Computation of Ancillary Service Requirement Assessment Indices for Load Frequency Control in a Restructured Power System using SMES unit

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Abstract: - This paper proposes various design procedures for computing Power System Ancillary Service Requirement Assessment Indices (PSASRAI) for a Two-Area Thermal Reheat Interconnected Power System (TATRIPS) in a restructured environment. In an interconnected power system, a sudden load perturbation in any area causes the deviation of frequencies of all the areas and also in the tie-line powers. This has to be corrected to ensure the generation and distribution of electric power companies to ensure good quality. The disturbances to the power system due to a small load change can even result in wide deviation in system frequency which is referred as Load-Frequency Control (LFC) problem. Quick system restoration is of prime importance not only based on the time of restoration and also stability limits also plays a very vital role in the power system operation even for the unexpected load variations in power systems. As the simple conventional Proportional plus Integral (P-I) controllers are still popular in power industry for frequency regulation as in case of any change in system operating conditions new gain values can be computed easily even for multi-area power systems, this paper focus on the computation of various PSASRAI for Two Area Thermal Reheat Interconnected Power System in restructured environment based on the settling time and peak over shoot concept of control input deviations of each area. Energy storage is an attractive option to augment demand side management implementation, so Superconducting Magnetic Energy Storage (SMES) unit can be efficiently utilized to meet the peak demand. So the design of the Proportional plus Integral (PI) controller gains for the restructured power system without and with SMES unit are carried out using Bacterial Foraging Optimization (BFO) algorithm. These controllers are implemented to achieve a faster restoration time in the output responses of the system when the system experiences with various step load perturbations. In this paper the PSASRAI are calculated for different types of possible transactions and the necessary remedial measures to be adopted are also suggested.

Key-Words: - Bacterial Foraging Optimization, Load- Frequency Control, Superconducting Magnetic Energy Storage, Proportional plus Integral Controller, Restructured Power System, Ancillary Service, Power System Ancillary Service Requirement Assessment Indices.

1 Introduction

Power system network comprises of several control areas and the various areas are interconnected through tie-lines. The scheduled energy exchange between control areas is enhanced through tie-lines. A small load fluctuation in any area causes the deviation of frequencies of all the areas and also of the tie-line power flow. These deviations have to be corrected through various supplementary controls. Maintaining frequency and power interchanges with interconnected control areas at the scheduled values are the major objectives of a Load Frequency Control (LFC) [1, 2]. The electric power business at present is largely in the hands of Vertically Integrated Utilities (VIU) which own generation, transmission and distribution systems that supply power to the customer at regulated rates. The electric power can be bought and sold between the interconnected VIU through the tie-lines and moreover such interconnection should provide greater reliability [1]. The major change that had happened is with the emergence of Independent Power Producers (IPP) which can sell power to VIU. In the restructure environment it is generally agreed that the first step is to separate the generation of power from the transmission and distribution companies, thus putting all the generation on the same footing as the IPP [2]. In an interconnected power system, a sudden load perturbation in any area causes the deviation of frequencies of all the areas and also in the tie-line powers. This has to be corrected to ensure the generation and distribution of electric power companies to ensure good quality. This can be achieved by optimally tuning Load-Frequency controller gains. Many investigations in the area of Load-Frequency Control (LFC) problem for the interconnected power systems have been reported over the past six decades. A number of control strategies have been employed in the design of load-frequency controllers in order to achieve better dynamic performance [3-7]. The efficient incorporation of controllers will modify the transient response and steady state error of the system. Among the various types of load-frequency controllers, the most widely employed is the conventional Proportional plus Integral controller (PI). A lot of studies have been made related to LFC in a deregulated environment over last decades [8-12]. These studies try to modify the conventional LFC system to take into account the effect of bilateral contracts on the dynamics [3] and improve the dynamical transient response of the system [4-7] under various operating conditions. With the restructured electric utilities, the Load-Frequency Control requirements especially the nominal frequency in an interconnected power system besides maintaining the net interchange of power between control areas at predetermined values should be enhanced to ensure the quality of the power system. The importance of decentralized controllers for multi area load-frequency control in the restructured environment, where in, each area controller uses only the local states for feedback, is well known. The stabilization of frequency oscillations in an interconnected power system becomes challenging when implemented in the future competitive environment. So advanced economic, high efficiency and improved control schemes [12- 14] are required to ensure the power system reliability for which Ancillary Services have to be adopted. Ancillary services can be defined as a set of activities undertaken by generators, consumers and network service providers and coordinated by the system operator that have to maintain the availability and quality of supply at levels sufficient to validate the assumption of commodity like behavior in the main commercial markets. There are different types of ancillary services such as voltage support, regulation, etc. The real power generating capacity related ancillary services, including Regulation Down Reserve (RDR), Regulation Up Reserve (RUR) in which regulation is the load following capability under Load Frequency Control (LFC) and spinning reserve (SR) is a type of operating reserve, which is a resource capacity synchronized to the system that is unloaded, is able to respond immediately to serve load, and is fully available within ten minutes but Non Spinning Reserve (NSR) are the one in which NSR is not synchronized to the system and Replacement Reserve (RR) is a resource capacity non synchronized to the system, which is able to serve load normally within thirty or sixty minutes. Reserves can be provided by generating units or interruptible load in some cases. Ancillary services can be divided into the following three categories and are listed below [15]. (i) Related to spot market implementation, short-term energy-balance and power system frequency. These will be labeled Frequency Control Ancillary Services (FCAS). (ii) Related to aspects of quality of supply other than frequency (primarily voltage magnitude and system security). These will be labeled Network Control Ancillary Services (NCAS).(iii) Related to system restoration or re-start following major blackouts. These will be labeled System Restoration Ancillary Services (SRAS).

