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Real Time Dynamic Performance of Multi-Machine System Using Smart Technology

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Abstract: This papers represents implementation of smart power system using inter device communication and supervisory control through Simulink integrated with physical system. This control includes features of real time control, load management, fault detection and self-healing. Prototype is designed in hardware which takes in required parameter via sensors to PC via RS-232 power meter interface and actuator interfaced with Arduino microcontroller board which is integrated with MATLAB Simulink. Simulink simulate the model and predict control signals depending upon input parameters and it send control signal back to Arduino which then control the hardware through hardware in the loop (HIL) simulation. In the case of severe fault, these control techniques detect system variation and compensate this variation or remove the faulty part by using relays, which represents self-healing nature of developed model.

Keywords: Smart grid (SG), HIL, Simulink, Power system, Micro grid, Smart control.

I. INTRODUCTION

ELECTRICITY is the best known form of energy that can be harnessed to meet human needs for an equilibrated and progressive civilization. Electrical energy generated at power stations is transferred to consumers through a complex transmission and distribution network known as power grid. Currently, electric energy production is centralized and flows from generating stations to consumers through one-way hierarchical flow [1]. This one-way, uncontrolled flow of electric energy poses a number of challenges to grid and its operators, thus questioning the security, reliability and quality of the power being supplied [2][3].

The Smart grid (SG) or future grid that uses information and communication technologies to transfer power from central generating stations to consumers in a two-way manner and also from Distributed Energy Resources (DERs) to other consumers and controls all the processes in an intelligent and pervasive manner [4]. Thus, it uses a network architecture instead of hierarchical approach for multi-directional power flow and information exchange among the producers and consumers. Equipped with communication and intelligent controlling infrastructure the future SG will successfully cope with the ever increasing demand of the bulk consumers and will sustain the market with economy and environmental benefits [5].

Current power grid is subjected to structural weaknesses and environmental shortcomings. These limitations have severe effect on the quality, reliability of system. Hence, there is a great need of advance and sustainable grid that implies modern information technologies for safer, reliable dispatch of electricity both from bulk generating stations in a multi-directional and flexible manner with exchange of information in real time [6].

Efficiency of a power system decreases due to the losses in it. Similarly, the instability of multi-machine depends upon the transients produced during its operation. To overcome these losses a micro grid model should be assembled in such a way that all the controlled parameters should apply on it [7]. The results of these parameters should have the ability to apply on macro grids and with the help of these parameters control on the losses is possible. With the development of electrical energy new era regarding the control of generating systems responsible for electrical energy begins. Progress in the electrical power generating systems give birth to the limitations or constraints in their working. In our proposed model, we use two motor generator set as a generating station and 3 busses for load.

Objective of this paper is to simulate and develop the model in such a way that all the controlled parameters i.e. optimal power flow analysis, damping of transients, improvements in power factor, smart load sharing, and system stability are applicable on it. And also capable of smart power generation and distribution including automatic load shedding, forecasting and multi-agent system for inter-device communication.

We also implement future grid concept to make grid automated and self-healing under the widespread control of ultra-smart management and control systems providing a number of benefits to both utilities and consumers [8].

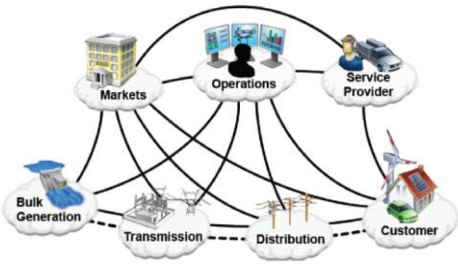

Fig. 1 NIST Conceptual Model for Future Grid [9]

Being aware of huge landscape of the SG, future grid will be comprised of smart infrastructure, smart information, communication, management and protection.

In Section II, the prototype implementation is described and it's working according to different load condition for the system. In Section III, discussion and implementation of prototype in SIMULINK are explained while results and analysis are discussed in the Section IV. In Section V, a conclusion about more stabilized and automated future power system by using more advance technologies is highlighted.

II. PROTOTYPE IMPLEMENTATION

Prototype is implemented in two ways,

A. Software Implementation

For the control and monitoring of the power system, input and output interfaces and control algorithms are developed in Simulink which takes inputs from system in real time and control the system parameters through its output interface. Arduino is also integrated with MATLAB for faster and precise numerical computations of the load forecasting and reliability assessment of the system.

B. Hardware Implementation

Smart Generation and distribution system is developed and interfaced with software model. Hardware model consists of generators with control equipment and smart distribution system. Distribution system consists of resistive and inductive loads, solid state control circuits which are used to distribute and control power in a smart manner.

