An optimized PID parameters for LFC in interconnected power systems using MLSL optimization algorithm

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AN OPTIMIZED PID PARAMETERSFOR LFC IN INTERCONNECTED POWER SYSTEMS USING MLSL OPTIMIZATION ALGORITHM

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ABSTRACT

This research presents the load frequency control (LFC) of three interconnected power systems using a Multi-Level Single Linkage algorithm (MLSL) and a proportional-integral-derivative (PID) control approach. The conventional PID controller is developed using MLSL optimization algorithm including the LFC loop to minimize the frequency deviation and regulate the power exchange because of the load disturbance changes in area1 and area2. In order to enhance the dynamic performance, the optimal parameters of the PID scheme which optimized by the proposed MLSL algorithm are compared with that one's obtained by GA algorithm. Integral Square Error (ISE) is considered as an objective function for both algorithms to determine its performance index value for the same interconnected power system. The results show that the performance of the proposed method is more accurate and faster as well in response to the settling time, maximum deviation, and peak time. The combination algorithms set of MLSL_PID_ISE and GA_PID_ISE are coded and simulated using MATLAB.

Keywords: LFC, MLSL optimization algorithm based PID controller, GA algorithm, ISE.

1. INTRODUCTION

One of the most significant current discussions in power systems is the load frequency control. Power systems consist of a number of generating units interconnected together in response to changes between the power demand and the power generated. To make the power system in an equilibrium status, the system frequency must be a balance among the utilities over the tie-line power transmission line. If there is any load disturbance, all areas which are interconnected together through the tie-lines will be affected as well [1]. Thus, the basic control mechanism of the load frequency control (LFC) is used to keep the interchanges of the scheduled tie-line power and the system frequency values as close as possible to the specified limits as in multi-area power systems [2]. Meanwhile, LFC is a very important part in the operation of power systems to control the real power output and minimize the frequency deviation [3].

In an interconnected power systems, The LFC has two major advantages; to monitor the tie-line power flow and maintain the system frequency at the scheduled values through an area control error (ACE) in each power system unit. ACE term is considered the coherent controller among the combination of several power generators such as renewable energy sources, hydro nuclear, thermal, gas, and etc. [4].However, it calculates the fault tolerance of the required generation according to the load demand to keep it at a low value. In more realistic, the errors of the tie line power and the system frequency are adjusted to be zero depending on the ACE value which is represented as the controlled output of the LFC [5].

In recent decades, the researchers in [6] are broadly presented several strategies for the solution of the automatic generation control problem especially during the small load disturbance to maintain the tie line power flow and the system frequency at their scheduled values. Based on this literature survey, it is noted that the most of the automatic generation control has carried out the decentralized methods based on artificial intelligence controllers such as; sliding mode control [7-9], artificial neural network (ANN) controller [10,11], fuzzy logic (FL) controller [12-15], and neuro-fuzzy controller [16,17]. To reduce the complicities of these techniques, many researchers have investigated the centralized method for tuning the PID parameters in multiple-interconnected power plants using trial-and-error approach [18, 19]. Additionally, one more offer to use the PID controller with optimization techniques is the reliability and its structure simplicity to get the desired performance of the optimal PID gains under different operation conditions. The optimization methods have the ability to tune the PID parameters for determining the minimum global optima such as Differential Evolution [20], Practical Swarm Optimizations [21-23], Ant Colony Optimization [24], and Genetic Algorithms [25, 26].

In this paper, an efficient artificial intelligent based on soft computing MLSL optimization algorithm is employed to determine the optimal values of K_p, K_i, and $K_d$ofthe proposed PID controller for the load frequency control in three interconnected power systems. Then, this optimization technique has been designed and implemented using MATLAB Simulink/Coding. After that, dynamic performance of the proposed MLSL_PID algorithm is compared with GA_PIDin terms of time settling, maximum deviation, and peak time for a step load change in area1 and area2. An objective function is considered for both algorithms which is known as an Integral Square Error (ISE) to determine the minimum index value of the overall system performance.

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2. PROPOSED POWER SYSTEM USING LFC MODEL

The overall power system of three interconnected power systems including the LFC model and the PID controller is investigated as shown in Figure-1. Each power system has primary and secondary loops respectively and feedback controller. U_1, U_2, and $U_3$are the control outputs of the proposed PID controllers respectively, DPL_1,$DPL_{2,}$ and $DPL_2$are the disturbance load changes, DW_1, DW_2, and $DW_3$are represented the frequency changes in each power system. The nominal parameters of the overall power system are given in [27].

An area control error (ACE) is used for each area to reduce its own value to be zero [28], which is defined as:

$$ACE_1 = -\Delta P_{12} + \Delta P_{31} - B_1 \Delta\omega_1 \quad (1)$$

$$ACE_2 = +\Delta P_{12} - \Delta P_{23} - B_2 \Delta\omega_2 \quad (2)$$

$$ACE_3 = +\Delta P_{23} - \Delta P_{31} - B_3 \Delta\omega_3 \quad (3)$$

Where ΔP_{12}, ΔP_{23} and, ΔP_{31} represent the changes in the tie line power plant, B_1, B_2 andB_3 are the bias frequencies for each area, $\Delta\omega_1$, $\Delta\omega_2$ and $\Delta\omega_3$represent the frequency deviation for each area.

