



Asynchronous motor traction drive simulation using Simulink dynamic systems analysis package

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Abstract

This paper describes the modelling of an asynchronous motor traction drive system using the Simulink dynamic systems analysis package. Structured simulation of such a complex system has, in the past, been difficult if not impossible. The system consists of a PWM rectifier which converts the ac overhead supply to a dc bus voltage of 1500 V. This is fed to the variable voltage, variable frequency (VVVF) inverters which supply the traction motors. The PWM rectifier displays unity power factor operation with minimal harmonic distortion of the supply current waveform. The rectifier may operate in a regenerative mode, thus allowing energy savings. The most significant results of the simulation are highlighted and presented.

1. Introduction

The Drives, Power Electronics and Traction Systems Laboratory at the University of Central Queensland is currently conducting a programme of continuing education for Queensland Rail engineering and technical staff, [1]. The work mainly focuses on the area of asynchronous induction motor drives suitable for railway traction service. This technology, which is relatively new in the railway traction area, is fast becoming widespread. Far faster than the transfer of knowledge of this technology. The motivation of this project was therefore to promote technology transfer in this area.

The development of simulation tools is a relevant step in the process of technology transfer. A simulation tool can have many advantages including

- demonstration of hardware operation



- fault finding and fault diagnosis
- fault prediction (preventative maintenance)
- evaluation and demonstration of new technology (topology, control)
- used as a design aid in the emergence of new technology

The traction system, however is a complex mixture of electrical, mechanical and control systems. This mixture is not easily simulated on known commercial software, [2]. Most software dedicated to simulating electrical circuits has limited capability in control and mechanical simulation. The same applies to mechanical system and control system simulation. In addition a circuit simulator often has a high level of accuracy, whilst in a system simulation such as this the accuracy at a device level is not required. The simulation then becomes much lengthier than required.

The best starting point for a simulation tool capable of simulating mixed systems is at the fundamental level. All elements, whether electrical, mechanical or control, can be described by mathematical equations. This is the basis for all simulation tools. The Simulink dynamic systems analysis package was chosen as the fundamental starting point, [3]. This package contains the basic blocks from which a system may be developed (ie: add, subtract, multiply, and other linear and nonlinear blocks). In addition the graphical user interface and hierarchical structure of Simulink make this software easy to use and understand. The background software package, MATLAB, provides the user with powerful postprocessing tools, [4].

2. Simulation Technique

Dynamic systems software has, in the past, been used to model systems in state space forms. This technique, being unstructured does not form a flexible simulation tool, [5]. The modelling process requires that the state model for a system be developed and implemented. This meant that changes to the topology or control required a new set of equations. The mathematical model did not relate to the original circuit, thus making debugging difficult.

The simulation system developed, although initially intended for a specific task, is flexible enough to enable system changes and extensions. The electrical circuit elements are modelled in a consistent fashion with voltages as inputs and currents as outputs. The join between two circuit elements is the node as shown in figure 1.

The node in this technique is modelled as a parasitic capacitance which accumulates the stored charge produced by the injection or removal of current. Because the node is a dynamic element this technique is known as the Dynamic Node Technique (DNT), and the resulting library of electrical elements is the Power Electronics Laboratory (PEL), [6-8]. New models may

be developed for use with the DNT by conforming to the standard of differential voltage input and current output. Further discussion on the structure will follow in the traction drive simulation.

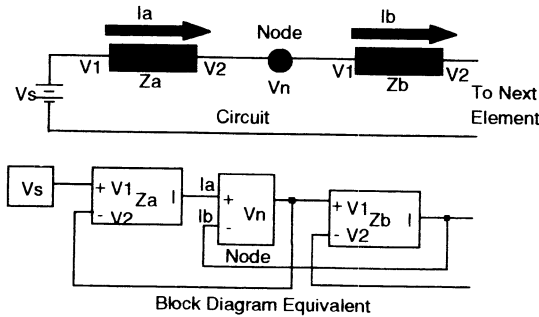


Figure 1. A typical circuit is connected by nodes

3. Traction System Configuration

The traction system to be simulated consists of a source, a PWM rectifier, a dc link, a VVVF inverter and an induction motor as shown in figure 2.

