

Energy Saving Using Intelligent Controller Based on Fuzzy Logic Control

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ABSTRACT

To reduce the impact of the high current on the power grid from the start process of the large induction motor and eliminate the negative influences of traditional reduced voltage start on the electronic and mechanical equipments and enhance the ability of the energy saving of the system. We studied and improved the intelligent soft start of such motors, this paper presents the design of intelligent soft starting controller in viewpoint of energy saving for power electronic systems. The proposed controller was compared through experimental studies under identical conditions with the thyristor soft starting controller (conventional controller). The performance comparison is made on the aspects of power quality and energy saving advantages. It is found that the proposed controller has superior operating and performance characteristics as compared to the conventional one.

Keywords: energy saving, energy consumption, variable speed drive, induction motors, power electronics.

حفظ الطاقة باستخدام مسيطر ذكي اعتمادا على السيطرة بالمنطق المضبب

الخلاصة

من أجل تقليل تأثير التيار العالي في شبكة القدرة من جراء عمليات التشغيل الابتدائي للمحرك الحثي ذو القدرة العالية وحذف التأثيرات السلبية للطرق التقليدية لتقليل فولتية البدء في الاجهزة الميكانيكية والالكترونية وأمكانية تحسين حفظ الطاقة للنظام، نقدم دراسة وتحسين بدء تشغيل سلس وذكي لهذه المحركات، هذا البحث يقدم تصميم مسيطر ذكي لبدء التشغيل من وجهة نظر حفظ الطاقة لانظمة القدرة الالكترونية. المسيطر المقترح قورن من خلال الدراسات المختبرية تحت ظروف متطابقة مع مسيطر بدء تشغيل سلس تقليدي يعمل بالثايرستور، قورن الاداء من جوانب مميزات كمية القدرة وحفظ الطاقة ووجد ان عمل وخواص الاداء للمسيطر المقترح يعمل بشكل ممتاز مقارنة مع المسيطر التقليدي.

INTRODUCTION

Starting up and energy saving technologies for AC motors are a focus people study [1]-[4].

Three-phase induction motor is the central equipment in modern industrial and agriculture production process. Statistically, its power consumption reaches to 50%-60% of the whole generated energy in the world. When the load factor is low, the efficiency and power factor steps down rapidly. Modern induction motors should meet the variable speed drive requirements firstly for the provision of energy saving and high reliability under operating conditions.[5] During the starting of induction motor the line current can reach (5-7) times larger than that at the normal operation and the starting torque can be twice larger than that in the normal operation.

The big starting current will cause voltage drop and influence the normal operation of other equipment connected to the same power line, and even causes the electrical network to lose stability. [6]. To overcome this problem, the large capacity power needs to be transformed to start the corresponding motor, this will bring great energy waste for power grid. So, it is important to use the soft starter in the process of the starting.

This paper is focused on the issue of energy-savings of induction motor intelligent soft start drive systems based on fuzzy logic control, in which the IGBT is used as the main on-off parts, comparison with conventional soft start drive controlled by thyristors.

The quantitative analysis of energy saving is done according to the different indices such as power factor, current and input power. The comparison between the two controllers with different load is given and the control strategy with minimum current is decided, the results show that the proposed soft starter is proved to be efficient to solve energy saving when compared with thyristor controller.

CONVENTIONAL THYRISTOR CONTROLLER

The conventional soft starter consists of Silicon Controlled Rectifiers (SCRs), sensing and control circuits to control the firing of SCRs. Fig (1) shows the main circuit of this controller, when the soft start is achieved by progressive phasing back of the firing of SCRs in the present time to achieve energy saving the phase angle between the voltage and current is monitored continuously to obtain a signal proportional to the phase angle, based on which the firing of the SCRs is controlled.

When the phase angle increases, (which is indicative of low power factor), the control circuit adjusts the firing angle to decrease the average voltage applied to the motor and vice versa.

The conventional controller has the following features [7]:

- § Smooth start and steeples gradual acceleration of motor and consequent elimination of shocks during starting.
- § Reduction in motor peak current during starting.
- § Improved Power factor.

§ Reduced power consumption.

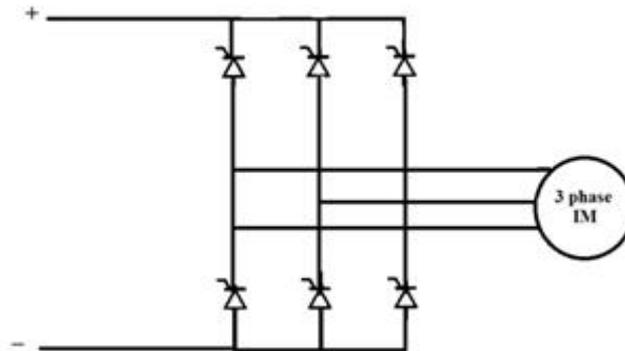


Figure (1) voltage source PWM conventional inverter topology

PROPOSED INTELLIGENT CONTROLLER

The proposed system consists of following main stages as shown in block diagram of Fig. (2) with following units:

- 1-Rectifier and Inverter unit.
- 2- Pulse width modulation drivers unit.
- 3- Data Acquisition unit.
- 4- Initial fuzzy control Circuit.
- 5-Tracking fuzzy control Circuit.

