ELECTRONIC CONTROLLED CAPACITOR FOR SINGLE PHASE INDUCTION MOTOR

Radu CAMPEANU*, Constantin SUCIU*, Aurel CAMPEANU**

**"Transilvania" University of Brasov; rcampeanu@marconi.unitbv.ro*
***University of Craiova*

Abstract – **This paper presents an electronic controlled capacitor used to increase the efficiency of the Single Phase Induction Motors (SPIM). The principle of operation and the system schematic are described. The values of the emulated capacitor for circular rotating field are established.**

Keywords: *single phase induction motor, electronic emulated capacitor, circular rotating field*

1. INTRODUCTION

A capacitor is used to enhance the performance of a single phase induction motor which has two phases designed to operate in quadrate. Quadrate fluxes are produced by connecting a capacitor in series with one of the windings.

Appropriate choice of capacitance can optimize performance. The capacitor is important both at starting and in steady-state. The main problem is in the choice of the capacitor. The capacitor size must carefully determined according to the terminal impedance and from the fact that two different values of the capacitor are required for starting and steady state running.

The capacitor used in the steady state is between five and ten times as small as the capacitor used for starting. The difference between these two values results in the use of two different capacitors, the large value is placed in series with the auxiliary winding during starting and the small one is switched in the circuit when the machine reaches full speed. At the instant of switching in the small capacitor, the large capacitor is switched out of circuit

2. SWITCHED CAPACITORS METHODS

The research efforts were focused in finding solutions of emulating the starting capacitor and two methods were developed: one introduced by T.H. Liu[1] and E. Muljadi[2] and another one presented by T.A Lettenmaier [3].

Liu's and Muljadi's methods consist of placing in series with an a.c. RL circuit, an a.c. capacitor in parallel with a solid state switch that must allow bidirectional current flow as with a mechanical switch (fig. 1). When the switch is open, current flows through the capacitor and a RLC circuit is formed. The current bypasses the capacitor when the switch is closed (RL circuit case). The switch is closed at the instant the voltage across the capacitor reaches zero. Thus, a zero voltage switching operation is performed and the switch is reopened after the shorting interval γ has passed. By shorting the switch periodically, the fundamental component of the voltage across the capacitor appears to be lower than the case without the periodic shorting interval so that the effective size of the capacitor appears to be larger than the actual size. As the shorting interval γ reaches π rad, the effective size of the capacitor approaches infinity.

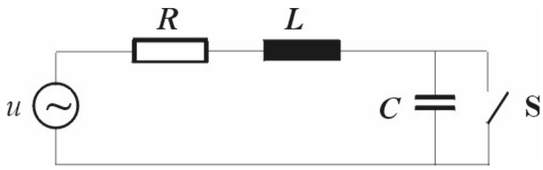

Figure 1: Liu's and Muljadi's switched capacitor.

In [1] it is stated that the emulated capacitance has the value:

$$C_{effective} = C_{running} \frac{1}{1-d} \quad (1)$$

where: $$d = \frac{\gamma}{T_s} \quad (2)$$

and $$T_s = \gamma + t_{off} \quad (3)$$

where t_{off} is the turn off interval of the electronic switch.

The principal drawback of this method is that the resulting current is quite distorted.

Another drawback is the dependence of the period T_s on the charge and discharge times of the capacitor. This defines the interval when the switch is off. In fact, this means that t_{off} is function of circuit parameters and supply frequency.

Lettenmaier [3] proposed a method of using electronic switching to replace centrifugal switch that introduces/removes the starting capacitor in the

auxiliary winding of the single phase induction motor.
The method used presents the motor with a continuously variable capacitance. It is achieved by using a transistor H bridge to switch a DC charged capacitor (fig. 2).
The capacitor is charged from the motor AC supply

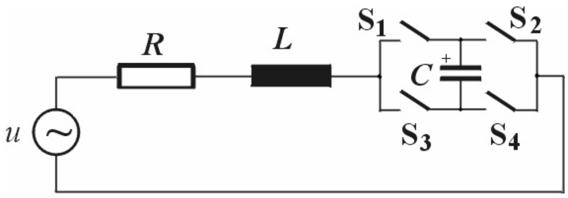

Figure 2: Lettenmaier's switched capacitor.