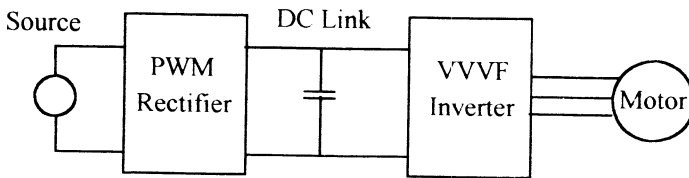


Figure 2. Traction system

The source is a 600 V ac single phase supply. Normally a transformer would be used to transform the ac overhead down to 600 V, however the addition of a ideal transformer adds no benefit in the simulation and has been excluded.

From the source the ac power is converted to dc by the PWM boost derived rectifier, [9]. The dc voltage is higher than the ac peak by a factor of about two. The rectifier is controlled to maintain unity power factor and regulate the dc bus voltage with minimal harmonic distortion of the supply. The dc is then converted to three phase variable voltage variable frequency ac to control the traction motor. The operation of each converter will be described separately with figures as the complete system model would be illegible even at full page size.

4. PWM boost rectifier

The Simulink model of the PWM boost rectifier is shown in figure 3. The "Control" and "Load" blocks are deliberately left blank to show that any form of control or load may be represented. The source consists of a sinusoidal input voltage. The input filter is an inductor, which is typical of a boost derived converter, and the output filter is a capacitor. The circuit connection by the use of nodes is clearly seen within the circuit of figure 3.

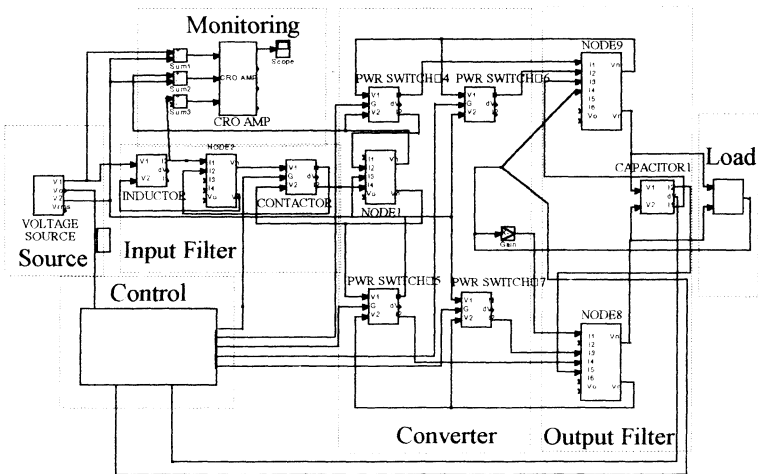


Figure 3. Simulink representation of boost rectifier

The main power circuit consists of four power switches (typically a GTO thyristor) connected in a full bridge configuration. The use of a capacitor as a dc filter allows the assumption that the dc voltage is stiff. The switching of the four power switches is then controlled to synthesise an ac waveform at the input to the converter. The relationship of the magnitude and phase of this synthesised voltage to the magnitude and phase of the source voltage determines the magnitude and phase of the source current. Thus by adjusting the magnitude and phase of the synthesised voltage the power factor and power flow can be adjusted.

There are several techniques available for determining the reference value for this synthesised voltage however the technique which has been found most applicable to the current research work is that of predictive current control, [10]. The predictive current control aims to determine (or predict) the duty cycle required to force the actual source current to equal some reference in one switch cycle. The reference current is a sinusoidal current in phase with

the line voltage so as to force unity power factor. The predictive current control is then very mathematical in nature and whilst the implementation would prove difficult in some (if not all) circuit simulators the implementation is simple in Simulink. The software provides the user with function blocks to solve any desired equation.

The determination of the reference current is an important element of the control system. The current reference is determined by a feedforward signal from the load combined with a PI regulator on the bus voltage, [11]. This technique has proved to have a good response both in the simulation and in practical converter studies.

The system load is the three phase VVVF inverter which will now be discussed.

