Improve Reliability and Training
of
Power Plant Electrical Distribution System Operation
by
Dynamic Load-Flow Simulation

By
Sadashiva Godbole, et. al.
nHance Technologies, Lynchburg, Virginia, USA
828 Main Street
Suite #903
Lynchburg, VA 24504

Phone: (434) 582-6110, Ext. 16
Fax: (434) 582-6112
e-mail: Sadash.Godbole@nhancetech.com

Power Plant Electrical Distribution System

A typical three-phase electrical distribution system in a power plant consists of one or more synchronous generators interconnected with each other and connected to the electrical power grid and several house loads through busses at different voltages and interposing transformers. The house loads include 3-phase induction motors for components such as boiler feedwater pumps, circulating water pumps, condensate pumps, air and gas fans, coal pulverizer mills, (reactor coolant pumps for nuclear plants). Electric current limiting reactors may be used for interconnecting generators and grid. Circuit breakers are included in the system to change network configuration under normal and fault conditions (e.g., synchronizing a generator, changing load bus power supply from startup supply to plant auxiliary supply, adding or dropping a load, protecting connected equipment).

Dynamic Load Flow Simulation

Dynamic load flow simulation is a necessary component in a power plant operator training simulator. It is used to train the operator in following the procedures for tasks such as

- Synchronizing generators,
- Properly sequencing large motor startup to prevent trips due to large inrush currents and temporary voltage drop,
- Switching power supply path for load busses (e.g., grid to in-house),
- Switching speeds of multi-speed induction motors, and
- Monitoring generator stability margin via load angle during operation.

Dynamic load flow simulation is also valuable for developing system operating procedures and verifying plant control system and equipment upgrades. It can play an important role in familiarizing electrical power staff and engineering students with various aspects of the power plant electrical distribution system and component dynamics.

During dynamic load flow simulation, the voltages and currents, active and reactive power, and other parameters throughout the power plant electrical distribution system are dynamically calculated and displayed under changing system configuration caused by operation of circuit breakers. Through the HMI (Human-Machine Interface), the simulation allows virtual "hands-on" and "on-the-fly" operation of the system to verify

- Synchronizing and loading/unloading of the generators,
- Assignment of loads to busses,
- Continuity of power supply to critical loads,
- Settings of protective relays and frequency and voltage regulators.

This virtual hands-on, on-the-fly aspect of the dynamic simulation described here provides increased insights into the electrical system use and behavior over what may be achieved from a typical load flow analyses.

Modular Modeling System

The dynamic load flow model and simulation described in this paper are developed by using MMS (**M**odular **M**odeling **S**ystem[1]). MMS is a graphical software system for developing simulation of power plant dynamics. It includes graphical icons that correspond to pre-engineered software modules of power plant components (e.g., boiler, steam generator, reactor, pumps, fans, valves, pipes, tanks, heat exchangers, turbine, and condenser) that can be selected and connected to represent a power plant system. Electrical modules include synchronous generators, two- and three-winding transformers, one- and two-speed induction motors, reactors, circuit breakers, busses, and others. The generator module uses saturation characteristics and "V curves" supplied by the generator manufacturer to determine the pre- and post-synchronization induced voltage and expected excitation current. The 3-winding transformer module uses the impedance data supplied by the transformer manufacturer to determine the reactance of the windings. The induction motor module uses the nameplate data and motor efficiency to calculate the stator and rotor resistance and reactance. Control logic modules corresponding to control functional blocks (e.g., PID, Hi/Lo alarm, set/reset, AND, OR) are also available. Another software tool permits the user to develop custom modules.

The load flow solution is based on first principles; i.e., on the fact that all current vectors (voltage/impedance) entering a node must add up to zero.

MMS simulation tools also includes HMI and hard panel emulation to mimic control room displays, dials and gauges, switches, push buttons, indicator lights, and other

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[1] MMS is developed and distributed by nHance Technologies.

control/instrumentation animation. Tools for generating trends of any simulator variable and for monitoring/changing parameters on-line are also available. Control logic and HMI translators for several DCS (e.g., ABB-Bailey, Westinghouse, Honeywell, …) are also supported.

MMS employs an easy-to-use and efficient graphical drag-and-drop procedure for configuring the system to be simulated. An extensive on-line help system is available.

MMS is also used to provide or upgrade the electrical system models for simulators based on third-party platforms.

Procedure for Developing a Dynamic Load Flow Simulation

The electrical system simulation development starts with identifying portions of the one-line diagram of the electrical distribution system to define the scope of the simulation, i.e., what is to be included in the simulation model and what part of system operation is to be simulated. The next step is to select the MMS modules from the on-line list and connect them according to the one-line diagram. Each icon typically has an input data form for specifying the attributes of the component, e.g., rated voltage, current, power factor, impedance, horsepower, speed, moment of inertia. The data is next entered in US or SI units. The units can be readily toggled by a mouse click. The simulation model is then built by clicking the "Build Model" button.

