Journal of Advanced Engineering Trends
ISSN : 2682 - 2091

Vol.42, No.1. January2023

http://jaet.journals.ekb.eg

Optimized Load Frequency Control for Single Area Power System Using Linear Quadratic Gaussian Technique and Coefficient Diagram Method

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Abstract

The aim of load frequency control (LFC) is to save the frequency at the allowable limits in different zones of power system operation. This advanced control system has a lot of advantages over conventional integral controllers in practical applications. In this paper, LFC for a single area power system using a Linear Quadratic Gaussian Method (LQG) and a coefficient diagram method (CDM) has been developed. Furthermore, an improved technique based on Multi-Verse Optimizer (MVO) is applied for optimal adjustment for the LQG controller. In order to control the turbine load output, the governors' parameters must be adjusted to reduce the error rate and increase confidence in the proposed system. The CDM system has been studied in theory for its own transactions and data, in order to take advantage of the governor and turbine model for its response and high efficiency. The division of the frequency value and all system transactions are identified using the Kalman filter where they are controllers in the LQG module, this provides an ideal income signal for the system. The strength and effectiveness of the model give an initial impression of the extent of taking advantage of a practical system, so digital simulation must be used for access to the target. The behavior of non-confidence in the performance of the system has been addressed, and this has enhanced the results of simulation for a comprehensive and integrated performance with (CDM + LQG). The control process was evaluated by a comparison between the proposed scheme and only CDM. The comparison showed that the process outstanding the proposed scheme in the appropriate control process during the processing process. In this work, the two control systems (CDM & LQG), are effective with high performance, and stability in the face of LFC problems with the superiority of (CDM + LQG).

Key words: *load frequency control LFC; linear quadratic Gaussian (LQG); coefficient diagram method (CDM)*

1. Introduction

To solve load frequency problems, many methods and techniques have been applied. A lot of these control methods have been used to obtain the best results [1-4].

Received: 24 July, 2021, Accepted:1 October , 2021

According to various operating conditions,

the developed controllers with fixed parameters will be not applicable. Synthesis of LFC has been used adaptive gain scheduling. The lack of stability of the system because of sudden changes causes great disadvantage, this leads to its failure and lack of reliability [5-23]. In Proportional Integratal Control (PID) systems, a problem is not accessible after a period of time, as a result of overshoot and this is a problem with the system and has no access to the Steady State stage. Moreover, optimal design of PID controllers has been reported to improve the system response [20-23]. To solve PID problems and to ensure the system response speed The Fuzzy Logic Controllers has been used, and it is characterized by control of two regions of electrical strong systems without increasing the error proportion compared to each region [6,7]. Due to the importance of LFC has been working, many researchers have taken control of artificial intelligence, specifically neurons because they have a simulation of human brain work [8,9]. In [19], adaptive load frequency control based on different optimization algorithms have been presented. The authors apply the genetic algorithm (GA), Grey Wolf Optimizer (GWO) and Particle swarm optimization (PSO) to tune the PI controller. The reported results show the superiority of the GWO algorithm. As application of intelligent controllers, Fuzzy controller have been applied for damping the frequency oscillations of interconnected two-area power systems [20]. In [21], PID based GA has been applied for controlling the load frequency division with presenting of the renewable energy sources. Fraction-Order PID controller has been applied to solve the problem of load frequency control with running the parameters of the controller using Harris hawk optimizer [22]. For optimizing the control systems without using the artificial techniques and to reduce the time implementation, linear quadratic regulator (LQR) has been reported in [23]. This reported design for LQR entails all the state of the system which led the complexity of the control system.

To treat LFC problems, Model Predictive Control (MPC), this module features its ability to be employed in multiple areas and overlapping interference between these areas. The algorithm control system is quickly distinguished to respond to mistakes but discretion of complexity [10]. MPC was used in renewable energy systems, especially in generating electricity using wind turbines, in various and multiple areas, these models are characterized by frequency control and determining the ideal value of the network [11]. Using MPC as a control system has been obtained high response, reliability during frequency change processes resulting from the system load change, but the difficulty and complexity of its calculations [10,11].

The development of LFC control systems has been held in three main stages. The initial stage was using dynamic control models, developing it to avoid slow dynamic response to replace analog control systems, but its low sensitivity is somewhat and slowly responded to reach stability. One of the former type problems The Multi-Verse Optimization (MVO) systems is simply characterized by a highly manufacturing structure, high response speed and highly valid results for high energy and sensitivity flow processes in dealing with frequency control tools such as boilers and governors [12-17].

Diagrams such as Bode and Nyquist provide evidence on stability and time response of the control systems, CDM is a powerful diagram which is used to examine the stability, time response and robustness characteristics of systems. CDM can be considered essential single diagram to study the system of large characteristic polynomial degree. CDM has been shown to be more accurate and easier for the plication in real industrial plants and their control design [12, 15]. For tuning an appropriate characteristic polynomial for the controlled system, Lipatov Stability studies may be applied [12].

In this paper, the development process has been developed for the CDM model using LQG. This method is characterized by linear systems by reducing noise so as to get ideal in the output. Through assumptions, a perfect controller can be derived. This is known as the control law and is unique, with Kalman filter. The expected value of the cost can be calculated in order to obtain ideal gains for the system. It can also be used in non-linear systems and gives high response speed.

2. Coefficient Diagram Method

The process of designing control models is divided into three types of classical, modern and algorithms control. The method of designing the forced schema for the CDM model does not fully perform BODE schemes but benefit from Lipatov so as to get enough stability of the system to be found in theory [15]. The CDM model is a technique aimed at getting a quick response to reduce the time required for the system stability. To provide all data on low stability and obstructive stability, many differential equations must be used to provide the necessary account processes [12].

In CDM chart, the horizontal axis corresponds to each coefficient while the vertical axis shows through which the laboratory scheme is as follows: -

- Coefficients polynomial characteristics (ai).
- Stability indicators characteristics (γ_i).
- Equivalent time constant characteristics (τ).
- The variant of the shape of the ai curve as a result of plant parameter variation has been used for measuring the robustness.

Through the general tilt of curved can be obtained measurement of the time response system. Multiple transactions can also be determined for the calculation, the degree of transactions is mainly considered. The durability indicators of the system appear in ai curved where design differences appear in Figure 1. The system stability can be obtained through the fixed time by Single Input Single Output (SISO for the CDM model [12-17].

