Fuzzy Logic Control of an Induction Generator as an Electrical Brake

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ABSTRACT

Fuzzy logic systems (FLS) have been designed to control a self-excited induction generator (SEIG), which is used as a brake. This electrical brake has been designed for the sugar cane industry in Queensland, Australia, which uses brake vans coupled to the end of cane trains to produce a given braking torque. The brake would be suitable for similar applications of electrical brakes in electrically driven machines such as electrical vehicles. This project was established to investigate electrical braking as an alternative to existing mechanical systems.

Three fuzzy logic controllers have been designed to control the output retarding torque produced by an induction machine. One of these controllers adjusts the value of a shunt capacitance to maintain the excitation required for the generating operation. The other two adjust the duty cycle of a PWM converter, which drives the load of the induction machine. The duty cycle is adjusted in such a way to keep the retarding torque, produced by the machine, fixed at a given value.

Keywords:

Fuzzy Logic Applications; Induction Generators; Intelligent Control; Electrical Machines and Drives

INTRODUCTION

Electrical braking using a self-excited induction generator (SEIG) [1] can provide a maintenance advantage compared with the mechanical braking systems. The implementation of an SEIG as a means of braking will improve the existing mechanical braking system for the trains that are specifically used for the sugar cane industry in Queensland, Australia. However, several important issues must be addressed in the design of the electrical braking system [2].

One of these problems is that the output voltage of the induction generator depends greatly on the speed and load of the train; this will cause a significant variation in the power consumption in the load of the machine during braking. Therefore, the power dissipated in the load must be adjusted with speed so that a constant braking torque is generated.

Another problem is related to the excitation requirements of the SEIG. In order to provide a source of reactive power for the excitation of an induction generator, capacitor banks may be connected across the stator terminals [3]. These capacitors provide the means for initiating the self excitation of the machine. For a given capacitor value, self-excitation can only be achieved and maintained under certain load and speed combinations. Therefore, the capacitor bank has to be dimensioned according to a defined narrow range of speed and load values [4]. However, when the speed falls below or the load rises beyond certain values, the machine demagnetizes and stops generating. This means that although the capacitive self-excitation of an induction machine is a simple and viable solution, an additional mechanism has to be added in order to avoid demagnetization and to accept the full scale of the output voltage [2].

Fuzzy logic controllers will be used in solving the problems outlined in the previous paragraphs. Since the time that Lotfi A. Zadeh proposed a new approach to the analysis of complex systems and decision processes in 1973 [5], fuzzy logic has been applied in many areas of science and engineering. However, fuzzy logic actually gained popularity when it was applied to industrial problems by engineers [6]. This popularity can be attributed to the fact that fuzzy logic provides a powerful vehicle that allows engineers to incorporate human reasoning in the control algorithm. In contrast with the conventional control theory, fuzzy logic design is not solely based on a mathematical model of the plant; although having an approximate mathematical model helps in the fine tuning of a fuzzy logic controller. A fuzzy logic controller implements human reasoning that has been programmed into fuzzy logic language (fuzzification, membership functions, rules and defuzzification) for controlling a plant [7]-[9].

This paper presents fuzzy logic systems (FLS) to adjust the values of load and capacitance with variations of the generator shaft speed. The control scheme is designed to keep the output braking torque fixed and to maintain the magnetic field required for the operation of the SEIG.

FUZZY LOGIC CONTROL FOR AN INDUCTION GENERATOR

As mentioned earlier, the sugar cane industry in Australia uses brake vans, coupled to the end of cane trains, to produce a given constant braking torque. Currently, brake vans operate using compressed air, which is supplied by an onboard compressor. The compressor activates a brake calliper, which clamps a ventilated disc rotor on each of the four wheel sets. This system needs maintenance due to the wear on the brake pads and rotors. Electrical braking can be an alternative to this mechanical system. With the application of electrical braking, the kinetic energy is converted to electrical energy then dissipated as heat energy in well ventilated resistors as shown in Figure 1 [2].

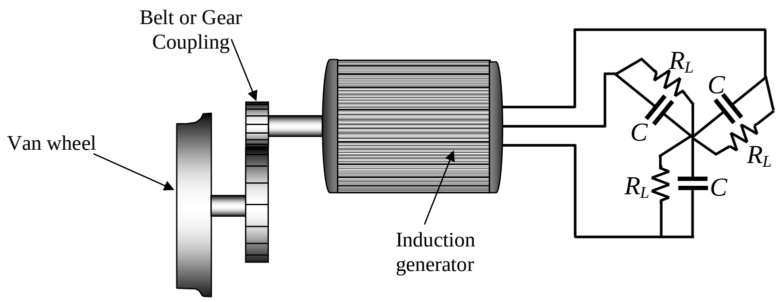

Figure 1 Electrical braking system using an induction generator (adapted from [2])

Both R_L and C must be adjusted with the change in the shaft speed of the induction generator. In this paper, it is proposed that R_L be controlled by a Mamdani-style FLS [10] and C be adjusted by a Sugeno-type FLS [11]. The block diagram of the control scheme is shown in Figure 2.