The model can be executed in two ways: verification and analysis, and real-time on-the-fly interaction. In the verification and analysis mode, the model is executed by a combination of on-line and pre-built commands. In the real-time mode, the model is executed from the HMI as the actual system is operated in the plant.

Example Dynamic Load Flow Model

The example load flow simulation pertains to the power plant electrical distribution system (see Figures 1 and 2) described next. As shown in the one-line diagram of Figure 1, the system consists of a 618 MVA, 0.9 pf, 22 kV generator connected to the 230 kV grid bus through a 620 MVA step-up transformer, and connected with two 4.16 kV station service busses through a 18-30 MVA 3-winding step-down transformer. These busses receive startup power from the grid through another 24-40 MVA 3-winding step-down transformer when the generator is off-line. Major loads on the station service busses (8 motors totaling 9000 hp on bus 1A and 9 motors totaling 11800 hp on bus 1B) are shown in the one-line diagram of Figure 2.
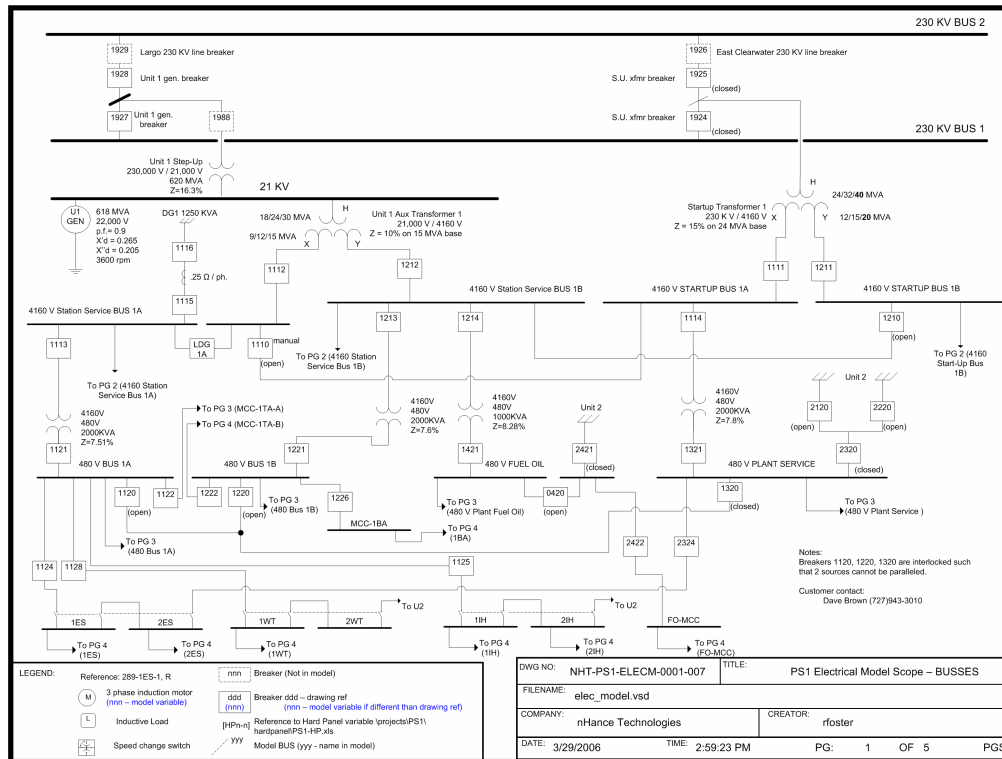
Figure 1 (one-line diagram of generator and busses):

230 KV BUS 2

1929 — Largo 230 KV line breaker
1926 — East Clearwater 230 KV line breaker
1928 — Unit 1 gen. breaker
S.U. xfmr breaker — 1925 (closed)
1927 Unit 1 gen. breaker — 1988
S.U. xfmr breaker — 1924 (closed) — 230 KV BUS 1

Unit 1 Step-Up
230,000 V / 21,000 V
620 MVA
Z = 16.3%
21 KV

Startup Transformer 1
230 K V / 4160 V X
Z = 15% on 24 MVA base
24/32/40 MVA H
12/15/20 MVA

U1 GEN
618 MVA
22,000 V
p.f.= 0.9
X'd = 0.265
X'd = 0.205
3600 rpm

DG1 1250 KVA
1116

18/24/30 MVA H
9/12/15 MVA X Y
Unit 1 Aux Transformer 1
21,000 V / 4160 V
Z = 10% on 15 MVA base

1111 1211

.25 Ω / ph.
1115
1112 1212

4160 V Station Service BUS 1B
4160 V STARTUP BUS 1A
4160 V STARTUP BUS 1B

4160 V Station Service BUS 1A
1113
LDG 1A
1110 manual (open)
1213 1214
1114
1210 (open)

To PG 2 (4160 Station Service Bus 1B)
To PG 2 (4160 Start-Up Bus 1B)

To PG 2 (4160 Station Service Bus 1A)
1121

4160V 480V 2000KVA Z=7.51%
To PG 3 (MCC-1TA-A)
To PG 4 (MCC-1TA-B)

4160V 480V 2000KVA Z=7.6%
4160V 480V 1000KVA Z=8.28%

Unit 2
2120 (open) 2220 (open)