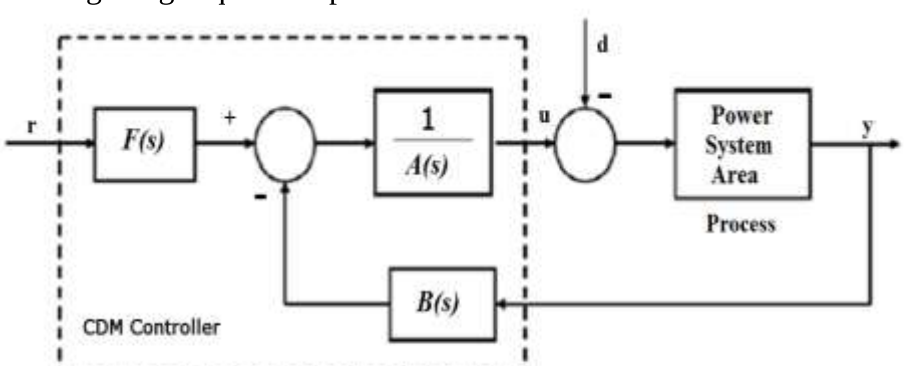


Fig. 1: A Block Planning for CDM Control System

where; F(s), B(s): Rugs reference and multiplayer reactions.

(A(s)): polynomial forward denominator.

(N(s)): polynomial numerator.

(D(s)): plant transfer function denominator polynomial.

By referring to the previous terms mentioned, each job has been made of freedom in statistical accounts in accordance with the system structure (2DOF).

Steps to work accounts:

- (r) : Input signal to the system.
- (u) : Control signal.
- (d) : External disorder signal.
- (Y) : Control system output.
- *(P*(s)): closed-loop system polynomial characteristic.

$$y = \frac{N(s)F(s)}{P(s)} r + \frac{A(s)N(s)}{P(s)} d \qquad (1)$$

$$P(s) = A(s)D(s) + B(s)N(s) \qquad (2)$$

A (s) and (b) (s) as multi-boundary control and knows it.

$$A(s) = \sum_{i=0}^{P} l_i s^i \ and\ B(s) = \sum_{i=0}^{q} k_i s^i \qquad (3)$$

To achieve practical, the requirement must be satisfied p ≥ q. For a distinctive multimeter P (s), multiple control is replaced from (3) in (2) and given as

$$P(s) = \sum_{i=0}^{P} l_i s^i \, D(s) + \sum_{i=0}^{q} k_i s^i \, N(s)$$

$$P(s) = \sum_{i=0}^{n} a_i s^i \ , a_i > 0 \qquad (4)$$

Model CDM need a lot of transactions borders according to the following: -

- Equivalent time constant (τ) (which gives the closed loop response).
- (γi) is a stability index that gives the form of response and its speed
- It gives an inverted stability index and known as (γi *).

Multiple transactions (ai) can be classified as possible to write their equations and ease of formulation:

$$\gamma_i = \frac{a_i^2}{a_{i+i} a_{i-1}} \ , i \in [1, n-1] \quad , \gamma_0 = \gamma_n = \infty \quad (5)$$

$$\tau = \frac{a_1}{a_0} \qquad (6)$$

$$\gamma_i^* = \frac{1}{\gamma_{i-1}} + \frac{1}{\gamma_{i+1}} \qquad , i \in [1, n-1] \qquad (7)$$

The γi model May be specify values according to the sequence follows [2.5, 2, 2 ... 2]. Through the model can get values to train order. Transactions (τ and γi), can be used to test the system after trained on values not recognized before, the purpose is to ensure its discovery of variables and to achieve many functions of functions that are formulated by the value$P_{target}(s)$.

$$P_{target} = a_\circ \left[\left\{ \sum_{i=2}^{n} \left(\prod_{j=1}^{i-1} \frac{1}{\gamma_{i-j}^{j}} \right) (\tau s)^i \right\} + \tau s + 1 \right] \qquad (8)$$

where $P(s) = P_{target}(s)$

Also, multi-boundaries spectacular F (s) can be calculated from:

$$F(s) = \frac{(P(s)|_{s=0})}{N(s)} \qquad (9)$$

3. Linear Quadratic Gaussian Technique

Through this paper, a frequency control model has been developed for a single electrical energy system, depending on the CDM and LQG models to control algorithm. And signals issued by fully deducted disorders, which led to increased gain form. [14-17].

To calculate gain in the ideal case, the control law and according to the following law (u = -kx) will increase the value of U performs the performance indicator of the system [17].

$$H = \int_0^{\infty} (X^T Q X + u^T R u) dt \qquad (15)$$

The variables (Q and R) can be expressed in a matrix or polarity as a value and angle, and also can be represented by composite numbers, representing a real and generous image. For the values of actual stability of the system, U value is for the previous law to clarify the value of stability [15-17].

In this paper, chosen conditions are to be:

- deviation of frequency Δf.
- change of mechanical power ΔP_{mi}.
- output governor change ΔP_g.

Signals are measured by the supplementary control action ΔP_c and deviation of frequency Δf , is used to be the only signals to fed Kalman, the real value of energy generation must be made by the state. Because they are calculating the overall cost of fuel, transportation, employment and unlike. Estimation of the state can be done by using The Kalman filter estimator.

$$\hat{x} \;\; = [\Delta \hat{f} \quad \Delta \hat{p}_m \quad \Delta \hat{p}_g \qquad]$$

Using U = -K X equation shows for systems for system, and the state can estimate the tariff through it.

$$(\hat{\dot{x}}) = (A - Bk - LC)\hat{x} + Ly \qquad (16)$$

Through Kalman filter, the L value is calculated on the basis of the actual noise values in accordance with QN and RN measured values. The accuracy of this filter depends primarily accurately the accuracy of the variables that nourishes the system. The A and B matrices are trained with expected values that do not work, but then the test is performed to make sure the form response. The Kalman filter works well with linear systems.

To calculate the actual gain of the Kalman filter, the form account must be out of expectations through the results provided by the calculations, which necessarily will depend on them. The resulting transactions may be calculated, so they are simplified by using differential equations or transfers of Laplace or Appendix. Thus, the proposed model design of the unit to be controlled is more easily and will decrease the value of the cost of devices.

4. Optimization Algorithm

A. Multi- Verse Optimizer

The purpose of using algorithms in this research in order to work in two stages, the identification of the problem and then work to solve it using the concepts available for scientific research, this is quite similar to the universe research where white drilling and black holes are studied. The MVO system applies as follows:

1. If inflation increases to give high probability This indicator is for the white hole.
2. If inflation increases but given the likelihood of being expressed by black hole.
3. The purpose of white holes is to send high-probisal signals.

4. The black holes are low-probable, and this is reflected on the nature of its low cost.
5. The indiscriminate experience must be made for access to natural probes.
6. This algorithm can be represented according to figure 2.

