Modeling Electrical Power Systems Using EASY5

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Overview

- List of electrical components modeled using EASY5
- Fundamentals of electrical machine modeling
- Fundamentals of power electronic component modeling
- Examples of electrical components used in EASY5 models
- Summary

Electrical Component Macros

- Modeling is facilitated by use of macros developed by Boeing over the last two decades. Many of these components have been validated by laboratory and field testing.

Electrical Machines
Synchronous Machines
Induction Machines (1, 2, 3 phases)
Permanent Magnet Machines
DC Machines
Stepper Motors

Electronic Controller
PWM Inverters
Transformer Rectifier Units
Flyback Converters
Push-Pull Converter
Boost Converters
SCR Controller

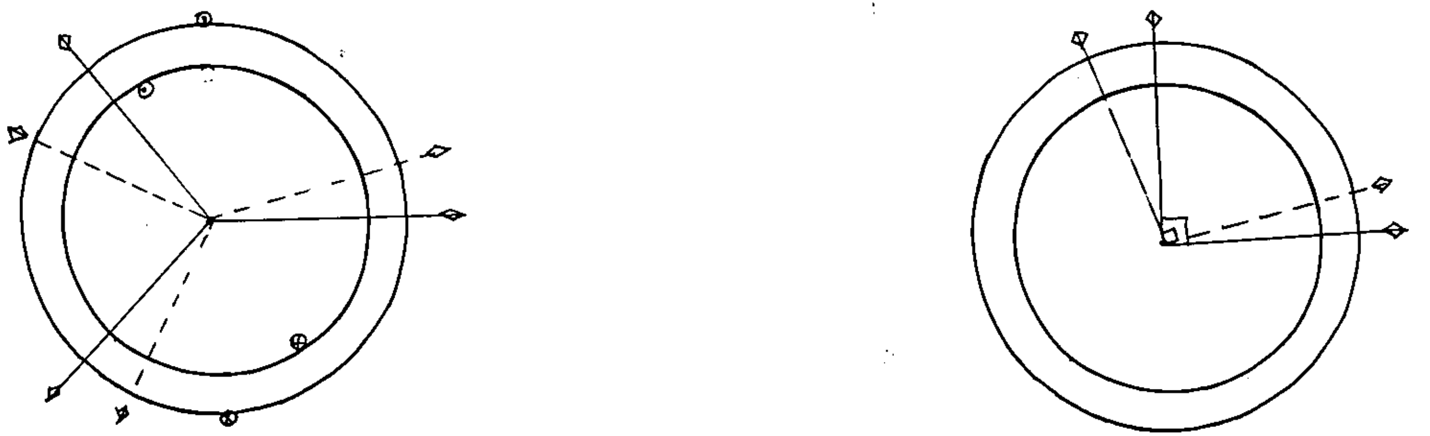
Connection Components
Breakers
Transmission Lines
Transformers
Static Loads

Misc. Components
Battery
Synchronous Machine Excitation
Measurement Components (freq,
(volt, current)
EMI Filters
Power Supply (Constant Power)

Fundamentals of Electrical Machine Modeling

- Two-axis theory used to model electrical machines
  - Three-phase machine in terms of its two-phase equivalent
  - Magnetic axis orthogonality simplifies analyses significantly
  - Machine impedances are now constants and do not depend on rotor positions.
  - Assumes structural symmetry exists inside the machine.

Fundamentals of Electrical Machine Modeling (Cont'd)



- Simplification in resulting equations

Phase variable method:

$$V_{as} = R_s{*}i_{as} + (L_{ms} + L_{ls})pi_{as} - \frac{L_{ms}}{2}p(i_{bs} + i_{cs}) +$$

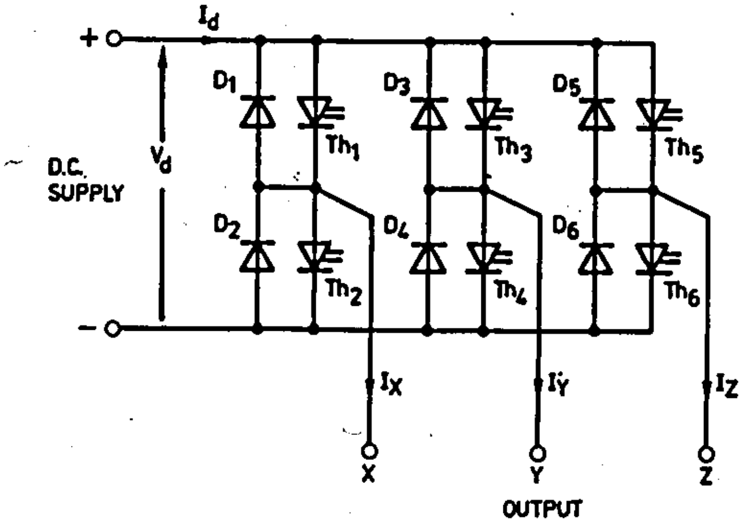
$$\frac{N_r}{N_s}L_{ms}{*}[p(i_{ar}\cos(\theta_r) + p(i_{br}\cos(\theta_r + \frac{2{*}pi}{3}) + p(i_{cr}\cos(\theta_r - \frac{2{*}pi}{3})]$$

Two-axis theory:

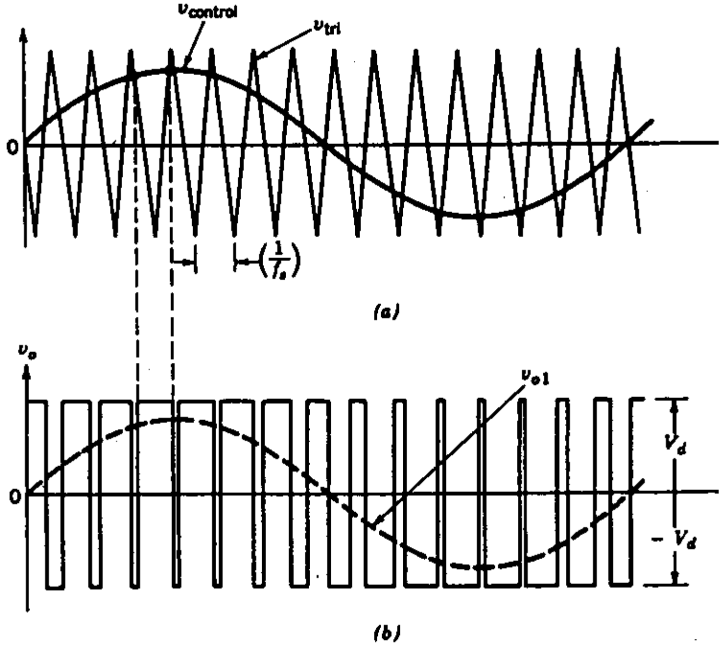
$$V_{qs} = R_s i_{qs} + p\lambda_{qs} + \omega\lambda_{ds}$$

Fundamentals of Power Electronics Modeling Using EASY5

- Logic used to model a sine-triangle, pulse-width-modulated (SPWM) three-phase inverter

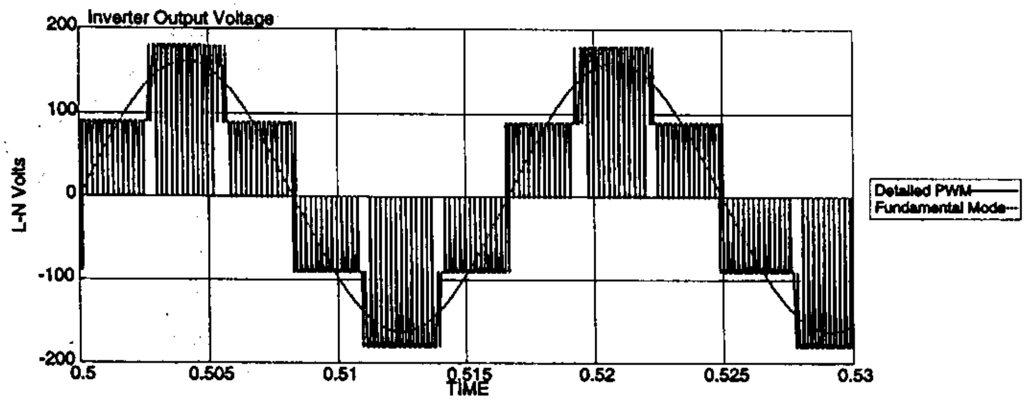


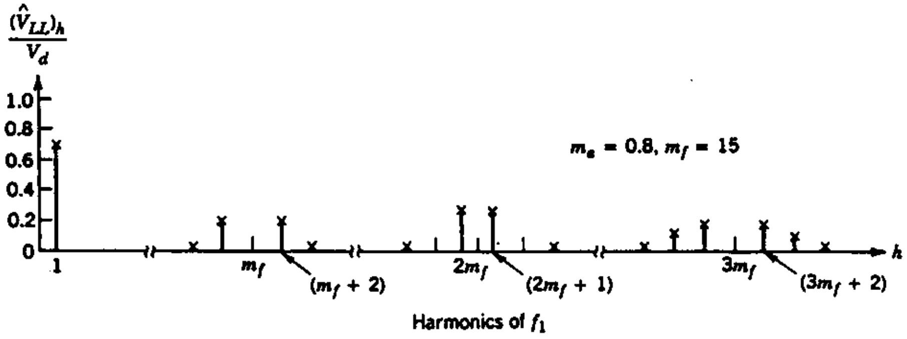
+
−
I_d
V_d
D.C. SUPPLY
D_1
D_2
D_3
D_4
D_5
D_6
Th_1
Th_2
Th_3
Th_4
Th_5
Th_6
I_X
I_Y
I_Z
X
Y
Z
OUTPUT



Fundamentals of Power Electronics Modeling Using EASY5 (Cont'd)

- Output of sine-triangle PWM inverter





Example Models Utilizing Electrical System Components

- Induction Motor Drive System
- Airplane Electrical Power System
- APU Starter / Generator System Model

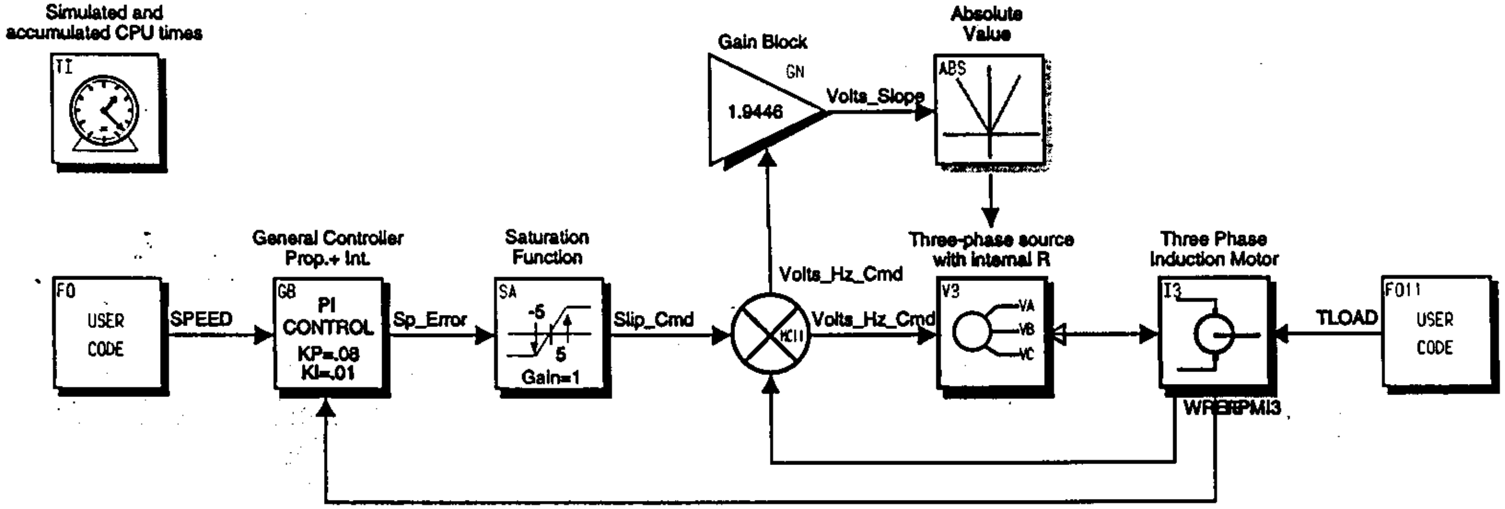
Induction Motor Drive System

- Frequently the speed/position of the induction motor shaft needs to be controlled to optimize the output of the final process.

