State of the Art in the Industry

180A POWER SYSTEM SIMULATOR

Hampden Engineering Corporation

The World Leader in Teaching Equipment

GENERAL

The essence of all operations are modeled on a typical central station utility. Basic system operations include:

- Time
- Diversity of Loads
- Multiple Sources of Generation
- Interconnection of Systems

Understanding of these concepts is necessary for any successful presentation or study of basic central station utility systems, and also form the basis for the design and development of new sources of reliable power.

The control panel of Hampden's Power System Simulator has been designed to provide full functionality and control for the following operational factors:

1. LOADS

The panel includes simulations for constantly varying levels of consumer loads including; industrial, commercial, residential, and street lighting requirements.

The primary element of time is introduced, for example; daytime industrial loads, evening commercial applications, 24-hour residential utilizations, and street lighting. The standard time cycle has been compressed so that a 2 hour real-time session will include a complete 24-hour normal load cycle.

2. VARIABLES IN THE SUPPLY OF ELECTRICITY

There are two variables—frequency and voltage. There exist thoughts in the minds of customers of electric power companies that variations in the operations of their individual plants are somehow traceable to the characteristics of the electric supply.

As a teaching station, the control panel has features for this discussion and to demonstrate the effects of variations in frequency, voltage or both.

3. DEMAND METERING

Short-period demands exist. The control panel provides the user of the panel the major consideration of demands in the allocation of charges applicable to customers' peak loads. Such discussion leads into the ratings of equipment as needed to carry certain loads over stated periods. Again, working backwards from load to generation, this diversity governs the ratings of major places of equipment.

4. TRANSMISSION

The entire economic justification for higher and higher levels of voltage cannot be portrayed simply. Yet, leaving aside all the considerations of right-of-way which govern the total cost of ownership, technically, the importance of higher voltage transmission can be readily made demonstrable by voltage changing equipment in combination with some relatively simple metering of line loss and voltage drop.

5. RELIABILITY OF SERVICE

The board serves to emphasize the fundamental objective of maintaining service with a minimum of interruption. This is somewhat in contrast to one which may emphasize relaying, as relaying usually stresses protection of equipment.

The basic conception of the purpose of protective switch-gear is to isolate faulty equipment and thereby preserve the continuity of supply. This basic concept can be shown with the control panel.

The common residential service overcurrent equipment either serves to protect customers' wiring or to isolate a faulty member of a utility system, depending upon one's viewpoint.

6. LOCAL GENERATION

The control panel demonstrates the use of local generation relative to its assistance in maintaining continuity of service and fulfilling requirements of peak-load periods.

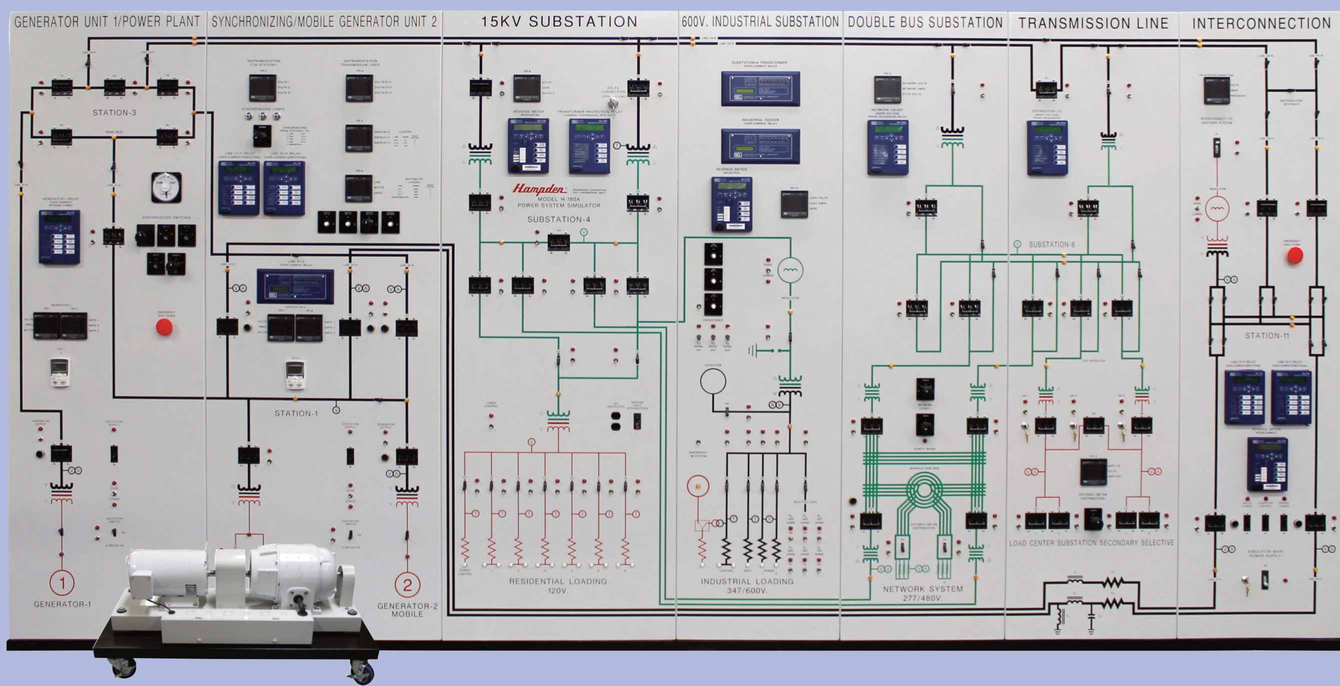
7. FEEDER DESIGN

The board has sectionalizing switches in feeders. These switches add flexibility. They are used to locate faults through line sectionalizing. Also, for continuity of supply, they are used as selective switches to normal or emergency sources.

Double busses at substation are included with alternate switching for purposes of discussion about circuit breaker testing and maintenance.

8. OTHER EXPERIMENTS

Other experiments concerned with aspects of the utility field can be worked.



SPECIFIC MATERIALS

Instruments

All instruments for the power simulator are of the switchboard mounting type with an accuracy of 1% and will be manufactured by the Yokogawa Electric Company or Schweitzer Engineering Laboratories, Inc.

Circuit Breakers

The circuit breakers are of two types, the first being the de-ion air type enclosed in bakelite housings and properly rated for voltage and current required and manufactured by the Westinghouse or General Electric Corporations. The second type is hydraulic magnetic, properly rated for the voltage and current required in each specific application, and of the relay trip type where required, and manufactured by Airpax or Heinemann Electric Company.

Transformers

All transformers for use in the power simulator are dry type, double wound units with two 2 ½% taps above/below nominal voltage on all 3Ø units. It will be as manufactured by the Nothelfer Winding Laboratories, EPCO, Westinghouse, or General Electric Companies.

PANEL DESIGNATION

All receptacles, switches, circuit breakers, and other equipment required on the various panels are silk-screened with proper nomenclature of ratings, polarity symbols and other necessary description to clearly identify the functions.

The top of each panel of the main board is silk-screened with 1-1/2 inch (3.8 cm) high letters designating the service of the panel.

Equipment contained within the confines of the panel, such as transformers, etc., are silk-screened on the face of the panel and all connecting lines and bussing are silk-screened also and/or striped on the panel so that the entire system is graphically represented by the one-line diagram and symbols.

The lines are weighted in relationship to their voltage level, i.e. the higher voltages are heavier lines and substation or busses are also of heavier weight to depict a main feed.

