Frequency Control of Microgrid Based on Compressed Air Energy Storage System

R. Latha, Assistant Professor, Dept. of Instrumentation and Control Systems Engg., S. Palanivel, PG Scholar, Dept.of Instrumentation and Control Systems Engg., J. Kanakaraj, Associate Professor, Dept. of Electrical and Electronics Engg.,

PSG College of Technology, Coimbatore, Tamilnadu, India.

ABSTRACT

The electrical power system operates under variable load condition, so the load tracking problem will arise which can cause voltage and frequency instabilities. Energy storage devices are able to balance the fluctuation of power generation and consumption. In this article the use of Compressed Air Energy Storage (CAES) system for microgrid is proposed. Under variable load conditions, the stored compressed air from the CAES system will be utilized to meet the demand. During power generation an excess power is used to compress the air. An air flow controller for CAES is designed to control the air flow from the CAES system, so that the microgrid follows the various load demands to maintain the stable frequency. The performance of the proposed system is validated through simulation study for various load conditions is carried out using MATLAB/Simulink.

Keywords: Microgrid, Compressed Air Energy Storage, Air Flow Controller, Variable Load Demands.

INTRODUCTION

The demand for the electricity is continually growing and the formation of microgrid is attractive option to meet the expanding energy demands. A microgrid is a collection of micro sources, energy storage systems and loads, operating as single controllable system [1]. Microgrid is now commonly used in distribution systems to produce continuous power supply during abnormal condition and also to reduce the power losses in the system. If any fault occurs in the generator or in any lines, microgrid acts as an individual generator and maintains the stability of the system. The most important process in microgrid is to generate power based on the normal and abnormal condition. If any fault occurs in the system, it loses its stability condition. So, in order to maintain the system stability, a microgrids need to generate power based on the present condition. Compressed Air Energy storage (CAES) technologies are used to balance the fluctuation of the power generation and consumption. In a CAES system, the excess power is used to compress air which can be stored in a vessel or a cavern. The energy stored in compressed air will be used to generate electricity when required [2,3].

When the system operates under variable load condition, then the load tracking problem will arise which can cause voltage and frequency instabilities. That is whenever there is an unbalance between active power production and active power load demand the frequency deviates from its nominal value. Therefore, the system should be able to maintain frequency in an acceptable operating range and to ensure power quality. In the grid all the generators need to be in operation to provide a stable frequency and voltage for arbitrarily varying loads. The low inertia generator speed will be changed for large step loads, creating fluctuation in system frequency [1,4]. In this article, an air flow controller

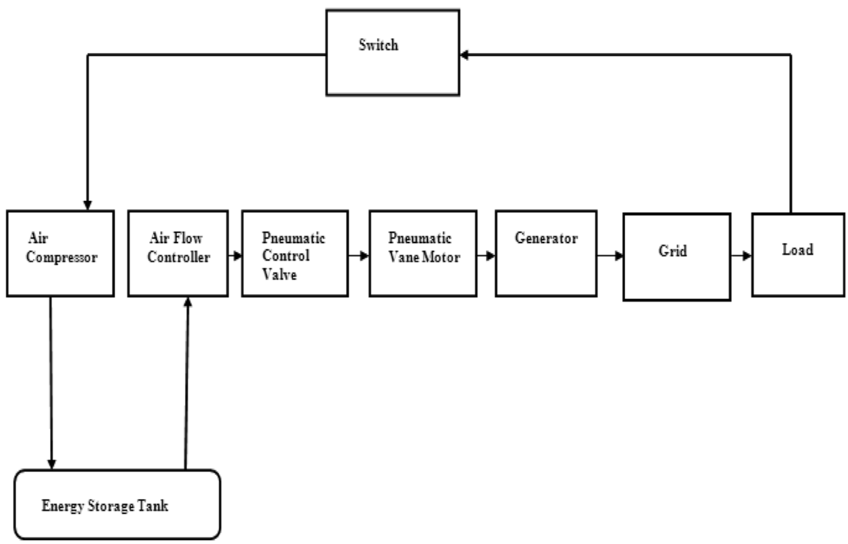


Figure 1. Block diagram of Compressed Air Energy Storage Generation System

is designed to control the air flow from CEAS in order to maintain the frequency in an acceptable range.

