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# ROBUST PID DESIGN FOR THE DEREGULATED POWER SYSTEM USING HSA

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Abstract: The frequency load control system was modeled in the two-area restructured system. In case of a sudden load variation in one area, the system frequency undergoes a corresponding change (normally accompanied by a series of transient oscillations). Therefore, the feedback and control mechanisms must be designed in such a way that proper power generation regulation in the generators can be implemented by regulating the control signal in the turbines. Thus, in the steady state, power generation would be exactly equal to the load; and the power passing through transmission lines, frequency drift, and ACE error in the zones would be zero. A high-pass PID filter was used in the controller for damping frequency oscillations. The controller control parameters were converted into an optimization problem and the harmonic search algorithm was used to solve this problem. For obtaining an optimal and efficient design, different working points were considered. The simulation results were compared with the results obtained from genetic algorithms and particle swarm optimization (PSO) algorithms for the purpose of evaluating the efficiency of the proposed controller.

Keywords: RPID, Controller, deregulated power system, HSA, Robust

## 1. INTRODUCTION

A load frequency control (LFC) system is a control system which meets the following three criteria:

1. Maintaining the system frequency at its nominal value or a value close to the nominal value (e.g., 50 Hz),
2. Maintaining as an integer value the power exchanged between different areas, and
3. Maintaining (power) generation at its most economically feasible value.

The power system frequency depends on the balance between generation and consumption of the real power. A change in load consumption at one point in the system would affect the whole grid due to the frequency change it is introduced in the system. Any unbalance between power load and power generation causes a frequency drift from the nominal value. Frequency control and power generation (better known as load-frequency control or LFC) are considered as the most important functions of an automatic generation control (AGC) system. One significant purpose of LFC is to maintain at the planned value the power flow through transmission lines between different areas. If there is a power generation shortage in one area, the power generation companies in other areas shall take action to help that area. An LFC system creates the required balance between load and power generation. In this system, the frequency drift from its nominal value and the deviation from the planned value of the power passing through transmission lines are measured to calculate the application control error (ACE) signal which is subsequently fed to the controller (Padhan, *et al.*, 2013).

In case of a sudden load variation in one area, the system frequency undergoes a change (normally accompanied by a series of transient oscillations). Therefore, the feedback and control mechanisms must be designed in such a way that proper power generation regulation in the generators can be implemented by regulating the control signal in the turbines. Thus, in the steady state, power generation would be exactly equal to the load; and the power passing through transmission lines, frequency drift, and ACE error in the zones would be zero (Raheel, *et al.*, 2014).

Although such traditional systems used to produce the required response in the past, they will have no place in today’s free market structure. Power generation companies no longer exclusively own the generation-transmission-distribution cycle. Instead, generation companies (GENCOs), transmission companies (TRANSCOs), and distribution companies (DISTCOs) have entered the competition in the market arena. With the introduction of restructured power systems, fundamental changes have occurred in the power grid management and operation systems. A main purpose of such management restructuring or separation is to create competition in the generation and distribution levels. An important problem in the restructured environment is providing peripheral services. Within this new structure, all peripheral services including LFC, reactive power control, reserve power, etc. are considered as merchandise. In a restructured power system, many of the engineering concepts in planning and operation must be reformulated. Due to the presence of GENCOs, TRANSCOs, and DISTCOs as well as independent system operators (ISOs), many peripheral services in the restructured system undergo fundamental developments (Debbarma, *et al.*, 2013). LFC is one such peripheral service. In the new scenario, a DISTCO can conclude a contract with the GENCO of its choice, with their contract being monitored by the ISO. Local control shall face the same limitation as in the previous case. However, the DISCOs in this case are free to conclude contracts with any GENCO they like, both inside and outside their own area (Rakhshani, *et al.*, 2010)..

The RPID controller in this study was designed for the worst case contract and worst case working point (dynamically) using the harmonic search algorithm. The simulation results presented in the two-area restructured power system showed maximal improvement in overshoot and frequency drift settling time in response to step-load variations.

Researchers used GA in (Radmehr, *et al.*, 2015) for adjusting parameters of FOPID controllers for control an Autonomous Underwater Vehicle (AUV). Two well-known standard function GA and PSO are utilized to assess the proposed method. Optimization based on GA has shown better responses compared with others in a same condition. Calculated FOPID parameters by GA under variations give better and more robust responses. Other methods such as TLBO has been applied for designing FOPID controllers (Bayati, *et al.*, 2016).