5. VVVF inverter motor drive

The operation of a VVVF inverter as a standard induction motor controller is not a new technique and detail on this control will not be discussed. Readers unfamiliar with induction motors are referred to alternate reading, [12]. The Simulink representation of the induction motor drive is shown in figure 4.

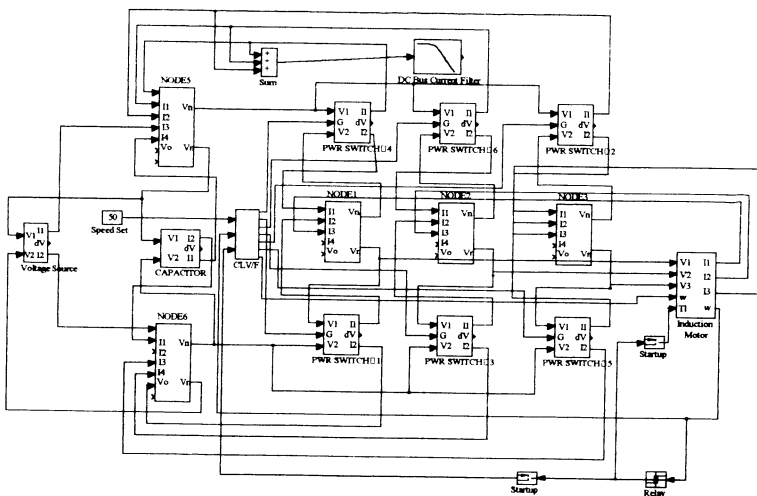


Figure 4. Simulink representation of VVVF drive

In this figure the voltage source is in fact the PWM rectifier discussed previously. The inverter is a standard six switch inverter controlled using a



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sine-triangle comparison PWM scheme. The motor control is achieved with a closed loop constant volts/Hertz scheme. This technique is not typical of a traction controller, however because of its simplicity it has been used to serve as a demonstration. Again interested readers are referred to [12].

The induction motor itself is modelled using the two axis representation which results in a simplified model of the induction motor. This simplification gives no loss of accuracy for the simulations presented and the two axis representation is a widely accepted model of the induction motor, [13-14].

6. Simulation Results

The simulation model presented may be used to simulate several different conditions of operation (motor acceleration, deceleration, load change, fault condition, etc) however due to space limitations, only selected results are presented here. Figures 5 through 12 show the following traces respectively

Figure 5. Graph of line current vs. time

This trace shows the line current drawn from the source. Initially the current is low (no load) and just sufficient to overcome the losses in the system. Upon application of a load the current increases until the average input power matches the load power drawn. The current returns to the no load condition when the load is removed.

Figure 6. Expanded view of line current under load

This trace show 2.5 cycles of the line current and supply voltage under a loaded condition. Near unity power factor is obvious from the phase relationship of voltage and current. Harmonic distortion can also be seen to be low.

Figure 7. Expanded view of line current under Regeneration

This trace shows 2.5 cycles of the line current in a regenerative state. Regeneration is indicated by the 180° phase shift between voltage and current.

Figure 8. DC bus voltage vs. time

This trace shows the dc bus voltage under application and removal of a load. Initially the system is in a no load state. The application of the load increases the power supplied by the rectifier. Since this power varies at a rate of 100 Hz, the 100 Hz ripple can be seen in the dc voltage. The dynamic response can be seen to be very good as the voltage deviates only slightly from the setpoint.