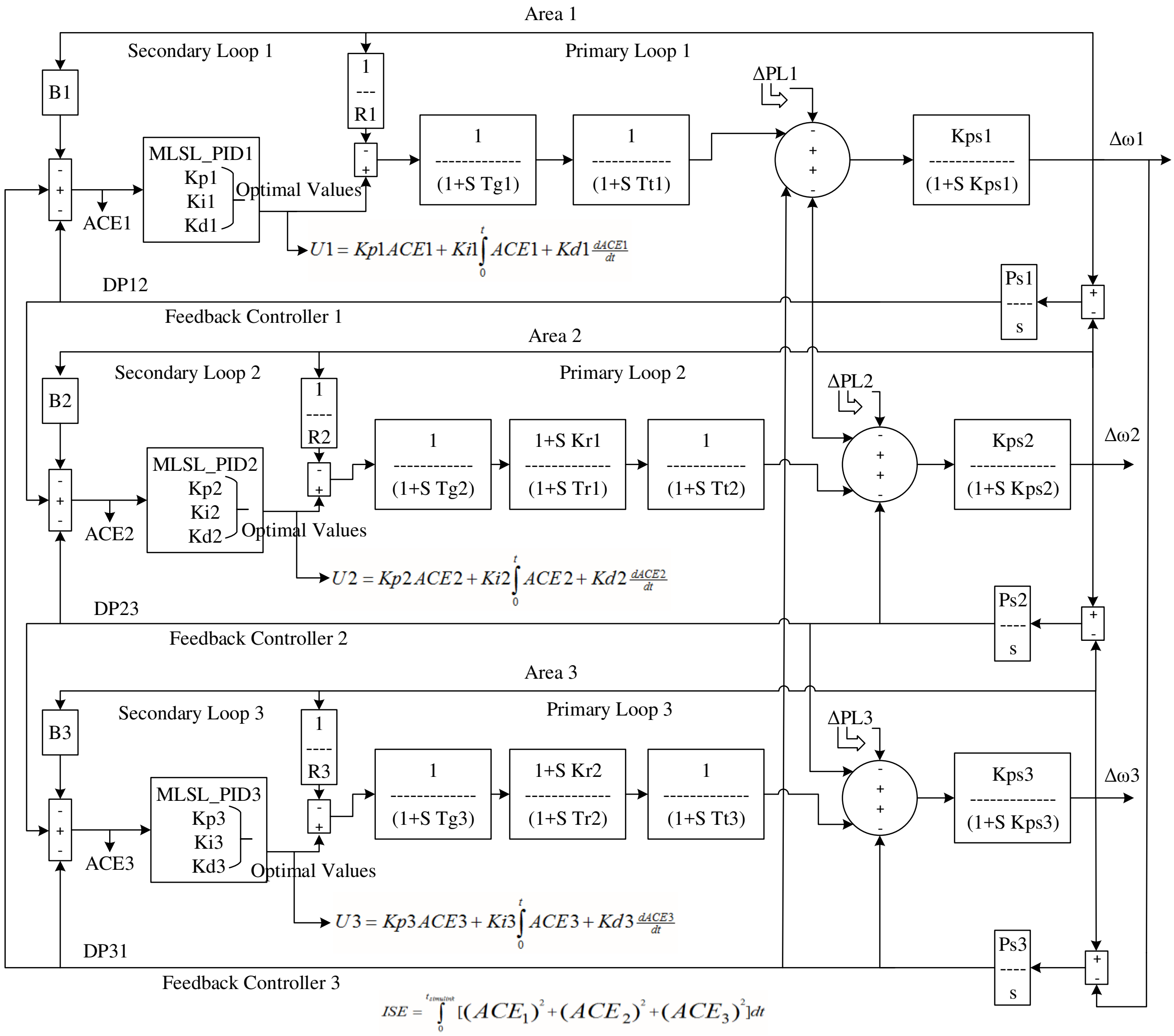

Figure-1. Proposed power system with LFC Model.

Basically in interconnected power systems, the main objective of the LFC is to keep the system frequency at scheduled value, and to control the tie line power exchanges [29]. When a change in step load input (DPL) occurs for each area in the system, the generation of all areas is increased to meet the changing for the tie line power and the reduction in the system frequency as well. ISE criteriais interfaced with the M-file technique of the MLSL_PID heuristic optimization to generate the best optimized PID parameters based on its performance index value. The expression of the ISE objective function used in this research is shown as below [5]:

$$ISE = \int_0^{t_{simulink}} [(ACE_1)^2(t) + (ACE_2)^2(t) + (ACE_3)^2(t)]\, dt \quad (4)$$

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Where $t_{simulink}$ is the range of the simulation time. ISE (Integral Square Error) is used to determine the optimal values of the PID controller, which is explained as the sum of square of cumulative errors in the area control errors (ACE_1, ACE_2, and ACE_3).

3. CONVENTIONAL PID CONTROLLER MODEL

PID controller is one of the popular feedback controller used with the load frequency control for providing an excellent control performance and higher stability. The transfer function of the PID consists of three basic parameters; Proportional (P), Integral (I), and Derivative (D) as shown in Figure-2. The advantages of each parameter are [30]; proportional is used to reduce the system peak overshoot, an integral is employed to eliminate the effect of the steady state error to be zero, and the system will be stable by using the derivative and its transient response will be improved as well.

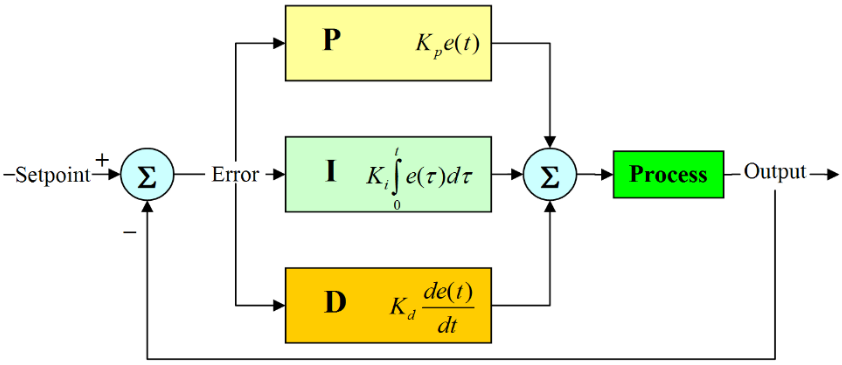

Figure-2. Classical PID controller model [30].