The fractional order PID controller is used in (Bayati, *et al.*, 2015) for a Load frequency control. The utilized method, obtained controller parameters by the GA are used for design FOPID controller and hence controller optimally conform to different conditions. This controller applied to a three area power system. Following parts show the advantage of FOPID over PID controllers and also the efficiency of optimization algorithm which has been used for finding a local optimum point.

In (Guolian, *et al.*, 2012), the Fuzzy PI controller is said to control a dual zone system and comparing its results with the results of an ordinary PI controller demonstrates the more efficiency of fuzzy controllers. To obtain better results, inventive algorithms could be used as optimization methods for designing fuzzy controllers. A change in demand in the network, will be reflected as a change in total frequency of the system (Chandra Saikia, *et al.*, 2013). Generator output torque will change as a result of any small disturbance of the load due to change in consumers’ demand. So, nonconformity of mechanical and electrical torques will be the cause of speed change and consequently frequency deviation (Nanda, *et al.*, 2009).

Frequency should remain constant to guarantee the appropriate operation of the power systems. Exact control of frequency provides the stability of speed in electric motors. Speed stability in prime movers is important in operation of generation units. Frequency reduction in a large order may engender high magnetic current in electric motors and transformers (ES, *et al.*, 2011). RPID controller is designed had been designed using HSA (harmonic search algorithm). Simulation results for a dual zone restructured power system show improvement in overshoot and settling time of frequency deviation.

## 2. MODEL OF RESTRUCTURED DUAL ZONE POWER SYSTEM

In the last decades of the $20^{th}$ century, many of countries decided to increase the economic efficiency of electrical industries. Hence, it caused deregulation in the power industry. Frequency control in many parts of the restructured power systems became very hard and followed by attention of many countries. So, frequency control should be provided by GENCOs as an ancillary service.

In conventional power systems, VIU was responsible for the generation, transmission and distribution which were supplying consumers’ demand. Control zone was defined by VIU operation bounds. Generation companies in an open energy market may participate in LFC or may not. On the other side, TRANSOs may make contracts with GENCOs in different zones for buying energy.

Generation and transmission companies send their bids to the market operator to determine the most economic solutions. Contracts are made based on these data and participation factors are assigned. Essential constraints should be considered in generation side activities.

The basic conception of conventional LFC structure doesn't change, technically, so it's probable to change the design of conventional LFC for using in restructured power systems. In this section, an adjusted dynamic model of LFC for restructured power systems is given based on the proposed conception in (Shayeghi, *et al.*, 2009). AGPM has been used in (Shayeghi, *et al.*, 2009) for simulating possible contracts. AGPM indicates GENCOs commitment in providing load following for TRANSCOs according to the contracts. Number of rows and columns of this matrix are equal to the number of GENCOS and TRANSCOs, respectively. In a big power system, the structure of the AGM would be as follows:

$$(1)\ AGPM = \begin{bmatrix} AGPM_{11} & \cdots & AGPM_{1N} \\ \vdots & \ddots & \vdots \\ AGPM_{N1} & \cdots & AGPM_{NN} \end{bmatrix}$$

Considering GENCOs contribution:

$$(2)\ AGPM_{ij} = \begin{bmatrix} gpf_{(s_i+1)(z_j+1)} & \cdots & gpf_{(s_i+1)(z_j+m_j)} \\ \vdots & \ddots & \vdots \\ gpf_{(s_i+n_i)(z_j+1)} & \cdots & gpf_{(s_i+1)(z_j+m_j)} \end{bmatrix}$$

$$For\ i, j = 1, 2, \ldots N,\ s_i = \sum_{k=1}^{i-1} n_i,\ z_i = \sum_{k=1}^{j-1} m_i,\ s_1 = z_1 = 0$$

The sum of all the coefficients of a column in AGPM is 1. Diagonal submatrices of AGPM is related to the local loads and non-diagonal submatrices are for situations that TRANSO and GENCO are in different areas. Block diagram of the LFC in a restructured environment is depicted in Fig. 1.