CONSTRUCTION

The entire switchboard consists of seven enclosed sections fastened together to make a total approximate length of 16 feet (4.88 m) and they measure a total of 93.5" (237.49 cm) high overall and 36" (91.44 cm) deep. Width for each section is as follows: Section 1 - 32.5" (82.55 cm), Section 2 - 37" (93.98 cm), Section 3 - 36.5" (92.71 cm), Section 4 - 26.5" (67.31 cm), Section 5 - 27" (68.58 cm), Section 6 - 28.5" (72.39 cm), Section 7 - 28" (71.12 cm).

All construction of the main board is fabricated of 1/8" (.3 cm) thick furniture stock steel formed back four inches (10.2 cm) on all sides with an additional 1-1/2" (3.8 cm) return form on the rear of the panel so that equipment can be fastened to the rear.

POWER INPUTS

The typical power requirements are as follows:

- 120/208V–3Ø–4W–40A,
  or 220/380V–3Ø–4W–25A,
  or 240/415V–3Ø–4W–25A

POWER SYSTEM SIMULATOR—GENERAL

The intent of the Power System Simulator is to incorporate all aspects of a power system from generation and interconnection through transmission to distribution. Three distinct levels of voltage are utilized. The 208* or 220* volt level will be used for interconnection and generation, as well as for residential and network voltages, 380* volts will be used by the distribution and industrial levels and 600* volts will be used for the transmission levels.

** These voltages are adapted to the voltages at the end user's site.*

Section 1 contains facilities for generation and a substation incorporating the generation and power transmission.

Section 2 contains facilities for synchronization and generation and a station incorporating the generation and power transmission.

Section 3 incorporates a distribution sub-station and distribution functions covering residential distribution.

Section 4 is an industrial sub-station and distribution functions covering industrial distribution.

Sections 5 & 6 incorporate a double bus distribution sub-station, a network system and a selective secondary distribution load center.

Section 6 incorporates the line settings for two transmission lines.

Section 7 incorporates facilities for inter-connection with a separate power system (in the case of this power system simulator, it would be a local power company) and contains facilities for generation and a substation incorporating the generation and power transmission.

TRANSMISSION LINE STUDIES

In order to expand the utilization of the Power System Simulator, additional equipment has been added to various sections of the switchboard, enabling an expanded study of transmission lines.

Additional equipment provides the means of studying the following topics:

A. General Transmission Lines
B. Overhead Transmission Lines
C. Parallel Transmission Lines
D. Underground Transmission Lines

The first experiment covers a general introduction to the various aspects of electric power transmission.

The second experiment covers overhead lines. Specifically it involves:

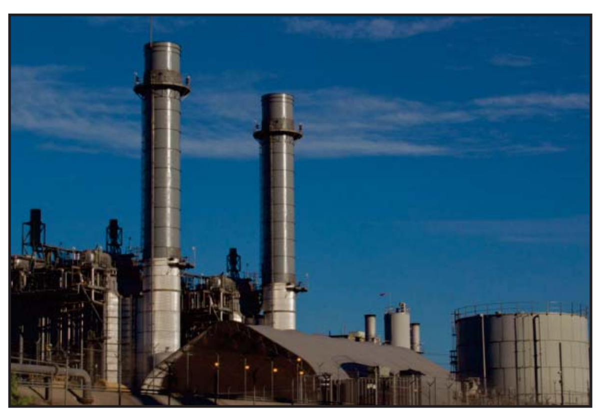
A. The effect of line impedance on voltage regulation and line losses.

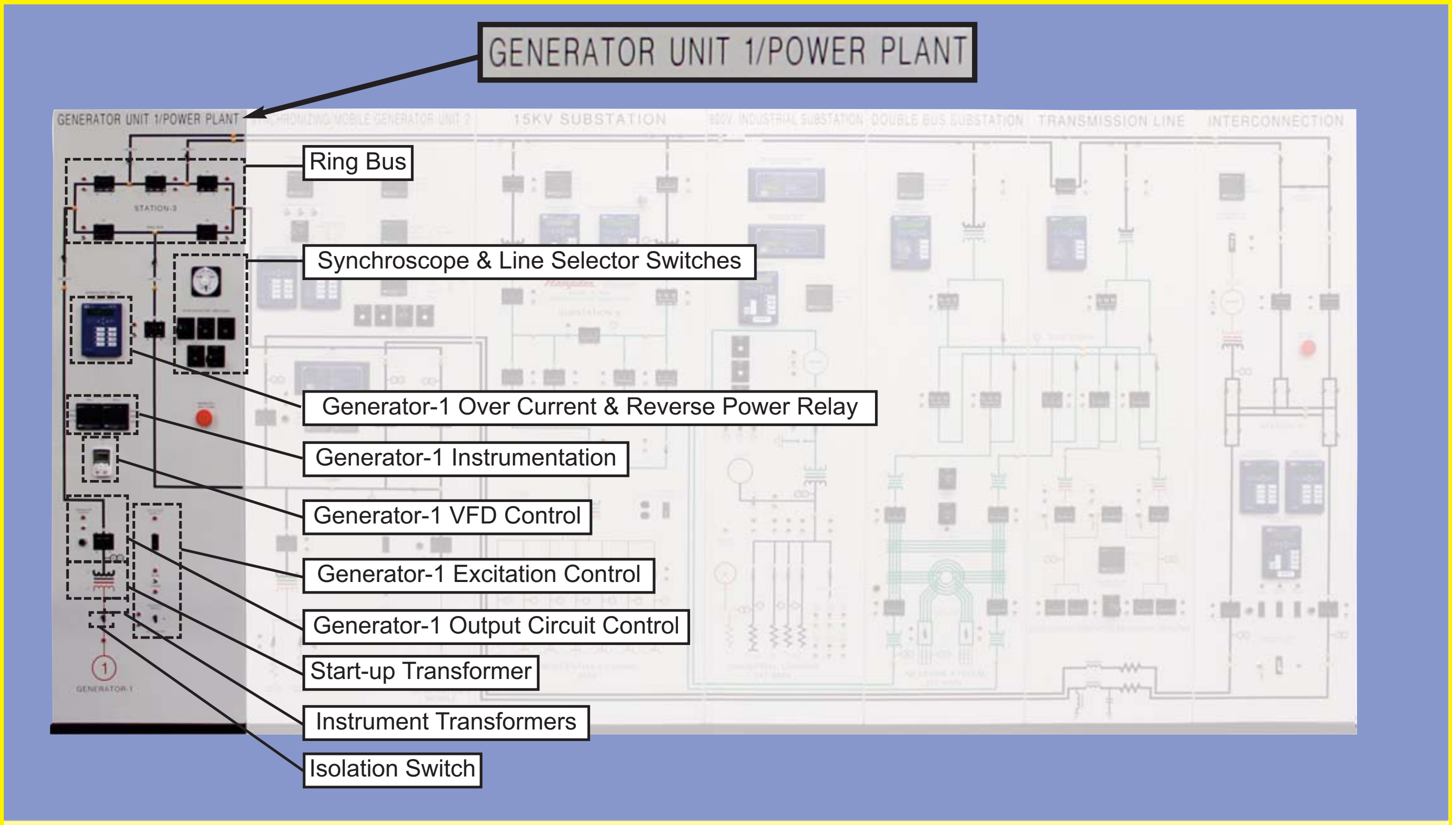
B. The relationship between voltage, load, power factor, and losses.

