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Automatic Generation Control for Three Area System Using Improved Bacteria Foraging Optimization Algorithm (IBFOA)

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***Abstract*— Simultaneous optimization of certain parameters like Ki, Ri and Bi has been done which grants not only the best dynamic response for the system but also permits us to use quiet larger values of Ri than put into practice. This will help the industries concerning power for simpler as well as cheaper realization of the governor. The performance of IBFOA is also investigated through the convergence characteristics which reveal that that the Bacteria Foraging Algorithm is relatively faster in optimization such that there is drop in the computational load and also minimum use of computer resource utilization.**

Keywords—(IBFOA-Improved Bacteria Foraging Optimization Algorithm)

I. INTRODUCTION

Power systems are very large and complex electrical networks consisting of generation networks, transmission networks and distribution networks along with loads which are being disturbed throughout the network over a large geographical area. The rapid growth of industries has further lead to the increased complexity of the power system. The successful operation of interconnected power system requires the matching of total generation with total demand and associated system losses [1][2]. With time, the operating point of a power system changes, and hence, these systems may experience deviations in nominal system frequency and scheduled power exchanges to other areas, which may yield undesirable effects. In actual power system operations, the load is changing continuously and randomly. The ability of the generation side to track the changing load is limited due to physical/technical consideration, causing imbalance between the actual and scheduled generation quantities. This action leads to a frequency variation. The difference between the actual and the synchronous frequency causes mal operation of sophisticated equipment like power converters by producing harmonics [3].

In the power system, the system load keeps changing from time to time according to the needs of the consumers. Changes in real power affect mainly the system frequency, while reactive power is less sensitive to changes in frequency and is mainly dependant on changes in voltage magnitude. Thus active and reactive powers are controlled separately. The Load Frequency Control (LFC) loop controls the real power & frequency and Automatic Voltage Regulator (AVR) loop regulates reactive power & voltage magnitude. Load frequency control has gained in importance with the growth of interconnected systems and has made the operation of interconnected systems possible [4].

Since, frequency is greatly depends on active power and voltage greatly depends on reactive power, so the control difficulty in the power system may be divided into two parts. One is related to the control of active power along with frequency and the other is related to the control of reactive power along with voltage regulation. The active power control and the frequency control are generally known as the Automatic Load Frequency Control (ALFC) [4].The major objectives of AGC are

- To take care of the required MW power output of a generator matching with the changing load.
- To take care of the appropriate value of exchange of power linking control areas.
- To facilitate control of frequency for larger interconnections.

II. CHARACTERISTICS OF PROPERLY DEGINED POWER SYSTEM

A properly designed power system should respond to the changes in the load smoothly and it should maintain the balance between the powers generated and demanded. Further, the power system should have the following characteristics:

- It should supply power wherever demanded by the costumer.
- It should supply uninterrupted power to the consumer.
- The power system should be capable of meeting the changing load demands.
- The supplied power should be of good quality.
- The power system should supply power at economic rate.
- The necessary safety requirements should be satisfied.

The power delivered must satisfy certain minimal necessities with regard to the quality of supply. The quality of the power system is considered superior if the system frequency is kept around the specified value i. e. 50 Hz and the magnitude of the bus voltage is maintained within the prescribed limits around the normal value. Voltage and

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frequency controls are the necessary requirements for the effective operation of the power systems. The safety requirements covers the insulation, height of the transmission & distribution line, material used for conductors, population density around the generating & distribution stations and more importantly the protection system employed and many more [6][7].

III. AUTOMATIC GENERATION CONTROL

Today's power system consists of control areas with many generating units with outputs that must be set according to economics. The analysis and design of Automatic Generation Control (AGC) system of individual generator eventually controlling large interconnections among different control areas play a vital role in automation of power systems. The purposes of AGC are to maintain system frequency very close to a specified nominal value, to maintain generation of individual unit at the most economic value, to keep the correct value of tie-line power among different control areas. Automatic Generation Control is defined as the regulation of the power output of electric generators within a prescribed area in response to changes in system frequency, tie-line loading, or the regulation of these to each other, so as to maintain the scheduled system frequency and/or the established interchange with other areas within predetermined limits. AGC has evolved rapidly from the time when the function was performed manually, through the days of analog systems to the present day application of sophisticated direct digital control systems. Most of the work concentrates on the net interchange tie-line bias control strategy making use of the Area Control Error (ACE). The Automatic Generation Control (AGC) necessary to calculate area control error and monitor the system frequency and tie-line power flow computes the net change in generation required such that the time average of ACE is at a low value. The existence of ACE means that there is excess or deficient of spinning stored energy in an area and a correction to stored energy is required to restore the system frequency to scheduled values. The AGC problem has been extensively studied during the last four decades. Automatic Generation Control (AGC) is defined as the regulation of power output of controllable generators within a prescribed area in response to change in system frequency, tie-line loading or a relation of these to each other, so as to maintain the scheduled system frequency and/or to establish the interchange with other areas within predetermined limits. Thus a plan is required to maintain the frequency and the desired tie-line power flow as well to accomplish zero steady state error [1][2][8][9][10].

