Arithmetic Optimization Algorithm Based Tilt Integral Derivative Controller for Frequency Regulation of a Smart Grid System

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Abstract:- The presence of renewable source uncertainties, varying loading circumstances and lack of rotating inertia makes the frequency regulation of a Smart Grid (SG) system a tedious task. This necessitates an intelligent frequency control strategy for stable functioning of the SG system. In the present study, an Arithmetic Optimization Algorithm (AOA) tuned Tilt Integral Derivative (TID) structure is proposed for frequency regulation of a Smart Grid (SG) system. The studied SG system includes different elements like solar, photovoltaic, wind, flywheel, battery, and electric vehicles. It is demonstrated that TID structure is more effectual than PI & PID structures for frequency regulation of studied SG system. Finally, the results of TID is compared with PI & PID under varied load, solar and wind power conditions to demonstrate the benefit of TID over PI & PID structures.

Keywords: *Smart grid system, Frequency control, PI controller, PID controller, Tilt Integral Derivative (TID) Arithmetic Optimization Algorithm (AOA)*

1. Introduction

Renewable sources lessen the reliance on fuel resources, but introduce generation load disparity due to the unpredictable character of solar/wind powers. This causes deviation in system frequency. The frequency changes are regulated within a satisfactory limit by employing controllers [1]. Numerous methods have been projected for frequency regulation of power systems [2-4]. Various optimization methods like Genetic Algorithm (GA) [5], Particle Swarm Optimization (PSO) [6], Cuckoo Search Algorithm (CSA) [7], Firefly Algorithm (FA) [8], Salp Swarm Algorithm (SSA) [9], Grasshopper Optimisation Algorithm (GOA) [10], Sine Cosine Algorithm (SCA) [11] have been proposed in literature, A Smart Grid (SG) system typically contains various sources like Wind Turbine Generator (WTG), Diesel Engine Generator (DEG), Battery Energy Storage System (BESS), Fuel Cell (FC), Photo Voltaic (PV), and Flywheel Energy Storage System (FESS). The power generated by PV and WTG chiefly relies on the environment situation and therefore they are uncontrolled generations [12]. Controllers are to be used to control other power sources to control the frequency. This study proposes a Tilt Integral Derivative (TID) structure for the frequency regulation of SG. In TID controller, the proportional element of PID controller is supplemented with a tilted part with a Transfer Function (TF) of $s^{-1/n}$. Recently, Abualigah*et al.* projected a arithmetic-based technique known as Arithmetic Optimization Algorithm (AOA)[13]. It is apparent from [13] that the AOA technique provides better outcomes compared to PSO, GA, Biogeography Based Optimization (BBO), Flower Pollination Algorithm (FPA), Grey Wolf Optimization (GWO), Bat Algorithm (BAT), FA, CSA, Gravitational Search Algorithm (GSA), Moth-Flame Optimization (MFO), and Differential Evolution (DE). In view of the above AOA method is employed in this work to design the proposed TID controller. The performance of TID controller is equated with PI & PID structures under varied load, solar and wind power conditions to demonstrate the advantage of TID over PI & PID.

2. System Modelling

The studied SG system is shown in Fig. 1 [14]. It includes WTG, PV, AE (Aqua Electrolysers), an FC a DEG, a FESS, a BESS an EV. Different nonlinearity such as rate limiter for the storage elements and the time delays are included in the system model.