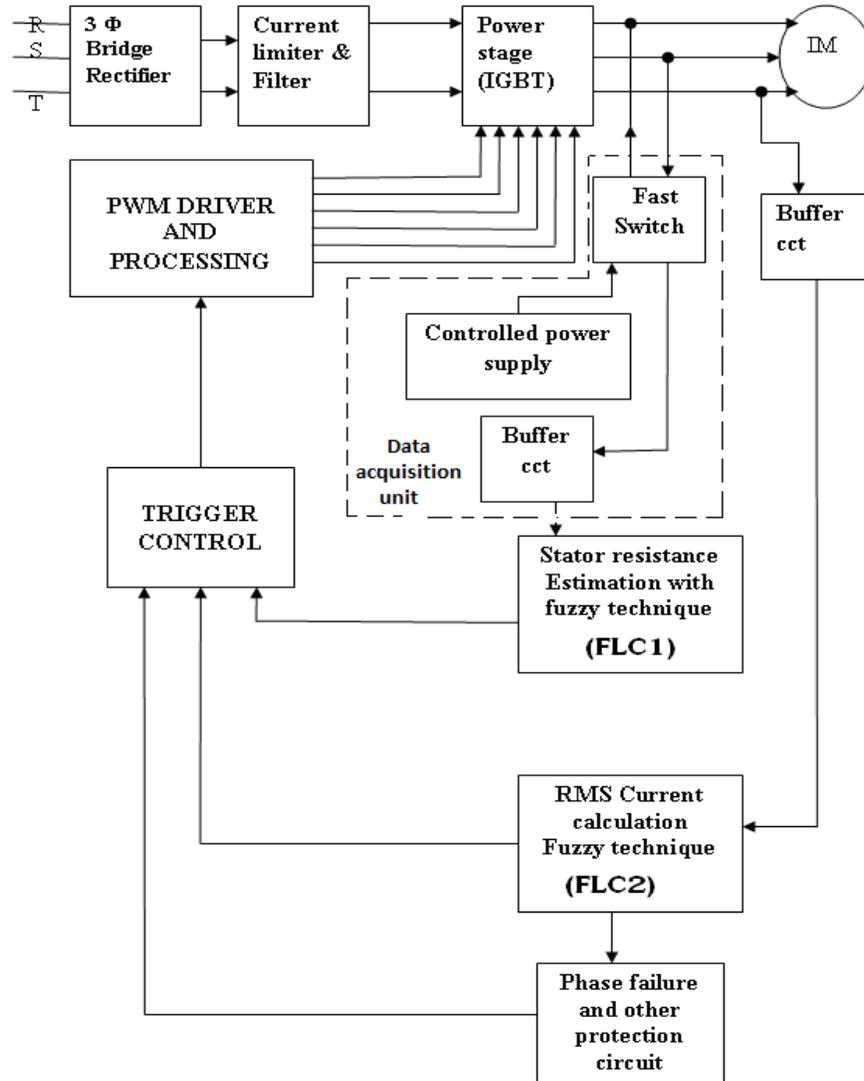


Figure (2) Simplified block diagram of proposed intelligent controller

Rectifier and Inverter Units (power stage)

For a higher power application and where three-phase power supply is available, a three-phase bridge rectifier should be used. The implementation circuit for this unit is shown in Fig. (3). This circuit consists of six IRG4BC30UD IGBTs, each containing an ultra fast anti-parallel diode Rectifier. Snubber capacitor is used to limit the IGBT turn-off dv/dt .

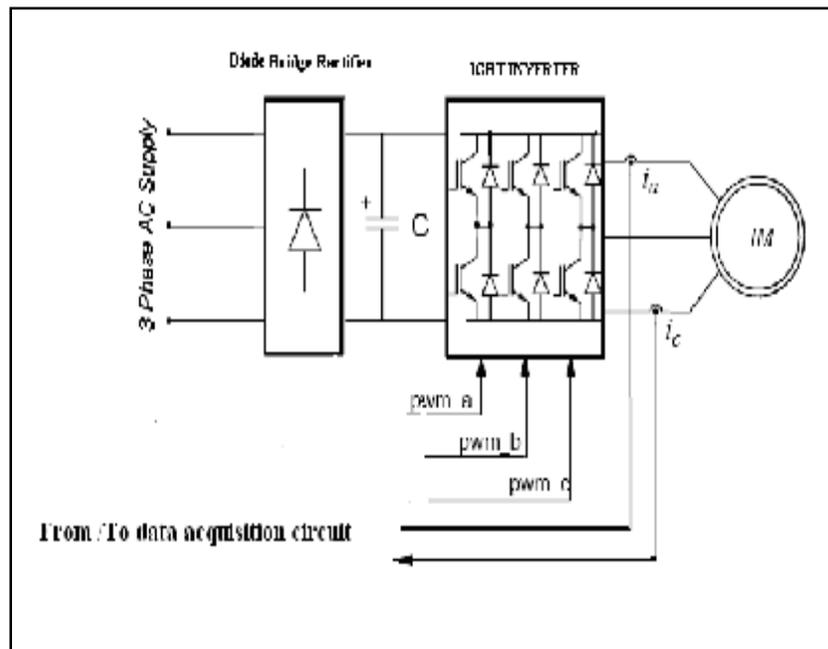


Figure (3) Proposed Inverter circuit design

Data Acquisition Circuit

Data acquisition circuit works to determine the motor parameters in time period of (5) sec and send signal to initial fuzzy. The implemented circuit is shown in Fig. (4).