The two basic inter-area regulating responsibilities of AGC are as:

(a) When system frequency is on schedule, each area is expected automatically to adjust its generation to maintain its transfer with other areas on schedule, thereby absorbing its own load variations. As long, all areas do so; scheduled system frequencies as well as net interchange schedules for all areas are maintained.

(b) When system frequency is off schedule, because one or more areas are not fulfilling their regulating responsibilities, other areas are expected automatically to shift their respective net transfer schedules proportionally to the system frequency deviation and in direction to assist the deficient areas and hence restore the system frequency. The extent of each area's shift of net interchange schedule is programmed by its frequency bias setting. Therefore, a control strategy is needed that not only maintains constancy of frequency and desired tie-power flow but also achieves zero steady state error and inadvertent interchange. Numbers of control strategies have been employed in the design of load frequency controllers in order to achieve better dynamic performance [5].

To keep interconnected power system reliable and safe, it is required to keep the tie-line power and system frequency within specified limits. In interconnected power system, when there is an uncertainty of load variation, the frequency and tie-line power deviate from their scheduled values, which lead to unsuccessful performance of entire grid system. There is an operational co-ordination which is required between generation and load demand to make system reliable & stable, that phenomenon is termed as automatic generation control (AGC) or Automatic load frequency control (ALFC) [3][9][11][12].

IV. REASONS FOR LIMITING FREQUENCY DEVIATION

The active and reactive power demands are never steady and they continuously changes with the rising or falling trend of load demand. There is a change in frequency with the change in load which causes problems as:

(a) Most AC motors run at speed that is directly proportional to the frequency. The speed and induced electro motive force (e.m.f.) may vary because of the change of frequency of the power circuits. So the variation of frequency will directly affect the motor performance.

(b) The blades of the steam turbines are designed to operate at a particular speed and the frequency variation will cause change in the speed. This will lead to excessive vibration and cause damage to the turbine blade.

(c) The changes in frequency can cause mal-function of power converters by producing harmonics.

(d) For power stations running in parallel, it is necessary that frequency of network must remain constant for synchronisation of generators.

(e) The frequency error may produce havoc in the digital storage and retrieval process.

(f) Variation of frequency causes error in many control applications where synchroscopes, servo motors or servo potentiometers are used.

(g) The frequency error also leads to error in measurements and thus causes problem in medical measurements.

V. CONCEPT OF CONTROL AREA

Almost all generating companies have tie-line interconnections to neighbouring utilities. Tie-lines allow the sharing of generation resources in emergencies and economy of power production under normal conditions of operation. For the purposes of control, the entire interconnected system is subdivided into control areas which usually confirm to the boundaries of one or more companies. The net interchange of power over the tie lines of an area is the algebraic difference between area generation and area load (plus losses). A schedule is pre-arranged with neighbouring areas for such tie-line flows, and as long as an area maintains the interchange power on schedule, it is evidently fulfilling its primary responsibility to absorb its own load changes. But since each area shares in the benefits of interconnected operation, it is expected also to share in the responsibility to maintain system frequency.

A control area is interpreted as a system where we can apply the common generation control or the load frequency control. Usually a self-governing area is made reference to as a control area. Electrical interconnection is very strong in every control area when compared to the ties in the midst of the adjoining areas. Within a control area all the generators move back and forth in logical and consistent manner which is depicted by a particular frequency. Automatic load frequency control difficulty of a bulky interrelated power system have been investigated by dividing the whole system into number of control areas and this power system is termed as multi-area power system. The interconnected large power system generally consists of different control areas and the system frequency and tie-line power remain constant for stable operation of the system. To make system stable, it is necessary to keep Area Control Error to zero value in each area. This is done by AGC action [10][13][14][15].

In the common steady state process, power systems every control area must try to counterbalance for the demand in power by the flow of tie-line power through the interconnected lines. Generally the control areas encompass only restricted right to use to the information of the total grid: they are able to manage their own respective buses however they cannot alter the parameters at the unknown buses directly. But an area is alert of the dominance of its nearby areas by determining the flow in and flow out of power by the side of its boundaries which is commonly known as the tie-line power. In every area, the power equilibrium equations are computed at the boundaries, taking into consideration the extra load ensuing from the power that is being exported. Later on, the areas work out the optimization problem in accordance to their objective function which is local [16][17].

