www.jatit.org

# ADAPTIVE PSO BASED OPTIMAL FUZZY CONTROLLER DESIGN FOR AGC EQUIPPED WITH SMES AND SPSS

## <sup>1</sup> R.Shankar Naik, <sup>2</sup> K.ChandraSekhar, <sup>3</sup> K.Vaisakh

<sup>1</sup>M.E Student, Department of Electrical Engineering, AUCE, Visakhapatnam, India-530003
 <sup>2</sup>Assoc. Prof., Department of Electrical Engineering, AUCE, Visakhapatnam, India-530003
 <sup>3</sup> Prof., Department of Electrical Engineering, AUCE, Visakhapatnam, India-530003
 E-mail: shankar02234@gmail.com, sekhar\_kona@yahoo.com, vaisakh\_k@yahoo.co.in

#### ABSTRACT

This paper presents the optimal fuzzy controller design for load frequency control (LFC) of two area power system using Adaptive Particle Swarm Optimization (APSO). Firstly, the controller is designed according to Fuzzy Logic rules such that the systems are fundamentally robust. Secondly, the Fuzzy Logic controller (FLC) used earlier was optimized with PSO so as to obtain optimal adjustment of the membership functions only. Finally, the FLC is completely optimized by Swarm Intelligence Algorithms. Digital simulation results demonstrate that in comparison with the FLC, the designed FLC-APSO speed controller gives better dynamic performance of the LFC, as well as without any overshoot. The proposed controller is compared against other controllers. The results show that the proposed controller outperforms other schemes.

**Keywords:** Intelligent fuzzy control, Particle swarm optimization, automatic generation control, load frequency control

### 1. INTRODUCTION

The problem of load frequency control has been one of the most accentuated topics in the operation of interconnected power systems. The LFC of an interconnected power system has two principal aspects such as maintenance of frequency and power exchange over tie-lines on scheduled values. The objective of LFC is to maintain the area generation-demand balance by adjusting the outputs on regulating units in response to deviations of frequency and tie-line exchange. In steady state, the output of the generators at any instant will exactly equal the load on the system and all the generating units operate synchronously at the same frequency. Immediately after a change in the total power demand, the flywheel governor of the synchronous machine try to return the system to the initial frequency but it is unable to do that. Therefore, the system needs to use supplementary control i.e AGC to limit the deviation in frequency [1].

In the interconnected power system, the supplementary control is added to the system to compliment the primary control to eliminate the frequency and net tie-line interchange deviations. The following objectives are considered due to the load perturbations: (1) maintain frequency of each area and the net tie-line Power at scheduled value. (2) Each area regulates its own load changes.

A large number of controllers are used to maintain a power system in a normal state of operation. To maintain the system at a normal operating state, different types of controllers based on optimal control theory [2,3,4,5], and variable structure control theory [6,7,8,9] have been developed in the past for LFC. In conventional studies, frequency oscillations of the system are minimized by using conventional linear controllers [10, 11]. However, they resulted in longer settling times and higher oscillations. Power system is a nonlinear, complex system and is subjected to different kinds of events. Therefore, it is difficult to effectively solve the significant power system control problems depending only on the conventional approaches. As a way to solve these problems, gain scheduling controllers as a type of adaptive controller had been used for AGC by many researchers, [12]. It gave better performance than conventional control methods but the dynamic response may be unstable because of

www.jatit.org

the abruptness in system parameters. In addition, it is difficult to design a linear time invariant models for different operating points [13].

Recently many researchers applied intelligent techniques (i.e neural network, fuzzy logic, optimization algorithms, etc.) to solve the load frequency control problem [14-17]. FGPI controllers were proposed by different researchers, [12, 13]. A FGPI controller proposed by [13] with seven triangular membership functions. This controller gave better dynamic performance when compared with three different controllers.

