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Ac Network Analyzer—A Dynamic Benchmark For Power System Study

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ABSTRACT

One of the purposes of constructing this dynamic model is to make a firsthand study of various aspects related to economic management of electrical power trans-mission.

The AC Network Analyzer designed and constructed is a versatile tool to setup any practical problem related to power system studies in an interconnected grid network of different configurations comprising four generators, four loads and four transmission lines. Power flow can be controlled in the transmission lines and loads as per the experimental study through FACTS Devices and auto transformers provided for the purpose.

The Multi Function Meter indicates six parameters Voltage, current, Volt Amp, Watts, Vars, Power Factor of the load, generators and transmission lines. Control can also be exerted for the Power Factor of the load.

This Analyzer was used for generation, transmission and utilization of power flow / fault studies: symmetrical & unsymmetrical faults / regulation / power factor / energy utilization / interconnection / expansion planning / forecasting, reliability and protection; research projects assignments in some areas of power network modernization, energy audit; power system economics, contingency analysis (when a line is switched on or off the system through circuit breaker, line currents are redistributed throughout the network) by adding or removing multiple lines can be studied. Thus, the studies on this model would help in the economic and optimized management of the operation of the grid power system.

Keywords: AC Network Analyzer, Power Flow, Fault Studies, Lab Experiment and Teaching Aid.

INTRODUCTION

This AC Network Analyzer also includes the hardware for data acquisition and software to view the data of the Multi Function Meters of AC Network Analyzer—a dynamic model for the practical planning studies and training to the engineers from the industry and engineering institutions for their laboratory.

A critical review of literature has been presented here. [1] Anand Khare (1985) AC Network Analyzer model for use in practical fault analysis was published in a book, 'Reliability in Electrical Systems'. This model had higher capacity and worked on conjugate impedance principle that is capacitive reactance represented inductive reactance it was used by electrical utility services.

In 2009 Aaron St. Lager et.al [2] Developed and an analog Emulator for training in power System Laboratory. Here the software interfaces with the hardware to allow for control of data acquisition and analysis. The equipment has limited capacity of 2 generators, metering is also limited. It does not have feature of Supervisory Control.

Amit Shrivastava and Anand Khare (2013) [3] have discussed the Micro Grid model which simulates a power system and has the features of SCADA automation to study its advantages and to finally implement it in real power system. It suggests the approximate cost to build the model along with the SCADA Architecture. It also suggests some experiments which can be done on this proposed smart GRID Model.

The Power System Monitor designed by Ramleela Khare, Filipe Rodrigues E Melo 2013 [4] is the latest equipment for practical study of power system networks; assembled on scaled down parameters to represent generator, transmission lines and distribution of power to simulate the real time generation and transmission of power in electrical industry. The SCADA architecture transmits the data to computer software and parameters of generation and transmission can be controlled by changing rotary switch positions on the model through PLC and relays by wireless arrangement.

Experiments were conducted for Power Flow through transmission line and Fault Analysis. The results were compared with and without UPFC – Unified Power Flow Controller. This will help to study the efficient and economic management of power generation and transmission.

The Power System Monitor developed demonstrates the application of SCADA architecture for automation. Supervisory Control and Data Acquisition (SCADA) has been demonstrated on the Power System Monitor. From this model one gets clear understanding of how to implement SCADA automation in an industry to improve economic and efficient management of activities.

Generator represented here is through stepped down Auto Transformer Mains operated 0 to 100 Volts 50 Hz. This is customized for the Analyzer.

There are several other components like auto transformer that are provided with each Transmission line and one with each load which are customized to work at 50 Hz analyzer base for the specific tapping bucking or boosting in steps of 5%.

On the Analyzer digital multi-function metering is customized to measure low voltages, low current parameters on the analyzer and one such multi-function meter is provided with each generator, load and transmission line. In this case 24 multi-function meters that would simultaneously display Voltage, Current, VA, VARS, Watts, and PF information.

Experiments comprise practical power systems of different configurations of generators, loads and transmission lines for optimization studies.