4160V 480V 2000KVA Z=7.8%

480 V BUS 1A
1221
480 V BUS 1B
1421
480 V FUEL OIL
2421 (closed)
1321
480 V PLANT SERVICE
2320 (closed)

1120 (open) 1122
1222 1220 (open)
1226
0420 (open)
1320 (closed)

To PG 3 (480 Bus 1B)
MCC-1BA
To PG 3 (480 V Plant Fuel Oil)
To PG 4 (1BA)
To PG 3 (480 V Plant Service)

To PG 3 (480 Bus 1A)
1124 1128
1125
2422 2324

1ES 2ES
1WT 2WT
To U2
1IH 2IH
To U2
FO-MCC

To PG 4 (1ES) To PG 4 (2ES)
To PG 4 (1WT)
To PG 4 (1IH) To PG 4 (2IH)
To PG 4 (FO-MCC)

Notes:
Breakers 1120, 1220, 1320 are interlocked such that 2 sources cannot be paralleled.

Customer contact:
Dave Brown (727)943-3010

LEGEND:
Reference: 289-1ES-1, R
M — 3 phase induction motor (nnn – model variable)
L — Inductive Load
Speed change switch
nnn — Breaker (Not in model)
ddd (nnn) — Breaker ddd – drawing ref (nnn – model variable if different than drawing ref)
[HPn-n] — Reference to Hard Panel variable \projects\PS1\hardpanel\PS1-HP.xls
yyy — Model BUS (yyy - name in model)

DWG NO: NHT-PS1-ELECM-0001-007
TITLE: PS1 Electrical Model Scope – BUSSES
FILENAME: elec_model.vsd
COMPANY: nHance Technologies
CREATOR: rfoster
DATE: 3/29/2006
TIME: 2:59:23 PM
PG: 1 OF 5 PGS

Figure 1. One-line diagram of generator and busses

Figure 2:

From PG 1
4160 V Station Service BUS 1A (SS1AM)

Load	Motor	Ref
Fuel Oil Burner Pump 1A 250 HP 3568 RPM (MFOBP1A) 4000V 31A	FBP1A (BFOBP1A)	[HP11-5]
Fuel Oil Burner Pump 1C 250 HP 3568 RPM (MFOBP1C) 4000V 31A	FBP1C (BFOBP1C)	[HP11-9]
Dilution Wtr. Pump 1A 500 HP 1766 RPM (MDP1A) 4000V 63A	DP1A (BDP1A)	[HP1-13]
Circ. Water Pump 1A 1000 HP 295 RPM (MCWP1A) 4000V 164A	CWP1A (BCWP1A)	[HP1-7]
Boiler Circ. Pump 1A 900 HP 1750 RPM (MBCP1A) 4000V 138A	BCP1A (BBCP1A)	[HP3-1]
Boiler Circ. Pump 1C 900 HP 1750 RPM (MBCP1C) 4000V 138A	BCP1B (BBCP1C)	[HP3-5]
Condensate Pump 1A 1250 HP 1185 RPM (MCP1A) 4000V 161A	CP1A (BCP1A)	[HP5-3]
F.D. Fan 1A 4000/2250 HP 1171/871 RPM (MFDF1A) 4000V 502/298A	FDF1A (BFDF1A)	[HP11-15]

From PG 1
4160 V Station Service BUS 1B (SS1BM)

