ISSN : 2455-9679
Impact Factor : 4.256

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INTERNATIONAL JOURNAL OF RECENT TECHNOLOGY SCIENCE & MANAGEMENT

# "A ROBUST LOAD FREQUENCY CONTROL IN TWO-AREA POWER SYSTEMS WITH THE HELP OF SCA USING MATLAB/SIMULINK"

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## ABSTRACT

***Load frequency control (LFC) has emerged as one of the potential research areas in the field of power system. In an interconnected power system, if a load demand changes randomly, both frequency and tie line power vary. The main aim of load frequency control is to minimise the transient variations in these variables and also to make sure that their steady state errors is zero. Many modern control techniques are used to implement a reliable controller. The objective of these control techniques is to produce and deliver power reliably by maintaining both voltage and frequency within permissible range.***

***In this study, design and application of controller based on sine-cosine algorithm (SCA) is utilized for LFC of interconnected power system. A proportional-integral-derivative (PID) controller with a filter consisting of derivative term is used and its parameters are tuned using SCA. The performance criterion chosen for tuning process is the minimization of integral error of variations in frequency and tie-line power. The technique is compared with ANFIS based controller.***

***The proposed SCA based controller gives good results as compared with other technique. For two area interconnected system, proposed controller gives 40 % lesser settling time and 29 % lesser peak overshoot as compared to ANFIS for the same system parameters and same system model. This work studies the reliability of various control techniques of load frequency control of the proposed system through simulation in the MATLAB-Simulink environment.***

***Key Words:*** *Sine-cosine algorithm, Two area system, Area control error, Integral error, Load frequency control, PID controller, ANFIS.*

## I. INTRODUCTION

The development of electrical power was envisaged in the nineteenth century, and in the late nineteenth century electrical power generating units were installed throughout the world. The fast growth of these units was witnessed in the twentieth century. In India at the time of independence, the total generating capacity of electrical power was around 1362 MW. In early stages, the electric-power generating stations were installed around big cities, and the need for commissioning transmission systems was not given due consideration at that time. Under the five-year plans, a huge volume of industrial units was planned, and consequently the need for development of more electric power coupled with a large network of transmission systems at a faster rate was evident. The schemes for this have been implemented first at the state level and then at regional levels. The power industry is trying hard to meet the load demands on the system. In the new millennium much more efforts will be needed to meet the requirements of load demands, not by generating electrical power according to our load demands, but also by meeting the economic

ISSN : 2455-9679
Impact Factor : 4.256

and environmental standards set up through legislation from time to time.

Presently the total installed capacity of electrical power in India is around 128,000 MW. The breakup of this power according to different types of generating modes is hydro 32,326 MW; thermal 81,207 MW; nuclear 3360 MW; nonconventional 6,190 MW [1]. In India, due to various technical, economical, and environmental considerations, the electric power generating units have been installed at remote locations from load centres. However, they have to operate in an 2 interconnected fashion to share the benefits of utilizing variability in generation mixes and load patterns and other technological advantages. Therefore, there is a requirement of such transmission links which are capable of exchanging large chunks of electrical power between widely spread power pools effectively and efficiently. A Huge transmission network has already been laid in India to cater to the energy needs at reasonably good cost and in a human-friendly environment. In a normal power system, it is expected that both active and reactive power demands will vary from time to time. In order to cope up with this accordingly, it is essential that system inputs, namely mechanical power and field voltage are to be increased or decreased. This will ensure quality of supply to be standard in terms of its frequency and level of voltage. Therefore, it can be stated that electricity is a unique commodity whose production and consumption must be matched instantaneously and continuously.

## II. LITERATURE REVIEW

**Mokhtar Shouran et al. in [1]** discussed that on using the Bees Algorithm (BA) to tune the parameters of the proposed Fuzzy Proportional–Integral–Derivative with Filtered derivative (Fuzzy PIDF), Fractional Order PID (FOPID) controller and classical PID controller developed to stabilize and balance the frequency in the Great Britain (GB) power system at rated value. These controllers are proposed to meet the requirements of the GB Security and Quality of Supply Standard (GB-SQSS), which requires frequency to be brought back to its nominal value after a disturbance within a specified time.

