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PERPERFORMANCE-PARAMETER PREDICTION OF DOUBLY FED INDUCTION GENERATOR (DFIG) USED IN WIND GENERATOR APPLICATION BY ARTIFICIAL NEURAL NETWORK (ANN)

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Abstract
In modern large wind turbines, doubly-fed induction generators are commonly used. In these generators, both stator and rotor windings are connected to grid through power electronic DC/AC converters. The torque depends on the strength of two fields and the phase angle between them. The speed range is approximately + - 30% of the grid frequency. Considering these special features, the DFIG analysis is performed using 'd q o' transformation [1]. A design data bank is generated for machine ratings from 1000kW to 3000kW. With the help of Artificial Neural Networks (ANN), equivalent circuit parameters, stator and rotor voltage and current, and reactive power supplied to and received by the grid are predicted.

Keywords: DFIG, Performance prediction, Articial Neural networks.

Abbreviations

ANN	Artificial Neural Networks
AI	Artificial Intelligence
DFIG	Doubly fed induction generator
MATLAB	Proprietary multi-paradigm programming language

List of symbols

V_{ds} , V_{qs} ,v_{ds} , v_{qs}	Stator voltage in the dq frame
I_{ds} , I_{qs}, i_{ds} , i_{qs}	Stator current in the dq frame
I_{dr} , I_{qr} , i_{dr} , i_{qr}	Rotor current in the dq frame
s	Slip
R_s , R_r	Stator and rotor winding resistance
X_s, X_r	Stator and rotor reactance
L_s, L_r	Stator and rotor inductance
X_m	Magnetizing reactance
L_m	Magnetizing inductance
ω_s	Angular stator frequency
ω_r	Angular rotor frequency
φ_{ds} ,φ_{dr}	Stator, rotor direct axis flux
φ_{qs} ,φ_{qr}	Stator, rotor quadrature axis flux

Introduction
Doubly Fed Induction Generator, has gained popularity due to its high energy transfer efficiency, and flexible control characteristics. A typical configuration of a DFIG wind turbine is shown in Figure 1. The mechanical construction of DFIG is similar to that of a wound rotor induction generator with slip-rings. The variable speed operation which is required for wind generator application. is achieved in DFIG by injecting a controllable voltage into the rotor at slip frequency. The torque and active power characteristics are determined by the magnitude injected rotor voltage where as the reactive power is controlled by adjusting the phase of rotor voltage. In DFIG, both stator and rotor are fed with different voltages and frequencies, necessitating higher order model for analysis. Fifth-order model is used for steady state analysis, while a third order model is employed for transient analysis. This analysis requires the 'd q o' transformation.

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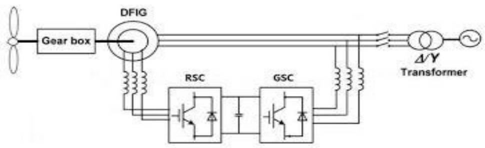

Figure 1: Schematic diagram of a DFIG wind turbine

The three-phase stator and rotor wingdings are represented by two sets of orthogonal coils. The 'Park' transformation, which converts a three phase system to a 'd q o' rotating reference frame, is detailed in [1]. The electrical equations, for stator and rotor, voltages and currents, are shown below [Equations 18 to 23 of ref 3]:

$$V_{qs} = - R_s I_{qs} - X_s I_{ds} + X_m I_{dr} \quad (1)$$
$$V_{ds} = - R_s I_{ds} - X_s I_{qs} + X_m I_{qr} \quad (2)$$
$$(V_{qr} / s) = (R_r / s) I_{qr} - X_s I_{ds} + X_m I_{dr} \quad (3)$$
$$(V_{dr} / s) = (R_r / s) I_{dr} - X_s I_{qs} + X_m I_{qr} \quad (4)$$
$$V_{as} = V_{qs} - jV_{ds} \text{ ; Stator phasor voltage } (5)$$
$$I_{as} = I_{qs} - jI_{ds} \text{ : Stator phasor current } (6)$$
$$V_{ar} = V_{qr} - jV_{dr} \text{ : Rotor phasor voltage } (7)$$
$$I_{ar} = I_{qr} - jI_{dr} \text{ : Rotor phasor current } (8)$$