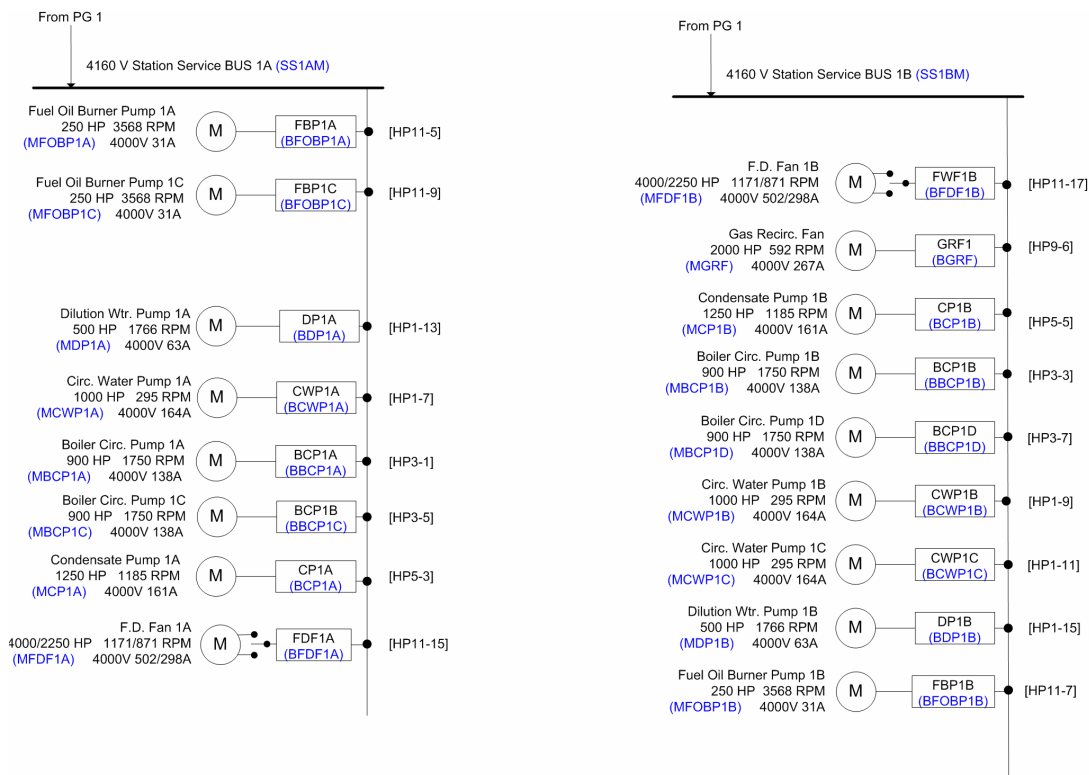| Load	Motor	Ref
F.D. Fan 1B 4000/2250 HP 1171/871 RPM (MFDF1B) 4000V 502/298A	FWF1B (BFDF1B)	[HP11-17]
Gas Recirc. Fan 2000 HP 592 RPM (MGRF) 4000V 267A	GRF1 (BGRF)	[HP9-6]
Condensate Pump 1B 1250 HP 1185 RPM (MCP1B) 4000V 161A	CP1B (BCP1B)	[HP5-5]
Boiler Circ. Pump 1B 900 HP 1750 RPM (MBCP1B) 4000V 138A	BCP1B (BBCP1B)	[HP3-3]
Boiler Circ. Pump 1D 900 HP 1750 RPM (MBCP1D) 4000V 138A	BCP1D (BBCP1D)	[HP3-7]
Circ. Water Pump 1B 1000 HP 295 RPM (MCWP1B) 4000V 164A	CWP1B (BCWP1B)	[HP1-9]
Circ. Water Pump 1C 1000 HP 295 RPM (MCWP1C) 4000V 164A	CWP1C (BCWP1C)	[HP1-11]
Dilution Wtr. Pump 1B 500 HP 1766 RPM (MDP1B) 4000V 63A	DP1B (BDP1B)	[HP1-15]
Fuel Oil Burner Pump 1B 250 HP 3568 RPM (MFOBP1B) 4000V 31A	FBP1B (BFOBP1B)	[HP11-7]

Figure 2. One-line diagram of major loads on busses

The MMS simulation model schematic is shown in Figure 3.