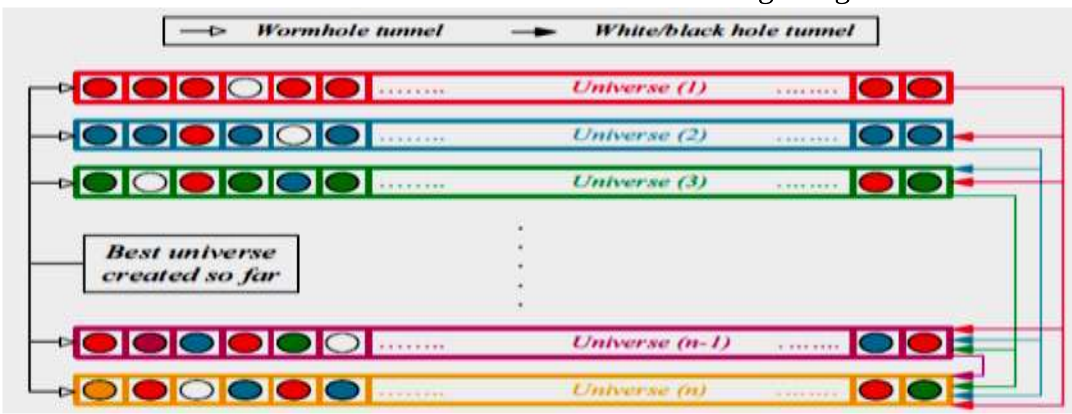


Fig. 2: The concept of MVO algorithm.

The MVO model can be described in accordance with the following mats and equations:

$$U = \begin{bmatrix} x_1^1 & x_1^2 & \cdots & x_1^d \\ \vdots & \vdots & \cdots & \vdots \\ \vdots & \vdots & \cdots & \vdots \\ x_n^1 & x_n^2 & \cdots & x_n^d \end{bmatrix} \quad (17)$$

The equations can be searched in accordance with the following style, the variable u is considered a set of solution and variable D is a representation of dimension variables, variable N is the number of buttons that the system contains and thus the proposed solutions can be described as follows.

$$x_i^j = \begin{cases} x_k^j & r1 < NI(U_i) \\ x_i^j & r1 < NI(U_i) \end{cases} \quad (18)$$

To calculate the rate of natural inflation, procedures according to composite numbers. The x_k^j value represents the parameter of the Creator, the value of inflation is in accordance with the expectancy of the X-value X, which is virtual value. This test was carried out using a mechanical-designed roulette wheel to calculate equations, so inflation can be found between 0 & 1.

If the regime contains a large number of butts, a balance of each system must be bounded, dancing and consistency of work, without disruption. So, MVO model has been taking advantage of being separately and deals with everyone collectively. The problem facing each region is the process of inflation so it must be reduced and improved filters in order to reduce the error rate. Therefore, these equations must formulate the lack of any disturbance that skip the permitted value, and this can be described as follows:

$$x_i^j = \begin{cases} \begin{cases} X_j + TDR \times \left(\left(ub_j - lb_j \right) \times + lb_j \right) & r3 < 0.5 \\ X_j - TDR \times \left(\left(ub_j - lb_j \right) \times + lb_j \right) & r3 \geq 0.5 \end{cases} & r2 < WEP \\ x_i^j & r2 > WEP \end{cases} \quad (19)$$

The arranger for the configuration of the X_j can be configured by lb_j and ub_j,its arranged through TDR (Traveling Distance Rate) and WEP (Wormhole Distance Probability). the parameter of ith universe and $r2, r3\ and\ r4$ are random numbers between values 0 & 1 and expresses them as follows.

$$WEP = min + l\left(\frac{max - min}{L}\right) \quad (20)$$

$$TDR = 1 - \frac{l^{1/p}}{L^{1/p}} \quad (21)$$

The minimum and census has been determined for repetitions of the current, which is between (0.2 to 1). The value of L has been maximized as well as the study is set at 6 reference value, The MVO system has been set for algorithms accurately depends on.

- The number of times repeated form.
- Number of times used.
- Roulette mechanism with mechanical system.
- Screening mechanism of cosmic models.

The Roulette wheel has its importance where it is used with each repeat, so to sort quick to classify the agents used with algorithms.

When designing the MVO model, they must be steps from the flow maps, so as to illustrate the implementation processes with the form according to the figure 3.

B. Application of the MVO for Load Frequency Control

MVO has been used to tune and reach the optimal configuration of the LQR controller. The MVO has been used to minimize the frequency deviation signal in order to determine the feedback gains of LQG controller. The objective function has been selected as integral time multiplied absolute error (ITAE).

$$J = \int_{t=0}^{t_{sim}} t(|\Delta f|) \quad (22)$$

So, the optimization problem has been presented as:

Minimize J

Subjected to:

$$K_{min} > K > k_{max}$$

where the k represents the gains of LQG.