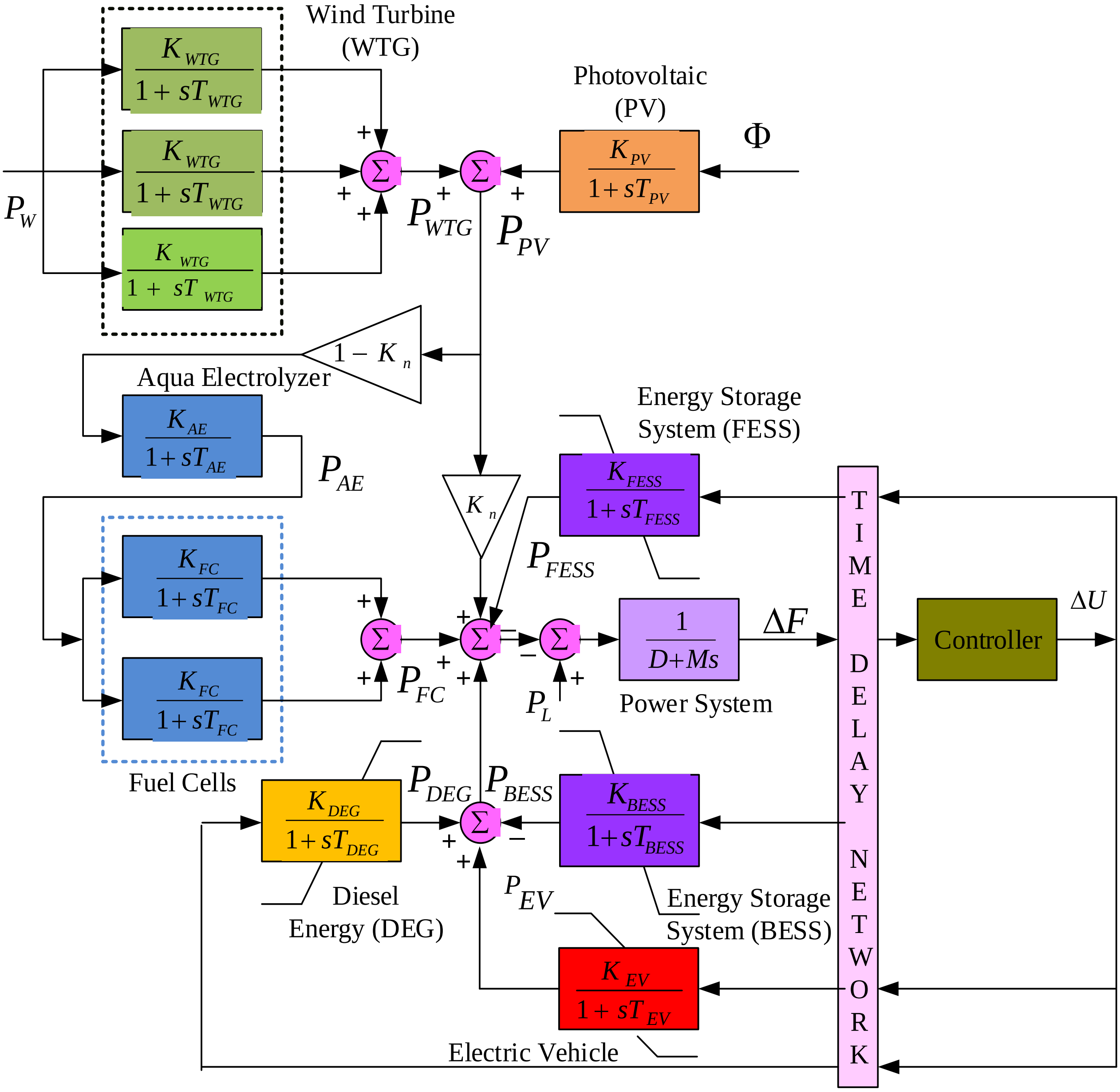

Fig.1 Smart grid system under study

The components of SG are represented by transfer function and the parameters are [14]: Solar PV parameters: K_{PV}=1.0, T_{PV}=1.8 s; WTG parameters: K_{WTG}=1.0, T_{WTG}=1.0 s; FC parameters: K_{FC}=0.01, T_{FC}=4.0 s; DEG parameters: K_{DEG}=0.003, T_{DEG}=2.0 s; AE parameters: K_{AE}=0.002, T_AE=0.5 s; BESS parameters: K_{BESS}=-0.003, T_{BESS}=0.1 s; FESS parameters: K_{FESS}=-0.01, T_{FESS}=0.1 s, K_n=0.6.

3. Controller Structure and Objective Function

Generally PI/PID controllers are used in control systems for their modest design, less cost, and their practicality for linear systems. However, traditional PI/PID structures are usually not competent for nonlinear systems. The controller used in the present study is a TID controller as revealed in Fig. 2 [15]. The TID controller is basically a tunable compensator having K_P, K_I and K_D as gains with a tilted element as n.