Each control area should accomplish its individual load demand in addition to the power transfer all the way through tie-lines on the basis of communal agreement. Every control area must have adjustable frequency according to the control. Frequency changes occur because system load varies randomly throughout the day. This is the reason, why, an exact forecast of real power demand cannot be assured. The imbalance between real power generation and load demand (plus losses) throughout the daily load cycle causes kinetic energy of rotation to be either added to or taken from the on-line generating units, and frequency throughout the interconnected system varies as a result. Each control area has a central facility called the energy control centre, which monitors the system frequency and the actual power flows on its tie-lines to neighbouring areas. The deviation between desired and actual system frequency is then combined with the deviation from the scheduled net interchange to form a composite measure called the area control error, or simply ACE. To remove area control error, the energy control center sends command signals to the generating units at the power plants within its area to control the generator outputs so as to restore the net interchange power to scheduled values and to assist in restoring the system frequency to its desired value. The monitoring, telemetering, processing, and control functions are coordinated within the individual area by the computer based automatic generation control (AGC) system at the energy control centers [1][10][18]. The interconnected system has following advantages:

- Reserve capacity is reduced and thus there is reduction in the installed capacity.
- For larger units, the capital cost per KW is reduced.
- Generators are used effectively.
- Generation is optimised, so there is reduction in the installed capacity.
- The reliability of the system is increased.
- Power can be supplied to larger area of population.

With these advantages, the interconnected system also faces some of the disadvantages. In an interconnected system, the faults get propagated, for which faster switchgear operation is required. High rating circuit breakers are to be used. For interconnected power system, qualified management staff and high skill manpower is required [21].

The Automatic Generation Control (AGC) necessary to calculate area control error and monitor the system frequency and tie-line power flow computes the net change in generation required such that the time average of ACE is at a low value. The existence of ACE means that there is excess or deficient of spinning stored energy in an area and a correction to stored energy is required to restore the system frequency to scheduled values. ACE which is defined as a linear combination of power net interchange and frequency deviations is generally taken as the controlled output of AGC. As the ACE driven to zero by the AGC, both frequency and tie-line power errors will be forced to zeroes. Each of the power generating area considers ACE signal to be used as the output of the plant. By making area control errors zero in all areas, all the frequencies along with errors in the tie-line power in the system can be made as zero.

In order to take care of the total exchange of power among its areas within the neighbourhood, ALFC utilizes real power flow determinations of all tie-lines as emanating through the area and there after subtracts the predetermined interchange to compute an error value. The total power exchange, jointly with a gain B, known as the bias in frequency, as a multiplier with the divergence in frequency is known as the Area Control Error (ACE) specified by,

$$ACE = \sum_{K=1}^{k} P_k - P_s + B(f_{act} - f_0) MW$$

Where,

P_k = power in the tie-line (if out of the area the +ve)
P_s = planned power exchange
B = bias
f_{act} = actual frequency
f_0 = base frequency

Positive (+ve) ACE shows that the power flow is out of the area [25][26]

$ACE_1 = \Delta P_{12} + b_1\Delta f_1$
$ACE_2 = \Delta P_{23} + b_2\Delta f_2$
$ACE_3 = {}_{\Delta P31} + b_3\Delta f_3$ Where, b_1, b_2 and b_3 are known as bias in frequency in area1, area 2 and area 3 respectively.

VI. THREE AREA SYSTEM

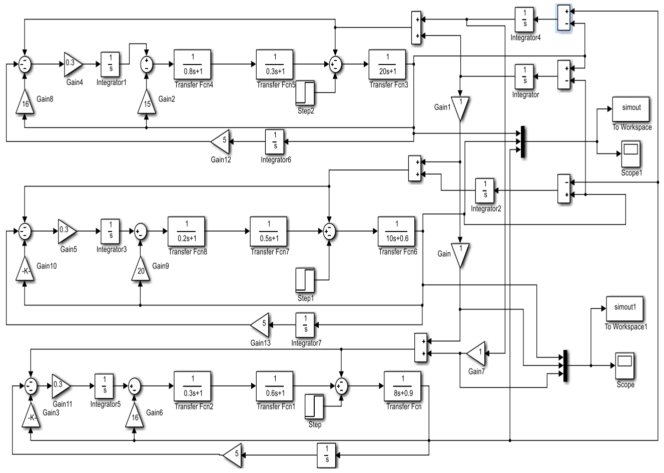

Fig 1: Three Area Power System

The tie-line power flow among three areas is as follows

$$\Delta P_{12}(s) = \frac{2\Pi T^0}{s} \quad [\Delta f_1(s) - \Delta f_2(s)]$$

$$\Delta P_{13}(s) = \frac{2\Pi T^0}{s} \quad [\Delta f_1(s) - \Delta f_3(s)]$$

$$\Delta P_{23}(s) = \frac{2\Pi T^0}{s} \quad [\Delta f_2(s) - \Delta f_3(s)]$$

VII. IMPROVED BACTERIA FORAGING ALGORITHM

During the foraging process of a true bacterium, locomotion is accomplished by means of a group of flagella which is tensile. Flagella facilitate an *E.coli* bacterium to undergo tumble or swim. These two are the essential operations carried out by a bacterium during foraging. While they turn around the flagella in the clockwise direction, every flagellum drags the cell such that the flagella moves freely and eventually the bacterium tumbles with reduced number of tumbling but during a damaging situation it tumbles often to seek out a nutrient gradient.

