The circuit of open phase fault has just a little differences with Fig. 1. The element which is used to break the phase is called Sbreak.

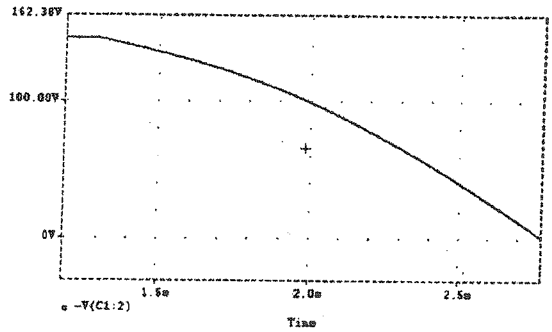

Fig (11): O. Ph - Rotor speed

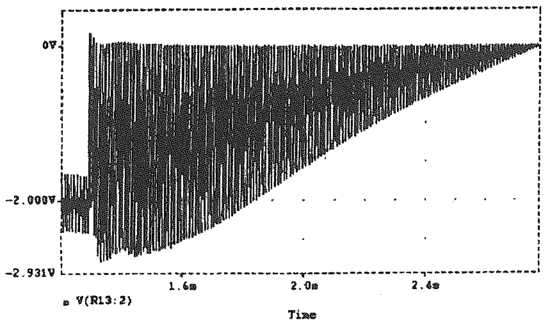

Fig (12): O. Ph - Elect. torque

In this case, the Sbreak is placed between phase A of inverter & motor & will be opened by a pulse source at the failure time.

Both of the circuits for shorting the gate of M3 & opening the gate of M4 in Fig. 1 will be removed.

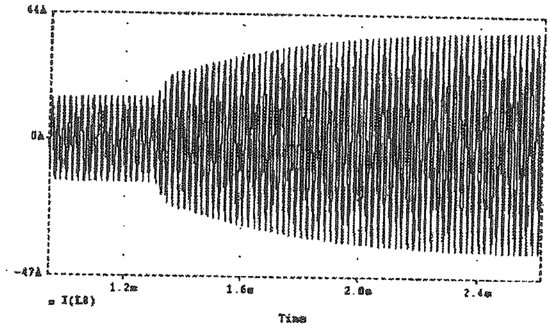

Fig . (13) O. Ph - phase B current

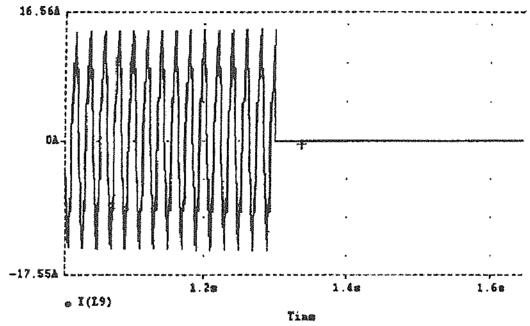

Fig. (14) O. Ph - phase A current

Conclusion

A complete motor - inverter model in PSPICE is presented. Some possible faults were analysed & discussed . It's also notable that other faults can be applied to this system. Also effect of parameter variations can be considered by use of the presented scheme. PWM supply can be also applied to the motor but the time of calculations will be increased considerably due to the several switchings of PWM system, compared to the six step inverter.

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Fig. 7 shows the motor speed before & after the fault

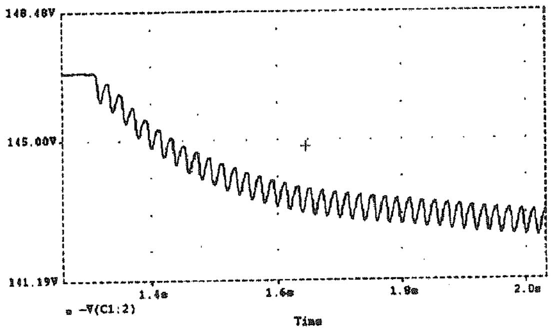

Figure (7) O.G. motor speed

Motor speed will be stable (with small vibrations) after a few seconds. This condition can be continued for several minutes & protecting devices can announce the gate failure to be fixed immediately if there is just some loose connections. This is a good advantage of this condition for critical loads.