COMPRESSED AIR ENERGY STORAGE SYSTEM

Compared to other types of energy storage schemes such as pumped water, battery, hydrogen and capacitors for energy storage, the compressed Air Energy Storage (CAES) is a well known affordable technology. During off-peak period, the CAES system stores the air into an underground reservoir, by powering the motor connected to a compressor and during peak periods the compressed air is utilized to generate power with turbine [5,6].

PROCESS OF AIR ENERGY CONVERSION

The air energy conversion for both compression and expansion are considered as an isothermal process in which the temperature is constant. The energy conversion process of the proposed system consists of three main components: air compressor, energy storage vessel and compressed air generator. The energy conversion starting with the compressor; the electrical power from the grid is converted into me-

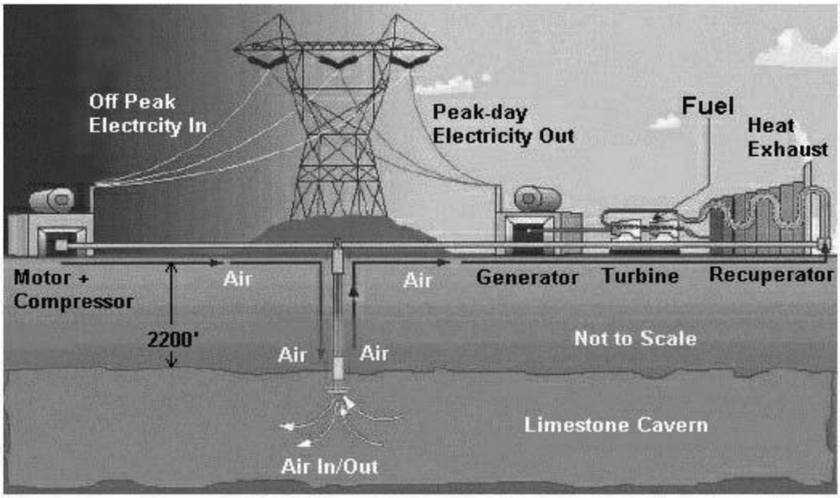


Figure 2. Schematic diagram of compressed air energy storage (CAES) unit

chanical torque for suck and compresses air from the atmosphere and store in the tank. Then the compressed air transmits the air power to drive the prime mover coupling with generator, which the mechanical power converts back to electric power. The compressed air is released back into atmosphere again [3].

A device used in compressed air expansion process is called as air motor. In this article sliding vane type air motor is used as air motor because of their simple construction and less weight. There is a rotational drive shaft with four slots, each of which is fitted with a freely sliding rectangular vane. When the drive shaft starts to rotate, the vanes tend to slide outward due to centrifugal force and are limited by the shape of the rotor housing. Depending on the flow direction, this motor will rotate in either clockwise or counter clockwise directions. The difference in air pressure acting on the vane results in a torque acting on the rotor shaft [6].

DESIGN OF AIR FLOW CONTROLLER

The block diagram representation of pneumatic control system is shown in Figure 3.

In this article the PI controller is used to control the air flow through the valve. So that the power applied to the generator is regulated by means of controlling the speed of the turbine. During the application of the load, the frequency gets affected. But with PI controller the frequency control is obtained.

Pneumatic Control Valve

The directional control valve controls the passage of air signals by generating, cancelling or redirecting signals. 5/3-way valve is used

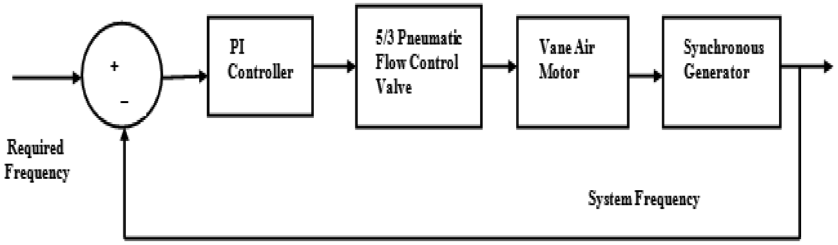


Figure 3. Pneumatic Control System

control the flow of air. The 5/3-way valve has five working ports and three switching positions. With these valves, double-acting cylinders can be stopped within the stroke range. This means a cylinder piston under pressure in mid position is briefly clamped in the normally closed position and in the normally open position, the piston can be moved unpressurised. If no signals are applied at either of the two control ports, the valve remains spring-centred in mid position [8]. The pneumatic Symbol of 5/3-way pneumatic control valve is shown in Figure 4.