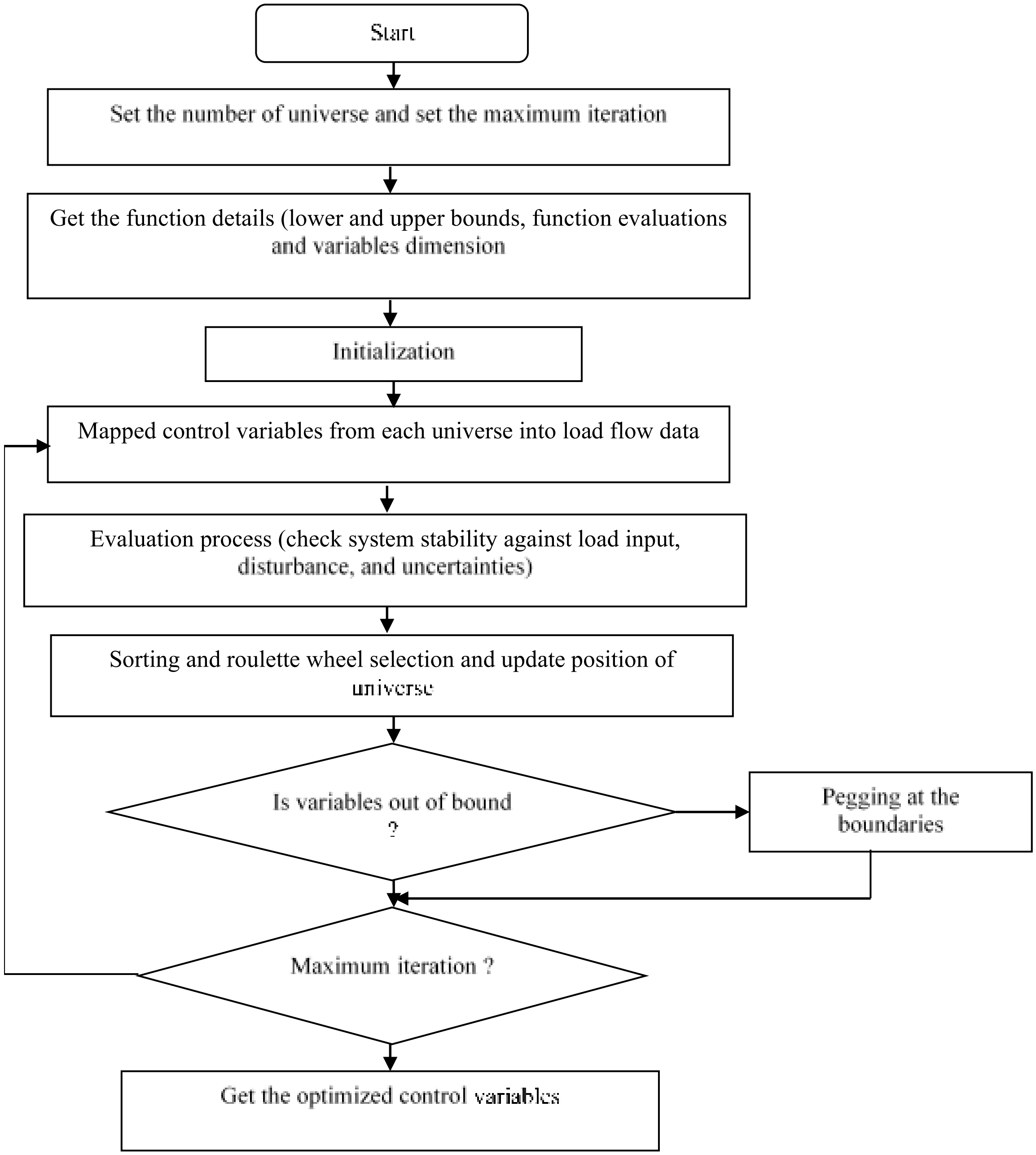


Fig.3: Flow chart of the proposed MVO to solve the LFC problem.

5. System Configuration

A. System Dynamics

The system dynamics of the load frequency control for single area power system has been shown in Fig. 4.a) and can be expressed as:

$$\boldsymbol{p}.\Delta\mathbf{f} = \left(\frac{\mathbf{1}}{\mathbf{2H}}\right).\Delta\mathbf{P_m} - \left(\frac{\mathbf{1}}{\mathbf{2H}}\right).\Delta\mathbf{P_L} - \left(\frac{\acute{\mathbf{D}}}{\mathbf{2H}}\right).\Delta\mathbf{f}$$

(23)

$$p.\Delta P_m = \left(\frac{1}{T_t}\right).\Delta P_g - \left(\frac{1}{T_t}\right).\Delta P_m \quad (24)$$

$$p.\Delta P_g = \left(\frac{1}{T_g}\right).\Delta P_c - \left(\frac{1}{R.T_g}\right).\Delta f - \left(\frac{1}{T_g}\right).\Delta P_g \quad (25)$$

where

ΔP_g : the governor output change;

ΔP_m: the mechanical power change;

Δf : the frequency deviation;

ΔP_L : the load change;

ΔP_c : supplementary control action;

p : Differential operator.

$\left(\frac{1}{s}\right)$ is the integral Laplace operator.

$T_g,\ T_t$: governor and turbine time constants.

y : the system output of area i.

H : equivalent inertia constant of area i.

D : equivalent damping coefficient.

R : speed droop characteristic.

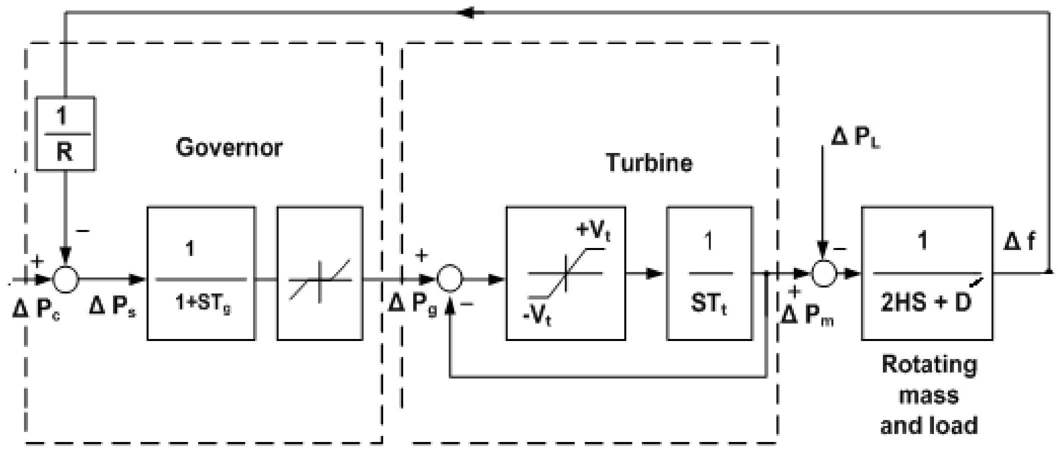
B. Complete Control System

The CDM and LQG control models, the primary purpose is to control the system's response speed and the possibility of adjusting the frequency value, the block diagram has been streamlined as described in figure 3. The system consists of:

- Rotating mass and load.
- Nonlinear turbine.
- Control the value of the governor at the Dead band [2].

The frequency deviation is normal in electrical power system, but a closed control system must be worked to ensure that the system is not exit from moderation and control. The reverse nutrition value of the frequency accounts in the normal situation must be with a hit, but when disruption and change of output must be the value of negative-value ΔP_c with income signal. Through the change in the value of income ΔP_s gives a reference to the governor who represents mechanical income to control the speed of electric generator, so mechanical control is made to adjust the power generation process. ΔP_L Change The generator must be controlled by controlling the governor, which represents the Mechanical Energy ΔP_m so that the actual deviation of Δf. Frequency has to be exempted by this image.

