Real Time Control Centre Lab for Research and Training for Power System Operation and Control

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Abstract: Controlling a power system network through a control centre using a SCADA system is a quite different philosophy from controlling through distributed team of local operators, local panels and phone call orders. Thus control centre engineers is required to know the power system and automation system in details for the efficient operation and handling of the SCADA system. Therefore there is a great need of a training system that resembles the real control center environment and can be extensively used to train and educate the operators and students about the dynamics of power system and automation system under single roof. This paper proposes development of a real time control centre lab for research and training for power system operation and control, by integrating the OPAL-RT power system simulation system with computer based real time control system and customized open source SCADA system available under GNU license scheme .The control centre lab will not only provide an insight into the contemporary SCADA systems but will extend the capabilities of developing , testing traditional and advanced control algorithms for a large and complex power system models. To show the extended capability of the lab a sample power industry automatic generation control is discussed and procedure to implement on the proposed system is presented.

Keywords: Automatic Generation Control, HMI , Operator Station, remote terminal unit. rapid control prototyping, real time simulation, SCADA.
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I. INTRODUCTION

The increased complexity of electrical power systems network have emerged the requirements for operation, monitoring and controlling the power system through computer system that can guarantee an effective, economic and professional operation and supervision of the power system. However the power system management is the process of monitoring, coordinating, and controlling the generation, transmission, and distribution of electrical energy. The physical plant to be managed includes generating plants that produce energy fed through transformers to the high-voltage transmission network, interconnecting generating plants and load centers. Transmission lines terminate at substations that perform switching, voltage transformation, measurement, and control. Substations at load centers transform to sub-transmission and distribution levels. These lower-voltage circuits typically operate radially, i.e., no normally closed paths between substations through sub-transmission or distribution circuits. Since generation is controlled by turbine governors at generating plants, and automatic generation control is performed by control center computers remotely from generating plants. Now a days power system operation and control is based on transducers and actuators installed throughout the system The components at control centers such as computer , interfaces and software perform basic set of functions like monitor, log and control that are called SCADA functions. Therefore SCADA system is a computer based system to supervise and control a process, e.g. the power system and mainly focuses on the supervisory level. The process can partly be supervised by remote terminal units (RTUs) and with communication links to master terminal units. SCADA as such it is a purely software package which provides the basic functions to supervise the power flow and voltage measurements, protection relays and messages. This software package is commissioned on top of the hardware-software system of the computers to which it is interfaced generally via programmable logic controllers (PLC) or other commercial hardware modules and the typical software functions would be the updation of the data base, event log file and the display of data for operator. The supervising operator would be responsible for the grid operations needed for maintenance, grid flow control and in the case of a fault the restoration of the network to normal operation. Now a days SCADA systems is widely used in power industry as it allows remote location sites to communicate with a control facility for bidirectional transfer of data for monitoring and control processes. Broadly major elements of SCADA system are the Operator station, master terminal unit , communication system and remote terminal unit commissioned at different level of automation system. A general architecture of SCADA system is shown in fig.1. The major components of the SCADA system are distributed at different levels are such as Level 1 is the instrumentation level in the process field at which the transmitters, transducers, switches , motorized valves, actuators etc are installed like voltage, current , frequency and power transducers are commissioned at different buses , feeders and load centers. Level 2 is control bus in the process field where all the sensors and actuators are interfaced or marshaled to the remote terminal unit (RTU) which gathers and hold analogue , digital or pulse data in their memory and wait for a request from the master unit to transmit the data. Remote terminal unit (RTU) equipped with interposing relays , Input/output cards, programmable logic controller, power supply , ethernet card , modbus card etc for sending and receiving the data from remote location usually from SCADA control center. Lastly Level 3 is for operation located at remote location usually in control center at which the master unit initiates all communication, gathers data, archive and displays the information in operator console For the supervisory operation. The relationship master unit and remote terminal unit is analogous to master and slaves and cyclic polling mode is a common interaction method between the master and remote terminal unit.