One of the HMI screens (plant one-line) is shown in Figure 4, while the hard panel emulations featuring the synchroscope and startup loads are shown in Figures 5 and 6.
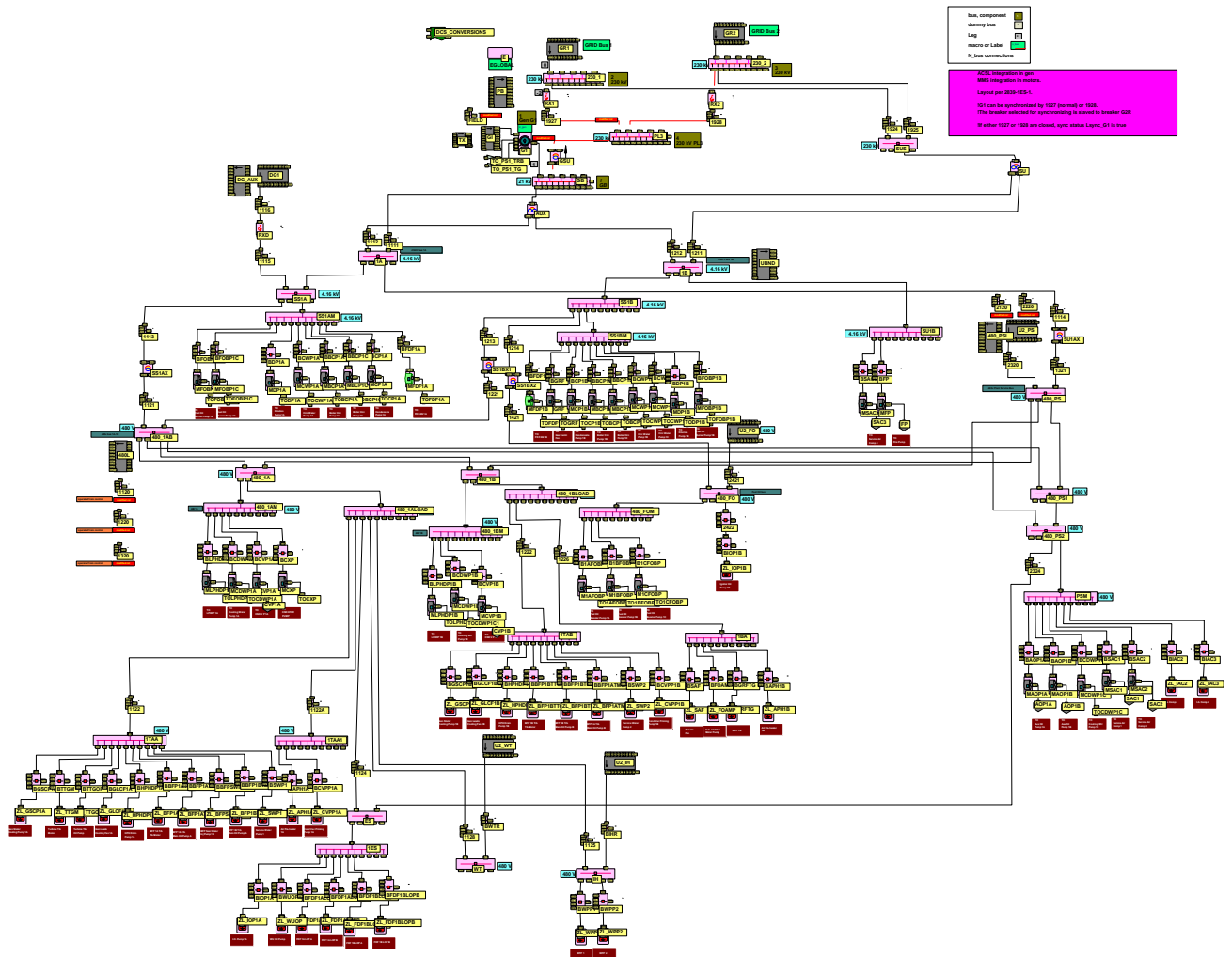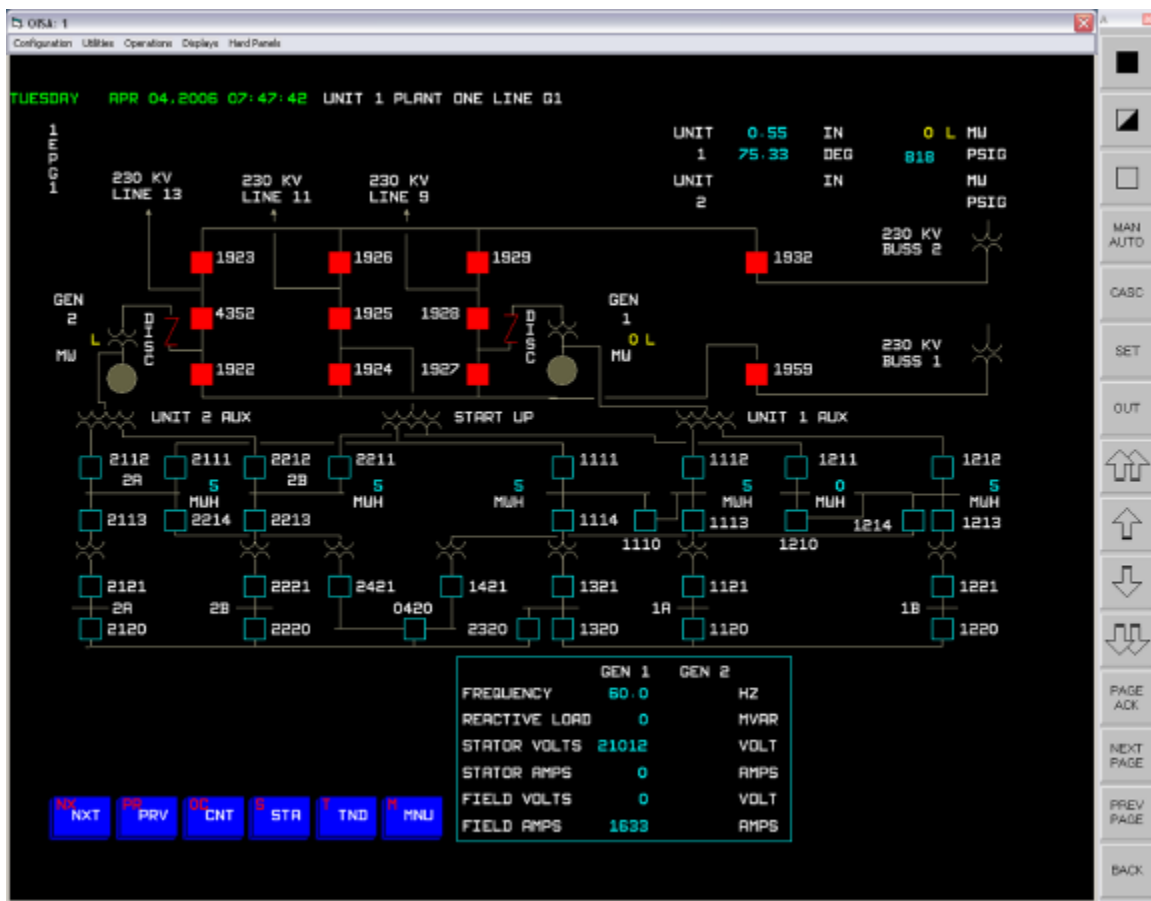