**Amin Safari, Farshad Babaei, MeisamFarrokhifar in [2]** discussed that large frequency oscillations happen when the unbalanced power is not compensated by Load Frequency Controller (LFC) system. In recent years, the using of electric vehicles (EVs) has increased with renewable generation sources such as solar cells, wind turbines, fuel cells, and so on. The large-scale integration of these new types of generation sources and demand in power grids will have a significant impact on operations, planning and stability control. This work sets out to design an effective PID controller for LFC in an island Micro-grid (MG) and also proposes a model for EVs to contribute to LFC system.

**Li Jin, Yong He et al. [3]** discussed an effective method such that the robust load frequency control (LFC) scheme can be designed efficiently for the large-scale power system with time delay. A novel constraint time-delayed ordinary differential equation (CTODE) model is proposed, based on which a new bounded real lemma (BRL) is established for the $H\infty$ performance analysis. The CTODE model is investigated considering the small number of remote signals influenced by delays in the LFC scheme. It consists of three parts, i.e., a delayed part includes the remote states, whose order is far less than that of the original system and remains unchanged with the increased scale of the power system, and a delay-free (related) part involves the local signals irrelevant (subjected) to the delayed states.

**Sunil Kumar Bhatta et al. in [4]** addressed a robust three-dimensional fuzzy-PID controller (Fuzzy-3D PID) to control frequency of a diverse energy source integrated hybrid power system under various loadings. In order to obtain stability over system frequency under any disturbances, a secondary control loop called load frequency control (LFC) loop is required in the system. LFC tries to monitor power generation irrespective of load demand. Further, a novel hybridized harmonysearch and random search (hyHS-RS) algorithm is proposed to optimally design the suggested Fuzzy-3D PID controller.

**Amir Bagheri, Ali Jabbari, Saleh Mobayen in [5]** discussed that in today's electric networks, micro-grids are highly integrated into power system regarding their technical, environmental, and economic advantages. Due to the stochastic behavior of loads and intermittent nature of renewable energy resources, the micro-grids are subjected to frequency oscillations especially in the islanded mode of operation. In this paper, an intelligent Terminal Sliding Mode Control (TSMC) based on Artificial Bee Colony (ABC) optimization algorithm is proposed for load-frequency control in islanded micro-grids composed of several energy resources.

**Reza Alayi Farhad Zishan, et al. in [6]** studied the load frequency control (LFC) of a multi-source microgrid with the presence of renewable energy sources. To maintain a sustainable power supply, the frequency of the system must be kept constant. A Proportional– Integral–Derivative (PID) controller is presented as a secondary controller to

ISSN : 2455-9679
Impact Factor : 4.256

control the frequency of the microgrid in island mode, and the integral of squared time multiplied by error squared (ISTES) is used as a performance index. The use of the Craziness-Based Particle Swarm Optimization (CRPSO), which is an improved version of Particle Swarm Optimization (PSO), improves the convergence speed in optimizing the nonlinear problem of load and frequency controller design.

**Xiaodong Wang, Yingwei Wang, Yingming Liu in [7]** discussed that the frequency stability of power systems can be improved by the participation of high-penetration wind power in grid frequency regulation. However, the wind turbine (WT) fatigue load will be increased after the wind power participates in the load frequency control (LFC). This paper proposes a control method that takes into account the WT fatigue load and the frequency response of the power system.

**Abhishek Saxena, Ravi Shankar in [8]** discussed that an effort has been revealed in this paper to develop a novel quasi-oppositional harmony search (QOHS) algorithm-based PID controller for frequency stability in a two-area power system including multiple sources. Both regions with multi- source scheme comprised of a reheat thermal unit and a hydro unit.