and the bridge is pulse-width modulated using the sine-triangle modulation algorithm. The author uses a reference voltage V_{ref} synchronized with V_s. The capacitor is considered to be large enough for the capacitor voltage V_{cap} to be considered to be DC with negligible ripple. Therefore, the bridge output voltage V_{br} is a pulse width modulated approximation to the sine wave with a fundamental component phase angle adjustable in relation to the supply voltage V_s. The phase angle between the bridge voltage V_{br} and V_s is called bridge phase angle and is the primary adjustment factor used to control the transistor switching. The bridge output synthesizes a capacitance that can be varied if the

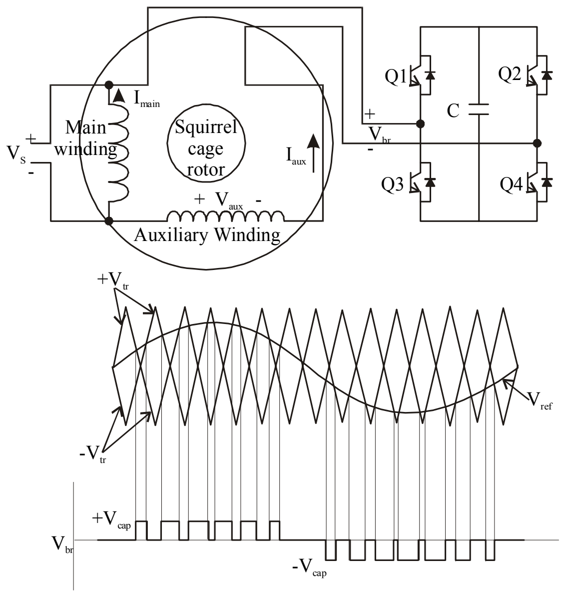

Figure 3: Switched capacitor-motor system

switching is made in an appropriate manner (fig. 3).
The author states that the size of the DC capacitor from the bridge needs only to be large enough to compensate the AC ripple at the capacitor terminals. Controlling the peak of the triangle wave V_{tr}, it is possible to adjust the magnitude of the modulation. The effect of this adjustment is to change the capacitor DC voltage.

3. CONTROLLED CAPACITOR SCHEMATIC

The electronic capacitor has two main parts that are given below:

- the power circuit;
- the command system;

3.1. Power circuit

Bi-directional switch has been implemented as in figure 4.

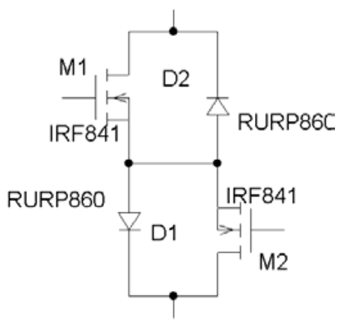

Figure 4: Power switch.

3.2. Command system

It is important that the control strategy prevents the simultaneous conduction of the switch pairs S_1, S_4 and S_2, S_3 (fig. 4.14). Simultaneous conduction creates a discharge path for the capacitor. Even though the discharging process is incomplete, it influences the system behavior.
The command systems comprises of:

- Pulse generator and reference circuit; it has been used a standard pulse generator.
- Delay circuit shown in figures 5;

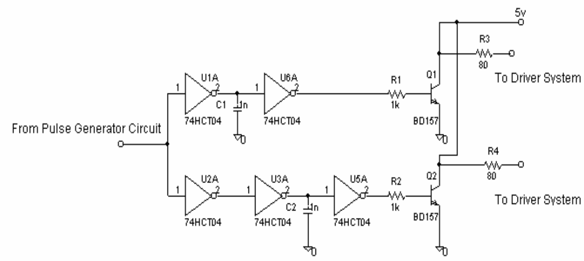

Figure 5: Delay circuit.