Figure 3. MMS model schematic
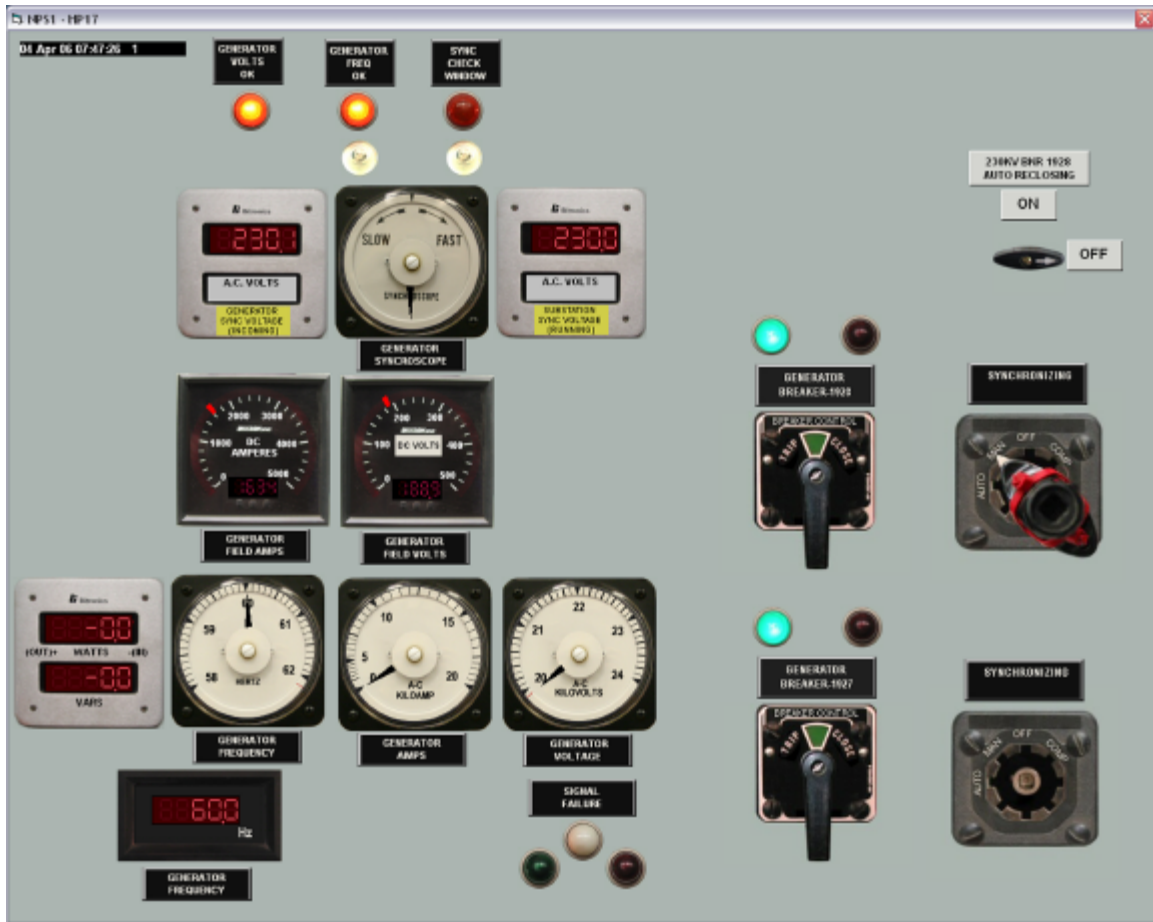
Figure 4. Plant's one-line HMI screen