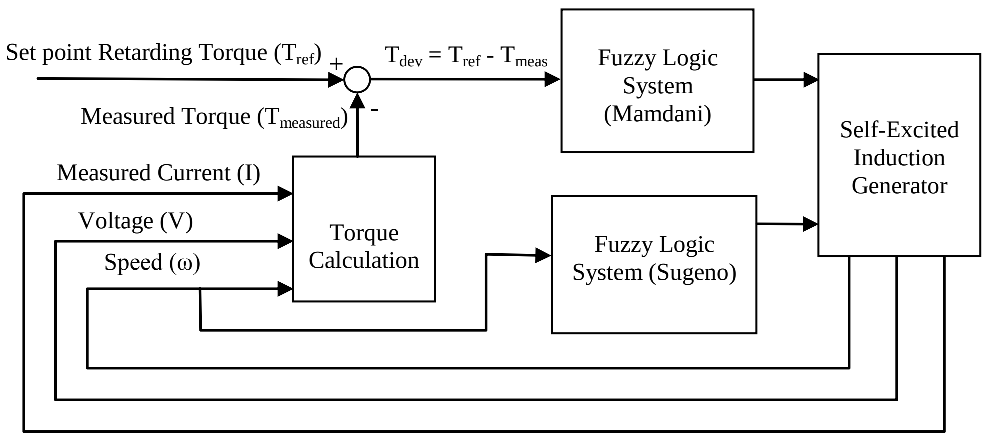

Figure 2 Control scheme of a self-excited induction generator using two fuzzy logic systems

A comparator obtains the deviation of the measured torque from a fixed set point for the retarding torque (i.e. $T_{error} = T_{ref} - T_{measured}$). Two samples of T_{error} are used to calculate its rate of change. Then, T_{error} and its rate of change are used as two inputs to a Mamdani-type FLS, which provides a duty cycle k as its output in order to compensate for changes in the torque value during transient periods. This duty cycle is added to the output of another fuzzy logic controller, which provides a steady-state value for the duty cycle based on the operational speed of the machine. The combined steady-state and transient duty cycles are applied to a Pulse Width Modulator (PWM) converter, which is applied to a power electronic switch that adjusts the load on the induction generator (i.e. R_L). Also, a Sugeno FLS uses the value of shaft speed to provide a suitable value for C, which is used to keep the magnetic field required for the operation of the induction generator.

Different types of fuzzy logic systems have been used in this application because of different requirements, which are associated with the calculations of k and C. The FLS for obtaining k needs a continuous-type control, which is easily obtained with a Mamdani style FLS with seven membership functions for its output. On the other hand, the FLS that is used to obtain C requires a system that imitates a look-up table. A Sugeno style with more singleton functions defined for the output C, in this case 16 singletons, is more suitable for the calculation of C. Sixteen singletons have been used in this application because four delta-connected three-phase capacitors have been used, which will be controlled by a four-digit binary switch. The switch has 16 different states.

SIMULATION RESULTS

A mathematical model of an induction generator [2] has been used to validate the performance of the fuzzy logic control scheme proposed in this paper. A block diagram is provided in the appendix, which shows a MATLAB Simulink model. It includes the mathematical model of the induction generator, two Mamdani-type fuzzy logic controllers that control the load on the induction machine and a Sugeno-type fuzzy logic controller that provides suitable values of a capacitor bank, which is connected in parallel to the terminals of the generator.

Figure 3 shows the voltage build-up process of the generator, when its shaft speed is kept constant at 1250 rpm. The shunt capacitor is initially charged to 50 volts, which excites the generator to start the voltage build-up process.

