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Enhanced Performance of Modified PID Load Frequency Controller with Frequency Control Techniques of WU for Two Area Interconnected System

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***Abstract:** This paper demonstrates a modified PID controller that gives enhanced performance in terms of amplitude of first peak, overshoot, and time of settling. The significance of this research work stems from the point that modified PID controller for unit of wind power (WU) with inertial control (C-I), integration of controller of inertial and droop (C-D), and integration of controller of inertial, droop, and pitch angle (C-P) has not been counted in literature so far in totality. In addition, the same controller is not implemented for the TP with WU for C-P with different step load perturbations. The suggested controller is established by cascading of derivative filter with PID controller to restrict the noise sensitivity in PID controller. For validation of the proposed controller, it is employed in different scenario and compared its performance with conventional PID controller. Also, this article compares different frequency regulation techniques of WU separately and gets the best possible combination of controller to offer the boosted performance of the system. The suggested controller has been simulated in MATLAB/SIMULINK ver. 2013 environment. Simulation results show the reductions in frequency deviation and tie line power deviation when TP is subjected to modified PID controller. The major contribution of this work is to advance regulation of frequency and power, which leads to enhanced grid stability.*

***Index Terms:** Active power controller, droop controller, inertial controller*

I. INTRODUCTION

The decent process of interlocked power system urges the levelling of entire power generation to entire demand and related losses. The operating point of power system altered as the load deviates from its scheduled value and therefore, system may face the deviations in scheduled system frequency and predefined power trades [1]–[5]. The area of load frequency control of power system is focused to preserve the frequency and the power trade among control areas in identified bin [6]. Controllers based on proportional integral (PI) and proportional integral derivative (PID) have preference in LFC application as a result of easiness in engagement [7].

In the year of 1942, the two approaches i.e. the step and the frequency response scheme is demonstrated clearly by Ziegler and Nichols (Z-N) for tuning of PID controller's variables [8]. Proportional controller gain (K_C) and oscillation time (T_C) period plays the deciding role in evaluation of variables of PID controller for frequency response scheme and is obtained from the definite process. The PID controller embraces for four variables for instance time constant of integral (K_I) proportional gain (K_P), time constant of derivative (K_D), and filter constant (N). Nonetheless, the value of K_P , K_I , and K_D obtained by same scheme yet value of N is preset [9]. Load frequency control is wide-open to noisy environment due to noise in frequency measurements which is produced by frequent on/ off process in utility. Hence, differential feedback loop becomes difficult for implementation [10]. The major setback of derivative filter as a vital portion of PID is the gain generated at upper frequency. This issue can be resolved by using modified PID controller. It can be offered better performance in contrast to conventional PID controller. Renewable energy sources have appealed the power sectors as a result of problems for instance weakening of fossil fuel and rigorous environmental concern. Whole global fitted volume of renewable energy source (RES) is 1,081 GW (excluding hydro power) in year 2017.The wind power is approximately 49.86% of net global power capacity in 2017 [11]. International wind power capacity is 591 GW by the end of 2018 [12]. India has collective installed size of 35.815 GW by the end of April 2019 [13]. The various resource assessment and evaluation techniques for different RES have been reported in literature without considering the grid integration issues [14]-[15]. It is perceived from the above statistics that wind power is a mighty source of power between all RES and able to curtail the power requirement. The option of RES used to maximize the production of electricity and most of research is going into this area in previous few years and mostly focused on maximum power tracking techniques for both dominating sources solar and WU. Later, problems with its increasing dimensions are identified. It is expected to fulfill the all requirement from the WU likewise traditional power units were doing. The expectation of frequency regulation from WU is one of the most talked topics. Reliability and stability of the power system is a crucial topic since starting and this area become the leading area with addition to RES due deficiency of some services from RES for instance frequency regulation.

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The WU is having moving system therefore expectation for frequency regulation is more from it.