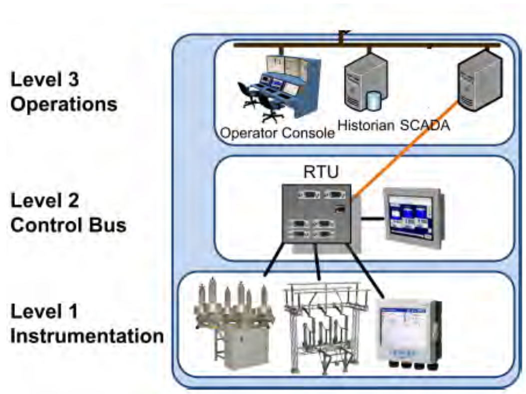

Fig. 1. General Configuration of SCADA system

It has been observed that power system behavior is influenced deterministic and stochastic elements. During contingency period the interpretation of the network alarm status, the event classification and the execution of proper control orders need a lot of operators' experiences. Missing experiences may result in operator' errors and may cause huge damage to the power system and grid , therefore frequent training sessions will result in professional acting and experiences during emergencies period. However training and research on the SCADA system in the lab, one need to know industrial automation system and associated the power system network for which application is designed but building the physical prototype or scaled down version of power system network is quite expensive , complex and have limited functionality. Therefore experiments designed for learning the SCADA systems have bounded scope and the development of new application for a different power system network is long assignments associated with a high cost. However the conventional and practical form of mediating practical experience is on the job training of operators for power system operation where the training takes place in the control centre during shift hours. Operating procedures under normal system conditions are mostly performed as practical exercises done by the trainees at the control desk using SCADA functionality under the supervision of an experienced operator or instructor. Procedures dealing with 'abnormal' system conditions have mainly to be studied by the operators themselves and are trained as paper exercises which might be supported by some calculation. Whilst the theoretical background is trained, improvement of practical skills and experience is not dealt with. It must be noted that during restorative processes decision making and acting to fast changing system situations often under time pressure have to be done without any support from EMS functionality and automatic devices (e.g. switched off AGC)[1][3][5]. The training at the power system control centers are limited to operational procedure of the specific system and the trainees do not have an opportunity to change the control algorithm or change the power system network configuration to deploy the newly developed algorithm and test it on the real power system network however now a days Hi-fidelity simulator based training is also widely used in utilities and power plant control centers to the extent of imparting best operating practices under normal and abnormal conditions but has limited usage in conducting the research work by changing the process models of the plant . On the other hand the real time simulation is widely used for research and development purpose that not only provides rapid controller prototyping techniques to implement and validate control strategies during the development process but can also be used for operation training purpose. A typical design flow for the real time simulation is shown in fig.2. In the first stage the function design of model development and associated plant is done followed by the offline simulation of the system for stability and specification is done which is popularly known as Model-in-loop simulation. After validation of Model-in-loop simulation the rapid control prototyping is done on some target microprocessor with or without real time operating system to implement the control function in real time . In the last stage the real time simulation of hardware-in-loop is carried out to test and validate the developed control system for a specific application.

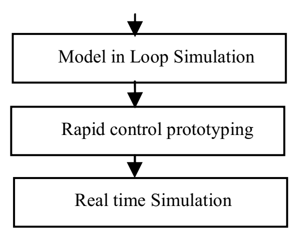

Fig. 2. Real-time Simulation design phases

Commonly the real time simulation system includes two parts, one is the hardware equipped with central processing unit , memory, data acquisition card, communication ports and real time operating system which provide the run-environment for real-time task execution on the hardware and the other part of the system host PC equipped with related modeling simulation software through which application program can be developed and download executables on real time system. Here only the hardware platform without any real time operating system is proposed and typical structure of the system is shown in fig.3. A common method of development of real time simulation program is through MATLAB/SIMULINK and other related software like real time workshop, C compiler etc. However if the system is used for real time simulation of complex power system then additional power system library is also required for modeling .The data acquisition card on the hardware platform is used to interface with the external system like oscilloscope or to other hardware which can effect the dynamics of the real time simulation of the system. Additionally any hardware like relay can also be interfaced with data acquisition card for hardware-in-loop testing of the relay.

