Two Speed Single Phase Induction Motor with Electronically Controlled Capacitance

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Abstract—An experimental exploration of using an Electronically Controlled Capacitor (ECC) in the supply system of a two speed single phase induction motor drive is presented. The ECC solution and the method with solution with a fixed value capacitor are comparatively analyzed in terms of efficiency and maximum torque availability. The losses and the over-voltages due to the electronic commutation are also analyzed. The paper proves the feasibility of the ECC solution and underlines its advantages and drawbacks. The optimal value of the switching frequency of ECC has been experimentally determined.

Index Terms—Electronic Controlled Capacitor, Energy Efficiency, Single Phase Induction Motors, Circular Rotating Field, PWM Control.

I. INTRODUCTION

The single phase induction motor is widely used in both industrial and home appliances. The power is small for one motor but the number of the motors is high. Consequently, the optimization of the single phase motor performances is a central problem.

An essential condition is to achieve a circular rotating magnetic field. From among different solutions the most used is to add a series capacitor to the auxiliary winding. This solution assures the optimal circular rotating field in one single operating mode point, which is currently the stationary operating mode. The main disadvantage of the method is that, at the start up, in dynamic operating mode and in the case where there are more stationary points, the motor has very poor performances and efficiency.

Another system uses two capacitors, a higher one for starting it and the other for the stationary operating mode. The first one is disconnected after the starting of the motor mainly by a centrifugal system.

The disadvantages regarding the dynamic operating mode or in the case when there are more stationary points remains the same. The rotating field is elliptical most of the time and its efficiency and other performances are poor.

In the case of a motor with two independent windings for two distinct speeds the problems are doubled as well.

II. ELECTRONIC SWITCHING METHODS TO EMULATE A VARIABLE CAPACITANCE

There are multiple methods to optimize the induction motor regarding design, manufacturing process, driving or starting [1-5]. For single phase motor a promising method is to emulate a variable capacitor, starting from a fixed capacitor and the value of this being modified by electronic variable duty cycle commutating it at a higher frequency.

A first variant was introduced by T. H. Liu [6] and E. Muljadi [7] followed by other researchers [8, 9]. Liu and Muljadi use an AC voltage capacitor, C, placed in series with a RL series circuit. An electronic bidirectional switch is connected in parallel with the capacitor, being PWM (Pulse Width Modulation) controlled at supply frequency (Fig. 1).

![Figure 1. Liu - Muljadi method to emulate a variable capacitor.](image1)

The advantage is simplicity but the great disadvantage of this method is that the current is distorted.

T. A. Lettenmaier [10], proposes another method, a DC charged capacitor placed in a switched transistors bridge. The bridge is controlled by a high frequency PWM. A reference voltage synchronized with the source voltage is needed. He was followed by other researchers as well [11, 12].

A similar but simpler method was proposed by C. Suciu [13]: the same switches bridge but with an AC capacitor. (Fig. 2). An ECC model has been established and verified [13, 14]. He later focused on control methods [15-17].

Suciu method was used to control the capacitor and the ECC model to estimate the ECC value.

![Figure 2. Suciu method to emulate a variable capacitor.](image2)

III. THE TWO WINDING MOTOR AND THE TEST BENCH

A MSP-311 model, two winding capacitor-run motor produced by ANA IMEP Pitești Ltd., Romania, has been used. The motor is specifically designed for washing machines with two different duty cycles: washing at low speed and spinning at high speed. The low speed winding has 12 poles, designed to allow a two direction operation while the high speed winding has 2 poles. The motor parameters are presented in Table 1 and Table 2 [18-20].