Following steps should be followed, first of all make a motor-generator set. For this purpose, connect the synchronous machine with tachometer. Also connect the available D.C motor of suitable rating with same tachometer. Here we use D.C motor as a prime-mover. Purpose of connection of D.C motor as well as synchronous machine with tachometer is to determine the speed, torque and power of these machines at any instant of time Tachometer has two parts, one is called Sensor Unit while second is called Display Unit. Sensor Unit is connected with motor and generator shaft for sake of sensing and determining the change in speed and torque of the motor and generator. These determined values will display on Display Unit with the help of serial cable connected with Sensor Unit.

Fig. 2 Hardware implemented model

Output of generator is connected with 3-phase A.C power meter to determine the output voltages of generator.

And Block diagram is given in fig 3. The aim is to automate the same system and control it with computer or by any other type of software based device. Use Buck Converter in-place of rheostat. To control all these circuits such as Buck Converter, Current Sensor and Voltage Sensor, use software based Arduino which is connected to operating system such as computer via its software driver.

Arduino is basically programmable device which has number of I.Cs. The limiting values of parameters i.e. maximum and minimum values of current, voltage of motor-generator set is pre-programmed in Arduino. So that the maximum and minimum range of parameters of motor-generator system should not exceed. If there is any change in values occur, Arduino gets signal of that change and it corrects that undesirable change and stable the output value to its pre-programmed value. Basic purpose of buck Converter is to regulate the D.C source supply so that the input to field could be controlled and varied. Buck Converter get pulse with modulated signal through Arduino [10].

- **Block Diagram and Component Specification:**

To monitor and its stable operation, our prototype follow following control structure in hardware and software implementation. Both generator feed power to the load through Bus1 and Bus 2 to common load bus and generator change its speed and other parameter according to load on the common load bus. Control structure sense variation in load current and voltage through current and voltage sensors respectively and different protection devices i.e. relay and breaker to common load bus. These variation feed directly to Arduino and in the same way, model developed in MATLAB also working on the same specifications. Shown in fig 3.

Arduino work as a communication channel between hardware and software model and integrate them in such a way that they respond each other in any variation.

Component Name	Ratings
Arduino Due	3.3V
Generating station	1.2kW, 1400 RPM
Power pack	3.5A, 220V,230V, 10A(3-phase)
Torque power meter	3000 RPM, +/- 5.5kW, +/-17.5Nm
Compound motor	1kW, 220V Excitation(0.55 A)
Load switch	3-pole, 16A,250V DC/440V AC
Voltage Sensor	3.3 V
Resistive Load	1KΩ

Table 1: Rating of different Component in HIL model

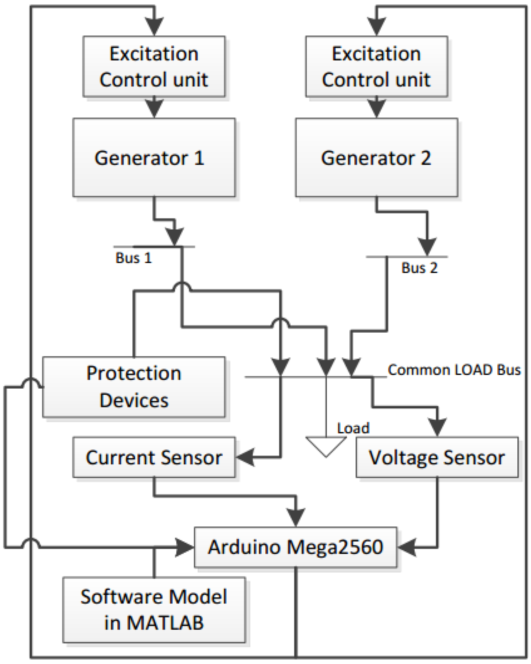

Fig. 3 Flow diagram of HIL Model

Arduino Compare the MATLAB values and hardware model and generate signal to make system stable. Like, in case of failure of any generating station load shift on healthy generating station, Arduino sense the change and increase/decrease the excitation of generator to meet the load demand and remove faulty generator through circuit breaker. And similarly load variation cause different abnormal behaviors, current sensor measure and communicate with Arduino to check the current limit. If it is in permissible range then it will generate the signal and change the excitation of generator by changing the duty cycle of buck converter to meet load variation. If current variation is not in permissible range then it will generate signal to remove the extra load to make it stable.

In this way, both hardware and software interlink with each other and communicate to make the system self-healing and whole system performance can be consider as a hardware in the loop (HIL) simulation.