According to [31], the typical transfer function of the classical PID controller in terms of Laplace domain is described below:

$$G_{PID}(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s \quad (5)$$

Where, $U(s)$ and $E(s)$ are the control signal and the error signal which is thedifference between the input and the feedback correspondingly; K_p is the proportional gain, K_i is the integration gain and K_d is the derivative gain. Moreover, the output value of the proposed PID controller is given below which generates the proper control signal to keep the system parameters within the nominal values [32];

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \quad (6)$$

Where $u(t)$ and $e(t)$ are the control and tracking error signal which is in the form of time domain.

For area1:

$$u_1(t) = K_{p1}ACE_1(t) + K_{i1} \int_0^t ACE_1(t)dt + K_{d1}\frac{dACE_1(t)}{dt} \quad (7)$$

For area2:

$$u_2(t) = K_{p2}ACE_2(t) + K_{i2} \int_0^t ACE_2(t)dt + K_{d2}\frac{dACE_2(t)}{dt} \quad (8)$$

For area3:

$$u_3(t) = K_{p3}ACE_3(t) + K_{i3} \int_0^t ACE_3(t)dt + K_{d3}\frac{dACE_3(t)}{dt} \quad (9)$$

Based on the researcher's survey, it usuallyrefers to Ziegler-Nichols PID approach for tuning its parameters [33]. In this research, the initial parameters of the PID controller are generated randomly and then the optimal values of the proposed PID parameters can betuned using an optimization technique such as MLSL algorithm which can lead the controller to meet the desired control requirement.

4. PROPOSED MLSL INTELLIGENCE ALGORITHM

Multi-Level Single Linkage (MLSL) is considered a multiple decision criteria which can be optimized simultaneously especially with the science fields including engineering to find a set of optimal solutions [34, 35]. Itis a heuristic optimization which used to find multiple local minima for bound constrained problems [36]. The parameters of the proposed PID are formulated as an optimization problem and the MLSL algorithm is able to search for that optimal parameters.

The basic principle of MLSL algorithm operation is presented in Figure-3, which starts local searches within groups of points around the local minimizersin order to find global optima. It works with a set of given solution boundaries represented asstart points. After specify the properties of MLSL, local searches based on initial parameter 'x0' are started to generate start points. Next, the proposed algorithm is called the overall system to search for the optimal values of the PID controller. According to the run of local search, the best optimal value is chosen as the starting point in the current iteration and the generated optimal valueis stored for next iteration. Then, a comparison between the best optimal valueand the generated optimal value is usually done to check the criteria of stopping conditions "which one has the minimum value". In every iteration when the answer is no, all the start points will be updated by generate a new start

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point based on deceasing the iterations number "K-1"for the runningof the overall system and then run the local solver again to get the best start point as compared with previous local solution. Finally, the optimal solutions of K_p, K_i, and K_d are found and the objective function (ISE) of the MLSL optimization workflowis computed as well.

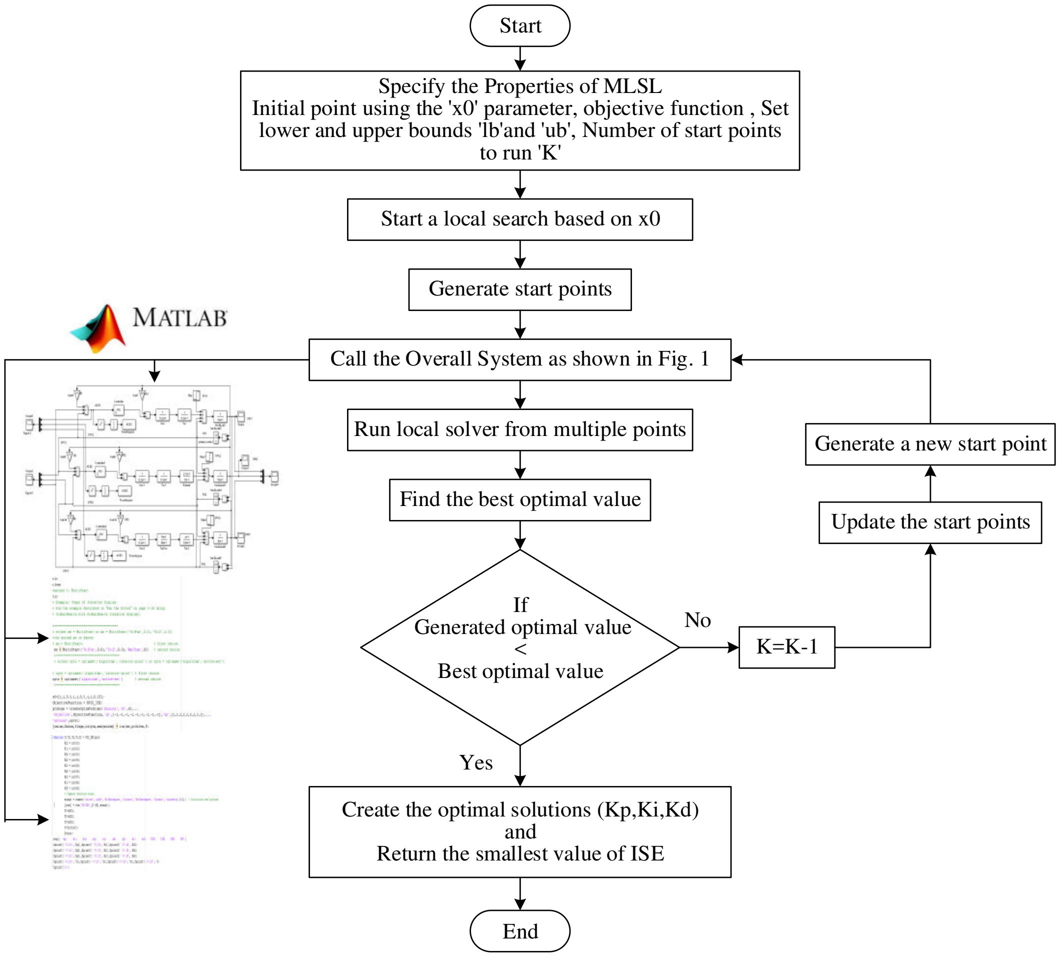

Figure-3. MLSL optimization workflow.