**Mohamed A. Mohamed, et al. in [9]** discussed that with the rapid growth of renewable energy resources, wind energy system is getting more interest everywhere throughout the world. However, its extensiveuse in power systems prompts many power system dynamics and stabilityproblems.Load variation and anomalous operating conditions prompt inconsistencies in frequency and planned power trades. These inconsistencies should be remedied by load frequency control.

**Naladi Ram Babu, Lalit Chandra Saikia in [10]** discussed that load frequency control (LFC) of an unequal three-area thermal system integrated with dish stirling solar thermal system (DSTS) in area-1, 2 and thermal system in area-3. The DSTS system is provided with various solar insolations namely fixed and random insolation. A new secondary controller named by PI minus DF is proposed for LFC study. A new algorithm named by coyote optimization algorithm (COA) is used for controller gain optimization. Performance comparison among various controllers like PID, PIDF are compared with the proposed PI-DF controller and is found to be best over others.

## III. INTRODUCTION TO LOAD FREQUENCY CONTROL

In the steady-state operation of the power system, the load demand is increased or decreased in the form of Kinetic Energy stored in the generator prime mover set, which results in the variation of speed and frequency accordingly. Therefore, the control of load frequency is essential to have a safe operation of the power system. Neglecting resistances

$$P = \frac{EV}{X}\sin\delta$$

If $\delta$ changes to $\delta + \Delta\delta$, then P changes to $P + \Delta P$

$$P + \Delta P = \frac{EV}{X}\sin(\delta + \Delta\,\delta) = \frac{EV}{X}[\sin\delta\cos\Delta\delta + \cos\delta\sin\Delta\delta]$$

Since $\Delta\delta$ is very small,

$$\cos\Delta\delta \cong 1 \; and \;\; \sin\Delta\delta \cong \Delta\delta$$

$$P + \Delta P = \frac{EV}{X}\sin(\delta) + \frac{EV}{X}[\cos\delta.\Delta\delta]$$

$$\Delta P = \frac{EV}{X}[\cos\delta.\Delta\delta]$$

Or

$$\Delta P \propto \Delta\delta$$

Small power changes mainly depend on $\Delta\delta$ or $\Delta f$.

Moreover, frequency is also a major stability criterion for large-scale stability in multi-area power systems. To provide the stability, a constant frequency is required which depends on active power balance. If any change occurs in active power demand/ generation in power systems, the frequency cannot behold as its rated value. Hence, oscillations increase in both power and frequency. Thus, the system is subjected to a serious instability problem. To improve the stability of the power networks, it is necessary to design load frequency control (LFC) systems that

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Impact Factor : 4.256

control the power generation and active power at tie lines of an interconnected system. In interconnected power networks with two or more areas, the generation within each area has to be controlled to maintain the scheduled power interchange. The load frequency control scheme has two main control loops.

**Representation of Load Frequency Control**

A complete block diagram representation of an isolated power system comprising the turbine, generator, governor, and load is easily obtained by combining the block diagrams of individual components. In this case, no controller action is applied given actual system performance due to a step change of load. The dynamic behavior for the nominal system as the change in frequency consists of a Hydraulic Amplifier, Turbine, and Generator model.

$$\dot{x} = Ax + Bu + F\rho$$

Were,
$$A = \begin{bmatrix} -\frac{1}{T_p} & \frac{K_p}{T_p} & 0 \\ 0 & -\frac{1}{T_t} & \frac{1}{T_t} \\ \frac{1}{RT_H} & 0 & -\frac{1}{T_H} \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{T_H} \end{bmatrix}$$

$$F = \begin{bmatrix} -\frac{K_p}{T_p} \\ 0 \\ 0 \end{bmatrix}$$

$$\rho = [\Delta P_E]$$

$x^T$ = State vectors, $[\Delta f \quad \Delta P_T \quad \Delta P_H]$

u = Control vector, it is zero in uncontrolled case.