The power converter devices has exploited to interconnect the wind power system to grid and responsible for the decoupling of generator speed and frequency leads lessening in system inertia. The system become more defenseless with increasing installed wind power with reduced inertia in case of fluctuation in frequency. Therefore, frequency regulation supports from wind power unit (WU) are expected with the intention of upholding the system stability and reliability [16]-[19]. A number of researchers have testified the various control techniques for frequency regulation such as controlling pitch angle, controlling inertia , and controlling rotor speed [20]-[23].

The inertial response has been obtained by additional inertia control loop has reported in [20]-[22]. However, the inertial response cannot be increased after a specified level because of the narrow availability of wind speed and its output power. Hence another control technique named Droop controller has come into picture and advocated with inertial control to offer frequency support during generator outage. This new technique has been testified on electronic controller and pitch angle controller [23]. Nevertheless, the restricted pitching rate causes slow response by pith angle control technique.

LFC based on PI, for DFIG type of wind turbine, is considered in [24]-[25]. However, frequency regulation capability with wind turbine is not considered for exploration. The reduction in frequency deviation has been recorded by a different PI –LFC having speed controller and inertia control [26]-[27]. The peak value of amplitude and the settling time has reduced in case of automatic generation control with inertial control, droop control and speed control [28]-[29]. Yet, the pitch angle control has not been a part of the study in above stated research works. Though, all the above control techniques and its combination have not been compared in totality. The coordinated control of wind power unit is tested for multi area system [30]. But, MPID controller is not analyzed.

In noisy network, the LFC using derivative filter is advocated for different types of area interconnected system [10], [31]. A better result is obtained using modified PID controller than using normal PID controller for a two area interconnected system (TP) having conventional generation unit [7], [32]-[31]. TP with wind unit has been authenticated in case of MPID controller with different frequency control technique of wind power unit [33]-[37]. The Pitch angle controller is not considered for the analysis. Modified PID controller is not validated for TP with WU with different combination of frequency regulation techniques in literatures for 1%, 2%, 3%, and 4% step load perturbation. Also, the complete comparison of these frequency regulation techniques along with MPID controller has been untaken.

This article is concurrently dedicated on performance of load frequency control and frequency control techniques of wind turbine. The load frequency controller is based on modified PID controller is advocated and its performance is compared with convention PID controller. Additionally, the wind turbine frequency control techniques have also been compared. A performance analysis has been presented and the performance indices such as first peak amplitude, overshoot, and settling time are compared with each other.

II. PROBLEM STATEMENTS

The worth mentioning noise in measurement of frequency is evident by reiterated switching in the utility portion. So, the LFC needs to work into the noisy circumference that creates the hindrance in application of loop of differential feedback. The key setback of derivative filter as an additional portion of PID is that of yielding gain at a greater frequency. So, a unique fusion of a PID controller is expected that exhibit perforate healthier than the traditional PID controller [10], [7], [31]-[32]. The talked constraint would be circumvented by pouring low pass filter with PID controller and it is the incentive for the controller displayed here. Many industrial fields are tested the modified PID controller [38]-[39].

As the involvement of renewable energy sources in power system is enlisted to a hefty level, it is crucial to observe the suggested controller with the RES. The development in installed wind power is outstanding amid all RES. Therefore, proposed controller has been instigated with WP. Conventionally, there is no share in frequency regulation process by WU by reason of decoupling betwixt generator velocity and frequency. Consequently, the system becomes more sensitive to grid disturbances [16]-[19]. Hence, contribution of WU in frequency regulation is essential to maintain frequency in its limit. The different techniques have been studied but very few are reported with load frequency control issue. Therefore, the current controller with different combination of frequency regulation techniques of WU also analyzed.

III. SOLUTION METHODOLOGIES

The LFC consisting MPID controller has been verified in case of TP with WP for various step load perturbations in all areas. The WP is having different frequency regulation technique such as virtual inertial control (VC), droop control, PC and different combination of these techniques has exploited in this research paper. The comparison between enactment of PID and modified PID controller along with WU is presented in following sections.