5. RESULTS AND DISCUSSIONS

Three parallel-interconnected power systems including the combination of MLSL_PID and GA_PID optimization algorithms with AGC system are implemented using Simulink/Code MATLAB program as shown in Figure-1. For the MLSL algorithm, the step size is chosen as 0.01 and the optimization process is repeated around 30 iteration. The lower and upper boundaries values for PID parameters are -1 to 2 respectively. The simulation of the step load disturbance (DPL_1, DPL_2) at t=1 sec in area1and area2 which are 0.1 pu and 0.2 pu respectively is realized to check the effectiveness of the proposed MLSL_PID controller and compared with the GA_ PID controller. Table-1 shows the optimal values (K_p , K_i , and K_d) of the optimization process obtained by both algorithms to minimize the ISE value, which is explained as the sum of square of cumulative errors in each area control error.

Table-1. Optimal values of tuning PID using MLSL and GA.

	PID Parameters	GA_ISE	MLSL_ISE
Area 1	Kp1	0.533	1.04
	Ki1	1.5	1.29
	Kd1	1.21	1.5
Area 2	Kp2	1.1	1.99
	Ki2	1.2	2.0
	Kd2	0.96	2.1
Area 3	Kp3	0.79	-0.12
	Ki3	-0.02	-0.02
	Kd3	0.814	1.18
	Min_ISE	**0.07**	**0.03**
	Elapsed Time(sec)	**30.0**	**21**

In term of dynamic performance; the transient response specifications of the settling time, maximum deviation and peak time for ACE, $\Delta\omega$, and ΔP_{ij} are given in Figure-4-6. It is observed that the MLSL_PID control strategy with the objective function produces good dynamic performances. Meanwhile, it extracts a better solution as compared to GA_PID strategy.

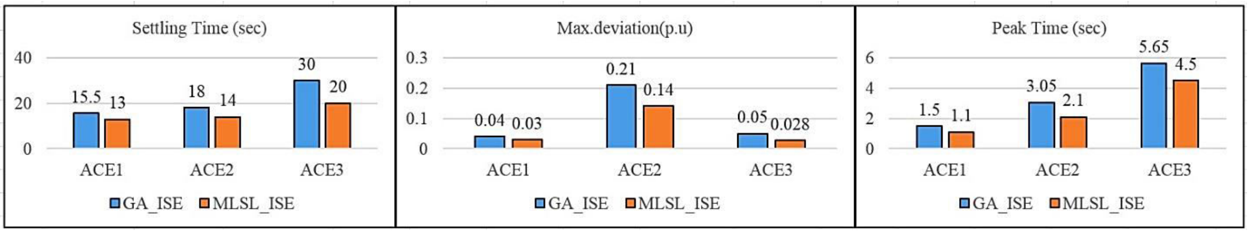

Figure-4. ACE parameters using MLSL and GA based on ISE.

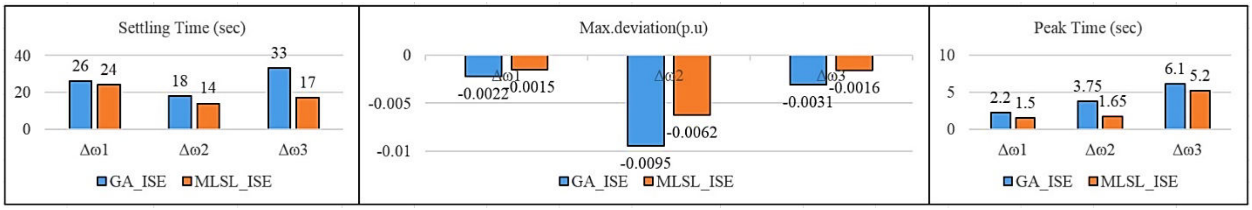

Figure-5. $\Delta\omega$ parameters using MLSL and GAbased on ISE.

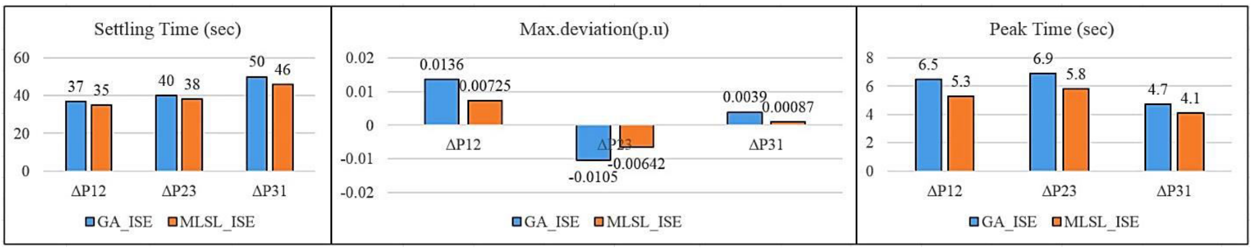

Figure-6. ΔP_{ij} Parameters using MLSL and GAbased on ISE.

Figures 7-9 illustrates the simulation comparisons of the MLSL algorithm and GA algorithm based on PID controller to show the responses of ACE obtained by GA and MLSL algorithms. It is noted that, the transient response of the red line graph of the proposed algorithm characteristics is able to make the steady stateerror zero faster than the blue oneand also the maximum overshoot and the settling time is minimized as well.

