DOMINATION OF META-HEURISTIC ALGORITHMS OVER NATURE ALGORITHMS IN AUTOMATIC LOAD FREQUENCY MANAGEMENT

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Abstract : This paper depicts a completely unique scheme to develop a much better automatic load frequency (ALF) management for an interconnected power facility. In an interconnected power system, tiny load disturbance in any of the area results in frequency and tie line power fluctuation in each and every area. Due to an increase in complexity of an electrical power system, there is a requirement to reinforce and develop new control tactics. Though most of the acceptance literature does not base on the attempt that power system performance does not solely depend on the control structure, however conjointly depends on well-tuned controllers. For this purpose, a domination of meta-heuristic algorithms over nature algorithms has provided insight that every of them has their own fruitful characteristics to find solution if the application is used for particular purpose. The conventional two area interconnected thermal power system has been considered with non-linearities. For optimal control, meta heuristic algorithms i.e fruit fly optimization algorithm (FFA) and Backtracking Search Optimization Algorithms (BSA) were employed for tuning control parameters under load perturbation and sensitivity analysis. Further, the results were validated in response of change in the frequency and tie line variables obtained using objective functions based on Integrated Time multiplied Absolute Error (ITAE) and compared with Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and Evolutionary Learning, Design and Search Algorithms.

***IndexTerms* - Automatic Load Frequency (ALF), Automatic Generation Control (AGC), Fruit Fly Optimization Algorithm (FFA), Backtracking Search Optimization Algorithm (BSA), Particle Swarm Optimization Algorithm (PSO), Genetic Algorithm (GA), Area Control Error (ACE), Integrated Time multiplied Absolute Error (ITAE)**

1. INTRODUCTION

Power system is one of the largest networks with several interconnected systems which aims to supply undisturbed power to all consumers. To make the system stable and reduce the losses, generation equals to demand through a control mechanism and the frequency of the system should be close to the preference value at all instances. To achieve the stability of an electrical power system, there are two control variables to be maintained. The frequency variable maintains the real power balance and tie-line power or reactive power exchange maintains the voltage profile [1-3]. The combined effects of the two variables are weighted together to form one variable which is the Area Control Error (ACE). In addition, the total ACE can be used to improve the stability of an isolated power system with a single control area. Thus, the input to the Automatic Load Frequency Control (ALFC) or Automatic Generation Control (AGC) is the ACE, as the ACE is adjusted to zero by the AGC, both the tie-line power and frequency errors become zero. Therefore, Generation Control simultaneously maintain the power exchange between control areas at the scheduled values by adjusting the power of specific generating units and it is required to regulate frequency at specified nominal values [4, 5]. The AGC of an interconnected power system limited to the optimal selection of controllers by observing the effect of physical constraints, impact of Flexible AC transmission systems (FACTS) devices [6, 7] and Energy Storage Systems [8-10].

The standard and non-standard definitions for ALFC on electric power systems were approved by the IEEE standards committee in 1968 [11]. The operating problems of system regulation and factors influencing interconnected systems were summoned [12]. To meet the standards for AGC, there is a need to have a model with issues to improve the performance of AGC. These parameter variations, uncertainties, time delay [13, 14], generator rate constraints (GRC) [15, 16], governor dead band nonlinearity, impacts of deregulation and load characteristics were portrayed in literature. In context to the issues, control techniques such as modern control, classical control and intelligent control methods have been utilized to the ALFC problem [17-18]. A proportional-integral (PI) controller is proposed for ALFC with its gains optimized using genetic algorithm (GA) [19] for a proper AGC evaluation and performance. A concept proposed by Ahamed et al. based on reinforcement learning approach in ALFC [20]. The discussion on the design of PID controller for two-area non-reheat interconnected system using bacteria foraging optimization algorithm (BFOA) based on LFC has been portrayed in [21].

The concept of utilizing Flexible AC transmission System (FACTS) devices improve power operation and control during dynamic and steady state condition, the FACTS devices have improved the controllability of both real and reactive power. An effort was made to enhance the dynamic stability of the power system by introducing a damping controller based on the thyristor-controlled phase shifter (TCPS), Kazem et al [22]. A particle swarm optimization based non-linear time-varying acceleration coefficients (NTVAC-PSO) is presented for solving optimization problems and modeling of unified power flow controller (UPFC) for damping of power oscillation [23]. Balancing of power supply and demand is always a challenge particularly at peak loads. As an outcome, serious observations about reliable operations may likely to occur. So, it is convenient to include battery energy storage (BES) systems to improve the AGC problem. [24-26]. Accomplishment with Interline Power Flow Controller (IPFC) to tie- line and Redox Flow Batteries (RFB) for enhanced system performance was portrayed [27]

2. INVESTIGATION

2.1 *Proposed model under study*

For the verification of advanced methodologies; FFA and BSA, a model of a two area reheat interconnected thermal power system with non-linearities like dead-band, generate rate constraint (GRC) and time delay are considered. The considered work is simulated using MATLAB for various load conditions with cost functions or objective functions for meta-heuristic algorithms seizing signals from numerous positions of the considered model. The results obtained using two algorithms are evaluated and then compared with the nature algorithms. The model depicted is a two area thermal reheat system with non linearities or physical constraints to obtain optimal control of power system, analysis of cost/objective functions and parameters sensitivity towards controller