IV. MATHEMATICAL MODELLING OF TWO AREA INTERCONNECTED SYSTEM

This section has discussed mathematical modelling of the TP with DFIG as follows.

A. Two area interconnected power system with WU

Interconnection of solo area system results better reliability and steadiness of power flow [1]-[2]. Fig.1 shows TP comprising of non reheat thermal unit and wind power unit with frequency control methods.

The addition of thermal power output (ΔP_c) and WU output is output of each area as given in (1).

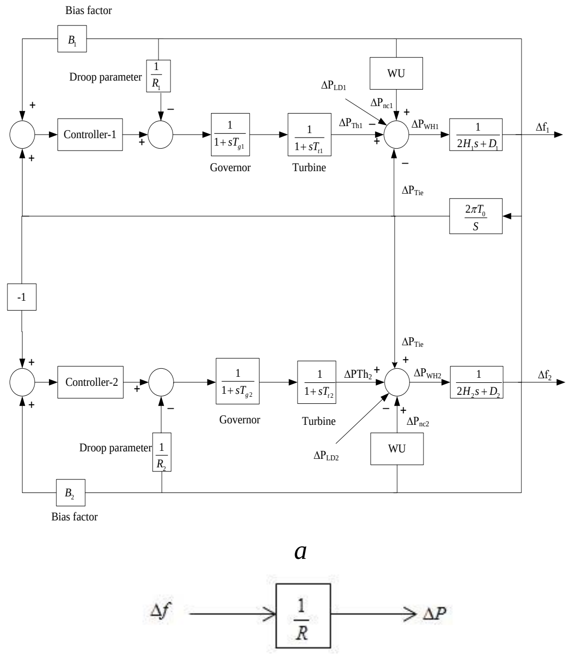
$$\Delta P_{WH} = \Delta P_{Th} + \Delta P_{nc} - \Delta P_{LD} - \Delta P_{tie} \quad (1)$$

where, ΔP_{Th} and ΔP_{nc} are thermal unit output power and WU respectively. ΔP_{tie} and ΔP_{LD} are tie line power and demand, respectively.

The transfer function of thermal unit turbine ($T_t(s)$) and governor ($T_g(s)$) are articulated in terms of time constants of governor (T_g) and turbine (T_t)

$$T_t(s) = \frac{1}{1+sT_t} \tag{2}$$

$$T_g(s) = \frac{1}{1+sT_g} \tag{3}$$



a

b

Fig.1. Block diagram of component of TP

a TP including DFIG based WT with frequency regulation capability [35]

b Droop control [36]

B. DFIG

The wind turbine can be represent the in s domain by (4) [30].

$$T_{wt}(s) = \frac{1}{1+sT_{wt}} \tag{4}$$

Speed controller output of wind turbine (ΔP_w) is expressed

$$\Delta P_w = W_{gp} e + W_{pi} \int e dt \tag{5}$$

V. PROPOSED MODIFIED PID CONTROLLER

In frequency domain, the PID controller is expressed in (6) [7], [32].

$$G_{PID}(s) = K\left(1 + \frac{1}{sK_I} + sK_D\right) \tag{6}$$

Great gain is observed due to derivative term that results to increment in sensitivity. Hence, restriction on the same gain is required. The approximation of derivative term does the same and given in (7).

$$G_{PID\_Approx}(s) = K\left(1 + \frac{1}{sK_I} + \frac{sK_D}{1+\frac{sK_D}{N}}\right) \tag{7}$$

A fix value of gain is given by the controller that is expressed in (8). It is take out by low pass filter and it is represented in (9).

$$\lim_{s \to \infty} G_{PID}(s) = K(1+N) \tag{8}$$

$$T(s) = \frac{1}{(1+sT_f)^n} \tag{9}$$

The capacity and filtering is a deciding factor for assigning the value to filter time constant. Consequently, arrangement of PID controller is shown by (10).

$$G_{PID-Filter}(s) = K\left(1 + \frac{1}{sK_I} + sK_D\right) \times \left(\frac{1}{(1+\frac{sK_D}{N})^n}\right) \tag{10}$$

where, n = Order of the filter.