To estimate and calculate the deviation in the frequency value of a complementary control using Kalman filter. The system can be expressed $\hat{x} = [\Delta\hat{f} \quad \Delta\hat{p}_m \quad \Delta\hat{p}_g \quad]$, These functions have been hit their own values in the value of gain order to optimize the closed control signal. This signal is added to the original system income and the expression is ΔP_c as a complementary picture. The reverse nutrition signal to be negative, this is to maintain the governor, which controls its value in its own value, and this is a signal turbine to give ΔP_m , The range of mechanical energy ΔP_m change is an electrical load change ΔP_L. Through rotating block input and knowledge of electrical pregnancy, the actual frequency deviation Δf can reduce the system.



a)

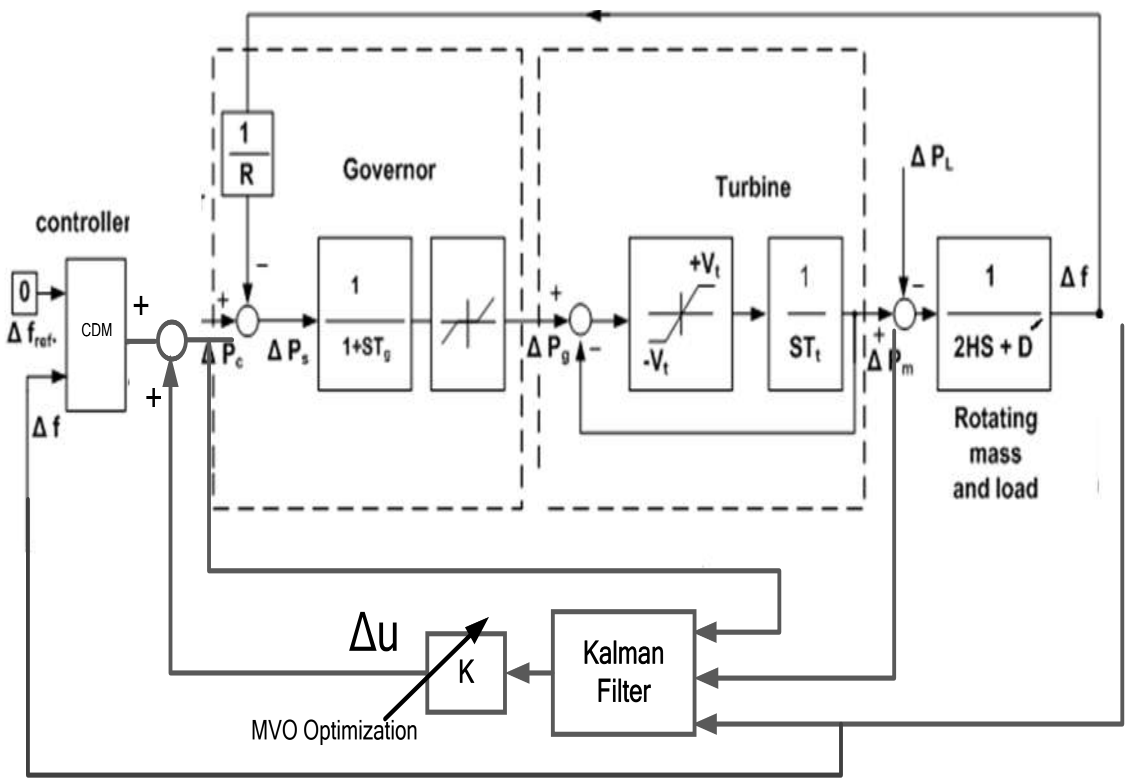


Fig.4: a) The block diagram of uncontrolled single-area power system. b) Single area power system including CDM + LQGs proposed based on MVO optimization algorithm.

Table 1. Parameters and data of the studied system ($(P_e)_{Base}$=800MVA).

D(pu/Hz)	$2H$(pu.sec)	R(Hz/pu)	T_g(sec)	T_t(sec)
0.015	0.1667	3.00	0.08	0.40

6. Results and Discussions

The simulation programs provided by the computer environment is made to ensure that the proposed form, MATLAB/Simulink Software provides this by simulating electrical applications through its formulation in the form of sports equations, and also by training and testing [2], as shown in table 1.

Change factors in the experiment for the CDM form formulated in the following:

- Fixed time can be expressed worth $= 1\ sec.$.
- For controller choosing $k_{0,1}$=23.

Then,

$D1 = 0.348S + 0.1739S^2 + 0.0805S^3 + 0.005334S^4$

$N1 = 2.826 + 0.3483S$

Stability indicators have been selected and determined (γi, 1) according to me:

$\gamma_{i,1} = [0.24, 18.28, 0.76, 3.96, 8.66]$

$i \in [1,5] \quad , \gamma_0 = \gamma_6 = \infty$

and stability limits ($\gamma_{i,1}^*$) can be formulated in the following picture:

$\gamma_{i,1}^* = [0.054, 5.475, 0.306, 1.42, 0.2525] \quad , i \in [1,5]$

$$P_{tareget,1} = 65 + 65S + 263.32S^2 + 61.7S^3 + 18.5S^4 + 1.4S^5 + 0.001S^6$$

$B_1 = 23 + 20.16S + 63S^2$

$A_1 = 225S + 2S^2$

Simulation studies on proposed control models are restricted at this version (GRC) for the importance of economic factors. The maximum value of the error at the dead point of the governor will be 0.05 pu [2].

Case 1:

To test the performance of the CDM + LQG system controller, the values of nominal variables must be determined and compared to the CDM module only without loading. Simulation results are described in figure 4, which illustrates the frequency of frequency deviation so that control of the ΔPm valve must be provisions for each of the former models. Income signals that control the two systems must be (the ΔPL assumed to be 0.02 pu at t = 30 sec.). So, notes that the console is more stable for the system and speed performance when you use CDM + LQG Controller instead of using CDM only. Once you change the two systems when you change the download, the attribute is attributed to be (the ΔPL assumed to be 0.02 pu at t = 30 sec.). In this picture, the CDM + LQG console is more efficient and reliable in performance from CDM.