Figure 5. Emulation of generator synchronization hard panel

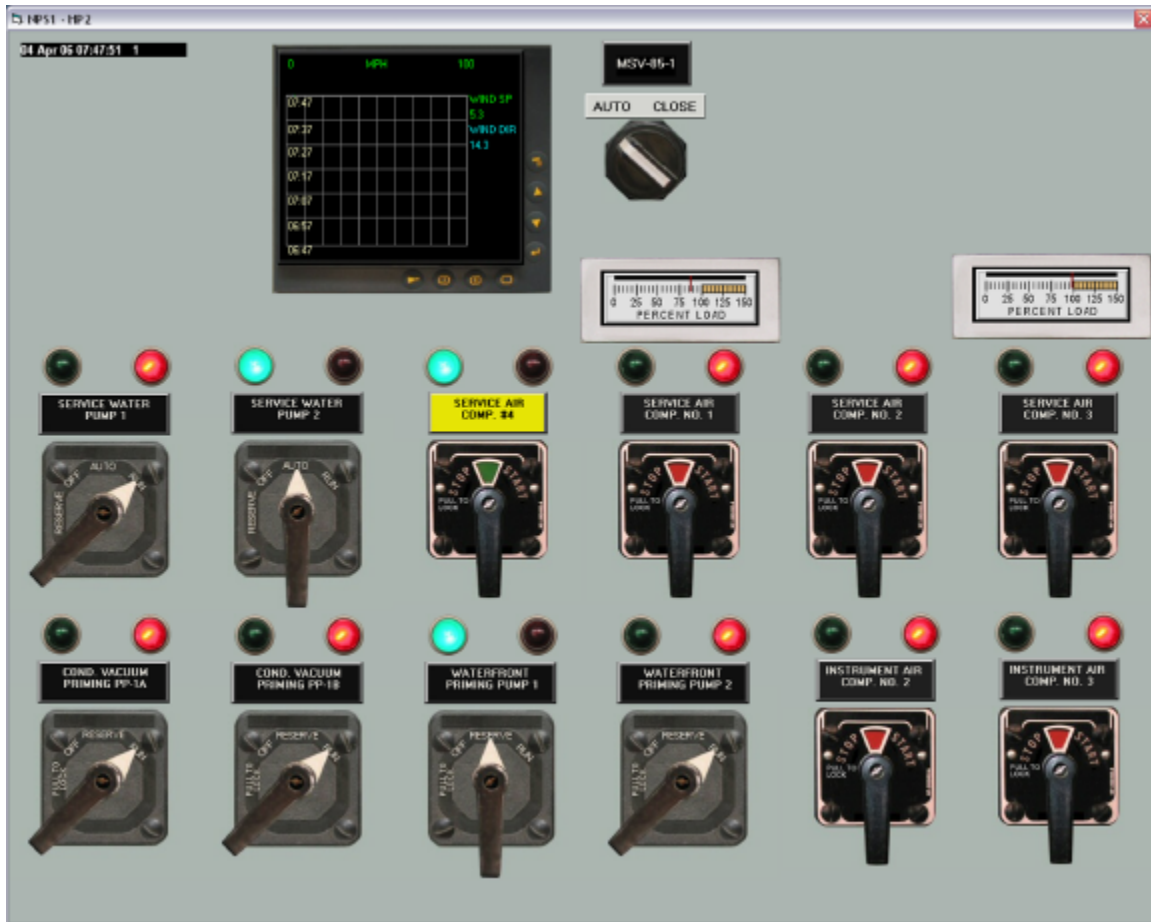Figure 6. Emulation of startup load, start/stop hard panel

Example Dynamic Load Flow Simulation

Before the generator is synchronized, the power for the startup and station service loads is obtained from the startup power supply by closing the appropriate breakers and starting the motors. Startup loads include auxiliary oil pump, cooling water pump, service air compressor, instrument air compressor, etc. Station service loads include condensate pump, forced draft fan, fuel oil burner pump, etc. Then the generator is brought up to synchronous speed by operating the turbine steam valves, the excitation current is adjusted to obtain matching terminal voltage, and the generator is synchronized from the synchroscope. The generator power output is then increased by opening the turbine throttle valves, and adjusting the excitation current from the automatic voltage regulator. The power for the station service loads is then changed from startup supply to the generator by closing and opening appropriate breakers.

