A Remote and Sensorless Stator Winding Temperature Estimation Method for Thermal Protection for Induction Motor

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ABSTRACT

Three-phase induction motors are the “workhorses” of industry; they are the most widely used electrical machine; because of its simple structure and high reliability. This paper proposes a new technique to model the stator winding of the induction motor in Matlab Simulink® software. This simulation of the induction motor would have the thermal behavior of its stator winding; to study the induction motor temperature estimation using motor parameter-based method. The modified model is used to validate a remote and Sensorless stator winding temperature estimation technique; therefore a thermal protection is obtained for soft-starter-connected to induction motors. The soft-starter is used to inject a DC signal in the induction motor terminal voltage and current. The stator winding resistance/temperature is estimated from DC signal injection by changing the gate drive signals of the Thyristor in the soft starter. The level of the injected DC signal is adjusted by the value of the delay angle. The accuracy of stator winding temperature estimation increased with the increase of DC signal level; however the pulsation of the output torque increased also. The thermal behavior is simulated utilizing a thermal resistor block from the Matlab Simscape™ software. It is used to replace the fixed resistor value of the induction motor model in the Matlab Simulink. The thermal monitoring scheme has been validated from the simulation results of a 7.5 kW induction motor under various loading conditions.

Keywords: Induction Machine, Matlab, Sensor Less, Signal Injection, Simscape, Simulation, Soft Starter, Temperature Estimation, Thermal Protection

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1. INTRODUCTION

Induction motor is a critical component in many industrial processes and it is very important part to support industry in producing the product. It is also frequently integrated with any commercially available equipment and the process itself (Widodo et al., 2009). Induction motor condition monitoring has been a theme of study during last decades. The relevance of this subject arises from the fact that induction motors are key elements in most industrial processes and in some tasks of the daily life (Cabal-Yepez et al., 2012). The stator winding insulation is normally the most weakness component during thermal overload, since its thermal limit is reached before that of any other motor component. About 35-40% of induction motor failures are associated to stator winding insulation failure (Enany et al., 2013). Stator insulation failures are normally the results of long term thermal aging because deterioration of the insulation is a function of both time and temperature.

The precise monitoring of the stator winding temperature is critical to proactively protect the motor, hence estimating the stator winding temperature ($T_s$) has great importance as explained by Boys et al. (1994). The thermal model-based techniques are used to estimate the stator temperature of the induction motor. The first estimate of the rotor temperature from the rotor resistance using the motor’s electrical model is proposed by Gao et al. (2009), and then estimate the stator temperature. Nevertheless, these approaches still require the identification of the thermal parameters, which is easier said than done, because the identification needs to be accomplished for every motor under each cooling condition. Bousbaine et al. (1995) proposed higher-order thermal models in order to model the thermal behavior of different components of the induction motor, because the second-order thermal models can only model the stator and rotor of the motor. Nestler et al. (1993) proposed an example of a five-component thermal model of induction motor. Staton et al. (2005) proposed to calculate the thermal parameters based on the dimensions of the motor. Nevertheless, the identification of thermal parameters associated with convection mode of heat transfer is difficult, which limits the accuracy of thermal parameter identification using this approach. Generally, the practical applications of these higher-order thermal models are narrow owing to the difficulty in the motor loss estimation and the thermal parameter identification. Moreover, given that these approaches cannot adapt to a change in the motor’s cooling capability, thermal parameter identification is required under each operating condition using embedded sensors as illustrated in Staton et al. (2005). Therefore, this is often impractical, especially for small- to medium-size induction motors owing to economic reasons.

The other technique to estimate the stator winding temperature for the thermal protection of the electrical motors is the motor parameter-based technique. Parameter-based stator temperature estimation approaches estimate the stator temperature from the stator resistance estimation. Stator resistance can be estimated using motor model-based; Mir et al. (1998) estimated the stator resistance based on the error between the measured stator current and the current command. As adopted from Bhattacharya et al. (2006), the proposed stator resistance estimation techniques are generally used for improving the field-oriented control performance at low speed or improving the sensorless speed estimation accuracy. The stator resistance is estimated based on the error between measured stator current and the current command, and use it to get the rotor-flux-linkage that is used to obtain the stator-flux linkage as presented in Habetler et al. (1998); the value of stator resistance is then estimated from the stator-flux linkage. Minami et al. (1991) proposed to determine the stator resistance using the estimate of the rotor resistance, by assuming the ratio between the stator resistance and the rotor resistance is constant. It is proposed by Zhen et al. (1998), a mutual model reference adaptive system (MRAS) approach for estimating the stator resistance and the rotor resistance. Lee et al. (2002) proposed a cascade stator resistance and
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