The third experiment is an expansion of the second experiment covering the same parameters on parallel lines having unequal impedance.

The fourth experiment covers the inherent limitations of high voltage underground cables due to shunt capacitances. It also simulates typical corrective measurements in present use.

The additional equipment consists of the simulated transmission line components as shown graphically on the bottom of the sixth switchboard section labeled sub-stations, additional instrumentation is also required and is shown on sections two, four, and seven, as control switches for various motors.

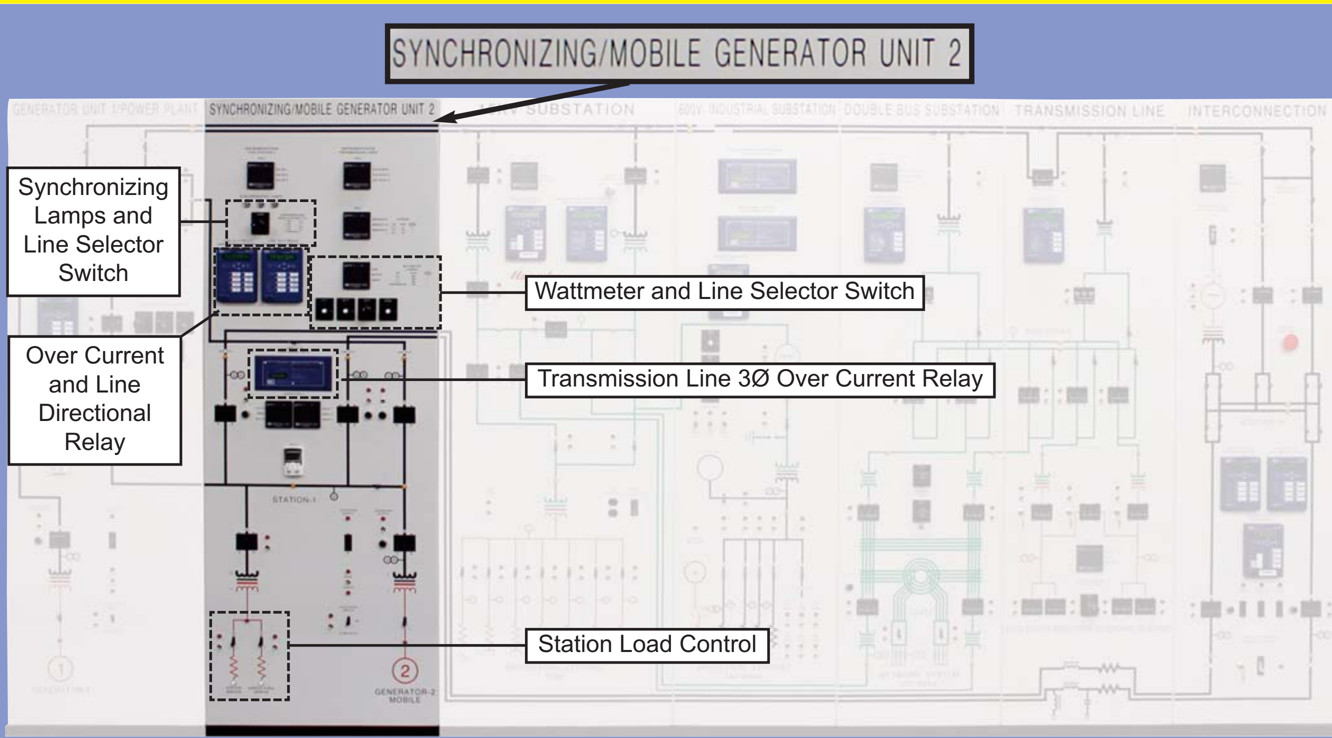




SECTION 1—GENERATOR UNIT-1/POWER PLANT

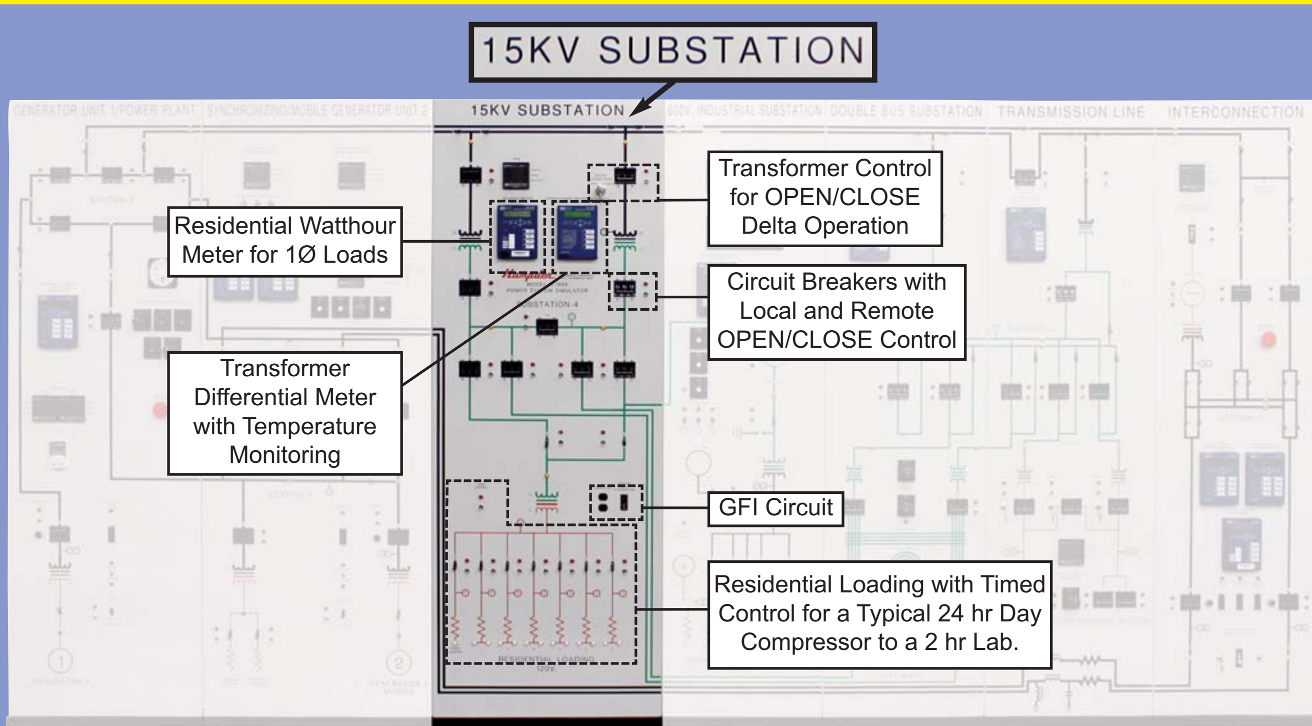
- This section contains provisions for two separately supplied 1.5-kilowatt 3-phase AC alternators.
- Voltage, current in each phase, power factor, and power instrument is provided for each alternator.
- Also supplied is a provision for the control of the field excitation of each alternator.
- Provisions are made for control of (1) 125V DC power supply from the station service to be used as a power source for relaying.
- Generator-1 has protection for differential, ground overcurrent, reverse power, ground fault, loss of excitation, under / over frequency, under / over voltage, over current, loss of synchronization, and transformer protection.
- The end of Section-1 contains amphenol connectors for Generator-2 excitation, Generator-2 drive motor and Generator-2 output for the connectors of the mobile Generator-2.
- Provides one synchroscope with five synchroscope instrument switches, one for each of two generators, and one for each of three lines coming onto the main bus in generating station #1.
- Also provide a ring bus network complete with isolation circuit breakers. This bus serves as Station #3 and ties the generation and transmission lines together at the high voltage level.