2.2 *The Proposed Approach*

The present work considers a two area interconnected thermal reheat system model with physical constrains like generation rate constraints, time delay and governor dead band [28, 29]. As represented in fig. 1, B_1, B_2 are frequency bias parametric values; ACE_1, ACE_2 represent the area control error values; u_1 and u_2 depict the control outputs from the designed controller; R_1, R_2 show the governor speed regulation parametric values in p.u. Hz; T_{g1}, T_{g2} are speed governor time constants in seconds; T_{t1}, T_{t2} are turbine time constants in seconds; ΔP_{D1}, ΔP_{D2} are the load demand values; ΔP_{Tie} is a change in an increment of the tie line power (p.u.); K_{p1}, K_{p2} are power system gains; K_{r1}, K_{r2} are Reheat gains; T_{p1s}, T_{p2s} are power system time constants in seconds; T_{12} is the synchronizing coefficient and Δf_1, Δf_2 are system frequency deviations in Hz. The relevant parameters are given in the Appendix, A.2

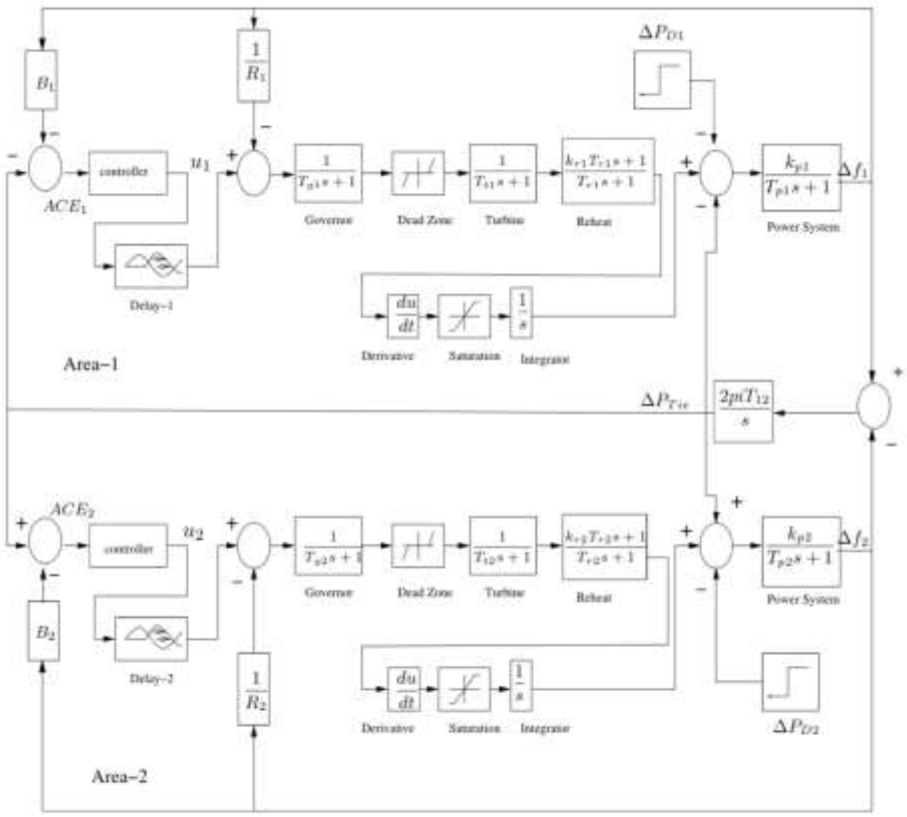

Fig 1: Two Area Interconnected Reheat Thermal Power System

2.3 *Analysis of Cost Functions and Values Sensitivity Towards Controller*

From literature these algorithms to have better performance than their predecessor when implemented in various fields of engineering. So the performance comparison of these two algorithms for tuning an AGC controller is needed. The AGC controller tuned for optimal action requires to mitigate the changes in frequencies of each area and to limit the tie line power. So the error signals from these quantities should guide the tuning for optimal controllers. The objective functions of the meta-heuristic algorithms are composed of these error signals. The performance of proposed controller is evaluated based on indices such as Integrated Absolute Error (IAE), Integrated Squared Error (ISE), Integrated Time Multiplied Absolute Error (ITAE), Integrated Time Multiplied Squared Error (ITSE) etc., are used as in [30]. Among them Integrated Time Multiplied Absolute Error, ITAE is frequently used in literature. To test and compare algorithms, three objective functions J_1, J_2 *and* J_3 are constructed using the error signals obtained at various locations of proposed model which is based on ITAE function.

First objective function J_1 designed using $\Delta f1$,$\Delta f2$,$\Delta PTie$ signals and ITAE function.

$$J1 = ITAE = [|\Delta f1| + |\Delta f2| + |\Delta PTie|].t.dt. \quad 1.1$$

The tested algorithms use this function J_1 and tunes controllers for the model at load disturbances of 5% and 25%.