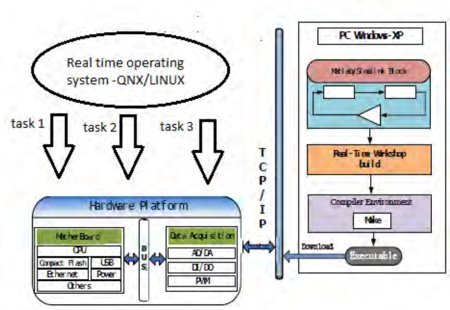

Fig.3. Real-time Simulation System structure

The section 2 presents system architecture of the proposed system for the training and research lab. Section 3 presents the sample case and project execution phases of an application. Section 4 presents the procedure for implementation of example of AGC on the proposed system. The concluding remarks of mere benefits of customized real time systems used for power system research and training in labs is given in section 5.

II. PROPOSED SYSTEM ARCHITECTURE FOR LAB

A three tier system architecture is proposed for the power system control laboratory. First is the power system field , second is the control system and third is the operator console.

The power system network is to be simulated in real time on Opal RT real time power system simulator which is equipped with input/output card , multiple processor unit and ethernet port for communicating with host pc. The host pc is used for modeling and downloading model on the real time simulator as well as instructor station for generating the malfunctions in the power system network during real time simulation. The architecture of real time simulator is shown in fig 4. The system is used to run different power system models in real or non real time environment.

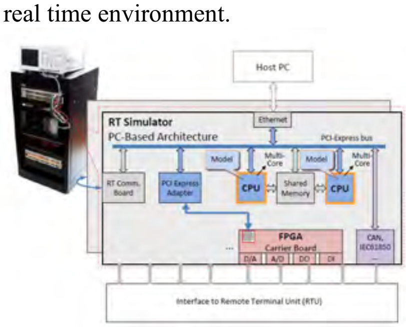

Fig. 4. Real time Simulator for Power System Network

The host PC of RT simulator is used to model different power system model using MATLAB/SIMULINK software and downloading it on real-time simulation computer via TCP/IP communication channel. The host PC and real time simulation computer have windows based client server architecture that not only helps in visualization of power system parameters on host PC but can also be used in generating the abnormal conditions or malfunctions for testing the developed control algorithms. The second part is the development of control system analogous to remote terminal unit , and the third is the operator console with SCADA software the configuration diagram of the whole system is shown in fig 5. The different systems are commissioned at different levels and each level are described as at level-3 the real time power system simulation computer is used to run different power system models in real or non real time environment where as PC based (RTU) Remote terminal unit with prototype or virtual controller and communication port is stationed at level-2 and finally at level-1 engineering station is used for two purpose one is to use as database station using MS Access and second SCADA software development tool is installed through which human machine interface (HMI) of the power system is designed and commissioned at the operator console for real time monitoring and supervisory control. The advantage of using PC based RTU is that conventional and intelligent control algorithms such as fuzzy , genetic etc can be easily implemented on the prototype controller using MATLAB/SIMULINK software and tested in real time scenario.

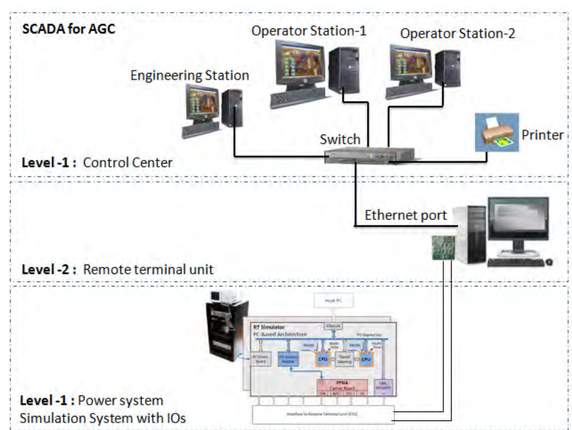

Fig.5. Configuration diagram of SCADA for AGC Lab

The proposed configuration is a cost effective solution and analogous to conventional SCADA system supplied from different companies like ABB, Honeywell, Emerson etc. The commercially off the shelf components and open source SCADA software under GNU license scheme provides ample opportunities for a researcher to setup , develop and test power system model , control algorithm and protocols etc. under the real time and controlled environment. Moreover the tested control algorithm can also be converted to functional block diagram (FBD), SAMA or C code which can be directly used on commercially available control system.