- General purpose drives are used when modest speed regulation requirements exist (5% speed error max.)

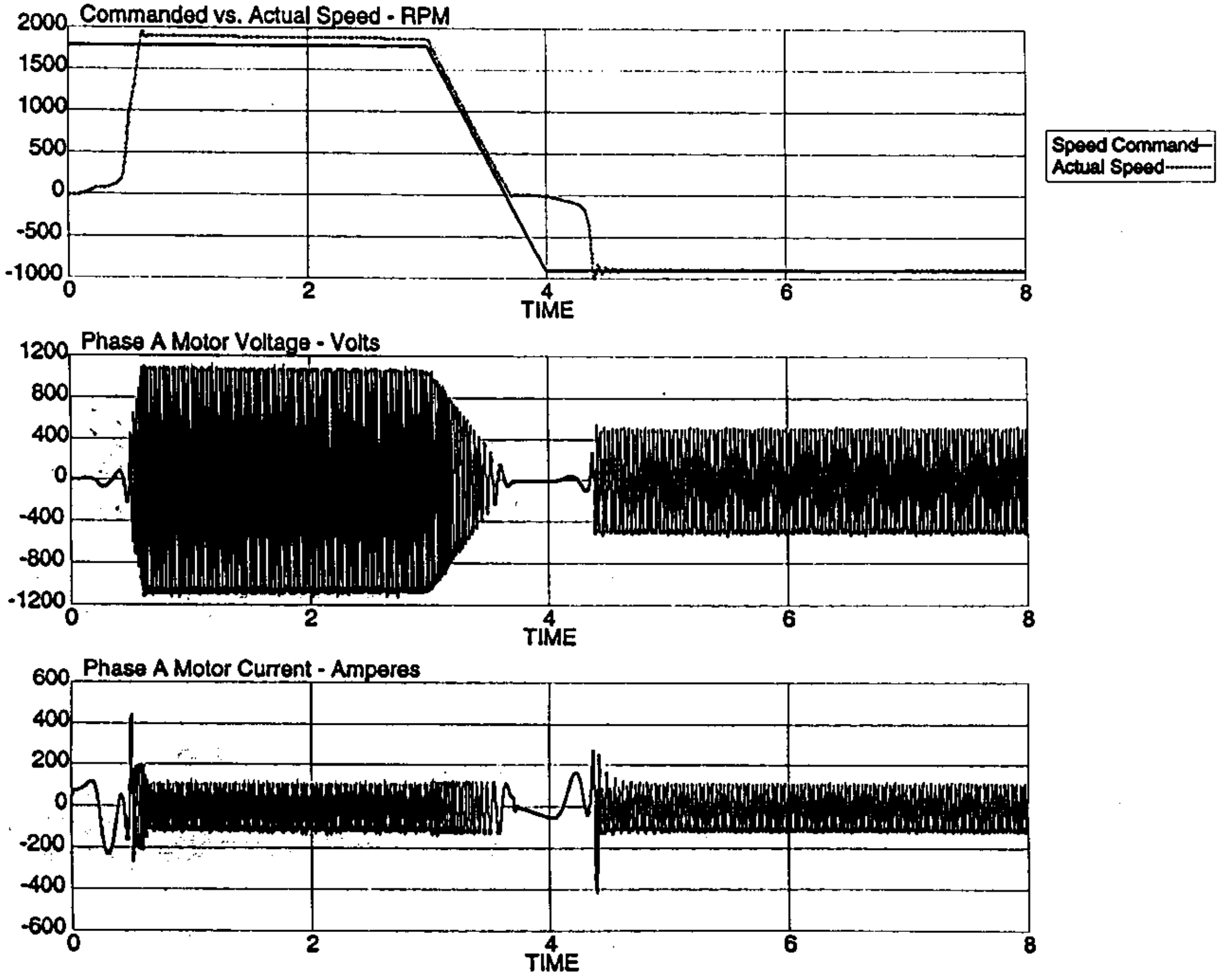
- These drives typically employ a constant 'volts/hertz' ratio type of control

Induction Motor Drive System (Cont'd)



Simulated and accumulated CPU times
TI
Gain Block
GN
1.9446
Volts_Slope
Absolute Value
ABS
F0
USER CODE
SPEED
General Controller Prop.+ Int.
GB
PI CONTROL
KP=.08
KI=.01
Sp_Error
Saturation Function
SA
-5
5
Gain=1
Slip_Cmd
Volts_Hz_Cmd
MC11
Volts_Hz_Cmd
Three-phase source with internal R
V3
VA
VB
VC
Three Phase Induction Motor
I3
WRERPMI3
TLOAD
F011
USER CODE

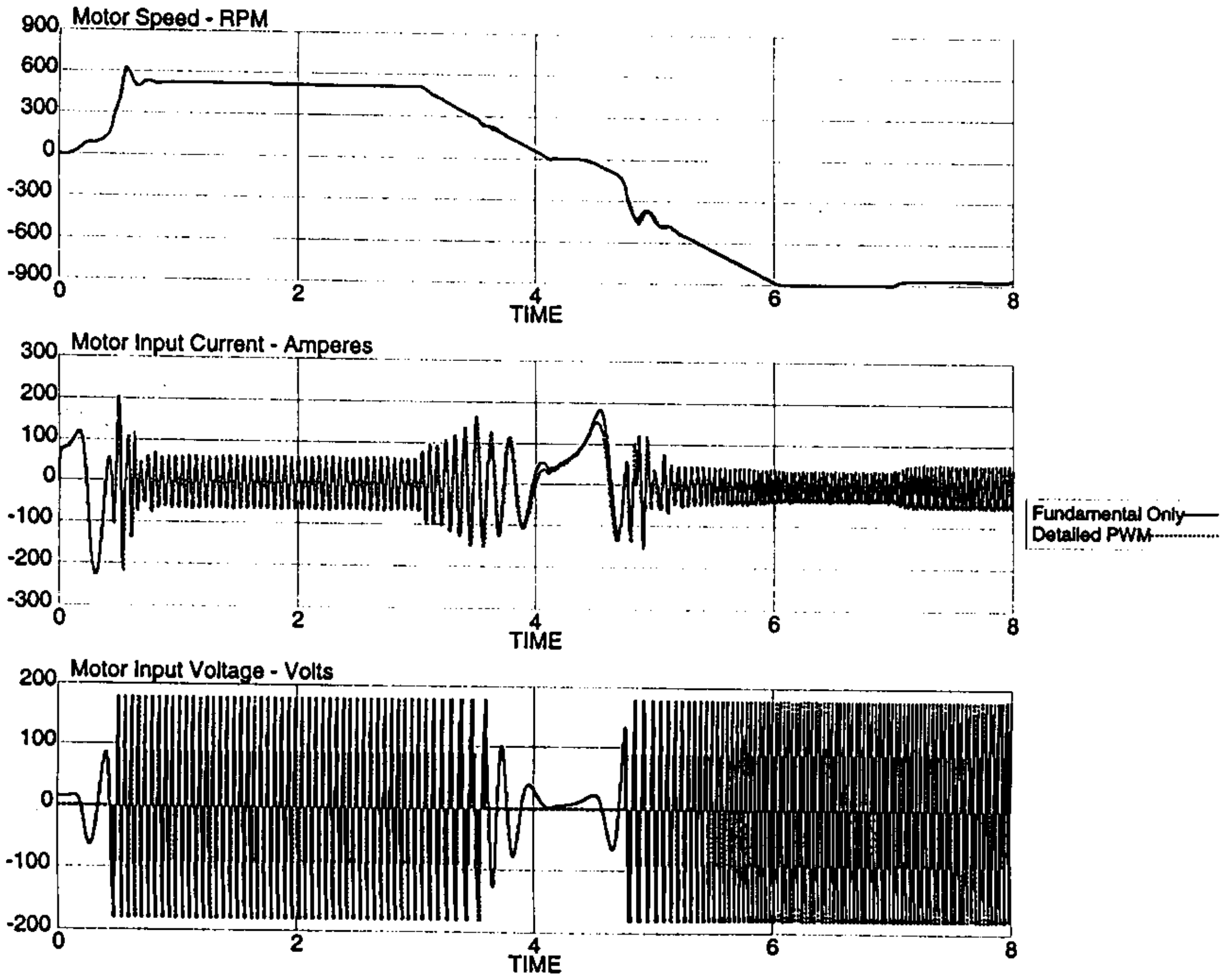
Induction Motor Drive System (Cont'd)



Constant Volts / Hertz Induction Motor Drive Control

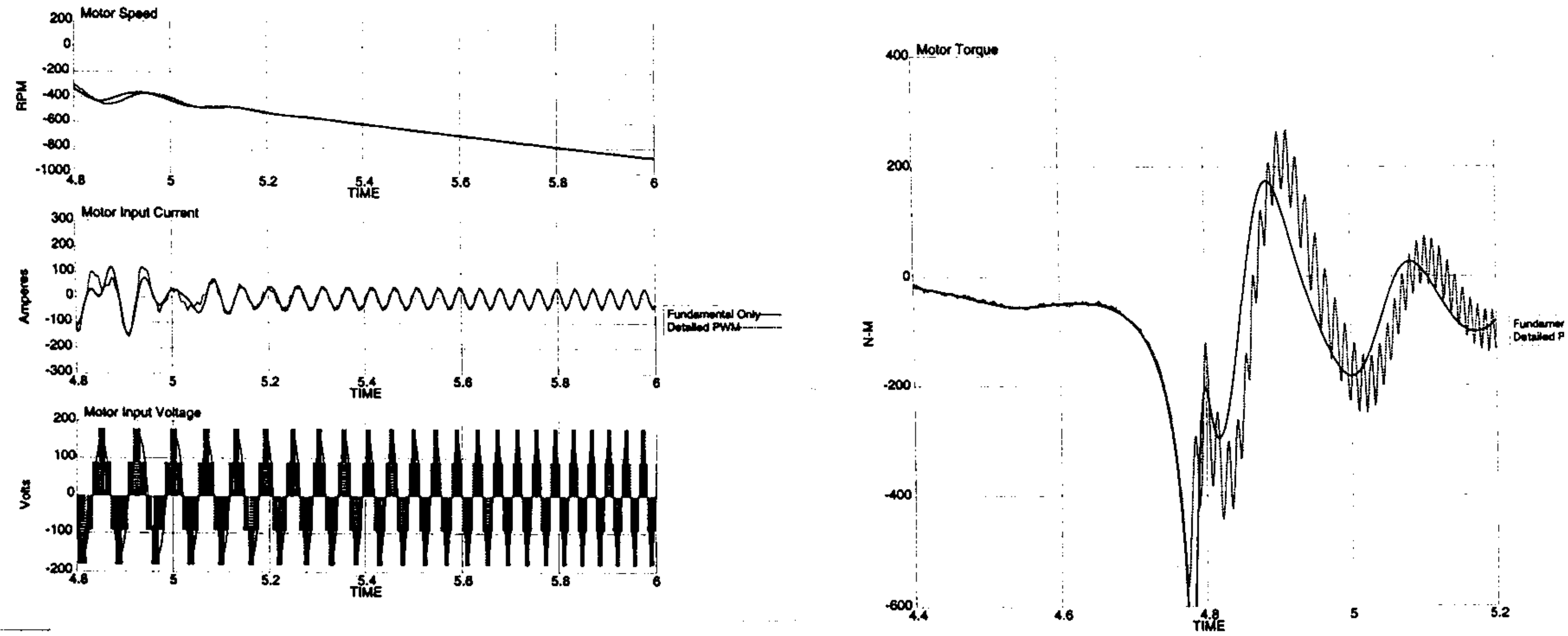
Induction Motor Drive System (Cont'd)