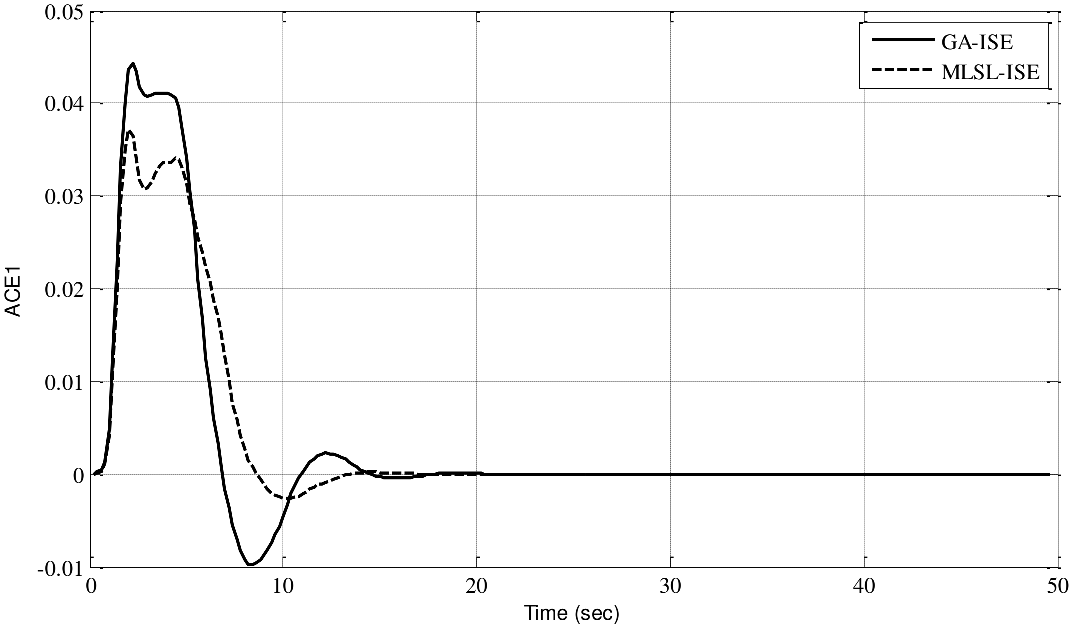

Figure-7. ACE1 with PID tuning by MLSL and GA.

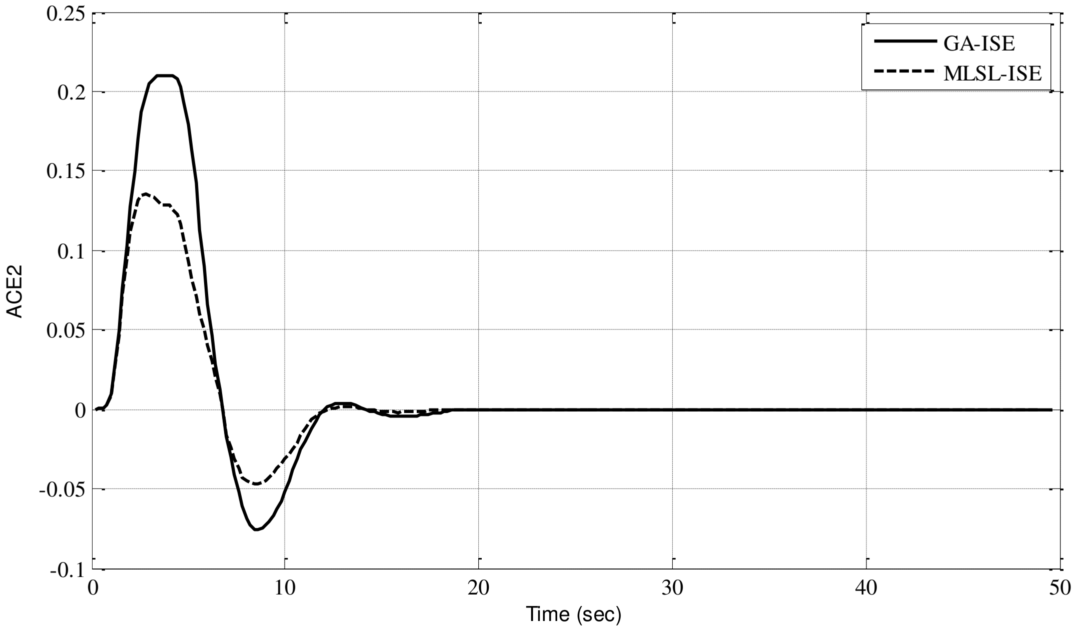

Figure-8. ACE2 with PID tuning by MLSL and GA.

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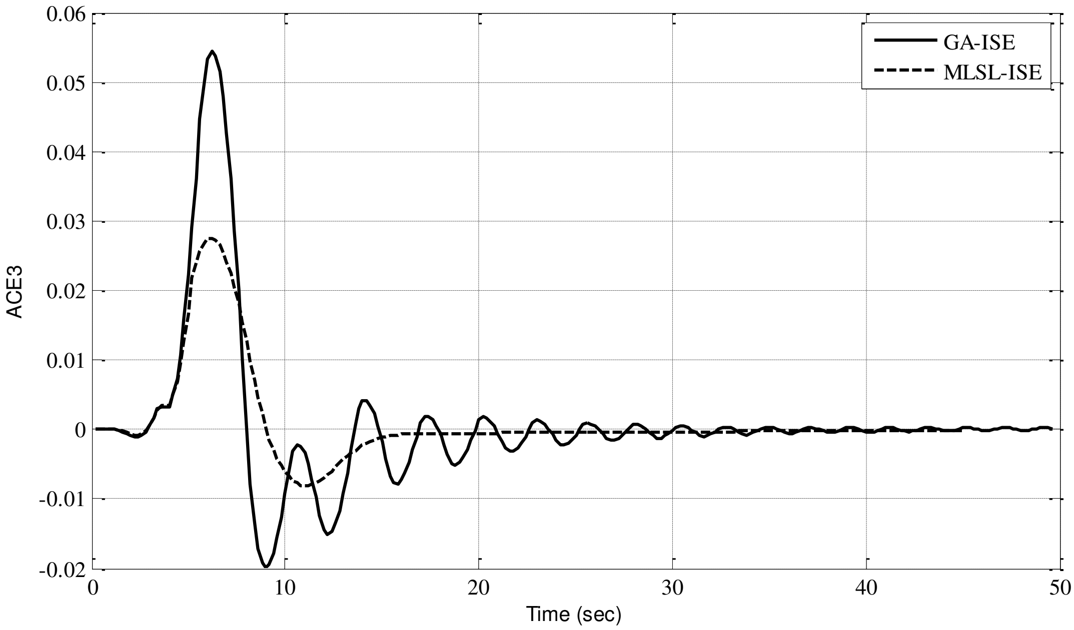