SECTION TWO



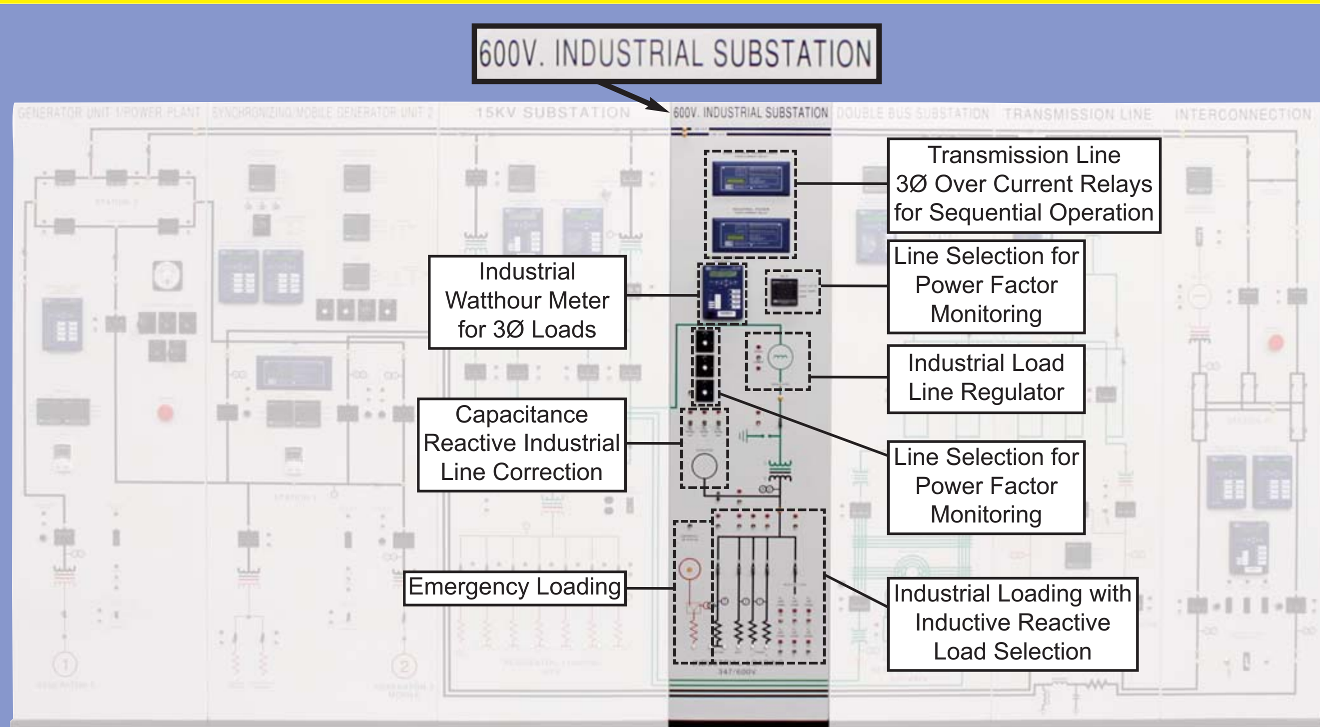
SECTION 2—SYNCHRONIZING AND GENERATOR UNIT-2

- This section also contains provisions for the second generator, station and agricultural service, line #B1-3 instrumentation, and station-I instrumentation.
- The station and agricultural service consists of a step-down transformer; disconnect means and loading scaled to depict a similar circumstance on a typical power system.
- Line #B 1-3 contains over-current relays, voltage, current and power instrumentation, so that the accumulated power output of station 1 can be monitored and recorded.
- Station #1 contains frequency monitoring for several points in the system, and transmission line directional relaying.



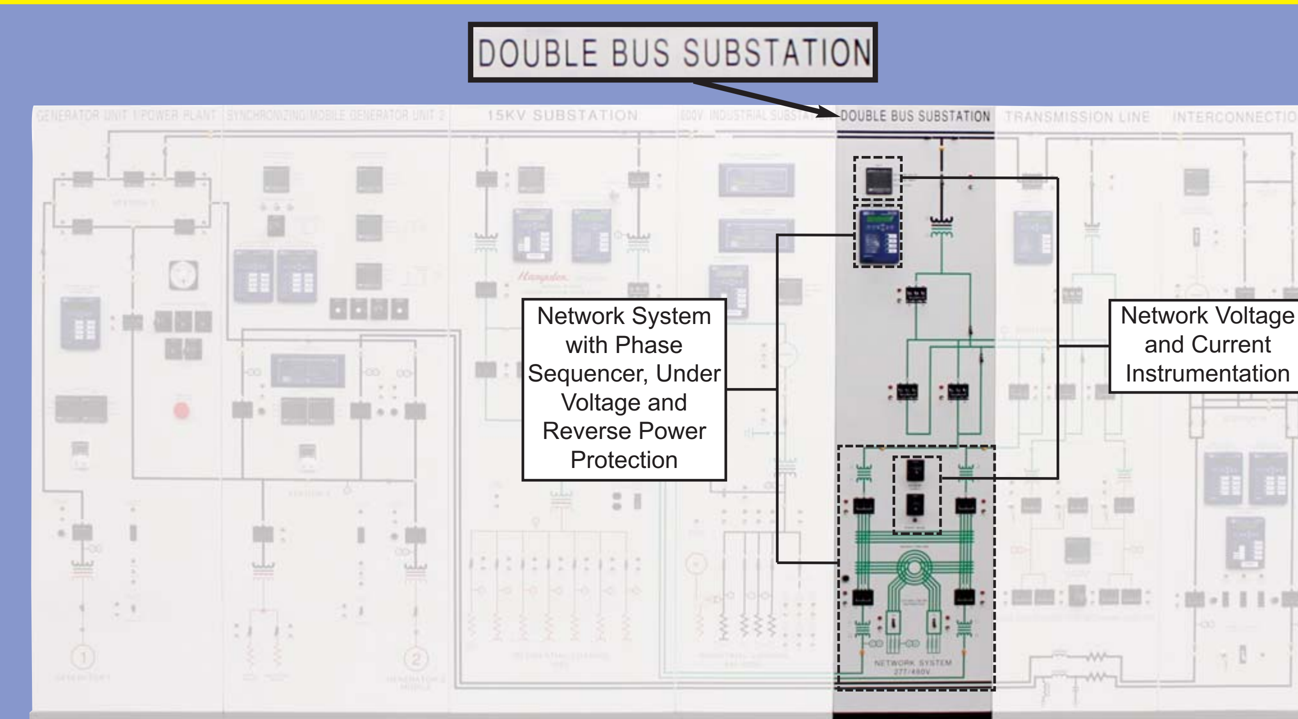
SECTION 3—15KV SUBSTATION

- Section 3 provides provisions for sub-station #4, which transforms the transmission voltage down to distribution voltages and from distribution voltages down to residential and industrial voltages. The five circuit breakers in sub-station #4 depicts air circuit breakers which would actually be used in the substation application.
- One of the transformers is constructed in such a manner that it has a built-in fault which can be manually controlled, and which will overload the unit, yet not destroy it. We have also provided a differential relay for the study of transformer faults, and provision for trending current flow, and a recording temperature meter for the transformer study.
- Seven residential loads are included, each with its own fused disconnect switch operable from the front of the board with the fusing on the rear of the board.
- Each load is timer controlled with indicating light and control switch. The load is a multi-step so that a cycle of loading can be plotted, forming a discreet loading curve for a typical period of time.
- The residential loads are complete with a revenue kilowatt-hour meter to monitor groups of loads by phases, with recording capabilities.
- Also included is a 1Ø residential type ground fault detector so that an analysis can be made of its function.