III. SAMPLE APPLICATION ON PROPOSED SYSTEM

The purpose of sample application is to give a inside picture of the automatic generation control application, that can be performed on the proposed system. Since the working on the proposed system is quite similar to real world control system engineering project for the plant, hence project implementation will have subsequent phases with some design flow, a sample design flow is shown in fig. 6. Starting from functional design specification which is the key objective of the project which includes the

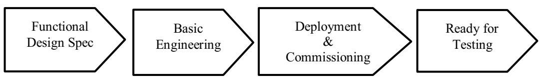

Fig. 6. Phases of Project Implementation

details like objective of simulation , scope of simulation , power system models, control system algorithms , number and type Input-output , system integration hardware and software. The basic engineering includes the modeling of power system models, development of control algorithms , development of power system graphics or HMI for Operator stations and configuration of input output channels for data acquisitions. The Deployment and commissioning stage includes the downloading of power system model on real time simulation computer, configuring operator station, downloading control algorithms on PC based remote terminal unit , hardwiring of different systems at different levels. An sample application of automatic generation control that is one of the basic functionalities of power system automation system widely used in power industry is discussed and the procedure to implement on the proposed system is presented in the next section. The single line diagram of large power system network consisting of ten (10) turbine generators feeding in house loads of the process plant at different voltage scattered over a large distance is shown in fig 7.

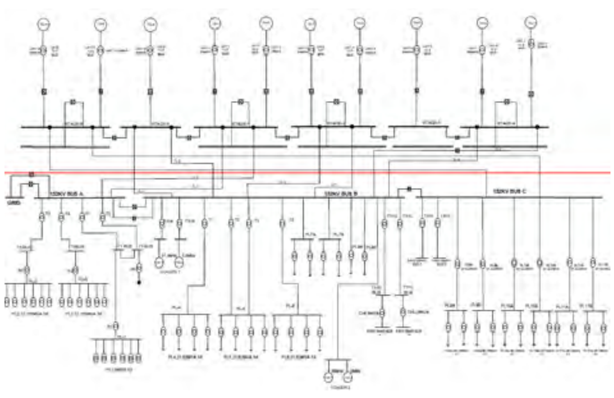

Fig. 7. Single line diagram for power system network

All the power plant generators are synchronized with the grid for exporting power to grid as well as feeds its own auxiliary loads. Since units are distributed over large area it is connected via ac tie-line. Similarly the block diagram of automatic generation control used for load frequency control of unit including turbine governing system is shown in fig.8 The automatic generation control is an integral part of an power system management system and its basic functions are to maintain grid export with in limit, maintain frequency of the system under steady state load disturbance condition, maintain active power of individual generator within capability limits of generators and minimizes the deviation of tie-line power . The operator can select automatic or manual mode of operation. In automatic mode control system initiates a corrective action when there is any frequency deviation in the network where as in the manual mode the operator have to manually monitor and initiates a turbine governor demand for any deviation in frequency of the power system.

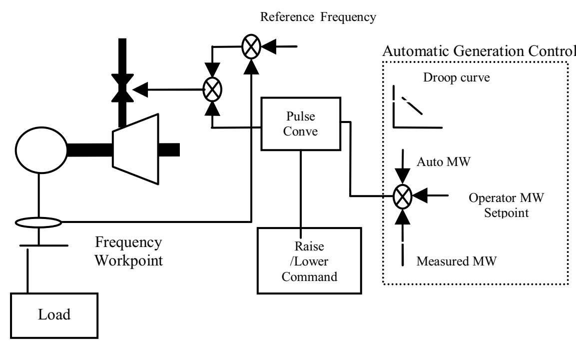

Fig. 8. Block diagram Automatic Generation Control

The automatic generation control (AGC) algorithm works for two condition (a) when the unit is connected to grid (b) when the unit is not connected to grid or islanded condition.