VI. FREQUENCY CONTROL TECHNIQUES OF WIND TURBINE AND TUNING METHOD

Frequency control techniques of WU and tuning method for parameters of PID controller has been deliberated in the following subsections.

A. *Inertial Control*

The inertial control makes the WU to behave as synchronous machine. WU issue kinetic energy from rotating mass. Power pull out from rotating mass of WU is given by (11) [21]-[22], [41].

$$P = \frac{dE_k}{dt} = J\omega_m \frac{d\omega_m}{dt} \tag{11}$$

Per unit torque (*T*) express in respect of inertia (*H*) and per unit speed ($\overline{\omega_m}$) as in (12)

$$T = 2H \frac{d\overline{\omega_m}}{dt} \tag{12}$$

The noise got in the speed measurement is the origin of great deviation in torque set point. This is eliminated by using low pass filter.

B. *Droop Control*

This scheme is analogous to droop characteristics of synchronous generator and makes wind power unit capable to share load according to frequency deviation. The delineative diagram of droop contro1 is exposed in Fig. 1 b. Margin in the WU power is required to implement this control scheme and the power contribute by this is given by (13) [24], [33].

$$\Delta P = \frac{\Delta f_{sys}}{R} \tag{13}$$

where, Δf_{sys} and R are fluctuation in frequency and speed adjustment rate frequency respectively.

C. Pitch Angle Control

The pitch angle has significant role in regulating the power from the WU. The pitch angle has shown the inverse proportion to output power. It is dexterous to alter the power in both directions depending on the availability of the wind speed and is sluggish in nature due to involvement of mechanical mechanism. This power can be increased to a certain level for a given wind speed and is maintained to rated value by lessening pitch angle. The speed error and actuator served as input to the PI controller of this system [22], [40].

VII. RESULTS AND DISCUSSION

The tuning of variables of load frequency control is acquired by Z-N tuning scheme for the given system. The inertia has reduced by same amount as the installed wind power increase in the system. The assumption need to be realize for afore said nature of rise in WU that the no change in entire demand is occurred and WU is not accountable for the fluctuation in system frequency [42]. Wind speed has been taken 10 m/s and wind power contribution level has been considered 10% for examination other parameter has been taken from [30], [43].

The proposed controller's act is inspected with the help of time domain analysis technique for the considered system with 1%, 2%, 3%, and 4% step load deviation (SLD) in individually area. The amplitude of peak, time of settling and overshoot have count for performance investigation. The Table 1toTable 3 are shown the results for all load deviations with pictorial evaluations for both types of controllers. Also, the Fig. 6 to Fig. 8 is spectacled the enhancements in percentage in performance indices offered by suggested controller for 1%, 2%, 3%, and 4% SLD.

A. Comparison of conventional PID and modified PID controller

Proposed controller is implemented for TP with thermal unit and WU. There are following cases of DFIG have analysed with conventional PID and modified PID controller.

- Case 1 Base case: WU without frequency regulation capability
- Case 2 WU with inertial control (C-I)
- Case 3 WU with integration of inertial control and droop control (C-D)
- Case 4 WU with integration of inertial control, droop control and pitch angle control (C-P)

All discussed techniques comprise of speed controller. Fig. 2 a, 2 b, 3 a, 3 b, 4 a, 4 b, 5 a, and 5 b shows the dynamic response of frequency deviation for conventional PID and modified PID controller with above mentioned methods, respectively. Dynamic response of alteration in power flow of tie line (ΔP_{tie}) with frequency control techniques have made known in Fig. 2 c, 3 c, 4 c, and 5 c. It has observed from the Fig. 2 to Fig. 5 that alteration in frequency and power flow of tie line (ΔP_{tie}) have reduced for suggested controller with all techniques and also, reduction in oscillation has been witnessed.