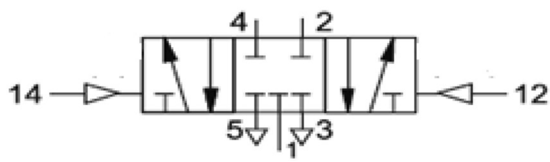


Figure 4. Pneumatic Symbol of 5/3-way pneumatic control valve

PI Controller Design

The Proportional and Integral (PI) Controller is used to adjust the valve position of the 5/3-way pneumatic control valve.

$$U(t) = K_p * e(t) + K_i * \int e(t) \quad (1)$$

Where K_p and K_i are the tuning parameters of PI controller.

SYSTEM SPECIFICATION

Generator Specification

Synchronous Generator
Nominal power = 4 kW
Line to line Voltage = 400 V
Frequency = 50 Hz
Rotor type -> Round Rotor

Vane Air Motor Specification

Power = 6.7 hp or 5 kW
Speed = 3000 RPM
Flow rate = 4.7 m3/min
Pressure = 5 Bar

SIMULATION RESULTS

The dynamic performance of the proposed system is assessed through digital simulation in MATLAB/Simulink environment. Simulation diagram of the proposed system is shown in Figure 5. Two different case studies are considered, to carry out the dynamic performance of the system under various load conditions. The first case study consider the stabilization of frequency and air flow rate when there is a load variation under grid connected mode. The second case study represents the stabilization of frequency and air flow rate when there is a load variation under islanded mode of microgrid.

Case 1

Figure 6 shows grid frequency stability under load changes (Load 'A' is added at t=0.1sec and another Load 'B' is added at t=8sec). Consider the total load demand is less than the generated power. During off-peak load period, it can be seen that grid frequency is fluctuating at t=8sec and it can be suppressed effectively by air flow controller by changing air flow from the CAES system. When the applied load power is less than availability of grid power (Grid connected mode), the excess unutilized grid power is used to switch on the Compressor. Based on the load variations the stabilized frequency response, air flow changes and the switching status of the compressor are shown in Figure 6(a), 6(b) and 6(c) respectively. In this case the excess electrical power from the grid is converted into mechanical torque, and used for sucking and compresses air from the atmosphere and store in CAES tank.

The stabilized voltage response and the rotor field changes based on the load variations is shown in Figure 7(a) and 7(b) respectively. It can be seen that grid voltage is fluctuating at t=8sec. And it is suppressed immediatetly by changing the rotor field excitation.

Case 2

Figure 8 shows grid frequency stability under load changes (Load 'A' is added at t=0.1sec and another Load 'B' is added at t=8sec). Consider the total load is greater than the generated power.

During peak load period, it can be seen that grid frequency is fluctuating at t=8sec. By controlling the flow of air through air flow controller, the fluctuation is suppressed. When the load power is more than the grid power (Islanded mode), the stored compressed air is extracted