B_1, B_2, R_1, R_2, T_{g1}, T_{g2}, T_{t1}, T_{t2}, T_{r1}, T_{r2}, K_{r1}, K_{r2} are various system parameters that could effect the performance of the controller. For studying each parameter sensitivity in the design of controller by the proposed algorithms, a sequence of performance is seen by considering variations in the system parameters. This is observed for −25%,+25% change in each parametric value by keeping other parameters as constant as per the proposed system .

$$ACE1 = B1\Delta f1 + \Delta PTie. \quad 1.2$$

$$ACE2 = B2\Delta f2 + \Delta PTie. \quad 1.3$$

These signals (1.2),(1.3) can be used to guide the algorithm for design of the optimal controller. So ACE_1 & ACE_2 signals are utilized along with ITAE to create an objective function J_2 .

$$J2 = ITAE = [|\Delta ACE1| + |\Delta ACE2|]tdt. \quad 1.4$$

AGC controllers are designed for 5%, 25% load disturbances in proposed model using these algorithms and their performances are compared.

It can be observed from fig. 1 that u_1 and u_2 are the output signals of controller (PID) which are given as

$$u1 = KP1ACE1 + KI1ACE1. \quad 1.5$$

$$u2 = KP2ACE2 + KI2ACE2. \quad 1.6$$

substituting (1.2) & (1.3) in (1.5) & (1.6) respectively we have

$$u1 = \left(Kp1B1 + KI1IB1 + KD1\frac{dB1}{dt}\right)\Delta f1 + \left(Kp1 + KI1I + \frac{KD1d}{dt}\right)\Delta PTie \quad 1.7$$

$$u2 = \left(Kp1B2 + KI2IB2 + KD2\frac{dB2}{dt}\right)\Delta f2 - \left(Kp2 + KI2I + \frac{KD2d}{dt}\right)\Delta PTie \quad 1.8$$

from equations (1.7),(1.8) it is seen that u_1 and u_2 also depends on Δf_1, Δf_2, ΔP_{Tie}. So these signals are used along with ITAE to form objective function J3 for algorithms for optimum design of controller

$$J3 = ITAE = [|\Delta u1| + |\Delta u2| + |\Delta ACE2 - \Delta ACE1|].t.dt \quad 1.9$$

By using cost/objective function J3 equation 1.9 in context to the above model, the system is simulated for 5%, 25% load disturbances..

2.4 Scope Analysis and Results

From control system theory characteristics of transient response are calculated using parameters like maximum overshoot *(O_{sh})* maximum undershoot *(U_{sh})*, settling time *(t_s)* in the time domain analysis of a power system. For tuning PID controllers to a given system the signals considered are; change in frequency and exchange of tie line power. The transient response characteristics recovered from these considered signals are minimum if the controller is tuned well otherwise it is referred as poorly tuned controller. To verify tuning capabilities of both algorithms the corresponding response characteristics are needed to be executed for respective tuned controllers.

As proposed algorithms are typically heuristic in nature and produce a near optimal solution, the statistical calculation of these response characteristics is needed. So proposed system with J1 objective function is simulated for 30 times and at every instant each controller parameters are acquired and reserved. This method is prolonged for FFA algorithm, later to PSO & GA algorithms for comparison and validation purpose. For every runtime of simulation, the considered signal response characteristics like peak overshoot *(O_{sh})* undershoot*(U_{sh})*, settling time *(t_s)* are executed. The standard deviation and mean are obtained for these executed response characteristics.

The controller parameters obtained for each simulation case to test the system parameter sensitivity towards tuning of optimal controller by BSA and FFA algorithms are tabulated in table 1. This table shows the variation of gains of PID controller w.r.t the change in the system parameters of the schematic model. The objective function J2 has signals ACE_1, ACE_2, that are linear combinations of Δf_1, Δf_2, ΔP_{Tie} whose minimal response is the desired criteria. Here objective functions J2, J3 provided to algorithms does not give the direct calculation of these desired signals rather a linear combination of (Δf_1,Δf_2 & ΔP_{Tie}) that would effect the algorithms efficiency.

Table 1: The controller gains obtained while testing sensitivity of system parameters when tuned for optimal controller using FFA & BSA for parameters T_g, T_t, T_r, K_r, B and R at 25% load disturbances.

PID CONTROLLER GAINS OF BSA AND FFA													
		BSA						FFA					
		Area 1..(f1)			Area 2..(f2)			Area 1..			Area 2..		
		K_{p1}, K_{I1}, K_{d1}			K_{p2}, K_{I2}, K_{d2}			K_{p1}, K_{I1}, K_{d1}			K_{p2}, K_{I2}, K_{d2}		
T_g	+25%	0.355	0.498	0.148	0.372	0.564	0.201	0.125	0.213	0.082	0.078	0.172	0.135
	-25%	0.458	0.702	0.299	0.395	0.557	0.301	0.382	0.180	0.130	0.143	0.214	0.093
T_t	+25%	0.339	0.472	0.098	0.415	0.643	0.283	0.305	0.113	0.145	0.093	0.128	0.078
	-25%	0.496	0.790	0.374	0.407	0.702	0.362	0.093	0.341	0.107	0.115	0.131	0.074
T_r	+25%	0.408	0.729	0.342	0.437	0.724	0.265	0.148	0.135	0.089	0.115	0.13	0.074
	-25%	0.386	0.526	0.221	0.370	0.218	0.044	0.183	0.414	0.094	0.138	0.099	0.082
K_r	+25%	0.320	0.475	0.091	0.371	0.618	0.207	0.089	0.120	0.164	0.138	0.099	0.082
	-25%	0.440	0.515	0.357	0.437	0.686	0.310	0.145	0.147	0.137	0.292	0.139	0.044
B	+25%	0.358	0.502	0.209	0.323	0.567	0.304	0.126	0.195	0.899	0.086	0.116	0.111
	-25%	0.442	0.794	0.343	0.368	0.510	0.099	0.111	0.223	0.139	0.098	0.115	0.179
R	+25%	0.266	0.443	0.125	0.336	0.503	0.184	0.071	0.196	0.200	0.103	0.122	0.069
	-25%	0.453	0.820	0.339	0.356	0.685	0.332	0.149	0.196	0.245	0.401	0.326	0.086