Many researchers worked on the analysis of fuzzy control rules and membership function parameters [18]. The PSO (particle swarm optimization) algorithms were used to get the optimal values and parameters of our FLC. The PSO searches a space by adjusting the trajectories of individual vectors, called "particles", as they are as moving as conceptualized points in multidimensional space. The individual particles are drawn stochastically towards the positions of their own previous best performances and the best previous performance of their neighbors. Since its inception, two notable improvements have been introduced on the initial PSO which attempt to strike a balance between two conditions. The first one introduced by Shi and Eberhart [19] uses an extra \_inertia weight\_ term which is used to scale down the velocity of each particle and this term is typically decreased linearly throughout a run. The second version introduced by Clerc and Kennedy [20] involves a constriction factor in which the entire right side of the formula is weighted by a coefficient.

PSO algorithms are applied to search globally optimal parameters of fuzzy logic. The best ranges of membership functions, the best shapes of membership functions and the best fuzzy inference rules are dug out at the same time. Furthermore, the performances of three different fuzzy logic controllers are compared. Simulation results are given to show the effectiveness of FLC-Swarm controller.

The PSO algorithms are applied to choose membership functions and fuzzy rules. However, the expert experiences or knowledge are still necessary for the ranges of membership functions. In this paper, a novel strategy is proposed for designing the optimal fuzzy controller. The results of the proposed controller are compared against the conventional controller. The results demonstrate that the proposed controller provides better performance than other types of controllers.

Recently much attention has been paid on the research for enhancing electrical power system to achieve the high performance of operation by utilizing high speed electronic power devices, based upon the concept of FACTS ( Flexible AC Transmission System) [21]. Among of them the combination of SMES and Solid-state phase shifter (SSPS)[4], has been expected high effective apparatus in power system, since SMES is capable of controlling active and reactive power simultaneously, while SSPS is effective for power flow control. In [22] SMES with SSPS in significantly successful in stabilization of long distance bulk power transmission system even though it is located far from the generator. Consequently it is possible to apply the combination of them with suitable control strategy to other problems in power systems such as LFC, as proposed in [23] by the authors.

This paper also present a decentralized direct tie line power flow control strategy of a SMES and decentralized SSPSs for LFC and power system stabilization in muti area interconnected power system. A SMES and decentralized SSPSs are utilized as the load frequency control for each area by using only the local frequency deviations as their feedback input signals under the occurrence of sudden load changes or some disturbance in areas, the active power output of SMES and tie line power modulation control by SSPS are utilized to suppress not only frequency but also inter-area oscillations modes among any areas simultaneously.

# 2. MODELING FOR AGC OF A 2-AREA POWER SYSTEM

#### 2.1 General two are system

The system considered in this study is consisting of two control area connected by a tie-line as shown in Fig. 1. Each control area is containing non-reheat turbine type thermal unit. Detailed block diagram of a single area power system is shown in Fig. 2. The system can be represented in the state-space form by the following equation:

$$x = Ax(t) + Bu(t) + \Gamma \Delta P_d(t)$$
(1)

where

A is the state matrix, B and  $\Gamma$  are input and disturbance matrices,  $uand\Delta P_d$  are input and disturbance vectors.

www.jatit.org



Fig.1.General diagram of a two-area power system

Also x(t) is the state vector, given as

$$x(t) = \begin{bmatrix} x_1 x_2 \dots x_7 \end{bmatrix}^T = \begin{bmatrix} \Delta f_i \ \Delta P_{gi} \ \Delta X_{Ei} \ \Delta P_{tie} \end{bmatrix}^T$$
(2)

Where  $\Delta f_i$  is increment frequency deviation of area  $i \Delta P_{gi}$  is mechanical power deviation of area i,  $\Delta X_{Ei}$  is increment change in governor valve position of area i,  $\Delta P_{tie}$  in the tie line increment power deviation, i is the area index 1,2,  $u(t) = [u_1 \ u_2]^T$  and  $\Delta P_d = [\Delta P_{di} \ \Delta P_{d2}]^T$ .

First control area is interconnected with tie-line to other control area. The i -th control area net interchange equals the megawatts on outgoing tieline. To maintain frequency of each area and the net tie-line power at scheduled value, the Area Control Error (ACE) of i -th area is minimized to zero.

$$ACE_{i} = \sum_{j=1}^{m} \Delta P_{iie,ij} + b_{i} \Delta f_{i}$$
(3)

Where bi is the frequency bias coefficient of i-th area, and  $\Delta P_{tieij}$  is tie-line interchange error between the i-th and j-th areas. Detailed block diagram of the two-area interconnected power system including controllers is shown in Fig. 3.