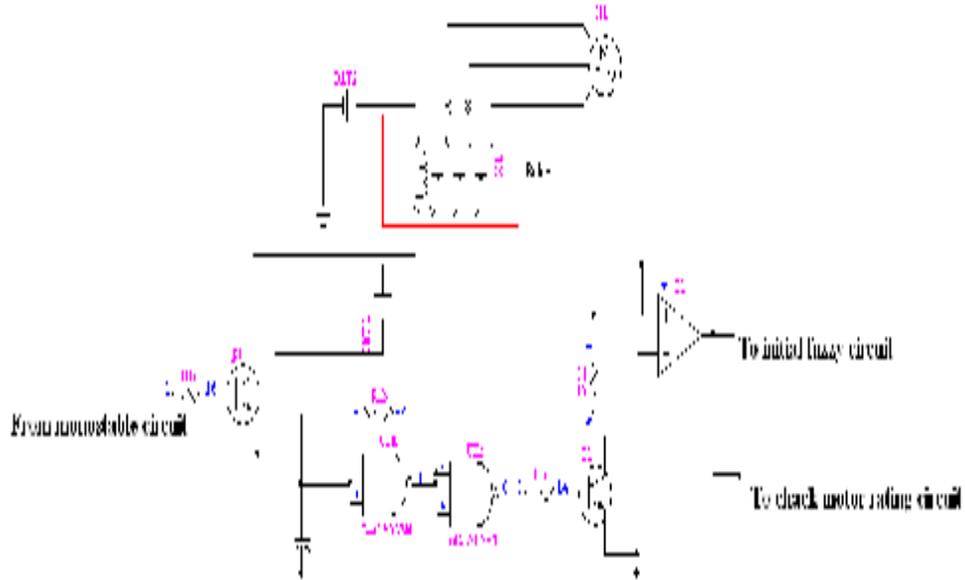


Figure (4) Practical circuit of data acquisition

Initial Fuzzy Control Circuit

Fig (5) shows the wiring connection for initial and tracking fuzzy control units. The fuzzy controller (initial and tracking) has three components: a Fuzzifier, a Rule base and a Defuzzifier.

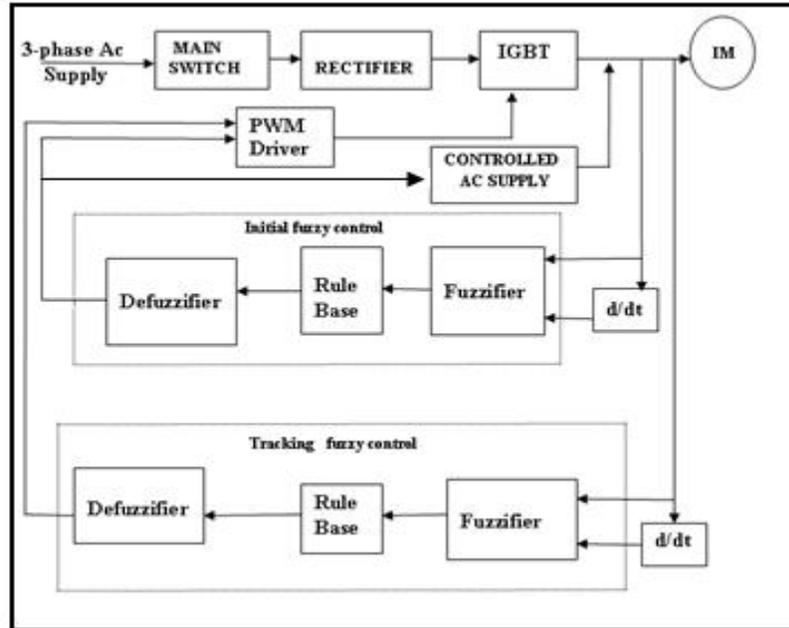


Figure (5) Block diagram of fuzzy variable speed induction motor with two units initial and tracking

Fuzzifier Circuit

The implemented fuzzifier circuit has two inputs the first is the signal measured in data acquisition circuit and the second is the same signal measured after time delay which are fed from memory bank, which consist of 8- ROM stores, the sides of triangular membership function. The ROM has 243 location is divided by 60 for each side of triangular. The output signal from data acquisition circuit expresses the applied voltage to the motor winding and that means the motor current rating. This signal is converted to digital data and input to bank ROM which stores the membership function, (see Fig. (6)). The time delay is (5) sec and limited by monostable circuit. In this time the first measured signal is directly measured and the second signal is indirectly measured because they are measured after time delay and this process is repeated, where the first signal becomes indirect signal and the second is direct signal and so on till 5 sec time. The input signals to fuzzy circuit are represented by equation:

$$\Delta I = I(t) - I(t-1) \quad \dots\dots\dots(1)$$

Where: $I(t)$: is direct signal measured from data acquisition circuit in real time.
 $I(t-1)$: is the storage measuring signal from data acquisition circuit.

The output of fuzzy circuit represents data set from direct signal and indirect signal that are conditioned and transmitted by tri-state buffer in order to get high stability and isolation between the two signals. The two signals are converted to digital data as addresses of two banks Rom. The first stores membership of direct signal and second stores membership of indirect signal. The two outputs data are stored in two ROMs and compared in rule base and decision making circuit. [7].

