FAST BUS TRANSFER OF INDUCTION MOTOR LOAD

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Abstract—This paper investigates electromechanical transients as a result of bus-transfer of an induction motor load from a main (preferred) supply to an auxiliary (alternate) supply. The bus-transfer is carried out by two sets of three-phase thyristor switches and is referred to as fast bus-transfer when compared with transfer process by means of mechanical switches. The Electromagnetic Transients Program for DC Systems (EMTDC) is used for investigation of transients associated with fast bus transfer. The studies conclude that fast bus-transfer by means of semiconductor switches can be properly adopted to limit transients and consequently prevent load interruption and possible damage to induction motor shaft system.

Keywords: Bus-Transfer, Transient Torques, Thyristor-Switch Simulation, Induction Motor.

1. INTRODUCTION

A sensitive electrical load which is expected to be continuously operational is provided access to two feeder lines. The feeder which supplies power to the sensitive load under normal conditions is known as preferred source. When the preferred source experiences disturbances, e.g. due to voltage sag, voltage swell and faults, the sensitive load is disconnected from the preferred source and connected to the auxiliary feeder which is known as alternate source. The assumption is that alternate source is available and can supply the required load. After the disturbance is over and the preferred source is under normal conditions, the sensitive load is disconnected from the alternate source and reconnected to the preferred source. Disconnection of the load from one source and connection to the other source is called bus-transfer.

Conventionally bus-transfer has been carried out by two sets of mechanical switches. Due to inherent slow response of mechanical switches, this type of transfer will take several cycles [1], i.e. more than 10 cycles. Bus-transfer of motor loads by means of mechanical switches have been extensively discussed in the literature and the difficulties associated with this type of bus transfer are well understood and documented [1-8].

Availability of semiconductor (static) switches for high power applications permits utilization of static switches instead of mechanical switches for bus transfer. As compared with mechanical transfer switch, static transfer switch (STS) can (1) significantly increase the transfer speed, and (2) provide higher level of controllability on the transfer process. Furthermore STS permits application of fast bus transfer concept for those sensitive loads for which transfer process has to be completed within 2 cycles [9]. This type of bus transfer is not possible by means of mechanical transfer switches. Application of STS for passive loads have been reported in the technical literature [9]. The objective of this paper is to demonstrate technical feasibility and salient features of STS for induction motor loads.

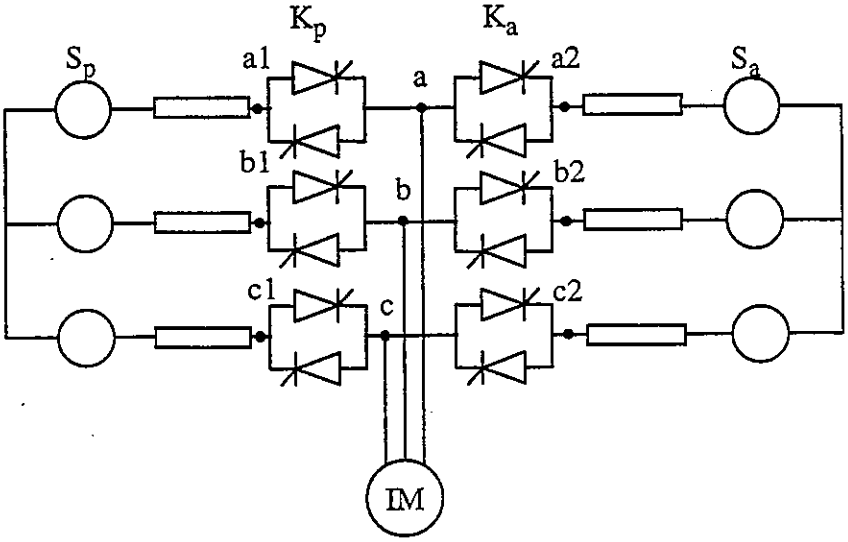

Fig. 1: Schematic diagram of study system.

