Vectorized Control of a Three Phase Induction Motor Drive Subjected to Three Phase Inverter Faults

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Abstract: **This paper focuses on development of a vectorized model of multi inverter-motor combinations as used in locomotive. The main aim of this paper is to reduce the overall simulation time which is very large when six inverter-motor combinations are run serially. Method of vectorization is introduced to reduce the time taken during simulation of six inverter-motor sets.**

I. Introduction

Induction motor has been established as the workhorse of industry ever since 20th century. In the last few decades the induction motor has evolved from being a constant speed motor to a variable speed variable torque machine. Variable frequency voltage source inverters are widely used to control the speed of three phase squirrel cage induction motors over a wide range by varying the stator frequency. Variable speed drives are widely used in all application areas of industry; these include transport system such as ships, railways, elevators,conveyors, material handling plants and utility companies for mechanical equipment e. g. machine tools, fans, pumps and compressors.

Transient performance of electric drive in a high power system is the burning topic as it has a direct impact on mechanical robustness, durability and overall efficiency of the system. In typical high power traction device such as a diesel electric locomotive during the occurrence of inverter faults there can be development of high magnitude transient torque which may cause damage to the components.

Therefore it becomes necessary to study the nature of different transient torques that may be imposed on the mechanical system.

Diesel electric transmission system consists of induction motors, inverter, rectifier and alternator. Our work focuses on the design and performance of the drive system that serves to produce electromagnetic torque required for propulsionsystem. A MATLAB/SIMULINK model has been developed to study a combination of detailed induction model and detailed model of three phase inverter. This simulation model can be considered as a healthy motor drive system. Then different fault conditions are created in the simulation model and the behaviour of induction motor during fault condition is compared to that during healthy condition.

In the case of locomotives driven by three phase induction motor, six induction motors fed by six sets of three phase inverters run their respective gear boxes, which in turn move the axles and finally the wheels. Modelling of such a locomotive will require the simulations of six different inverter motor models running in a serial manner. But the total time taken in the simulation is very high and would hamper the development of an integrated simulation platform encompassing all the parts of a locomotive system that is alternator, rectifier, inverter and motor. Especially the simulation time consumed by the six inverter/motor sets will be a very high percentage of the total simulation time. In order to model six machines and six inverters that form part of an AC locomotive, the induction machine and inverter models are vectorized. The model obtained by this approach runs faster than a model that would use six sets of inverters and motor models.

II. MODELLING THE TRACTION MOTOR DRIVE SYSTEM

The traction motor drive system shown in Fig.1 consists of following:

1. Rectifier unit

The ac drive is supplied by the electrical network via a rectifier. The rectifier unit can be uni-directional or bi-directional.

2. DC circuit

The dc circuit will store the electrical energy from the rectifier for the inverter to use; in most cases the energy is stored in high power capacitors.

3. Inverter unit

The inverter unit takes the electrical energy from the dc circuit and supplies it to the motor. The inverter uses modulation techniques to crate the needed three phase ac voltage output for the motor. The frequency can be adjusted to match the need of the process. The higher the frequency of the output voltage is, the higher the speed of the motor and thus the output of the process.

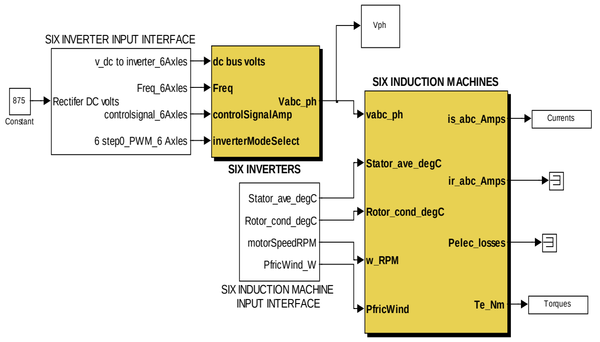

Fig. 1 Traction motor drive system

III. Defining inverter faults

Although induction motor drives are highly reliable,they are susceptible to many types of faults that can become catastrophic and cause machine shut downs, personalinjuries and wastage of other resources. A short circuit can result from a damaged switch which may lead to development of severe transient which may lead to development of high current values. These severe transient conditions may also lead to application of inverter input dc link voltages across the stator windings and since the motor is already carrying a large enough current, the circuit results into a ferocious braking torque to the motor. In order to prevent the complete failure of the system and unexpected production costs, a series of protecting devices are placed to detect the faults. A three phase voltage fed inverter can develop various types of faults as follows

1. Single device fault
2. Two upper device fault
3. One upper and one lower device fault
4. Line to line fault at ac terminals
5. Three phase faults at ac terminals

Through this fault simulation it can be determined that how much damaging the transient conditions of current and torque would be for a certain other inverter driven traction drive.

