Original Research Paper

Volume-8 | Issue-1 | January-2018 | PRINT ISSN - 2249-555X

Engineering

PID CONTROLLER TUNING METHODS FOR LOAD FREQUENCY CONTROL (LFC)

Prof. Webby Mwaku Department of Electrical Engineering, School of Engineering, Copperbelt University, Zambia

Mr. George Mugala Department of Electrical Engineering, School of Engineering, Copperbelt University, Zambia

Gabriel Musonda Department of Electrical Engineering, School of Engineering, Copperbelt University, Zambia

ABSTRACT The power system in Zambia relies on the southern Africa regional power system control center based in South Africa for load frequency control (LFC) [1]. If the tie-line connection or communication to the control center fails, cascading failure occurs because the power system cannot compensate frequency deviation by its self [2]. This paper presents brief study of automatic PID controller tuning methods that can be utilized to implement Load Frequency Control for the power system in Zambia. LFC in the power system minimizes Area Control Error (ACE) to zero. ACE is the integral sum of power system frequency deviation and tie-line power flow error. ACE minimization using a PID controller can utilize any of the following algorithms or search criteria; Absolute Magnitude of the Error (IAE), Integral of Time multiplied by Absolute Error (ITAE), Integral of the Square of the Error (ISE), and Mean of the Square of the Error (MSE). However, the Integral Square Error (ISE) algorithm is re-Known for producing excellent results in various experimental works. Therefore, ISE and Particle Swarm Optimization (PSO) are investigated to determine suitable load frequency control for the power system in Zambia.

KEYWORDS : Load Frequency Control (LFC), Rules of tie-line control, Area Control Error (ACE), Integral Square Error (ISE), Particle Swarm Optimization (PSO).

I. INTRODUCTION

Security and reliability are a primary requirement in a power system in ensuring continuous power supply to the customer. Power system reliability is achieved through load frequency control (LFC). Technically, LFC divides the load between generators and controls the tie-line power to pre-determined values to maintain sensibly uniform frequency. This is achieved using a power system control scheme called the rules of tie-line control. Rules of tie-line control attempts to ensure that power generation follows changes in load, but fails short of restoring system frequency to nominal value. Constant frequency is identified as the mark of a normally operating system and this is realized through load frequency control (LFC).

A. Literature Review

LFC is an essential process on the power system for reliability and stability to be guaranteed. Ensuring that Area Control Error (ACE) is zero in a power system is called Load Frequency Control (LFC) or Automatic Generation Control (AGC). Zero ACE is realized by ramping generators in the power system up and down as the load fluctuates. Control of generators depends on controllers installed in the power system to ensure that power generation follows the load. Controllers used in power systems are usually the Proportional Integral Derivative (PID) type. Tuning methods of PID controller determines how effective Area Control Error (ACE) in a power system is maintained at zero.

Fluctuation in real power demand on the power system is determined by frequency monitoring in at the power generation control center. Below nominal value frequency is an indication that the load real power demand is higher than real power generation. Above nominal value indicates low real power demand.

Therefore, frequency deviation on the power system is indication load-generation imbalance. The process of ramping generation up and down in response to load changes is called load frequency control (LFC) or automatic generation control (AGC).

Without LFC the power would transcend into cascading failure of generators and power system blackouts. Technically, therefore LFC ensures that the power system operates in normal state. In summary, LFC in a multi-area interconnected power system has four principle objectives when operating in either the normal or preventive states:

i. Ensuring that the power system operates in the normal state;
ii. Matching total system generation to total system load;
iii. Regulating system electrical frequency error to zero and;
iv. Distributing system generation amongst control areas so that net area tie flows match net area ties flow schedules [3]

Therefore, a robust tuning method ensures all the principle objectives required for a power system to remain in normal and preventive states are maintained.

Load-generation error in a sub-system does not only result Frequency error, but also results in tie-line power flow errors. Tie-line power flow error is an integral of the frequency change between adjacent areas. Therefore, it is a requirement to consider the information of the tie-line power flow in control input to the PID controller.