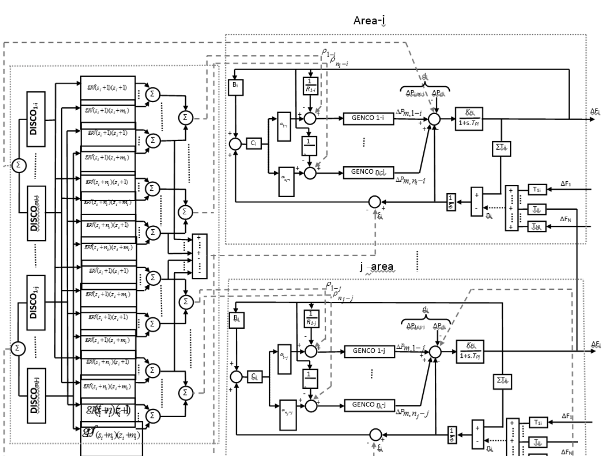


Fig.1. Block diagram of the LFC in a restructured environment

Dotted lines show the link between zones and load signals based on possible contracts. These signals with contracts data are new in the restructured form of the systems. ACE signal should distribute based on unit commitment factors.

$$(3)\ d_i = \Delta P_{Loc,j} + \Delta P_{di},\ \Delta P_{Loc,j} = \sum_{j=1}^{m_i} \Delta P_{Lj-i},\ \Delta P_{di} = \sum_{j=1}^{m_i} \Delta P_{ULj-i}$$

$$(4)\ \eta_i = \sum_{\substack{j=1 \\ j\neq 1}}^{N} T_{ij}\Delta f_j$$

$$(5)\ \xi_i = \Delta P_{tie,i,sch} = \sum_{\substack{k=1 \\ k\neq 1}}^{N} \Delta P_{tie,ik,sch} = \sum_{j=1}^{n_l}\sum_{i=1}^{m_k} \alpha_{(s_l+j)(z_k+i)} \Delta P_{L(z_l+i)-k} - \sum_{i=1}^{n_k}\sum_{j=1}^{m_l} \alpha_{(s_k+i)(z_l+j)} \Delta P_{L(z_l+i)-l}$$

$$(6)\ \Delta P_{tie,i,error} = \Delta P_{tie,i} - \xi_i$$

$$(7)\ \rho_i = [\rho_{i1} \ldots \rho_{ki} \ldots \rho_{n_i i}],\quad \rho_{ki} = \sum_{j=1}^{N}[\sum_{t=1}^{m_j} gpf_{(s_l+k)(z_j+t)} \Delta P_{Lt-j}]$$

$$(8)\ \Delta P_{m,k-i} = \rho_{ki} + \alpha_{ki}\Delta P_{di},\ k = 1, 2, \ldots n_i$$

Considering Fig. 1, three signals $d_i$, $\zeta_i$ and $\rho_i$ could be calculated from contract matrix (Shayeghi, 2005). PID controller block in each control area is as Eq. (9).

$$(9)\ PID = k_p + \frac{k_i}{s} + k_d$$

Producing ideal PID controllers is not possible in a real situation. In industrial PID controllers, it's necessary to use a low pass filter in the derivative input for omitting high frequency noises. Hence, in this paper, the derivative transfer function in PID controllers is assumed as $k_D S/(1+T_d S)$ where $k_D = T_d$ (Khodabakhshian, *et al.*, 2004).

Fig. 2 shows a more complete model of governor and turbine where the constraints of VSL and GRC are taken into account (Pingkanf, *et al.*, 2002) Considering saturation boundaries, the system would become non-linear and settling time and maximum overshoot will increase compared with the linear case (Heon-su, *et al.*, 2002)

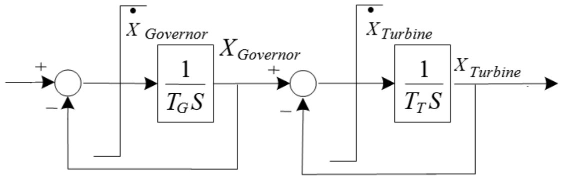


Fig.2. Model of Governor and Turbine

## 3. LOAD-FREQUENCY CONTROL

New theory of the RPID controller, which reduce $\Delta F$ in response to $\Delta P_L$ is introduced In this section. Initial objective function consists of ITAE objective function and a punishment factor for saturation limits. ITAE objective function is as below (Zarighayar, *et al.*, 2010):

$$(10)\; f_{ITAE} = \int_0^\infty t\,|e(t)|\,dt$$

Without considering uncertainties, Eq. (3) describes the initial objective function for a specified scenario c.