SECTION 4—600V INDUSTRIAL SUBSTATION

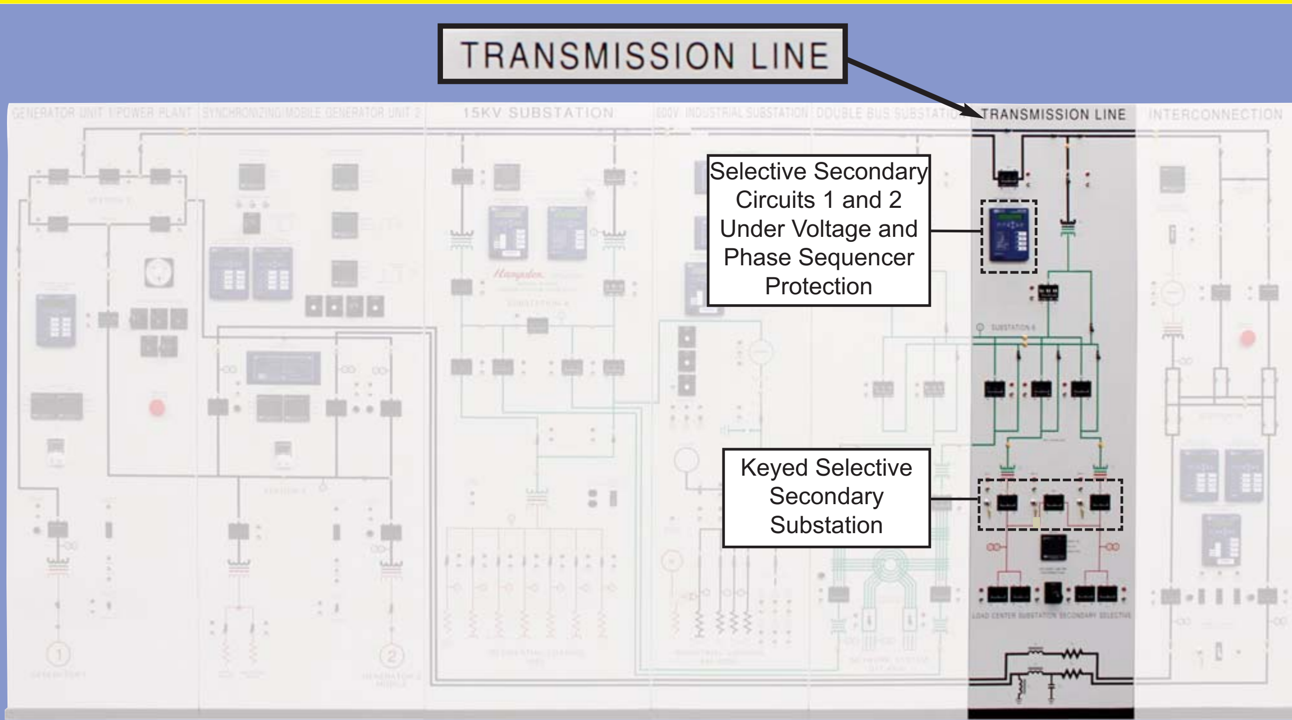
- This section contains provisions for industrial loading, transformer over-current relaying, and feeder over-current relaying and power factor correction.
- The industrial load consists of power, heat, and lighting loads which will be monitored by voltage, current, and watthour instrumentation. A power quality and revenue type watt-hour meter is used so that its function can be investigated. The industrial loads are timer controlled similar to those provided on the residential loads so that the industrial power requirements can be included into the total system loading curve.
- The feeder to the industrial loads contains a manual voltage regulator, and VAR meter. The manual voltage regulator is used to depict the varying effects of over and under voltage. The power quality and revenue meter provides a record of all current requirements to the industrial load. Plus it is used to indicate the effects of the inductive load supplied as part of the industrial load and of the capacitance added as line correction.
- The emergency source is used to depict transference of lighting from standard power to emergency power and this contains its own voltmeter and pilot light indicator.
- One 3Ø transformer over-current relay is provided to be used with the transformer on Section 3. Also provided is one 3Ø feeder over-current relay to be used in conjunction with the transformer over-current relay and the generator over-current relay so the system can be set up to depict sequential relaying as would be found in a typical power system.



SECTION 5—DOUBLE BUS SUBSTATION

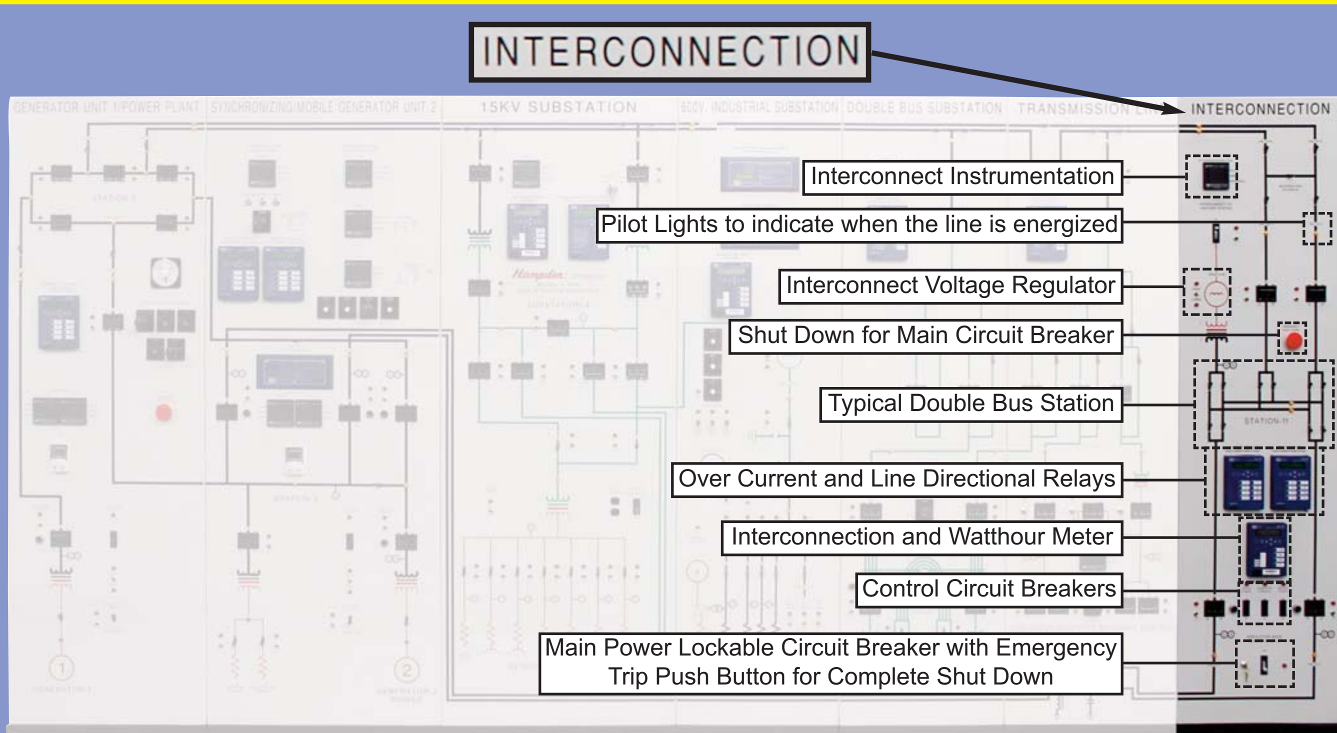
- Section 5 provides a distribution system as would be found in a commercial area. It consists of a network system fed from four different points with a reverse power relay on one transformer so that network problems can be analyzed.
- Two 3-phase 4-wire distribution circuits are supplied from the network system complete with a disconnect switch and behind the panel fusing. These circuits are available for termination at a remotely located site. The distribution circuit has a voltmeter and ammeter, each with phase selection instrumentation switches.
- A portion of sub-station 6 double bus substation is incorporated into the switchboard section and consists of one feeder circuit and part of the distribution circuits and a voltmeter to monitor the bus voltage.