Figure-9. ACE3 with PID tuning by MLSL and GA.

Figures 10 to 12 give the response of $\Delta\omega$ obtained by MLSL algorithm and GA. It is observed from Figures 10 and 11 that the objective function produces good result as shown in $\Delta\omega1$and $\Delta\omega2$. In addition, the maximum overshoot and settling time becomes low and also reduced. Based on Figure-9, it is also cleared that the number of oscillation is more as in case of $\Delta\omega3$ for the GA_PID algorithm as compared with the MLSL_PID algorithm which make the system relatively unstable. This is to say that the ISE gives a better control performance by minimizing the system frequency.

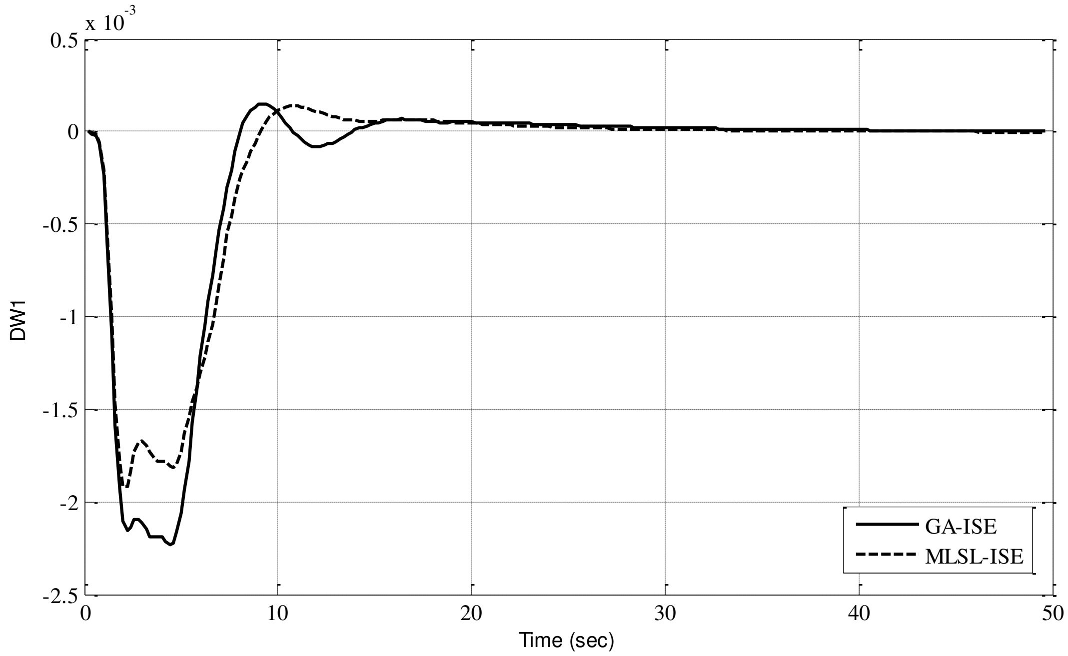

Figure-10. $\Delta\omega1$ with PID tuning by MLSL and GA.

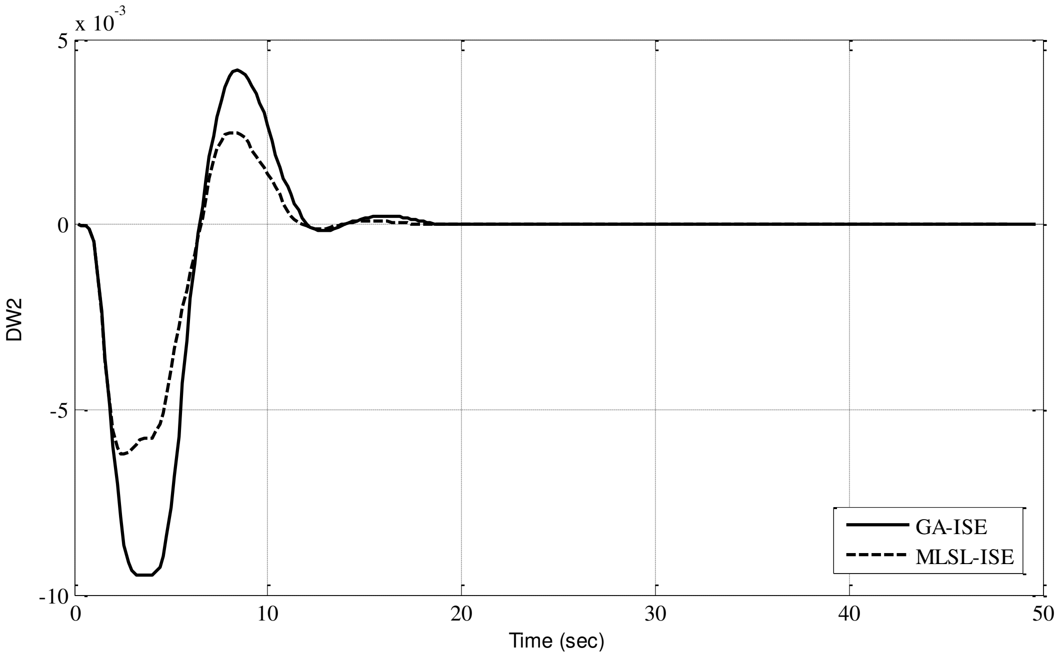

Figure-11. $\Delta\omega 2$ with PID tuning by MLSL and GA.