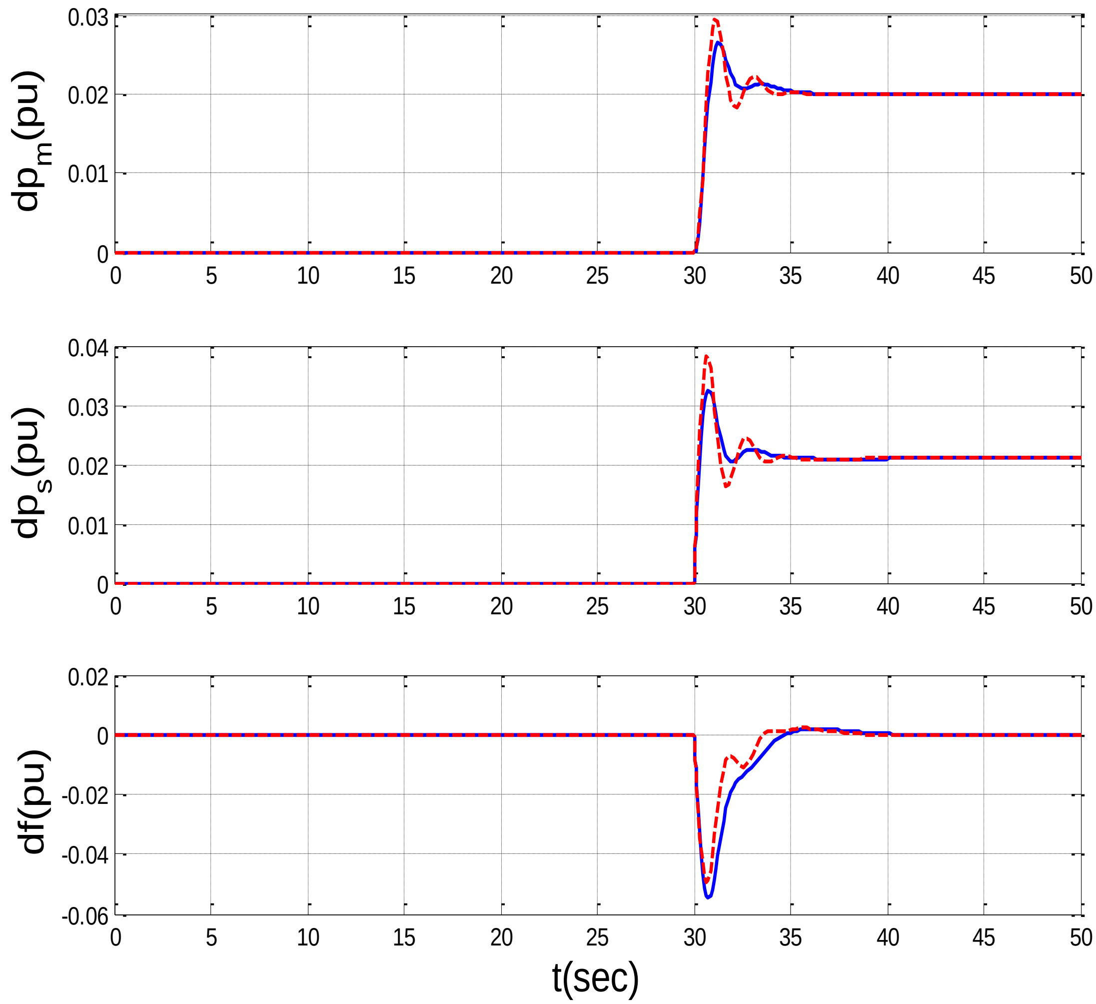


Fig.5: Shows the reaction of electric power system for case No. 1; a) Determine the governor's objective value ΔPm, b) Determination of frequency deviation Δf, and c) The actual control signal for the governor ΔPs. CDM+LQG (solid line) and CDM (dashed line).

Case 2:

The system test process has been changed in a significantly changed (the ΔPL assumed to be 0.06 pu at t = 30 sec.), Figure X-1 shows the sample response model CDM + LQG and also reaction of the CDM form. The CDM + LQG model is much faster than CDM and when the electric load is changed and efficiently.

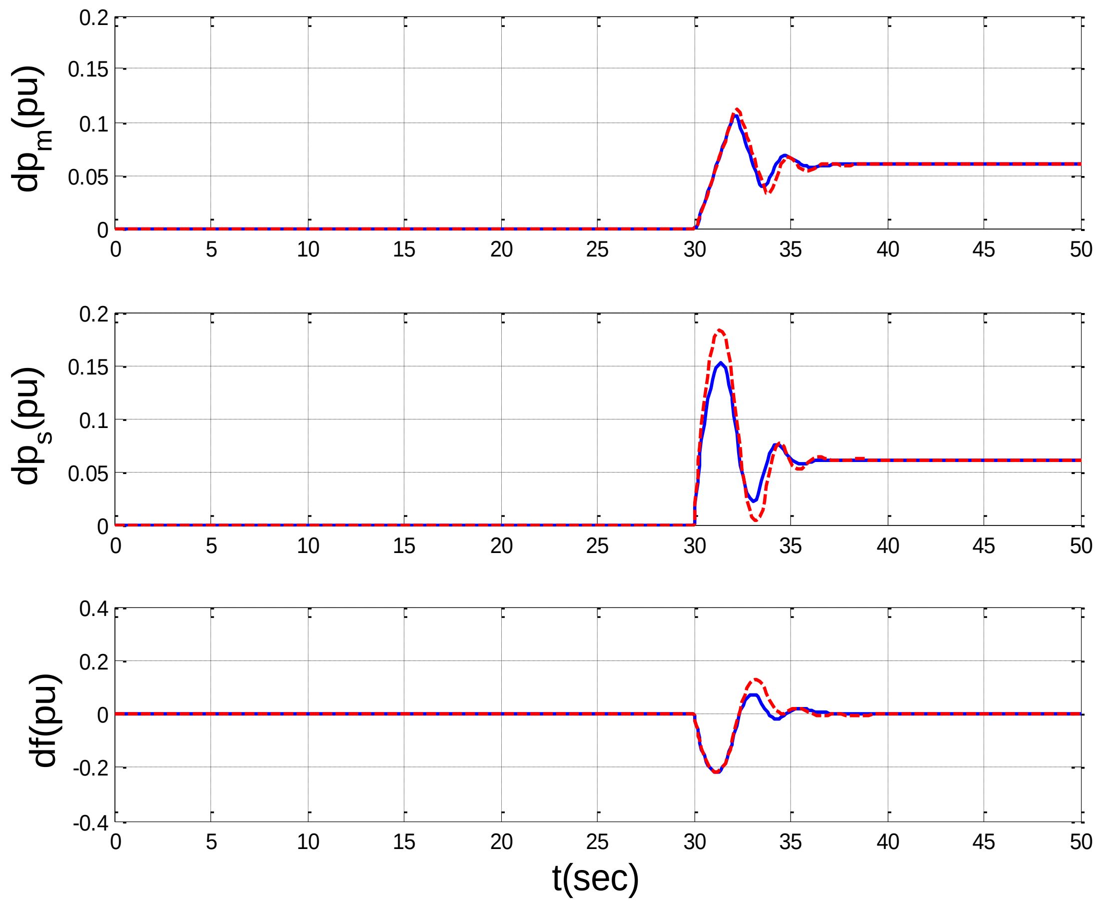


Fig.6: Shows the reaction of electric power system for case No. 1; a) Determine the governor's objective value ΔPm, b) Determination of frequency deviation Δf, and c) The actual control signal for the governor ΔPs. CDM+LQG (solid line) and CDM (dashed line).

Case 3

In this case the CDM + LQG model has been experimented with the variation of the plant parameters values to ensure that the training process is correct. The constants for the governor and turbine were increased to Tg = 0.12 sec (≅31% change), and Tt = 0. 975 sec (≅140 % change), respectively. Form No. 6 shows the sample response of the CDM + LQG model when the electrical load changes. The result shows the performance of the CDM + LQG of them when you only use CDM.