In this paper various methodologies were adopted in computing Power System Ancillary Service Requirement Assessment Indices (PSASRAI) for Two-Area Thermal Reheat Interconnected Power System (TATRIPS) in a restructured environment. With the various Power System Ancillary Service Requirement Assessment Indices (PSASRAI) like Feasible Assessment Indices (FAI) , Feasible Service Requirement Assessment Indices (FASRAI) Comprehensive Assessment Indices (CAI) or Comprehensive Service Requirement Assessment Indices (CASRAI) the remedial measures to be taken can be adjudged like integration of additional spinning reserve, incorporation of effective intelligent controllers, load shedding etc. In the early stages of power system restoration, the black start units are of the greatest interest because they will produce power for the auxiliaries of the thermal units without black start capabilities. Under this situation a conventional frequency control i.e., a governor may no longer be able to compensate for sudden load changes due to its slow response. Therefore, in an inter area mode, damping out the critical electromechanical oscillations is to be carried out effectively in the restructured power system. Moreover, the system's control input requirement should be monitored and remedial actions to overcome the control input deviation excursions are more likely to protect the system before it enters an emergency mode of operation. Special attention is therefore given to the behavior of network parameters, control equipments as they affect the voltage and frequency regulation during the restoration process which in turn reflects in PSASRAI. Now-a-days the complexities in the power system are being solved with the use of Evolutionary Computation (EC) such as Differential Evolution (DE) [16], Genetic Algorithms (GA), Practical Swarm Optimizations (PSO) [17] and Ant Colony Optimization (ACO) [18], which are some of the heuristic techniques having immense capability of determining global optimum. Classical approach based optimization for controller gains is a trial and error method and extremely time consuming when several parameters have to be optimized simultaneously and provides suboptimal result. Some authors have applied GA to optimize the controller gains more efficiently, but the premature convergence of GA degrades its search capability [19]. Recent research has brought out some deficiencies in using GA, PSO based techniques [20- 21]. The Bacterial Foraging Optimization [BFO] mimics how bacteria forage over a landscape of nutrients to perform parallel non gradient optimization [22]. The BFO algorithm is a computational intelligence based technique that is not affected larger by the size and nonlinearity of the problem and can be convergence to the optimal solution in many problems where most analytical methods fail to converge. This more recent and powerful evolutionary computational technique BFO [23-24] is found to be user friendly and is adopted for simultaneous optimization of several parameters for both primary and secondary control loops of the governor. Most options proposed so far for LFC have not been implemented due to system operational constraints associated with thermal power plants. The main reason is the non-availability of required power other than the stored energy in the generator rotors, which can improve the performance of the system, in the wake of sudden increased load demands. A fast acting Superconducting Magnetic Energy Storage unit (SMES) can effectively damp the electromechanical oscillations occurring in the power system, because they provide storage capacity in addition to the kinetic energy of the generator rotor which can share the sudden changes. In this study, BFO algorithm is used to optimize the Proportional plus Integral (PI) controller gains for the load frequency control of a Two-Area Thermal Reheat Interconnected Power System (TATRIPS) in a restructured environment with and without SMES unit. Various case studies are analyzed to develop Power System Ancillary Service Requirement Assessment Indices (PSASRAI) namely, Feasible Assessment Index (FAI) and Complete Assessment Index (CAI) which are able to predict the normal operating mode, emergency mode and restorative modes of the power system.