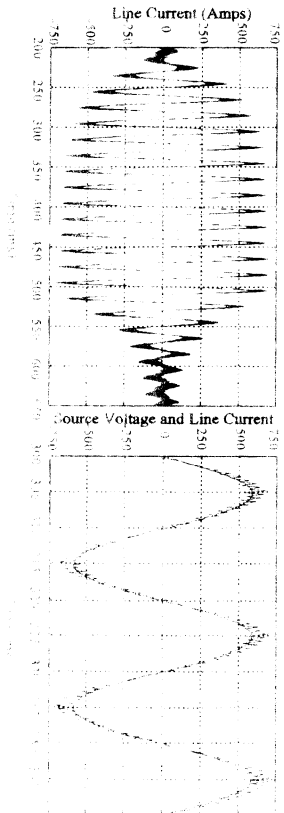


Figure 5. Graph of line current vs time

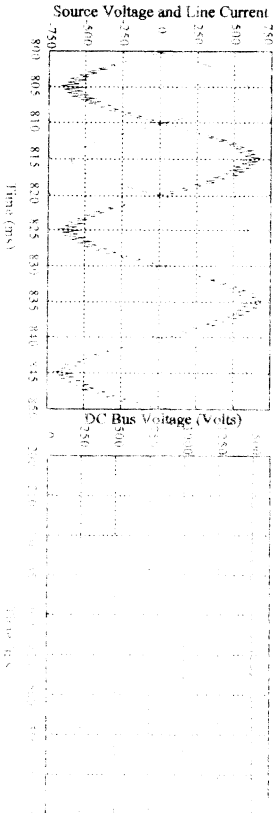


Figure 7. Graph of line current and source voltage vs time

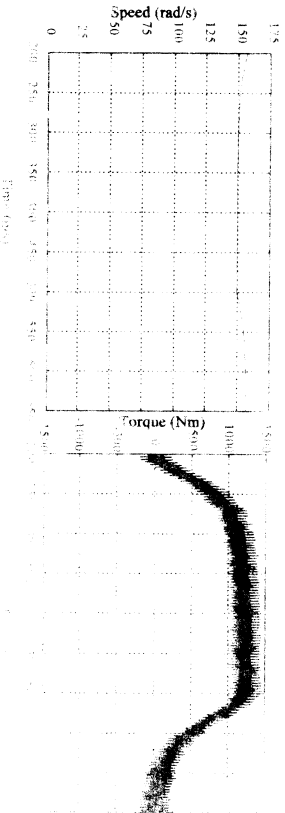


Figure 8. Graph of torque vs time

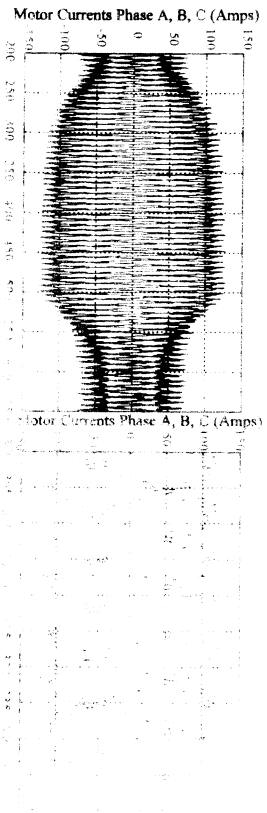


Figure 9. Graph of speed vs time

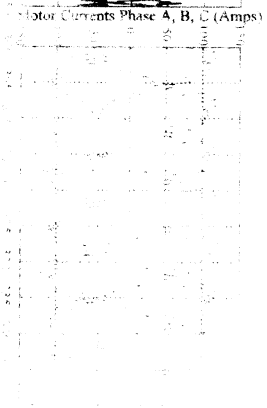


Figure 10. Graph of Motor Currents Phase A, B, C (Amps) vs time



Figure 9. Motor speed vs. time

This trace shows the motor speed under load application. The speed drops when the load is applied. Since only a proportional speed controller is used the speed has some error, even in the steady state.

Figure 10. Motor torque vs. time

This trace shows the motor electrical torque. The application of a load causes the speed to droop, which in turn causes the torque to rise. The ripple in the torque waveform is due to the inverter switching. The switching harmonics cause torque pulsations.

Figure 11. Motor currents vs. time

This trace shows the three phase motor currents under the load change.

Figure 12. Expanded view of motor currents vs. time

This trace shows an expanded view of the motor currents under full load conditions. The switching harmonics can be clearly seen. Also of note is the symmetry between the phases, indicating correct operation.

7. Conclusions

This paper successfully demonstrates the simulation of an asynchronous motor traction drive system using the Simulink dynamic systems analysis package. This type of simulation has been difficult in the past, however the application of Simulink and the DNT has resulted in a consistent, user friendly, PC based approach to modelling mixed systems. The results presented demonstrate that complex systems can be modelled with relative ease. This technique offers great potential to traction studies.

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