amplitude of the additional frequency components generated at certain side bands of the source frequency also increase with increasing SEF fault level. In addition, it has been determined according to eddy and hysteresis loss data that these losses vary in direct proportion with the fault level.

It was determined as a result of the acquired data that eccentricity fault results in harmonic generation in the voltages produced by this generator and thus having adverse effects on the general performance of the generator.

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