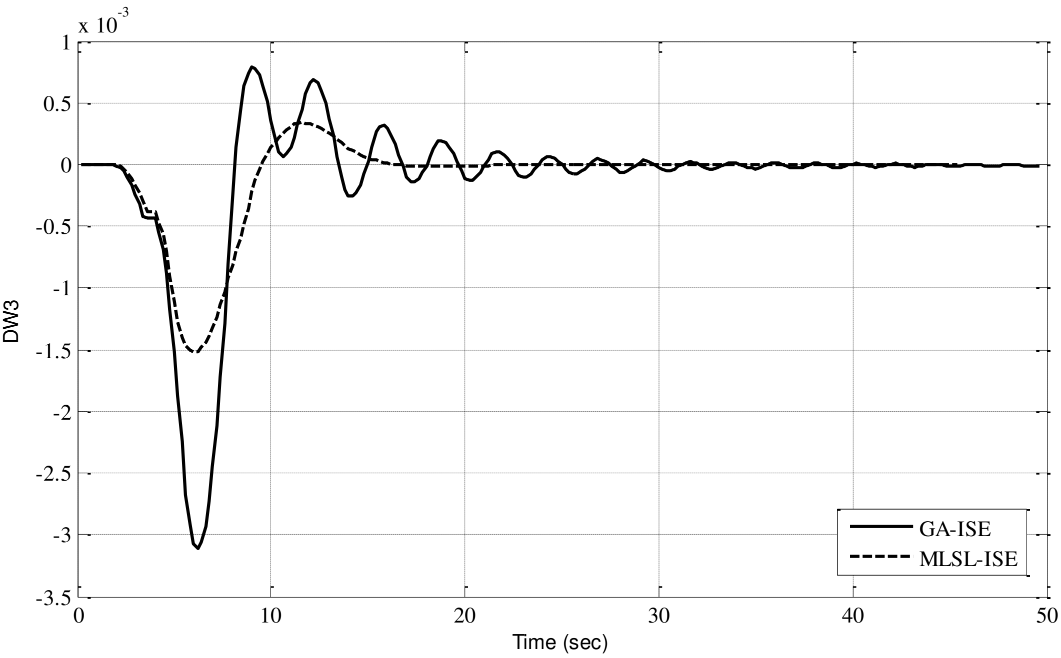

Figure-12. $\Delta\omega 3$ with PID tuning by MLSL and GA.

Figures 13-15 give the responses of ΔP_{ij} obtained by GA and MLSL algorithms. Based on ΔP_{12} and ΔP_{23}; the settling time, maximum deviation and peak time which are reduced by MLSL for tuning of PID parameters are more effectively. Also, the stability and the damping characteristics of the power system are improved as compared to that's one obtained by GA algorithm. It is clearly seen that the MLSL based PID controller with the derived function gives a better control performance by minimizing the tie line power deviation to be zero. There is no oscillation in the transient part especially as in ΔP_{31} which make the system relatively more stable.

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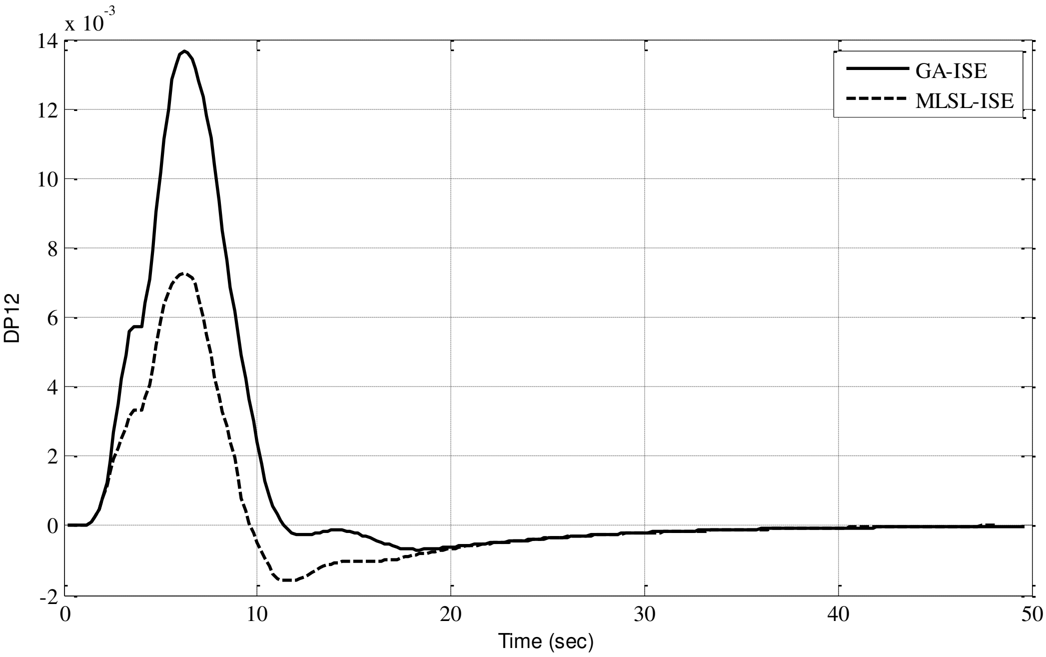

Figure-13. ΔP_{12} with PID tuning by MLSL and GA.