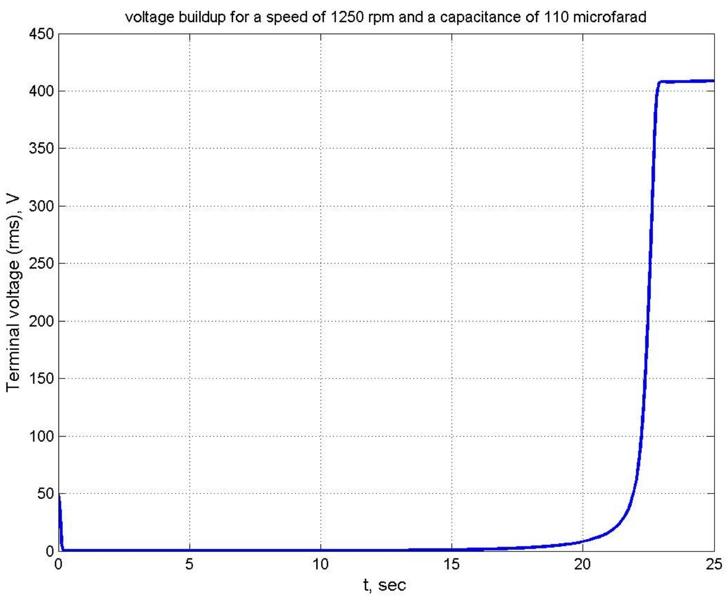

Figure 3 The initial voltage build up, with a charged capacitor and at a constant speed

In order to test the performance of the proposed control scheme, after the voltage is built up, the machine load is increased at t = 25 sec. Then, at t = 40 sec, the speed of the machine is gradually changed (firstly decreases, down to about 1107 rpm, and then increases) as shown in Figure 4.

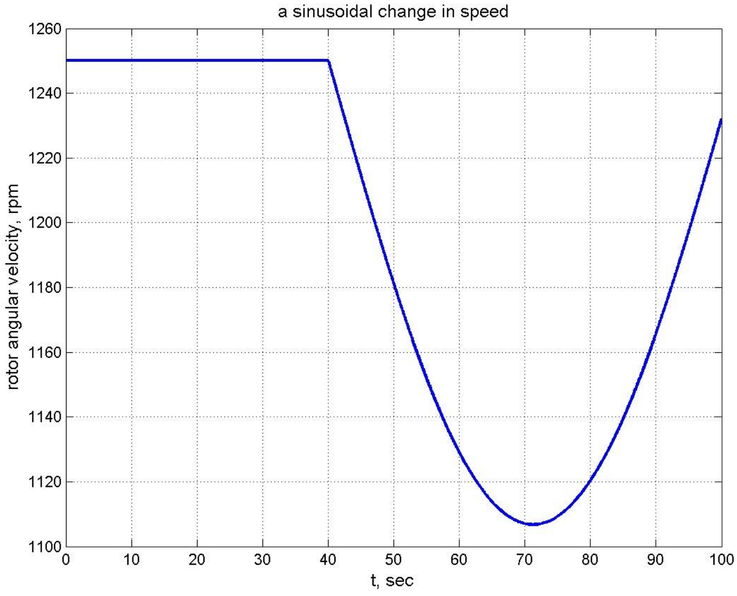

Figure 4 A change in the machine shaft speed occurring at t = 40 sec

If the duty cycle is kept at a fixed value (i.e. an uncontrolled load), the retarding torque that is produced by the induction machine will also change, as shown in Figure 5.

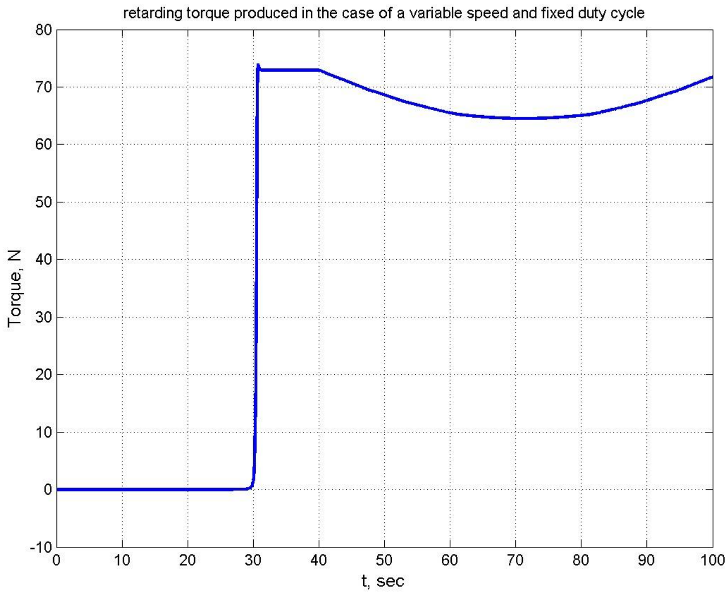

Figure 5 Retarding torque changes as a result of the change in speed

The purpose of the Mamdani fuzzy logic controller, which changes the duty cycle of the PWM converter, is to keep the retarding torque generated by the machine constant in spite of changes in the shaft speed of the machine, which comes from the speed changes of the train. Figure 6 shows the output of the fuzzy logic controller (the duty cycle applied to the PWM converter).