But same failure can be produced by gate drive circuit & in this case motor should be shut downed.

Fig. 8, shows motor torque curve.

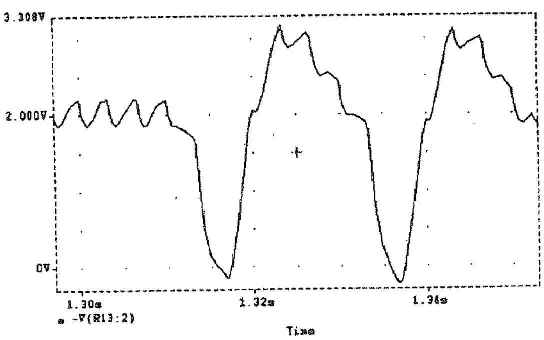

Figure (8) O.G. torque curve

The mean value of torque is positive & equal to the load torque but the magnitude of the oscillations is too high.

Figures 9 and 10 show phase B current & failed device current respectively.

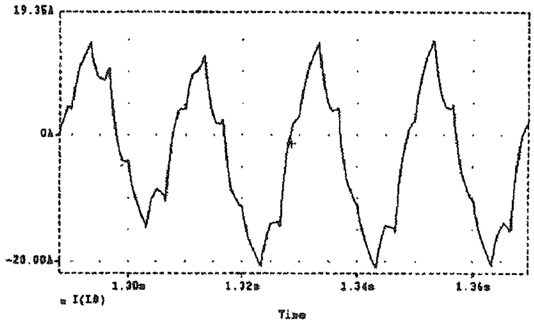

Fig. (9) O. G. Phase B current

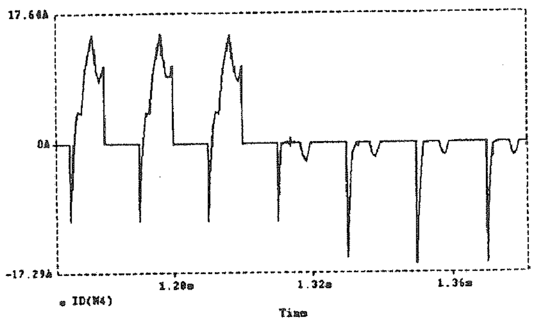

Fig (10) O.G. M4 current

The negative conductions is carried by anti parallel diode which is mostly equipped inside of the device package.

Open phase fault

In this case, motor will completely loose one phase and is drived just by two phases.

Figures 11, 12, 13 & 14 show the rotor speed, motor torque (electrical), phase B current & faulty phase (phase A) current respectively.

Device fault situations

A - Mosfet short circuit fault:

Referring again to Figure 1, V10 turns on M3, continuously after 1.3 seconds.

V8, simultaneously, turns off M4 to prevent short circuit of DC line (V7).

Diode D1, prevents loading effect of V10 on V1 during the normal start of motor.

Fig.3, the speed curve, shows that motor will stop, after short circuit fault & then oscillates around the zero speed.