III. SIMULINK MODEL

In software implementation observer can observe the effects of change in values of parameters while output of motor-generator set remains same. Voltage Sensor and Current Sensor controls and limits the value of applied voltage and current, to avoid the excessive flow of current in the field winding of motor. Voltage Sensor and Current Sensor measures the input line current and limit this value to a definite ratio or some pre-determined ratio and gives signal to Arduino device. Arduino compare these receiving values with its pre-programmed value and perform the necessary change in value so as to keep the stable output value. Real-time output value is displayed on the screen of software based device such as computer etc. Graphical representation of change in values can be displayed on screen for graphical analysis [11].

We basically integrate hardware model with software model which takes the input from hardware model and compare it with Simulink design model which is working under the ideal condition and error signal is generate by the Arduino then feed into prime mover to change the system performance. When system undergoes from the severe fault then this part can automatically remove or try to move it towards its stable state. Rating of different component is shown in table 1.

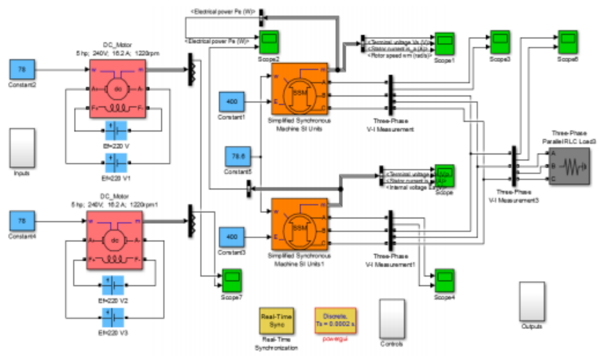

Fig.4 MATLAB Simulink model

Prototype is designed in hardware which takes in required parameter via sensors to PC via RS-232 power meter interface and actuator interfaced with Arduino microcontroller board which is integrated with MATLAB Simulink shown in fig 5.

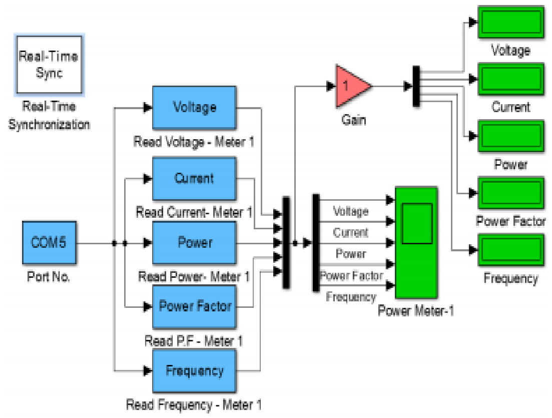

Fig.5 Power Meter RS-232 Protocol

We observe our system under different condition like, timing variation, frequency variation, and many more. We can estimate timing behavior because under this observation we are able to observe the system stability and also system response under various condition by using MATLAB Simulink. The main purpose of hardware in the loop is that we run the prototype simultaneously in software and hardware at a time and do the analysis by observing the results showing in graph and time response is about 1ms. We can improve it by introducing more sensitive devices.

System voltage variation is actuated by following MATLAB Simulink model,

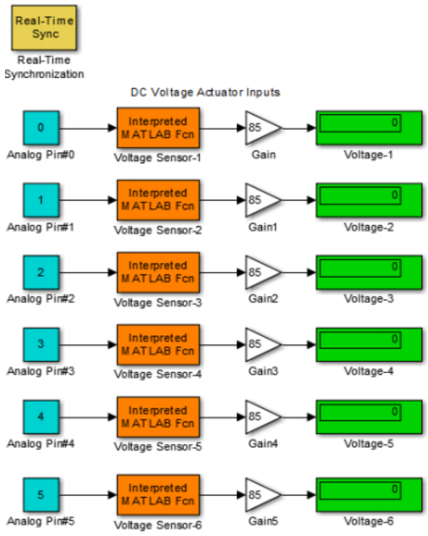

Fig.6 System Input Voltage Sensor Model

IV. ANALYSIS AND RESULTS

The system when completely synchronized with the Simulink model, all the inputs from physical systems are passed on the virtual system using actuators and sensors. AC power meter is used to transfer Electrical parameters of the generators and loads to the virtual model. DC voltage and current sensors pass on the DC voltage and current values to the system running in the Simulink. Torque and tachometer unit displays the values of shaft torque, RPM and power produced by each prime mover thus keeping a check on each prime mover's real power input to the generator.