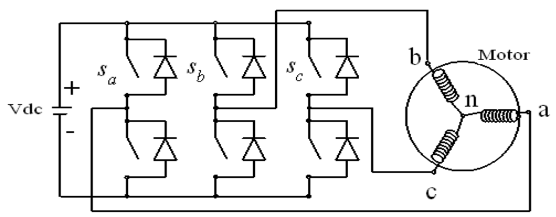

Fig. 2Healthy model

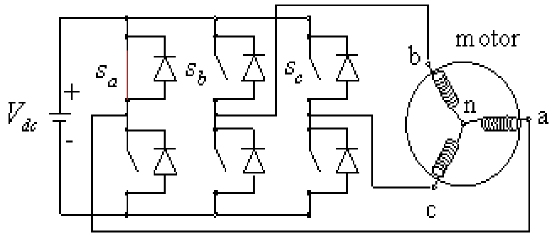

Fig. 3Single device fault

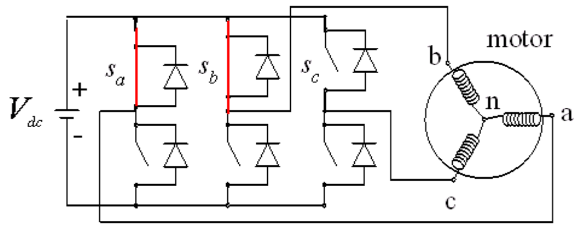

Fig. 4Two upper device fault

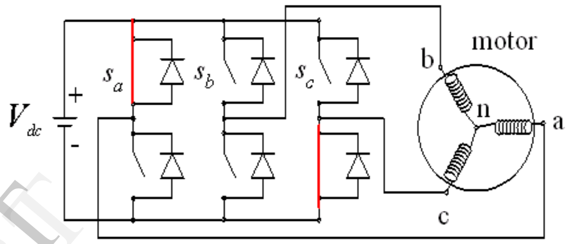

Fig. 5 One upper device and one lower device fault

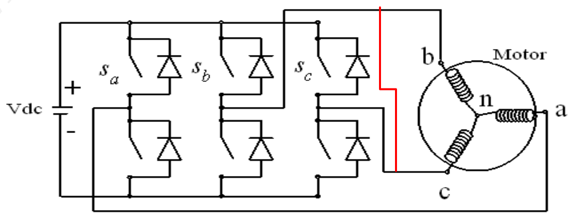

Fig. 6Line to line fault at the ac terminals

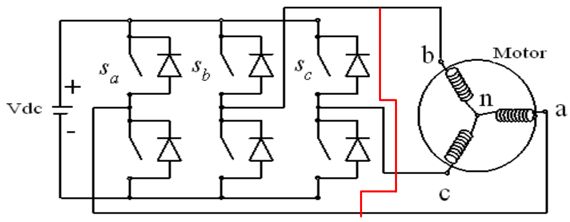

Fig. 7 Three phase fault

IV. INVERTER MODEL DETAILS

The internal details of the block are shown in Fig. 8 and it consists of four sub blocks

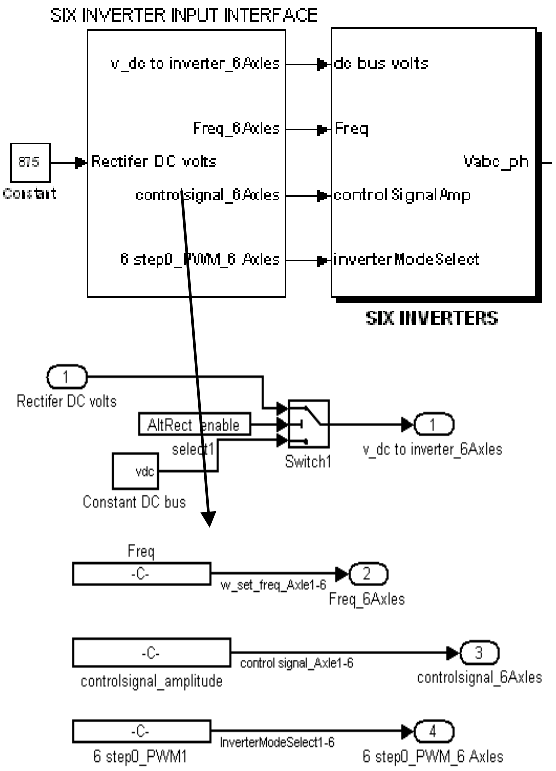

Fig. 8 Six inverter input interface

The first sub block sets the frequencies of six inverters through the constant blocks. Vectored inputs of dimension six are given in it. The second sub block gives the control signal to the inverter through the constant having an array dimension of six. The third sub block is an enable that changes the inverter mode between six step and PWM (Pulse Width Modulation). The fourth block is a switch which when enabled selects between the fixed dc voltage and the rectifier's output voltage to be given as the inverter input.