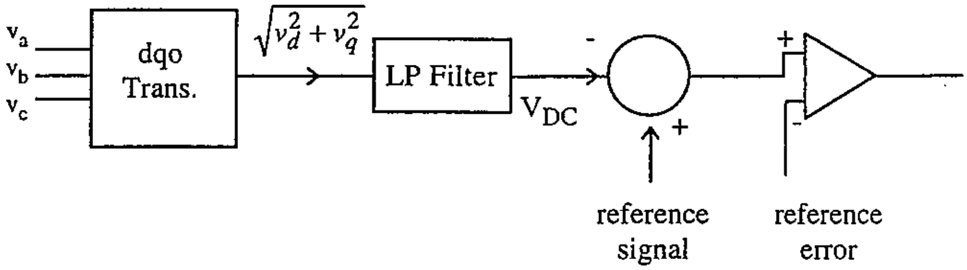

Fig. 2: Basic functions of disturbance detection system.

2. STUDY SYSTEM

Figure 1 shows schematic diagram of the study system. The system is composed of two independent feeders S_p and S_a. S_p represents the preferred source which is expected to supply the motor load under normal conditions. S_a represents the alternate source which is to supply the load when the preferred source is disturbed. Transfer from the preferred source to the alternate source is by means of an STS which is composed of switches K_p and K_a. K_p and K_a are closed and open respectively during normal conditions. When preferred supply is subjected to a disturbance, K_p disconnects the load, and K_a connects the load to the alternate supply. When the disturbance is over, the load will be transferred to the preferred source. The assumption is that when one of the supply systems is subjected to a disturbance, the other one is available to supply the load.

The transfer process requires (1) continuous monitoring of the two supply systems and detection of disturbances, (2) decision making process to identify if the detected disturbance falls in the category that requires transfer and (3) generation of gating signals for the semiconductor valves of the STS system to carry out the transfer process.

2.1 *System Model*

The Electromagnetic Transients Program for DC Systems (EMTDC) is used for time-domain simulation of the test system. The component models used for the simulation studies are as follows. Each of the preferred and alternate feeders is represented by a three-phase voltage source behind a balanced three-phase series R-L components. Each three-phase static switch is represented by three anti-parallel thyristor switches. Turn-on and turn-off characteristics of each thyristor are assumed to be ideal. Parallel Snubber circuit of each thyristor switch is represented by a series R-C branch. System data is given in Appendix A.

2.2 *Induction Machine Model*

Electrical system of the induction motor is represented in a two-axis (dq) frame. The motor is a squirrel cage induction motor. Magnetic saturation characteristic of the machine is included in the model. Mechanical system of the motor and its mechanical load are represented by two rigid rotating masses which are connected through spring constant and damping constant of the shaft segment. Viscous damping of the rotating masses are also included in the model. Electromechanical data of the induction machine is also given in Appendix A.

2.3 *Disturbance Detection & Thyristor Firing*

Figure 2 shows basic functions of disturbance detection system. Instantaneous system voltages are measured and transformed in a dqo reference frame. Output signal from the first block (Fig. 2) is passed through a low-pass filter which can be approximated by transfer function 1/(1+TS). The measured dc signal is compared with the desired reference value. The error is then compared with a reference value to determine whether transfer process has to be started or not.

Industrial loads, e.g. induction motor loads, are often inductive and consequently current lags voltage depending on the power factor. One scheme for firing a thyristor valve of STS is to provide the gating signal based on current zero-crossing detection. Another approach is to provide the gating signal based on voltage zero-crossing detection. The former is referred to as "current firing method" and the latter as "voltage firing method". Under steady-state conditions, both methods are identical with respect to the operation of thyristor values. However, for an active load during transient conditions, the current firing method can result in significant overcurrent in the load and voltage firing method can result in complete interruption of the load current. The decision regarding which method is to be used depends on the load characteristics and requirements. This paper compares the two firing approaches in Section 3.

3. STUDY RESULTS

3.1 *Load Transfer Due to Voltage Sag*

Initially the system of Fig. 1 is under steady-state condition and the induction motor provides the rate torque at 0.90 lagging power factor. the preferred source is subjected to a three-phase voltage sage with the magnitudes of 23%. Figure 3 shows transients due to transfer process when voltage firing method is used. Figure 3 shows that the load current is completely interrupted due to the transfer process.