Detailed Switching vs. Fundamental Mode Model



Induction Motor Drive System (Cont'd)

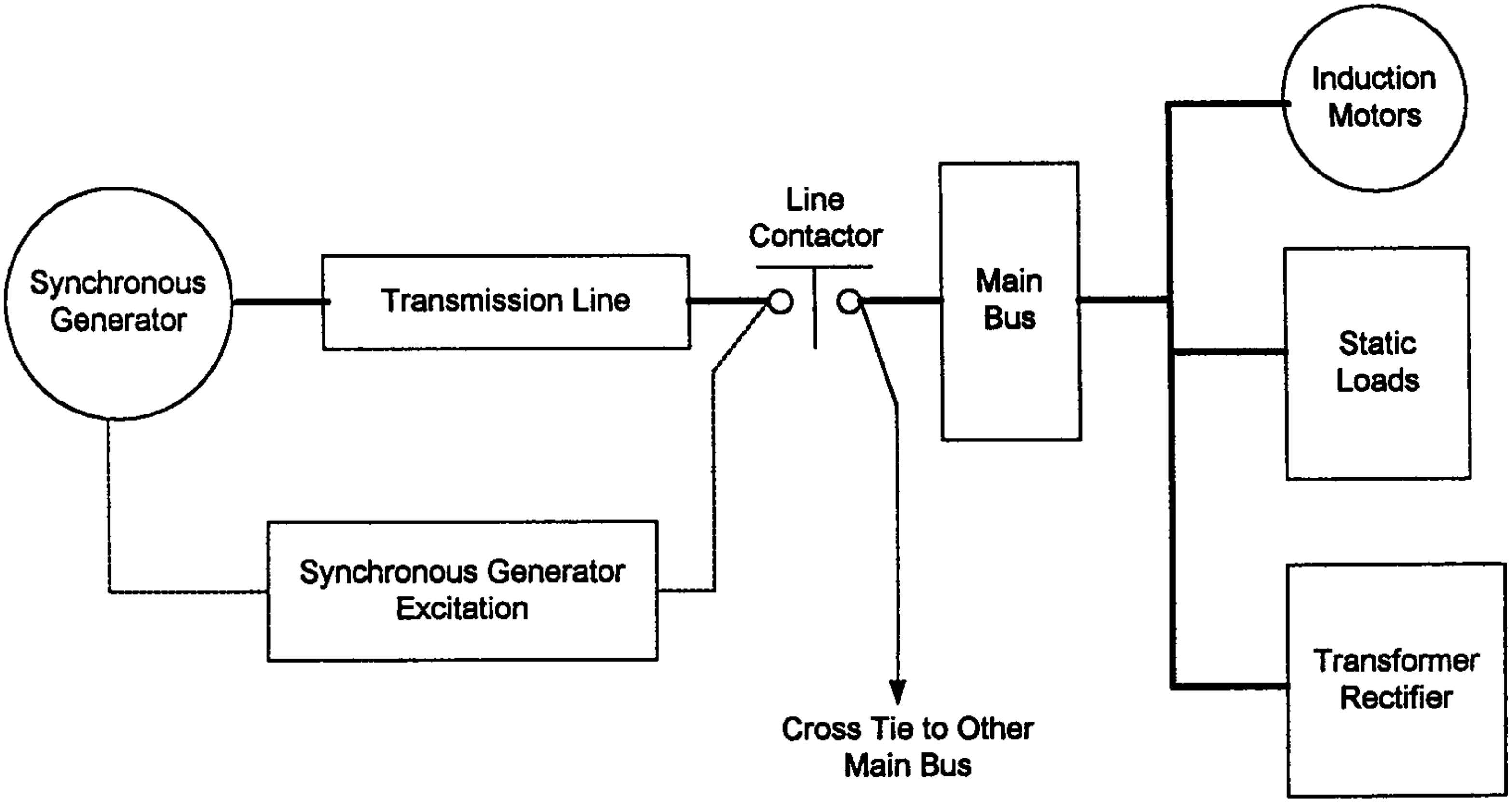
Detailed Switching vs. Fundamental Mode Model



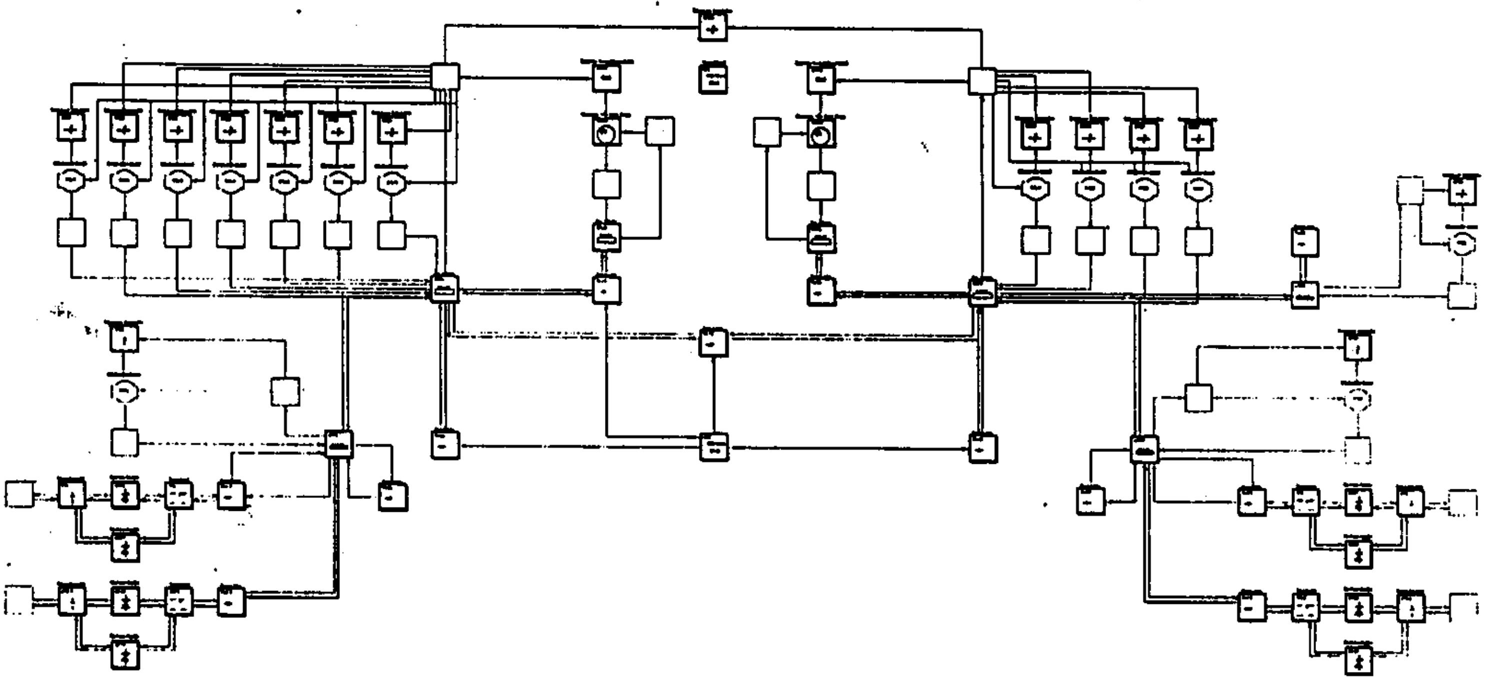
Airplane Electrical Power System Modeling

- Includes following electrical macro components:
  - ➢Synchronous generators with excitation systems;
  - ➢Induction motors;
  - ➢Transformer-rectifier units (TRUs);
  - ➢Static Loads;
  - ➢Breakers with associated controls

Airplane Electrical Power System Modeling (Cont'd)


Synchronous Generator
Transmission Line
Line Contactor
Main Bus
Induction Motors
Static Loads
Transformer Rectifier
Synchronous Generator Excitation
Cross Tie to Other Main Bus

Airplane Electrical Power System Modeling (Cont'd)

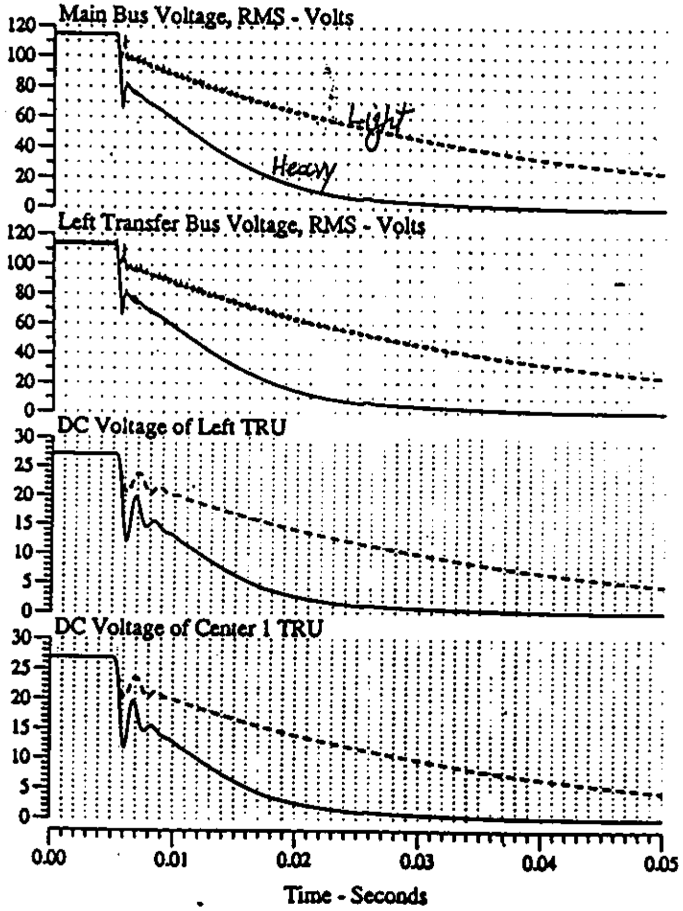


Airplane Electrical Power System Modeling (Cont'd)