The movement of the flagella in the counter-clockwise direction promotes the swim of the bacterium at quite a very faster speed and the bacterium undergoes chemo taxis in which they prefer to travel towards a nutrient gradient by avoiding toxic surroundings. Typically the bacterium moves for an extended distance during a favourable surrounding.

When they search out sufficient food they elongate length wise and in existence of appropriate temperature they breakdown in the central point portion to form two exact duplicates. This phenomenon shows reproduction in BFOA. Events of unexpected changes in environmental conditions or attack destroy the chemo tactic progress furthermore a set of bacteria move to another places or some other are introduced to the concerned swarm. Thus the process of elimination-dispersal takes place in the population. Each and every bacterium in that particular region is either killed or a cluster of bacteria is moved to a new location.

Thus it can be said that BFOA consists of four chief mechanisms as seen in an actual bacterial system: chemo taxis, swarming, reproduction, elimination-dispersal to resolve an optimization problem. A virtual bacterium is in fact a trial answer or a search mediator which moves on the functional plane to find the global optimum.

Let us consider
b = Indicator for the chemo tactic step
c = Indicator for the reproduction step
d = Indicator for the elimination-dispersal event
p = Search space dimension
S = Number of total bacteria within the population,
Sc = Chemo tactic steps number
Ss = Length for swimming
Sre = Reproduction steps number
Sed = Elimination dispersal steps number
Ped = Probability of elimination-dispersal
C(a) = Step size considered randomly in any direction stated by the tumble.
P(b,c,d) = $\{\Theta^a$ (b,c,d)|a=1,2,……..S$\}$= Position of individual bacterium within the population of S number of bacterium at the b-th chemo tactic event, c-th reproduction event and d-th elimination-dispersal step.

The BFO Algorithm
Step 1: BFO Parameters initialization:
S = total sample number of the bacteria that is to be utilized for finding in the sample region.
P = total quantity of parameters to be optimized. Here either KIi or (KIi and Ri) or (KIi, Ri and Bi) are optimized.
Ss = length of swimming subsequent to which the tumbling takes place in a chemo tactic loop.
Sc = iterations number in a chemo tactic loop.
Sre = utmost number of steps of reproduction.
Sed = utmost number of elimination and dispersal action forced on the bacteria.
Ped = probability for the continuation of elimination as well as dispersal process.
Each bacterium P has a location that is stated by the arbitrary quantities within [1,-1].
Value of C(a) is considered to be fixed for simplification.
Values of $d_{attract}$, $\omega_{attract}$, $h_{repelent}$ and $\omega_{repelent}$ are also to be initialized.
Step 2: Algorithm for optimization
1) Elimination-dispersal loop: *d*=*d*+1
2) Reproduction loop: *c*=c+1
3) Chemo taxis loop: *b*=*b*+1
(i) For a = 1, 2, ………., S take a chemo tactic step for bacterium a and calculate fitness function, J(a, b, c, d).
Let,
$J_{sw}(a, b, c, d) = J(a, b, c, d) + J_{cc}(\Theta^a(b, c, d), P(b, c, d))$
(i.e. insert on the cell to cell attractant-repellant effect profilefor simulating the behaviour of swarming).

$$J_{cc}(\Theta, P(b, c, d)) = \sum_{a=1}^{S} J^a_{cc}(\Theta, \Theta^a(b, c, d))$$

Where,

$$= \sum_{a=1}^{p} [-d_{attract} \exp(-\omega_{attract} \sum_{a=1}^{p} (\Theta_m - \Theta^a_m)^2]$$

$$+ \sum_{m=1}^{p} [-h_{repelent} \exp(-\omega_{repelent} \sum_{m=1}^{p} (\Theta_m - \Theta^a_m)^2]$$

Let $J_{last} = J_{sw}(a, b, c, d)$ to preserve this quantity because we might get an improved cost through a run.

End for this loop.

(ii) For a = 1, 2, …………….. S tumble/swim decision is taken.

Tumble: The random vector Δ(a) is generated on [1, -1].

Move: Let

$$\Theta^a(b+1, c, d) = \Theta^a(b, c, d) + C(a) \frac{\Delta(a)}{[\Delta^T(a)\Delta(a)]^{1/2}}$$

This gives us a step of size C(a) in the path of the tumble for a-th bacterium.