1. Power flow studies have been made by simulating a given power system on the Analyzer. Voltage, Current, Active and Reactive Power, Angle and Power Factor were measured at all nodes through the instruments provided on the Analyzer panel at each Generator, Load & Transmission Lines. Power is made to flow by amplitude control (through output that represents the generator) and varying phase angle (through UPFC) on the generator Bus–Bar. Auto-transformers are provided with Transmission lines & Loads for bucking & boosting voltage.
2. Fault Studies (symmetrical and unsymmetrical) of three phase fault, single phase line to ground faults, line to line faults and double line to ground faults by using the theory of symmetrical components.
3. Helps in Energy Audit necessary to diagnose the state of the efficiency and quality of energy applications.
4. As this Analyzer is a single phase dynamic equivalent of the real system all types of experiments were setup including some cases of stability of system that falls within the capacity of the analyzer.

Higher transmission of power results in offsetting cost of installing UPFC in the system.

SCADA Architecture will introduce efficiency due to automatic control to a predetermined optimization limits set for its operation. Thereby concluding to the economic factors related to the operation, control and transmission of power.

The decision can be quickly taken by the professional staff in-charge for operation of the electrical system through supervisory control facility on the software of the computer and finally this provides automatic management of distribution of power by pre-selection of parameters. Apart from computer based system now the GPRS facility made it still more versatile by transferring information through wireless system. The SCADA devices could be detached from the model for taking over manual operation.

Test Result with table: Practical experiments were conducted by simulating a real power system on the model by scaling down voltage, power through the base values and after the study the result of the model are converted back to the real quantity of practical system. Photo of the AC Network Analyzer show the layout of the model that was constructed.

AC Network Analyzer assembled here is a single phase replica of the real power system. A mains step-down voltage of 20/30/40 volts is provided at the generator. The base values of the real system set for studies are:

BASE VALUES OF POWER SYSTEM
Base Power – 20 MVA
Base Voltage – 200 KV
Base Current – 100 Amps
Base Impedance – 2000 Ohms
BASE VALUES ON THE MODEL
Base Voltage – 20 V
Base Impedance – 2000 Ohms
Base Current – 10 mA
Base Power – 200 mVA
Frequency – 50 Hz

3.1 CONSTRUCTION OF AC NETWORK ANALYZER

3.1.1 GENERATORS
Generators of the real system are simulated by single phase supply source variable in magnitude on the working model of the AC Network Analyzer
Voltage to be adjusted as per the requirement for the Power flow studies at the Generator Bus, Transmission Line or Load Bus.

3.1.2 MULTIFUNCTION METER
Signal Frequency – 50 Hz
The input voltage signal to this meter would be in the range Voltage: upto 50V, Current: upto 250mA, VA: upto15 VA

3.1.4 AUTO TRANSFORMER
1. The Auto Transformer with taps are provided at load Bus for adjusting the voltage and flow of Power (without altering the Generator bus voltage)
2. Regulating Transformers are provided at Transmission lines for bucking or boosting the Voltage (without altering the voltage at the generator bus)

3.3 OPERATION OF THE AC NETWORK ANALYZER
After interconnecting the circuit elements on the model to represent the power system to be studied for Power flow, the Resistance, Inductance and Capacitance (RLC) units provided on the model in per unit values on the rotary switches from 0.1 to 0.9, and 0.01 to 0.09 are adjusted to the given values of resistance & reactance. Preliminary adjust-ment of the amplitude & phase angle is made at generator Bus Bars.

The auto-transformers are set for preliminary tap positions and readjusted for the required operating conditions. Load units are adjusted to the values of resistance and reactance to draw the specified load at a given voltage.

The voltage on each load unit is kept constant by adjusting auto-transformers connected to each unit, so that the resistance and reactance of the load unit need not be changed if voltage at the load bus-bar differs from that for which resistance and reactance are set initially to give required real and reactive power for the load. Initial adjustment usually take time since each change to achieve required conditions at any bus-bar affects the values of pertinent quantities at the other bus-bars. Adjustment is made at each generator and load until the required operating conditions are reached.

Here the generators, transmission lines, and loads represented by miniature electrical components with scaled down values in proportion to the modeled system. Model components are interconnected with flexible patch cords to represent the schematic of the system.

To reduce the size of the model components, the network analyzer has been energized at a frequency of 50 Hz and model circuits are energized at relatively low voltages to allow for safe measurement with adequate precision. The ends of the lines, loads and generator terminate on sockets on the front panel for easy interconnection to form any interconnected network under study.

The measured results are converted into per unit data by using the above base values. All components and sub-systems are designed to suit the Analyzer and these have to be manufactured to the design requirements. Auto transformers, inductors & phase angle meter, special rotary switches and passive components are custom manufactured according to the design.