$\rho$ = Disturbance vector

## IV. INTRODUCTION: SINE COSINE ALGORITHM (SCA)

The Sine Cosine Algorithm (SCA) is a new optimization technique for solving optimization problems. The SCA creates multiple initial random candidate solutions and requires them to fluctuate outwards or towards the best solution using a mathematical model based on sine and cosine functions. Several random and adaptive variables also are integrated to this algorithm to emphasize exploration and exploitation of the search space in different milestones of optimization.

The SCA algorithm was proposed by Seyedali Mirjalili in 2016. It is a population-based metaheuristic algorithm applied to optimization problems.

As is common to algorithms belonging to the same family, the optimization process consists of the movement of the individuals of the population within the search space, which represent approximations to the problem.

For this purpose, SCA uses trigonometric sine and cosine functions. At each step of the calculation, it updates the solutions according to the following equations:

$$X_{ij}^{(t+1)} = X_{ij}^{(t)} + r_1 \sin(r_2) \left| r_3 P_{ij}^{(t)} - X_{ij}^{(t)} \right|$$
$$X_{ij}^{(t+1)} = X_{ij}^{(t)} + r_1 \cos(r_2) \left| r_3 P_{ij}^{(t)} - X_{ij}^{(t)} \right| \quad (1)$$

Generally, the above equations are combined as follows:

$$X_{ij}^{(t+1)} = \begin{cases} X_{ij}^{(t)} + r_1 \cos(r_2) \left| r_3 P_{ij}^{(t)} - X_{ij}^{(t)} \right|, & r_4 \geq 0.5 \\ X_{ij}^{(t)} + r_1 \sin(r_2) \left| r_3 P_{ij}^{(t)} - X_{ij}^{(t)} \right|, & r_4 < 0.5 \end{cases} \quad (2)$$

Where $X_{ij}^{(t)}$ represents the current individual $i$ at iteration t, $P_{ij}^{(t)}$ shows the best individual's position at iteration t, and r1, r2, r3, r4 are random parameters.

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SCA uses the latter parameters to avoid entrapment in suboptimal solutions and to balance the exploration and exploitation processes:
r1 conditions the shift in updating a solution, towards the best solution (r1<1) or outwards it (r1>1). r1 decreases linearly from a certain constant value to zero:

$$r_1 = a - t\frac{a}{T_{\max}} \quad (3)$$

where a is a constant, t is the current iteration, and $T_{max}$ represents the maximum iterations allowed. The above equation allows for the balance between exploration and exploitation.

- $r_2$ has values in the range [0:2pi] and determines how big the movement of a solution is towards or outwards of the destination.
- $r_3$ has values in the range [0:2] and is used to assign a weight to the destination, reinforcing or inhibiting the impact of the destination point on the updating process of the other solutions.
- $r_4$ with values in the range [0:1], is a switch between the sine and cosine functions.

**4.2 SCA process**

SCA begins the optimization procedures with a set of initial random solutions. The best solution achieved becomes the destination point (target), which is used to update the other solutions. SCA refreshes the ranges of sine and cosine functions to maintain the exploitation of the search space as the iteration number increments. The SCA stops the optimization procedures when the iteration number reaches the maximum number of iterations.
The following figure illustrates the entire process:

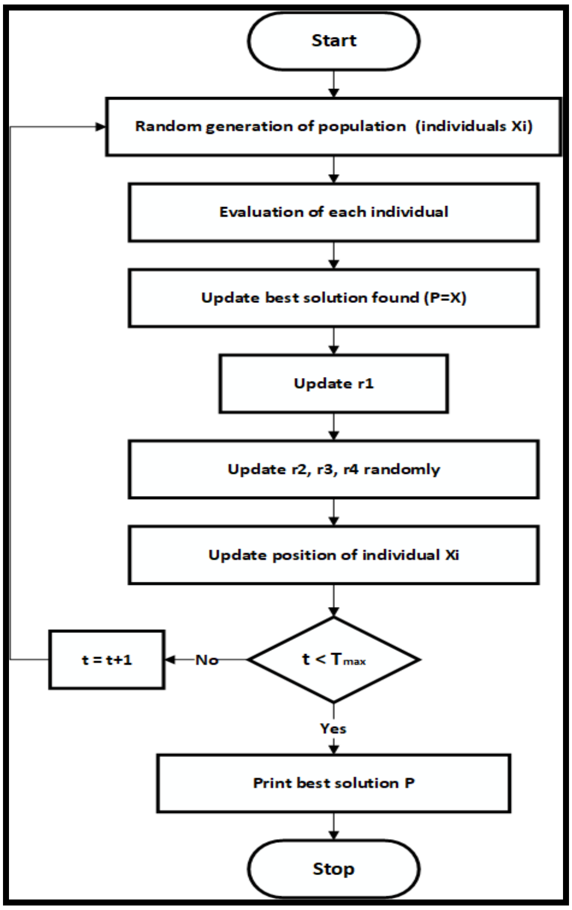


Fig 1 Flow chart of SCA

As happens to all optimization algorithms in general, and to metaheuristic algorithms in particular, the goodness of the SCA solutions depends on an optimal balance between exploration and exploitation. To explain how this balancing, we will start from the following figure, which represents two functions dependent on sine and cosine in the interval [0:2*pi] for the independent variable, with values of the functions within the range [-2:2].

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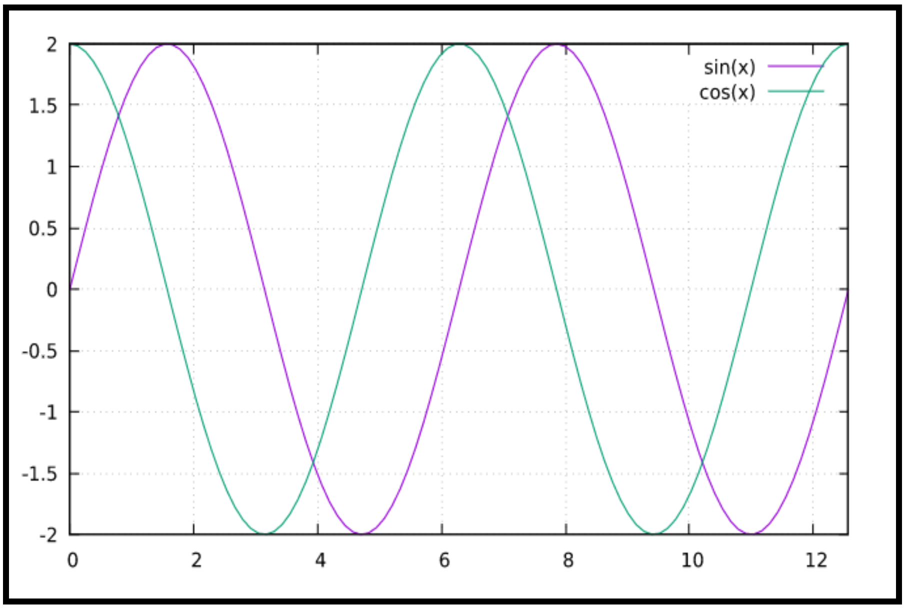


Fig 2 Sine cosine waveform

The variable x represents the set of independent variables that define the search space.

As we can see, the range of variability in the x domain is much greater for the values of the functions located in the upper and lower part of the curves, compared to the central section. This fact allows us to state the following heuristic rule:

- For values of the sine and cosine functions in the intervals [1:2], and [-2:-1] we have a predominance of the exploratory process since the SCA tests many different points in the problem space.
- For values of the sine and cosine functions in the range [-1:1], there is a predominance of the exploiting phase.