2 Modelling of a Two-Area Thermal Reheat interconnected Power system (TATRIPS) in restructured scenario

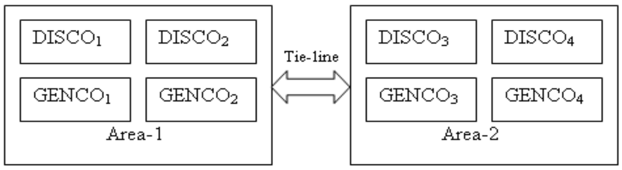

Fig.1. Schematic diagram of two-area system in restructured environment

In the restructured competitive environment of power system, the Vertically Integrated Utility (VIU) no longer exists. The deregulated power system consists of GENCOs, DISCOs, and Transmissions Companies (TRANSCOs) and Independent System Operator (ISO). GENCOs which will compete in a free market to sell the electricity they produce. Mostly the retail customer will continue for some time to buy from the local distribution company and distribution companies have been designated as DISCOs. The entities that will wheel this power between GENCOs and DISCOs have been designated as TRANSCOs. Although it is conceptually clean to have separate functionalities for the GENCOs, TRANSCOs and DISCOs, in reality there will exist companies with combined or partial responsibilities. With the emergence of the distinct identities of GENCOs, TRANSCOs, DISCOs and the ISO, many of the ancillary services of a VIU will have a different role to play and hence have to be modeled differently. Among these ancillary service controls one of the most important services to be enhanced is the Load-frequency control [18]. The LFC in a deregulated electricity market should be designed to consider different types of possible transactions, such as poolco-based transactions, bilateral transactions and a combination of these two [19, 20]. In the new scenario, a DISCO can contract individually with a GENCO for acquiring the power and these transactions will be made under the supervision of

ISO. To make the visualization of contracts easier, the concept of "DISCO Participation Matrix" (DPM) is used which essentially provides the information about the participation of a DISCO in contract with a GENCO. In DPM, the number of rows has to be equal to the number of GENCOs and the number of columns has to be equal to the number of DISCOs in the system. Any entry of this matrix is a fraction of total load power contracted by a DISCO toward a GENCO. As a results total of entries of column belong to DISCOi of DPM is $\sum_i cpf_{ij} = 1$. In this study two-area interconnected power system in which each area has two GENCOs and two DISCOs. Let GENCO 1, GENCO 2, DISCO 1, DISCO 2 be in area 1 and GENCO 3, GENCO 4, DISCO 3, DISCO 4 be in area 2 as shown in Fig 1. The corresponding DPM is given as follows [1 -4]

$$DPM = \overset{DISCO}{\begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix}} \begin{matrix} G \\ E \\ N \\ C \\ O \end{matrix} \quad (1)$$