It has been concluded from the above analysis that the modified PID controller has improved the performance in respect of amplitude of first peak, overshoot, and settling time for all cases which revealed its effectiveness. Hence, modified PID control has support its applicability and feasibility.

B. Impact of wind turbine frequency control techniques on two area interconnected system performance

The complete comparison has been presented in the following Table 1 to Table 3 and Fig. 6 to Fig. 8. It is displayed by these tables that C-P controller has produced least value of performance indices and makes the WU system capable to generate the frequency support. The order of capability of controllers to amend the deviation in frequency (DF) and tie line power are C-I controller, C-D controller, C-P controller. The C-P controller is skilled to afford primary frequency response with the help of droop characteristics.

C. Variation of load

The suggested and conventional controller has been tested for a distinguish step demand deviation e.g. 1%, 2% 3%, and 4%. The improvement offered by suggested controller for different parameters has been presented in the graphs. Proposed controller has offered enhanced results in respect of amplitude of peak, time of settling and overshoot, as shown in Fig.6 to Fig. 8 for both 's frequency deviation plus for alteration in power flow of tie line and therefore attested its fittingness. It is obvious from the Fig. 6 to Fig. 8 that the modified PID controller has yielded best possible results in case of C-P with both controllers for different step load perturbation.

Table 1 Comparison between PID and modified PID controller for overshoot

		Case – 1		Case-2		Case 3		Case 4	
SLD	Parameter (p.u.)	PID (10×$^{-3}$)	MPID (10×$^{-3}$)	PID (10×$^{-3}$)	MPID (10×$^{-3}$)	PID (10×$^{-3}$)	MPID (10×$^{-3}$)	PID (10×$^{-3}$)	MPID (10×$^{-3}$)
1%	Δf_1	11.59	9.57	10.51	8.20	5.27	4.02	3.01	2.12
	Δf_2	17.5	15.2	12.9	11.2	11.2	9.5	10.8	9.1
	ΔP_{tie}	73.5	68.9	57.1	53.2	14.3	12.2	11.8	9.4
2%	Δf_1	22.2	18.8	21.8	17.5	10.1	8.1	7.9	6
	Δf_2	37.7	34.0	44.2	39.5	21.5	19.1	19.6	17.0
	ΔP_{tie}	150.1	143.4	115.2	109	31.6	28.3	28.3	23.4
3%	Δf_1	29.6	27.2	28.2	24.5	15.3	13.1	12.9	10.4
	Δf_2	56.8	52.4	66.5	60.1	32.2	27.8	31.3	26.9
	ΔP_{tie}	225.3	215.8	173.2	165	50.1	45.7	44.8	37.4
4%	Δf_1	39.7	37.2	34.4	30.8	21.9	18.9	16.9	14.0
	Δf_2	71.1	67.0	88.9	80.9	42.2	37.7	41.4	35.7

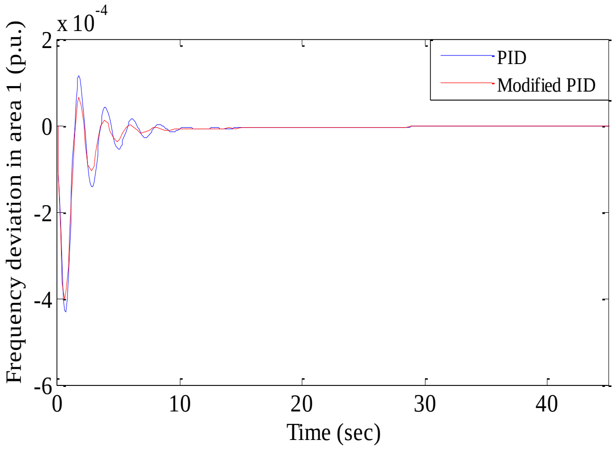
	ΔP_{tie}	231.6	221.3	231.0	218.8	51.6	47.1	51	42.4