When voltage sag occurs, the motor internal voltage does not change instantaneously. Consequently, currents rapidly decrease (Fig. 3) and K_p interrupts the current flow at zero crossings. The motor currents remain zero until transfer occurs. During current interruption, electrical

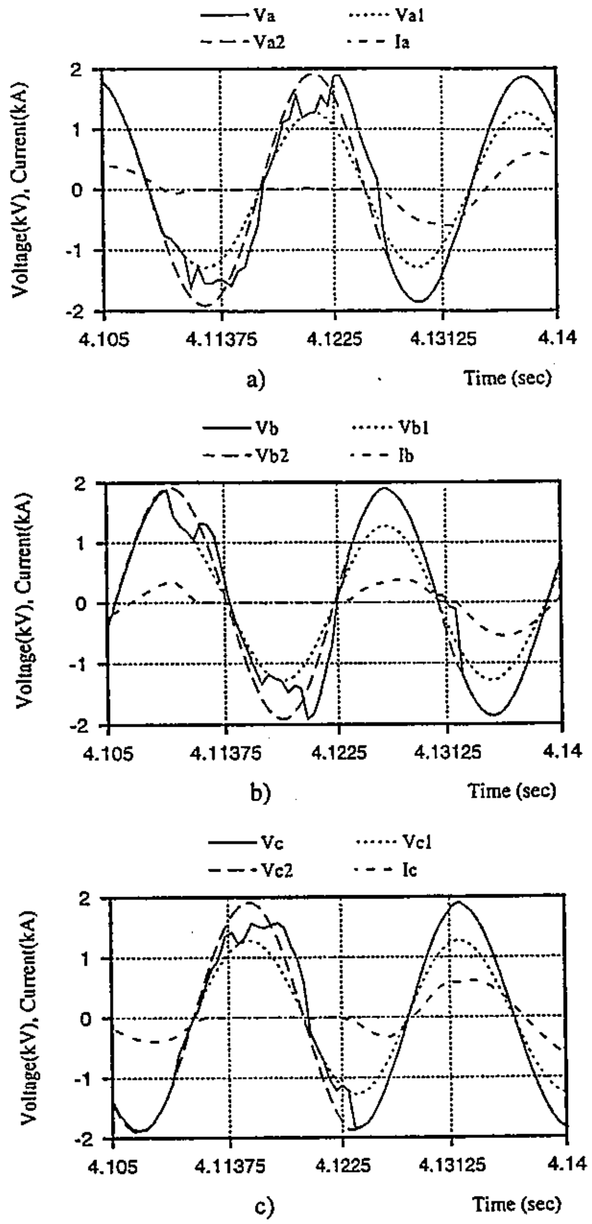

Fig. 3 Current and voltage waveforms due to static transfer process (voltage firing method). Nodes a, b, and c are identified in Fig. 1.

torque is zero and motor decelerates. Transfer to the alternate source is conceptually identical to motor re-energization. Since interruption period associated with a static transfer is short, the re-energization transients are relatively small and practically should not be of major significance. Figure 4 shows transients in speed, shaft torque and electrical torque due to the transfer process.

Figure 5 shows transients of the motor load variables as a result of the above voltage sag and its subsequent transfer process when current firing method is adopted. Comparison of Fig. 5(b) and Fig. 3 shows that current firing method does not result in current interruption. However, higher transient currents are experienced.