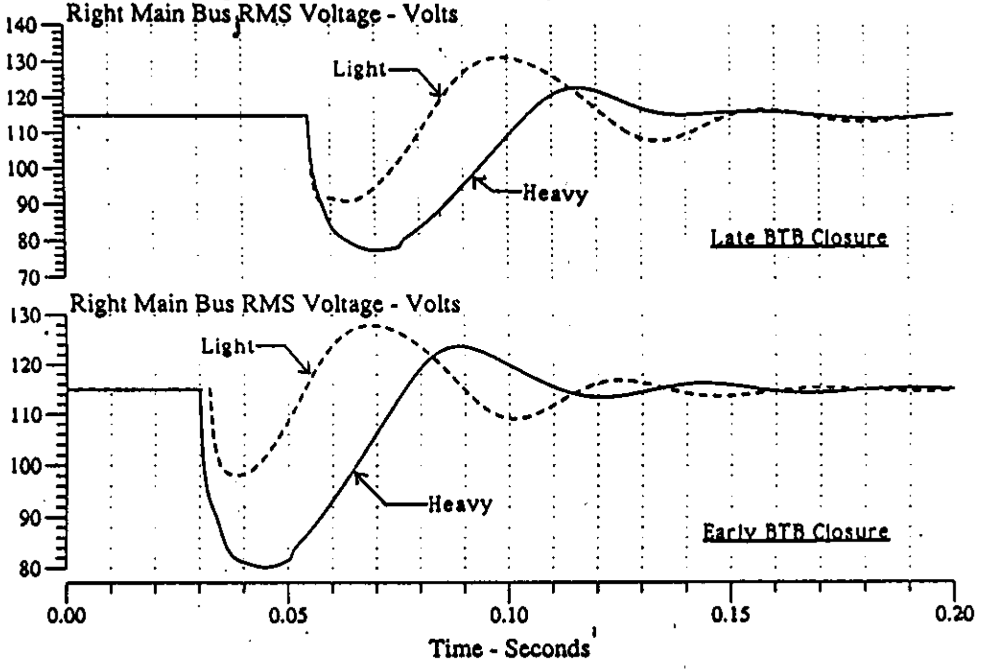
- Type of analyses performed on electrical power system model;
  - ➢Bus voltage characteristics during loss of generator and subsequent pickup by operational source;
  - ➢Voltage transient due to load application and removal;
  - ➢Fault application and removal transients.

Bus Voltage During Generator Loss

Scenario 1, Loss of Left Channel Generator
Heavy and Light Load Cruise Conditions



Bus Voltage During Generator Loss (Cont'd)



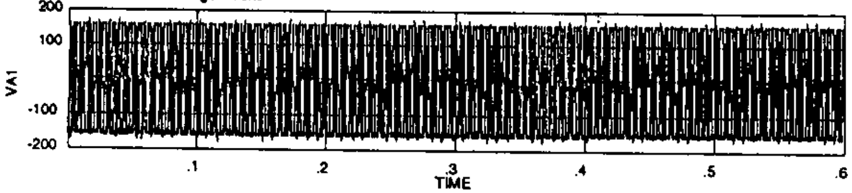
Voltage Transient on Healthy Channel
Heavy vs. Light Load Condition for Early and Late BTB Closure

Load Application Transients

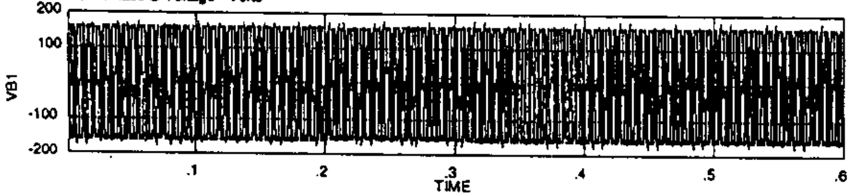
- Transients during application of static load;
- Transients during application of motor load;
- Investigation of internal generator excitation parameters.

Static Load Application Transients

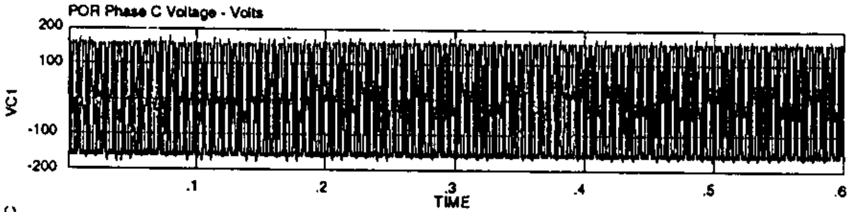
POR Phase A Voltage - Volts



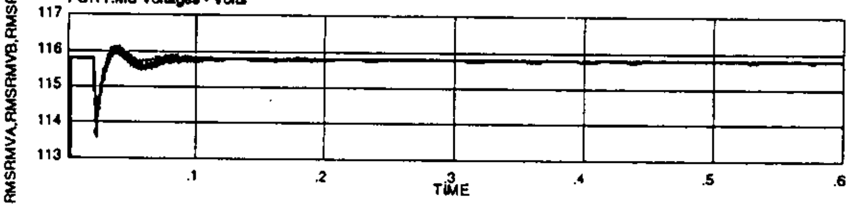
POR Phase B Voltage - Volts



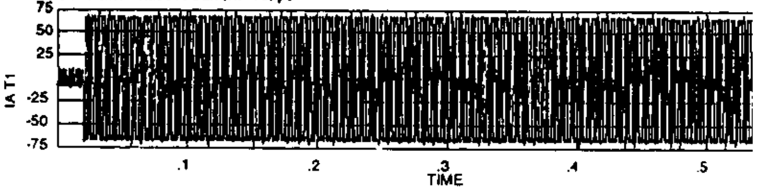
POR Phase C Voltage - Volts



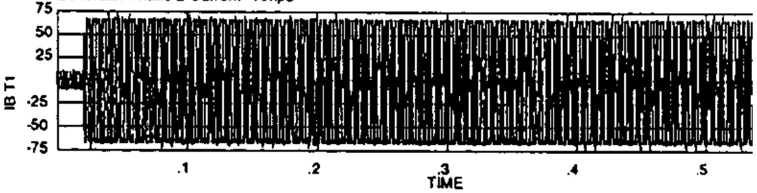
POR RMS Voltages - Volts



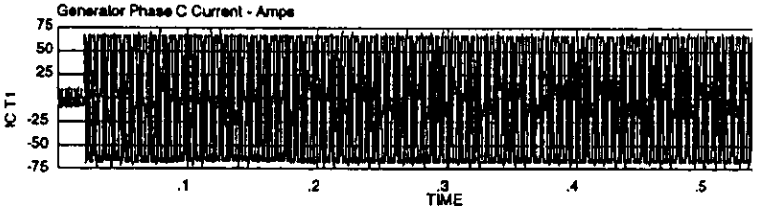
Generator Phase A Current - Amps



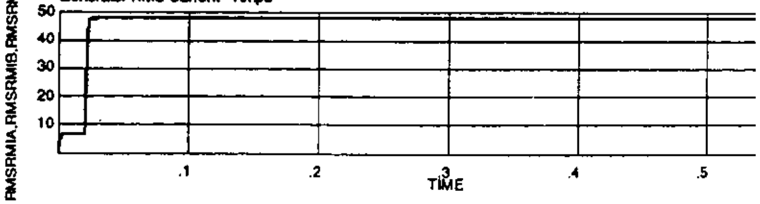
Generator Phase B Current - Amps



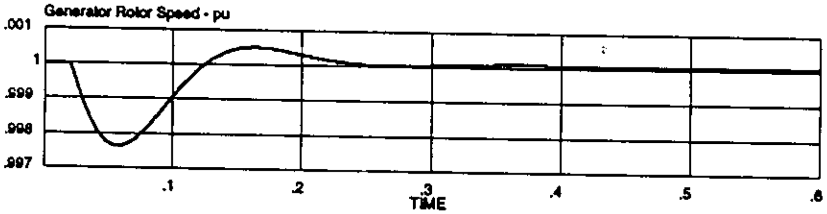
Generator Phase C Current - Amps

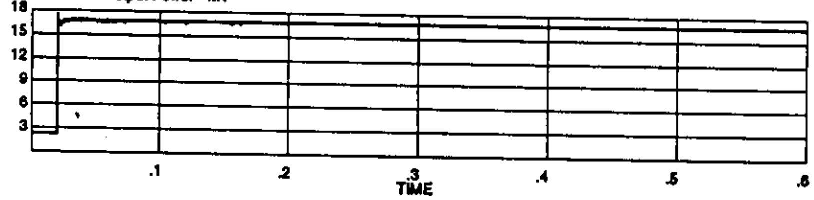


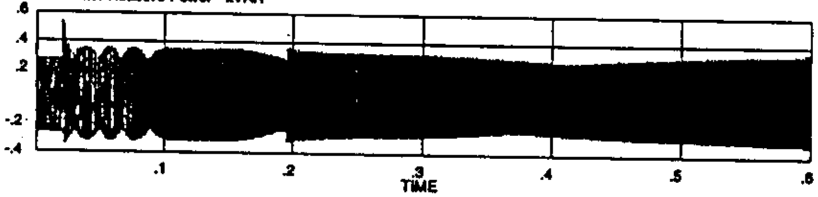
Generator RMS Current - Amps

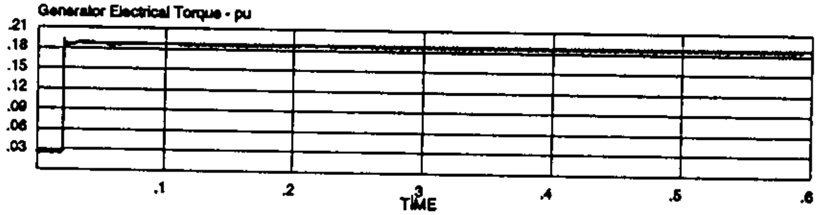


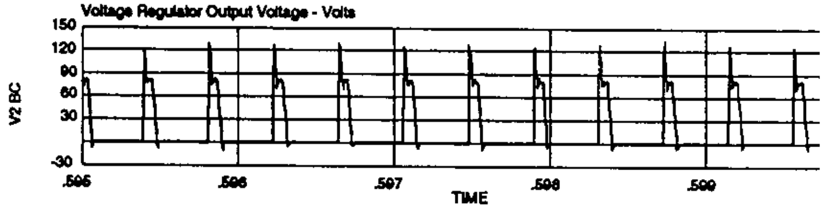
Static Load Application Transients (Cont'd)