Where *cpf* represents "Contract Participation Factor" and is like signals that carry information as to which the GENCO has to follow the load demanded by the DISCO. The actual and scheduled steady state power flow through the tie-line are given as

$$\Delta P_{tie1-2,\,scheduled} = \sum_{i=1}^{2}\sum_{j=3}^{4} cpf_{ij}\Delta P_{L\,j} - \sum_{i=3}^{4}\sum_{j=1}^{2} cpf_{ij}\Delta P_{L\,j} \quad (2)$$

$$\Delta P_{tie1-2,\,actual} = \left(2\pi T_{12}/s\right)\left(\Delta F_1 - \Delta F_2\right) \quad (3)$$

And at any given time, the tie-line power error $\Delta P_{tie1-2,\,error}$ is defined as

$$\Delta P_{tie1-2,\,error} = \Delta P_{tie1-2,\,actual} - \Delta P_{tie1-2,\,scheduled} \quad (4)$$

The error signal is used to generate the respective ACE signals as in the traditional scenario [6]

$$ACE_1 = \beta_1 \Delta F_1 + \Delta P_{tie\,1-2,\,error} \quad (5)$$

$$ACE_2 = \beta_2 \Delta F_2 + \Delta P_{tie\,2-1,\,error} \quad (6)$$

For two area system as shown in Fig.1, the contracted power supplied by i[th] GENCO is given as

$$\Delta Pg_i = \sum_{j=1}^{DISCO=4} cpf_{i\,j}\Delta PL_j \quad (7)$$

Also note that $\Delta PL_{1,LOC} = \Delta PL_1 + \Delta PL_2$ and $\Delta PL_{2,LOC} = \Delta PL_3 + \Delta PL_4$. In the proposed LFC implementation, contracted load is fed forward through the DPM matrix to GENCO set points. The actual loads affect system dynamics via the input $\Delta PL_{,LOC}$ to the power system blocks. Any mismatch between actual and contracted demands will result in frequency deviations that will drive LFC to re dispatch the GENCOs according to ACE participation factors, i.e., apf_{11}, apf_{12}, apf_{21} and apf_{22}. The state space representation of the minimum realization model of 'N' area interconnected power system may be expressed as [14].

$$\dot{x} = Ax + Bu + \Gamma d \qquad y = Cx \quad (8)$$

Where $x = [x_1^T, \Delta p_{ei} \ldots x_{(N-1)}^T, \Delta p_{e(N-1)} \ldots x_N^T]^T$,

n - state vector

$$n = \sum_{i=1}^{N} n_i + (N-1)$$

$u = [u_1, \ldots u_N]^T = [\Delta P_{C1} \ldots P_{CN}]^T$, N - Control input vector

$d = [d_1, \ldots d_N]^T = [\Delta P_{D1} \ldots P_{DN}]^T$, N -Disturbance input vector

$y = [y_1 \ldots y_N]^T$, $2N$ - Measurable output vector

where A is system matrix, B is the input distribution matrix, Γ is the disturbance distribution matrix, C is the control output distribution matrix, x is the state vector, u is the control vector and d is the disturbance vector consisting of load changes.