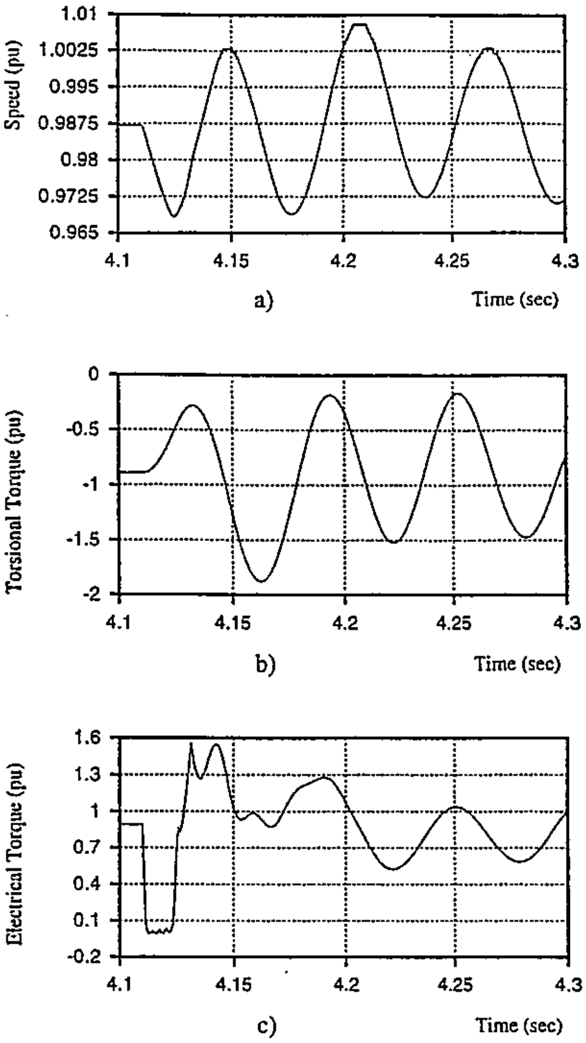

Fig. 4 Transients in velocity, shaft torque and electrical torque due to static transfer process (voltage firing method).

Higher magnitudes of current transients will translate in higher electrical torque, and consequently shaft stresses can be more severe.

3.2 Effect of Voltage Sag Magnitude

Figure 6 shows impact of voltage sag magnitude on the shaft torsional torque, electrical torque, mechanical speed and maximum phase current when voltage firing method is used for the STS. Figure 6 indicates that peak magnitudes of variables are not very sensitive to the magnitude of voltage sag. To the contrary, magnitude of voltage sag will have a significant impact on peak values of load variable if "current firing method" is used. Figure 6 clearly shows that phase-angle difference between the preferred and alternate supplies will have a significant impact on the transients due to transfer process. Phase-angle difference is particularly important with respect to the shaft stress of the induction motor load.

