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Enforcement of cost-effective energy conservation on single-fed asynchronous machine using a novel switching strategy

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ABSTRACT

Electric motors consume around 30 to 80% of total energy in industries. Part load operation of which leads to lower efficiency. To improve efficiency and conserve energy under such partial load operating conditions, a novel switching strategy is proposed. Wherein, the stator and rotor windings are alternatively energized (switched) in accordance with the varying load. Adopting this technique with different ratings machine (2.2–150 kW) for linear and non-linear loads, exhibits energy saving of 5–15% and reactive power reduction in the range of 15–70%, over conventional method. Besides energy conservation, the proposed strategy involves less capital cost as well. Sensor fault detection & isolation, stability and overload protection are the additional features addressed in the controller. Techno economic analysis with existing contactor based and power electronic switching strategies are also carried out. In apart, the impact of changes in switchover point on energy savings and payback period is also analyzed.

1. Introduction

Energy conservation (EC) is an essential criterion of any industry, the economic aspect is being chased by many industries. Usually, the industries with high torque applications like grinding, crushing, lifting, etc., prefers wound rotor induction machine due to its operational flexibility [1]. This wound rotor induction machine is also termed as single-fed asynchronous machine (SFAM), as it is energized from one side. Performance of this machine can be easily altered through rotor circuit and it can be made suitable for any specific speed-torque application [2]. In such industrial applications, the machines are frequently operated with partial loads. Electric machines are designed to attain maximum efficiency and elevated power factor in and around the full load. Thus, the machine with part load leads to poor power factor and cause inefficiency [3]. Electric grid, which has many such partly loaded motors causes low power factor, resulting in voltage instability. Ideally, betterment of efficiency and power factor scales down the motor operating cost and reactive energy bill respectively [4]. Therefore, an energy optimal strategy without affecting the machine performance is mandatory for all industries.

Although plenty of techniques are available to conserve energy, most of the industrialists show less interest in adopting energy efficient technologies due to investment constraints. In the above aspect, various low budget energy conservation strategies are developed by many researchers that receives considerable attention [5]. Initially, *Kothals Altes.*, initiated star delta scheme for induction motor (IM) to reduce magnetizing current [6]. Later, energy saving aspect of the scheme with harmonic distortion analysis has been attempted by *Alger* et al. [7]. Optimum motor torque demand based on load is compensated by automatic star-delta configuration by *Taylor* et al., [8]. *Gjota.*, altered motor windings to enhance the performance of IM [9]. *Ferreira* et al., projected the star delta energy conversion scheme for power factor improvement using PIC microcontroller [10].

In another track, various energy conservation schemes are implemented by adopting drive technology. Advancement of power electronic topologies and control techniques possesses energy efficient operation on industrial drives, but these power electronic controls are not cost-effective. Moreover, power electronic switches could be the source of harmonics, causing vulnerability to machines and gird [11]. Besides, overall efficiency of the power electronic drive system reduces due to switching and conduction losses [12]. Enhancing efficiency and energy conservation of constant speed IM drives is performed by regulating flux using various control techniques [13–15].

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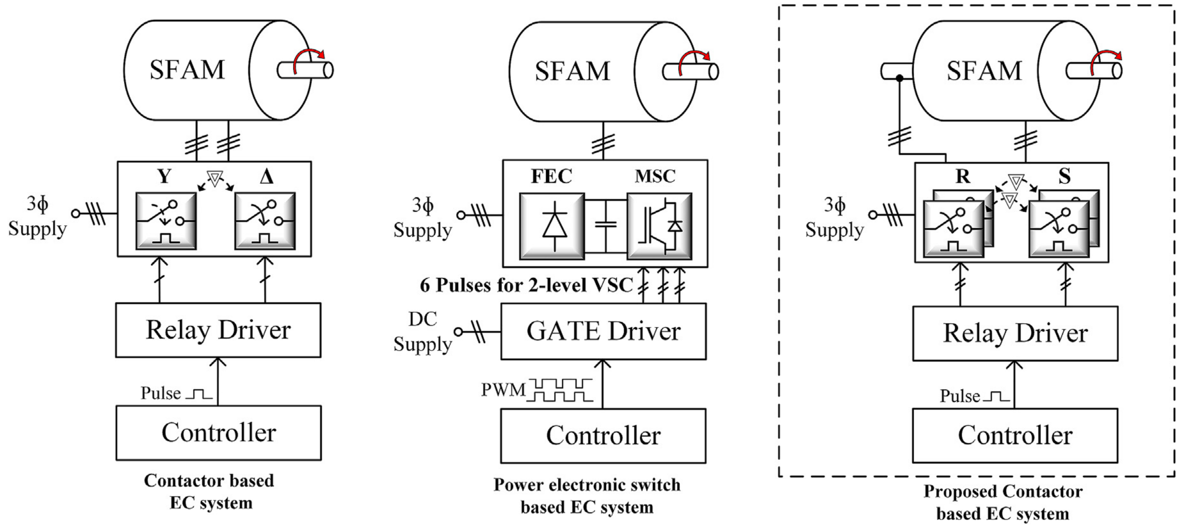

