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NON CONVENTIONAL METHOD FOR SOFT STARTING OF THREE PHASE INDUCTION MOTORS

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Abstract - This paper presents a nonconventional method for soft starting of three-phase induction motors, which achieved by flux weakening technique. Flux weakening is not done by reducing the applied voltage as in the conventional methods. Flux weakening is achieved by increasing the supply frequency over the rated value while the voltage amplitude is kept constant. This method has advantage of reducing the stress on the electrical and mechanical systems. The feasibility of this basic idea has been confirmed through investigating the starting transient corresponding to this mode of operation. For this purpose, a rigorous state space mathematical model has been developed and simulated. The validity of the proposed method through the results from the mathematical model have been confirmed experimentally.

Keywords: Induction motors, transient analysis, flux weakening, and pulsating torque.

LIST OF SYMBOLS

v, i : p.u. instantaneous value of the voltage and current respectively
r,X : p.u. resistance, and reactance respectively.
F : supply frequency in Hz
D_m,H_m : p.u. damping coefficient and interia constant of the motor respectively.
T_e,T_L : p.u. motor and load torque respectively
θ_m : Rotor position in space in rad.
S : p.u slip
ω_m : The motor speed in rad/sec.
t, P : Time in sec.and *(d/dt)*,respectively.
ω_0 : Base speed in rad/sec.

SUBSCRIPTS

d-q d-q axis of synchronously rotating frame respectively.
r, s Rotor and stator, respectively.

1. INTRODUCTION

The starting of the three-phase induction motor by direct switching results in huge starting current of 5-7 times the full load current) for normal design induction motor [1]- 7]. This large current results in:

- Flicker in power system voltage that affects the operation of power system components.
- Large drop in the power system voltage, which leads to numerous disturbances such as:-

Motors loss synchronism, unsuccessful starting of the induction motor and large dip in the lighting loads. The drop in the system voltage may cause a complete black out [6]. Also the direct starting of the induction motors has harm impact on the mechanical system of the motor shaft and the connected load. It produces large pulsation torque superimposed on the average electromagnetic starting torque. These pulsation torques cause sever problems for the motor shaft. In the direct starting, the starting torque is about 1.5 to 2.5 of the full load torque. This large starting torque is not suitable for some applications such as:

- Conveyer belts used in lines of gathering and transpiration.
- Cranks and elevator, the need for low starting torque is necessary to insure smooth motion during lifting and landing of the products.
- Pumps and compressor where the low torque eliminate the instantaneously changes in the pressure of the liquids and gases inside the pipes, preventing the hammering inside the pipes.

This paper presents a new method for soft starting of three-phase induction motors by using the flux weakling technique. The air gap flux is related to the voltage and frequency by the following well known relation

$$\Phi = K\frac{V}{F} \tag{1}$$

As shown from Eq. (1), the flux is linear proportion with voltage magnitude and inversely with the frequency. Flux weakling in the proposed method is not achieved as conventional methods by increasing the voltage from very small value till it reaches the rated value. Flux weakling is achieved by applying high frequency at starting then at predetermine instant it will be switched to the rated frequency. The choice of the high frequency depends on the load requirements, motor design and power system. The advantages that can be gained of this method are:

- Reducing the starting current although the motor started with full voltage.
- Low starting torque by soft starting which is necessary for loads such as conveyer belts, cranks and hoists.
- Reducing the pulsations in the electromagnetic torque.

2. DESCRIBTION OF THE EXPERIMENTAL SYSTEM

The experimental system shown in Fig.1 consist of three-phase diode bridge rectifier, followed by large smoothing capacitor 620 μF, six pulse inverter and a control circuit , includes a speed sensor to detect the motor speed, and to compare the motor speed with a reference speed to decide the instant of frequency change. The data of experimental system is given in the Appendix.