3 Modeling of Superconducting Magnetic Energy Storage unit (SMES)

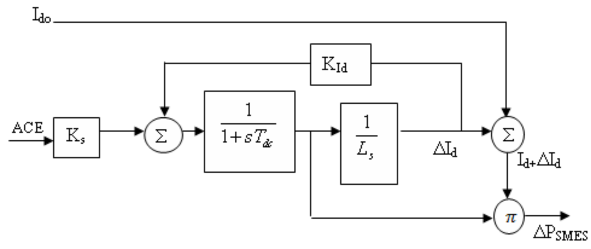

Fig.2 Block diagram representation of SMES unit

Generally the application of energy storages to electrical power system can be grouped into two categories i.e. Storage meant for load leveling application and to improve the dynamic performance of power system. SMES have the following advantages like the time delay during charge and discharging is quite short, Capable of controlling the both active and reactive power simultaneously, Loss of power is less, High reliability, High efficiency. Moreover, SMES stabilizes the frequency oscillations by absorbing/injecting the active power. Fig 2 shows the block diagram representation of the SMES unit. To achieve quick restoration of the current, the inductor current deviation can be sensed and used as a negative feedback signal in the SMES control loop [25]. In a two-area interconnected thermal restructured power system under with the sudden small disturbances which continuously disturb the normal operation of power system. As a result the requirement of frequency controls of areas beyond the governor capabilities SMES is located in area1 absorbs and supply required power to compensate the load fluctuations. Tie-line power flow monitoring is also required in order to avoid the blackout of the power system. The normal operation of a power system is continuously disturbed due to sudden small load perturbations. The problem lies in the fact that the inertia of the rotating parts is the only energy storage capacity in a power system. Thus, when the load-end of the transmission line experiences small load changes, the generators need continuous control to suppress undesirable oscillations in the control to suppress undesirable oscillations in the system. The SMES is a fast acting device which can swallow these oscillations and help in reducing the frequency and tie-line Power deviations for better performance of system disturbances. A SMES which is capable of controlling active and reactive power simultaneously has been expected as one if the most effective stabilizers for power oscillations [26- 29]. Besides oscillation control, a SMES allows a load leveling, a power quality improvement and frequency stabilization. A typical SMES system includes three parts namely superconducting coil, power conditioning system and cooled refrigerator. From the practical point of view, a SMES unit with small storage capacity can be applied not only as a fast compensation device for power consumptions of large loads, but also as a robust stabilizer for frequency oscillations.

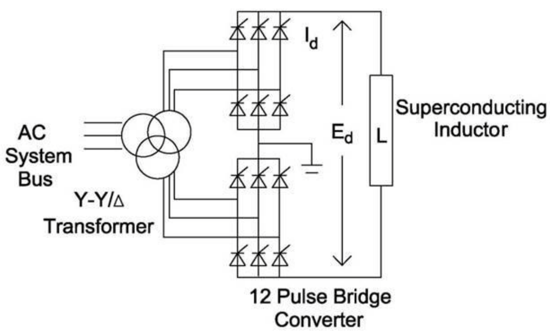

Fig .3. Schematic diagram of SMES unit

The schematic diagram in Fig.3 shows the configuration of a thyristor controlled SMES unit. The SMES unit contains DC superconducting Coil and converter which is connected by Y–D/Y–Y transformer. The inductor is initially charged to its rated current I_{do} by applying a small positive voltage. Once the current reaches the rated value, it is maintained constant by reducing the voltage across the inductor to zero since the coil is superconducting. Neglecting the transformer and the converter losses, the DC voltage is given by

$$E_d = 2V_{do} \cos\alpha - 2I_d R_c \quad (9)$$

Where Ed is DC voltage applied to the inductor, firing angle (α), Id is current flowing through the inductor. R_c is equivalent commutating resistance and V_{do} is maximum circuit bridge voltage. Charge and discharge of SMES unit are controlled through change of commutation angle α. In LFC operation, the dc voltage E_d across the superconducting inductor is continuously controlled depending on the sensed Area Control Error (ACE) signal. Moreover, the inductor current deviation is used as a negative feedback signal in the SMES control loop. So, the current variable of SMES unit is intended to be settling to its steady state value. If the load is used as a negative feedback signal in the SMES control demand changes suddenly, the feedback provides the prompt restoration of current. The inductor current must be restored to its nominal value quickly after a system disturbance, so that it can respond to the next load disturbance immediately. As a result, the energy stored at any instant is given by

$$W_{sm} = W_{smo} + \int_{t^0}^{t} P_{sm}(\tau)d\tau \quad (10)$$

Where, W_{smo} = 1/2 LI_{do}^2, initial energy in the inductor. Equations of inductor voltage deviation and current deviation for each area in Laplace domain are as follows

$$\Delta E_{di}(s) = \left(\frac{K_{SMES}}{1+sT_{dci}}\right)\left[\beta_1 \Delta F_1(s) + \Delta P_{tie1}(s)\right] - \frac{K_{id}}{1+sT_{dci}} \Delta I_{di}(s) \quad (11)$$

$$\Delta I_{di}(s) = (1/sL_i)\ \Delta E_{di}(s) \quad (12)$$

Where, $\Delta E_{di}(s)$ = converter voltage deviation applied to inductor in SMES unit

K_{SMES} = Gain of the control loop SMES

T_{dci} = converter time constant in SMES unit

K_{id} = gain for feedback ΔI_{di} in SMES unit.