Case A. When the unit is connected with grid it has to maintain an export which shall not greater than operator settable limit When total generation exceeds this limit the deference in set point (grid limit) and grid MW is calculated then Identifies available generator in the network and this power MW difference is distributed among the generators in that network by considering its participation factor . There after calculated automatic set points send to individual generators control which in turn generates lower or raise pulses. AGC action automatically stops when export become within the grid limit.

Case B. When the unit is isolated from grid, selection of busbar frequency set-point for control action is initiated followed by bus bar frequency measurement by checking healthiness of the measurement to calculate difference between frequency set-point and measured frequency and if the calculated difference in frequency is within the predefined dead band, there is no action performed by AGC and if the calculated frequency is greater than dead band then the difference will be distributed among the available generator by considering its participation factor. A sample control scheme for automatic generation control is shown in fig.9. Depending on the mode of operation the automatic set-point of power is calculated by giving the input of power mismatch to PI control and fed it to governor control for the desired effect. Generally AGC scheme have PI control for error reduction and the gains are generally tuned by some standard tuning techniques like Ziegler-Nichols, Cohen-coon etc. On the other hand main electrical graphics on Operator stations or the human machine interface (HMI) for AGC consists of individual generator with enable and disable window generator faceplate and real power (P) , reactive power (Q) control window that will be linked with AGC control scheme for monitoring and control.

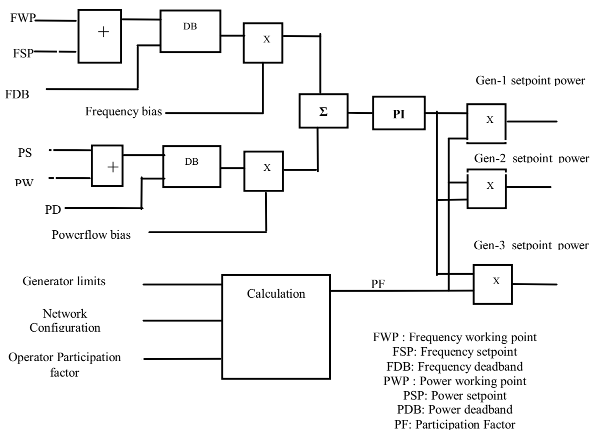

Fig. 9. Control scheme for automatic generation control

The sample SCADA graphics of the above power system network is shown in fig. 10. , used for monitoring and control by the operators in control centre. The basic feature of HMI consists of metering of generator, buses, load centers and breaker status. The power mismatch and governor limits are also displayed for better control.

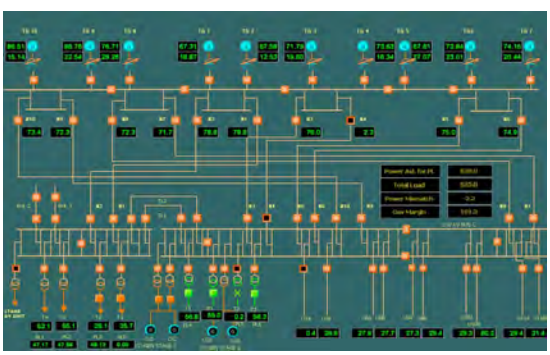

Fig. 10. SCADA - HMI of power system network

Depending on the AGC scheme, graphics have option of changing the mode of operation , setting the set-points for active power or the frequency and settings the limits of generator and the participation factor. A sample automatic generation graphics is shown in fig.11.

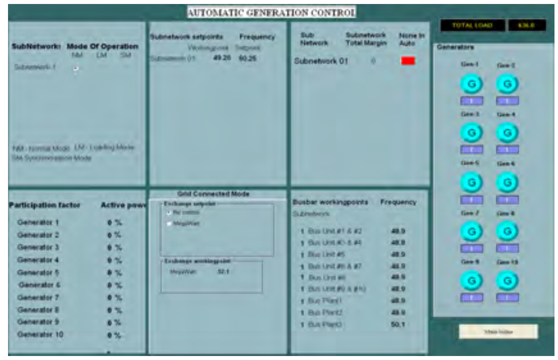

Fig. 11. Automatic generation control graphics

The real time values of the power system network can be continuously plotted or monitored on the operator station through trend application of SCADA software. However an important additional feature of SCADA system .i.e. log printing which is the chronological event of any disturbance, alarms or operator initiated actions can also reported in some format like crystal reports for management review , decisions and for analysis of sequence of events of any fault condition.