$$(11)\; f_c = \sum_{i=1}^{N}\left(\int_0^\infty \left|\Delta f_i^{sim.,c}\right| dt\right) + \sum_{j=1}^{n}\omega_g\left(\left|E_{g,j}^{c}\right| - E_{g,j}^{c}\right) + \sum_{j=1}^{n}\omega_t\left(\left|E_{t,j}^{c}\right| - E_{t,j}^{c}\right)$$

*In* Eq. (10), $\omega_g\left(\left|E_{g,j}^{c}\right| - E_{g,j}^{c}\right)$ and $\omega_g\left(\left|E_{t,j}^{c}\right| - E_{t,j}^{c}\right)$ are the penalty functions that give the optimum point of the objective function or optimum designed parameters for the RPID controller to guarantee the designed control signal of the controller stay in an allowable range of governor and turbine input.

$$(12)\; E_{g,j}^{c} = \overset{g}{X}_{g\,\max} - \overset{g}{X}{}_{g,j\,\max}^{sim,c}$$

$$(13)\; E_{t,j}^{c} = \overset{g}{X}_{t\,\max} - \overset{g}{X}{}_{t,j\,\max}^{sim,c}$$

## 4. HARMONIC SEARCH ALGORITHM

HSA, which is also known by "soft computing algorithm" or "evolutionary algorithm, is an algorithm which searches for optimum solution which is inspired by the improvisation process of jazz musicians. In the HSA, each decision variable generates a value for reaching to the global optimum.

Steps of HSA method are as follows:

1-definition of problem and algorithm parameters

Determining the harmony memory

Generating a new harmony

Updating the harmony memory

Checking stop area of algorithm

The optimization problem is defined in the first step as follows:

$$(14)\; \begin{array}{l} Minmize : \{f(x), x \in X\} \\ s.t \\ g(x) \ge 0 \\ h(x) = 0 \end{array}$$

HSA parameters are also determined in the first step. HM is where all the generated random vectors are stored. HMCR and PAR are parameters that are incorporated into the third step to improve the answer vector (Mahdavi, *et al.*, 2008).

### *1.1. Initial determination of HM*

In this step, HM matrix is generated randomly with many answer vectors and is filled with HMS [18].

$$(15)\; HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^1 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix}$$

### *1.2. Generating New Harmony based on improvisation*

In this step, a new vector which called improvisation vector, $x' = (x'_1, x'_2, ..., x'_N)$ is rules, including on three rules including memory consideration, the rate of choosing a neighboring value and random selection. The value of the first decision variable for new vector x11 is selected from any values which are in HM boundary. Other variable values are also selected like this (Kang Seok, *et al.*, 2004).

$$(16)\; x'_i \leftarrow \begin{cases} x'_i \in \left\{x_i^1, x_i^2, ..., x_i^{HMS}\right\} (HMCR) \\ x'_i \in X_i\,(1-HMCR) \end{cases}$$

HSA selects the value of the decision variable from total possible values . This action is done by using PAR parameter which is the rate of choosing a neighboring value and defined as below (Kang Seok, *et al.*, 2004):

$$(17)\; x'_i \leftarrow \begin{cases} Yes, \Pr(PAR) \\ No, \Pr(1-PAR) \end{cases}$$

If the decision was Yes for sound volume xi' will be replaced as follows:

$$x_i' \leftarrow x_i' \pm rand() \times bw \quad (18)$$

At the third step of HM considerations, additional work is performed on each variable of New Harmony vector if the value in Step 2 came from HM.

*1.3. Updating HM*

If the New Harmony vector $x' = (x_1', x_2', ..., x_N')$ be better than the worst harmony vector in HM based on selected objective function, New Harmony sit in the HM and the worst harmony will be deleted from HM.

If the NI is satisfied, the calculation is finished, otherwise, steps 2 to 4 should be repeated until a termination criterion (e.g. maximum iterations) is satisfied.

## 5. UTILIZING HSA ALGORITHM FOR DESIGNING RPID CONTROLLER IN DUAL ZONE POWER SYSTEMS

Contract simulation in researches is based on multilateral deals. In this scenario, GENCOs not only contribute in load adjustment for DISCOs of their own zone, but also can associate in load adjustment for other zones. Based on AGPM matrix and contribution coefficient of GENCOS, contract between GENCOs and DISCOs in this scenario is as follows (Shayeghi, *et al.*, 2010):

$$AGPM_2 = \begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix} \quad (19)$$

$$apf_{11} = 0.75, apf_{21} = 0.25, apf_{12} = apf_{22} = 0.5$$

It's assumed in simulation researches that a large load equal to 0.1 pu is requested by each DISCO. It’s also assumed that in addition to the contract between DISCOs and GENCOs, zones 1 and 2 face %3 and %5 random load disturbance, respectively. Using restructured power systems equalities and AGPM, power exchange between areas in steady state and also generation of each GENCO are calculated and given in Table 1 (Shayeghi, 2005).