The reasons for the efficiency of the SCA algorithm are different, some common to other metaheuristic techniques:

- SCA works with a population of solutions, which benefit from parallel exploration phenomena
- It investigates several regions of the solution space simultaneously for values of the sine and cosine functions outside the range [-1:1].
- During the exploiting process, with sine and cosine values in the range [-1:1], SCA investigates several promising solutions simultaneously
- The adaptive values of the parameters allow transferring the promising strategies and regions between the exploratory and exploitative processes.
- The best solution at a certain point in the calculation is saved in a variable and becomes the target of the problem, and therefore is never lost during the optimization phase.
- The optimization process is convergent

## V. ADAPTIVE NETWORK BASED FUZZY INFERENCE SYSTEM

A neuro-fuzzy technique called Adaptive network based fuzzy inference system (ANFIS) has been used as a prime tool in the present work. Adaptive network based fuzzy inference system (ANFIS) is a neuro fuzzy technique where the fusion is made between the neural network and the fuzzy inference system. In ANFIS the parameters can be estimated in such a way that both the Sugeno and Tsukamoto fuzzy models are represented by the ANFIS architecture. Again, with minor constraints the ANFIS model resembles the Radial basis function network (RBFN) functionally. This ANFIS methodology comprises of a hybrid system of fuzzy logic and neural network technique. The fuzzy logic takes into account the imprecision and uncertainty of the system that is being modelled while the neural network gives it a sense of adaptability. Using this hybrid method, at first an initial fuzzy model along with its input variables are derived with the help of the rules extracted from the input output data of the system that is being modelled. Next the neural network is used to fine tune the rules of the initial fuzzy model to produce the final ANFIS model of the system. In this proposed work ANFIS is used as the backbone for the identification of real-world systems.

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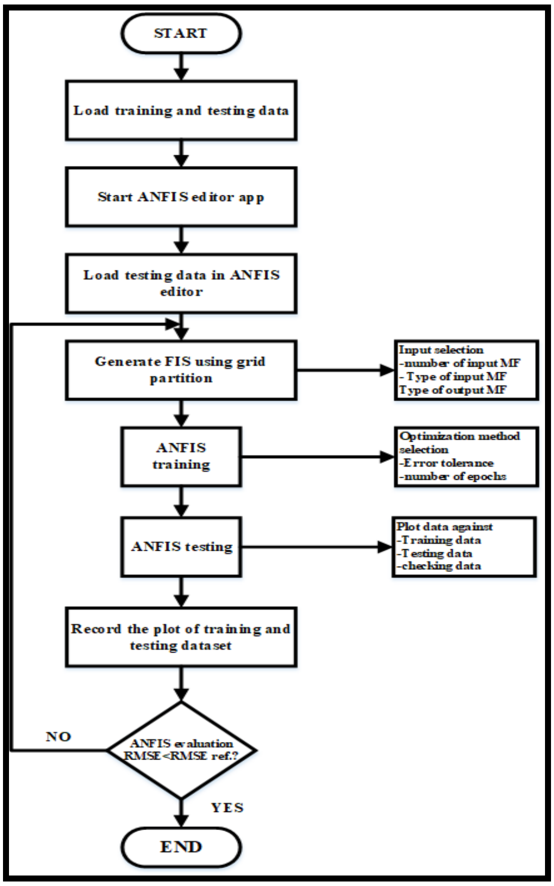


Fig. 3 flowchart of ANFIS

## VI. SCA TUNED PI CONTROLLER BASED LFC MODEL

In this section SCA, based PI tuner controller results are discussed. Below figure 5.1 shows the Simulink model for it. The SCA model is designed in MATLAB only. Input data consist of ACE and change in ACE and output data consist of Proportional gain and integral gain value.

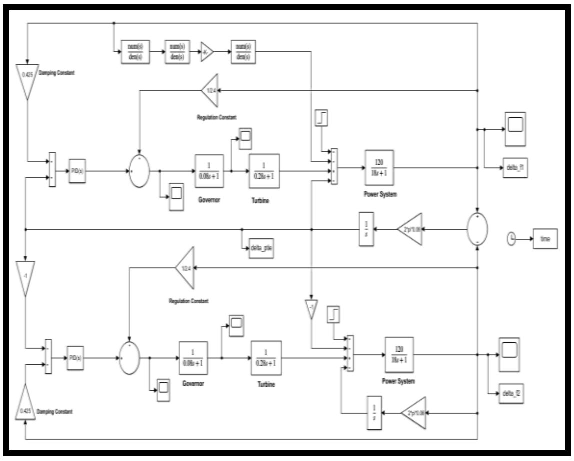

Fig 4 Simulink model of LFC using SCA-PID controller

The above figure 5 shows the Simulink model for load frequency control using the SCA-PI controller.