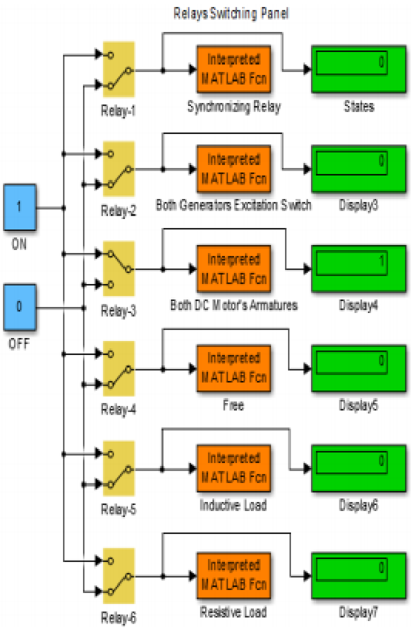

Fig.7 Relay Control Panel

The system controls the hardware parameters as well. Switching relays switch on and off the load and shed the load when high fault currents are passed through the system. DC voltage regulators (buck converter) control the excitation of each alternator and field voltage of each prime mover (DC motor) which is connected as separately excited motor. The system in up and running condition control the speed of each prime mover, voltage of each generator, automatically synchronize the two alternators when commanded from Simulink model, reads the electrical parameters of all the generators, motors and loads attached [12].

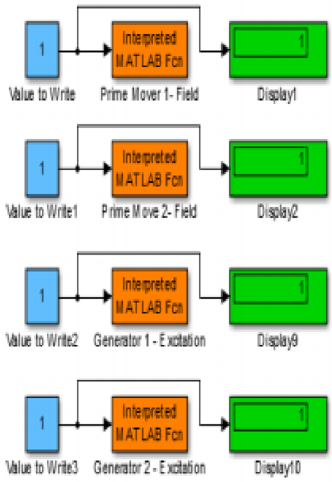

Fig.8 Buck Converter Duty Cycle

From system performance, we can observe that terminal voltage, stator current and rotor speed is constant at 78.7. But when load on a generator 1 increase then rotor speed also fluctuate and this effect also shifts towards generator 2. But after comparing it with our MATLAB model, it will try to move generator speed towards a constant rpm, internal voltage, stator current and all other parameter start to stabilize. And load current and voltage is also constant. Fig9-10 represents system performance and behavior under stable condition.

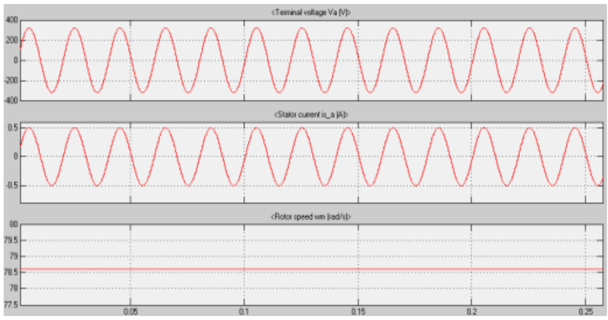
Fig.9 the outputs of Generator 1

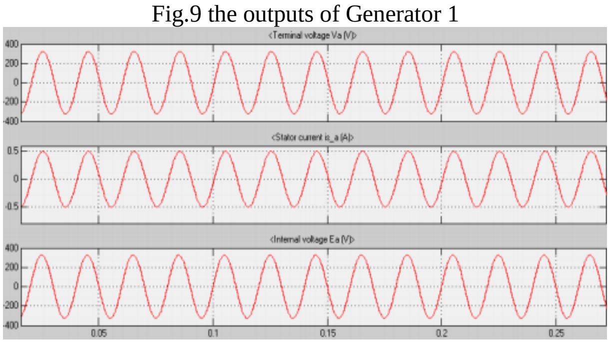
Fig.10 Output parameters of Generator 2

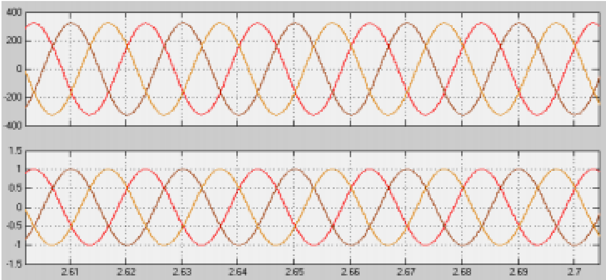

Fig.11 Voltage and Current at Load Terminals

V. CONCLUSION

Future grid is an ineludible technological innovation that would help us to build an environmental friendly and sustainable future for energy demands. This paper reviews major pilot projects initiated by various utilities, organizations and institutions. And tried to present a self-automated system, which undergoes different system variations and then stabilizes according to the system needs. The risks introduced due to deployment of advanced technologies were also assessed and solutions proposed by various researchers were presented. The system can be extended to a more advanced and reliable system that would incorporate a 3 machine 9 bus system with IEEE standard bus data. For the same prototype, the Simulink model can be extended into a GUI control panel which displays all the values of input parameters, provided controls for all variable parameters and provides options for system analysis and control.

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