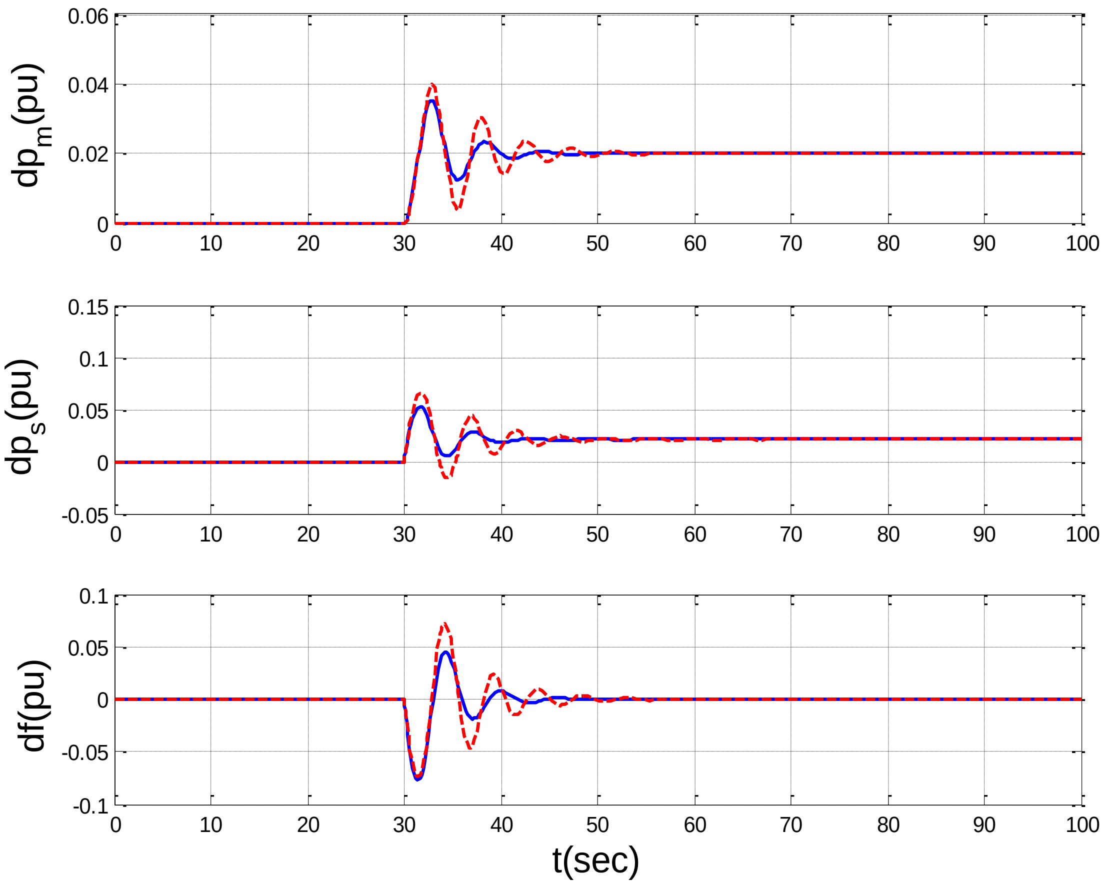


Fig.7: Shows the reaction of electric power system for case No. 1; a) Determine the governor's objective value ΔPm, b) Determination of frequency deviation Δf, and c) The actual control signal for the governor ΔPs. CDM+LQG (solid line) and CDM (dashed line).

Case 4:

A wide range of results were taken on the CDM + LQG model to make sure their ability to make results at the full test of the system. In previous cases, the process of increased the ruler and turbine constants, but in this case will be increased to Tg1 = 0.18 s (≅125% change), Tt1 = 1.4 s (≅260% change), respectively with changing M=.225 and D=.0195.

A representation of the fourth situation was as explained in the form of No. 7. A comparative process of confidence when the electrical pregnancy changes just as the situation. The result came confirming that the CDM unit alone does not give the desired efficiency but to model CDM + LQG because of its high response speed and fast stability of the system of deterioration. This situation also explained that the effectiveness of Kalman filter, which had a positive effect on the performance of LQG, Fig. 8 illustrates the estimated ΔP_g and ΔP_m.

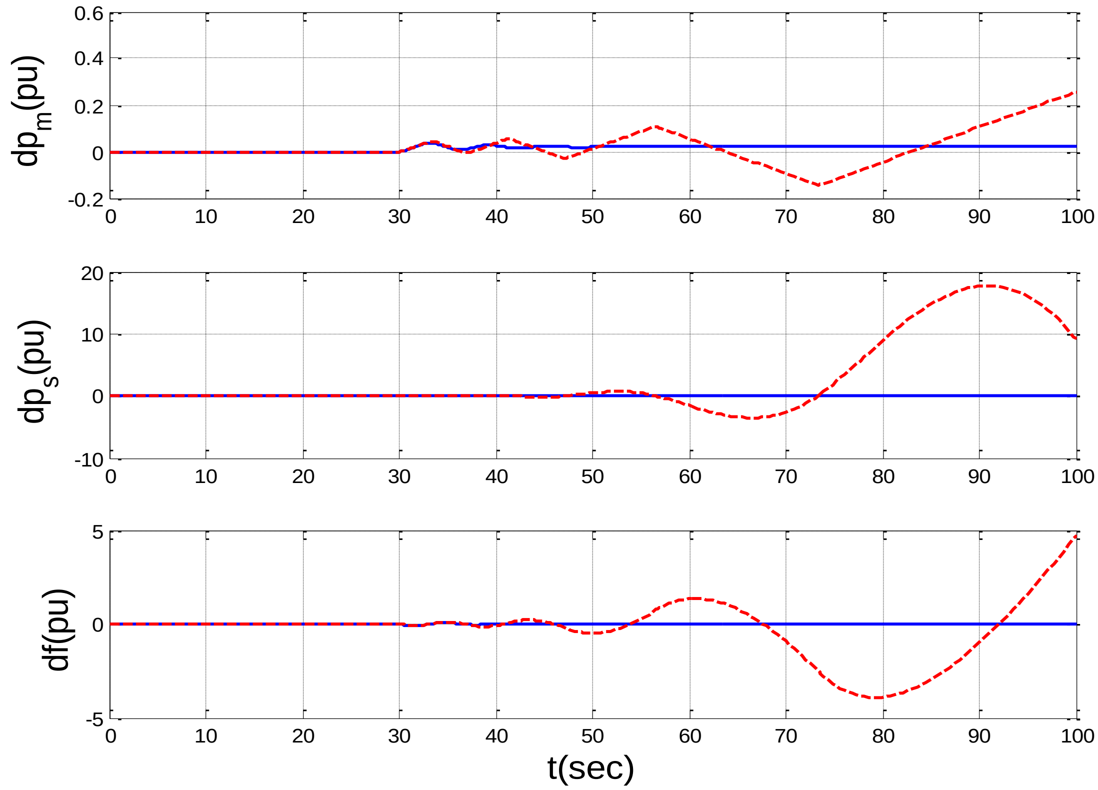


Fig.8: Shows the reaction of electric power system for case No. 1; a) Determine the governor's objective value ΔPm, b) Determination of frequency deviation Δf, and c) The actual control signal for the governor ΔPs. CDM+LQG (solid line) and CDM (dashed line).