$\Delta I_{di}(s)$ = inductor current deviation in SMES unit

The deviation in the inductor real power of SMES unit is expressed in time domain as follows [30].

$$\Delta P_{SMES\ i} = \Delta E_{di}\ I_{doi} + \Delta I_{di}\ \Delta E_{di} \quad (13)$$

The Linerized model of a two-area thermal reheat interconnected power system in restructured environment with SMES unit shown in Fig.4

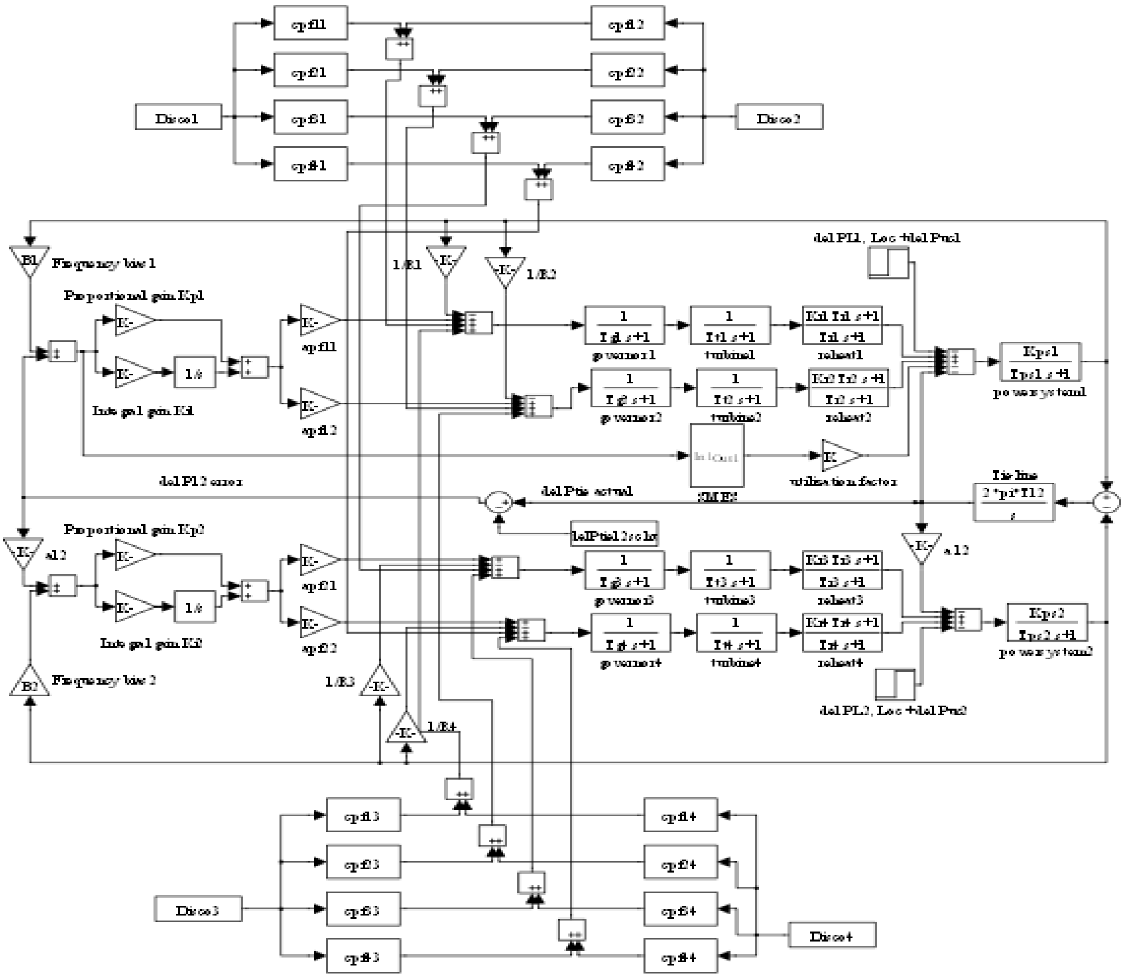

Fig .4. Simulink model of a Two- Area Thermal Reheat Interconnected Power System (TATRIPS) in restructured environment with SMES unit