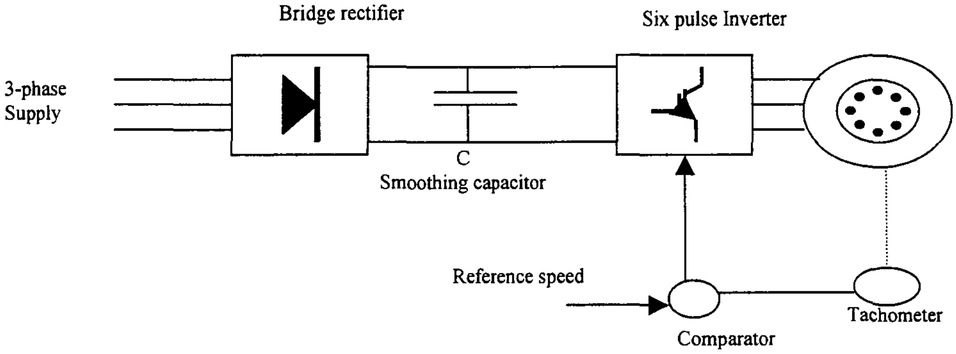


Fig. 1. Schematic diagram of the experimental circuit.

3. TRANSIENT ANLYSIS

The computer simulation of the starting process demands the solution of the electrical equations for the induction motor and the mechanical equations of the motor and the connected load simultaneously.

3.1 Electrical and Mechanical Equations

The voltages and currents equations can be represented in the d-q synchronously rotating frame [3] as shown in Eqn. (2). This equation has time variant coefficient due to variation in the motor speed "ω_m" and the slip "s" these variations are not so fast due to the presence of the large inertia constant of the motor, thus, they assumed to be constant during the small interval of integration. The values of the motor speed and slip are updated at each interval according to the values obtained by solving the mechanical equations of the motor. The electromagnetic torque equation in d-q synchronous rotating frame is

$$T_e = X_m(i_{qs}i_{dr} - i_{ds}i_{qr}) \tag{3}$$

T_e is the p.u. electromagnetic torque. X_m is the mutual inductance between the stator and the rotor i_{qs} , i_{ds} the stator currents in the synchronous rotating frame and rotor i_{qr} , i_{dr} are the rotor currents in the synchronous rotating frame

$$\begin{bmatrix} \frac{X_{xx}}{\omega_0} & 0 & \frac{X_m}{\omega_0} & 0 \\ 0 & \frac{X_{xx}}{\omega_0} & 0 & \frac{X_m}{\omega_0} \\ \frac{X_m}{\omega_0} & 0 & \frac{X_{rr}}{\omega_0} & 0 \\ 0 & \frac{X_m}{\omega_0} & 0 & \frac{X_{rr}}{\omega_0} \end{bmatrix} \begin{bmatrix} \dot{i}_{qs} \\ \dot{i}_{ds} \\ \dot{i}_{qr} \\ \dot{i}_{dr} \end{bmatrix} = \begin{bmatrix} -r_s & -\frac{\omega_e}{\omega_0}X_{ss} & 0 & -\frac{\omega_e}{\omega_0}X_m \\ \frac{\omega_e}{\omega_0}X_{ss} & -r_s & \frac{\omega_e}{\omega_0}X_m & 0 \\ 0 & -s\frac{\omega_e}{\omega_0}X_m & -r_r & -s\frac{\omega_e}{\omega_0}X_{rr} \\ s\frac{\omega_e}{\omega_0}X_m & 0 & s\frac{\omega_e}{\omega_0}X_{rr} & -r_r \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} v_{qs} \\ v_{ds} \end{bmatrix} \tag{2}$$

The mechanical equations of the motor and connected load can be represented by:

$$T_e = 2Hp\frac{\omega_m}{\omega_0} + T_L$$
$$\omega_m = \frac{d\theta_m}{dt} \tag{4}$$

Equations 2-4 are solved together simultaneous using Rung-Kutta forth order method to obtain the motor performance during the starting and steady-state periods