SECTION SIX



SECTION 6—TRANSMISSION LINES

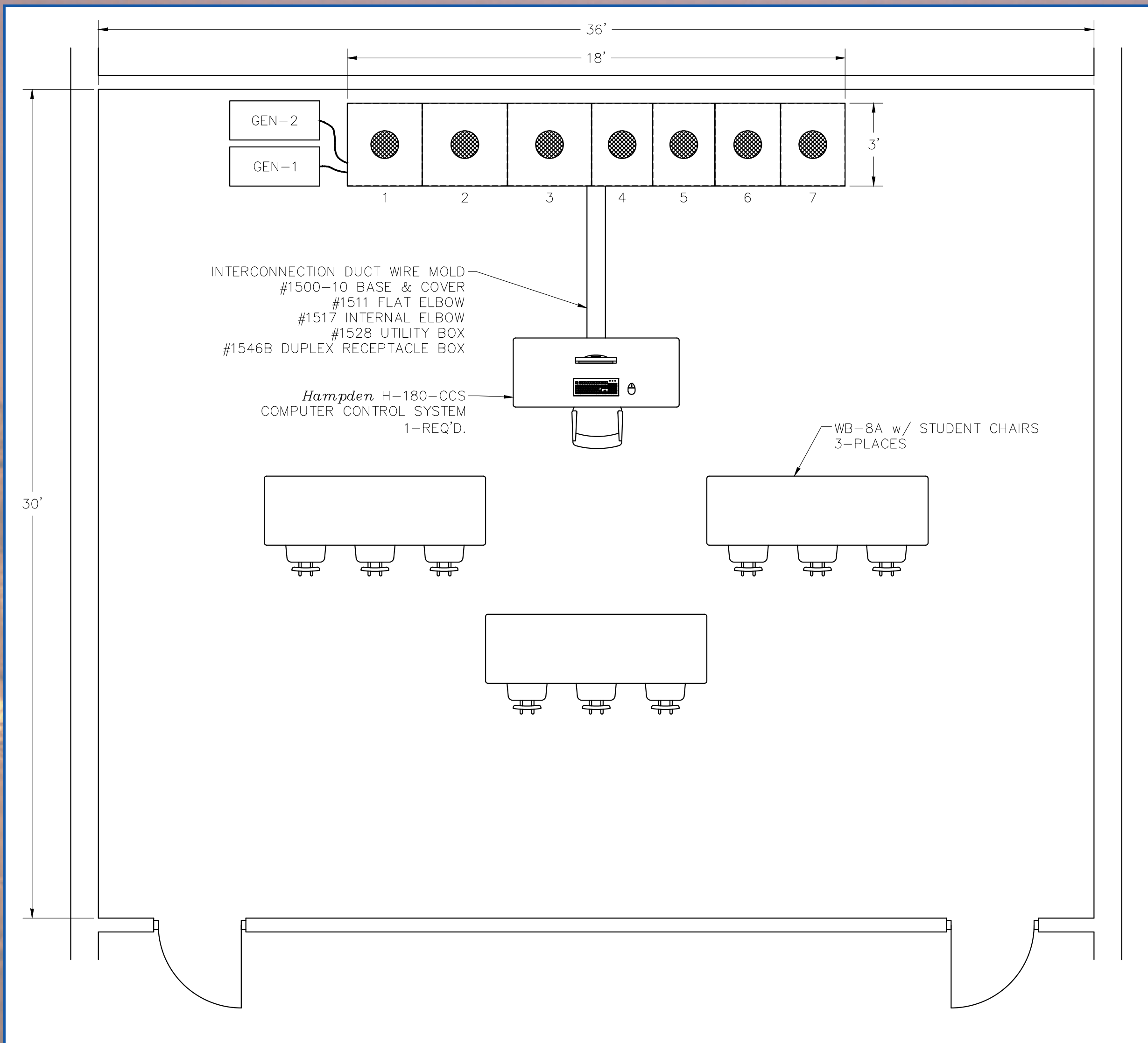
- This section provides the remaining portion of sub-station 6 double bus substation, including the second feeder. This sub-station depicts the two-bus system with the main bus and auxiliary bus, along with the proper bypass switches and connecting circuit breakers.
- The lower portion of this panel contains a selection of circuit breakers properly connected to depict a load center substation, with a selective secondary, consisting of proper interlocking of incoming power so that either line may feed the entire station or the station can be split into and fed from two sources of power.
- This sub-station has provision for monitoring the current coming in via each feeder and a bus voltmeter. The four distribution circuit breakers are available as feeders to a remotely located site, also being fed from the network system. Circuit #1 has provided a reverse phase relay so if motor studies are included at the output, the problem of phase reversal can be investigated.



SECTION 7—INTERCONNECTION

- Provision is made on this section for interconnection to the local utility company and this depicts one company tying in with another. The interconnection instrumentation includes a revenue kilowatt hour meter, voltmeter, ammeter and frequency meter. Also provided as part of the interconnection, is a 3-phase voltage regulator for adjusting the system voltage level. The interconnection feeds a double bus system which provides taps for the transmission lines to the other generating stations located at the other end of the board and also feed lines to the distribution network.
- Two directional relays are provided, so that a study of transmission line faults can be conducted on lines
- C1-11 and D1-11. Faults will be built into the panel so that proper operation of the relays can be investigated and the sequence of events studied.
- This section contains the main power circuit breaker with key lock for the entire switchboard. This circuit breaker controls both the power to the interconnection circuit breaker and the power to the DC system supply so that complete control of the system simulator is maintained from this single circuit breaker. Two emergency pushbuttons, one on this section and one on Section 1 are provided so that the system can be immediately shut down, should any problem develop, which could constitute a safety hazard. These emergency stations will operate the main simulator power supply circuit breaker so that no power will be left energized on the board. Provision will be made for further remotely located emergency pushbutton stations which can be located anywhere in the laboratory as required.
- Provision will be made for control of a 125V DC power supply from the station service to be used as a power source for relaying.
- Provision will be made for control of the computer power source and the 5 VDC control power source.

