Development of Electrical Power System Simulator.

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ABSTRACT

This paper describes how to utilize an electric power system simulator (PSS) as a useful instrument for teaching power flow studies in a power laboratory at the undergraduate level. An analogue PSS has been developed at Osun State College of Technology Esa-Oke, Nigeria.

This provides a user friendly environment that allows students to simulate and analyze events that occur on an electric power network. These events consist of changing the bus voltages at the generating stations, taking generating stations off-line, and taking transmission lines out of service. After each event the students calculates the voltage at each bus, and the real and reactive power flow through the system. The user can then analyze the change in these values because of the event. The completely self-contained teaching module for class and project work is provided as a supplement for practical teaching aid in electrical power system. This has increased students' ability to understand the way a power system responds to various loads and generation schedules. Examples of simulations are included.

(Keywords: electric energy, power system, simulation, equipment, instrument, generation, transmission, distribution, load, sub-station, high-voltage, substation, transformer, excitation system, grid, prime-mover)

INTRODUCTION

Electric energy is the most popular form of energy as it can be transported easily at high efficiency and reasonable cost. The only system that can process this phenomenon is the electric power system. An electric power system is defined in the I.E.E. Regulation as a complex inter-connection of simple electric devices (represented by active and passive elements) in which there is at least one closed path for the flow of current [1].

All electrical engineering students must be oriented on how to process electrical energy during their course of training with the aid of equipment otherwise known as electrical power system simulator (PSS) installed in the school power laboratory. The system (PSS) is a self-contained unit that simulates all parts of electrical power systems and their protection, from generation to utilization points [2]. The PSS consist of four major parts (sections), namely:

- Generation
- Transmission and sub transmission
- Distributions
- Load

Each section includes dedicated industrial standard protection relays that perform specific functions, from generator protection to distance protection on the transmission lines, and distribution transformer protection. Hereunder, therefore, is an updated summary of the major sections [5].

GENERATOR AND GRID SUPPLY

The generator is one of the essential components of PSS which is known as a three phase AC synchronous alternator. This machine has two synchronous rotating fields, one of which is produced by the rotor driven at synchronous speed and excited by DC current provided by the exciter and the other field is produced in the stator winding by the three-phase armature currents. The excitation system maintains alternator voltage and control the reactive power flow. However, the lack of commutator results to production of high power at high voltage level [3].

The source of mechanical power (prime mover) is an electric motor and the two machines are used to simulate power generation. This set has characteristics similar to industrial turbine and alternator sets for realistic experiments. The output of the generator passes through a generator transformer to a generator bus. The PSS includes a fully monitored and protected grid supply transformer. This transformer simulates the larger grid transformers used in national grid supply systems. The grid transformer reduces the incoming mains supply to give the correct distribution voltage bus. It also allows students to correctly synchronize the generator output to the grid supply. For realistic texts, students can use the grid supply on the generator as a power source for their experiments.

TRANSMISSION AND SUB-TRANSMISSION

The purpose of a transmission network is to convey electric energy from the generating unit to the distribution network which ultimately supplies the load. Figure 1 shows a typical layout of a transmission and distribution system. High voltage transmission line is terminated in substation, which is called high-voltage substation or primary substation. The function of this station is switching circuit in and out of service and it is referred to as a switching station. At the primary substation, the voltage is stepped down to a value more suitable to the text part of the journey toward the load. Very large industrial customers may be served from the transmission system.

The portion of transmission system that connects the high-voltage substation through step-down transformer to the distribution sub station is called the sub transmission network. Capacitor banks and reactor banks are installed in the substation for maintaining the transmission line voltage. A set of reactance simulate transmission lines of different lengths to simulate overhead or underground power cables. Each line includes test points to monitor the conditions along the lines. The user can simulate faults at different places along the transmission lines and discover the effects. A dedicated distance protection relay protects the lines and can indicate how far along the line the fault has occurred.