To find their effectiveness for tuning the optimal solution, these objective function are utilized at a 25% & 5% of load perturbation. The found optimal controllers has produced the responses for desired signals $\Delta f_1, \Delta f_2, \Delta P_{Tie}$ that are compared with J1 algorithm optimal responses at same loading conditions. The comparison of results are postulated in figs. 2 to 4. The statistical measurements of these algorithms are shown in Table 2. Similar analysis is carried out for J2 & J3 objective functions and are seen in Tables 3 & 4 respectively.

From above comparison of results in Fig 2 to 4, following observations about the algorithms for tuning controllers are proposed.

- FFA & BSA tuned controllers using J2 objective function gave a stable and stored response.
- Utilizing J2 objective function, controller response is degraded in performance as compared with J1 at both 5% & 25% load perturbation.
- J3 objective function is not capable to produce optimal controller using BSA algorithm for 5% load disturbance. While there is a satisfactory controller designed for 25% load disturbance.
- FFA proves to be good in tuning controller parameters at both percentage of load disturbance.
- The scope analysis gives insight about BSA abnormality to sense error signal when there is a large distortion of in-feed desire signals produced with small load disturbance.

From tables 2, 3 and 4 the following observations are made.

- BSA has least standard deviation for all response characteristics which shows good convergence compared to the other algorithms.
- The best scope response among the 30 runs of PSO has superiority over the other algorithms. While utilizing J2 objective function PSO performance seems poor compared to other algorithms and it completely distort to tune controllers for J3 objective function.

- GA algorithm provides consistent performance using all three objective functions, but it does not have better statistical results as compared to BSA. FFA almost has negligible overshoot (O_{sh}) as compared to all other algorithms, and also convergence to give optimal solutions.

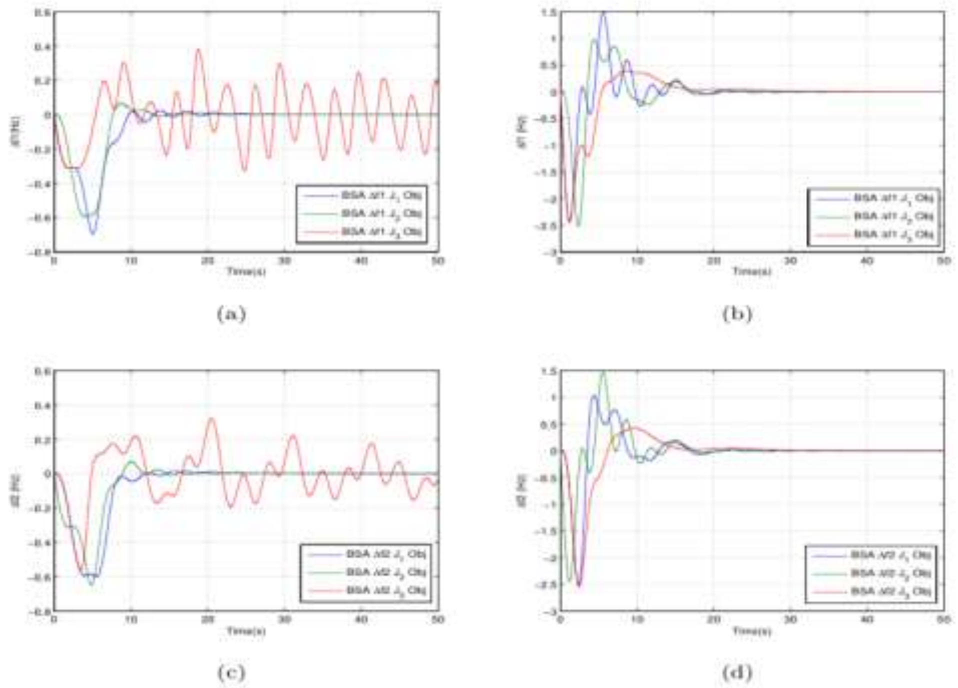

Fig 2: Comparison of change in frequency response obtained from area-1 and area-2 by using objective functions , BSA at 5% and 25% load disturbance (a) BSA−Model−5%−Δf1. (b) BSA−Model−25%−Δf1. (c) BSA− Model−5%−Δf2. (d) BSA−Model−25%−Δf2.

The evolution of meta heuristic algorithms has continuously developed in time. Advanced algorithms appear in each year, and it's not solely clear these algorithms add a new content for the research on the tidings computation. The demand to understand the characteristics of various algorithms like FFA, BSA, Strawberry Algorithms (SBA), Flower Pollination Algorithm (FPA) etc. The demand to understand the characteristics of various algorithms has a panel of steps which include; store a set of list of solutions, to construct a mimic solution using the present data, to develop the provisional solution with a detailed local search or the next algorithm and update the set of present solution with the new solution.