Fig-2. Detailed block diagram of the singlearea interconnected

2.2 Decentralized direct Tie- Line power flow control strategy of SMES and SSPS

A Two area interconnected system shown in figure 4. is utilized to describe the concept of decentralized direct tie-line power flow control by SMES and SSPSs supposed, for decentralized control, a SMES is located in one area, while SSPS is located on the tie-line between both areas for power flow control. When the sudden load fluctuations or some disturbance occur in any area, the active power output of SMES, is controlled to suppress the frequency deviation of its located area while the SSPS is utilized to modulate the tie-line power flow directly in order to diminish the frequency deviation of another area.



Fig. 3 Two-area power system including controllers

The block diagram of linear zed system model of the two area interconnected system with SMES and SSPS is illustrated in fig 5.BothSMES & SSPS are represented by first order lag controls. The decentralized control strategy of SMES &SSPS is stated As follows.



Fig.4: Two Area Interconnected System with SMES&SSPS

A SMES, which is located in area 2, is used to suppress the frequency deviation of this area, by utilizing local frequency deviation as SMES feedback signal input. At the same time, SSPS which is located on the tie-line near area 1, is used to minimize frequency deviation of area 1 by utilizing the frequency deviation of area1 as the SSPS feedback signal input.

For the SMES unit, energy feedback control loop is also equipped with SMES active power controller in order to suppress MJ energy deviation of SMES. It is assumed that, MW capacity of SMES or SSPSs equal the maximum load changes. To achieve this power outputs of SMES and SSPSs are constrained by the limiters in the Range from  $-P_{LOAD(max)}$  to  $P_{LOAD(min)}$ . Thus, the SMES &SSPS gains can be set suitable and freely.

In order to apply this proposed control strategy to a large interconnected system, the system with multi area interconnections is decomposed into several areas. Then, a SMES is located in one area while decentralized SSPSs are located on the tieline between the areas. Each area is controlled independently by the SMESs, or SSPS which is utilized as a local load frequency controller. Only the local frequency deviation of each area is used as feedback signal of a SMES or the SSPSs under the occurrence of load changes or some disturbance in areas the active power output of SMES and tie-line power modulation control by SSPS are utilized to suppress not merely frequency deviations but also undamped inter area oscillation modes of any area simultaneously.

#### 2.2.1 Performance measures

The two area systems (figures 4&5) are utilized to investigate and evaluate the effectiveness of proposed control strategy. In order to investigate the effectiveness of the SMES & SSPS for LFC, performance indices (PI) of system frequency

www.jatit.org

deviations are defined by Integral square error (ISE) as follows,

1. PI of frequency deviation of areal
$$PI_{freq1} = \int_{0}^{40} [\Delta f_1]^2 dt \qquad (4)$$

$$PI_{frq2} = \int_{0}^{\infty} \left[\Delta f_{2}\right]^{2} dt \tag{5}$$

#### 4 OVER VIEW OF PARTICLE SWARM OPTIMIZATION (PSO)

PSO is a population-based optimization method first proposed by Eberhart and Colleagues [24, 25]. Some of the attractive features of PSO include the ease of implementation and the fact that no gradient information is required. It can be used to solve a wide array of different optimization problems. Like evolutionary algorithms, PSO technique conducts search using а population of particles, corresponding individuals. to Each particle represents a candidate solution to the problem at hand. In a PSO system, particles change their positions by flying around in a multidimensional search space until computational limitations are exceeded.





www.jatit.org

The PSO technique is an evolutionary computation technique, but it differs from other well-known evolutionary computation algorithms such as the genetic algorithms. Although a population is used for searching the search space, there are no operators inspired by the human DNA procedures applied on the population. Instead, in PSO, the population dynamics simulates a 'bird flock's' behavior, where social sharing of information takes place and individuals can profit from the discoveries and previous experience of all the other companions during the search for food. Thus, each companion, called particle, in the population, which is called swarm, is assumed to 'fly' over the search space in order to find promising regions of the landscape. For example, in the minimization case, such regions possess lower function values than other, visited previously. In this context, each particle is treated as a point in a d-dimensional space, which adjusts its own 'flying' according to its flying experience as well as the flying experience of other particles (companions). In PSO, a particle is defined as a moving point in hyperspace. For each particle, at the current time step, a record is kept of the position, velocity, and the best position found in the search space so far.