The equivalent circuits in 'd - q' reference frame are shown below [5]:

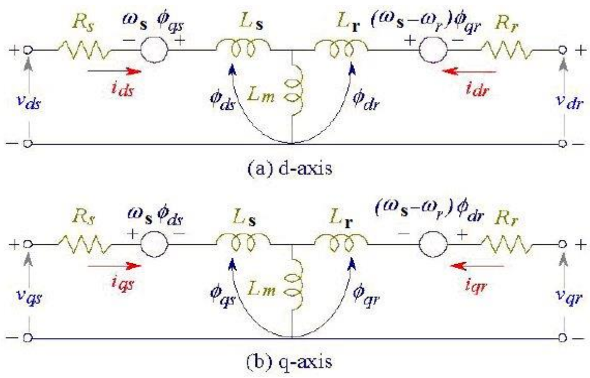

Figure 2: Equivalent circuit at synchronously rotating frame

Methodology

Unlike traditional fixed speed induction generators, in DFIG, the operating speed is determined by the wind speed and the injected rotor voltage. The torque and active power characteristics are governed by the magnitude pf the injected rotor voltage, while the reactive power is controlled by adjusting the phase of rotor voltage. These characteristics are typically computed using the 'd q' equivalent circuits. The equivalent circuit parameters, including stator and rotor winding resistances (Rs and Rr), leakage inductance (Ls and Lr) and mutual inductance (Lm), play a significant role in predicting DFIG performance.

In this paper, a new method is introduced for performance prediction and for determining DFIG equivalent circuit parameters using Artificial Neural Network.(ANN). ANNs are a powerful tool in the field of artificial intelligence (AI), are a type of machine learning model. Supervised learning algorithm which require a large amount of training data to perform effectively, are used to train ANNs.

MATLAB provides tool boxes for training ANNs which can be accessed via either 'nntool' or 'nnstart' depending on MATLAB version, (2019a or 2024a). The performance of ANN depends on several factors:

i) Network type
ii) Transfer function

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iii) Training function
iv) Adaption learning function
v) Performance function
vi) Number of neurons.

For the current problem, a'Feedforward backpropagation' is used. MATLAB supports, upto, fifteen different types of transfer functions, along with various options for other functions mentioned.

Dataset

For an ANN to learn and predict effectively, the dataset must be both large in size and high quality. A conservative rule-of-thumb is to use at least ten times number of weights in the ANN.
The data in dataset can be obtained either from test data or from generated designs. In this presentation, the data is generated from designs. The steps followed for generating the designs are as follows[5]:

i) The selected ratings are 1000kW, 1250kW,1500kW, 2100kW and 3000kW.
ii) For all the above ratings, adequate number of designs are generated by varying stator and rotor slot dimensions and lamination bore diameters and lamination stack length and radial air gap length between stator and rotor.

The figure 3 shows the variables considered for generating new designs
Four objectives functions are considered while generating these designs. They are a) minimum weight b) high reactive power capability c) Minimum transient torque under fault conditions d) Maximum efficiency [6]