The steps above are used to set up meta heuristic algorithms namely, storage of information, a constructive algorithm p, a local search and the definition of a mechanism for a solution methodology. Memory (storage) as the key principle for evaluating same daya between algorithmic breakdown of meta heuristics. Further enough, each meta heuristic algorithm applies a unique mechanism in the system procedure. The underlying principles depicting the same include; parallelism, selection, elitism, acceptance, decayed reinforcement, immunity, self adaptation and topology. Most used meta heuristic algorithms are used to solve some power and energy system problems including Unit Commitment, Economic Dispatch, Optimal Load Flow and Maintenance Scheduling as seen in [31,32]

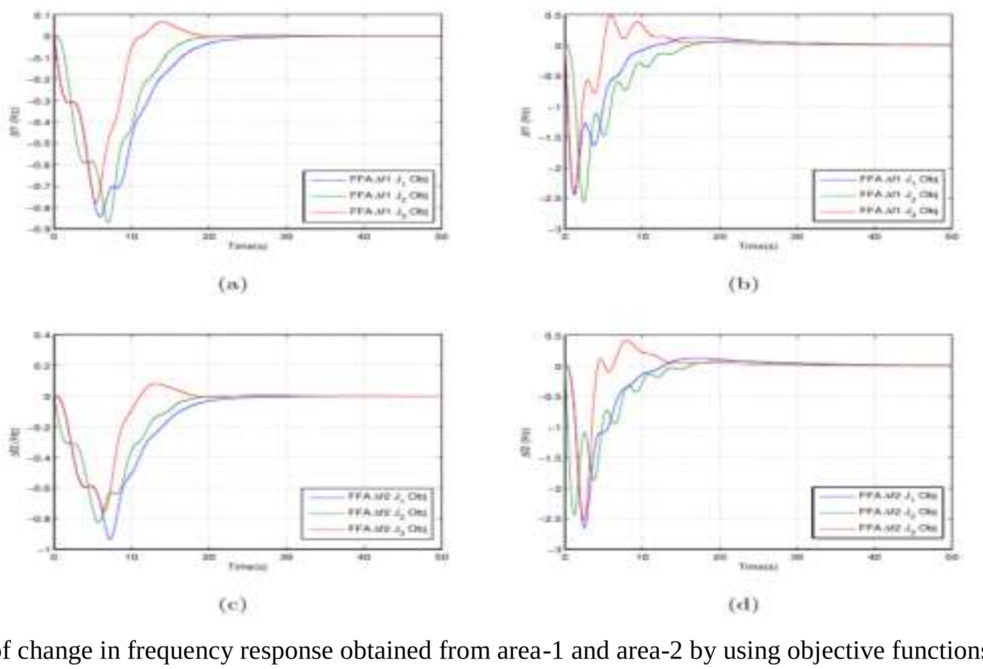

Fig 3: Comparison of change in frequency response obtained from area-1 and area-2 by using objective functions , FFA at 5% and 25% load disturbance (a) FFA−Model−5%−Δf1. (b) FFA−Model−25%−Δf1. (c) FFA− Model−5%−Δf2. (d) FFA−Model−25%−Δf2.

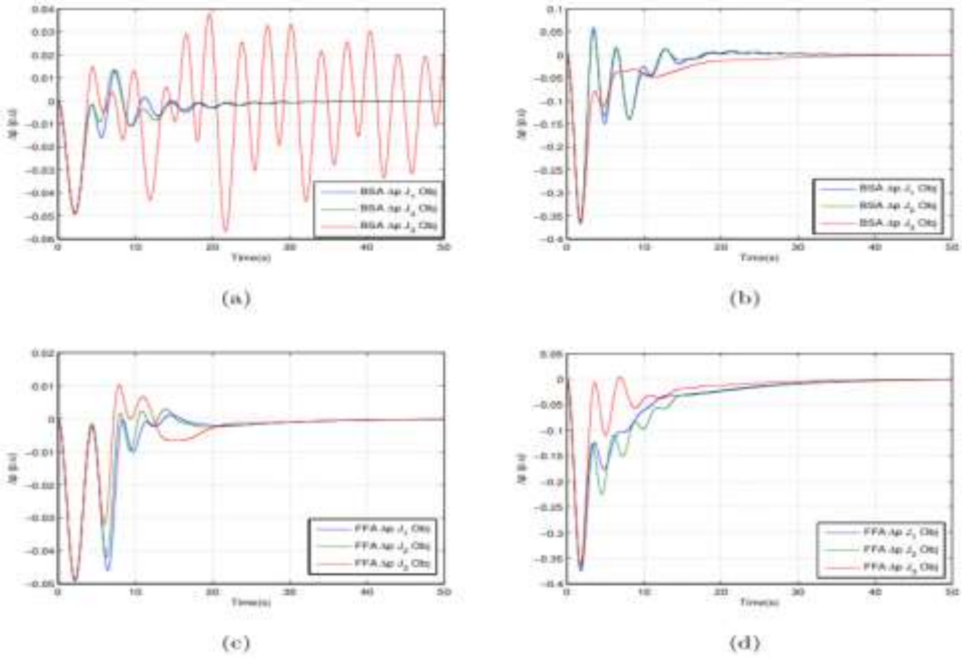

Fig 4: Comparison of response of change in tie line power obtained by using objective functions , FFA and BSA algorithms at 5% and 25% load disturbance (a) BSA−Model−5%−Δp. (b) BSA−Model−25%−Δp. (c) FFA−Model−5%−Δp. (d) FFA−Model−25%−Δp.