The assumption is a basic concept of PSO [25]. In the PSO algorithm, instead of using evolutionary operators such as mutation and crossover, to manipulate algorithms, for a d-variables optimization problem, a flock of particles are put into the d-dimensional search space with randomly chosen velocities and positions knowing their best values so far (Pbest) and the position.

In the d-dimensional space. The velocity of each particle, adjusted according to its own flying experience and the other particle's flying experience. For example, the i-th particle is

represented as  $xi = (x^{i1}, x^{i2}, ..., x^{id})$  in the dimensional space. The best previous position of the i-th particle is recorded and represented as: Pbesti = (Pbest<sub>i</sub> 1, Pbest<sub>i</sub>, 2, ..., Pbest<sub>id</sub>) (6)

The index of best particle among all of the particles in the group is  $gbest_d$ .

The velocity for particle i is represented as vi =  $(v_i 1, v_i 2, ..., v_{id})$ . The modified velocity and position of each particle can be calculated using the current velocity and the distance from Pbest<sub>id</sub> to gbest<sub>d</sub> as shown in the following formulas [12]:

$$v_{i,m}^{(i+1)} = wv_{i,m}^{(i)} + c_1 Rand()(Pbest_{i,m} - x_{i,m}^{(i)} + c_2 Rand()(gbest_{i,m} - x_{i,m}^{i})$$

$$x_{i,m}^{(i+1)} = x_{i,m}^{(i)} + v_{i,m}^{(i+1)}, i=1,2,...,n; m=1,2,...,d; (8)$$

Where

n - Number of particles in the group,

d - Dimension,

t - pointer of iterations(generations),

 $v_{i,m}^{(t)}$  - Velocity of particle i at iteration t,  $V_d^{\min} \le v_{i,d}^{(t)} \le V_d^{\max}$ 

w - Inertia weight factor,

c1, c2 - Acceleration constant,

Rand () - Random number between 0 and 1,

 $x_{i,d}^{(t)}$  - Current position of particle i at iterations,

Pbest  $_{i.d}$  - Best previous position of the i-th particle,

Gbest  $_i$  - Best particle among all the particles in the population.

The evolution procedure of PSO Algorithms is shown in Fig. 6. Producing initial populations is the first step of PSO. The population is composed of thehromosomes that are real codes. The corresponding evaluation of populations called the "fitness function". It is the performance index of a population. The fitness value is bigger, and the performance is better.

After the fitness function has been calculated, the fitness value and the number of the generation determine whether or not the evolution procedure is stopped (Maximum iteration number reached?). In the following, calculate the Pbest of each particle and Gbest of population (the best movement of all particles). The update the velocity, position, gbest and pbest of particles give a new best position (best chromosome in our proposition).

#### **5 OPTIMAL FUZZY CONTROLLER DESIGN**

Fuzzy logic is expressed by means of the human language [17]. Based on fuzzy logic, a fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database.





#### Fig-6 The evolution procedure of PSO

First set the error e(t) and the error variation d e(t) of the angular velocity to be the input variables of the fuzzy logic controller. The control voltage u(t) is the output variable of the fuzzy logic controller. The linguistic variables are defined as {NB, NM, NS, Z, PS, PM, PB} meaning negative big, negative medium, negative small, zero, positive small positive medium and positive big respectively. The membership functions of the fuzzy logic controller are shown in Fig. 7. The fuzzy rules are summarized in Table 1. The type of fuzzy inference engine is Mamdani. In order to design the optimal fuzzy controller, the PSO algorithms are applied to search globally optimal parameters of the fuzzy logic. The structure of the fuzzy logic controller with PSO algorithms is shown in Fig. 7. In this paper, the chromosomes of the PSO algorithms include three parts: the range of the membership functions (Ke and Kde), the shape of the membership functions (e1~e5, de1~de5 and u1~u5) and the fuzzy inference rules (r1~r25). The output voltage is thereby such that the steady-state error of the response is zero. The genes in the chromosomes are defined as:

www.jatit.org

Fuzzy logic is derived from fuzzy set theory where infinite number of memberships is allowed. The degree of each member ship for each element is indicated by a number in the interval [0 1], [24]. While traditional controllers are linear, fuzzy logic controllers are nonlinear. Moreover, fuzzy logic controllers do not need a controlled plant model, and not sensitive to plant parameter variations. By using fuzzy logic the human experience can be used in the design of the controller. Fuzzy logic controllers are rule-based controllers. The rules of the system are written in natural language and translated into fuzzy logic.



Fig 7. Basic structure of a fuzzy logic system

The control structure for the conventional ID controller is in the following form:

$$u_{t}(t) = -K \int e_{i}(t) dt - K_{D} e_{i}(t)$$
(7)

where

 $e_i = ACE_i$ ,  $K_1$  and  $K_D$  are the integral and derivative controller gains.

The correlation between the conventional controller and fuzzy logic system is chosen to improve the performance of the conventional controller. Here the gains of the ID controller are modified according to the disturbances.

The Mamdani fuzzy inference engine was selected and the range of the controller is chosen properly to improve outputs responses of the system. Here, error and its time derivative are used as inputs to the controller. Seven triangle membership functions are employed for the inference mechanisms i.e. Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB). The membership functions of the*e*, e &, *KI*, and *KD* for the proposed controller are shown in Fig. 8.

www.jatit.org

The fuzzy rules of the gains  $K_p$  and  $K_1$  are in the form: If e is  $L_n$  and e is  $M_n$ . Then Gain is  $Z_n$ . Where  $L_n$ ,  $M_n$  and  $Z_n$  are fuzzy sets, and n is number of rules. In this study 49 rules are used. The set of fuzzy rules are given in Table 1. The centroid method is used in Defuzzification process.









Fig.8.Membership function for the proposed controller of error KI, errors time derivative,  $K_D$ 

Table 1. Fuzzy logic rules for the proposed controller

			0		-		
e/e	NB	NM	NS	Ζ	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Ζ
NM	PB	PM	PM	PM	PS	Ζ	NS
NS	PB	PM	PS	PS	Ζ	NS	NM
Ζ	PM	PM	PS	Ζ	NS	NM	NM
PS	PM	PS	Ζ	NS	NS	NM	NB
PM	PS	Ζ	NS	NM	NM	NM	NB
PB	Ζ	NS	NM	NM	NM	NB	NB

#### **6 SIMULATION RESULTS**

The fuzzy logic controllers are designed for the computer simulation. First, fuzzy logic controller is based on the expert experience, as described in the above section. Second, the fuzzy logic controller is based on the APSO algorithms only to find the optimal range of the membership functions (FLC with APSO algorithms). Last, the optimal fuzzy controller is based on the APSO algorithms so as to search the optimal range of the membership functions, the optimal shape of the membership functions and the optimal fuzzy inference rules (FLC with APSO algorithms). After the evolution process, the optimal values of Ke and Kde in FLC with APSO algorithms are calculated as 0.001 and 0.005, respectively. The best chromosomes in FLC with APSO algorithms are pursued as:

Table 2.	Parameters	of PSO	algorithms
----------	------------	--------	------------

	· · ·
Population Size	50
Number of Iteration	100
W <sub>max</sub>	0.6
W <sub>mim</sub>	0.1
$c_{1} = c_{2}$	1.5
$K_{_{e}}$ and $K_{_{de}}$	[0.001 0.005]

www.jatit.org

In the present work, the intelligent controller based on Fuzzy Logic-APSO Algorithms is in agreement with the step reference of two area system. In the fuzzy logic LFC, the optimization of membership functions and rules was required, its significance being shown in the minimal over/undershoot time of speed response. Therefore the membership functions are adjusted in optimal values so as to give a steady state error in frequency deviation value equal zero. The computer MATLAB simulation demonstrate that the fuzzy controller associated to the APSO algorithms approach became very strong, giving very good results and possessing good robustness.