The objective of LFC to minimize the error in frequency of each area as well as to keep the tie-line power flow error to zero is quite difficult in presence of fluctuating load. The high-order interconnected power system could also increase the complexity of the controller design for LFC [4]. Therefore, a linear combination of tie-line power flows and frequency deviation called Area Control Error (ACE) of each sub-system is used to determine effective balance between sub-system load and generation in a power system [5].

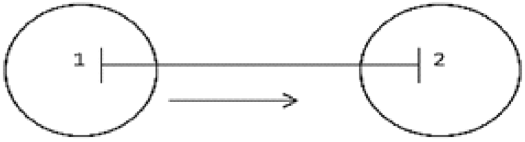
B. Rules of Tie-Line Control

It is a requirement that all areas in the maintain relative load-generation balance to maintain tie-line power flow schedule and zero frequency error. Therefore, LFC objective is realized based on an algorithm called rules of tie-line power control. Rules of tie-line control for a two-area interconnected power system are explained in the table 1.1 [6]. In the system below, of load-generation mismatch in area-1 will translate in frequency deviation across the entire system. Tie-line power flow from area-1 to area-2 will be negative and ACE value will not be zero. Ramping generation in Area-1 corrects load generation balance, but will not correct the power system frequency. Similar phenomenon occurs when load change occurs in Area-2. Therefore, additional control mechanism is required to ensure ACE becomes zero.

Table 1.1 Rules of Tie-line control

$\Delta\omega$	ΔP_{net}	ΔP_L	Control Action
-	-	ΔP_{L1} + ΔP_{L2} 0	Increase P_G is system 1
+	+	ΔP_{L1} - ΔP_{L2} 0	Decrease P_G is system 1

-	+	ΔP_{L1} 0 ΔP_{L2} +	Increase P_G is system 2
+	-	ΔP_{L1} 0 ΔP_{L2} -	Decrease P_G is system 2



ΔP_{L1} = Load change in Area-1

ΔP_{L2} = Load change in Area-2

C. Controller

The most important objective of power system controller is to maintain uninterrupted balance between electrical generation and varying load demand and related system losses while system frequency and voltage level are maintained constant. The load variation in the power system influences the quality of power. Thus a control system is essential to cancel the effects of arbitrary load changes and to keep the frequency and voltage at the stable level.

There are various methods available for realizing LFC in an interconnected power system. The first is Area Control Error (ACE) minimization using integral control action strategy. However, the main drawback of this control algorithm is that the dynamic performance of the system is limited by its integral gain. Despite the potential of modern control techniques with different structure, PID type controller is widely used for solution of LFC problem. PID type controller is not only used for their simplicities, but also due to its success in a large number of industrial applications and availability.

In fact, more than 95% of the industrial controllers are of PID type.

D. Tuning Methods

A suitable tuning method is required for PID controllers in an interconnected power system for ACE minimization.

There several tuning methods that can be applied to a PID controller, based their success in optimization solutions in Electrical and Electronics engineering, for ACE minimization in an interconnected power system. They include the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO).

ACE minimization in an interconnected power system using optimization algorithm requires determination of PID parameters lower and upper limits initial values through laboratory experiments.

II. CASE STUDY OF PID CONTROLLER TUNING METHODS FOR LFC

A typical large – scale power system is composed of several areas of generating units interconnected together and power is exchanged between the utilities. The problem of an interconnected power system is the control of electric energy at pre-determined system frequency, voltage profile and tie-line power interchanges within their approved limits.

Automatic tuning of PID controller for Area Control Error (ACE) minimization depends on the different dynamics of energy sources in the power system. In practice, a power system may comprise in each control area different sources of energy such as hydro, thermal, solar, gas etc. The various generations are connected by a rigid network and that is why the frequency deviations are assumed to be equal in an area [7].

Trial and Error, and Particle Swarm Optimization (PSO) algorithms are used for ACE minimization using PID controllers.

A. Trial and Error method

Trial and error method is used for manual tuning of PID controller gains for ACE minimization in interconnected power systems. This method is based on simulations in MATLAB/SIMULINK configuration of power system.