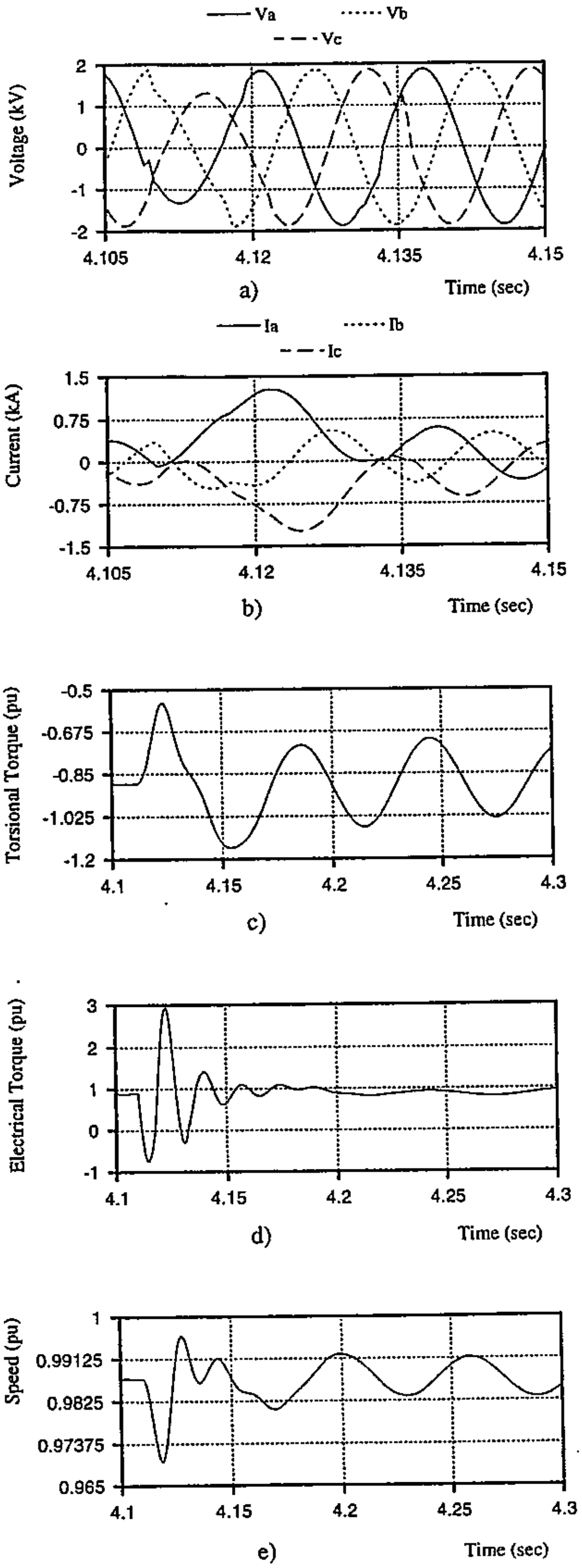

Fig. 5 Transients in voltage, current, shaft torsional torque, electrical torque and rotor speed due to static transfer process (current firing method).

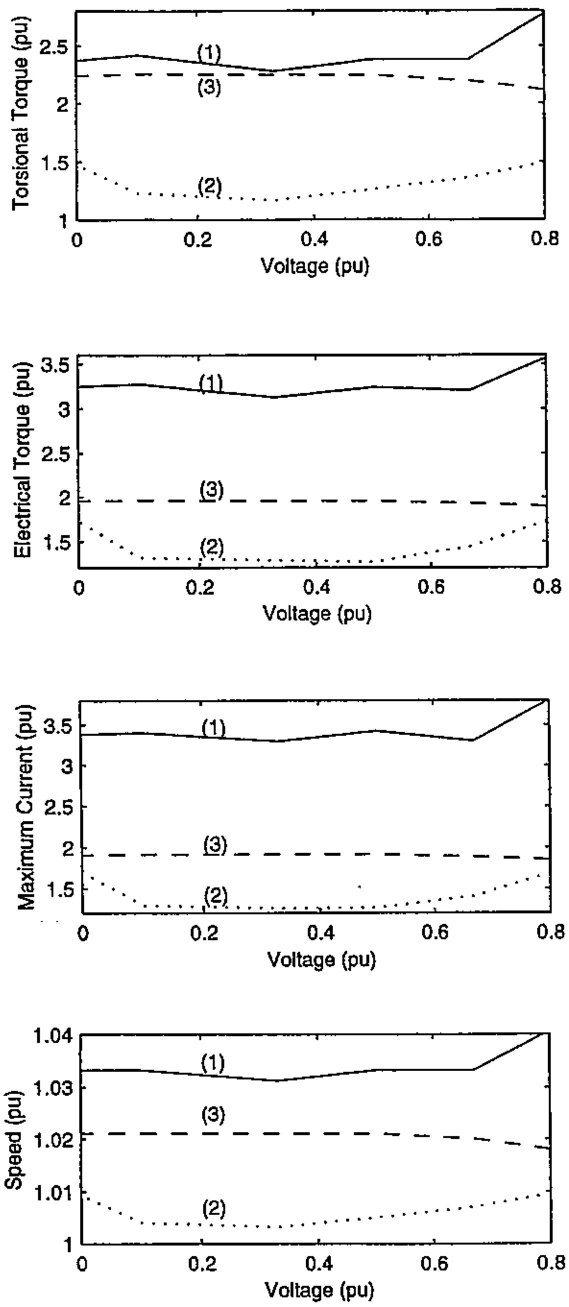

Fig. 6 Impact of voltage sag magnitude on torsional torque, electrical torque, speed and maximum current of the induction motor load.