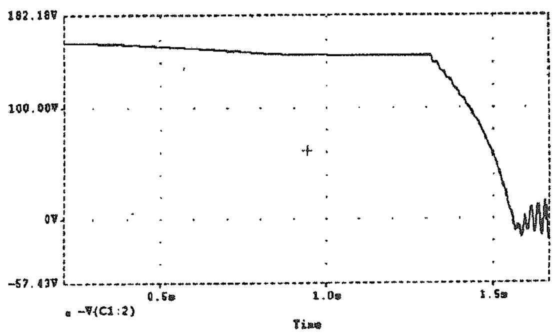

Figure (3) SC fault - Rotor speed

Phase B current (Fig. 4), is also showing the SC. fault condition

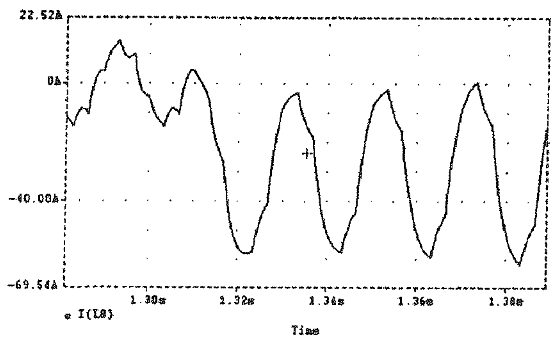

Figure (4) SC-phase B current

The figure also shows the DC offset which flows through phase B.

The torque waveform before & after SC fault is shown in Fig. 5. The curve clearly shows that the mean value of torque can not satisfy the load torque.

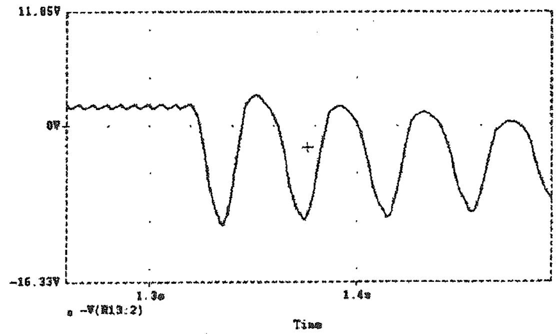

Figure (5) SC - electrical torque

Mosfet M3 current is shown in Fig. 6.

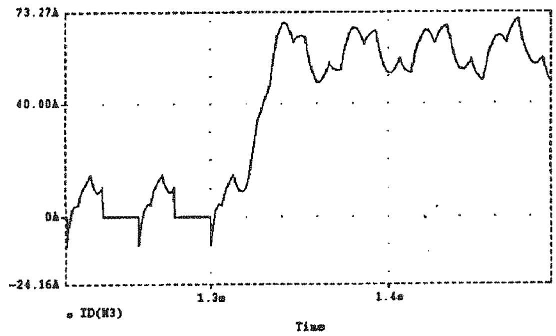

Figure (6) M3 Mosfet current

The high current may be fatal but can be detected & prevented by protecting devices.

B-Open gate fault

By omitting V10, R30 & D1, in Fig. 1 , an open gate fault can be simulated.

This fault is applied to the circuit & results shows that motor can handle the load but in lower speeds.