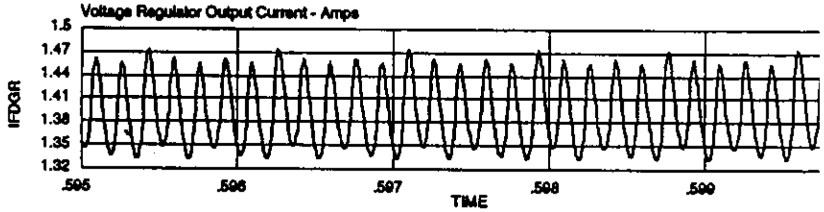

Generator Rotor Speed - pu

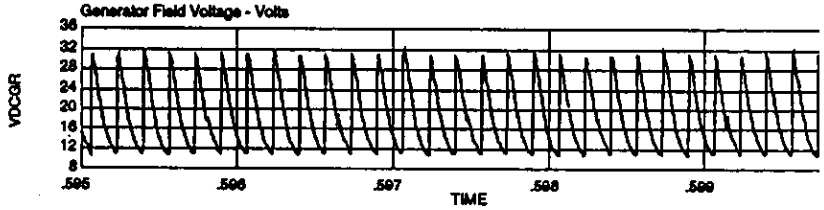

Generator Output Power - kW

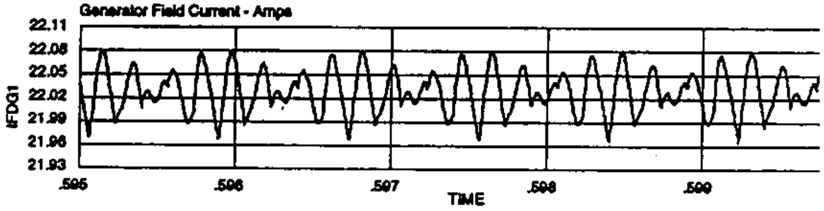

Generator Reactive Power - kVAR


Generator Electrical Torque - pu

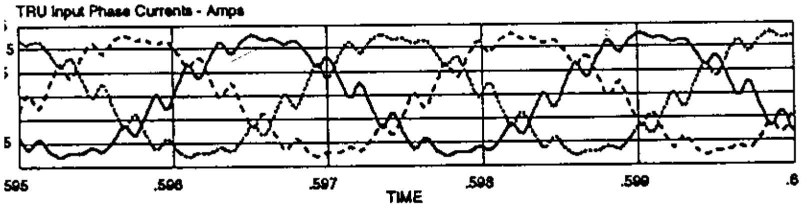

Voltage Regulator Output Voltage - Volts

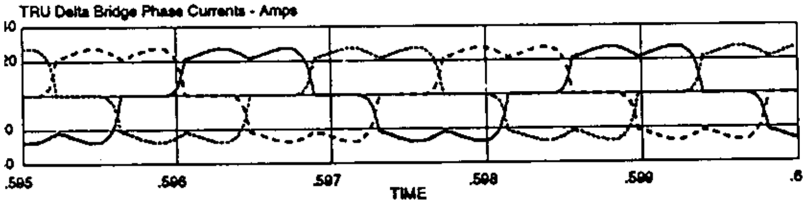

Voltage Regulator Output Current - Amps

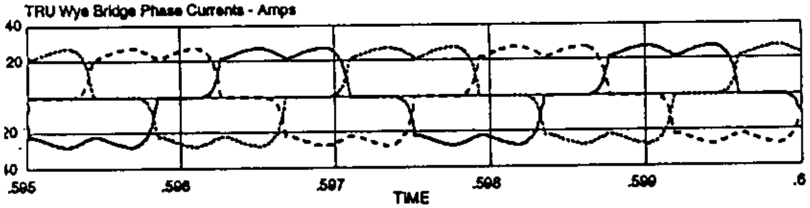

Generator Field Voltage - Volts

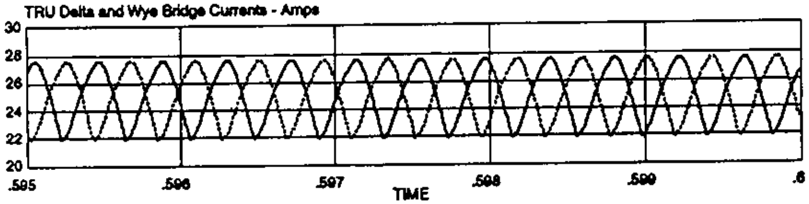

Generator Field Current - Amps

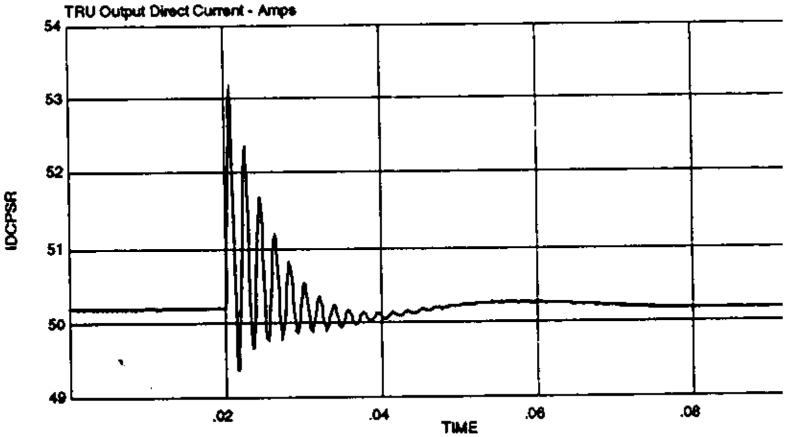
Static Load Application Transients (Cont'd)