ROOM LAYOUT



180A POWER SYSTEM SIMULATOR ROOM LAYOUT

A. Hampden 180A Seven-Section Power System Simulator

B. Hampden Pancake Duct

C. Hampden 262-180 Power System Simulator Console

D. Hampden HC-2563-1 Arm Swivel Chair

E. Hampden H-CS Computer Terminal

SYSTEM CONFIGURATION

The power system simulator is equipped with remotely programmable switching, relaying and generator control. Additionally, critical state variables within the power system simulator were brought out to a central point for easy access by data acquisition systems.

A small microcomputer capable of handling the on-line control problem and graphic display, was interfaced to the power system simulator.

The PC performs data acquisition on the power system simulators via a high speed data acquisition system. The PC then scales, error checks and displays the data on the VGA graphics system. On-line system simulation and unobserved state variables are determined as a separate task in the PC. This on-line simulation consists of a multi-bus, multi-area PC based load flow program.

POWER SYSTEM SIMULATOR

The simulator (Figure 1) is a small power system consisting of scale generators (2), a transmission system, a subtransmission system, substation and loads. The loads are both balanced and unbalanced and conformal and nonconformal loads. The generation is in the form of two DC motor/synchronous generator sets of 1 kilowatt. Additional tie capacity may be supplied to the simulator through the system interconnection. The high voltage (600 volts) transmission connects the generation of two distribution substations where residential and industrial loads are simulated. There is also a network system fed from both the substations, and the load center substation as well. The circuit breakers and certain control switches are specially modified allowing them to be operated remotely by the computer on command, thus simulating the supervisory control capability of an actual power system.

THE COMPUTER

The Instructor's computer consists of a Pentium class computer configured with 2Gb of random access memory, two serial ports (COM1 and COM2), a parallel ink-jet printer connected to LPT1, and an 22" (55.8 cm) VGA LCD graphics display as configured as the primary display. The computer is also equipped with a PC mouse, which allows the operator to interact with the displays being provided by the computer. This interaction consists of displaying the results of the embedded systems acquisition of specific voltage and parameters within the network and also allowing the operator to interface with the network to perform switching functions.

SIMULATOR INTERFACE

The simulator interface circuitry is used to perform level changes between the 4 volt TTL signals available on the TTL discrete controller board within the PC, and the 1Ø AC commands needed to operate the controls within the simulator. The purpose of this interface, in addition to the level conversion, is to offer a high level of isolation between the system simulator and the computer. In order to accomplish this, a relay triac opto-isolator arrangement has been utilized.

MICROCOMPUTER SUBCONTROLLER SYSTEM

The microcontroller subcontroller system is provided to perform closed-loop control of the generators during normal operation of the power system simulator and to provide synchronizing data to the PC when a generator is added or removed from the power system during normal operation of the power system simulator.

SYSTEM DESCRIPTION

The control software on the computer unifies and integrates the control of the distributed component. The computer performs normally closed-loop tasks, that is, providing automatic voltage and speed control and power control of the individual generating units. The computer provides a supervisory control to the generator controller in the form of AGC commands and whether or not the units are to be committed or not, and what the individual voltage levels are to be scheduled on each one of the units.

CONTROLLER SOFTWARE

The software is written in modular form, using Visual Basic as the primary language. The software is structured as a display software module, a data acquisition module, a controls module and a communications module. The display handles all interaction between the individual user and the software. In addition, it handles the display of individual network subsystems and the appropriate data from the data acquisition system. The control software gathers data from the display software as to the switching decisions of the operator. It then relays this to the I/O chips which then interact with the interface equipment to perform network switching in the simulator. The data acquisition module controls the Data Translations A/D converter. This data acquisition model gathers specific needed state variables from the power system simulator as to voltages, currents, phase information, and power flows. This data is then gathered and passed through a common array to the display module where it can be displayed on the various one-line diagrams that the operator brings forward. The communications modules also provide asynchronous communication to the mouse in order to give the display software an idea of where the operator currently wants to execute control. The asynchronous ports also provide communications to the Microcomputer Generator Control Module for purposes of changing the frequency, loading, or excitation of any specific generator in the system.

DESIGN & ANALYSIS

The second major off-line program is the 100Bus Commercial Power System Design & Analysis package which has the following capabilities:

• Modeling Capabilities:

Electrical — CAD modeling system, 100% AutoCad™-compatible with intelligent modeling and integrated test editor.

Model — 3-phase, 1-phase, DC, AC/DC, Loop, Radial, Balanced and Unbalanced network configurations.

• Analysis Capabilities:

Short circuit analysis

3-Phase IEEE method, ANSI C37, IEC 909, Fault X® and MF decrement, Breaker derating ä Reactor Sizing, Stress & Withstand, Arc Fault, Single Phase, Single-Phase Transformer

Full-Load Analysis

Motor Starting Load Flow Analysis

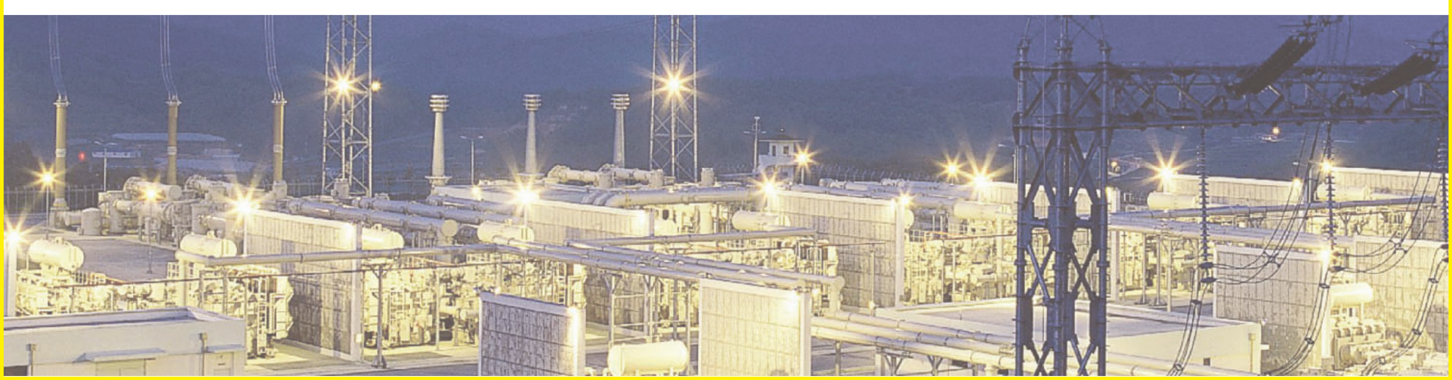
- Protective Device Coordination
- Electrical Schedules
- Wire and Conduit Sizing
- Short Line Parameters
- Transformer Sizing (Load Profile Method)
- Bare Wire Sizing
- Generator Set Sizing
- Power Factor Correction

SYSTEM PERFORMANCE AND UTILIZATION

The computer control and power system is used in research and the instruction of power system engineering students as part of the structured and discovery laboratory form. The student is situated at the power system control center. He then merely selects the interconnect and appropriate closing switches from the interconnect, thus bringing the interconnect to the system. The student can schedule or direct by means of the mouse which one of the generation systems to bring on-line. Once the operator selects the generation system to be brought on-line and supplies power, the computer selects a prescribed sampling algorithm. In a closed-loop fashion the microcomputer brings up to speed and puts on-line the selected generation units. The student or the operator can select specific loads to be brought on-line, whether they be distribution, light industrial or commercial. The software will readjust the generation to account for var flow, voltage regulation and automatic frequency control. The student can then select one of a group of unscheduled contingencies and 1) manually interact with the system to reschedule the system into a new schedule or 2) allow the computer to reschedule around the system contingencies. The student is then capable of observing the power system simulator both in a closed-loop automatic mode or open-loop manual control mode. The power system simulator can be utilized by both industry and academic use in both training and in research.