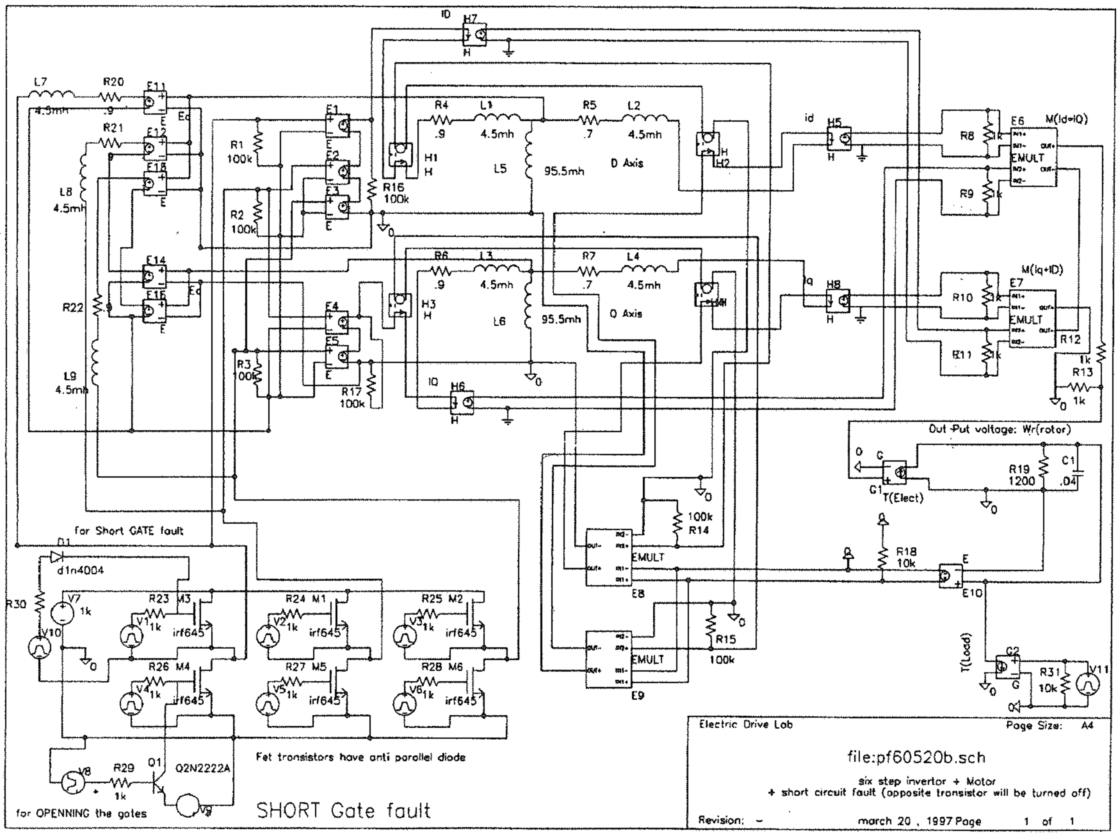

Fig (1)

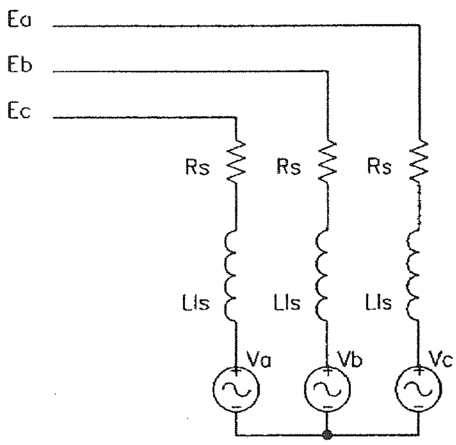

Fig (2): Applying airgap voltages to the three phase supply

Ea, Eb & Ec are calculated by using equations 6, 7, 8:

$$Ea = Ed \quad (6)$$

$$Eb = - (1/2)\, Ed - (\sqrt{3}/2)\, Eq \quad (7)$$

$$Ec = - (1/2)\, Ed - (\sqrt{3}/2)\, Eq \quad (8)$$

where, Ed & Eq are voltages across inductors L5 & L6 in Fig. 1.

Referring to Fig. 1 , these voltages are made by dependent voltages sources: E11, E12, E13 & E14, E15 with appropriate gains. (see Eq.s : 6, 7, 8).

Through this model, current will automatically injected to the voltage source & also there is no loss of generality under different fault conditions & different voltage sources. Phase A Current, according to Fig. 2 can be obtained by:

$$Va = (Ra + Lls\ S)\ Ia + Ea \quad (9)$$

As shown in Fig. 1, Va, Vb, Vc, (three phase voltages) are applied to E1, E2, E3 (dependent voltage sources) with proper gains to satisfy equations (1) and then connected in series to build VD, which will fed D axis.

The same things is done for Q axis by using E4 & E5 . (see equation 2)

Rotor dependent voltage source in D axis, V1:

V1 is defined by Equation 3:

$$V1 = \omega r \, (M^* IQ + L_{1r} * Iq) \tag{3}$$

Which , ωr is rotor speed in rad/s, M is mutual inductance, IQ is the Q axis stator current, L_{lr} is leakage inductance of rotor & Iq is the Q axis rotor current.