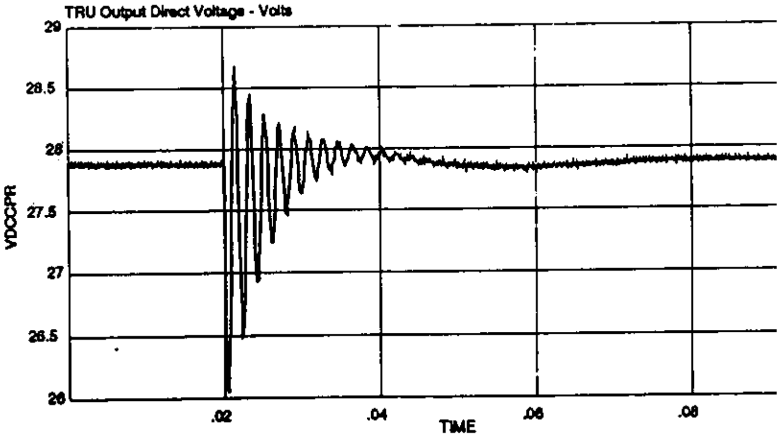

TRU Input Phase Currents - Amps


TRU Delta Bridge Phase Currents - Amps


TRU Wye Bridge Phase Currents - Amps

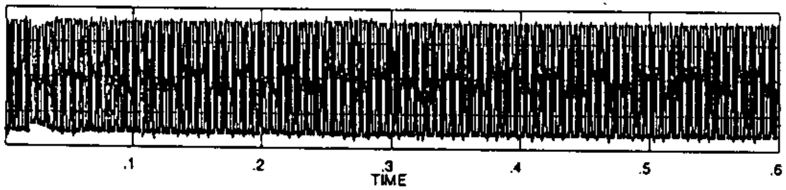

TRU Delta and Wye Bridge Currents - Amps


TRU Output Direct Current - Amps

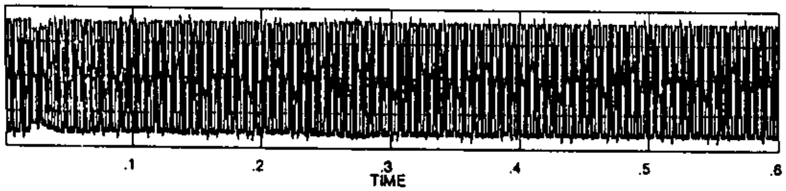

TRU Output Direct Voltage - Volts

Motor Load Application Transients

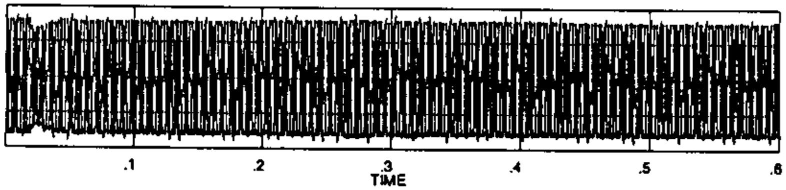
POR Phase A Voltage - Volts



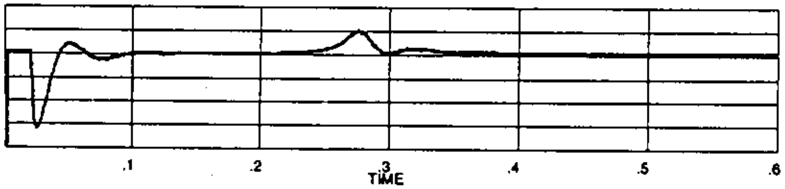
POR Phase B Voltage - Volts



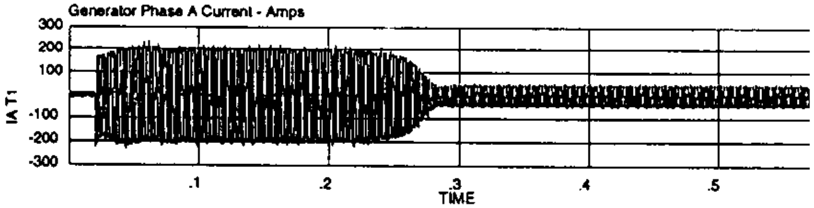
POR Phase C Voltage - Volts



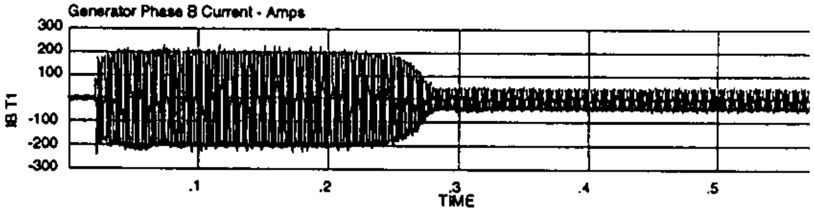
POR RMS Voltages - Volts



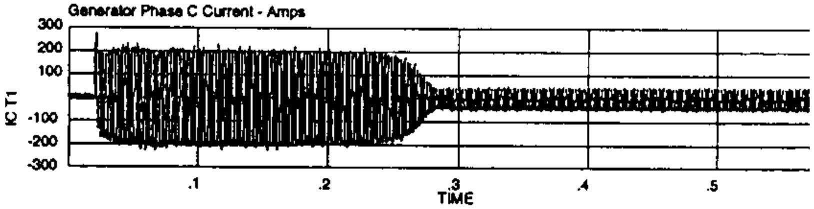
Generator Phase A Current - Amps



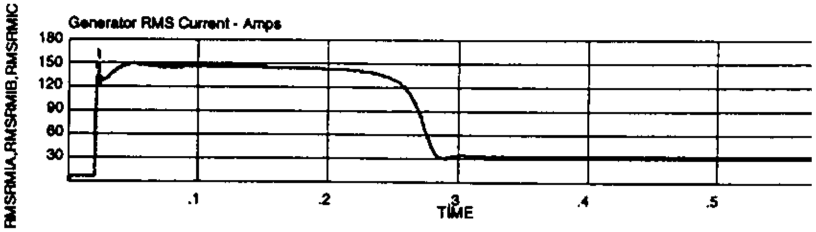
Generator Phase B Current - Amps



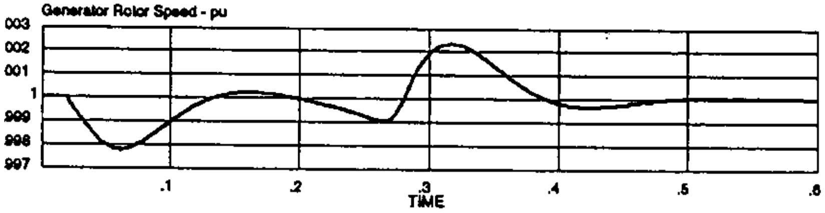
Generator Phase C Current - Amps

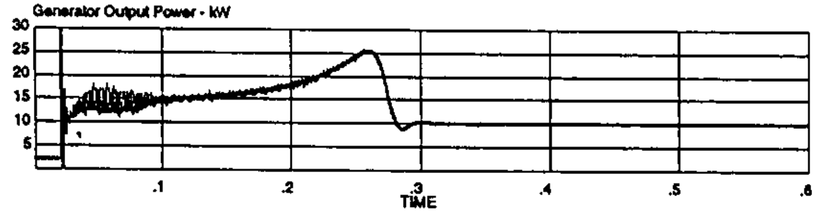


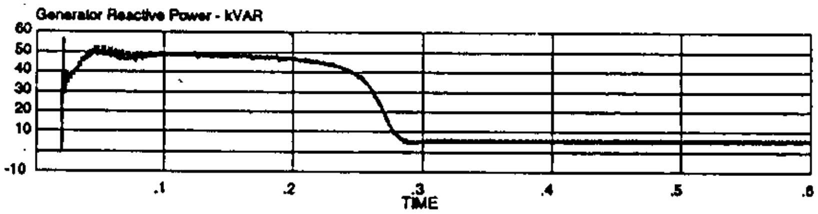
Generator RMS Current - Amps

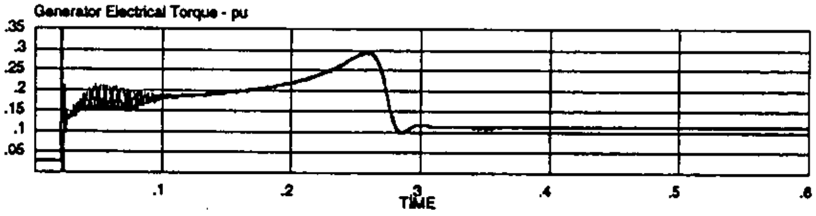


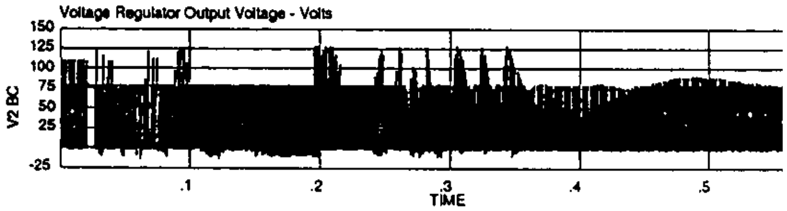
Motor Load Application Transients (Cont'd)

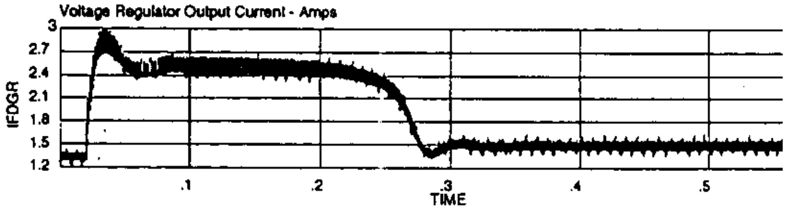


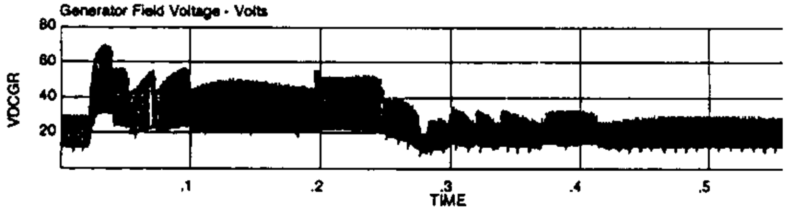


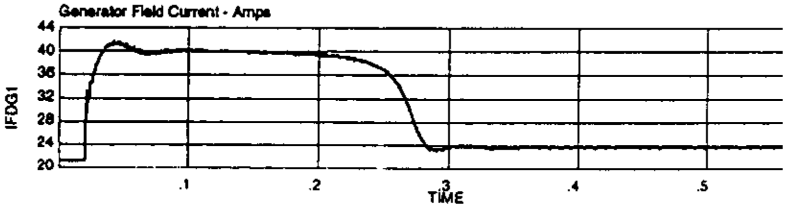








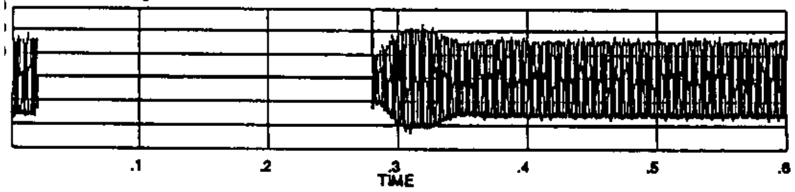




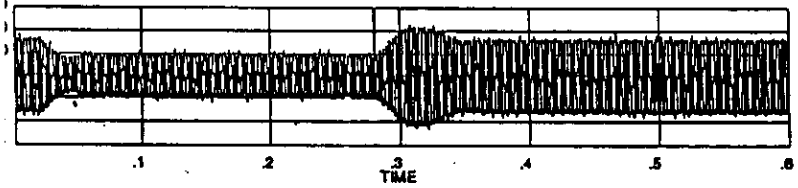
Bus Fault Transients

- Application of single-phase fault to the electrical system

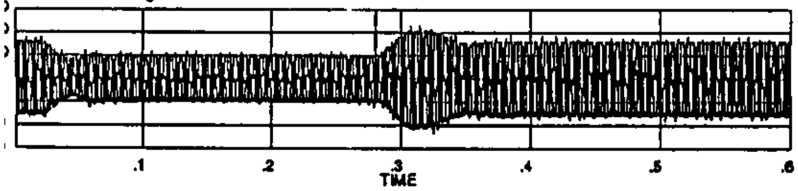
POR Phase A Voltage - Volts



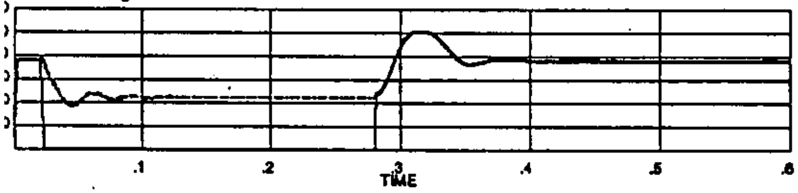
POR Phase B Voltage - Volts



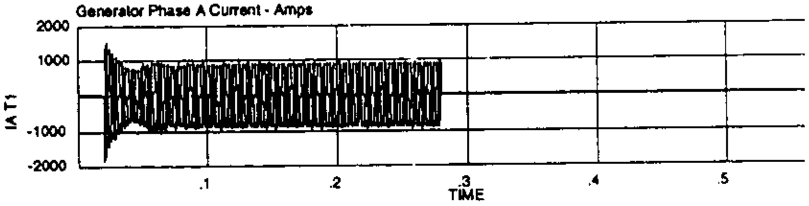
POR Phase C Voltage - Volts



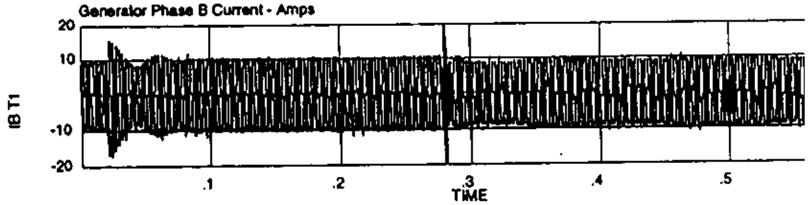
POR RMS Voltages - Volts



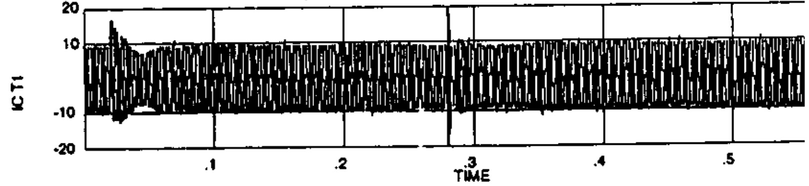
Generator Phase A Current - Amps



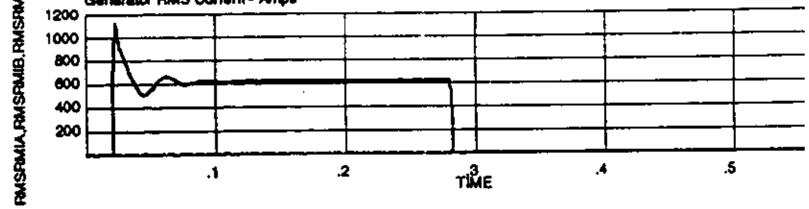
Generator Phase B Current - Amps



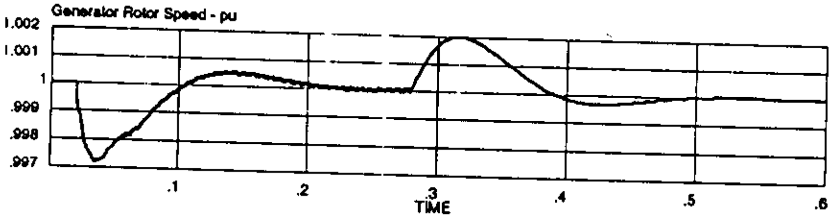
Generator Phase C Current - Amps

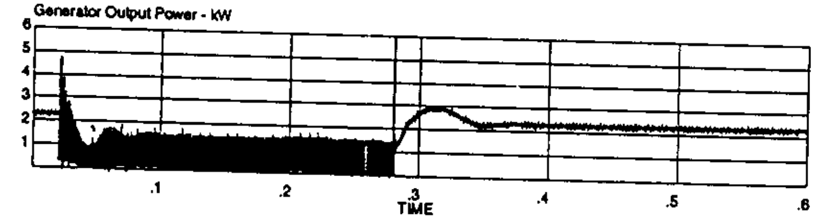


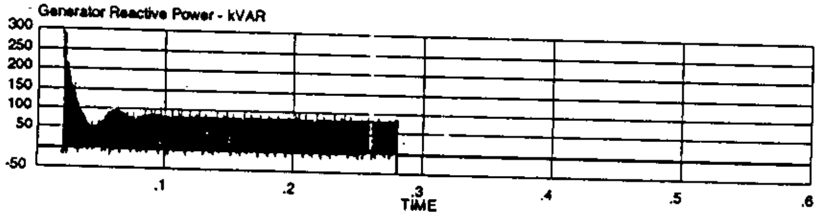
Generator RMS Current - Amps

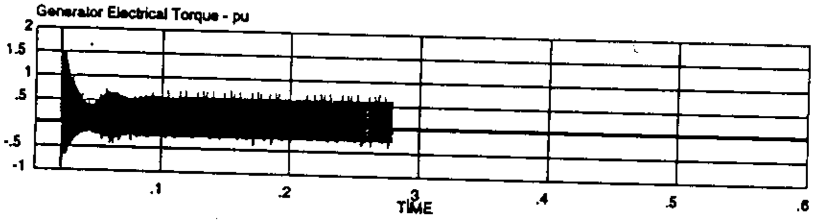


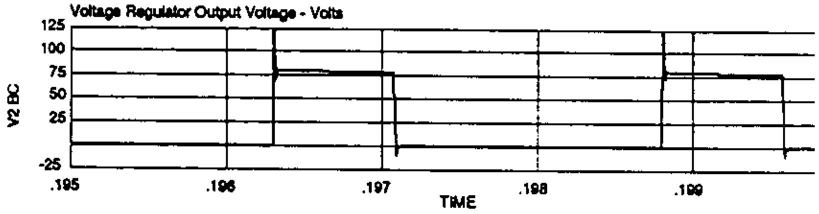
Bus Fault Transients (Cont'd)