Calculate J(a, b+1, c, d) and let $J_{sw}(a, b+1, c, d) = J(a, b+1, c, d) + J_{cc}(\Theta^a(b+1, c, d), P(b+1, c, d))$

Swim:

Let mswim = 0 (counter for swim length)

While mswim < S_s (if haven't brought down excessively long).

Let mswim = mswim + 1

If $J_{sw}(a, b+1, c, d) = J_{last}$(if doing better),

let $J_{last} = J_{sw}(a, b+1, c, d)$ and let

$$\Theta^a(b+1, c, d) = \Theta^a(b, c, d) + C(a) \frac{\Delta(a)}{[\Delta^T(a)\Delta(a)]^{1/2}}$$

And use this Θ^a (b+1, c, d) to find new J(a, b+1, c, d).

Else, let mswim = S_s.

This ends the while statement.

(iii) Go to the just succeeding bacterium (a+1), suppose a ≠ S {i.e., go to step (ii) to continue with the successive bacterium}.

4) If b < S_c, proceed on to step 3 and carry on with the chemotaxis process since the life time of the bacteria has not ended.

5) Reproduction:

(i) For the known c and d, and for every a= 1, 2, …………., S, let

$$J^a_{health} = \sum_{a=1}^{S_c+1} J_{sw}(a, b, c, d)$$

be the fitness value of the bacterium a (a quantity of the number of nutrients it acquired during its lifespan moreover how efficient it was at overcoming toxic substances).

Arrange bacteria and also chemo tactic parameters C(a) in sort of ascending cost J_{health} (high cost gives low health).

(ii) The S_r = S/2 bacterium with the maximum J_{health} values die and the rest of the *Sr* bacteria possessing the best values divide (this method is performed by the group of bacteria that are being placed at the similar location where the parent was present).

6) If $c < S_{re}$, proceed on to step 3 because we haven't reached the specified quantity of reproduction steps and therefore we begin the succeeding generation of the chemo tactic loop.

7) Elimination-dispersal: For *a* = 1,2..., *S* possessing probability P_{ed} every bacterium is eliminated and dispersed so as to keep the quantity of bacteria present in the population to a constant value. During this process if a bacterium is removed then simply scatter a new one to any arbitrary position on the optimization domain. When $d = S_{ed}$ then move on to step 2 else end it.

8) Obtain the optimized values of the parameters.

9) Employ BFO for final updating of the various parameters as desired in the system.

The flow chart for the Bacteria Foraging Optimization algorithm is as below in the Fig.

An algorithm of an adaptive adjustment of step length is called improved bacterial foraging optimization (IBFO) after making a detailed analysis of the impacts of the step length on the efficiency and accuracy of the algorithm, based on chemotaxis operation. This classic test functions show that the convergence speed and accuracy of the IBFO algorithm is much better than the original algorithm. With an increasing number of iterations and decreasing step sizes, the accuracy of the algorithm is greatly improved and the convergence speed of the algorithm is significantly increased. Therefore, the improved algorithm performance is much better than that of the basic algorithm. [24][28][30][31][33][34][35][36].

When several numbers of parameters that needs to be optimized is huge enough, classical technique for the purpose of optimization is never chosen. Some authors have utilized genetic algorithmic program (GA) to optimize gains of controller for a multi-area AGC system at the same time a lot more efficiently than is feasible with traditional approach. Here the optimization of parameters of secondary control, primary control plus frequency bias is being carried out all together for an AGC system so as to investigate as well as check their optimum values for every area under consideration and their exact effect on the complete dynamics of the respective system as made comparison to the case when only gains of secondary control is being optimized, taking into consideration the values of parameters for regulation of governor speed (Ri) and also parameters for frequency bias (Bi) identical as generally employed in reality. Optimization of parameters simultaneously at the same time additionally throws new conclusions for governor function and layout.