The output of the controller block after subtracting from the frequency regulator value is supplied to Governor Block. The output from this block is then provided to the turbine block. The output of this block, after subtracting the change in power value is supplied to the power system block to regulate output power so that frequency is maintained at a constant value.

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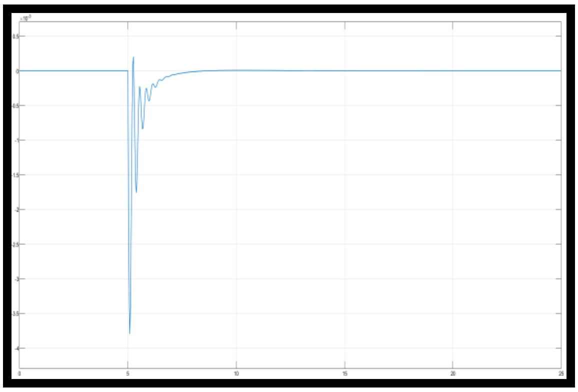

Fig 5 Change in frequency *(Δf)* response for SCA-PID controller.

Table1 shows the value of LFC response parameters for the SCA-PID controller. Based on these parameters the comparison between three controllers will be done to check their performance.

Table 1:LFC response parameters for SCA-PID controller

| | |
|---|---|
| **Rise Time:** | 1.2795e-05 sec |
| **Settling Time:** | 6.1955 sec |
| **Settling Min:** | -0.0049 Hz |
| **Settling Max:** | 6.3204e-04 Hz |
| **Overshoot:** | 9.9606e+05 |
| **Undershoot:** | 1.2898e+05 |
| **Peak:** | 0.0049 Hz |
| **Peak Time:** | 5.1062sec |

Table 1 shows the value of Frequency response parameters for the SCA-PID controller. Based on these parameters the comparison between two controllers will be done to check their performance..

## VII. ADAPTIVE NEURO FUZZY INTERFACE SYSTEM (ANFIS) CONTROLLER-BASED LFC MODEL

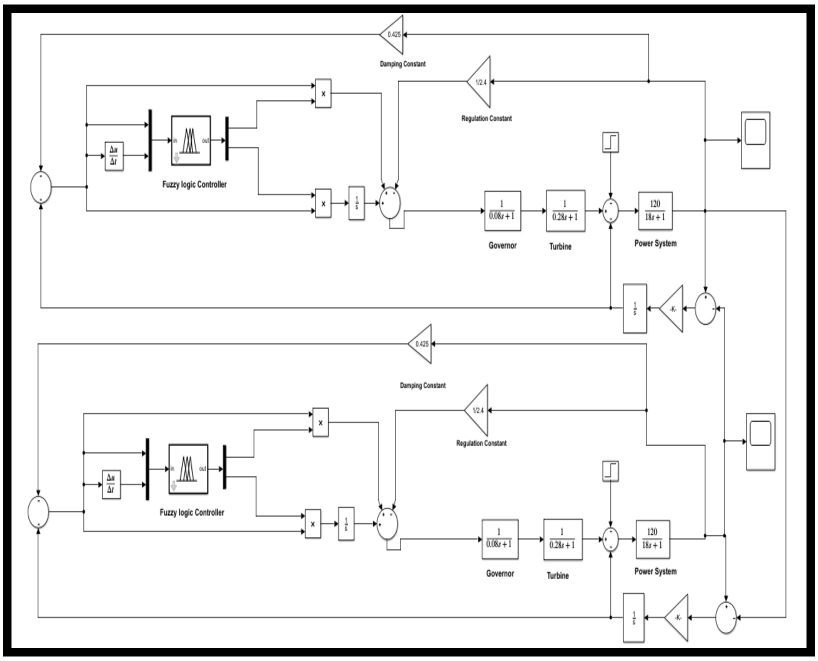


Fig 6 Simulink model of LFC using ANFIS controller

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The above figure 5.3 shows the Simulink model for load frequency control using the ANFIS controller. The output signal from the controller block after subtracting from the frequency regulator value is supplied to Governor Block. The output from this block is then provided to the turbine block. The output of this block, after subtracting the change in power value is supplied to the power system block to regulate output power so that frequency is maintained at a constant value.