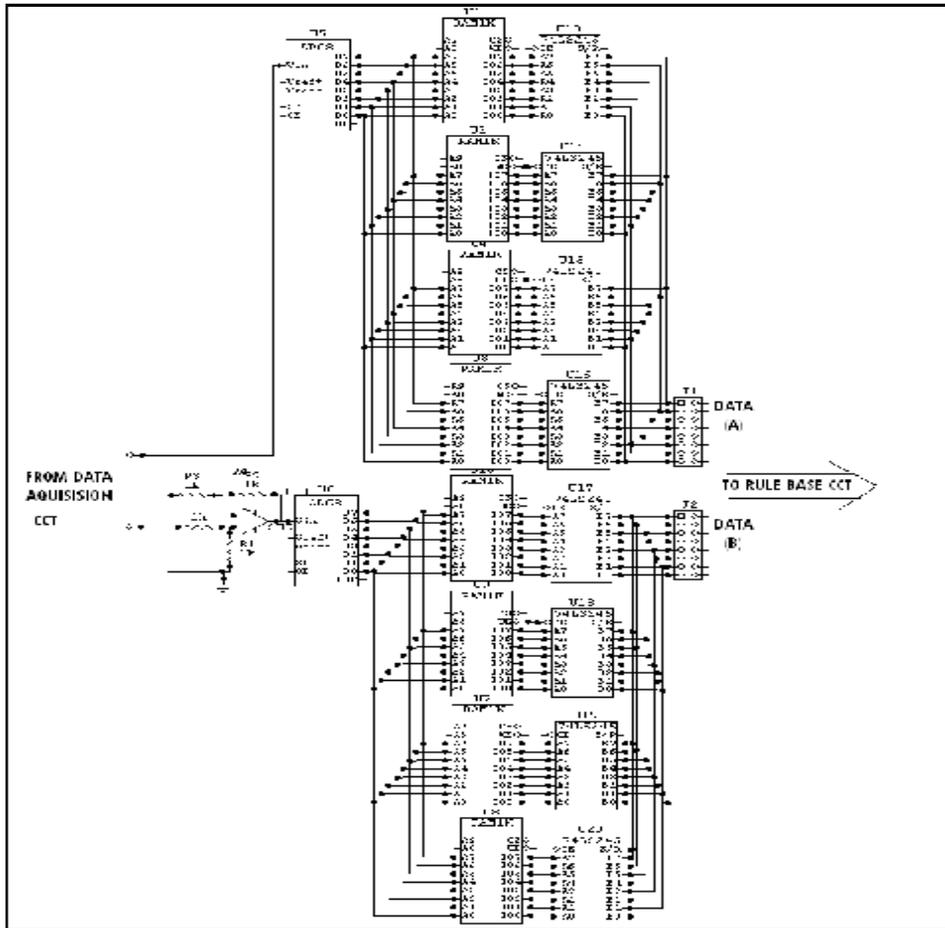


Figure (6) Implemented Fuzzifier circuit

Rule Base and Decision Making Circuit

The rule base maps are the inputs to the fuzzy sets and for the output and constitutes the core of the fuzzy controller .Table (1) shows a sample rule base. SN, LN, and LP are notations for fuzzy sets named Small Negative, Large Negative and Large Positive respectively. The Rule base has two dimensions corresponding to a Fuzzy controller with two inputs and one output. Each row gives the resultant output fuzzy set for each combination of input fuzzy sets. Thus if input 1 is LN and input 2 is SP, then the output is SN and so on. Different compositional rules have been defined which use different functions for the AND and OR operations.

Table (1) Sample rule–base.

		Input 2				
		LN	SN	ZE	SP	LP
Input 1	LN	LN	LN	LN	SN	ZE
	SN	LN	SN	SN	ZE	SP
	ZE	LN	SN	ZE	SP	LP
	SP	SN	ZE	SP	SP	LP
	LP	ZE	SP	LP	LP	LP

Let A denotes the fuzzy variable input 1, B denote input 2, O denotes the output value of output, a denotes the value of input 1,b denotes the value of input 2 and 0 denotes the value of output. Then using the minimum function for the AND operation, the rule is:

IF A is LN AND B is SP, THEN O is SN evaluated by

$$\mu_O^{SN-k}(O) = \min(\mu_A^{LN}(a), \mu_B^{SP}(b)) \dots (2)$$

where μ denotes the membership function. The membership function of the output for the set SN is obtained as a result of evaluation of the above rule and is denoted by $\mu_o^{SN,k}$. The subscript SNk denotes that the membership is for the fuzzy set SN as result of evaluating the kth rule.

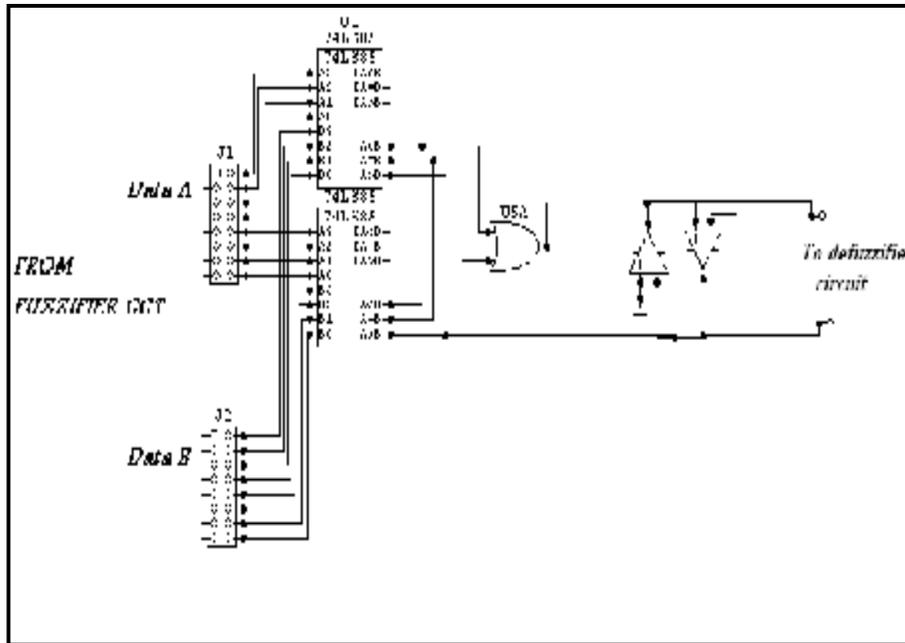


Figure (7) Hardware decision making circuit (Rule base)

The implemented Rule base circuit receives the output signal from fuzzifier circuit as shown in Fig (7) and consist of two analogue switch one to pass the data A (from bank ROM a) and other to pass the data B (from bank ROM b) and the two data a and B are compared to choose the minimum value if found.