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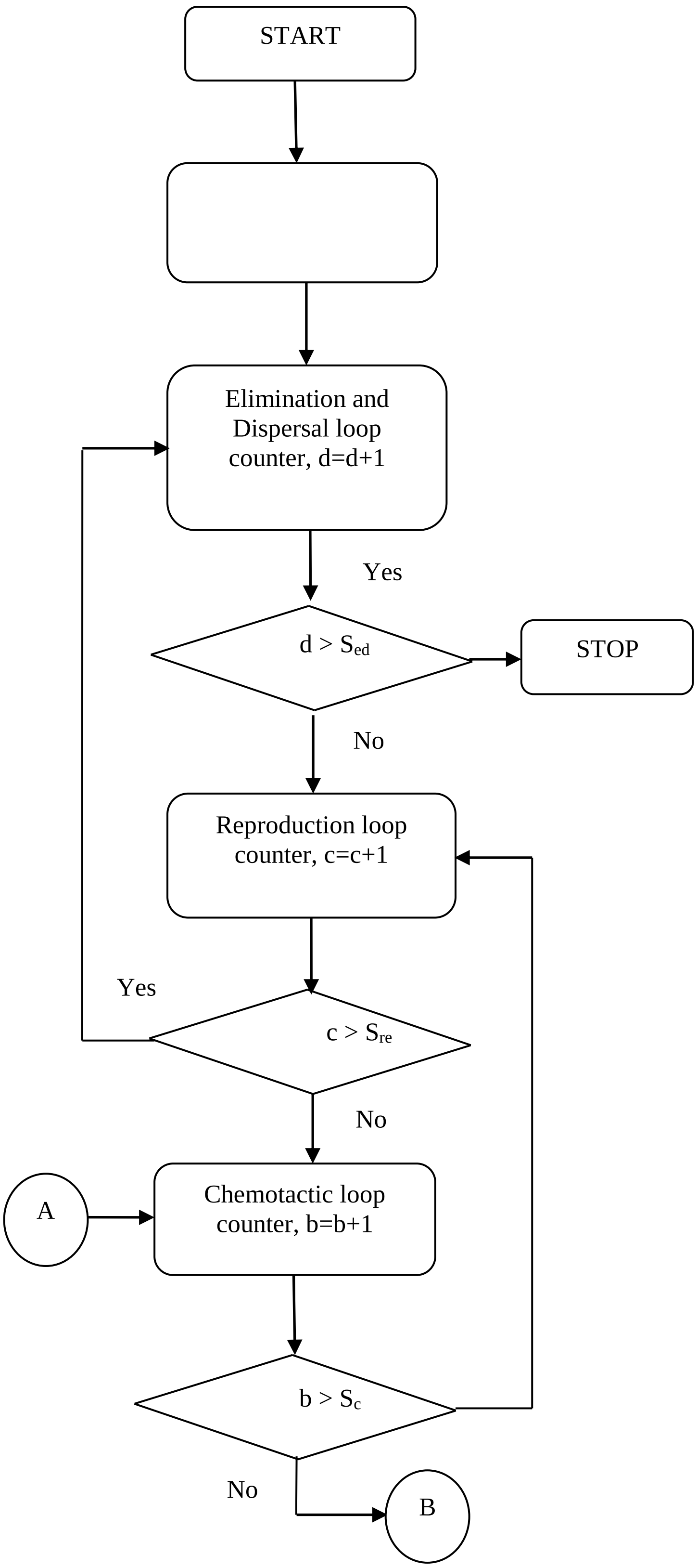