IV. IMPLEMENTATION ON SYSTEM

The above application of AGC can be realized on the proposed system. The procedure to implement starts at level-1 that will include the modeling of the above power system network on MATLAB/SIMULINK using power system block-set and OPAL RT power system library [6]. The parameters like voltage, current and frequency of the power system network is configured on data acquisition card for remote monitoring and control through level-2 and level-3 systems. An example of power system model with five steam generator interconnected system is shown in fig.13.

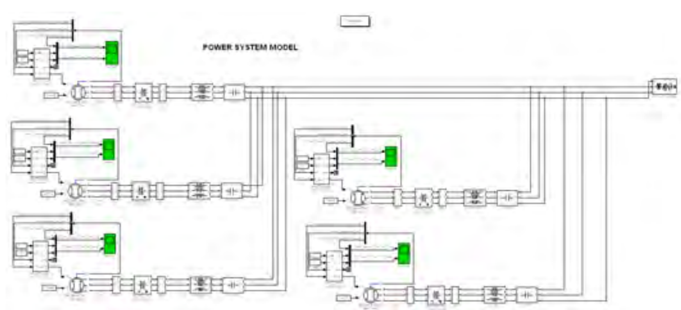

Fig. 13. Simulink diagram of Power system model for AGC

The turbine governing and generator system can be modeled using the MATLAB/SIMULINK and an example of turbine governor and generator is shown in fig. 14. The instrumentation for turbine and generator is configured using data acquisition blocks and cards for remote monitoring and control by operator at level-3.

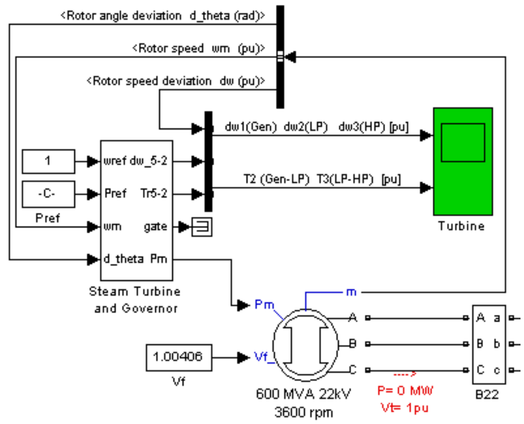

Fig. 14. Simulink diagram turbine governor system

All the control scheme are implemented at level-2 which consists a high end microprocessor or PC with DAQ card that will process all the data from field, power system model in our case to initiates a control action under abnormal condition and direct the data to control centre for remote monitoring and manual control by the operators. Generally a proportional integral (PI) scheme is used for the control of any process. Therefore a discrete time proportional controllers can be designed with appropriate input output channels for the communication with level-1 and level-3 systems for the control system implementation at level-2. Moreover for research purpose the gains can be tuned and optimized using intelligent techniques on MATLAB/ SIMULINK software and can tested on real time controller at level-2. Finally at level-3 , the operator station graphics can be designed and configured using the openSCADA or any other SCADA software available under GNU license scheme. The operator station should communicate with controller PC via TCP/IP protocol. All the systems at different level should be on the same network with client server architecture[7]. Once the simulator system is properly configured at all the levels , the operator can be trained for basic operation of power system. Moreover the researchers and students as a part of their research activities can modify the power system model or develop the new control scheme to test and validate results on the proposed real time system.

V. CONCLUSION

The paper proposes SCADA based control center lab for automatic generation control of interconnected power system. The proposed system is a cost effective solution for training and extending research in the area of power system operation and control. The power system field simulation computer reduces the risk of hazards of physical power systems and gives a more realistic picture and dynamic behavior of the system where as open source SCADA system such as Integraxor and openSCADA can be customized to study and implement more SCADA applications for power system network.

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