Fig. 1. Layout of energy conservation strategies.

To enhance energy conservation in wound rotor asynchronous machine, a novel switching strategy without any power electronic converters or perplexed control system is proposed in this paper. Proposed strategy, involves energization of the rotor side winding of WRIM during light load or part load operation, whereas the stator winding is energized during high load operation. According to the varying load, either the stator or rotor winding connections are switched to the supply. Meanwhile the secondary windings are short circuited. Above switching strategy accomplishes energy conservation in greater degree along with higher efficiency and better improvement in power factor. Protective features against sensor fault, overloading and switchover instability are addressed during experimentation. Technical analysis has been performed for variable load applications (linear torque load and non-linear torque load). Relative economic analysis was carried out between existing method and the proposed switching strategy for three different variable load applications.

Organization of the paper is as follows: Proposed energy conservation strategy with a brief discussion on existing scheme is presented in section 2. Experimental arrangement and analysis of which is provided in section 3. Section 4 discusses the employed control strategy, with results and discussion in section 5. Economic energy conservation analysis of linear and non-linear variable loads with case studies is presented in section 6. Sensitivity analysis is given in section 7, followed by conclusion in section 8.

2. Proposed energy conservation strategy

Generally, star-delta based EC scheme is the low-cost energy saving scheme adopted in low or medium scale IMs. In which, motor is operated in star configuration during light load and delta configuration during high load operation using contactors. As the machine is operated with the reduced voltage ($\sqrt{3}$ times of rated voltage) at light load region, it could be easily influenced by electrical perturbations. This module is recommended for applications where load changes are not too fast [3], [10]. Another EC strategy which is based on Power electronic switches involves high initial cost consisting of a pair of converters linked with DC capacitive filter, with complex control algorithm. Based on the rating and application, the switches are employed with optimal controllers or processors, for efficient operation at every operating load point [13], [14]. Though suitable switches enhance the efficiency, power factor improvement does not occur. In fact, switches in front-end converter (FEC) and machine side converter (MSC), could act as source of harmonics in the grid and machine side respectively [15].

A new switching strategy is proposed for improving machine's performance without any extensive modification from the existing schemes (Fig. 1). In this scheme, contactors are employed for switching between stator short circuit (SSC) connection and rotor short circuit (RSC) connection during light and high load operation respectively. As the machine is operated with reduced rated voltage during stator short circuit operation, this strategy accomplishes energy conservation in greater degree with higher efficiency and improvement in power factor, in spite of power quality disturbances. In addition, protective features against sensor fault, overloading and switchover instability is also taken care. Technical and economical comparison between the strategies is tabularized for constant speed variable torque application in Table 1. Increase in cost of the proposed scheme [10] over the contactor based scheme is compensated by reliability and protection. Whereas, when compared to semi-converter switch based EC systems, the proposed system is cost effective.

3. Experimentation

Based on the theory and empirical evidences, laboratory studies are conducted to identify the outcome of proposed EC strategy and investigate the behaviour of test machine (2.2 kW SFAM). Empirical evidence for analysis is obtained precisely by systematic operation of the apparatus.

3.1. Experimental arrangement

Experimental setup shown in Fig. 2a consists of a wound rotor induction machine (WRIM) also called singly fed asynchronous machine (SFAM) coupled with dynamometer loading arrangement (DC machine, lamp load and excitation system). A three-phase step down transformer is used to energize the rotor winding of WRIM through slip rings. Ratings of all the machines are provided in Table 2. To measure and record the motor input electrical quantities, a three-phase power quality analyser (PQA – Fluke 435) is used. Recorded data is analyzed graphically using fluke view software. Additionally, the thermal effect of motor (surface temperature) is directly measured using a thermal imager (FLUKE Ti-32)