CONCLUSION AND FURTHER WORK

The combination of the Hampden Model 180A Power System Simulator and the PC based controller provide an extremely economical means of providing a teaching and research test bed for power system automatic control. The computer-based system also provides an inexpensive operational support tool to test on-line load flow and on-line stability programs. It is also used to develop load flow and stability programs for systems other than the simulator.



MODEL 180-MS POWER SYSTEMS MODELING

This training method, Power Systems Modeling, starts the operator at the computer developing a power system model and verifying it on the simulator.

Through the use of the texts provided with the trainer, the student is shown how to create a power systems model using the graphic tools resident in software. Then this model, along with its predetermined responses and actions, can be applied to the simulator, and its performance studied. Various math and engineering analysis tools are provided, such as power factor analysis, curve shaping and fitting, speed control and automatic synchronization.

MODELING CAPABILITIES

Model up to 100 Buses/Nodes and 8,000 branches. This system includes award winning, 32bit, 100% AutoCAD compatible graphic engine. Import and Export: AutoCAD (DWG), Drawing Interchange (DXF), Windows Metafile (WMF) and more!

New intelligent modeling features. If you are a novice, you can let the system automate the modeling process. And if you're experienced, you will appreciate the control you get over all settings and parameters.

ANALYSIS CAPABILITIES

SHORT CIRCUIT ANALYSIS

3-phase IEEE method, ANSI C37, IEC 909, Fault X/R and MF decrement

Industrial Plant Designers, Consultants, Technical Managers, Engineering Maintenance, and Operating Personnel can now realize significant savings in manpower and cost, while considerably increasing the reliability, safety and efficiency of current and future industrial plants.

The system is a user-friendly, PC based software package specifically created for the design, analysis, simulation, component sizing, and control of electrical power systems.

It has modeling capabilities to 100 nodes and up to 8,000 branches. With the electrical power system implemented, it is possible to run analysis to answer your technical problems at the concept, detailed planning, or operational phase of your installations.

Calculation methodology, tables, and formulas are open to the user, providing complete control over all critical analysis parameters.

LOAD FLOW ANALYSIS

The system's Load Flow program has been designed to provide engineers with a very powerful tool to analyze and study a system from the following points: bus voltages (real and imaginary), angle of voltage, bus KW and KVAR, bus power factor, flow of current, flow of KW and KVAR through branches, and line losses in KW and in KVAR.

SCADA (Supervisory Control and Data Aquisition)

SCADA FOR H-180 POWER SYSTEM SIMULATOR

The term SCADA was first used in the early 1960's for data collection in a variety of industrial processes. Today, we use a computer, PLC (Programmable Logic Controller), or RTU (Remote Terminal Unit) for gathering and analyzing real time data.

Hampden's H-180 Power System Simulator utilizes SCADA to control and display data through customizable built-in programmable controllers and a customizable HMI (Human-Machine Interface).

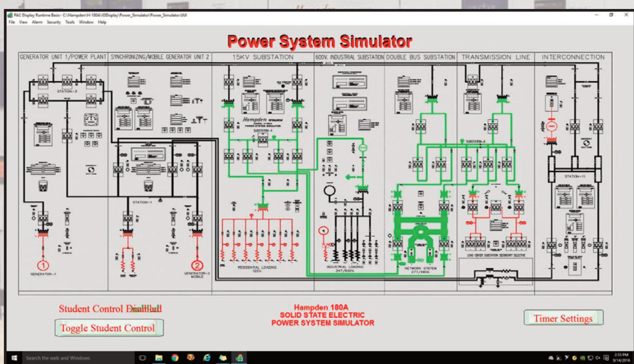


Figure #1: Hampden Engineering Corporations Power System Simulator

The SCADA system monitors power and controls power relays and equipment. It collects process data and displays real time data as it occurs. The data is analyzed to determine where relays have tripped on power lines, then central control is alerted that a fault has occurred, and control procedures are implemented, such as, reclosing a faulted breaker to determine if the fault is critical. The data is then stored and recorded in history files stored in individual RTU's.

Hampden's H-180 Power System Simulator is fully functional when power is turned on. The simulator has its own controllers/processors monitoring and recording data. When the supervisor connects through the network all data can be monitored and controlled via the simulators HMI.

Each section of the simulator screen has a detail button which can be accessed to reveal a detailed description of the section.

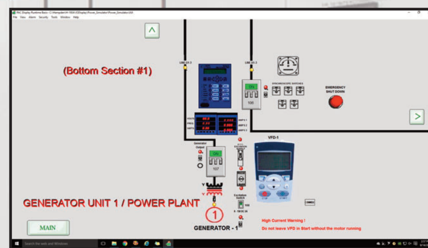


Figure #2: H-180 Power Simulator Section 1 bottom detail screen

The many connected devices feed real time data to the trainer's controller which immediately acts on the data. Information is updated, adjusted and displayed as it happens. Accurate power information is obtained and displayed such as power consumption data displayed in Figure #3.

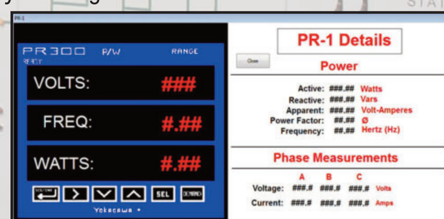
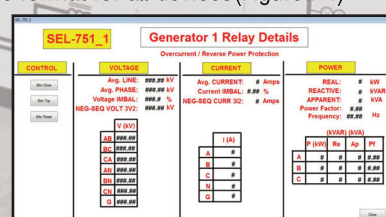
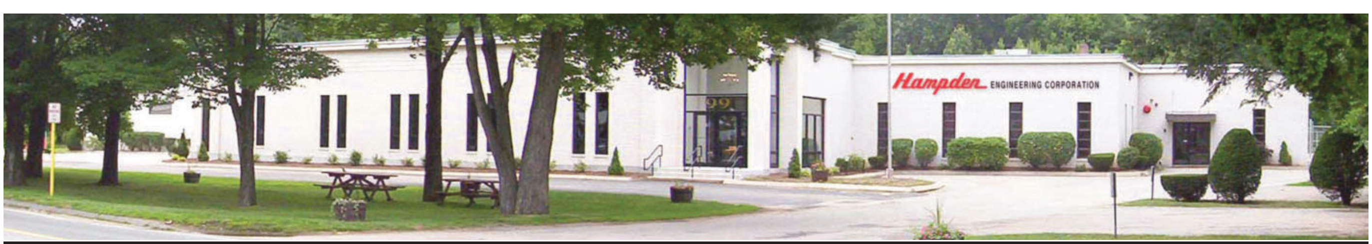


Figure #3: H-180 Power Meter 1 Detail Screen

Data is collected and stored in several devices for later historical retrieval. But real-time events and current readings are displayed in a general table format for all devices(Figure#4)



Figure#4: H-180 Generator 1 readings table for SEL-751-1.



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