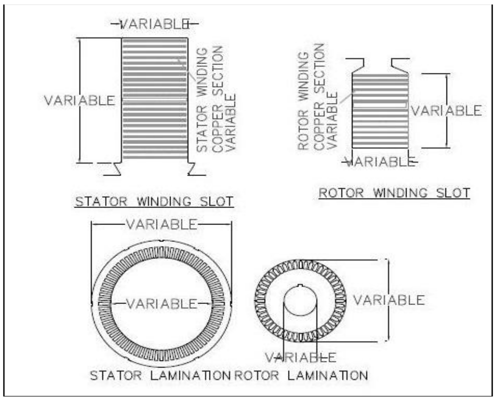

Figure 3:. Stator and rotor winding slot and lamination

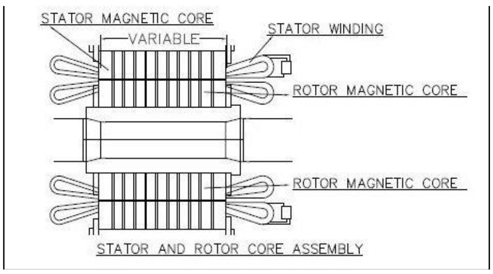

Figure 4: Stator and rotor core assembly

The dataset contains variables used for generating designs, equivalent circuit parameters, R1 , R2, X1, X2, Xm., and performance parameters are rotor voltage, current, active and reactive power of stator and rotor.

The data is computed for the selected ratings. Then the data is concatenated and shuffled row-wise by using MATLAB functions specifically 'concat_mat' and 'shuffledRow'

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Input and output data of ANN

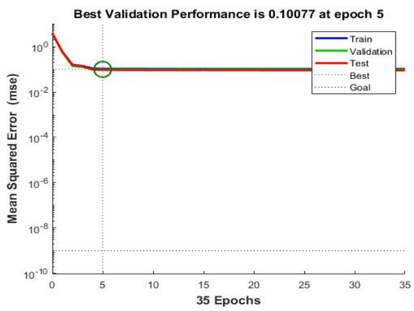
From the above data set, input data and target data are derived. In this presentation, three sets of input and target data are prepared. For each set of data, separate ANN is used.

ANN is solved using MATLABs 'nntool' or 'nnstart' and [7]

The functions used for the present problem in ANN are
I) Transfer function (Hyperbolic tangent sigmoid)..TRANSIG
ii) Training function (Bayesian regularization back propagation) TRAINBR
iii) Adaption learning function (Gradient descent with momentum weight and bias learning function) LEARNGDM

Table 1

Sl No	Input Data	Target Data
1	Radial air-gap length and diameter, minimum teeth width, core depth.	Equivalent circuit parameters.(R1,R2,X1,X2,Xm)
2	Equivalent circuit parameters,Omegar, (omegar,R1,R2,X1,X2,Xm)	Rotor voltage (R_v), current (R_a), stator current (R_a ,I_a)
3	Equivalent circuit parameters, Omegar, Machine rating (omegar, R1,R2,X1,X2,Xm)	Rotor active and reactive power,stator active power ($Q_{rr}2$,$P_{rr}2$,$P_{ss}2$)



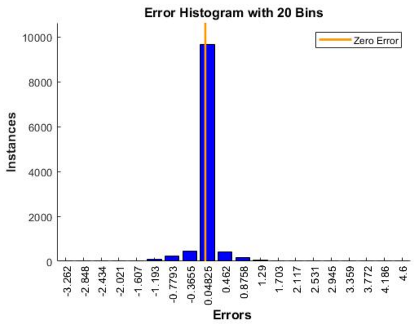
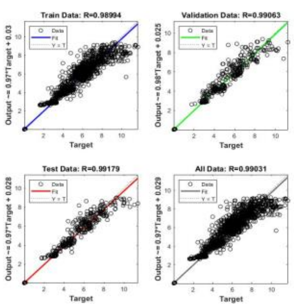


Figure 5: Training Performance for input and target data set of serial 1 of table 1

Figure 6: Neural network Histogram for input and target data set of serial 1 of table 1



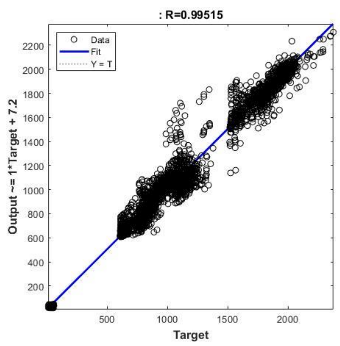


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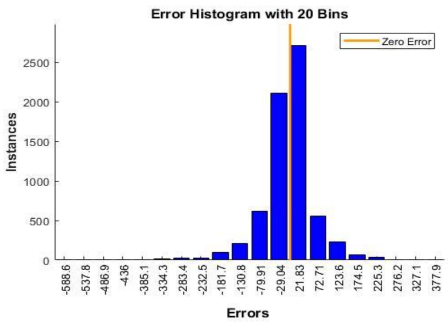
Figure 7: Regression Performance for input and target data set of serial 1 of table 1