4 Design of decentralized PI controllers

The proportional plus integral controller gain values (K_{pi}, K_{Ii}) are tuned based on the settling time of the output response of the system (especially the frequency deviation) using Bacterial Foraging Optimization (BFO) technique. The closed loop stability of the system with decentralized PI controllers are assessed using settling time of the system output response [31]. It is observed that the system whose output response settles fast will have minimum settling time based criterion [32] and can be expressed as

$$F(K_p, K_i) = \min(\zeta_{si}) \quad (14)$$

$$U_1 = -K_p\, ACE_1 - K_I \int ACE_1 \; dt,$$

$$U_2 = -K_p\, ACE_2 - K_I \int ACE_2 \; dt$$

Where,

K_p = Proportional gain

K_I = Integral gain

ACE = Area Control Error

U_1, U_2 = Control input requirement of the respective areas.

ζ_{si} = settling time of the frequency deviation of the i^{th} area under disturbance

The relative simplicity of this controller is a successful approach towards the zero steady state error in the frequency of the system. With these optimized gain values the performance of the system is analyzed and various PSRAI are computed

5 Bacterial Foraging Optimization (BFO) Technique

Review of Bacterial Foraging Optimization

The BFO method was introduced by Possino [21] motivated by the natural selection which tends to eliminate the animals with poor foraging strategies and favour those having successful foraging strategies. The foraging strategy is governed by four processes namely Chemotaxis, Swarming, Reproduction and Elimination and Dispersal. Chemotaxis process is the characteristics of movement of bacteria in search of food and consists of two processes namely swimming and tumbling. A bacterium is said to be swimming if it moves in a predefined direction, and tumbling if it starts moving in an altogether different direction. To represent a tumble, a unit length random direction $\phi(j)$ is generated. Let, *"j"* is the index of chemotactic step, *"k"* is reproduction step and "*l*" is the elimination dispersal event. $\theta_i(j,k,l)$, is the position of i^{th} bacteria at j^{th} chemotactic step k^{th} reproduction step and l^{th} elimination dispersal event. The position of the bacteria in the next chemotatic step after a tumble is given by

$$\theta^i(j+1, \quad k, \quad l) = \theta^i(j, \quad k, \quad l) + C(i)\ \phi(j) \qquad (15)$$

If the health of the bacteria improves after the tumble, the bacteria will continue to swim to the same direction for the specified steps or until the health degrades. Bacteria exhibits swarm behavior i.e. healthy bacteria try to attract other bacterium so that together they reach the desired location (solution point) more rapidly. The effect of swarming [22] is to make the bacteria congregate into groups and moves as concentric patterns with high bacterial density. Mathematically swarming behavior can be modeled

$$\begin{aligned} J_{cc}\ (\theta, P(j,k,l)) &= \sum_{i=1}^{S} J^i cc\left(\theta, \theta^i\ (j.k.l)\right) \\ &= \sum_{i=1}^{S}\left[-d_{attract}\ \exp\left(-\omega_{attract}\right)\sum_{m=1}^{p}\left(\theta^m-\theta_m^i\right)^2\right] \qquad (16) \\ &+ \sum_{i=1}^{S}\left[-h_{repelent}\ \exp\left(-w_{repelent}\right)\sum_{m=1}^{p}\left(\theta^m-\theta_m^i\right)^2\right] \end{aligned}$$

Where

J_{CC} - Relative distance of each bacterium from the fittest bacterium

S - Number of bacteria

p - Number of parameters to be optimized

θ^m - Position of the fittest bacteria

$d_{attract}$, $\omega_{attract}$, $h_{repelent}$, $\omega_{repelent}$ - different co-efficients representing the swarming behavior of the bacteria which are to be chosen properly.