4. RESULTS AND DISCUSSION

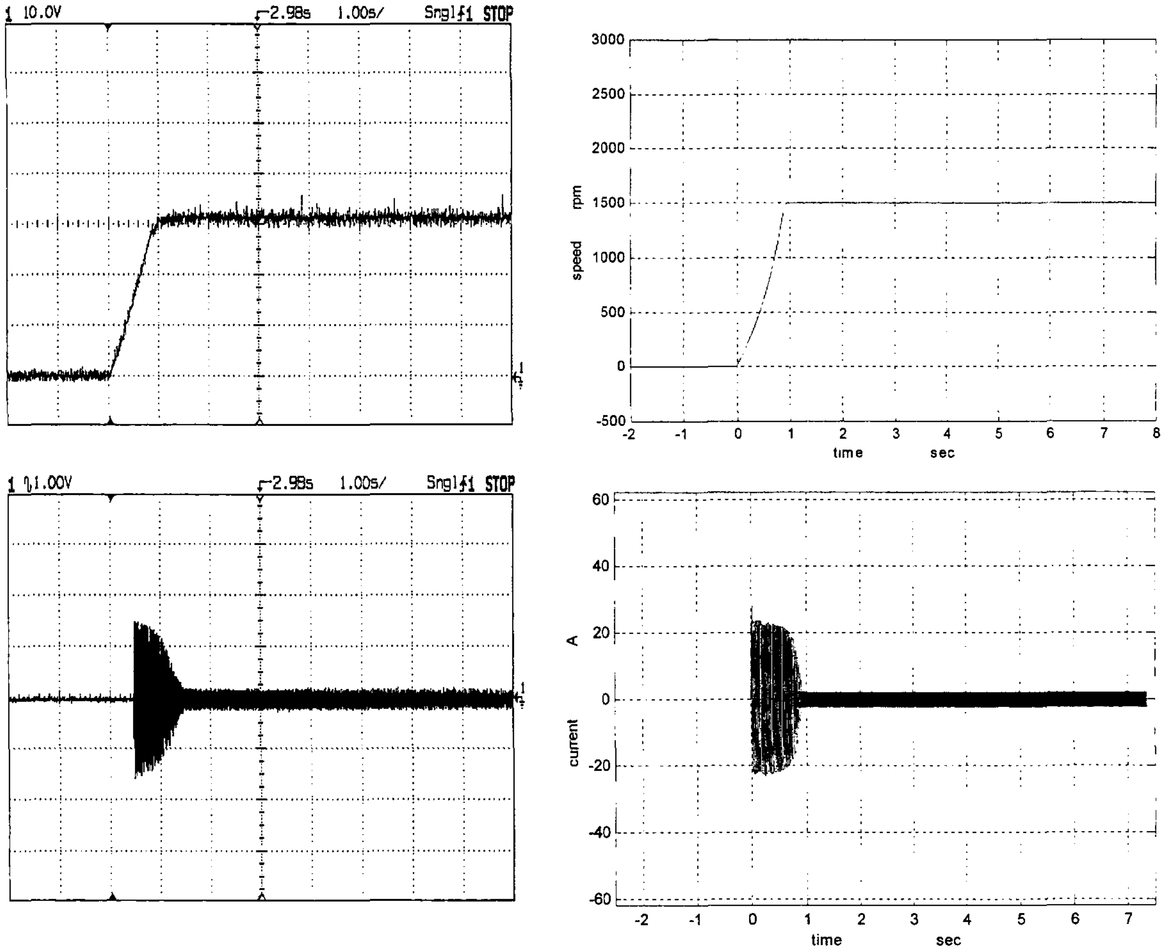
The obtained simulated and experimental results are discussed in the following figures.

The agreement between the experimental and the analytical results is evident. Fig. 2 shows the transient performance of the motor when started by applying rated frequency.

Starting of the induction motor by the proposed flux weakening is usually done by applying a reduced voltage and gradually increases it (by controlling the firing angle of tirac or the anti-parallel thyristor) until reaching the rated voltage while keeping the supply frequency constant. The flux is proportional to the voltage and inversely with the frequency and the torque is proportional to flux square as expressed in Eq. (5).

$$T_e = K\Phi_s\Phi_r \tag{5}$$

Therefore, the torque is reducing in square manner and the machine accelerates softly.



(A) Experimental (B) Simulation

Fig. 2. Motor speed and phase current for direct starting.