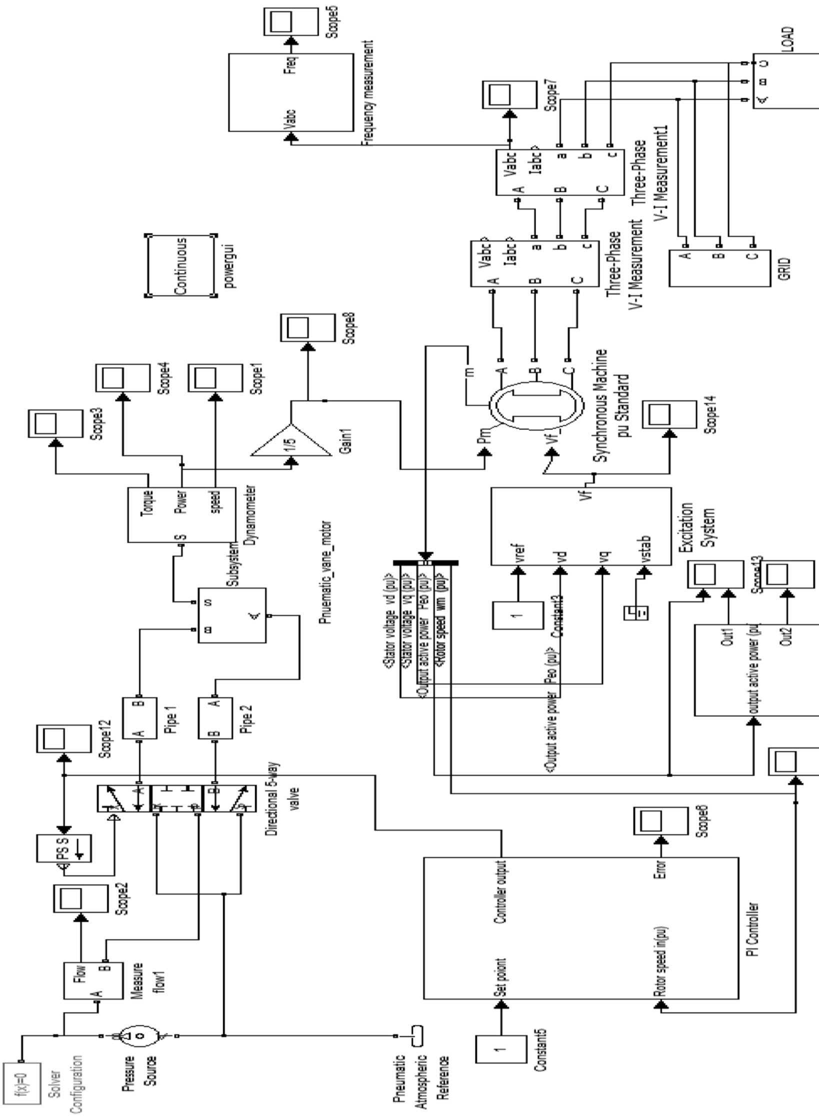
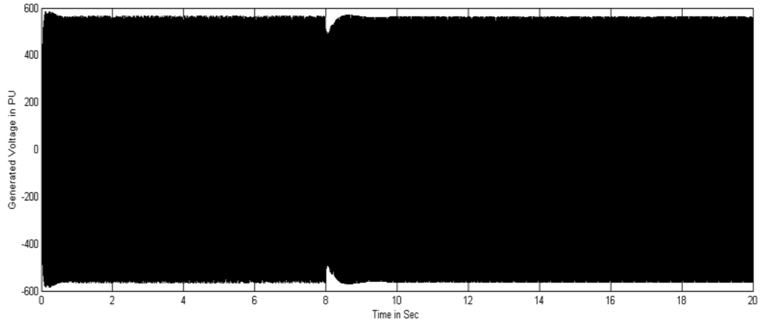
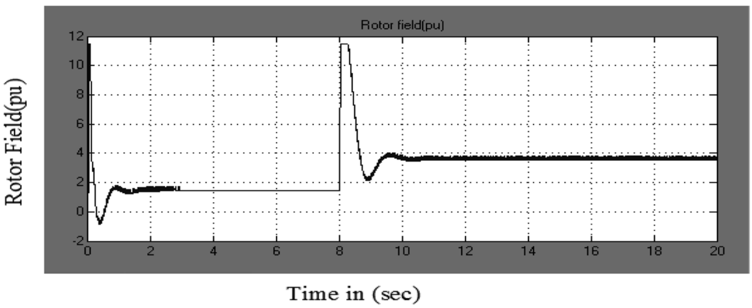


Figure 5. Simulation diagram of the proposed system



(a)

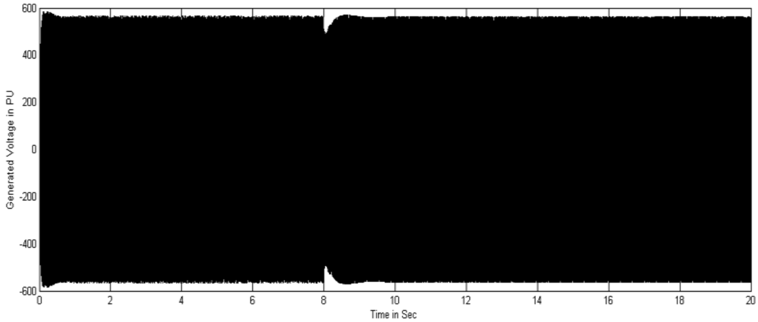


(b)