Fig 2: Flow chart of the Bacteria Foraging Algorithm program part-1

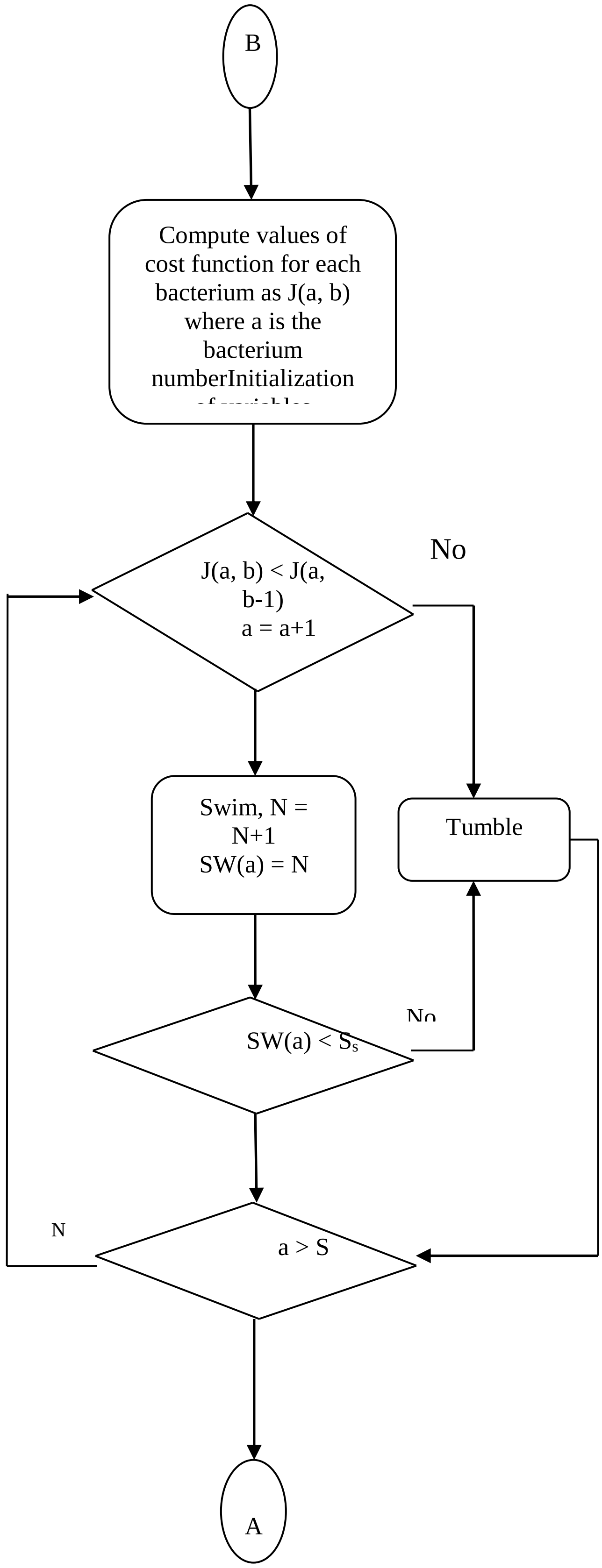

Fig 3: Flow chart of the Bacteria Foraging Algorithm program part-2

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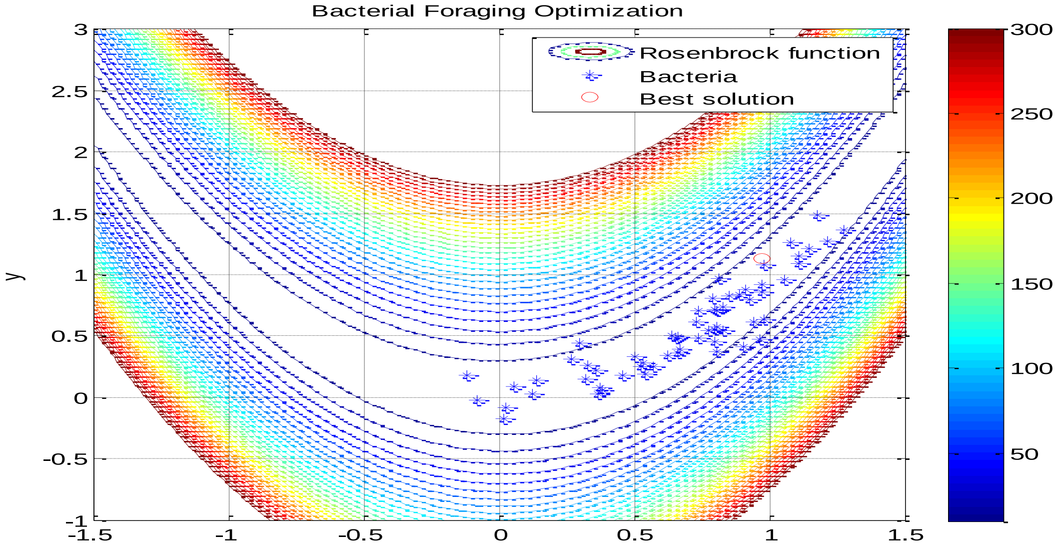

