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Application of artificial neural network to estimate power generation and efficiency of a new axial flux permanent magnet synchronous generator

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ARTICLE INFO

Article history:
Received 28 October 2016
Received in revised form
28 December 2016
Accepted 25 January 2017
Available online xxx

Keywords:
Artificial neural network
Axial flux permanent magnet synchronous generator
Efficiency
Estimation
Power

ABSTRACT

An estimation study on the output power and the efficiency of a new-designed axial flux permanent magnet synchronous generator (AFPMSG) is performed. For the estimation algorithm, a multi-layer feedforward artificial neural network (ANN) is developed. Various experimental results from the generator have been used for the training purpose in the cases of different electrical loads and rotational speeds. Some experimental data is kept out of the training process for testing the network and the errors have been evaluated after the formation of the network. According to the findings, a network with three layers has been adequate to achieve very good error percentage between the ANN and laboratory studies. The maximal testing error percentages are found to be nearly 3% and 4% for the output power and efficiency estimations, respectively. According to that finding, the developed ANN has a good property that it can be used in place of the designed generator, especially when the generator mathematical model is required. In addition, since power and efficiency are important for present applications, the present tool can be used to estimate the data for those characteristics of the machines and even it can be beneficial for the applications, where a nonlinear relationship among the power generation, generator efficiency, speed and load is required.

Introduction

The present technology achieves to produce efficient permanent magnets (PM) with desired shape and magnetization by using the rare earth elements. That accelerates the industry to use them in many renewable energy applications, especially the wind energy generators [1–3]. The most known magnets, namely NdFeB have many industrial and scientific applications over electrical machines. The main features can be mentioned for their higher magnetic flux densities, easy magnetization and shaping. According to literature, there exist some superiorities of the AFPMSGs over the current excited synchronous generators or squirrel cage ones: high efficiency, stability, reliability and cost [4,5]. After the application of optimization, high power densities with increased efficiency and reduced cogging torque can be obtainable for low wind turbines [6,7].

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http://dx.doi.org/10.1016/j.ijhydene.2017.01.168
0360-3199/

The axial flux machines become appropriate for many medium speed applications [8]. For instance, they are seen in robotics, machine parts and electrical vehicles. The AFPMSGs are useful due to the fact that they do not require any gear system in the turbine [3,9]. There exist a number of different AFPMSGs in terms of their flux morphologies. According to the flux circulation, a number of rotor and stator layers can be added to these axial machines and that can lead to higher powers up to hundreds of kW. According to literature [6,8–10], both rotor and stator units can have PMs however, each layer can be sandwiched in an accurate order with windings and PMs.

AFPMSGs suffer from the heating especially at high speeds as other generators. Rare-earth magnets and cores are both heated throughout the long-time machine operation. Other than heating, another problem is the reduction of the cogging torque. In the PM machines, the strong magnetic forces between rotor and stator should be eliminated in the design. For this aim, various cogging torque reduction techniques exist in the literature (see in Ref. [10]). The cogging torque is affected by the magnet shapes and the core. For instance, a single large core causes higher cogging torque values than the coreless structures or many small cores. Another vital point is to minimize the losses of the AFPMSG. With that regard, the efficiencies have been explored for different core masses, shapes and lamination types in Ref. [11].

Since the present study deals with the estimation of the generator output and efficiency via ANNs, some introductory literature can be given in that field. ANNs are basically computational models having structures inspired by a simplified human brain. ANNs can effectively learn the nonlinear relationship between input and output of any model without needing for complicated analytical methods. They are very efficient and useful where the equations representing the respective model are nonlinear, complex, distributed in nature, and particularly vague or totally unknown with uncertain parameters. One of the key features offered by ANNs is their inherent ability to perform parallel computations which allows high speed processing, thereby causing ANNs to be used in real time applications. They are also capable of operating in noisy environments. ANNs have found applications in various areas of engineering including pattern recognition, signal processing, adaptive control expert systems, fault detection, power electronics, control of electrical machinery, forecasting, function approximation, etc. [12–16]. In Ref. [12], authors make use of neural networks for predicting optimum tilt angle to keep solar energy maximum from the sun. While optimizing the tilt angle, they take into account latitude and also ground reflectivity, which the tilt angle is a nonlinear function of. In Ref. [13], in order to increase the estimation accuracy of the amount of power available from grid connected photovoltaic system, an improved ANN model is proposed, in which two more parameters, solar zenith angle and solar azimuth angle, are presented to the network as additional inputs, as well as the most common environmental information, plane-of-array irradiance and module temperature. As there exist rapid fluctuations in power produced by wind turbines owing to the continuous change in wind speed and its direction, developing tools being capable of predicting power generation in advance play a crucial role in power system industry to perceive any kind of uncertainties related to wind power generation. For this purpose, in Refs. [14,15], neural network-based estimation of power produced by electric wind turbines is developed. In Ref. [16], a hybrid algorithm that gathers features of genetic algorithm and simulated annealing is presented for training multi-layer neural network that is used in data classification problem. In switched reluctance motors, turn on and turn off angles are critical parameters for such kind of motors as they give rise to pulsating torque, following the speed fluctuation under the condition of improper adjustment of those parameters. To determine the angles optimally in an online manner, the neural network-based controller is used in Ref. [17] to minimize the pulsating components occurring in torque and speed. Likewise, in Ref. [18], a new approach based on ANN is introduced to estimate rotor position information of a switched reluctance motor. Using flux-current characteristics of the machine, the presented network can establish a good correlation for flux, current and rotor position, thereby eliminating the need for expensive rotor position sensor. A new online estimation scheme for stator and rotor resistance using ANNs is reported in Ref. [19]. The proposed neural network is tested in a vector controlled induction motor drive, and it has been observed that without the speed sensor, the drive yields reliable and high-performance operation.

In the present paper, a multi-layer feedforward neural network with standard back propagation learning algorithm is suggested in order to estimate the output power and efficiency of an innovative axial fluxed PM synchronous generator according to its ohmic load and speed. After trained by the example data coming from the experiments, the network's training and testing performances are checked. Depending upon the obtained results, the developed network with three layers has the capability to acquire the generator's nonlinear input–output relationships, which are constructed as generator output power and efficiency against the generator load and its working speed.

The organization of the rest of the paper is structured as follows: the ANN model, which is applied to the experimental findings of the generator, is initially described in Section 2. Then, experimental findings associated with the designed generator are given in Section 3. The following section, namely Section 4 reports the main part with the ANN-based estimation findings and discussion. Finally, Section 5 concludes the paper.

Artificial neural networks

Artificial neural network or, in short neural network (NN), is a structure that forms the interconnections of artificial neurons tending to mimic the nervous system of human brain. An artificial neuron that closely models its biological counterpart can be called as an op-amp like summer, where the weighted input signals are accumulated and the summed signal then passes to the output via an activation function which usually has a nonlinear structure. When thinking that a NN consists of such nonlinear computational elements of a great number operating in parallel, NN models appear to give good performance in mapping the input to a given output data without