Six inverters block

The inputs of six inverter block are taken from six inverter input interface block. The internal details of this block are shown in the Fig.9

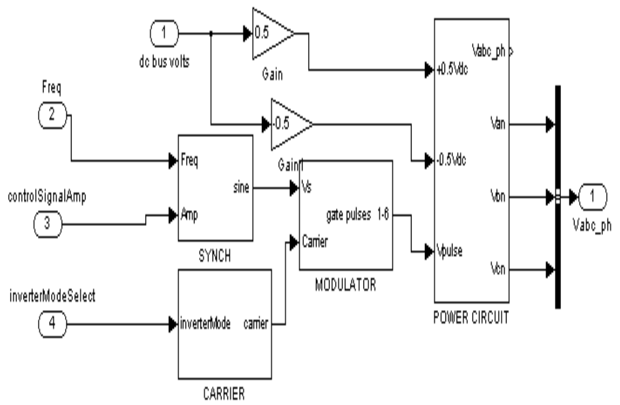

Fig. 9Six Inverter block details

PWM technique is used to generate gate pulses. A three phase sine wave is modulated with a carrier signal of high frequency to generate gate pulses. The outputs from the six inverter input interface block are used to construct the control signal and carrier signal. If the 'inverter mode select' input is high (i.e. 1), the carrier is constructed and vice versa. The 'dc bus volts' input splits the dc signal into two parts i.e. $+0.5V_{dc}$ and $-0.5V_{dc}$. These two are then fed as the upper inputs of the switches whose other inputs are the gate pulses. To generate the modulating signal of desired amplitude and frequency the frequency and control signal inputs are fed to the 'synch' block. Fig. 10 shows the details of the synch block.

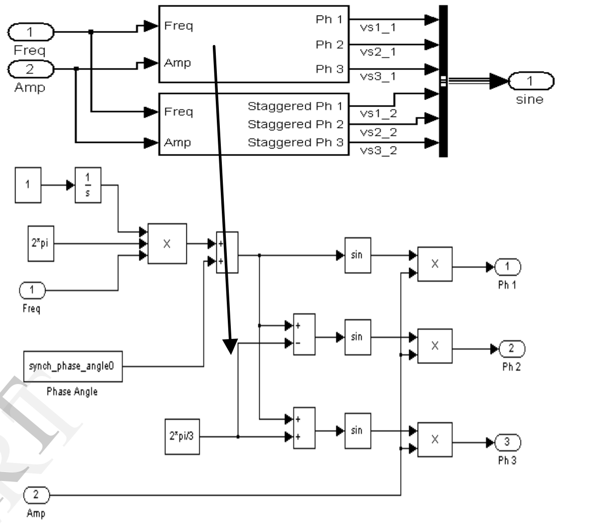

Fig. 10Synch block

The Fig. 11 shows how the carrier waveform is generated which is then made to pass through the switch to identify whether PWM operation is taking place or not.

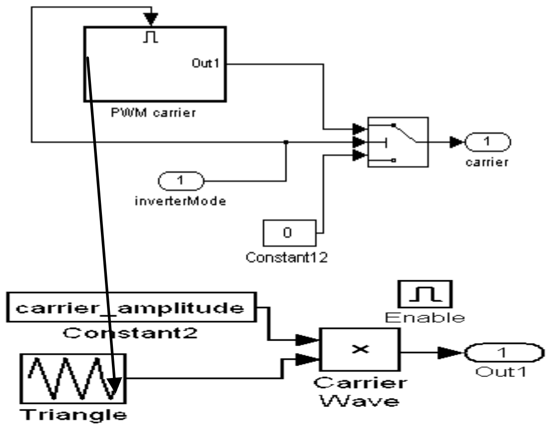

Fig. 11 PWM Carrier details

The modulator block compares the sine wave modulating signal and the carrier waveform to generate 36 gate pulses as shown in Fig. 12 the 36 gate pulses are divided such that 6 are available for each inverter.