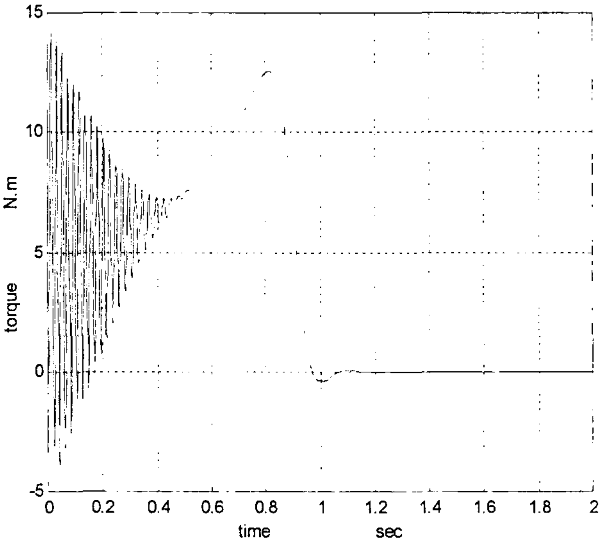


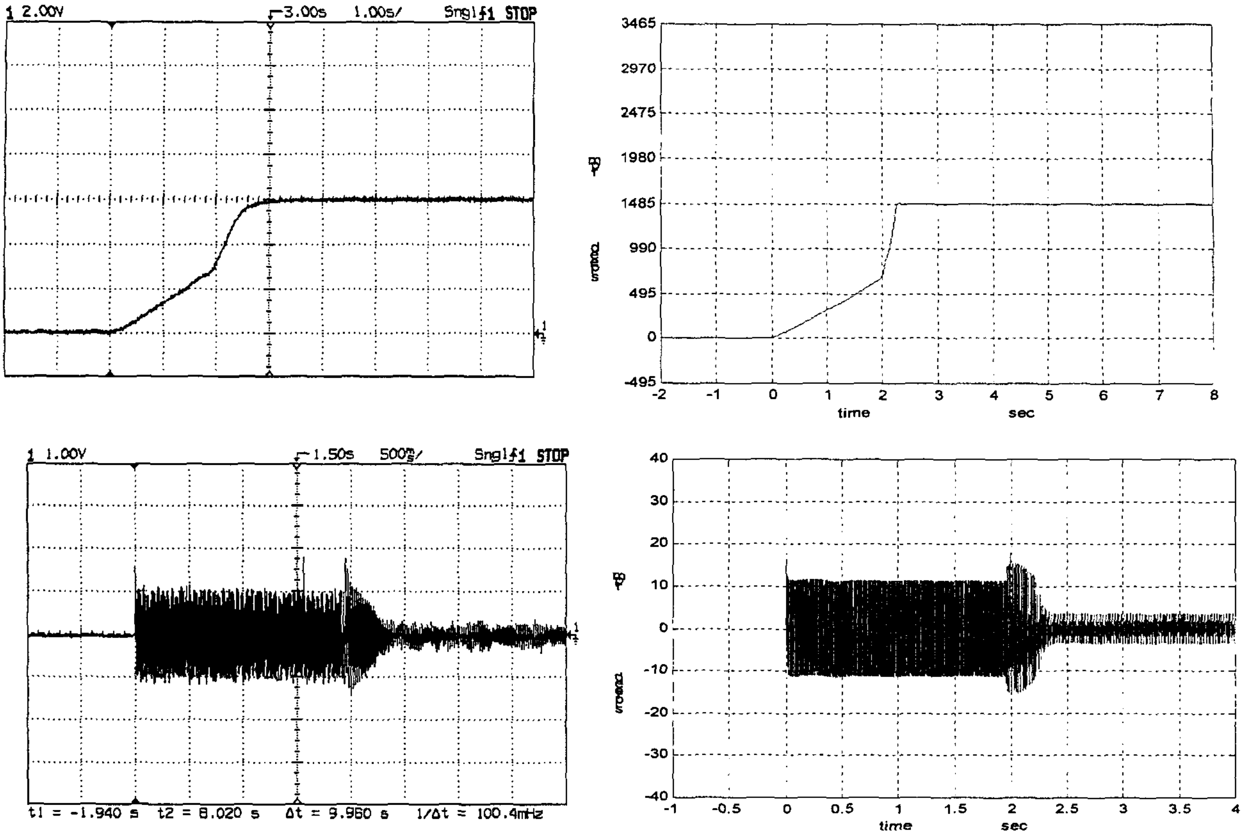
Fig. 3. Simulated electromagnetic torque for direct starting.