If the input $A < B$ then the output is data A

If the input $B < A$ then the output is data B

If the input $A = B$ then the output is data A and data B

The output of all circuits is a control signal to execute the decision and choose the defuzzification value to start the controller operation.

Defuzzification Circuit

The output of rule base and decision circuit is a fuzzy variable which is converted to analogue signal by the defuzzifier. The hardware implemented to execute a defuzzifier circuit is shown in Fig (8). The output will be as from Eq.(1).

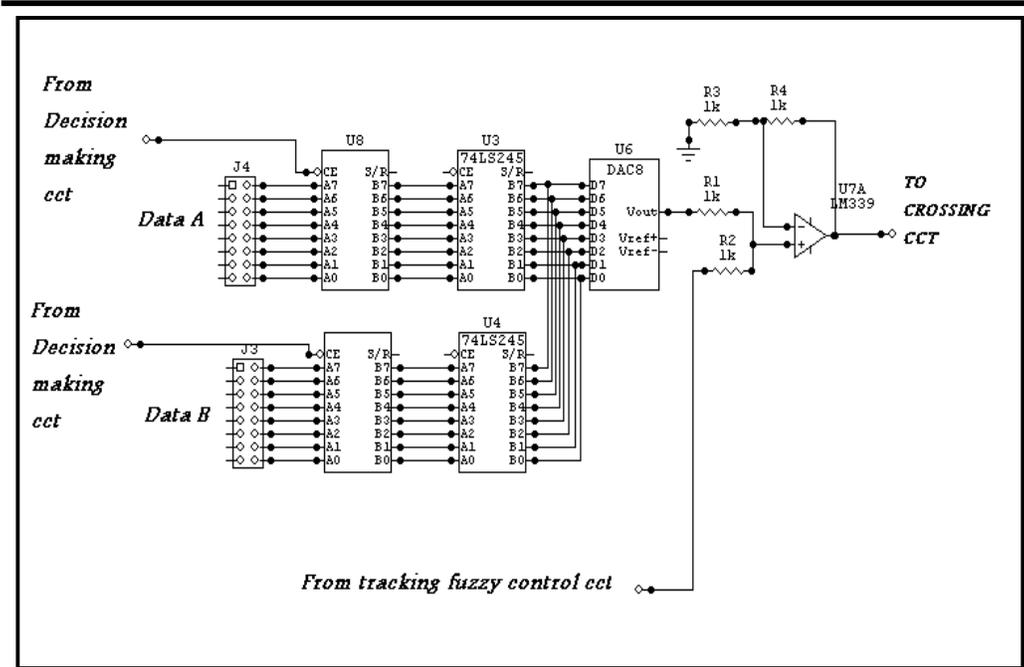


Figure (8) Defuzzifier circuit

Tracking Fuzzy Control Circuit.

This unit is designed and implemented in the same way as the initial fuzzy control circuit. The main functions of this unit are:

- (1)-Guarantee a continuous operation of drive.

Overall diagrams shows the tracking circuit receives direct signal through buffer circuit which is connected to current transformer of motor terminal. Tracking circuit includes three stages the same as detailed in the initial circuit and the same membership table. In order to guarantee a continuous smooth and soft start controlling, the initial circuit is disconnected after (5second) that is limited by monostable circuit. Then the continuous operation is done by tracking circuit only. The output of tracking circuit has two terminals: adder circuit and initial circuit. The separation of function of two stages(initial and tracking) which is adopted in the proposed research gives a high stability of operation as shown in the results of the startup current and voltage.

- (2) Processing the sudden loads.

The sudden faults often occur during the operation of drive with load, therefore the fuzzy controller should process these cases immediately.

EXPERIMENTAL RESULTS

Energy conservation is significant for induction motors drives. To compare the proposed soft starter with the conventional soft start one for the characteristic of energy saving, the following experimental results are used, which are performed with one motor.

The proposed system was tested with induction motor has specification shown in Table (2).

The corresponding experimental equipment consists of a squirrel-cage induction motor, the conventional thyristor controller with switching frequency of 2 kHz, the proposed soft starter controlled by IGBT with switching frequency of 2 kHz, and the motor monitoring meters which can display many motor parameters, such as input power, power factor, torque and speed.

Now, the measurements of the stator current, voltage, input power and power factor of the two controllers are carried out, and the results are compared with different loads. Figs. (9-12) shows the comparing curves of power factor with the fundamental voltage with no load, 0.3, 0.45, and 0.7 Nm load respectively. From these figures it is shown that two controllers can improve input power factor when operating on different loads. The power factor has the maximum value when reducing the stator voltage, but it is obvious that the power factor of the proposed soft starter is higher than that of the conventional soft starter with the same operating condition.

Figs.(13)-(16) give the input current curves with the fundamental voltage at no-load, 0.3, 0.45 and 0.7 Nm load respectively. The typical characteristic of input current is that the current has the minimum value during adjusting the output voltage and the input current of the proposed soft starter is smaller than the conventional one.

Fig.(17) shows the improvement in energy consumption which is supplied through proposed controller for unloaded motor, where the normalized output power is defined as the ratio between mechanical power to the rated power. Fig (18) shows the improvement in energy consumption for loaded motor, where the power saving is decreasing when the load is increased because the trigger angle is increased then the current increased.

Fig.(19) shows the efficiency versus normalized power curves from comparison between proposed and conventional controllers. It can be seen that the efficiency of the proposed controller is better than that of the conventional controller when the load exceeds half of the rated load, but it has small difference at low loads.

