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Neural network-based sensorless direct power control of permanent magnet synchronous motor

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Abstract In this paper, a sensorless permanent magnet synchronous motor (PMSM) drive was presented based on direct power control (DPC) technique. To estimate the rotor's position and speed of PMSM, a drastic sensorless strategy was developed according to artificial neural network (ANN) to reduce the cost of the drive and enhance the reliability. The proposed sensorless scheme was an innovative model reference adaptive system (MRAS) speed observer for DPC control PMSM drives. The suggested MRAS speed observer employed the current model as an adaptive model. The ANN was then designed and trained online by employing a back propagation network (BPN) algorithm. Performance of the proposed strategy was adopted using simulation analysis. The results showed the fast dynamic response, low ripples in motor's currents, power, and electromagnetic torque, as well as good performance in tracking speed and power references.

1. Introduction

Recently, PMSMs have received more interest, since they are more efficient and cost-effective and have an appropriate speed control range and reduced maintenance requirements [1,2]. For PMSM drives, several control strategies have been reported in the literature [1,3]. The well-known technique, direct torque control (DTC), is now being adopted by the industry. However, DTC still has some drawbacks such as relatively high ripples in flux and torque [4,5]. Also, the switching frequency of the inverter is not constant for a DTC without vector control method and changes with rotor speed, load torque, and bandwidth of the two hysteresis controllers. Direct power control (DPC) is a control technique which, without using current loops, directly selects output voltage vector states based on the power and flux errors using hysteresis controllers. In this respect, it is the same as DTC. Similar to DTC, DPC is a stator flux-based control technique with the advantages of robustness and fast control [6]. DPC has the following advantages: simpler voltage and power estimation algorithm, easy implementation of the unbalanced and distorted line voltage compensation to obtain sinusoidal currents (low THD),

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excellent dynamics, and no need for coordinate transformation [7].

Basically, DPC is applied to generators. In [8], the conventional DTC scheme for inducing motor drives was extended to directly control the active power (DPC) delivered to an active load by a wind turbine driven squirrel cage induction generator (SCIG). The SCIG was interfaced to the load through an AC–DC converter (PWM rectifier). The goal of this control system was to maintain the DC bus voltage at a constant value independent from the variations of the load. In [9], for a doubly fed induction generator (DFIG), an algorithm was developed for the independent control of active and reactive powers with high dynamic response. The instantaneous switching state of the rotor side converter (RSC) was determined based on the active and reactive powers measured in the stator circuit. Measurements were carried out in one terminal of the machine, whereas the switching action was performed in another terminal. The directly controlled quantities were the stator active and reactive powers. A new adaptive control strategy for a wind energy conversion system based on a permanent magnet synchronous generator and a pulse-width modulated current source converter were introduced in [10]. This conversion system was a good alternative because of its high efficiency and reliability. Electrolytic capacitors were not required in this type of converter and the voltage in the DC-link as well as the generated reactive power could be dynamically modified according to wind velocity, being even negative if required. However, it was challenging from the control and stability standpoints [11,12].

In [13], a combined vector and direct power control (CVDPC) was proposed for the RSC of DFIGs. The control system was based on a direct current control by selecting appropriate voltage vectors from a switching table. In fact, the CVDPC enjoyed from the benefits of vector control (VC) and DPC in a compacted control system. Its benefits, in comparison with VC, included fast dynamic response, robustness against variation of machine parameters, lower computation, and simple implementation [14–16]. A direct rotor current mode control (CMC) was suggested in [17] for the RSC of induction generators, which was aimed to improve the transient response in relation to the dynamic performance achieved by the conventional (indirect) CMC. A simple method for achieving the predictive direct power control (PDPC) for DFIG-based wind energy conversion systems was proposed in [18]. This approach was able to operate at low switching frequency and provide excellent steady-state and dynamic performances, which were useful for high-power wind energy applications. Three vectors were selected and applied during one control period to reduce both active and reactive power ripples. Compared to the prior three-vectors-based art using two switching tables, the approach only needed one unified switching table to obtain the three vectors [19,20]. Nowadays, it has been tried to employ DPC to control electrical motors instead of DTC techniques due to the problems of torque estimation and dependence on motor parameters in DTC. Thus, DPC technique relishes all the advantages of DTC such as fast dynamics and implementation ease without having its problems.

In machine learning and cognitive science, artificial neural networks (ANNs) are a family of statistical learning algorithms inspired by biological neural networks (the central nervous systems of animals, in particular the brain) and are used

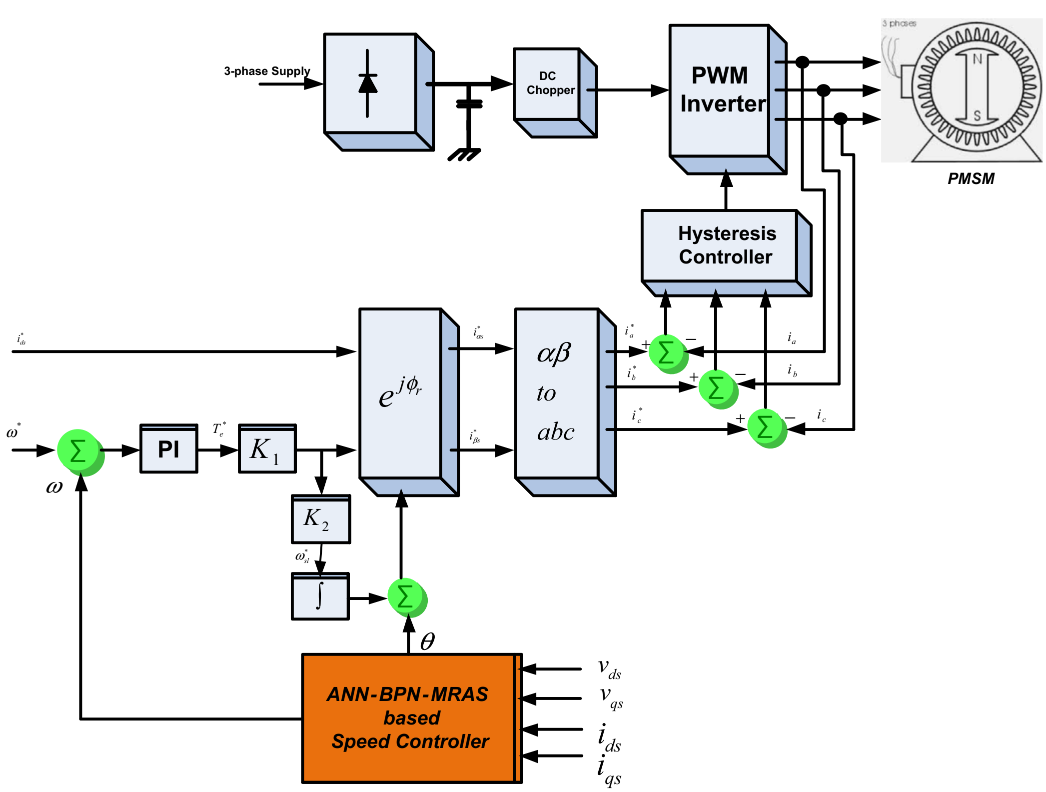

Figure 1 Overall diagram of sensorless control of PMSM drive using the proposed ANN-BPN-MRAS based speed estimator.