The values obtained after simulation run are critical for determining initial range of values for PID controller gains. The method can be used to determine initial PID controller gains and for comparison with optimization algorithms such as PSO and Genetic Algorithm (GA).

Application of step load change of between 1% to 2% produceThis approach is able to linearize systems

B. Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is an evolutionary computational method developed by Kennedy and Eberhart in 1995. It is developed from swarm intelligence and is based on the study of bird and fish flock group performance. The Particle swarm optimization algorithm is a multi-agent similar search method which maintains a group of particles and each particle represents a possible solution in the swarm. All particles fly throughout a multidimensional search space where each particle adjusts its position according to its personal knowledge and neighbour's experience [8] [9].

Each particle keeps pathway of its coordinate in the solution space which are coupled with the best solution (fitness) that have achieved so far by that particle. This value is called personal best, *bestp*. Another best value that is tracked by the PSO is the best value obtained so far by any particle in the neighbourhood of that particle. This value is called g_{best}[7].

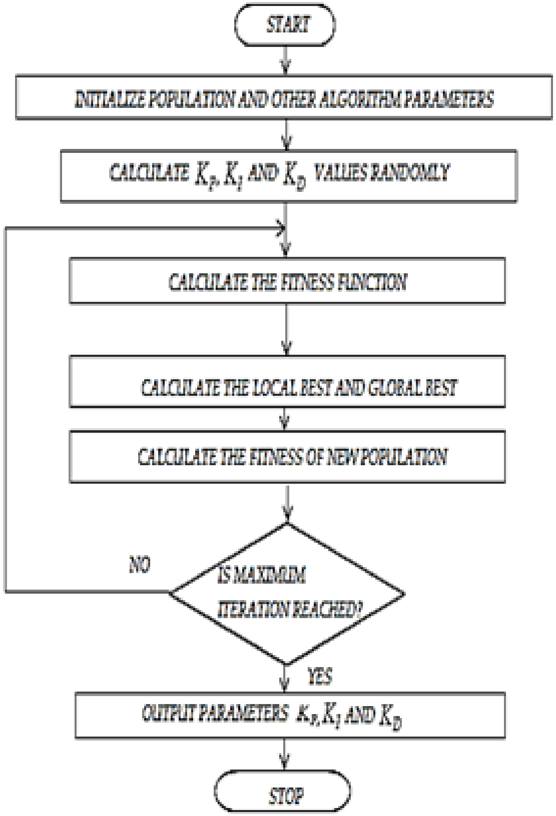


Fig. 2.3 Flowchart of typical PSO

Flow chart of the PSO algorithm in fig 2.3 shows that the algorithm is a multi-purpose optimization method that requires only a few changes to apply to the LFC problem. Therefore, PSO has been used for optimization problems in electronics and electrical, automatic control systems, communications theory, operations research, mechanical engineering, medical engineering etc. [10]

In the system presented by Gummadi, Obulesh and Kavya [7] a four (4) area interconnected power system comprising hydro, thermal, thermal with reheat and gas turbines was investigated for transient and steady state response step load change. Integral Square Error (ISE) algorithm and Particle Swarm Optimization (PSO) were used for tuning PID controllers to solve the LFC problem.

Simulation of the power system was done in MATLAB – SIMULINK and the PSO code was run in MATLAB for tuning of PID controllers. PSO parameters taken for optimizations were:

- Population size = 80,
- Maximum number of iterations = 50,
- c1 = 1.8;
- c2 = 1.7 and
- simulation time = 50s.

It is assumed that the power system load and generation were balanced before application of step load change. The transient and steady state frequency responses to a step load change of 0.01pu, applied to area-1, of individual areas as well as tie-line power flows were graphically observed and analyzed. Later, 0.01pu step load perturbation was applied to Area-2 and dynamic responses observed in Areas-1, 3 and 4 and respective tie-line power flows.

Simulation results proved that the tuning of PID controller using PSO optimization technique gave tremendous transient and steady state performance for frequency and tie line power deviation compared to conventional controllers [7].

- Frequency deviations settled quickly and the dynamic responses are less oscillatory with low amplitude of peak over shoots using Particle swarm optimization method (PSO).
- The tie line power deviation settles with zero steady state errors.