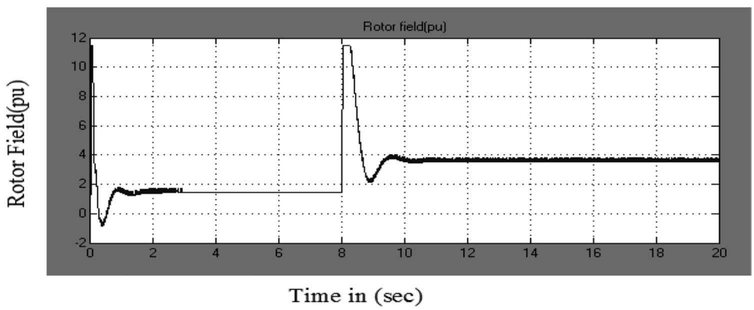
Figure 6. (a) Stabilized Frequency response for load variations; (b) Air flow changes based on the variable loads; (c) Compressor switching status (ON= 1 and OFF = 0)

from the CAES used to generate the electrical power in order to match the load demand. During that time Compressor is in "OFF" condition. Based on the load variations the stabilized frequency response, air flow changes and switching status of the compressor are shown in Figure 8(a), 8(b) and 8(c) respectively. In this case the compressed air transmits the air power to drive the prime mover coupling with generator in which the mechanical power converts back to electric power.

The stabilized voltage response for load variation and the rotor field changes based on the load variations is shown in fig 9(a) and 9(b) respectively. Here the change in grid voltage at 8sec can be suppressed effectively by changing the rotor field excitation.



(a)

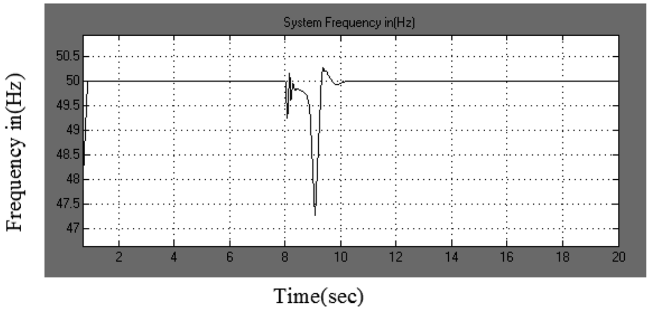


(b)

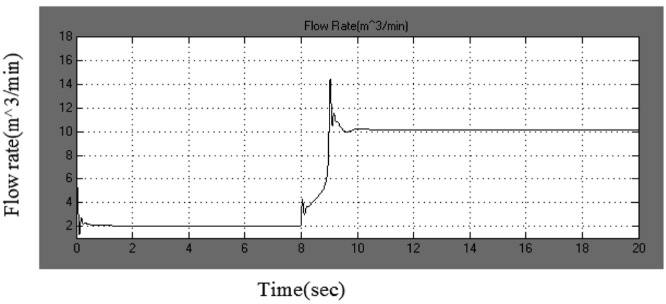
Figure 7. (a) Generated voltage during off-peak load (Grid Connected Mode); (b) Change in rotor field under load variations

CONCLUSION

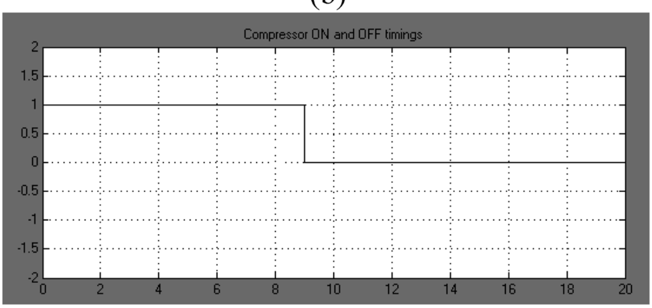
This article presented the use of Compressed Air Power Energy Storage system in combination with an air flow controller for power generation. The proposed air flow controller controls the air flow from the compressed air energy storage system. In this article, with CAES and an air flow controller the continuous supply with constant frequency is obtained during variable load conditions. The simulation results verify the stability performance of the grid under various load demands and the use of CAES system to balance the power generation and consumption.



(a)



(b)



(c)

Figure 8. (a) Stabilized Frequency response for load variations; (b) Air flow changes based on the variable loads; (c) Compressor switching status (ON= 1 and OFF = 0)