For building Vl, a multiplier element should be used which is presented in Fig. 1 as E9, which multiplies speed signal by second terms in brackets in Eq. (3). Later terms are made by connecting H3 & H4 in series with appropriate gains.

V2 is obtained in a similar way with elements: H1 & H2 & a multiplier E8.

ωr, rotor speed signal

According to Equation 4, we have:

$$Te = (2/3) \, P \, . \, M \, (Id * IQ - Iq * ID) \tag{4}$$

which, Te is an electrical torque & P is the number of poles in motor. Also we have:

$$J\dot{\omega} + B\omega = Te - Tl \tag{5}$$

where J is rotor inertia, B is damping factor & T1 is load torque.

Equation (5) can be modeled by elements G1 (as an electrical torque), G2 (as a load torque), R19 (as a damping factor) & C1 (as an inertia constant of rotor, Referring to Fig. 1.

For constant load torque, G2 can be replaced by a constant current source, but special cares are needed specially at the starting period. G2 produces a constant ramp current, which reaches to a fixed value after a certain time (i.e. after complete starting of motor).

The output voltage of C1 is speed signal and can be applied for building V1 & V2.

Te is modeled by using Eq. (4) and current to voltage converter sources H5, H6, H7, H8 and two multipliers, E6 & E7 . The voltage across R13 will be Te, an electrical torque.

Thevenin model of an induction motor

For injecting the real currents in 3 phase voltage source, reverse transformation of D-Q axis currents ones can be used, to ABC but in some special cases (i.e. during the phase disconnection) the generality of this method will be lost & results may be incorrect In this case, even anti parallel diodes of MOSFETs have no use. So, the **Thevenin model of an induction motor** is presented, which in a few words, is a transformed air gap voltage of a motor , connected by Rs (stator res.) & L_{ls} (stator inductance) to the three phase voltage sources. (Fig. 2)

These voltages are named Ea, Eb & Ec.

Modeling of Voltage Fed - Induction Motor Drive with PSPICE for Device Fault Analysis

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Abstract

In this paper, the PSPICE model of a three phase induction motor (with transformation elements for DQ to 3 phases and also current feedback from DQ system to 3 phase), plus six step power MOSFET inverter model will be presented and complete scheme will be analysed, during most probable faults for these systems like: Device Short Circuit fault, Device Open Gate fault & Open Phase faults. Also other features of this system will be discussed.

Introduction

Induction motors are widely used in industries nowadays. With power electronic drives, it is a good choice to use variable speed AC drive instead of DC motor. But drivers of these motors are more complicated than DC drives & the risk of faults for these drivers may be more than DC ones. Analysis of motor performances during these faults are very important specially when they are running critical loads. This paper presents a general model of such a system which can analyse complete motor - drive system during any load conditions or device faults.

Modeling of an Induction Motor in Pspice

For modeling of an induction motor in Pspice, two circuits for D & Q axis of an induction motor is presented which is shown as a part of a circuit of Fig.1.

This circuit is complete scheme of both motor model & inverter model, jointed together to run under the fault conditions.

Each part will be discussed elaborately & there will be a possibility to change any parameter for different tests.

D & Q axis models

Referring to Figure 1, D axis is based upon R4 (stator res.), L1 (stator inductance), R5 (rotor res.), L2 (rotor inductance) & a dependent voltage source of rotor which is function of speed & currents called V1.

The Q axis is just like D axis with R6, L3, R7, L4, L6 & V2 respectively.

Both D & Q axis voltages can be built by these equations (Eq. 1 & 2):

$$VD = 2/3\ (Va - 1/2Vb - 1/2\ Vc) \qquad (1)$$

$$VQ = 2/3\ (-\sqrt{3}/2Vb + \sqrt{3}/2\ Vc) \qquad (2)$$