Table 2: Statistical results obtained by tuning PID controller through PSO, GA, FFA & BSA algorithms using J1 objective function for 30 run times at 25% step load disturbance

J FUNC	FREQ, P_{TIE}	RESPONSES	STD, MEAN	PSO	GA	FFA	BSA
J_1	ΔF_1	O_{sh}	STD	+0.152	+0.176	+0.200	+0.018
			Mean	+1.234	+0.914	+0.136	+1.280
		u_{sh}	STD	+0.001	+0.002	+0.002	8*10^-5
			Mean	-2.440	-2.442	-2.443	-2.439
		t_s	STD	+1.292	+0.727	+4.082	+0.103
			Mean	+19.25	+20.70	+23.91	+19.42
J_1	ΔF_2	O_{sh}	STD	+0.150	+0.152	+0.164	+0.040
			Mean	+0.946	+0.658	+0.117	+0.923
		u_{sh}	STD	+0.015	+0.030	+0.032	+0.001
			Mean	-2.527	-2.553	-2.593	-2.521
		t_s	STD	+0.600	+0.597	+4.110	+0.073
			Mean	+18.77	+19.35	+22.18	+18.35
J_1	ΔP_{Tie}	O_{sh}	STD	+0.014	+0.013	+0.012	+0.005
			Mean	+0.063	+0.044	+0.003	+0.058
		u_{sh}	STD	7*10^-4	+0.002	+0.002	2.7*10^-5
			Mean	-0.367	-0.686	-0.371	-0.366
		t_s	STD	+2.502	+0.980	+3.443	+0.225
			Mean	+27.33	+24.21	+32.04	+22.21
STD: Standard deviation of 30 iterations, Mean: Mean of 30 iterations							

Table 3: Statistical results obtained by tuning PID controller through PSO, GA, FFA & BSA algorithms using J2 objective function for 30 run times at 25% step load disturbance

J FUNC	FREQ, P_{TIE}	RESPONSES	STD, MEAN	PSO	GA	FFA	BSA
J_2	ΔF_1	O_{sh}	STD	+0.231	+0.303	+0.243	+0.146
			Mean	+1.156	+1.004	+0.191	+1.212
		u_{sh}	STD	+0.001	+0.200	+0.002	6.3*10^-5
			Mean	-2.440	-2.412	-2.443	-2.440
		t_s	STD	+1.452	+1.143	+3.080	+0.830
			Mean	+19.09	+19.94	+23.05	+17.24
	ΔF_2	O_{sh}	STD	+0.203	+0.233	+0.198	+0.123
			Mean	+0.858	+0.729	+0.154	+0.883
		u_{sh}	STD	+0.017	+0.027	+0.036	+0.010

J₂			**Mean**	-2.531	-2.543	-2.603	-2.521
		t_s	**STD**	+0.700	+0.635	+3.206	+0.429
			Mean	+19.08	+19.15	+2.465	+18.65
	ΔP_{Tie}	***O_{sh}***	**STD**	+0.015	+0.020	+0.005	+0.107
			Mean	+0.053	+0.042	+0.001	+0.556
		u_{sh}	**STD**	8.7*10^-4	+0.001	+0.002	66*10^-4
			Mean	-0.367	-0.368	-0.372	-0.367
		t_s	**STD**	+2.839	+2.461	+4.176	+1.621
J_2			**Mean**	+2.140	+24.42	+31.63	+21.73
STD: Standard deviation of 30 iterations, Mean: Mean of 30 iterations							

Table 4: Statistical results obtained by tuning PID controller through PSO, GA, FFA &BSA algorithms using J3 objective function for 30 run times at 25% step load disturbance

***J* FUNC**	**FREQ, P_{TIE}**	**RESPONSES**	**STD, MEAN**	**PSO**	**GA**	**FFA**	**BSA**
	ΔF_1	***O_{sh}***	**STD**	+0.000	+0.155	+0.113	+0.064
			Mean	+0.000	+0.498	+0.122	+0.500
		u_{sh}	**STD**	9.1*10^-6	+0.043	+0.002	+0.003
J_3			**Mean**	-2.436	-2.434	-2.417	-2.423
		t_s	**STD**	0.000	+1.824	+4.917	+0.328
			Mean	Unsettled	+22.54	+24.49	+21.51
	ΔF_2	***O_{sh}***	**STD**	+0.000	+0.160	+0.087	+0.044
			Mean	+0.000	+0.408	+0.100	+0.342
J_3		***u_{sh}***	**STD**	4.5*10^-16	+0.147	+0.063	+0.035
			Mean	-2.729	-2.606	-2.539	-2.561
		t_s	**STD**	+0.000	+2.670	+3.849	+1.163
			Mean	Unsettled	+19.04	+21.73	+18.37
	ΔP_{Tie}	***O_{sh}***	**STD**	+0.000	+0.013	+0.000	+0.013
			Mean	+0.000	+0.014	+0.000	+0.013
		u_{sh}	**STD**	+0.000	+0.013	+0.002	+0.003
			Mean	-0.804	-0.370	-0.364	-0.366
J_3		***t_s***	**STD**	Unsettled	+1.844	+2.333	+0.538
			Mean	Unsettled	+26.38	+31.85	+25.55
STD: Standard deviation of 30 iterations, Mean: Mean of 30 iterations							