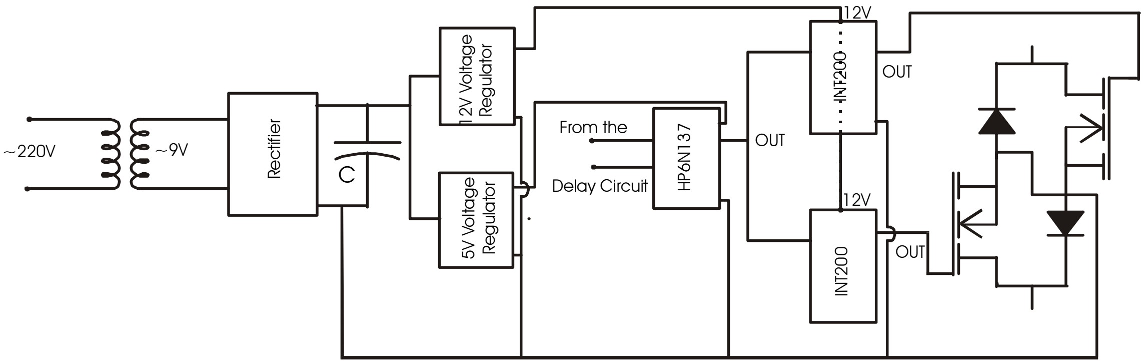

Figure 6: Driver system schematic

The role of the delay circuit is to introduce a dead time between the falling edge and rising edge of the signals that control the state of the complementary switches.

- Driver system modules is shown in figures 6.

Each switch is controlled by a driver module shown in figure 6. Each transistor is controlled through gate driver INT200. The command signal to the gate drive is received from the delay circuit through an opto-coupler (HP6N137).

The two winding transformer and the opto-coupler ensure isolation of the drive signals from power supply and between switches.

4. CAPACITOR VALUE

Even in the case the capacitor is electronic emulated the value in all of the important operating points must be known. More than that, the purpose of the emulation being to optimise the motor, the value of the capacitor for different stationary points must be calculated for the case that the rotating field is supposed to be circular.

This kind of evaluation is done here.

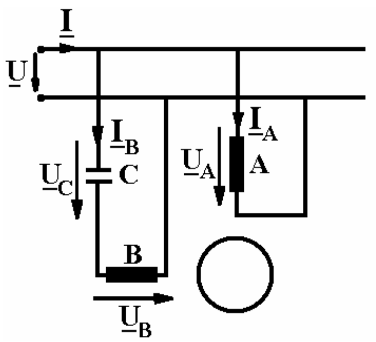

Figure 7: Single phase induction motor with auxiliary winding and capacitor.

The schematic of the single phase induction motor is presented in figure 7.

The principal winding A is electric orthogonal with the auxiliary winding B containing the series capacitor.

It results the phasor diagram presented in figure 8:

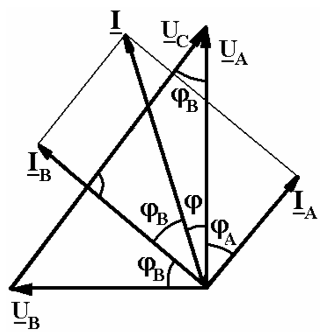

Figure 8: The phasor diagram of the single phase induction motor with auxiliary winding and capacitor

The conditions that the rotating field must be circular conduct to following relations:

$$U_A \cong \pi\sqrt{2} f N_A k_{BA} \Phi_h \tag{4}$$

$$U_B \cong \pi\sqrt{2} f N_B k_{BB} \Phi_h \tag{5}$$

where:

N_A, N_B - number of turns;

k_{BA}, k_{AA} - windings coefficients;

Φ_h - rotating flux.