The main objective function is to minimize fluctuations in system frequency (ΔF) and output of the controller (ΔU) which is expressed by Integral Square Error (ISE), which is provided as:

$$J = \int_0^T [K(\Delta F)^2 + (\Delta U)^2]dt \qquad (1)$$

Where value of K is chosen as 10 which gives equal weightage to both parts in equation no (1) during optimization. The controllers are tuned using AOA. For the optimum performance of the SG system, the value of ΔF and ΔU must give least value of J.

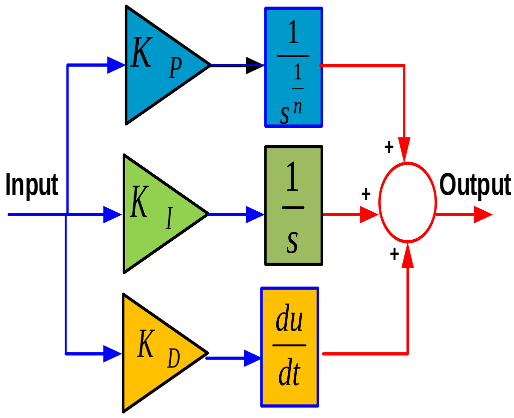

Fig. 2.Structure of TID controller

4. Arithmetic Optimization Algorithm

Recently, Abualigah*et al.* proposed an arithmetic-inspired technique known as Arithmetic Optimization Algorithm (AOA) [13]. In the working of AOA, arithmetic operators like Multiplication ($M, " \times "$), Division ($D, " \div "$), Subtraction ($S, " - "$) and Addition ($A, " + "$) are used to update the solutions in each iteration. The potential solutions of size Z are initialized arbitrarily inr the search area s, and are indicated by a matrix $P_{(Z\times s)}$ and expressed as:

$$P_{(Z\times s)} = \begin{bmatrix} p_{1,1} & \cdots & p_{1,j} & \cdots & p_{1,n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ p_{i,1} & \cdots & p_{i,j} & \cdots & p_{i,n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ p_{Z,1} & \cdots & p_{Z,j} & \cdots & p_{Z,s} \end{bmatrix} \qquad (2)$$

Then, the exploration or exploitation is decided by a coefficient Math Optimizer Accelerated (MOA), and is calculated as

$$MOA(C_{it}) = A_{min} + C_{it} \times \left(\frac{A_{max} - A_{min}}{M_{it}}\right) \qquad (3)$$

WhereC_{it} and M_{it}signify the present and maximum iterations, A_{min} and A_{max} are the range of the accelerated function,. Then, the jth position of ith solution is restructured in exploration stage using the Division and Multiplication operators as:

$$p_{i,j}(C_{it}+1)=\begin{cases} best(p_j)\div(MOP+\delta)\times\left((U_{bj}-L_{bj})\times\mu+L_{bj}\right), & rnd_1<0.5 \\ best(p_j)\times(MOP)\times\left((U_{bj}-L_{bj})\times\mu+L_{bj}\right), & otherwise \end{cases} \quad (4)$$

where coefficient MOP is Math Optimizer Probability and is found as

$$MOP(C_{it}) = 1-\frac{C_{it}^{(1/\alpha)}}{M_{it}^{(1/\alpha)}} \quad (5)$$

where α and μ indicate the sensitive and control parameter, $best(p_j)$ indicates the best solution found in jth positions. U_{bj} and L_{bj} are the limits of the jth position. δ and rnd_1 indicate the small integer and a arbitrary value.

Then, throughout the exploitation stage, both Addition and Subtraction are used to update the jth position of ith solution which is given by

$$p_{i,j}(it+1)=\begin{cases} best(p_j)-(MOP)\times\left((U_{bj}-L_{bj})\times\mu+L_{bj}\right), & rnd_2<0.5 \\ best(p_j)+(MOP)\times\left((U_{bj}-L_{bj})\times\mu+L_{bj}\right), & otherwise \end{cases} \quad (6)$$

where rnd_2 is a random number.