7. Conclusion

Frequency has great importance in electrical power systems, so it is controlled through LFC. In this paper, the control system has been designed using CDM + LQG for single area system. LQG has been designed using MVO. The variation of parameters has been taken into account. The response of the frequency deviations and system response are recognized in the paper with the application of the proposed controller. The results have been achieved using Matlab/simulink. The results showed the effectiveness of CDM + LQG methodology rather than CDM only. The limitation of the CDM diagram may be as example the numerator and denominator are calculated manually .Also, the analysis of the application of the online optimization process should be considered in future work considering the performance of the control system, its complexity, and the time of implementation.

REFERENCES

[1] Back T, "Evolutionary algorithms in theory and practice: evolution strategies, evolutionary programming, genetic algorithms,", Oxford university press, 1996 Jan 11.

[2] Mitchell, Melanie, "An introduction

to genetic algorithms," MIT press, 1998.

[3] Kundur, P. Power System Stability and Control, 1st ed.; Editors: N. J. Balu, M. G. Lauby; McGraw-Hill: New York, USA, 1194; pp. 40-88

[4] Bevrani, H. Robust Power System Frequency Control (Power Electronics and Power System), 1st ed.; Edit Pai, Alex Stankovic; Springer Science + Business Media, LLC; New York, USA, 11-65, 2009.

[5] Masiala, M.; Ghribi, M.; Kaddouri, A. An adaptive fuzzy controller gain scheduling for power system load-frequency control. Proceedings of the IEEE ICIT '04. IEEE International Conference on Industrial Technology 8-10 Dec.; Volume 3; pp. 1515 – 1520, 2004

[6] Lee, H. J.; Park, J. B.; Joo, Y. H. Robust Load Frequency Control for Uncertain nonlinear power systems: a fuzzy logic approach. Inform Sciences. Volume 176; pp. 3520-3537, 2006.

[7] E. Cam.; I. Kocaarslan. Load frequency control in two-are-a-ewer-systems using fuzzy logic controller. Energy Conveys Manage, Volume 46; pp. 233-243, 2005

[8] Sabahi, K.; Nekoui, M. A.; Teshnehlab, M.; Teshnhlab, M.; Aliyari, M. Load Frequency Control in Interconnected Power System Using Modified Dynamic Neural Networks of the Mediterranean Conference on Control & Automation, July 27-29, Athens, Greece; pp. 1- 5, 2007.

[9] Al-Hamouz, Z. M.; AI-Duwaish, H. N. A new load frequency variable structure controller using genetic algorithm, Electric Power Syst. Research. Volume 55, pp. 1-6,2006.

[10] Mohamed, T. H.; Bevrani, H.; Hassan, A. A. E.; Hiyama, T. Decentralized model predictive based load frequency control in an interconnected power system. Energy Conveys Manage, Volume 52; pp. 1208-1241, 2011.

[11] Mohamed, T. H.; Morel, J.; Bevrani, H.; Hiyama, T. Model predictive based load frequency control design concerning wind turbines, Electrical Power and Energy Systems Journal, 2012; Volume 43; pp. 859-867.

[12] Bernard, M. Z.; Mohamed, T. H.; Qudaih, Y. S.; Mitani, Y. Decentralized load frequency control in an interconnected power system using Coefficient Diagram Method, International Journal of Electrical Power & Energy Systems, 2014; Volume 63; pp. 165-172.

[13] Manabe, S. Importance of Coefficient Diagram in Polynomial Method, Proceedings of the 42nd IEEE Conference on Decision and Control; Maui, Hawaii, USA; 9-12 Dec Volume 4; pp. 3489 – 3494, 2003.

[14] Shunji Manabe, Case Studies of Coefficient Diagram Method - Practical Polynomial Design Approaches, 16th IFAC World Congress, Czech Republic, July 4 to July 8, 2005, Vol 16, no 1.

[15] Tarek Hassan Mohamed, Ahmed A. Zaki Diab and Mahmoud M. Hussein, "Application of Linear Quadratic Gaussian and Coefficient Diagram Techniques to Distributed Load Frequency Control of Power Systems", journal of Appl. Sci., 2015, 5, 1603-1615; doi:10.3390/app5041603

[16] A. A. Z. Diab and M. A. EI-Sattar, "Adaptive model predictive

based load frequency control in an interconnected power system," 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (ElConRus), Moscow, 2018, pp. 604-610. doi: 10.1 109/ElConRUS. 8317170,2018.

[17] Ahmed A. Zaki Diab, Tarek Hassan Mohamed “Load Frequency Control Using Coefficient Diagram and Linear Quadratic Gaussian Techniques", the 17thInternational Middle East Power Systems Conference MEPCON'15, IEEE conference, Mansoura University, Mansoura, EGYPT, December 15-17, 2015.

[18] Mirjalili, Seyedali, Seyed Mohammad Mirjalili, and Abdolreza Hatamlou. "Multi-verse optimizer: a nature-inspired algorithm for global optimization." Neural Computing and Applications 27, no. 2 (2016): 495-513.

[19] Hemeida, A., Mohamed, S., Mahmoud, M. (2020). Load Frequency Control Using Optimized Control Techniques. JES. Journal of Engineering Sciences, 48(No 6), 1119-11136. doi: 10.21608/jesaun.2020.42349.1011.

[20] Hemeida, A. M. (2010). A fuzzy logic controlled superconducting magnetic energy storage, SMES frequency stabilizer. Electric Power Systems Research, 80(6), 651-656.

[21] Liu, L., Senjyu, T., Kato, T., Mandal, P., Hemeida, A. M., & Howlader, A. M. (2020, September). Renewable Energy Power System Frequency Control by using PID controller and Genetic Algorithm. In 2020 12th IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC) (pp. 1-5). IEEE.

[22] Barakat, M., Salama, G., Donkol, A., Hamed, H. (2021). Optimal Design of Fraction-Order Proportional-Derivative Proportional-Integral Controller for LfC of Thermal-Thermal-Wind Turbines Considering Nonlinearities. Journal of Advanced Engineering Trends, 41(2), 275-283. doi: 10.21608/jaet.2021.64407.1090

[23] Alamgir Hossain "Linear Quadratic Gaussian Regulator Based Frequency Control of Power System to Enhance the Continuity of Power Flow" American Journal of Engineering Research (AJER), vol.8, no.04, 2019, pp.348-354.