3. CONCLUSION AND FUTURE WORK

The optimal building of controllers does not only develop with the category of objective function & constraints used but also with the methodologies that will foster these objectives. New meta-heuristic algorithms like BSA & FFA were used for optimal design of controller in two area interconnected reheat thermal power system at numerous percentage load perturbations. At the instant comparison of time domain responses in terms of undershoot, overshoot & settling time were also sketched and depicts approximately outcomes. A sensitivity analysis of system parameters of the model under investigation were considered in the range of −25% to +25% change with respect to their nominal values. It is observed that BSA has least standard deviation for all response characteristics which shows better concurrency as compared with the other algorithms . Statistical tidings to evaluate the meta-heuristic algorithms like FFA& BSA and their precursors like GA, GA-PSO, PSO were also obtained. Further analysis as disused on the literature point of view, Strawberry (SBA) Algorithm proved to obtain better results in the performance and design of controllers. Current study on the design of ALFC controller has ignited some solutions over the least areas of research which are broadly important for efficient and optimum operation of an electrical power system network as considered in the proposed model.

As ALFC control is through remote operation attained by an entity for instance Independent system operator (ISO) which is distant from generating units and stations. But the decentralized control unit is placed in each of these generation stations whose integral operation would yield good performance than the present ALFC. The advancement of decentralized control is in its theoretical level. Hence there is a further scope in this direction of research and analysis. The integration of more renewable energy to an electrical power system demands good controllers because they do not evolve natural inertia based kinetic energy to provide sudden deficiency of power. Modeling of these systems, evaluation and control performance w.r.t ALFC is a problem and requires time and resources. Due to deregulation of power system there is large increase in private partnerships for production and transmission of power through the electrical power system network. They are done based on power purchase agreement (PPA) which involves power transfer from one control area to another area. The private partnerships participants do not regulate the system parameters but employee ISO to provide spinning reserves to attain frequency and other parameters of the designed system. So this leads to a complex design constraint for the design of ALFC controller. So there is necessity for a good techniques to foster these constraints. To implement this idea there is requirement of practical tidings from which the model can be designed. Performing this work involves both resources and time.

APPENDIX A

Nomenclature and System Parameters

A.1 Nomenclature

ΔP_{Tie}	Change in Tie-line Power in p.u
Δf_1, Δf_2	System Frequency Deviation in Hz
f	Nominal Frequency in Hz
B_1, B_2	Tie-line Bias Factors
R_1, R_2	Governor Speed Regulators in p.u
T_{g1}, $-T_{g2}$	Governor Time Constants in Sec
T_{r1}, T_{r2}	Reheat Time Constants in Sec
T_{p1}, T_{p2}	Power System Time Constant Sec
T_{t1}, T_{t2}	Turbine Time Constant in Sec
K_{r1}, K_{r2}	Reheat Gains
K_{p1}, K_{p2}	Load Demand Gains
$ACE_{1,2}$	Area Control Error
GRC	Generator Rate Constraint
T_{12}	Synchronizing Coefficient
$U_{1,2}$	Control outputs
I	Integration symbol in Cost fn()
o_{sh}	Overshoot
u_{sh}	Undershoot
t_s	Settling time

A.2 Nominal Parameters of the proposed model

Two-area interconnected thermal power system parametric values

f	60Hz
B_1, B_2	0.045, 0.044
R_1, R_2	2.39, 2.4O Hz/p.u.
T_{g1}, $-T_{g2}$	0.08s
T_{r1}, T_{r2}	10.00s
T_{p1}, T_{p2}	20.00s
T_{t1}, T_{t2}	0.30s
K_{r1}, K_{r2}	0.50
K_{p1}, K_{p2}	120Hz/p.u.MW