5. Simulation and Result

The system model is developed and AOA is employed to tune the controller values. Study is done with TID, PID and PI controllers independently.. The following algorithm parameters are used while running the AOA algorithm: initial agents chosen are 30, simulation is run for 500 iterations (maximum) and total number of runs are 30. Table 1 provides the optimized controller parameters. It can be noticed from Table 1 that less *J* value is found with TID controller compared to PID and PI controllers. Thus, it demonstrates that the suggested AOA-TID scheme offers better outcomes than the AOA-PID & AOA-PI strategy. To evaluate the performance, various cases are taken. In the first case, constant load (P_D=0.5 p.u.), solar power (P_{PV}=0.4 p.u.) and wind power (P_{WTG}=0.3 p.u.) are assumed. The frequency deviation response with AOA optimized PI, PID and TID controller is displayed in Fig. 3. The comparison of integral errors, MOs/MUs, of ΔF are provided in Table 2. It can be noticed from Fig. 3 and Table 2 that, the results with TID is superior to PID and PI with low errors and MUs/MOs. The % reduction in J value with TID compared to PID and PI are found to be 57.91% and 64.24%. Similar improvements are also observed for other performance indexes.

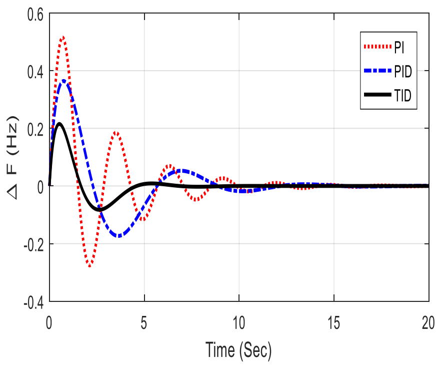

Fig. 3. Frequency deviation response under constant load, solar and wind power

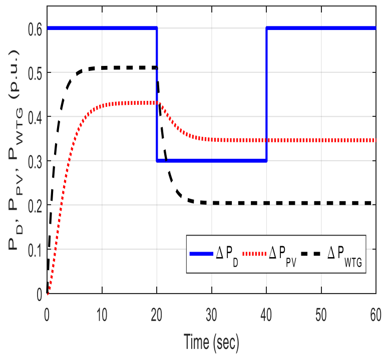

Fig. 4. Uncontrolled load and renewable power variations

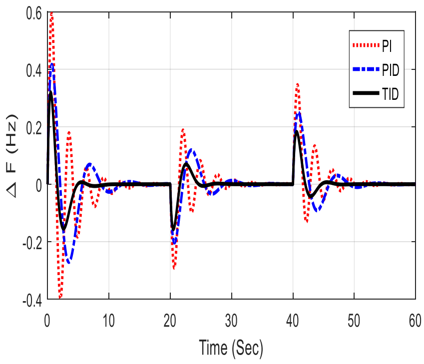

Fig. 5. Frequency deviation response under variable load, solar and wind power

For the second case, variations in load, solar and wind powers as demonstrated in Fig. 4 are considered and the frequency variation response with different controllers are revealed in Fig. 5. The comparisons of integral errors, MOs/MUs, of ΔF for both the cases are provided in Table 2. It is noticed from Fig. 5 and Table 2 that in this case also the performance with TID is improved compared to PID and PI. It is observed that the integral errors, MOs and MUs with TID are less compared to PI/PID in this case also. The % reduction in J value with TID compared to PID and PI are found to be 25.08% and 36.83%. The power outputs of different elements with all controllers are shown in Figs. 6-8 from which it is clear that the power outputs of controllable sources are suitably modified to control the system frequency under varied load, solar and wind powers.