CONCLUSIONS

The performance and robustness of the proposed controller have been evaluated under a variety of operating conditions of the drive system and the results demonstrate the effectiveness of these control structures.

It can be seen from results that the operating power factor is improved, and the consumed electrical energy is decreased, due to the developed energy-saving

controller. Moreover, the controller will bring about the larger energy-saving if the induction motor has the lighter load. Therefore, these experimental results validate the proposed energy-saving scheme. The proposed system demonstrates an improvement in efficiency by 88% compared with the conventional system by % 72 at full load.

The best selection of trigger angle gives an improvement in power saving by 42%. Finally, the advantages of proposed method are its simplicity, stability, and accuracy and fast response.

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Table (2) squirrel cage induction motor parameters

Type	3-phase Y -connected
Rated power	1/3 Hp
Rated voltage	380 v
rated current	1 A
Rated frequency	50 Hz
Rated speed	1500 rpm
Number of poles	4

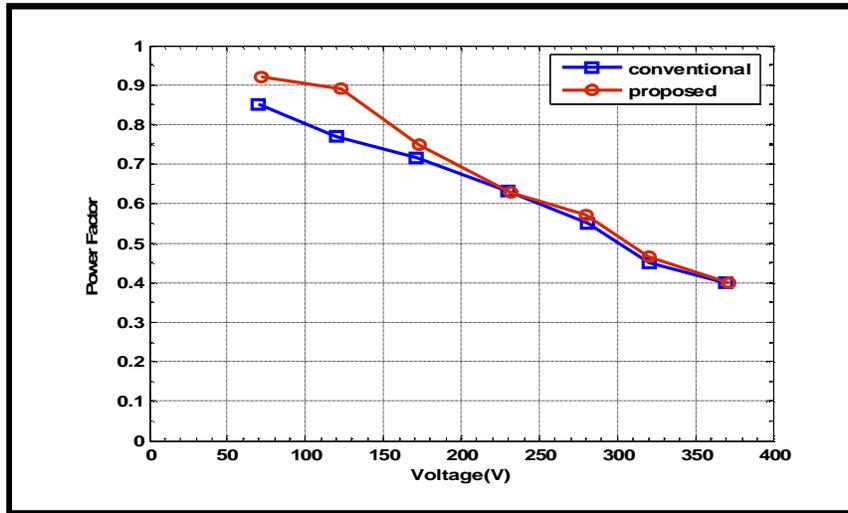


Figure (9) Voltage and power factor at no load

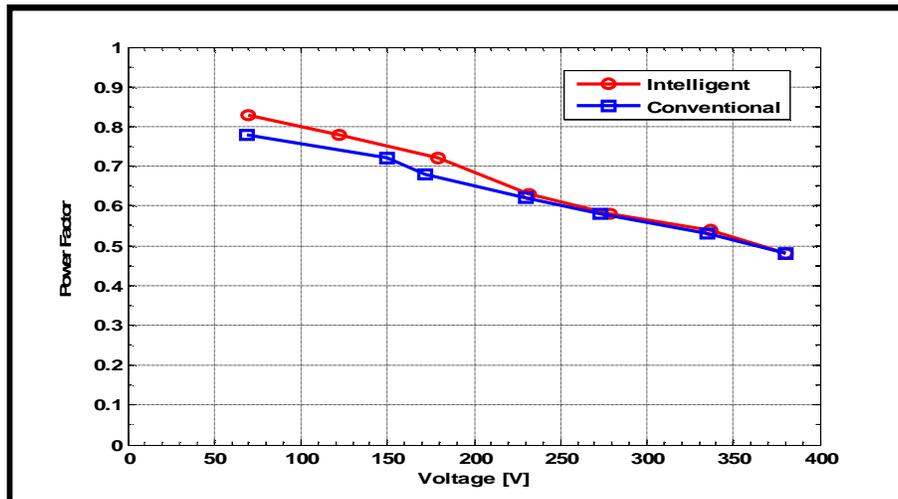


Figure (10) Voltage and power factor at 0.3 N.m load

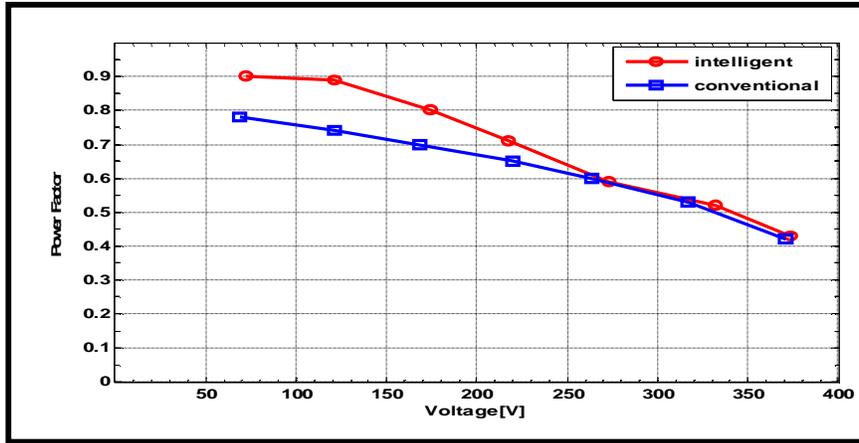


Figure (11) Voltage and power factor at 0.45 N.m loa

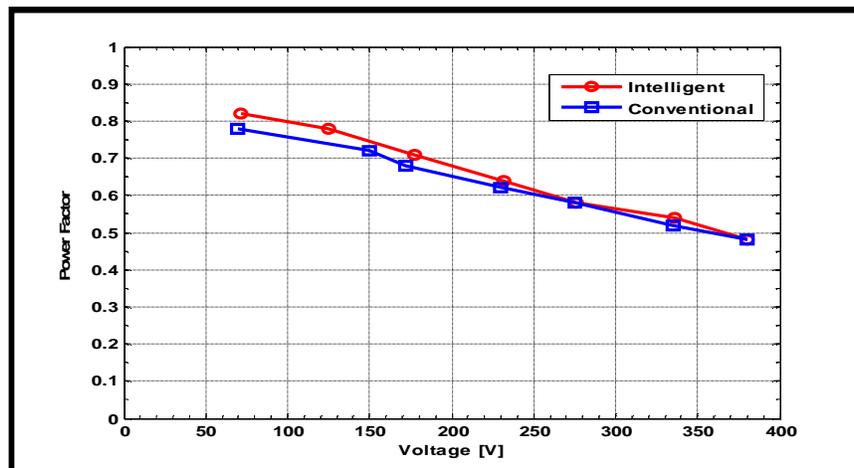