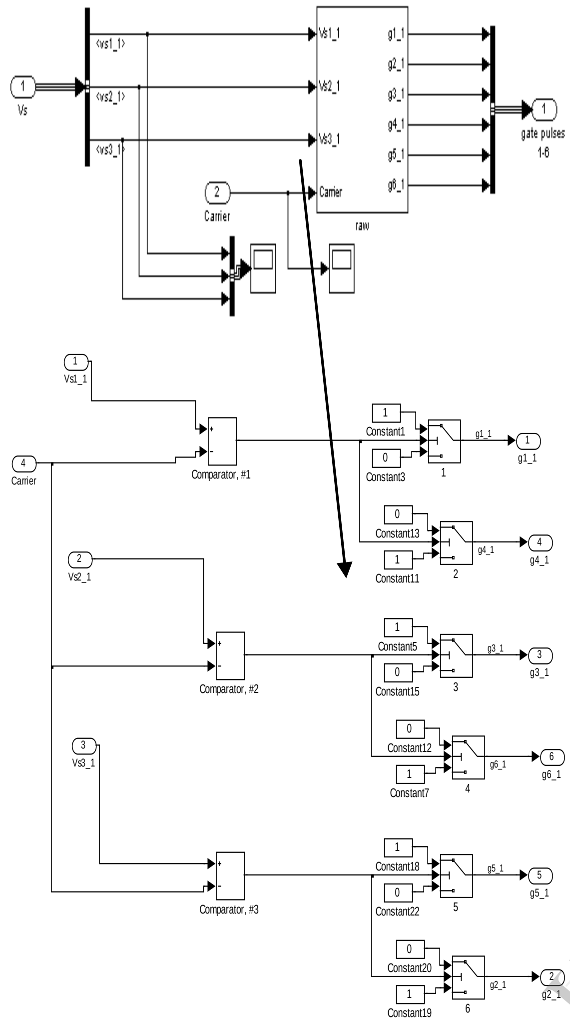

Fig. 12Modulator block details

When gating signal is present dc input voltage is passed on otherwise zero voltage is passed on. The required three phase voltages for all the six motors are obtained from the outputs of power circuit block. Fig. 13 shows the power circuit block in detail where there are six switches whose threshold inputs are previously received gating pulses.

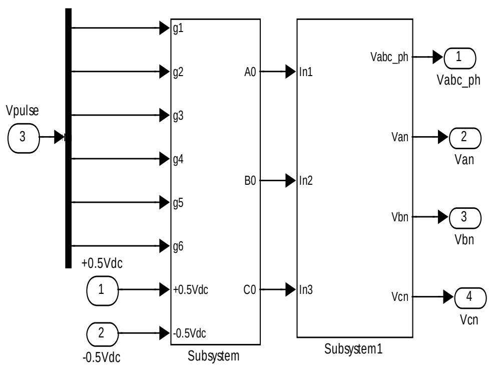

Fig. 13 Power circuit

$+0.5V_{dc}$ and 0 are the upper and lower signal inputs for the three top level switches whereas the other three bottom level switches have $-0.5V_{dc}$ and 0 as the upper and lower signal inputs. Thus according to the gating pulses various switch outputs are obtained. These outputs are then appropriately calculated to generate phase or line voltages. The fig shows the schematic diagram of the inverter model.

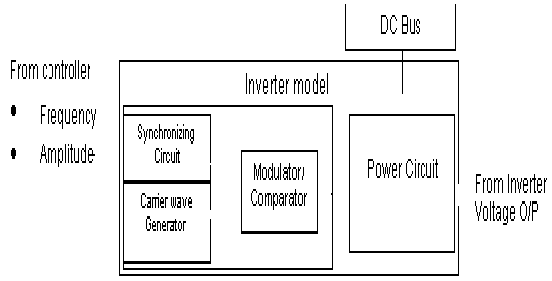

Fig. 14Schematicdiagram of the Inverter model

V. OPERATION OF INVERTER

The three phase inverter is operated in PWM (Pulse Width Modulation) mode. In this technique duty ratio of a pulsating wave form is controlled by another input waveform. The intersection between reference voltage waveform and the carrier waveform give the opening and closing times of switches. Changing the duty ratio of the switches changes the speed of the motor. In our model, triangular voltage waveform is compared with three sinusoidal control voltages which are 120 degree out of phase with each other and the relative levels of waveforms are used to control the switching of the devices in each phase leg of the inverter. The peak of the sine modulating waveform is always less than the peak of the triangular carrier voltage waveform. Thus depending on the switching states either the positive or the negative half dc bus voltage is applied to each phase. Since IGBT switches are characterised by turn off delays, a small delay is usually has to be introduced between firing of the bottom arm switch when turning off the top arm switch and vice versa. This is done to avoid shorting of the dc bus by the overlap of the conduction of the two switches of the same arm. This feature can be included in the model by introducing a phase delay control signal set as shown in the fig.