Figure 9: Regression Performance for input and target data set of serial 2 of table 1



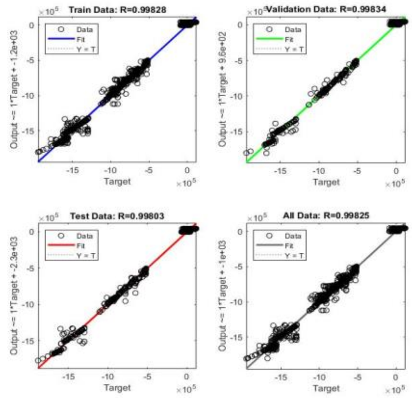
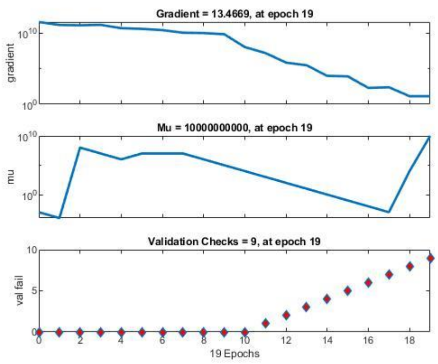


Figure 10: Neural network error histogram for input and target data set of serial 2 of table 1

Figure 11: Neural network regression for input and target data set of serial 3 of table 1



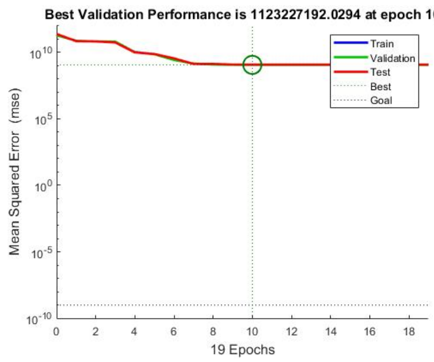
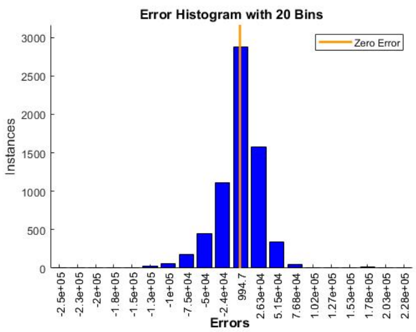


Figure 12: Neural network training state for input and target data set of serial 3 of table 1

Figure 13: Neural network performance for input and target data set of serial 3 of table 1



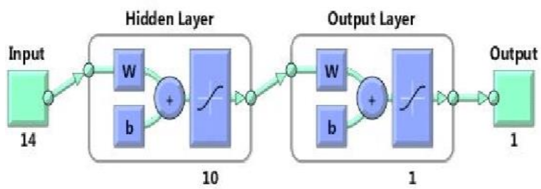


Figure 16: Neural net work (ANN) used for input and target data set. The number of neurons vary case to case.

Figure 14: Neural network histogram of errors for input and target data set of serial 3 of table 1

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Conclusion

The successful generation of a model using an ANN is highly dependent on the execution factors and the quality of the data bank. The critical factors influencing ANN execution include:

- Type of network
- Number of neurons
- Type of training function
- Optimization of weights and bias
- Adaption learning function
- Activation function
- Memory and speed
- Data normalization, method

To achieve better accuracy, it is necessary to experiment with various combination of functions and parameters. The designs generated in data bank, should ideally have polarity close to desired outcomes Similarly, the ratings should be around the required levels to improve output quality.

In the above predictions of Table 1, it is noted that, the equivalent circuit parameter estimation ANN performs well. However, there is room for improvement in case 2 and 3.

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Biography

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