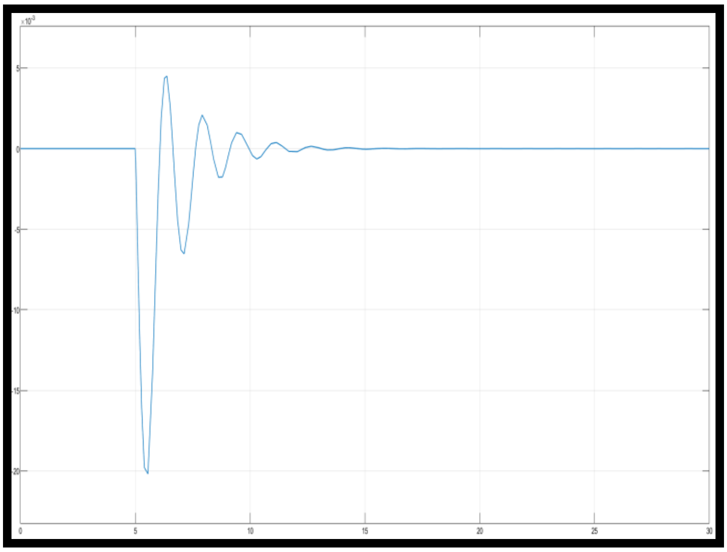

Fig 7 Change in frequency *(Δf)* response for ANFIS controller.

Figure 7 displays the output signal of Change in frequency response using the ANFIS controller. Table 2 shows the value of LFC response parameters for the ANFIS controller. Based on these parameters the comparison between two controllers will be done to check their performance.

Table 2

FLC response parameters for ANFIS controller

| | |
|---|---|
| **Rise Time:** | 3.7420e-05 sec |
| **Settling Time:** | 10.5160 sec |
| **Settling Min:** | 0.0202 Hz |
| **Settling Max:** | 0.0045 Hz |
| **Overshoot:** | 1.4082e+06 |
| **Undershoot:** | 3.1419e+05 |
| **Peak:** | 0.0202 Hz |
| **Peak Time:** | 5.5464 sec |

## VIII. CONCLUSION

In electric- power generation, disturbances caused by load fluctuations may cause changes in the desired frequency value and tie-line loadings. Load frequency control is thus very important in power system operation for supplying sufficient and reliable electrical power of good quality. There are essentially two objectives of load frequency control. Firstly, the system frequency is to be maintained at or, very close to specified nominal value. Secondly, tie-line deviations must also be made zero as fast as possible.

A comprehensive literature review on load frequency control problem is presented.

In this paper, essentially, two area systems are analyzed. Mathematical models with transfer functions of two area interconnected system is developed. The step load disturbance is applied in any one area of the system. Further control techniques are developed, obtaining the system responses in terms of settling time and peak overshoot on

ISSN : 2455-9679
Impact Factor : 4.256

sudden changes in load. Two control strategies:

- Sine-cosine algorithm (SCA) technique
- ANFIS technique

are implemented. Chapter 5 is dedicated to results obtained for two area system. The proposed SCA based controller gives good results as compared with other technique. For two area interconnected system, proposed controller gives 40 % lesser settling time and 29 % lesser peak overshoot as compared to ANFIS for the same system parameters and same system model. The performance of the controllers under study are tested and validated using MATLAB/SIMULINK tools.

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ISSN : 2455-9679
Impact Factor : 4.256

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