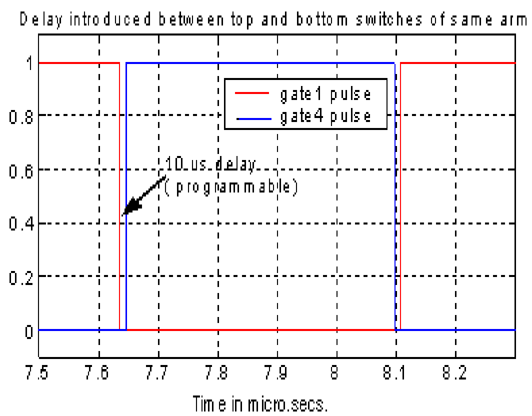

Fig. 15Blanking time between top and bottom switch of an arm

Six induction machines

A detailed three phase induction motor model is developed which incorporates stator and rotor core losses, stator and rotor stray load losses, magnetizing saturation and rotor conductor skin effects. This model is also linked to a thermal model considering the temperature dependent resistive elements.

Simulation of single device fault

When a single device fault is introduced by short circuiting one of the switches of one motor while the other motors remain as it is, the torque characteristic of the model depicts clearly a tremendous braking torque on advent of the fault.

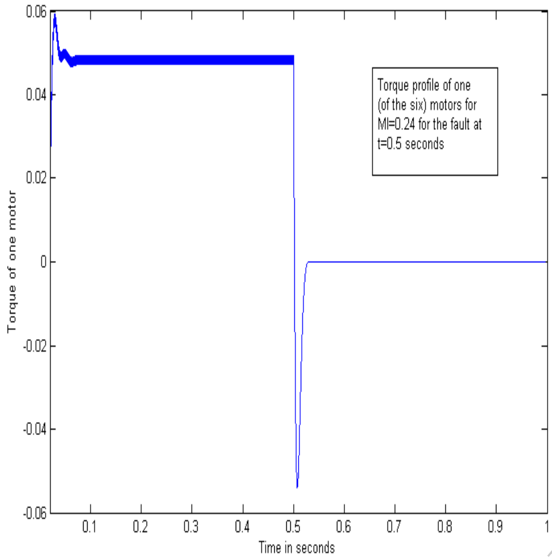

Fig 16. Relation between torque and time for single device fault

Vectorized multi motor model

In the case of three phase induction motor driven locomotives, six induction motors are fed by six sets of three phase inverters which move the wheels through a mechanical arrangement. If such a locomotive has to be modelled then a real simulation picture will require the simulations of six different inverter- motor models running in a serial manner. The simulation time consumed by six inverter/motor sets will be a very high percentage of total simulation time. Also total simulation time taken in this approach will be very high. In order to tackle this situation six machines and six inverter models are vectorized. In this method every constant value is given in a form of array containing six elements corresponding to each motor-inverter set. Thus a sort of parallel simulation is carried out which reduces the overall simulation time to a great extent. Therefore this modelling approach is elegant and around 8 times faster compared to connecting different copies of inverter and machine subsystem model. Real time taken for simulating 0.7seconds:-

1. Single inverter single motor model =14.5seconds

2.Six inverters six motors separate model=407seconds

3.Six inverters six motors vectorized model=52seconds

CONCLUSION

The prime focus of this paper was to draw a comparison between the simulation time needed for six motors and inverters to a vectorized six motor- inverter set. At first a MATLAB model of a healthy induction motor drive is developed. Then all the inputs are given to it in a vectorized way comprising of an array containing six elements. Subsequently faults are introduced in it and results generated depicting a tremendous braking torque at the advent of fault.Then an approximate comparison of real time taken for different simulation models is presented.As inferred from which the time taken for simulation of the vectorized model is much less than the six separate motor model.

REFERENCES:

[1] N. Retiere, D. Roye, P. Mannevy, " Vector based Investigation of Induction Motor Drive under inverter fault operations", IEEE, 1997, pp. 1288-1294.
[2] J. Holtz, W. Lotzkat, and A. M. Khambadkone, ―On continuous control of pwm inverters in overmodulation range including six-step, IEEE Transaction on Power Electronics, vol. 8, pp. 546–553, 1993.
[3] N. Mohan, T. Undeland, and W. Robbins, ―Power electronics converters, applications and design,‖ John Wiley, 1985.