Objective function (6) is used for designing RPID controller and applying HSA algorithm on (6). Maximum number of repeats to obtain better results is considered 100. Saturation boundaries of governors and turbines are assumed and $\overset{g}{X}_{t\max} = 0.2$, respectively (Young-Hyun, *et al.*, 1999; Heon-su, *el al*, 2002) The optimum calculated parameters for RPID controller are given in Table 2 for three algorithms HSA, GA (Sakhayati, *et al*, 2007) and PSO (Zarighavar, *et al.*, 2010). Fig. 3 shows the optimization procedure of HSA algorithm.

Table 1 GENCO's Power generation and power transmitted varations

| **Scenario** | **ΔP$_{m1-1}$** | **ΔP$_{m2-1}$** | **ΔP$_{m1-2}$** |
|---|---|---|---|
| 1 | 0/110 | 0/110 | 0/105 |
| 2 | 0/137 | 0/087 | 0/241 |
| **Scenario** | ΔP$_{m2-2}$ | ΔP$_{tie,12,sch}$ | |
| 1 | 0/105 | 0 | |
| 2 | 0/067 | -0/043 | |

Table 2 RPID settings

| **Algorithm** | **RPID** | | | | | |
|---|---|---|---|---|---|---|
| | Area 1 | | | **Area 2** | | |
| | $K_P$ | $K_I$ | $K_D$ | $K_P$ | $K_I$ | $\mathbf{K_D}$ |
| HSA | 2.02 | 1.65 | 1.28 | 2.15 | 0.44 | **0.89** |
| PSO | 0.88 | 2.05 | 0.28 | 0.01 | 0.69 | **0.16** |
| GA | 1.18 | 1.05 | 0.22 | 1.08 | 0.56 | **1.10** |

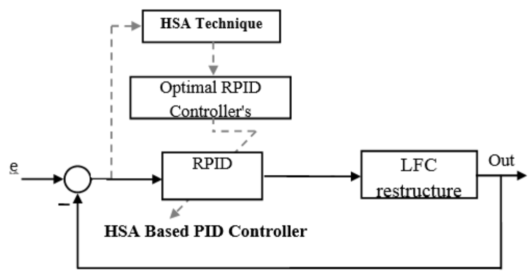


Fig.3. The optimization procedure of HAS

## 6. SIMULATION RESULTS

Frequency deviation in first and second zones and transmitted power between them as a result of uncertainties in power system parameters are given to assess the applicability of designed RPID controller based on HSA algorithm. Obtained results have been compared with the results of deigned controllers with GA and PSO algorithms. Calculated results for frequency deviation and changes in original *exchanges of power between* different *zones* for various algorithms are given in Figs. 4 to 7. Results show a robust behavior of the power system in both scenarios 1 and 2 with RPID controller designed based on HSA algorithm.

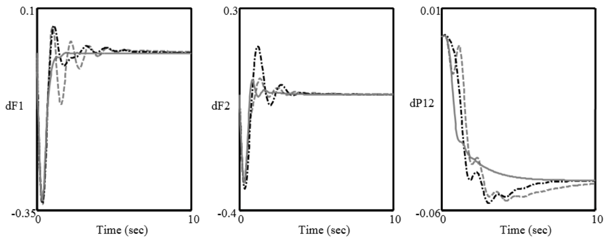


Fig.4. Frequency deviations in area 1 and 2, Power deviations in interconnected area for nominal parameters under scenario for HAS (—), PSO (-----), GA (-.-.-)

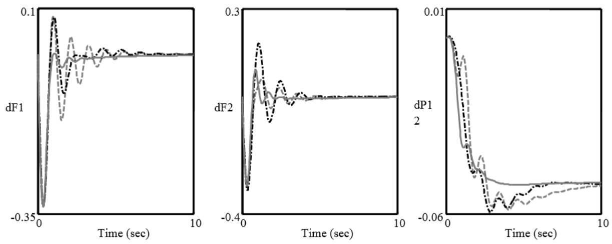


Fig.5. Frequency deviations in area 1 and 2, Power deviations in interconnected area for 25 percent reduction under uncertainties system under scenario for HAS (—), PSO (-----), GA (-.-.-)