In Reproduction step, population members who have sufficient nutrients will reproduce and the least healthy bacteria will die. The healthier population replaces unhealthy bacteria which get eliminated owing to their poorer foraging abilities. This makes the population of bacteria constant in the *evolution* process. In this process a sudden unforeseen event may drastically alter the evolution and may cause the elimination and / or dispersion to a new environment. Elimination and dispersal helps in reducing the behavior of stagnation i.e., being trapped in a premature solution point or local optima.

Bacterial Foraging Algorithm

In case of BFO technique each bacterium is assigned with a set of variable to be optimized and are assigned with random values [Δ] within the universe of discourse defined through upper and lower limits between which the optimum value is likely to fall. In the proposed method of proportional plus integral gain (K_{Pi}, K_{Ii}) (i =1, 2) scheduling, each bacterium is allowed to take all possible values within the range and the cost objective function which is represented by Eq (16) is minimized. In this study, the BFO algorithm reported in [22] is found to have better convergence characteristics and is implemented as follows.

Step -1 Initialization;

1. Number of parameter (*p*) to be optimized.
2. Number of bacterial (*S*) to be used for searching the total region.
3. Swimming length (*Ns*), after which tumbling of bacteria will be undertaken in a chemotactic loop
4. N_C - the number of iteration to be undertaken in a chemotactic loop ($N_C > N_S$)
5. N_{re} - the maximum number of reproduction to be undertaken.
6. N_{ed} - the maximum number of elimination and dispersal events to be imposed over bacteria
7. P_{ed} - the probability with which the elimination and dispersal events will continue.
8. The location of each bacterium *P (1-p, 1-s, 1)* which is specified by random numbers within [-1, 1]
9. The value of *C (i)*, which is assumed to be constant in this case for all bacteria to simplify the design strategy.
10. The value of $d_{attract}$, $W_{attract}$, $h_{repelent}$ *and* $W_{repelent}$. It is to be noted here that the value of $d_{attract}$ and $h_{repelent}$ must be same so that the penalty imposed on the cost function through "J_{CC}'' of Eq (16) will be "0'' when all the bacteria will have same value, i.e. they have converged. After initialization of all the above variables, keeping one variable changing and others fixed the value of "U'' is obtained by obtaining the simulation of system using the parameter contained in each bacterium. For the corresponding minimum cost, the magnitude of the changing variable is selected. Similar procedure is carried out for other variables keeping the already optimized one unchanged. In this way all the

the TATRIPS with SMES unit indicates that more sophisticated control for a better restoration of the power system output responses and to ensure improved Power System Ancillary Service Requirement Assessment Indices (PSASRAI) in order to provide good margin of stability than that of the TATRIPS without SMES unit.

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APPENDIX - A

A.1 Data for Thermal Reheat Power System [14]

Rating of each area = 2000 MW, Base power = 2000 MVA, f^o = 60 Hz, $R_1 = R_2 = R_3 = R_4$ = 2.4 Hz / p.u.MW, $T_{g1} = T_{g2} = T_{g3} = T_{g4}$ = 0.08 s, $T_{r1} = T_{r2} = T_{r1} = T_{r2}$ = 10 s, $T_{t1} = T_{t2} = T_{t3} = T_{t4}$ = 0.3 s, $K_{p1} = K_{p2}$ = 120Hz/p.u.MW, $T_{p1} = T_{p2}$ = 20 s, $\beta_1 = \beta_2$ = 0.425 p.u.MW / Hz, $K_{r1} = K_{r2} = K_{r3} = K_{r4}$ = 0.5, $2\pi T_{12}$ = 0.545 p.u.MW / Hz, a_{12} = -1.

A.2 Data for the SMES unit [25]

Ido = 4.5 kA, L = 2.65 H, Ko = 6000 kV/Hz, Kid = 0.2 kV/kA, K_{SMES} = 100 KV/ unit MW, T_{dc}= 0.03s