1) The first step is to interconnect the generators, transmission lines and loads as per the requirement of the experiment. Interconnection can be achieved on the central panel where the bus bar arrangement is terminated to the banana sockets. At this bus bar both the ends of generator, load and transmission line are brought for inter-connection. The voltage and phase control for generator and load is provided on panel1 and panel 2.

2) The network is simulated by adjusting R, XL parameters provided in per unit on the analyzer (on the rotary switches) for Generator, Load and Transmission line representation.

After setting up the R, L, and C parameters for generator/ load/ transmission line voltage and phase angle has to be adjusted as per the statement of the problem to achieve the desired results.

Digital Multi-function meter measures V, I, F, PF, Watts and Vars parameters. By balancing the voltage and phase angle at generator bus the desired load flow studies can be made.

SECTION A: POWER FLOW
EXPERIMENT – 1 POWER FLOW

This experiment comprises 4 Generators, 4 Loads and 4 Transmission lines. The figures 1 A & B show interconnections of load settings and flow of power from one generator to another as per the recommended load flow.

Table 3.1A tabulates the data of capacity of generators, loads and power flow from one bus bar to another through the respective transmission lines. See figure 1C for the system configuration.

STATION	POWER MVA
Generators	
G1	100
G2	240
G3	80
G4	40
Loads	
L1	100
L2	140
L3	110
L4	110
Trans Lines	POWER MVA
T1	40
T2	60
T3	30
T4	40

Table: 1 A gives data of generator capacity, loads and the requisite flow through transmission lines Check the Magnitude of Voltage and Phase angle (with reference to the slack bus) at each Generator and Load bus and also note Active and Reactive power in all Transmission Lines

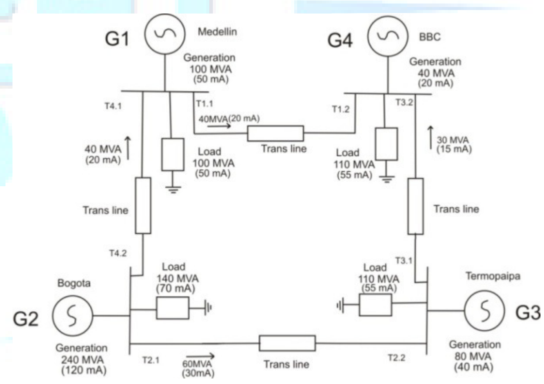

Figure 1 A

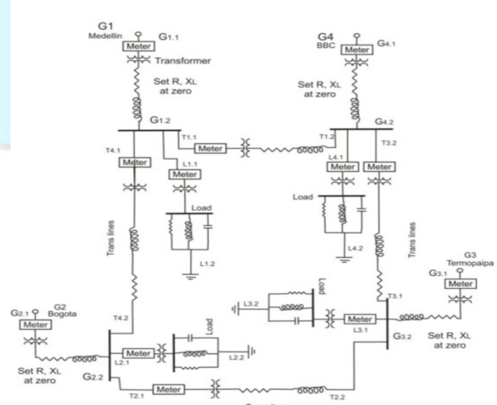

Figure 1 B gives the details of metering and loads and auto transformer

RESULTS OF STUDY FOREXPERIMENT

Table 1B shows that the requirement of the experiment that the desired power flow from their generated capacities is met and the data for VARS and Pf is also obtained.

SECTION B: FAULT STUDIES

The current which flow in different parts of a power system immediately after the occurrence of a fault differ from those flowing a few cycles later just before the circuit breakers are called upon to open the line on both sides of the fault. And all those currents differ widely from the current which would flow under steady state conditions if the fault were not isolated from the rest of the system by the operation of circuit breakers.

Selection of the circuit breaker depends upon the current flowing immediately after the fault occurs and the current which the breaker must interrupt. In fault analysis values of these currents are calculated for the different types of faults at various locations in the system. The data obtained from fault calculations also serve to determine the settings of relays which control the circuit breakers.

EXPERIMENT: 2 FAULT STUDIES

Set up of experiment 5 for load flow study is now modified for the study of 3-phase fault. Figure 2.2 shows the circuit, here the elements of the transmission line that is G1.1, G2.1, G3.1, and G4.1 are shorted together and supply is given to this point. The fault is created on the bus on G1.2 by connecting it to the common terminal C & voltage is adjusted to 20 volts and the results of V, I, VA, Pf, mW, mVAR are recorded on the table No.2.1 for voltage and current of all the multifunction meters that is G1 & all the transmission lines, here it can be seen that the fault current/power is maximum at the generator bus G1.2.