Similar experiments were performed in MATLAB-SIMULINK by Deepa Sharma and Bipul Kumar on a two-area interconnected power system comprising hydro turbines. Integral Square Error (ISE) algorithm and Particle Swarm Optimization (PSO) were used for tuning PID controllers [11].

The assumption is that the system is balanced before application of step load change of 0.01pu and 0.02pu respectively.

After application of step load change of 0.01pu to area-1, the system is unbalanced and goes in alert operating state. Frequency in both areas changed from nominal value and deviation was observed tie-line power.

For the two-area LFC system, the PSO parameters used were as follows;

- Population size = 40,
- Maximum number of iterations = 40,
- c1 = 1.5;
- c2 = 1.5 and
- simulation time = 50s.

Simulation results proved that the tuning of PID controller using PSO optimization technique gave tremendous transient and steady state performance for frequency and tie line power deviation compared to conventional controllers.

- Frequency deviations settled quickly and the dynamic responses are less oscillatory with low amplitude of peak over shoots using Particle swarm optimization method (PSO).
- The tie line power deviation settles with zero steady state errors.

III. POWER SYSTEM CASE STUDY

The power system in Zambia comprises hydro power plants at Zambian power system at Kariba north bank, Kafue gorge, Lusemfwa hydro company and thermal at Maamba. Power producers injecting less than 50MW of power into the national grid have less effective on LFC. Therefore, for the purpose of study, LFC contribution of small power producers (SPP) is neglected. It is assumed that the national grid would remain stable if the large power producers all, but participate in ensuring the LFC objective. LFC is realized through effective ACE minimization for the interconnected power system.

Determine appropriate means of ACE minimization trial and error tuning of PID controller k_P,k_I and k_D parameter's lower and upper limits is used to solve the LFC problem. The data in table 2.4 are used in simulation studies of the power system in MATLAB/SIMULINK.

Step load of 0.01pu and 0.02pu at time t=0*s* is applied to area-1 to determine the system response. The assumption is that the load change affects tie-line power flows and system frequency. Simulations confirm the assumption.

Lower and upper limits of PID controller gain values fork_P,k_I and k_D parameters obtained in the individual areas are noted.

The dynamics of non-reheat thermal, hydro and gas based units are taken from the literature [12-15] which are referred by most of the researchers for LFC study. The system data of a four area power system with multi-sources is represented in Table 2.4.

Table 2.4 Power system data

Parameters		values
Hydro Turbine		
Speed governor time constant	(T_{RS})	4.9s
Transient droop time constant	(T_{RH})	28.749s
Main servo time constant	(T_{GH})	0.2s
Water time constant	(T_W)	1.1s
Speed governor regulation	(R_{HY})	24Hz/pu MW
Steam Turbine without reheat		
Speed governor time constant	(T_G)	0.08s
Turbine time constant	(T_T)	0.3s
Speed governor regulation	(R_H)	24Hz/pu MW
Power system		
Frequency bias constants	(B١ ،B٢ ،B٣)	0.425puMW/Hz
	a = ٢ * pi * T١٢ = ٢ * pi * T٢٣ = ٢ * pi *٣٤	-1
Load model gain	(K_{PS})	68.96554 Hz/pu MW
Load time constant	(T_{PS})	11.49 s
Frequency		50 Hz

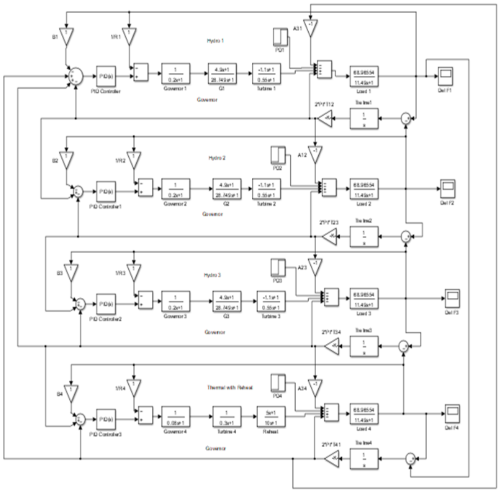


Fig. 2.5 Power system configuration

IV. SIMULATION RESULTS

Simulation is carried out with 1% step load perturbation in area-1. The PID controller was tuned using trial and error method. The values obtained after simulation run are critical for determining initial range of values for PID controller gains.