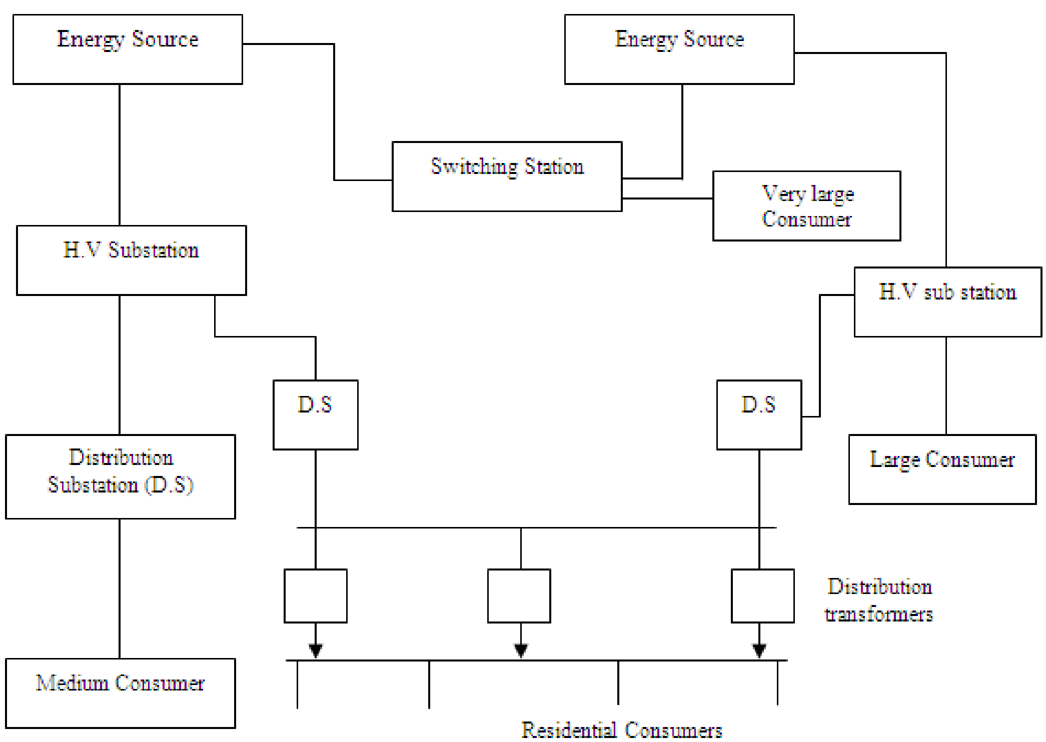

Figure 1: Components of Power System Simulator

ENERGY CONTROL CENTER

For reliable and economical operation of the power system it is necessary to monitor the entire system in a control center. The modern control center is called the Energy Control Center (ECC). An ECC is equipped with on–line computers performing all signal-processing through the remote acquisition system. The computers work in a hierarchical structure to properly coordinate different functional requirements in normal as well as emergency conditions. ECCs contains a control console of a Visual Display Unit (VDU), keyboard, and light pen. The computer may give alarms as advance warnings to the operators (dispatchers) when deviation from the normal state occurs. The dispatcher makes judgments and decisions and executes them with the aid of a computer. Simulation tools and software packages written in high–level language are implemented for efficient operation and reliable control of the system. This is referred to as SCADA, an acronym for "supervisory control and data acquisition [4]."

TRANSFORMATION, DISTRIBUTION, AND UTILIZATION

In addition to the grid supply and generator transformers, the power system simulator has two identical distribution transformers fitted near to factories or houses. These transformers have variable tappings and feed a 'utilization bus'. Dedicated relays protect the transformers and can work in different ways, determined by student experiments. The utilization bus simulates electrical consumers (houses and factories). It includes variable resistive, capacitive, and inductive loads, with an induction motor (dynamic) load.

A switched bus bar section includes a main, bus and a standby bus. These simulate a real bus-switching system in a power plant or power distribution station. Protection relays and contact breakers monitor and switch the incoming and outgoing feeders of the busbar.

Figure 2: Power System Simulator (PSS): A Self-Contained Unit, which Simulates all Parts of the Electrical Power Network and their Protection, from Generation to Utilization points.

One feeder of the busbar has a 'point-on-wave' circuit-breaker for studies of switching transients [3].

TEST POINTS, TRANSDUCERS AND FAULT SWITCHES

All of the important circuits have test points connected to a set of test sockets. The students can link out these sockets or connect them to other test equipment. A set of transducers allows students to connect the test sockets to an oscilloscope (supplied) for transient measurements.

There are two fault switches to apply faults to different parts of the power system simulator. One fault switch is a standard three-phase switch; the other is a timed circuit is a standard three-phase switch; the other is a timed circuit breaker with a digital timer to set a precise fault duration [3].

PROTECTION RELAYS AND INSTRUMENTS

All parts of the PSS include industrial-standard protection relays. The relays show students how actual power systems are protected and the difference ways that they are protected. The students can set the relays from their control panels. The more complex relays also include sockets to link them to a suitable computer (computer not included) for more detailed programming identification. The relays operate the circuit-breakers around the PSS. The circuit-breaks also include hand-operated switches, and lamps. The lamps show weather the circuit-breaker is open or closed.

Multi-function digital meters connect to all the important circuits to show the conditions of all three phases. A phase-angle meter shows the phase difference between any two voltages connected to it.

Moving coil meters show the frequency, power factor, voltage, current, energy and power.