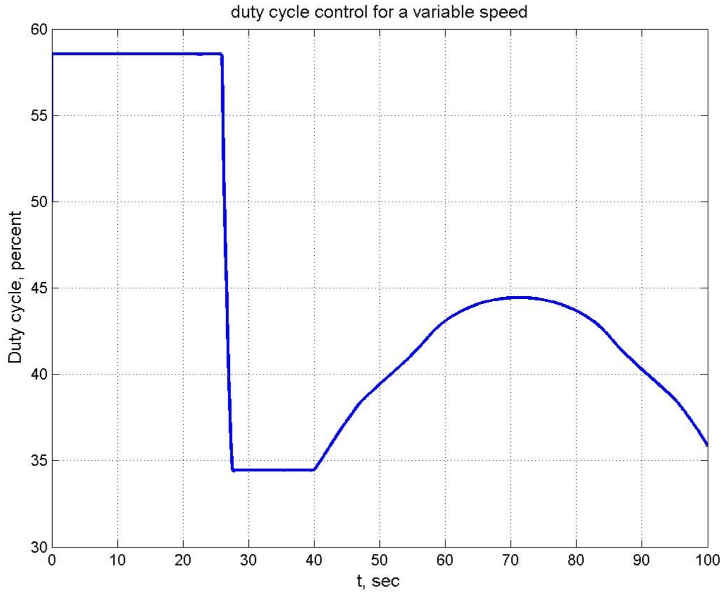

Figure 6 The fuzzy logic controller adjusts the duty cycle to maintain a constant torque

As seen from the figure, the duty cycle increases when the speed decreases and also when T_{error} has a positive value (which means the produced torque is less than a set-point torque). This will increase the power consumption in the load and will prevent the retarding torque from decreasing. As T_{error} comes down to a value close to zero and does not change any more, the duty cycle settles down to a steady state value which is correspondent to a normal load (a specific value for R_L, decided by the designer of the system according to the specifications of the machine for any specific speed). In other words, the duty cycle has two components. The first component is a steady state value for a given speed. The second component is a value for transient periods and is controlled by the torque error and its rate of change. The latter will settle down to zero when T_{error} settles down to zero.

As a result of the controller action, the torque remains fairly constant in spite of the changes in speed. This is demonstrated in Figure 7, which corresponds to the speed change of Figure 4 and control action of Figure 6. Note that the initial change in the torque value (prior to t = 40 sec) is during the voltage build-up process.

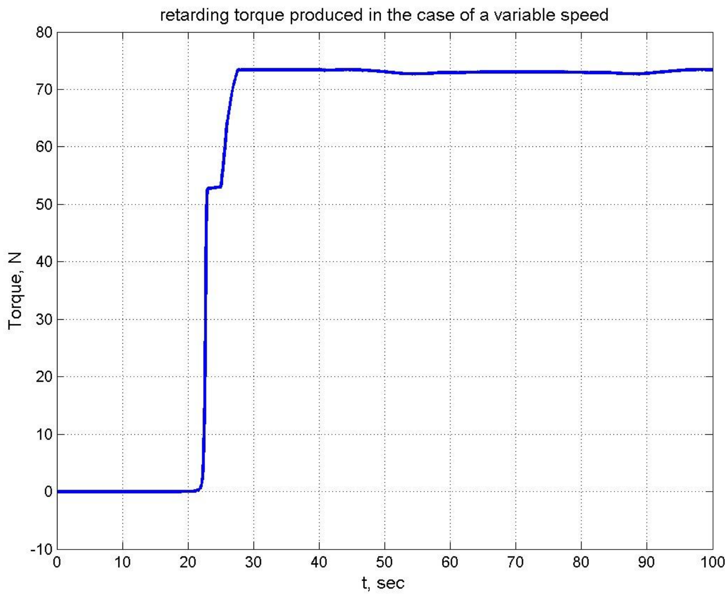

Figure 7 Torque output is kept fairly constant after the initial voltage build up

Comparing Figure 7 with Figure 5 demonstrates the improvement made by the fuzzy logic control in providing a fixed braking torque for the brake van application.

CONCLUSIONS

Three fuzzy logic controllers have been designed to control the output retarding torque produced by an induction machine, operating in the generating mode. One of these controllers, which is of a Sugeno type, adjusts the value of a capacitor bank in order to keep the required excitation for the machine.

The other two controllers provide the duty cycle required for a PWM converter, which drives the load on the machine. One of these controllers adjusts the value of the duty cycle according to changes in the speed of the machine and the other one responds to changes in the torque level. The combined duty cycle adjusts the level of power consumption to keep the produced retarding torque as close as possible to a set-point value.

The simulation results are promising as was demonstrated in the paper. The fuzzy logic controllers are going to be implemented on a digital signal processing (DSP) board and the authors are arranging performance tests on a physical machine.

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Appendix

MATLAB Simulink model of a self-excited induction generator, which is controlled by fuzzy logic controllers