Trends in Figures 7 and 8 show typical motor starting current and important parameters of the generator, respectively.
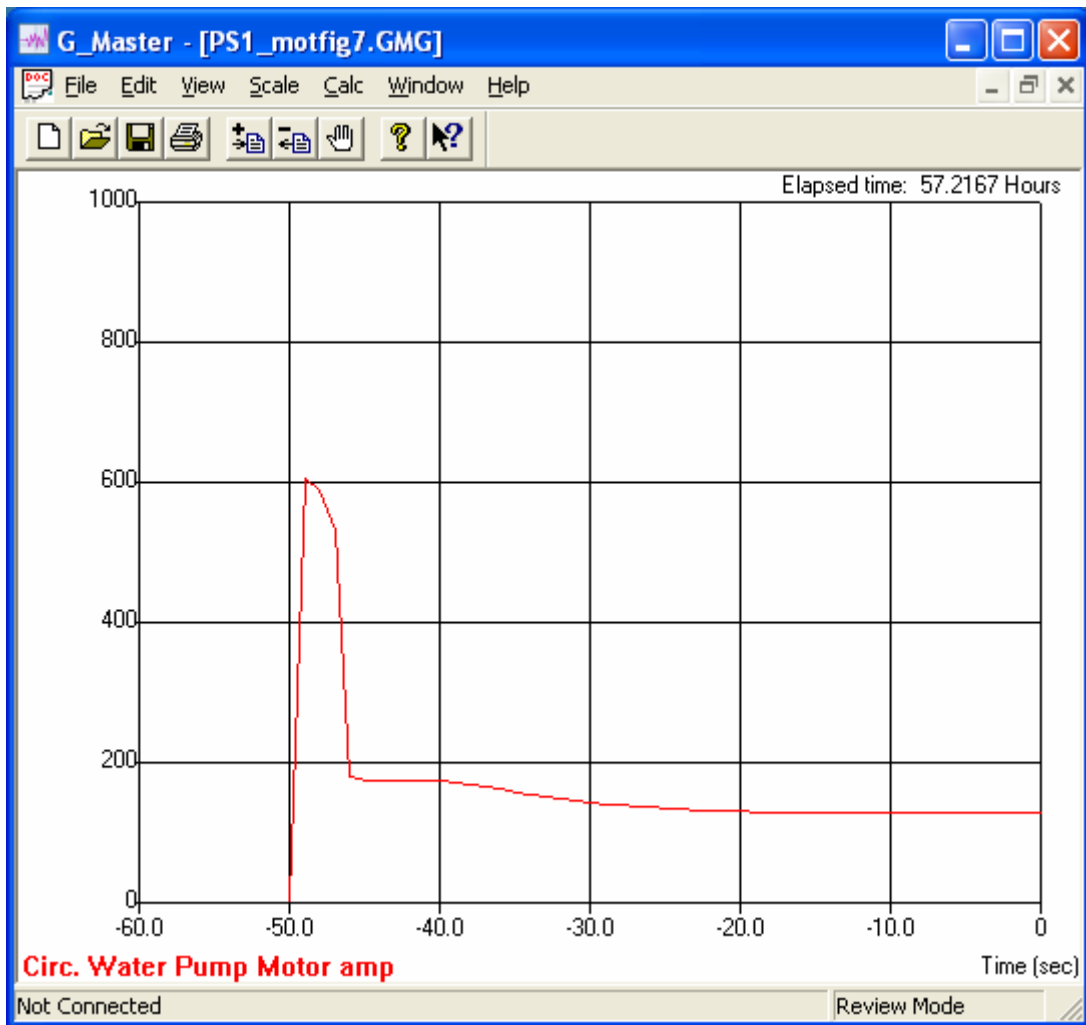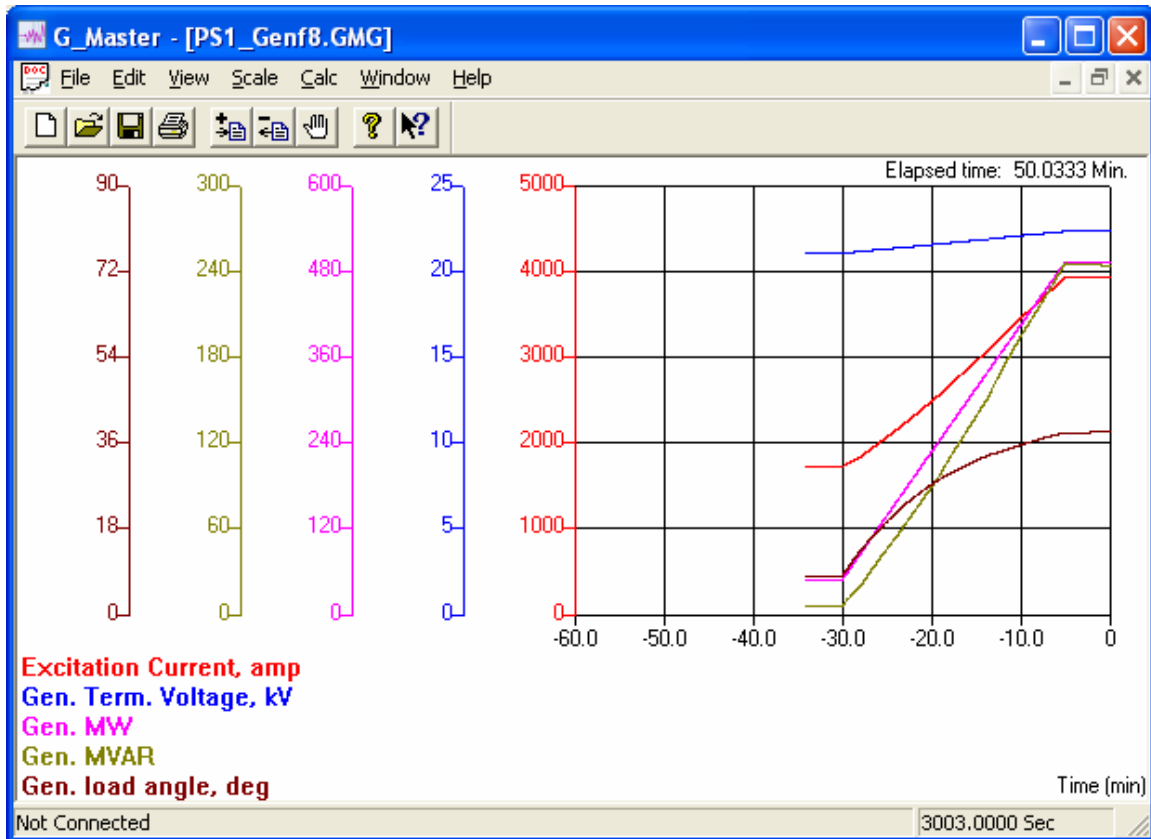
Figure 7. Motor starting current

Figure 8. Generator parameters

Biography

Sadashiva Godbole performs power plant simulation development at nHance Technologies, Lynchburg, Virginia, USA. Earlier he was an Advisory Engineer and Framatome Expert at Areva NP Inc. He holds a Ph.D. in Electrical Engineering from Virginia Polytechnic Institute and State University. He has numerous publications.