STANDARD FEATURES

- Supplied with comprehensive user guide
- Three-year warranty
- Made in accordance with the latest European Union directives

EXPERIMENTS

Transmission, distribution and utilization:

- Load flow
- Symmetrical faults
- Unbalanced faults
- Unsymmetrical faults
- Circuit interruption

Generator:

- Synchronization
- Characteristics and performance
- Voltage variation and control
- Voltage regulation
- Stability studies

Transformer:

- Unequal taps
- Unequal impedances
- Unbalanced loads

Over current protection:

- Relay grading
- Auto-reclose
- High-set instantaneous
- Back-tripping
- Directional; control

General protection:

- Phase fault
- Earth fault
- Distance protection
- Differential protection of generators
- Bus-bar protection
- Generator protection

Recommended Ancillaries

- Power system simulator SCADA package (PPS2) (*SCADA = Supervisory control and Data Acquisition). This is a computer, a printer, and communication hardware, with industrial-standard software that communicates with the relays and other instruments of the power system simulator. It allows students to remotely monitor and control the different parts of the PSS1.

- Second Generator (PSS3) This is a console that contains a duplicate of the prime mover and generator fitted in the PSS1, but includes added features and protection relays for extra experiments in embedded and central generation.

- ***Note*****:** the second generator is only for use with the power system simulator.

ESSENTIAL SERVICES

- Electrical supply: Three-phase 10 kW, 50Hz

- Floor space needed: Approximately 6 m x 3 m of solid, level floor

OPERATING CONDITIONS

- Operating environment: Laboratory environment

- Storage temperature range: -250C to + 550C (when packed for transport)

- Operating temperature range: +50C to + 400C

- Operating relative humidity range: 80% at temperatures < 310C decreasing linearly to 50% at 400C

- Sound levels: Less than 70 dB (A)

SPECIFICATIONS

Net Dimension:

- 5100 mm long (plus an additional 500 mm to the right of the cabinet for power connections)
- 1500 mm front to back (plus an additional 1.5 m at the back when the access doors are open)
- 2000 mm high
- 2860 kg net weight
- Packed volume and weight:
- 21.74 m3 and 3530 kg

Simulator Voltages:

- Distribution 220 V three-phase line to line
- Utilization 110 V three-phase line to line

Grid Transformer:

- Delta to star 5 KVA (Dy11) transformers
- Primary is matched to the incoming three-phase supply to give the 220 V three-phase line-to-line secondary distribution voltages. Includes earth-link for the secondary star point and a selectable tapping earth resistor for restricted earth fault protection tests.

Generator and Prime Mover:

- 6 KVA maximum (operated at a normal 2 KV), four-pole salient pole AC generator
- Brushless, with automatic and manual excitation.
- KVA maximum induction motor with shaft encoder and electronic four-quadrant AC vector-drive inertia control, with a four-position drive inertia switch

Generator Transformer:

- 1:1 ratio delta-to-star (Dy 11) impedance matching with adjustable secondary tapping

Transmission Lines:

Line reactances simulate 'per unit' (p.u) values of impedance:

- Line 1:0. 10 pu
- Lines 2 and 3:0.15 pu
- Lines 4 and 5: 0.25 pu
- Line 6: 5 x 0.1 pu length with four test points and dedicated three-zone distance protection
- Line 7 :4 0.01 pu (cable)

Capacitors are provided adjacent to the lines. Each capacitor ha selectable values and may be inserted in circuit to give π or T-line configurations for studies of closes.

Distribution Transformers:

- Two identical 2 KVA transformers, 220 V to 110V star-to-delta Yd1
- Adjustable primary tappings and matched impedances

Switch Busbar:

- Six bi-directional feeders, each with circuit-breakers-one circuit breaker is a 'point-on-wave' device
- Two circuit-breakers to break each half of each bus
- Twelve bus isolators, six on each half of the bus
- Two circuit-breakers that break the coupling between the main and reserve bus.

Protection Relays:

- Grid transformer protection
- Grid bus protection
- Generator protection
- Generator bus protection
- Distance protection
- 2 x double bus protection
- 4 x distribution transformer protection

Loads:

- Two separate 220 V (distribution) loads, each with delta-connected variable resistors and inductors; one load is near to the generator and the other near to the distribution bus.
- Two sets of 110 V (utilization) loads at the utilization bus; each has delta-connected variable resistors, inductors and capacitor banks.
- One dynamic load – an induction motor at the utilization bus.

CONCLUSIONS

In this paper, an easy-to-use power system simulator designed to be used as an educational aid is presented. Power system simulation has proven to be an effective tool for learning the behavior of power system under various operating conditions and configuration. Its scope is limited, but this introduction gives the students a better understanding the aspects of power system control and motivates them to learn more about power systems.

Future improvements could consist of modeling capacitor banks that the user could put on and take off the system, allowing the load to be adjustable at the PSSs, and incorporating tie lines with other power systems. Modeling a transformer with tap changers that would allow the user to adjust the voltage on the low side would also be an interesting and useful addition.

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Gbadebo Adedokun holds a B.Eng. and an M.Eng. in Electrical Engineering from the University of Ilorin, Nigeria. He is a member of Nigeria Society of Engineers. He is also a registered engineer with COREN. His areas of interest include development of programs to predict faults on electrical power networks and bifurcation analysis on electrical power networks. Presently he is a Lecturer in the Department of Electrical Engineering, Osun State College of Technology, Esa-Oke, Nigeria.

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