(1): S_a leads S_p by 20 degrees

(2): S_a and S_p are in-phase

(3): S_a lags S_p by 20 degrees

3.3 *Impact of Filter Cut-Off Frequency*

Cut-off frequency of the low-pass filter (Fig. 2) has a significant impact on the maximum values of electrical torque, torsional torque and phase current subsequent to static transfer process. Figure 7 shows that low cut-off frequency results in higher values of current and consequently higher electrical torque values. Higher electrical torques usually result in higher shaft torsional stresses.

4. CONCLUSIONS

This paper examines technical feasibility of induction motor bus transfer by means of thyristor-controlled static transfer switch (STS). The studies are carried out in time-domain using the Electro-Magnetic Transients Program for DC Systems (EMTDC). The studies conclude that:

- Fast bus transfer by means of static switches can minimize transient shaft torque and inrush current imposed on an induction motor load.
- Disturbance detection approach and gating strategy of thyristor valves have deterministic impact on transfer speed and peak transitory magnitudes of induction machine variables due to transfer process.
- Phase angle difference between the corresponding voltages of preferred and alternate sources results in high torsional stress of shaft segment of the induction motor load.
- Depending upon the induction motor load characteristics and the transfer requirements, a STS can be designed to transfer the induction motor load within the required time frame.

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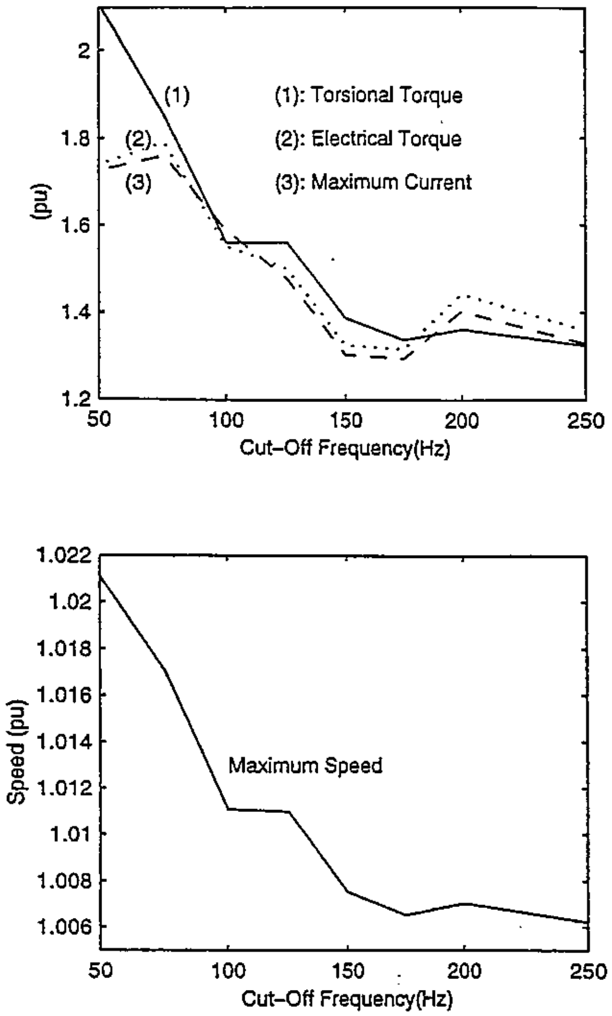

Fig. 7 Impact of filter (Fig. 2) cut-off frequency on magnitudes of load variables subsequent to static bus transfer.

Appendix A

System Voltage = 2.3-kV
R_p=R_a=0.0151-Ω
L_p=L_a=0.3522-mH

Induction Motor Electrical Parameters:
1339-hp, 2300-V, 1773-rpm
rs=0.0184 pu, xls=0.0850 pu
rr=0.0131 pu, xls=0.0850 pu
xm=3.8089 pu

Induction Motor Mechanical Parameters:
Hm=0.520 s, DmL=0.002 pu/(rad/s)
HL=0.750 s, Dm=0.001 pu(rad/s)
Ks=15.00 pu/rad, DL=0.001 pu(rad/s)