As shown in Eq. 1 the flux is inversely proportional to the frequency. Therefore in the proposed method, flux weakening is done by keeping the voltage constant at its rated value while applying high frequency at starting, then at predetermined instant switching back to rated frequency of motor is done. The selection e of the starting frequency depends on the following:

1-The load torque, as frequency increases above the rated value the flux decreases and the electromagnetic torque of the induction motor is decreased, that allows for soft starting which is essential for various types of loads mentioned before. Also the reduction in the electromagnetic torque reduces the burden on the mechanical elements of the motor and the connected load especially when the motor drives a high inertia loads.

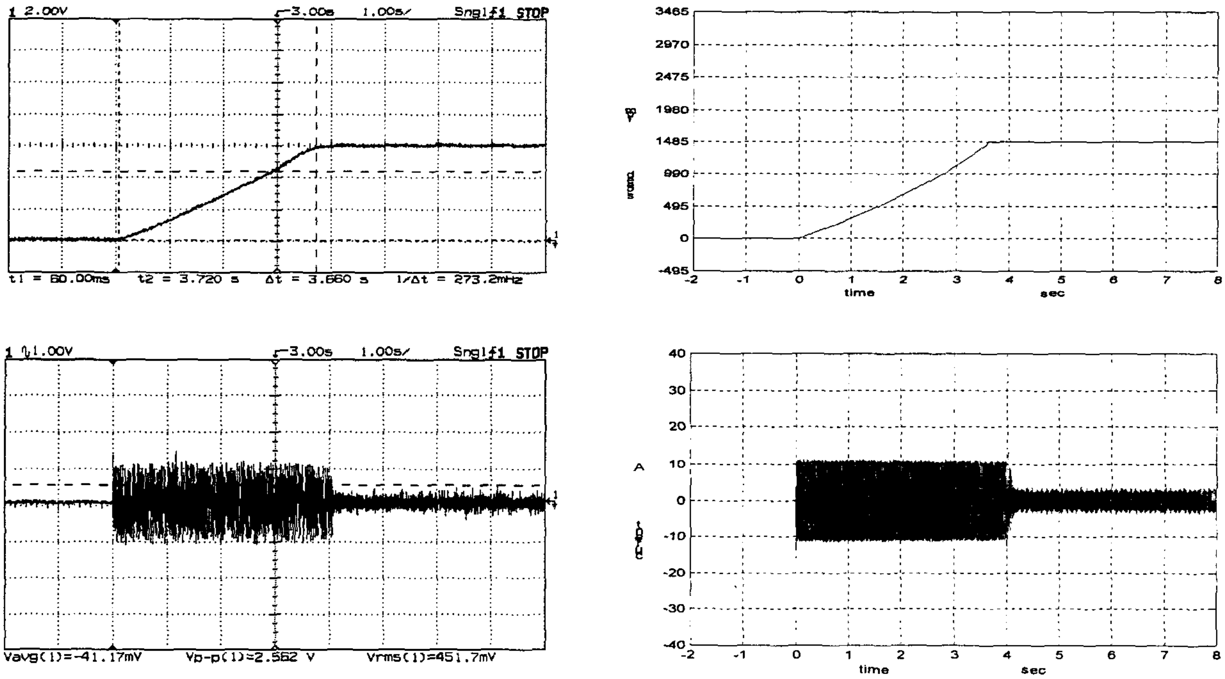
2- The starting current. The starting current decreases; as the starting frequency increase while keeping the supply voltage constant; as it can be explained by the following simple Eq.

$$i_{st} = \frac{v}{z} = \frac{k}{F} \tag{6}$$



(A) Experimental (B) Simulation

Fig.4. Speed and phase current for starting at a high frequency of 75 Hz and switching to the rated frequency 50 Hz at speed 71 rad/sec.



(A) Experimental (B) Simulation

Fig. 5 Motor speed and phase current for starting with high frequency 75 Hz then switching to the rated frequency 50 Hz at speed 141 rad/sec.