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rated supply voltage</td>
<td>V</td>
<td>230</td>
</tr>
<tr>
<td>2</td>
<td>Rated frequency</td>
<td>Hz</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>Rated speed</td>
<td>r/min</td>
<td>2840/2420</td>
</tr>
<tr>
<td>4</td>
<td>Pairs of poles number</td>
<td>μF</td>
<td>1/6</td>
</tr>
<tr>
<td>5</td>
<td>Capacitor-run value</td>
<td>μF</td>
<td>14</td>
</tr>
</tbody>
</table>

TABLE I. MOTOR RATED PARAMETERS
The experimental exploration has been performed on a test bench (Fig. 3) developed earlier [21] for single phase motors and mechanically adapted to MSP-311 motor composed by:

- Magtrol hysteresis dynamometer HD-805-8NA (DYN);
- Magtrol brake controller DSP-6001 (CONTR)
- Motor coupling system (CS);
- Motor fixing system (Fig. 4);
- Current (HY-5P) and voltage (HY-25P) transducers board (TR);
- Connection board National Instruments NI-SCC-68 (CONN);
- Data acquisition board National Instruments NI-6521 (DAQ);
- Relay board (REL);
- Computer (PC);
- Electronically controlled capacitor (ECC)

The test Bench is completed with an elaborated LabVIEW monitoring software [22].

The fixed capacitor-run motor MSP-311 has been previously analyzed [23] and some results are used here.

First of all, the optimum fixed capacitor values are used for different situations like rated or maximum torque and 2 or 12 pole configuration. In motor rated parameters this value is 14 μF (Table I) but the experiments have lead to the following values used as reference in controlled capacitor experiments:

- 2 pole configuration: 6 μF (rated torque); 14 μF (maximum torque);
- 12 pole configuration: 8 μF (rated torque); 12 μF (maximum torque).

Secondly the maximum torque value is a base for comparisons between fixed and switched capacitor cases.

IV. EXPERIMENTAL RESULTS

The experiments have been focused on the feasibility of driving the motor with ECC, the limits imposed to the motor, capacitor and to the power static devices as MOS transistors and switching diodes as well as on the comparison with the fixed capacitor case.

The measurements have been made in a variable supply arrangement (Fig. 5) with $U_{var}$ positioned at 115 V (instead 230) to avoid possible damaging over-voltages.

As it had been expected (Fig. 6, 7), there are commutation over-voltages in the range of about 50% from supply amplitude, but over-voltages from ECC principle as well. The amplitude of the fixed capacitor voltage ($U_{23}$ in Fig. 5) and ECC voltage ($U_{14}$ in Fig. 5) are twice as supply amplitude (Fig. 10).
In Fig. 8 and 9 the same detail is presented in two measurements methods, firstly with an oscilloscope and then with data acquisition system.

It can be observed that fast switching transitions can be seen on scope only.

But the data acquisition system has been proved to be useful when voltages presented in Fig. 5 are compared at the same time as in figure 10.

The main parameters have been the speed/torque, efficiency and the total current characteristics. The brake controller returns the characteristics presented Fig. 11 and a simple Matlab software has been used to interpolate them. Interpolated curves are presented in Fig. 12.

The main comparison has been made between the speed/torque characteristics, figure 13, and that proved for a fact the feasibility of this method.

The 4 kHz optimal control capacitor frequency has been experimentally established, Fig. 14.
Figure 14. Speed/torque characteristics, 12 pole configuration and different control frequencies: white, 5 kHz; red, 2 kHz; green, 4 kHz; blue, 8 kHz.

V. CONCLUSIONS

It is the first time when this Suciu method electronically controlled capacitor is used attached to a single phase induction motor and the main problem has been to check if this solution is feasible. The answer is yes even if there are serious drawbacks.

There are two principal drawbacks; first, the torque diminishes by about 5%. Here it must be said that in this diminishing enters the voltage fall over the power switches, about 2% from the supply voltage. The second drawback lies in over-voltages. The switching ones are not too serious, as there was no special concern about them in those experiments. But the experiments have revealed an important over-voltage with the motor itself due to the method, and there is not much to do about that. This method needs better motor isolation is the conclusion we have reached.

Passing on to the gains it can be said that the 5% diminishing of the torque driving the motor with a switched capacitor controlled according to the Suciu method is small enough and the advantages can counterbalance it. First of all it is about a two speed/windings motor and the possibility to electronically change the capacitor, as the operation mode is diminishing enters the voltage fall over the power switches, about 2% from the supply voltage. The second drawback lies in over-voltages. The switching ones are not too serious, as there was no special concern about them in those experiments. But the experiments have revealed an important over-voltage with the motor itself due to the method, and there is not much to do about that. This method needs better motor isolation is the conclusion we have reached.

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REFERENCES