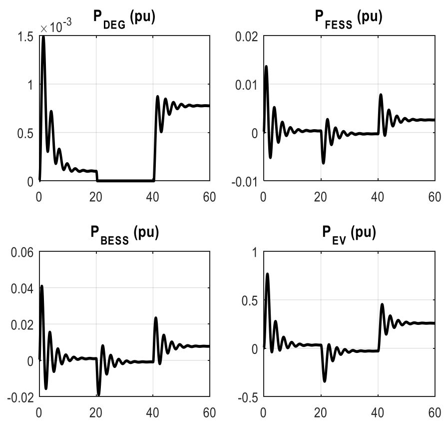

Fig. 6. Power output of controlled elements with PI

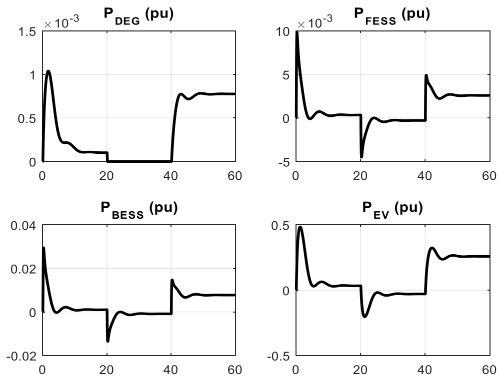

Fig. 7. Power output of controlled elements with PID

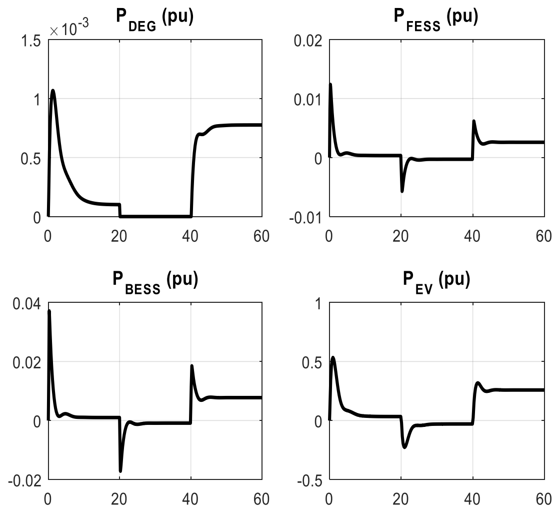

Fig. 8. Power output of controlled elements with TID

Table 1. AOA Optimized controllers value

S. No.	Controller	Values
1	PI	K_P=1.9997,K_I=0.7373
2	PID	K_P=1.0455, K_I=1.0473, K_D=0.8526
3	TID	K_P=1.9974, K_I=1.7697, K_D=1.0845, n= 0.2725

Table 2 Performance comparison of TID, PID and PI for both cases

Technique/ Controller	Integral errors				MO_S in ΔF	MU_s in ΔF (-ve)	*J* Value
	ISE	ITAE	ITSE	IAE			
Case-1: Constant load, solar and wind power							
PI	0.2864	3.4467	0.4221	1.1629	0.5152	0.2755	5.3392

PID	0.2014	3.2774	0.3510	1.0405	0.3642	0.1733	4.5362
TID	0.0452	0.6597	0.0479	0.3742	0.2152	0.0826	1.9093
Case-2: Variable load, wind and solar power							
PI	0.6406	51.6948	7.8598	2.8621	0.5932	0.3976	4.9071
PID	0.4709	48.3361	6.0832	2.6469	0.4158	0.2706	4.1375
TID	0.1686	19.7633	2.0096	1.1995	0.3202	0.1571	3.0995

6. Conclusion

In this paper, TID controller optimized by AOA technique is suggested for frequency regulation of a Smart Grid (SG) system. The SG system contains DEG, FESS, WTG, AE, PV, FC, BESS and EV. Different nonlinearity like time delays and rate are included in the study. The TID/PID/PI controller parameters are tuned using AOA algorithm using ISE based objective function. Different cases like constant and variable load, PV and WTG power are analyzed. It noticed that the suggested AOA-TID scheme offers better outcomes than the AOA-PID & AOA-PI strategy with constant load, solar and wind powers. It is observed that the % reduction in J value with TID compared to PID and PI are found to be 57.91% and 64.24% for constant load, solar and wind powers. It is also noticed that AOA based TID structure is more effectual for frequency regulation related to PID and PI structures under variable load, PV and WTG power. It is observed that the % reduction in J value with TID compared to PID and PI are found to be 25.08% and 36.83% under varied load, solar and wind powers. The power outputs of controllable sources are suitably modified to control the system frequency under varied load, solar and wind powers

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