A.3 BSA and FFA Coding

Part1: BSA.m

```
clc;
clear all;
N=20; %pop size
D=3; %dimension of parameter
max_cycle =100; %max iteration
mixrate =0.5; %parameter to control rate  crossover
low=[-2,-2,-2]; %bound constraints of parameters
upper =[2 ,2 ,2];
globalminimum=inf;
%intialize population
for i=1:N,
        P(i,:)=low+(upper-low).*rand(1,D);
        oldP(i,:)=low+(upper-low).*rand(1,D);
        fitnessP(i)=objective_fun(P(i,:));
```

```
end
for g=1:max_cycle ,
        a=rand;
        b=rand;
                if(a<b)
                for i=1:N
                l=randi(N);
                k=randi(N);
                tp=oldP(1,:);
                oldP(l,:)=oldP(k,:);
                oldP(k,:)=tp;
                end %permuting the arbitrary change in the old population
        end
                mutant=P+rand*3*(oldP-P);
                map=ones(N,D);
        c=rand;
        d=rand;
        for i=1:N,
                if (c<d)
                        map(i,1:round(mixrate*rand*D))=0;
                else
                        map(i,randi(D))=0;
                end
        end
        T=mutant;
        for i=1:N
                for j=1:D
                        if map(i,j)==1
                                T(i,j)=P(i,j);%crossover operation based on thhe map values
                        end
                        if (T(i,j)<low(j)||T(i,j)>upper(j))
                                T(i,j)=low(j)+rand*(upper(j)-low(j));% if unbounded then we randomlyinitiate
                        end
                end
                        fitnessT(i)=objective_fun(T(i,:));
        end
        for i=1:N,
                if(fitnessT(i)<fitnessP(i))
                        fitnessP(i)= fitnessT(i);
                        P(i,:)=T(i,:);
                end
        end
        [Pbest,I]=min(fitnessP);
         if(Pbest<globalminimum)
```

```
                    globalminimum=Pbest
                    globalminimizer=P(I,:)
          end
end
kp1=globalminimizer(1);ki1=globalminimizer(2);kd1=globalminimizer(3);
kp2=kp1;
 ki2=ki1;
kd2=kd1;
open('E:\ELE569_Ahmed(11919183)\Running\BSA\Two_Area_Interconnected_Reheat_TPS');
opt=simset('srcworkspace','current'); sim('E:\ELE569_Ahmed(11919183)\Running\BSA\Two_Area_Interconnected_Reheat_TPS ',[0 25], opt)
```

Part:2 BSA Cost/Objective Function

```
function H=objective_fun(x)
kp1=x(1);
ki1=x(2);
kd1=x(3);
kp2=kp1;
ki2=ki1;
kd2=kd1;
open('E:\ELE569_Ahmed(11919183)\Running\BSA\Two_Area_Interconnected_Reheat_TPS');
opt=simset('srcworkspace','current'); sim('E:\ELE569_Ahmed(11919183)\Running\BSA\Two_Area_Interconnected_Reheat_TPS ',[0 25], opt);
H=max(itae);
```

Part:1 FFA.m

```
clc;
clear all;
%intialize the location of flies
%function [del_f1,del_f2,del_p]=fruit_fly()
%initialization of parameters
maxgen =100;
parameters =3;
popsize =30;
X=zeros(popsize, parameters);
Y=zeros(popsize, parameters);
S=zeros(popsize, parameters);
D=S;% intialize the location of flies;
for j=1:parameters,
X_axis(j)=10*rand();
Y_axis(j)=10*rand();
end
%intialization of population
for i=1:popsize,
          for j=1:parameters ,
                    X(i,j)=X_axis(j)+2*rand()-1;%random direction distance for food smell
                    Y(i,j)=Y_axis(j)+2*rand()-1;
```

```
        D(i,j)=(X(i,j)^2+Y(i,j)^2)^0.5;
        S(i,j)=1/D(i,j);
    end
    kp=S(i,1);
    ki=S(i,2);
    kd=S(i,3);
    smell(i)=objective_fun(kp,ki,kd);
end
    [bestsmell bestindex]=min(smell);
for j=1:parameters ,
X_axis(j)=X(bestindex ,j);
Y_axis(j)=Y(bestindex ,j);
end
Smellbest= bestsmell;
for gen =1: maxgen ,
    for i=1:popsize,
    for j=1:parameters ,
        X(i,j)=X_axis(j)+2*rand()-1;%random direction distance for food smell
        Y(i,j)=Y_axis(j)+2*rand()-1;
        D(i,j)=(X(i,j)^2+Y(i,j)^2)^0.5;
        S(i,j)=1/D(i,j);
    end
    kp=S(i,1);
    ki=S(i,2);
    kd=S(i,3);
    smell(i)=objective_fun(kp,ki,kd);
    end
[bestsmell bestindex]=min(smell);
if bestsmell >Smellbest
for j=1:parameters ,
X_axis(j)=X(bestindex ,j);
Y_axis(j)=Y(bestindex ,j);
Z_axis(j)=Z(bestindex ,j);
end
Smellbest=bestsmell;
end
end
kp1=S(bestindex ,1);
ki1=S(bestindex ,2);
kd1=S(bestindex ,3);
kp2=kp1;ki2=ki1;kd2=kd1;
open('D:\ELE569_Ahmed(11919183)\Accepted\FFA_rev_2\FFA\FFA_pid\Two_Reheat_PID_Normal');
opt=simset('srcworkspace','current'); sim('D:\ELE569_Ahmed(11919183)\Accepted\FFA_rev_2\FFA\FFA_pid\Two_Reheat_PID_Normal ',[0 25], opt);
```

Part:2 FFA Cost/Objective function

```
function H=objective_fun(x,y,z)

kp1=x; ki1=y; kd1=z;

kp2=x; ki2=y; kd2=z;

open('D:\ELE569_Ahmed(11919183)\Accepted\FFA_rev_2\FFA\FFA_pid\Two_Reheat_PID_Normal');

opt=simset('srcworkspace','current'); sim('D:\ELE569_Ahmed(11919183)\Accepted\FFA_rev_2\FFA\FFA_pid\Two_Reheat_PID_Normal ',[0 25], opt);

H=max(itae);
```

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