Figure (12) Voltage and power factor at 0.7 N.m load

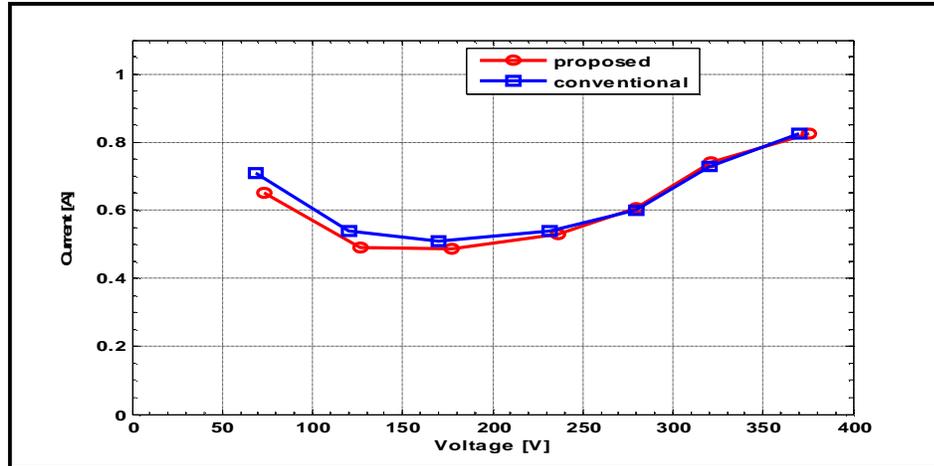


Figure (13) Voltage versus current at no load

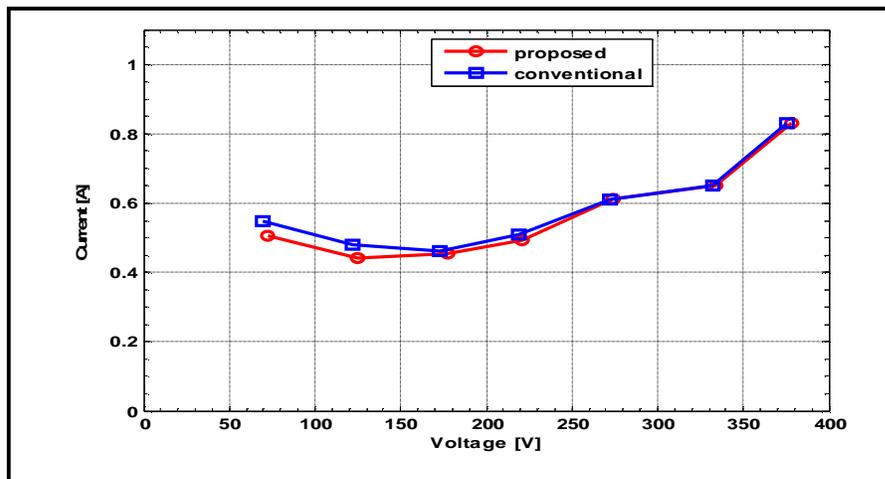


Figure (14) Voltage versus current at 0.3 N.m

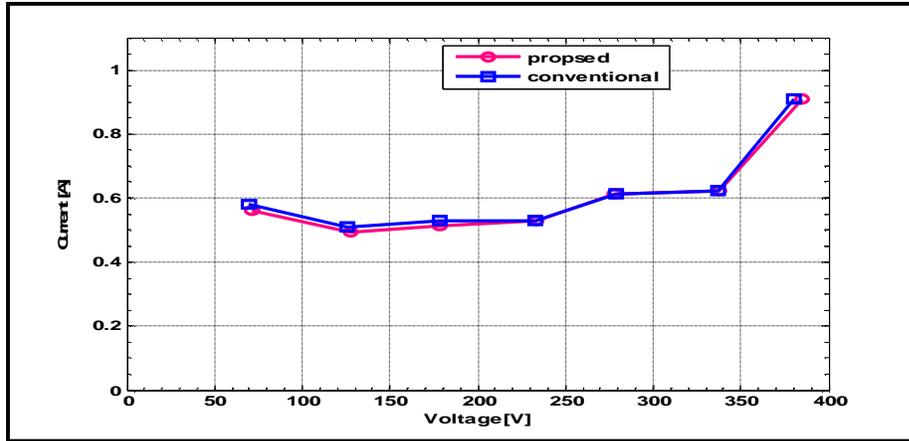


Figure (15) Voltage versus current at 0.45 N.m

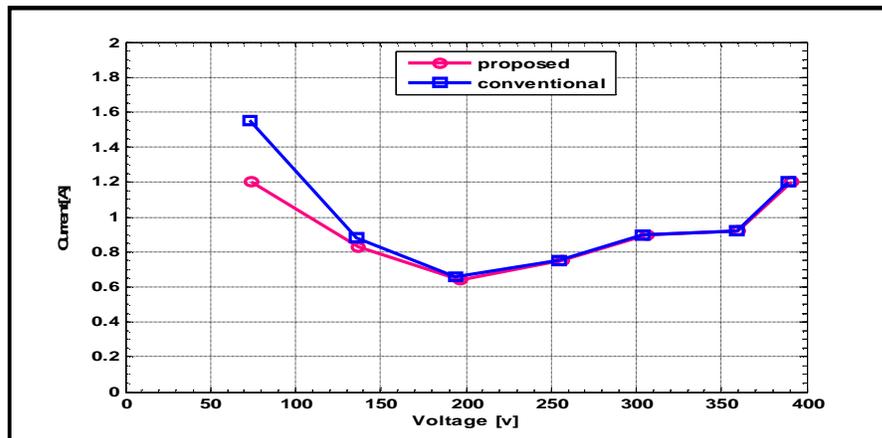


Figure (16) Voltage versus current at 0.7 N.m

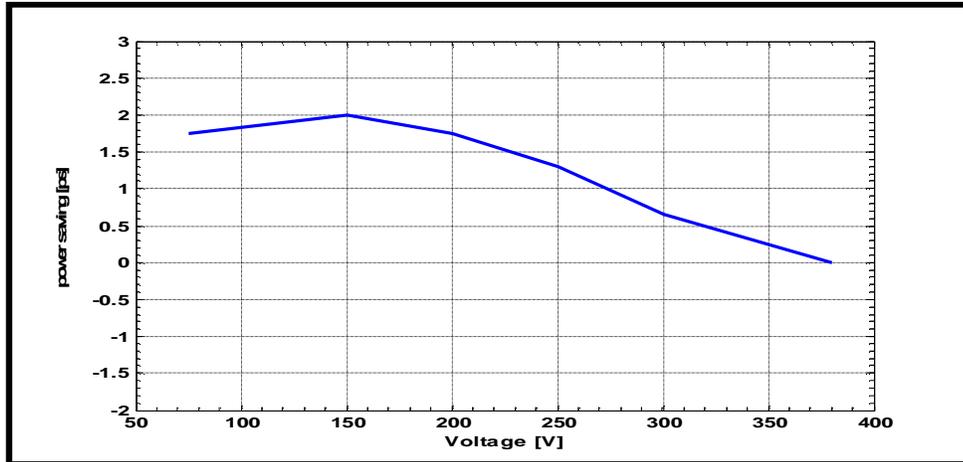


Figure (17) Normalized power saving for un-loaded motor

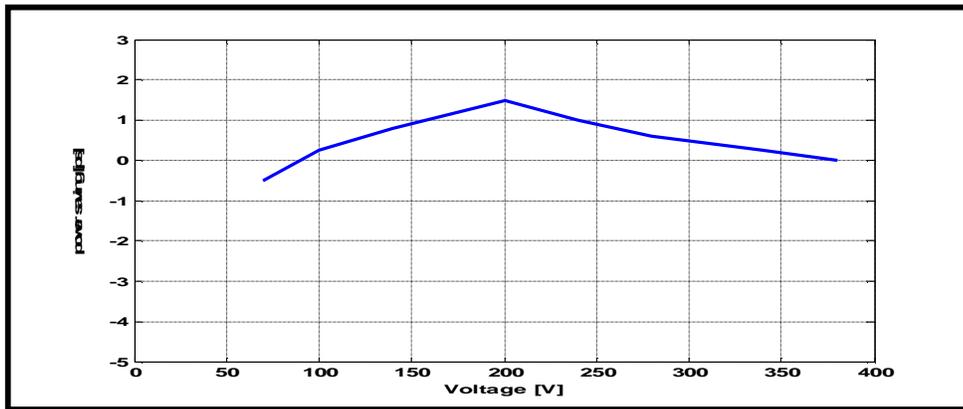


Figure (18) Normalized power saving with loading motor

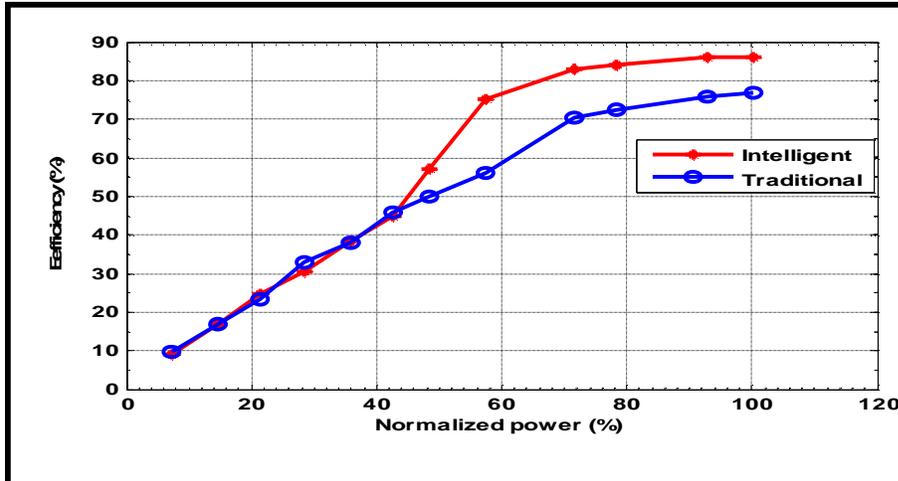


Figure (19) Efficiency versus normalized power for comparison proposed Intelligent and conventional controller