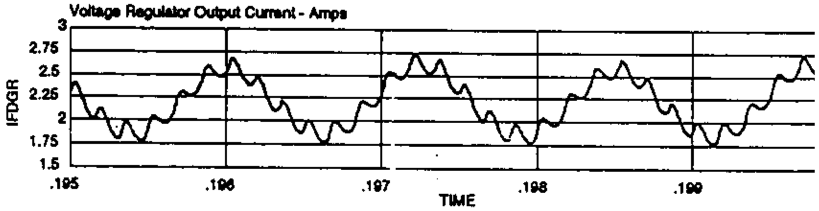

Generator Rotor Speed - pu

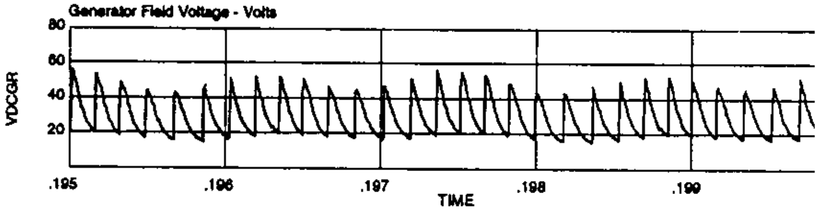

Generator Output Power - kW

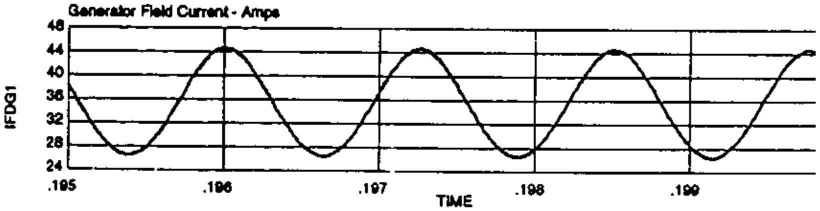

Generator Reactive Power - kVAR


Generator Electrical Torque - pu


Voltage Regulator Output Voltage - Volts

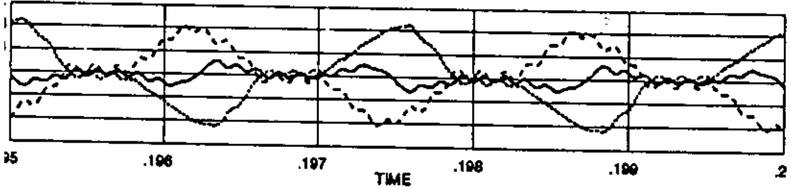

Voltage Regulator Output Current - Amps


Generator Field Voltage - Volts

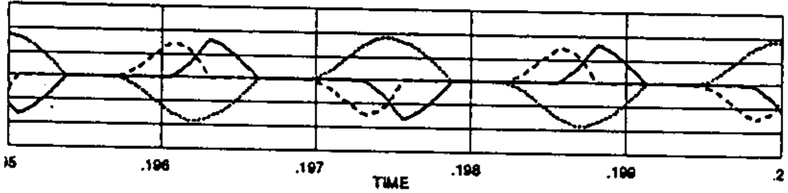

Generator Field Current - Amps

Bus Fault Transients (Cont'd)

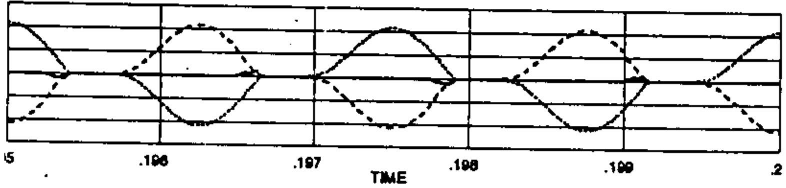
TRU Input Phase Currents - Amps



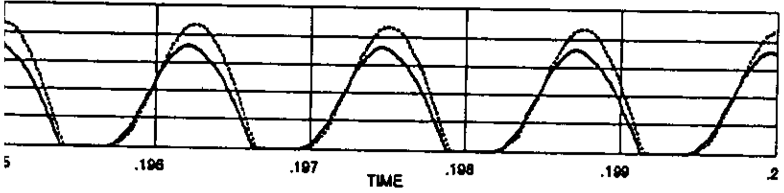
TRU Delta Bridge Phase Currents - Amps



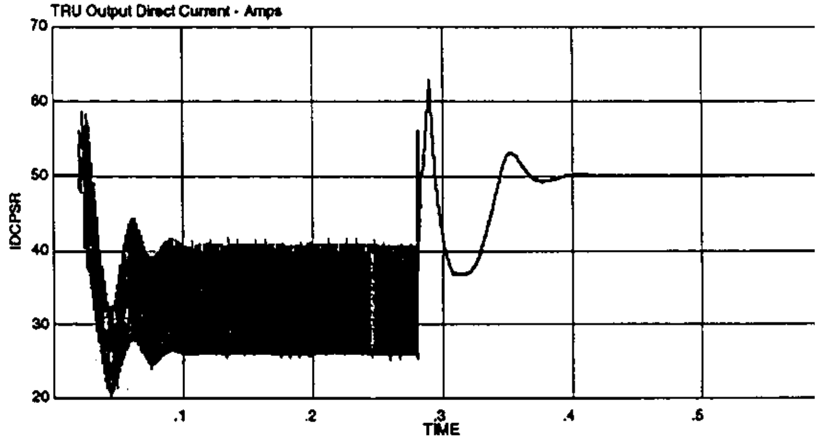
TRU Wye Bridge Phase Currents - Amps



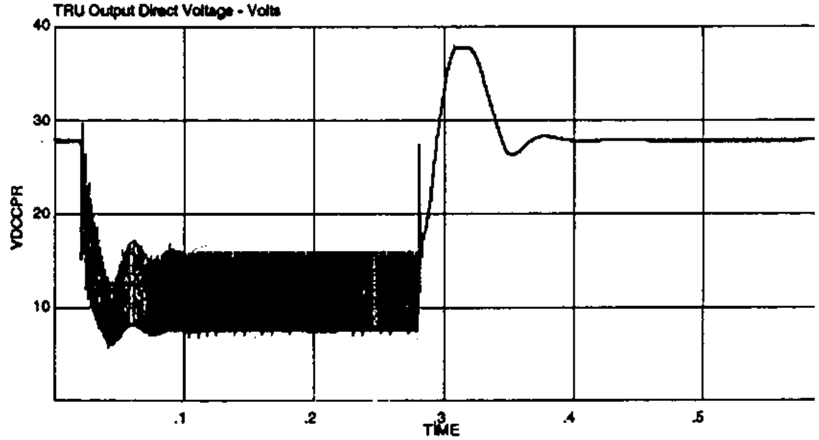
TRU Delta and Wye Bridge Currents - Amps



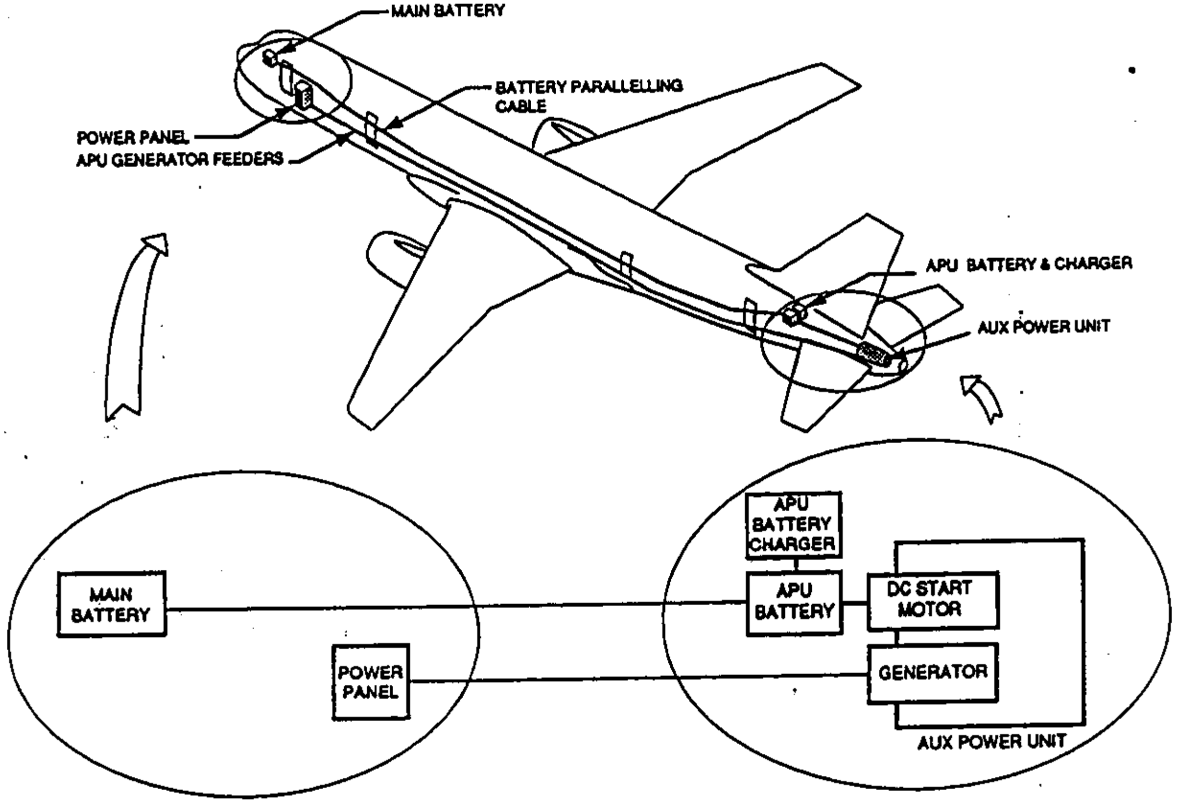
TRU Output Direct Current - Amps



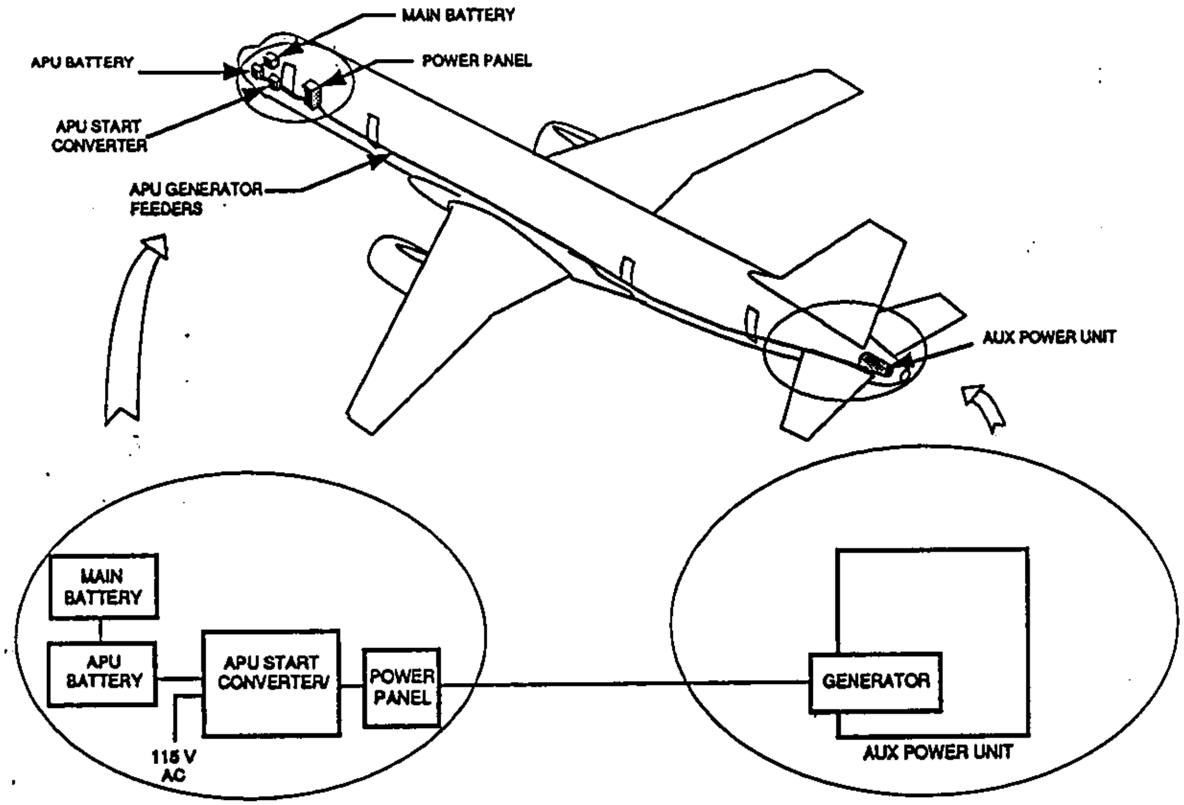
TRU Output Direct Voltage - Volts



APU Starter / Generator System Model


MAIN BATTERY
BATTERY PARALLELLING CABLE
POWER PANEL
APU GENERATOR FEEDERS
APU BATTERY & CHARGER
AUX POWER UNIT
MAIN BATTERY
POWER PANEL
APU BATTERY CHARGER
APU BATTERY
DC START MOTOR
GENERATOR
AUX POWER UNIT