Simulation results from manual tuning of PID Controllers provide a range of values for k_P,k_I and $k_D$that could be used for ACE minimization using optimization algorithm called particle swarm optimization (PSO).

The optimized controller gains obtained when 1% step load perturbation in area-1 is shown in Table 4.1

Method	Area	k_P	k_I	k_D
Trial and Error method	1	0.02325	2.4321e-08	4.579
	2	0.01934	2.7871e-08	3.798
	3	0.02388	2.6381e-08	4.722
	4	0.35131	1.9582e-08	5.345

The dynamic responses of a four area interconnected power system with 1% step load perturbation in area-1 are shown in the figures 16-23.

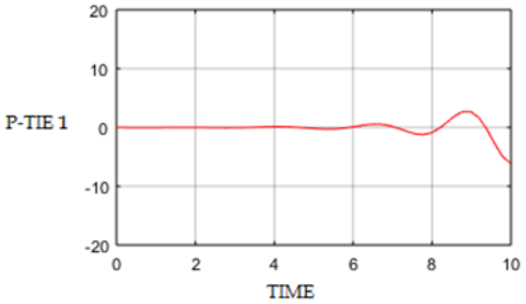


Fig. Tie-line 12 power deviation due to step change in area-1

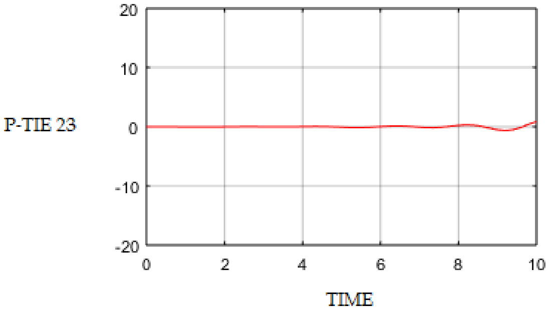


Fig. Tie-line 23 power deviation due to step change in area-1

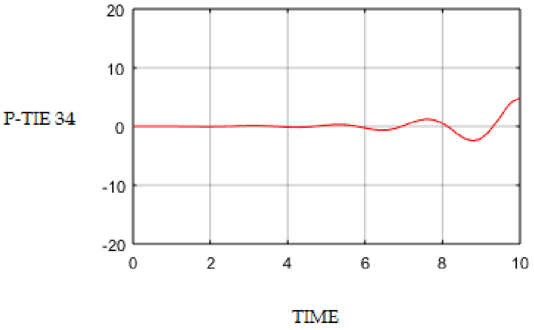


Fig. Tie-line 34 power deviation due to step change in area-1

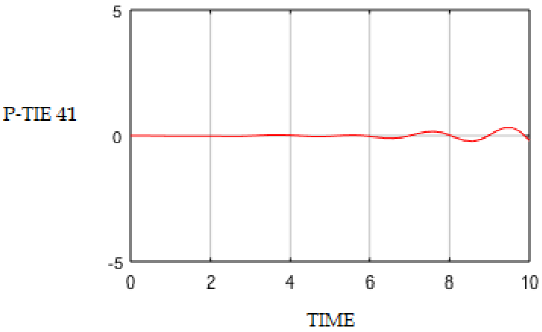


Fig. Tie-line 41 power deviation due to step change in area-1

V. CONCLUSION

In this work, four area load frequency control is established by using trial and error method to tune PID controller. Interconnection of the four area is very important issue in the power system because of the frequency deviation and tie line power deviation. Dynamic response of the power system tie-line power flow demonstrate that load frequency control can be realized for the grid in Zambia. However, for best results optimization algorithm such as PSO can produce better results.

The MATLAB/SIMULINK experiment demonstrates that PID controller can used for ACE minimization of the power system and bring system dynamics to comfortable limits.

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