In this rotating field the voltage ratio is:

$$\frac{U_B}{U_A} = \frac{N_B k_{BB}}{N_A k_{BA}} = \frac{1}{k_E} \tag{6}$$

or in complex:

$$\underline{U}_B = j\frac{1}{k_E}\underline{U}_A \tag{7}$$

From the condition for circular field:

$$\underline{\theta}_B = j\underline{\theta}_A \tag{8}$$

consequently:

$$N_B k_{BB} \underline{I}_B = jN_A k_{BA} \underline{I}_A \tag{9}$$

or:

$$\underline{I}_B = jk_E \underline{I}_A \tag{10}$$

From figure 8 results:

$$tg\varphi_B = \frac{U_B}{U_A} = \frac{1}{k_E} = ct. \tag{11}$$

and the relations:

$$\varphi_A = \varphi_B, \tag{12}$$

$$\varphi = \frac{\pi}{2} - 2\varphi_B. \tag{13}$$

It follows:

$$U_C = \frac{U_B}{\sin\varphi_B} \tag{14}$$

and

$$I_B = \frac{U_C}{X_C} = \frac{U_B}{\sin\varphi_B}\omega C = I\cos\varphi_B \tag{15}$$

In this case the capacitor value C is:

$$C = \frac{I_B \sin\varphi_B}{\omega U_B} \tag{16}$$

The active power from the grid is:

$$P_a = U_A I \cos\varphi \tag{17}$$

and from (15) results:

$$C = \frac{I\cos\varphi_B \sin\varphi_B}{\omega U_B} = \frac{P_a \cos\varphi_B \sin\varphi_B}{U_A U_B \cos\varphi} = \frac{\frac{1}{2}P_a \sin 2\varphi_B}{\omega U_A U_B \cos\varphi} \tag{18}$$

add from (6) and (10) results:

$$C = \frac{\frac{1}{2}P_a}{\omega U_A^2}\frac{\cos\varphi_B}{\sin\varphi_B} = \frac{P_a N_A k_{BA}}{2\omega U_A^2 N_B k_{BB}} = \frac{P_{mec} k_E}{2\omega U_A^2 \eta} \tag{19}$$

The capacitor C power is:

$$P_C = U_C I_B = \frac{U_B I_B}{\sin\varphi_B} \tag{20}$$

and the apparent power from the grid:

$$P = U_A I = U_C \cos\varphi_B I = \frac{U_B}{\sin\varphi_B}\frac{\cos\varphi_B I_B}{\cos\varphi_B} = \frac{U_B I_B}{\sin\varphi_B} \tag{21}$$

That means:

$$P_C = P. \tag{22}$$

The active powers for the windings A and B are equal:

$$P_{Aa} = U_A I_A \cos\varphi_A = P_{Ba} = U_B I_B \cos\varphi_B = \frac{1}{2}P_a \tag{23}$$

5. CONCLUSIONS

The capacitor value C is proportional with P_a as one can see from (19) or with I_B (16).

In any moment of time P_a and I_B can be experimentally verified and in this case C is univocal determinated regardless of the motor torque. In these conditions a motor circular rotating field can be permanently assured.

In further work a single phase motor will be connected with the electronically switched capacitor.

References

[1] T.H. Liu: *A Maximum Torque Control with a Controlled Capacitor for a Single-Phase Induction Motor*; IEEE Transactions on Industrial Electronics, Vol. 42, No. 1, February 1995, pp. 17-24;

[2] E. Muljadi, Y. Zhao, T.H. Liu, T.A. Lipo: *Adjustable ac Capacitor for a Single-Phase Induction Motor*; IEEE Transactions on Industry applications, Vol. 29, No. 3, May/June, 1993, pp.479-484;

[3] T.A. Lettenmaier, D.W. Novotny, T.A. Lipo: *Single-Phase Induction Motor with an Electronically Controlled Capacitor*; IEEE Transactions on Industry Applications, Vol. 27, No. 1, January/February 1991, pp. 38-43;

[4] A. Câmpeanu: *Introduction in ac electrical machines dynamics (in Romanian)*, Bucuresti, Editura Academiei Romane, 1998;

[5] C. Suciu, I. Dafinca, R. Campeanu, I. Margineanu: *Expert Phase Angle Control in a Variable RL Load Circuit;* Proceedings of PCIM 2001, June, Nurnberg.