*Figure 9 : variation of*  $\Delta f_1$  (*with SMES and SPSS*)



Figure 10 : variation of  $\Delta f_1$  ( with SMES and SPSS)



Figure 11 variation of  $\Delta f_1$  (with and without Integral control)



Figure 12 variation of  $\Delta f_1$  (without SMES and SPSS)



Figure 13: variation of  $\Delta f_1$  (with Integral control) and fuzzy control

#### www.jatit.org



*Figure 14: variation of*  $\Delta f_1$  (*with SMES and SPSS*)

#### 7 CONCLUSIONS

In this paper, the frequency deviation of a two area system is controlled by means of fuzzy controllers. The optimal fuzzy logic is designed using PSO algorithm. According to the results of the computer simulation, the FLC with PSO algorithms is better than the traditional FLC without PSO algorithms. The FLC with PSO algorithms is the best controller which presented satisfactory performances and good robustness. The major drawback of the fuzzy controller is insufficient analytical technique design (the selection of the rules, the membership functions and the scaling factors). It has been demonstrated that the proposed controller provides better improvement and good robustness.

#### REFERENCES

- [1] Saadat H., "Power System Analysis", McGraw-Hill, 1999.
- [2] C.E. Fosa and O.I Elgerd, 1970, "The Megawatt- Frequency Control Problem: A New Approach via Optimal Control Theory", IEEE Transaction on power Apparatus and System, Vol.PSA-80, pp.563-577.
- [3] S.M Miniesy and E.V.Bohn, 1972,"Optimum Load Frequency Continuous Control with Unknown Deterministic Power Demand" IEEE Transaction on Power Apparatus and System, Vol.PSA-91, pp.1910-1915.
- [4] M.Calovic, 1972. "Linear regulator design for load frequency control," IEEE Transactions on Power Apparatus and Systems, Vol.PSA-91, pp.2271-2285.

[5] J.D Glover and F.C.Schweppe, 1972 "Advanced Load Frequency Control", IEEE Transaction on Power Apparatus and System, Vol.PSA-91, pp.2095-2103.

1

- [6] Y.Y.Hsu and W.C Chan .1984. "Optimal Variable Structure Controller for the load Frequency Control of Interconnected Hydro-Thermal Power System", Electrical Power and Energy System, Vol,6, PP 221- 229.
- [7] A.Y.Siva Ramakrishnan, M.V. Haribaran , and M.C. Srisailam. 1984, "Design of variable structure and load frequency controller using pole assignment technique". International Journal of control, Vol.40, No.3, pp. 487-498.
- [8] D.Das, M.L.Kothari , D.P.Kothari , and J.Nanda 1991, "Variable structure control Strategy to AGC of an interconnected Reheat thermal System" proceedings IEE Pt.D , Vol.138, pp.579 -585.
- [9] Z.M.Al-Hamouz and Y.L.Abdel Magid,1993, "Variable structure load frequency controller for multi area power systems," International journal of Electric Power and Energy Systems, Vol.15,No.5, pp.90-101.
- [10] Elgerd O.I. and Fosha C.E., "Optimum Megawatt-Frequency Control of Multiarea Electric Energy systems",*IEEE Trans. on PAS*, vol. PAS-89, No. 4, April 1970, pp. 556-563.
- [11] Tripathy S.C., Hope G.S. and Malik O.P., "Optimization of Load- Frequency Control Parameters for Power Systems with Reheat Steam Turbines and Governor Deadband Nonlinearity," *IEE Proc.*, vol. 129, Pt. C. No. 1, Jan. 1982, pp. 10-16.
- [12] Chang C.S., Fu W. "Area load-frequency control using fuzzy gain scheduling of PI controllers", *Electric Power system Research*, Vol. 42, 1997, pp. 145-52.
- [13] Ibhan Kocaarslan, Ertugrul Cam, "Fuzzy logic controller in interconnected electric power systems for load-frequency control", *Electrical Power and Energy Systems*, Vol. 27, 2005, pp. 542-549.
- [14] H. Shayeghi, H.A. Shayanfar, "Application of ANN technique based on -synthesis to load frequency control of interconnected power system", *Electrical Power and Energy Systems*, Vol. 28, 2006, pp.503-511.
- [15] Ertugrul Cam, "Application of fuzzy logic for load frequency control of hydroelectrical power plants", *Energy Conversion and Management*, 48, 2007, pp. 1281-1288.
- [16] Aditya S.K., Das D., "Design of load frequency controllers using genetic algorithm for two area interconnected hydro power

www.jatit.org

system", Electrical *Power Components and Systems*, 31, 2003, pp. 81-94.