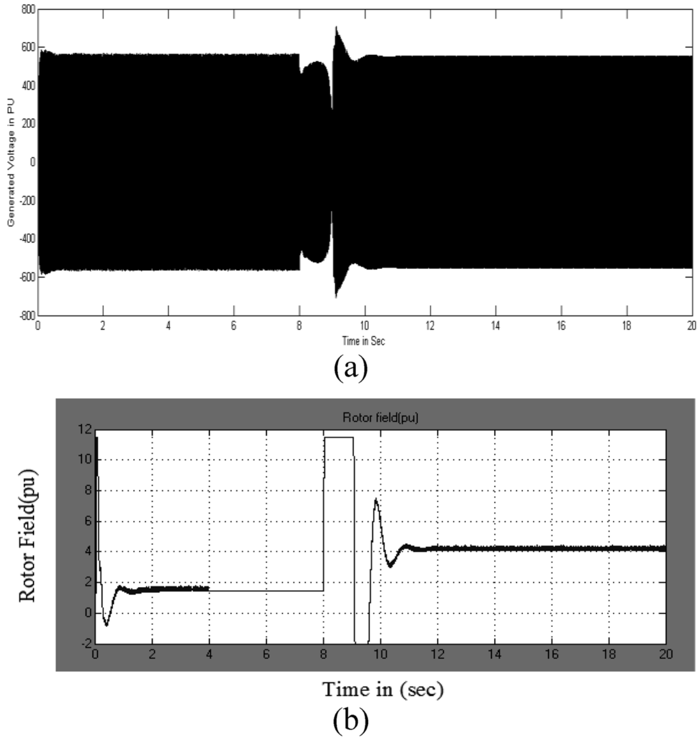


Figure 9. (a) Generated voltage during peak load (Islanded Mode); (b) Change in rotor field under load variations

References

[1] N. Jayawarna, X. Wu, Y. Zhang, N. Jenkins, M. Barnes, "Stability of a Microgrid," *3rd IET Int. Conf. on Power Electronics, Machines and Drives*, Apr. 2006, pp. 316-320.

[2] Ali Daneshi, Nima sadrmomtazi, Hossein Daneshi, Mojtaba hederzadeh, "Wind Power Integrated with Compressed Air Energy Storage," *IEEE Int.Conf. on Power and Energy*, Dec 2010, pp 634-639.

[3] Varin Vongmanee, Veerapol Monyakul, "A New Concept of Small-Compressed Air Energy Storage System Integrated with Induction Generator," *Int. Conf. on sustainable Energy Technologies*, Nov 2008, pp 866-871.

[4] I. Serbon, C.P. Ion, C. Marinescu, M. Georgescu, "Frequency Control and Unbalances Compensation in Autonomous Micro-Grids Supplied by RES," *Int. Conf. on Electric Machines and Drives*, May 2007,pp 459-464.

[5] Dustin Shively, John Gardner, Todd Haynes, James Ferguson, "Energy Storage methods for Renewable Energy Integration and Grid Support," *IEEE conf. on Energy 2030*, Nov 2008, pp 1-6.

[6] Hao Sun, Jihong Wang, Shen Guo and Xing Luo, "Study on Energy Storage Hybrid Wind Power Generation Systems, " *Proc. Of World Conf. on Engineering*, July 2010.

[8] T. Ackermann, G. Andersson, and L. Soder, "Distributed generation: A definition,"

Electric Power System Research, vol. 57, 2001, pp. 195-204.
[9] P. Croser, F. Ebel, *Pneumatics in Basic Level*, Festo Didactic GmbH & Co., 2002.

ABOUT THE AUTHORS

R. Latha received B.E degree in Electrical and Electronics Engineering from Coimbatore Institute of Technology, Coimbatore and Master's degree in Power System Engineering from Govt. College of Technology, Coimbatore. She is doing research on Power System Stability Control in Anna University, Coimbatore. She is in teaching since 2005 and is presently working as Assistant Professor in the department of Instrumentation and Control Systems Engineering at PSG College of Technology, Coimbatore. She is a member of ISTE. She has few International Journals and few conferences. Her research interests are Power Electronics, Electrical Machines, Power system stability and distributed generation. Email: lathasivak7@gmail.com

S. Palanivel is a PG scholar in the department of Instrumentation and Control Systems Engineering at PSG College of Technology, Coimbatore. His research interests include Control Systems, Power System Control and Power system stability. Email: palanieee.vel51@gmail.com

Dr. J. Kanakaraj obtained his B.E in Electrical and Electronics Engineering from the Coimbatore Institute of Technology in 1989, his Master's degree in Electrical Machines from PSG College of Technology, Coimbatore in 1991 and Ph.D in Control Systems from Anna University, Chennai in 2007. He is in teaching since 1993 and is currently working as Associate Professor in the Department of Electrical and Electronics Engineering at PSG College of Technology, Coimbatore. He has published 6 National and International Journals and few conferences. Presently he is guiding 10 research scholars. His research interests are Electrical Machines, Electrical Drives and Control. Email: jkr@ice.psgtech.ac.in.