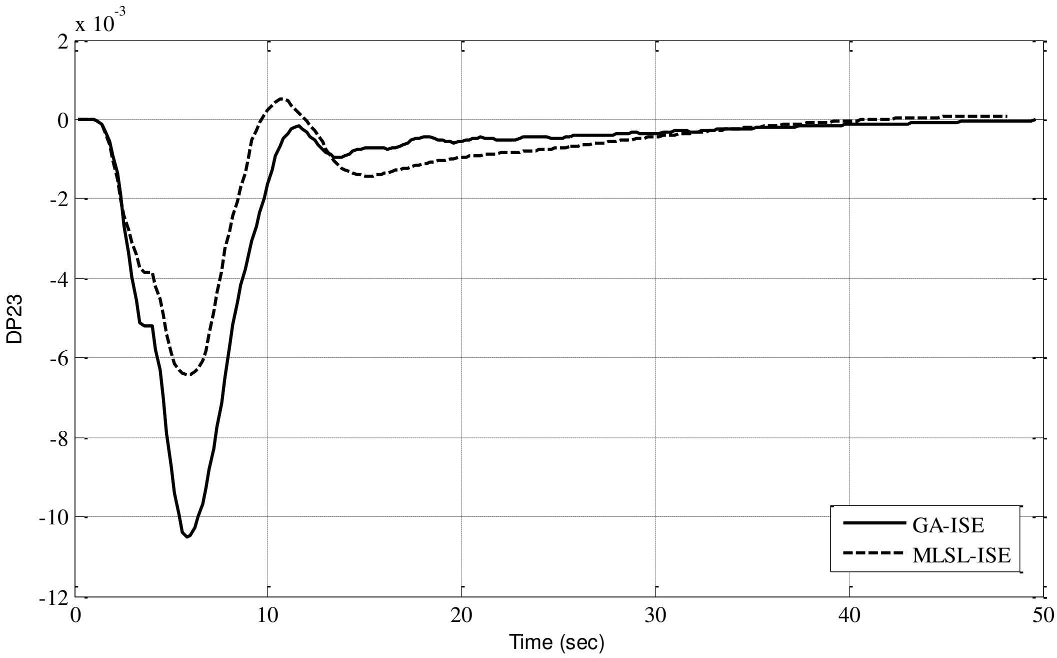

Figure-14. ΔP_{23} with PID tuning by MLSL and GA.

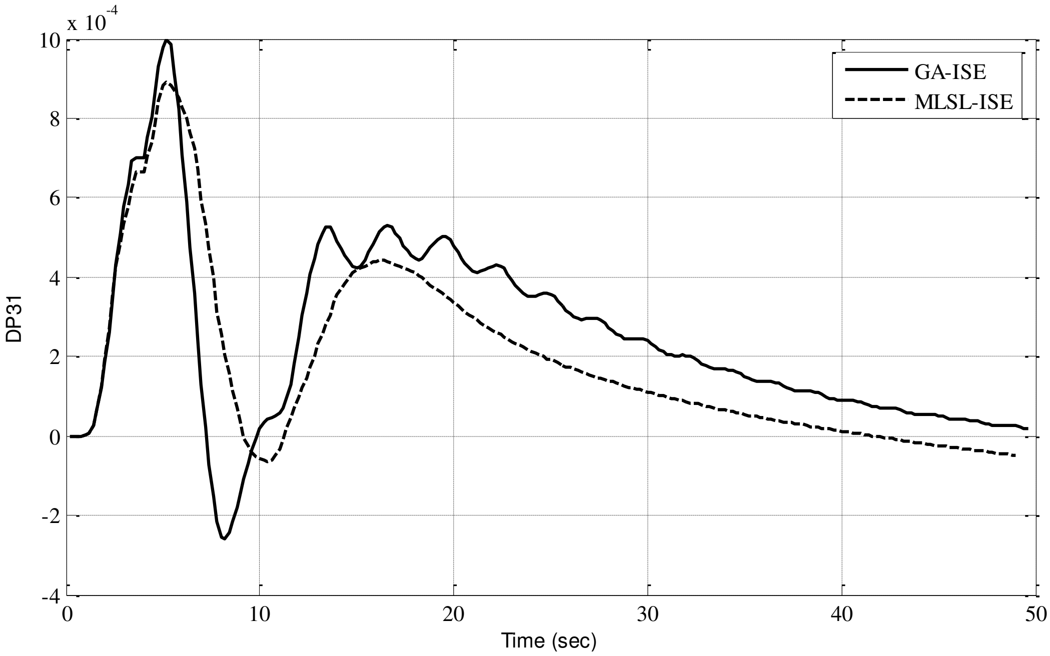

Figure-15. ΔP_{31} with PID tuning by MS and GA.

Eventually, TIC and TOC functions are used to determine the CPU elapsed time which is needed to calculate the optimum values of the proposed MLSL_PID_ISE algorithm and the GA_PID_ISE algorithm. The TIC is called at the program beginning and the TOC is afterwards. As a result, the execution time of the MLSL_PID_ISE algorithm is 21second as compared to using the GA_PID_ISE algorithm which is 30 second. This is to say that the MLSL_PID_ISE algorithm for improving PID parameters is faster than GA_PID_ISE algorithm.

6. CONCLUSIONS

The load frequency control of three interconnected power systems by the application MLSL optimization algorithm based PID controller has been proposed in this research to demonstrate the control methodology. With a load variation in ΔP_{L1} and ΔP_{L2},it is formulated to optimize the optimal parameters of the PID controller with inclusion of the objective function (ISE) in order to improve the dynamic performance. By the compression of the proposed MLSL algorithm based PID controller with the GA algorithm; it has clearly provided a very good transient specifications in view of reducing the oscillation deviation in both system frequency and power flow. Moreover, the execution time of the overall system running is fasteras well.

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