- [17] Ghoshal S..P.., "Optimaizations of PID gains by particle swarm optimizations in fuzzy based automatic generation control", *Electric Power Research*, 72, 2004, pp. 203-212.
- [18] Y.S. Zhou, L.Y. Lai: Optimal Design for Fuzzy Controllers by Genetic Algorithms, IEEE Trans. On Industry Application, Vol. 36, No. 1, January/February 2000, pp. 93 – 97.
- [19] Y. Shi, R. Eberhart: A Modified Particle Swarm Optimizer, Proc. 1998 Int. Conf. on Evolutionary Computation – The IEEE World Congress on Computational Intelligence, Anchorage, May 1998, pp. 69 – 73.
- [20] M. Clerc, J. Kennedy: The Particle Swarmexplosion, Stability, and Convergence in a Multidimensional Complex Space, IEEE Trans. Evolutionary Computation, Vol. 6, No. 1, Feb. 2002, pp. 58 – 73.
- [21] N.G. Hingorani, "Flexible AC transmission" ,IEEE Spectrum, April 1993,pp. 40-45.
- [22] Y.Mithani, T.Uranaka& K.Tsuji, "Power system stabilization by Super conducting Magnetic Energy storage with Solid-state Phase Shifter", IEEE Tran. On power apparatus & systems Vol. 10, No.3, Aug 1995, pp. 1614-1619.
- [23] I.Ngamroo, Y.Mithani, & K.Tsugji, " Application of Super- Super conducting magnetic energy storage( Super SMES) for Load frequency control", proceeding of International conference on Electrical Engineering, ICEE – 1997, Matsue, Japan, July 1997, pp. 46-49.
- [24] J. Kennedy, R. Eberhart: Particle Swarm Optimization, Proc. IEEE Int. Conf. on Neural Network, Vol. 4, 1995, pp. 1942 – 1948.
- [25] H. Yoshida, K. Kawata, Y. Fukuyama, S. Takayama, Y. Nakanishi: A Particle Swarm Optimization for Reactive Power and Voltage Control Considering Voltage Security Assessment, IEEE Trans. on Power Systems, Vol. 15, No. 4, Nov. 2000, pp. 1232 – 1239.
- [26] Z.L. Gaing: A Particle Swarm Optimization Approach for Optimum Design of PID Controller in AVR System, IEEE Trans. Energy Conversion, Vol. 19, No. 2, June 2004, pp. 384 – 391.



Ramavathu Shankar Naik received the B.Tech degree in Electrical Engineering from Vignan's Engineering College, Vadlamudi, Guntur, India, in 2006. He is pursuing M.E in Electrical Engineering with Power system Automation as

specialization in the Department of Electrical Engineering, Andhra University College of Engineering (Autonomous), Visakhapatnam, India. His area of interest lies in Power system operation and control.



Kona Chandrasekhar received the B.Tech degree in Electrical and Electronics engineering from Jawaharlal Technological University, Hyderabad, India, in 1981, and M.Tech degree in Electrical Power systems from Jawaharlal

Technological University, Hyderabad, India in 1986. He is pursuing PhD in the Department of Electrical Engineering AU College of Engineering (Autonomous), Andhra University, Visakhapatnam, AP, India where he is currently working as an Associate Professor in Electrical Engineering. His research interest includes power system operational and control, electrical machines, and power system dynamic stability and control.

**K. Vaisakh** is with the Department of Electrical Engineering, AU College of Engineering, Andhra University, VISAKHAPATNAM-530003, AP, India. His research area includes optimal operation of power systems, and FACTS.