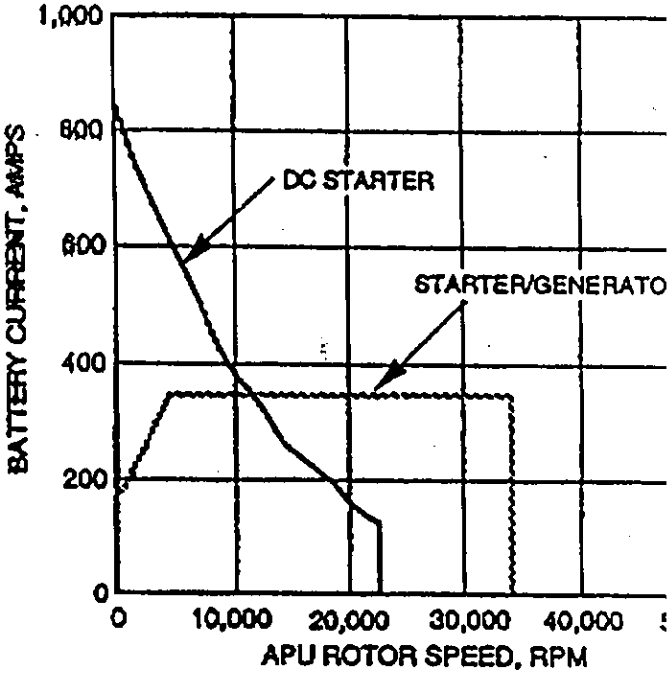
APU Starter / Generator System Model (Cont'd)


MAIN BATTERY
APU BATTERY
POWER PANEL
APU START CONVERTER
APU GENERATOR FEEDERS
AUX POWER UNIT
MAIN BATTERY
APU BATTERY
APU START CONVERTER/
POWER PANEL
115 V AC
GENERATOR
AUX POWER UNIT

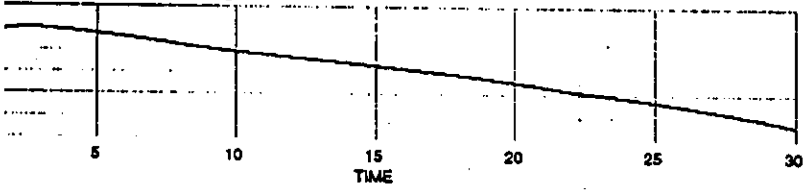
APU Starter / Generator System Model (Cont'd)

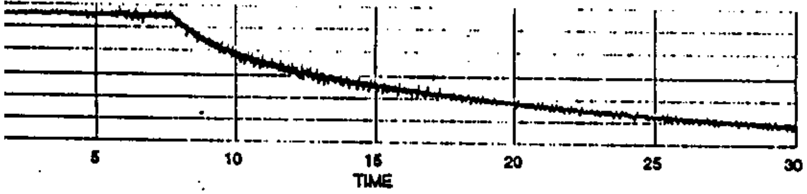
Benefits:

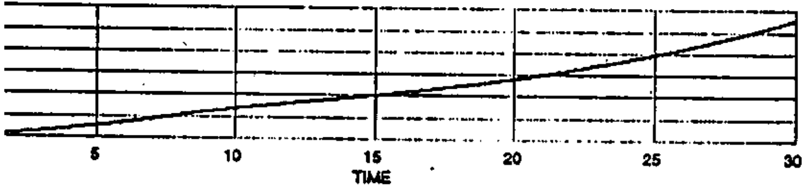
- Improved APU start reliability
- APU life extension
- Battery life extension
- Significant weight reduction
- Significant lifecycle cost reduction
- Brushless, clutchless programmable starts
- Controllable / soft starts

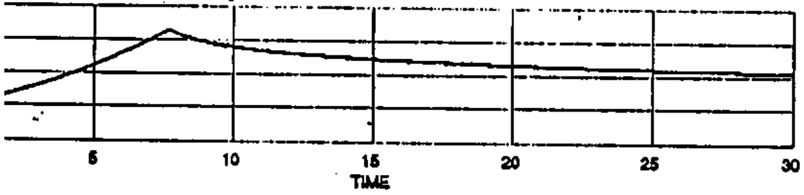


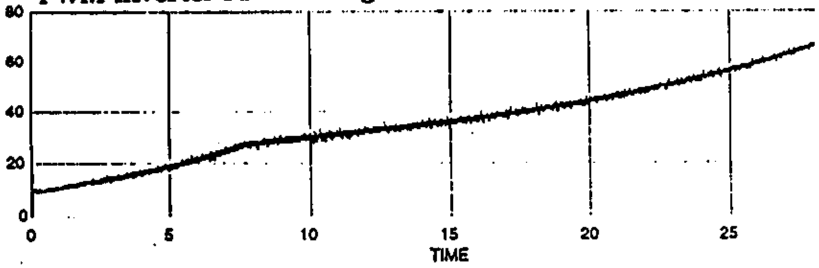
APU Starter / Generator System Model (Cont'd)

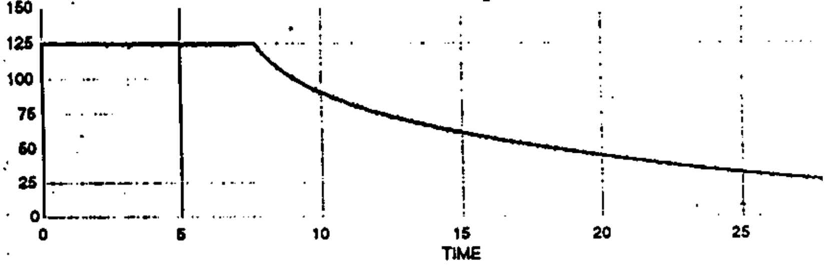

U Generator Drag Torque - ft-lbs

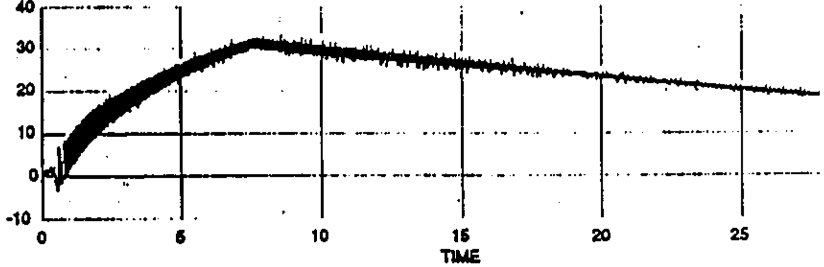

U Generator Start Torque - ft-lbs


U Generator Rotor Speed - per unit


art Converter Output Power - kW

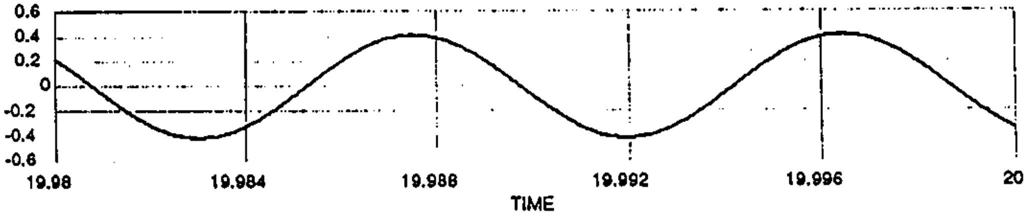

PWM Inverter RMS Voltage - Volts


PWM Inverter RMS Current - Amps

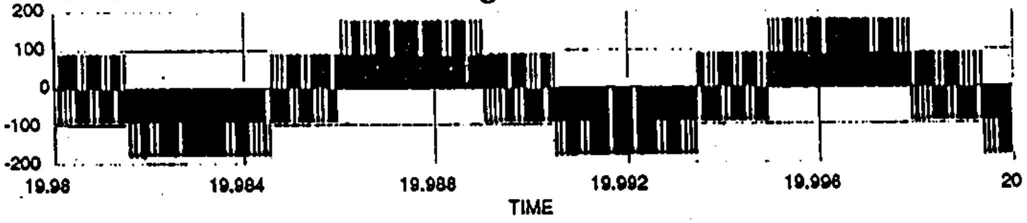

PWM Inverter Power Factor Angle - Degrees

APU Starter / Generator System Model (Cont'd)

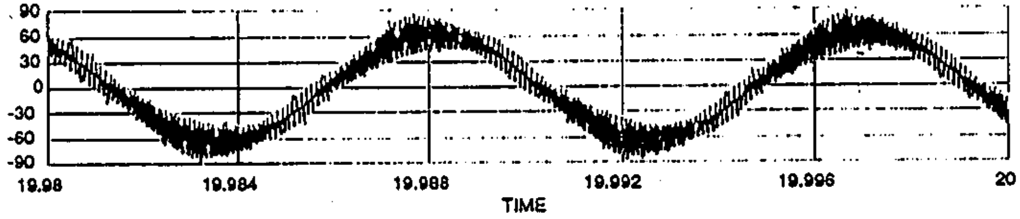
PWM Inverter Phase A Control Voltage - pu



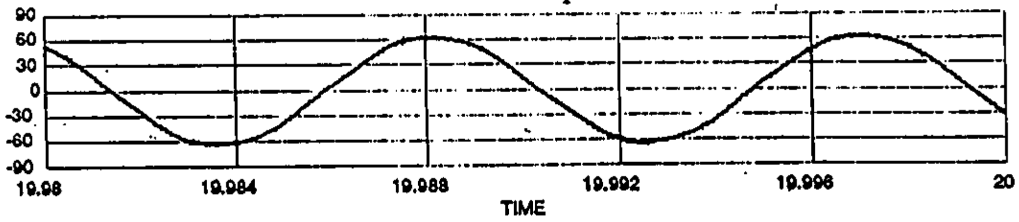
PWM Inverter Phase A Voltage - Volts



PWM Inverter Phase A Current - Amps



APU Feeder Phase A Current - Amps



Summary

- A variety of electrical component macros have been designed to facilitate electrical system modeling.
- A brief overview of electrical machine and power electronic converter modeling was presented.
- Electrical subsystems as well as entire electrical power systems can be modeled using EASY5.
- Examples provided of EASY5 models of electrical systems models.
- Engineer must be cognizant of detail required for model.