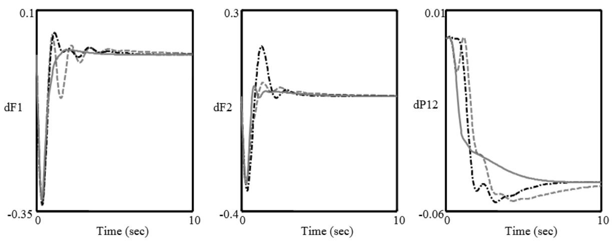


Fig.6. Frequency deviations in area 1 and 2, Power deviations in interconnected area for 25 percent increasing under uncertainties system under scenario for HAS (—), PSO (-----), GA (-.-.-)

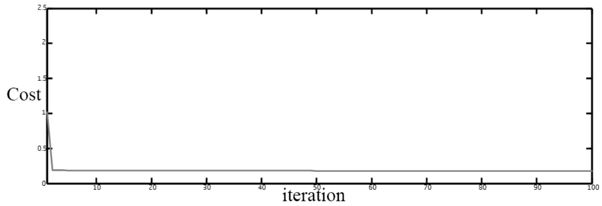


Fig.7. Varations of fitness function

In order to demonstrate the efficiency and robustness of the proposed controller in the face of power system uncertainties 3 criteria, $ITAE$ and FD are used as follows:

$$(20)\ FD = (OS\,(\Delta f_1)\times 100)^2 + (FU\,(\Delta f_1)\times 20)^2 + T_s\,(\Delta f_1)^2$$

$$(21)\ ITAE = \int_0^{t=10} t.(|ACE_1| + |ACE_2|)$$

In equation (11), the OS is the maximum overshoot, US is first negative overshoot and $T_s$ is the settling time. In FD, the settling time is calculated considering 5% error.

The numerical results of operational criterion FD and ITAE for dual zone restructured power systems are given in Table 3 for two different scenarios.

Table 3 Settings for RPID for different scenarios

| Change of parameters | ITAE | | |
|---|---|---|---|
| | HSA | PSO | GA |
| 25% | 0.1852 | 0.3150 | 0.4969 |
| 20% | 0.1753 | 0.3040 | 0.4800 |
| 15% | 0.1702 | 0.2966 | 0.4647 |
| 10% | 0.1646 | 0.2918 | 0.4510 |
| 5% | 0.1587 | 0.2876 | 0.4386 |
| nominal | 0.1531 | 0.2840 | 0.4275 |
| -5% | 0.1494 | 0.2796 | 0.4189 |
| -10% | 0.1511 | 0.2738 | 0.4126 |
| -15% | 0.1607 | 0.2688 | 0.4087 |
| -20% | 0.1755 | 0.2715 | 0.4079 |
| -25% | 0.1932 | 0.2843 | 0.4107 |
| Change of parameters | FD | | |
| | HSA | PSO | GA |
| 25% | 58.4653 | 98.8598 | 128.2186 |
| 20% | 56.4470 | 100.4691 | 127.7245 |
| 15% | 53.9857 | 102.4300 | 127.6563 |
| 10% | 48.4489 | 104.0632 | 128.0965 |
| 5% | 49.1454 | 115.1326 | 129.2889 |
| nominal | 49.3605 | 118.6904 | 131.5188 |
| -5% | 50.1343 | 122.7002 | 121.3013 |
| -10% | 54.8532 | 127.0224 | 125.7149 |
| -15% | 64.0384 | 132.0639 | 131.0680 |
| -20% | 70.6125 | 137.7541 | 138.4741 |
| -25% | 78.3489 | 145.1765 | 146.4793 |

## 7. CONCLUSION

Change in active power can effect on the frequency, while reactive power has less sensitive on frequency, but can effect on the voltage, so, active and reactive power must have separate controllers. Load frequency controls, control the active power and the frequency and Automatic voltage regulator controls the reactive power and the voltage. In this paper, RPID controller designed using harmony search algorithm for load frequency control. With growing the influence of interconnected power systems, the importance of load frequency control has been increased and with using new algorithms, operation of these systems are improved. The simulation results shows the efficiency of this method and prove that the RPID controller have robust behavior for a wide range of load variation and change in system parameters by considering nonlinear factors. The results of this method is compared with other methods, and the operation of this algorithm is better than other algorithms.

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