Fig 4: Output of IBFOA

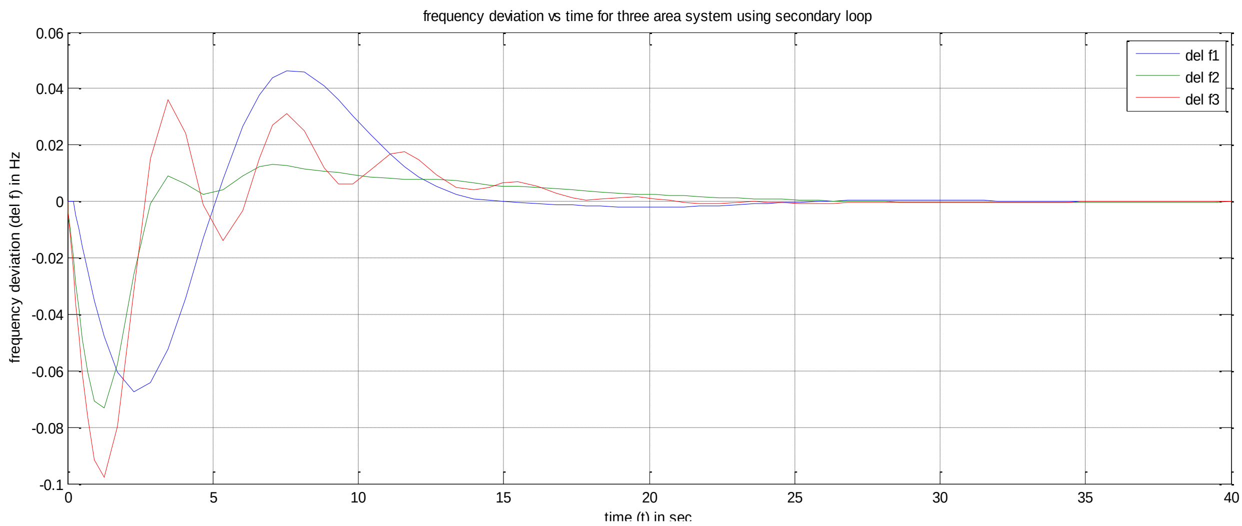

Fig 5: Frequency deviation vs time for three area system using IBFOA

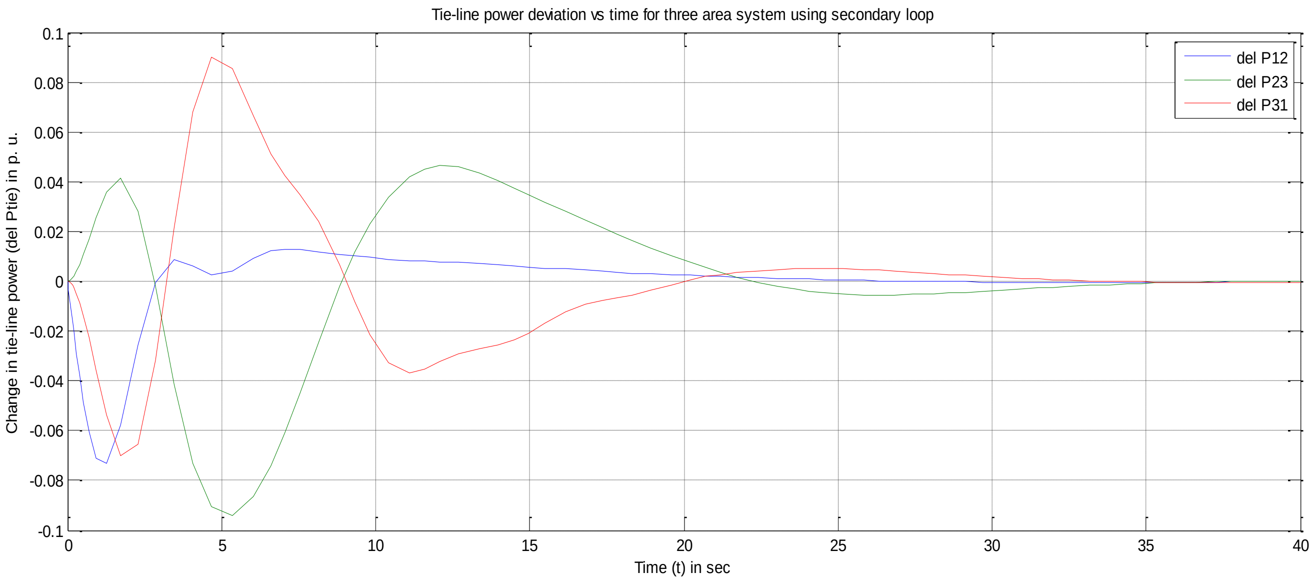

Fig 6: Tie-line power deviation vs time for three area system using IBFOA

number of parameters that are utilized for searching the whole space for solution is far more greater compared to the ones in GA and therefore the chance of prevailing local minimum in BF is far more greater than in GA. BF technique in the meantime has been put to use productively in a number of the areas in the field of electrical engineering and the superiority of Bacteria Foraging over GA is shown clearly.

Thus we've got the relevance of Bacteria Foraging method for optimization of many factors simultaneously like integral controller gains (KIi), for control of secondary loop, parameters for speed regulation of the governor (Ri) for control of primary loops along with parameters of frequency bias (Bi) for AGC of a three unequal area thermal power grid. It offers through investigation of the dynamic responses and then makes the comparison with those obtained with instantaneous optimization of KIi only (keeping Ri and Bi at values utilized in reality) or else simultaneous optimization of KIi and Ri only (keeping Bi at values utilized in reality) such that one can investigate what important results are lost when we aren't optimizing all the parameters (KIi, Ri, and Bi) at the same time. The performance of BF technique is seen.

VIII. CONCLUSION

The interconnection of two or more systems is being introduced to cope up with the load changes through tie line power exchange. Interconnecting two or more areas ensures the sharing of the power among the systems during the times of load changes which may occur in any area at any time. Therefore the burden on the controllers to minimize the changes in the frequency is reduced as a result of the rise in the power demand can be fulfilled by drawing power from the neighbouring areas and thus maintains the stability of the system.

There is introduction of an optimization technique i.e. Improved Bacteria Foraging Optimization Algorithmic program to change the values of the various parameters present in the power system under investigation so it can cope up with the changes in the load demand. As a result of which the changes in the frequency and also the tie line power is reduced and also the stability of the system is maintained. It is also seen that Bacteria Foraging technique has quicker convergence characteristics. Bacteria Foraging technique serves to be quite useful for obtaining the optimized values of the various parameters as compared to the general hit and trial technique which is extremely tedious and time taking method.

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