Figs. 4 and 5 show the response of the motor when switching from high frequency of 75 Hz to the rated frequency of 50 Hz is done before the rated speed (157 rad/sec-1500 rpm) at speeds of 71.7 and 141 rad/sec respectively. From the results it can be concluded that, when frequency is increased to 1.5 times the rated frequency the current at starting reduces approximately to 50% of its value at starting by direct switching. Also, the torque pulsation reduces to 25 % of its value at starting by the rated frequency. Also, when the instant of transfer from starting frequency to normal frequency is done early before the rated speed, the curve of the speed will not be smooth and there are positive pulses in the torque correspond to the instant of transfer as shown in Fig. 6.

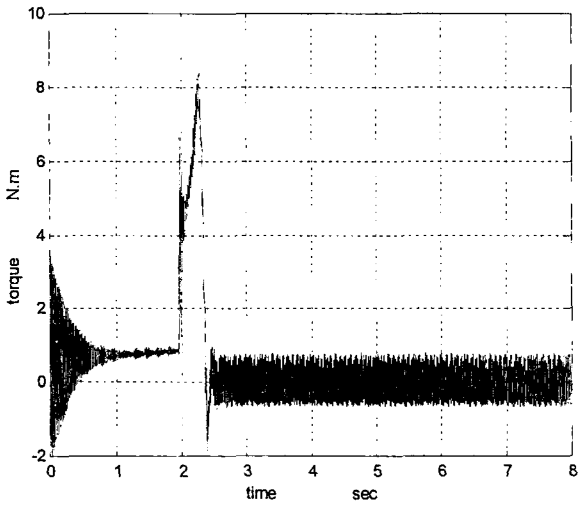


Fig. 6. Electromagnetic torque for the same case of Fig. 4.

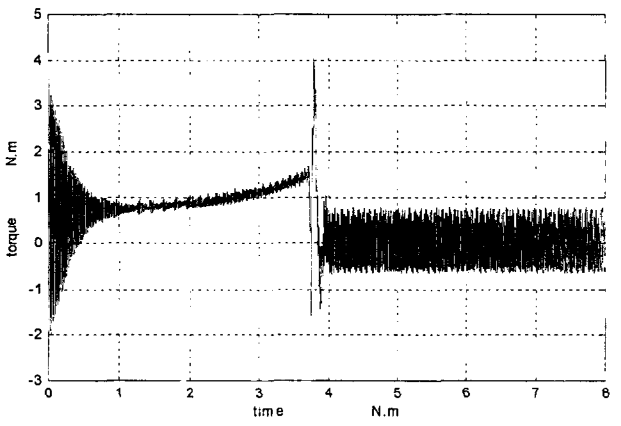


Fig. 7. Electromagnetic torque for the same case of Fig. 5.

If the transfer from the starting frequency to the rated frequency is done at speed very close to the rated speed of the motor as shown in Figs. 5 and 7, the speed curve will be linear which is most suitable to soft starting loaads. Also it is clear that the value of the current is reduced at the starting period. It can be noticed that the torque contains positive and negative pulsation at the instant of switching and this may due to low damping since the inertia constant of this machine is 0.0118sec.

5. CONCULSION

In this paper a new method for soft starting of the three-phase induction motors by flux weakling. Flux weakling is achieved by controlling the supply frequency. This is done by applying high frequency at starting then the motor switched back to the rated frequency at specific speed depends on the system requirements. The proposed method has the advantages:

- Reducing the pulsation in the electromagnetic torque and hence reducing the stress on the mechanical elements.
- Reducing the starting current which reduces the drop in the system voltage and increases the stability of the system.
- The motor starts more softly, which is very important for loads such as conveyer belts used for gathering and transporting the product.

ACKNOWLEDGMENT

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Appendix

System Parameters

X_m=2.068 .p.u. , w_0=314.0 rad/sec
H_m=0.0118 sec , T_l =0.0
D_m=0.0
r_s=0.27096 p.u , r_r=0.1597816p.u.
r_s=0.27096 p.u , r_r=0.1597816p.u.
Xss=2.27 p.u. , Xrr=2.27 p.u.