RESULT OF STUDY OF EXPERIMENT

Bus Bar	Current (mA)
G1	64
G2	26
G3	08
G4	10
T1	29
T2	06
T3	05
T4	15
Source G5	108

TABLE 2.1 tabulates the results of faults current when the fault is at generator bus G1

Bus Bar	Vol-tage (V)	Current (mA)	Power (VI) mVA	Active Power (W) mWatts VICos φ	Reactive Power (VAR) mVAR VISin φ	Power factor Cos φ
G1	20	50	1000	999.84	17.45	.999
G2	20	120	2400	2398.53	83.76	.999
G3	20	40	800	799.87	13.96	.999
G4	20	20	400	400	0	1
L1	20	50	1000	770	638	.77
L2	20	70	1400	1106	858	.79
L3	20	55	1100	891	645	.81
L4	20	55	1100	825	727	.75
T1	20	20	400			
T2	20	30	600			
T3	20	15	300			
T4	20	20	400			

CONCLUSIONS

The primary purpose of the design and construction of this Dynamic Model of AC Network Analyzer is to study how to implement effective management & optimize the grid network for the trans-mission and control of power.

Various experiments conducted using the AC Network Analyzer reflects on how the power system network can be interconnected for a reliable economic and efficient performance of the power system. How the power flow will be affected by addition of a generator or a transmission line and load and how the grid performance will be affected incase of outage of the transmission line, generator and load.

The other uses of this equipment are for the power system laboratory as a teaching aid. The system is flexible for interconnection of generator, transmission line and loads for a grid network that one wants to study.

The base values selected are such that they permit representation of higher power at lower voltages and currents without stressing the system. The system has also provisions for monitoring information on every node that is generator, transmission line and loads through Multifunction meter. The Analyzer also has UPFC Device to control the transmission of power.

Experiments were performed for different capacities of the grid involving up to 6 generators, 6 transmission lines and 6 loads to evaluate economic operation of the grid network for power flow, losses, regulation, study of optimization and energy audit etc.

The requisite power flow study could be made for all power problem set up and the design of the setup proved to be satisfactory. On the basis of its performance and utility the ACNA designed and constructed here is a dynamic benchmark for use in power system laboratory. Though low cost equipment, it is versatile for making various studies related to power transmission of interconnected grid network.

The equipment is suitable for electrical power laboratory in an educational institute as a teaching aid to cover the current syllabus in power system studies. This equipment presents a BENCHMARK for the power system laboratory on a miniature scale where the results can be interpreted for the real system through the suggested base values. This project was completed in collaboration with The MRPC Company.

The usage of the analyzer does not require any technical expertise. It is self explanatory and it is protected from wrong connections – failure safe equipment.

The model works with scaled down base values of the real system and the data on the model can be converted into the parameters of voltage, current and power of the real system by multiplying with base values. In this case for example 20 V bus voltage and 10 mA current on the model represent 200 KV, 20 MVA and 100 Amps of power of the real system.

Photo of AC Network Analyzer

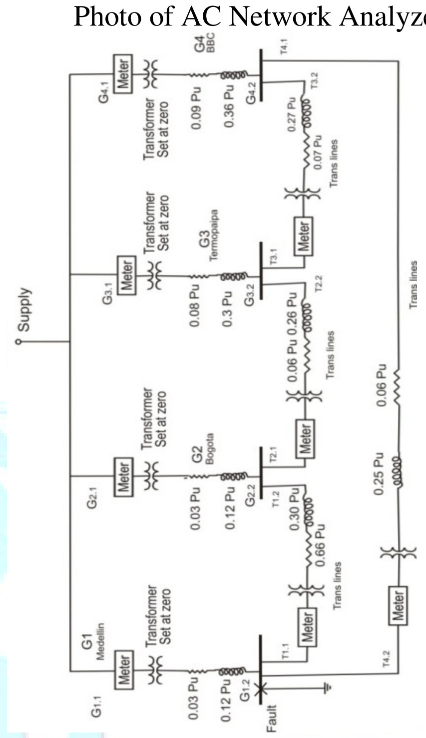

Figure 2.2

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