Table 2 Comparison between PID and modified PID controller for settling time (millisecond)

		Case – 1		Case-2		Case 3		Case 4	
SLD	Parameter	PID (10×^{2})	MPID (10×^{2})	PID (10×^{2})	MPID (10×^{2})	PID (10×^{2})	MPID (10×^{2})	PID (10×^{2})	MPID (10×^{2})
1%	Δf_1	124.4	121.1	82.2	79	50.78	47.0	50.3	40.4
	Δf_2	133.7	129	78	7.48	57.8	52.6	55.6	45.3
	ΔP_{tie}	221.1	214.8	219.5	209.8	215.7	201.3	179.3	165.8
2%	Δf_1	122	119.7	78.9	77.0	50.3	47.0	50.2	39.9
	Δf_2	122.1	119.7	85.3	83.0	54.9	50.3	51.2	41.1
	ΔP_{tie}	216.6	212.1	219	213.9	215.8	206.3	195.7	183.7
3%	Δf_1	121.4	119.3	78.5	76.6	50.1	47.1	50.2	39.7
	Δf_2	122	119.6	85.4	83.1	55.2	50.51	51.4	41.2
	ΔP_{tie}	221.2	217.4	218.3	213.6	212.2	206.4	199.1	192.3
4%	Δf_1	120	119.5	78.5	77.5	50.1	47.8	50.0	39.6
	Δf_2	119	116.9	85.4	83.4	55.8	52.9	51.6	41.2
	ΔP_{tie}	221.3	217.8	219.9	215.4	211.9	206.9	198.8	193

Table 3 Comparison between PID and modified PID controller for amplitude of first peak

		Case – 1		Case-2		Case 3		Case 4	
SLD	Parameter (p.u.)	PID (10×$^{-3}$)	MPID (10×$^{-3}$)	PID (10×$^{-3}$)	MPID (10×$^{-3}$)	PID (10×$^{-3}$)	MPID (10×$^{-3}$)	PID (10×$^{-3}$)	MPID (10×$^{-3}$)
1%	Δf_1	-43.1	-41.8	-40.4	-38.9	-14.8	-13.5	-13.4	-11.9
	Δf_2	-67.3	-65.2	-60.6	-57.3	-20.7	-19	-20.1	-17.9
2%	Δf_1	-87.0	-85.0	-81.3	-79.4	-32.8	-30.0	-32.7	-29.1
	Δf_2	-136.1	-134.7	-122.4	-119.7	-45.4	-43.0	-45.1	-41.0
3%	Δf_1	-131.1	-128.3	-122.4	-119.8	-50.7	-46.5	-50.5	-45.9
	Δf_2	-202	-199	-182.7	-179.2	-69.9	-66.2	-69.7	-64.2
4%	Δf_1	-175.8	-172.1	-163.4	-159.9	-68.6	-63.0	-68.2	-62.6
	Δf_2	-306	-299.6	-246	-240.4	-91.45	-90.3	-93.9	-87.3



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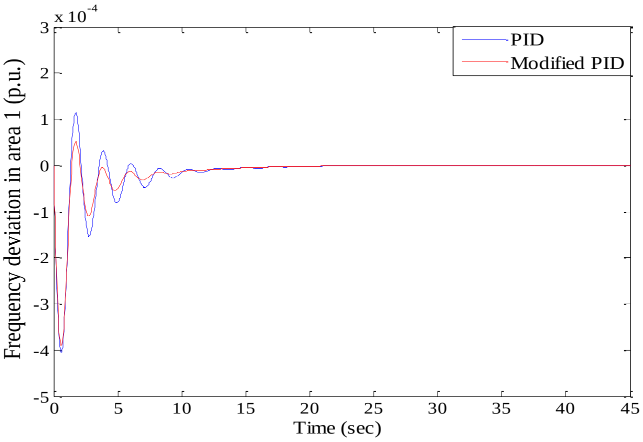

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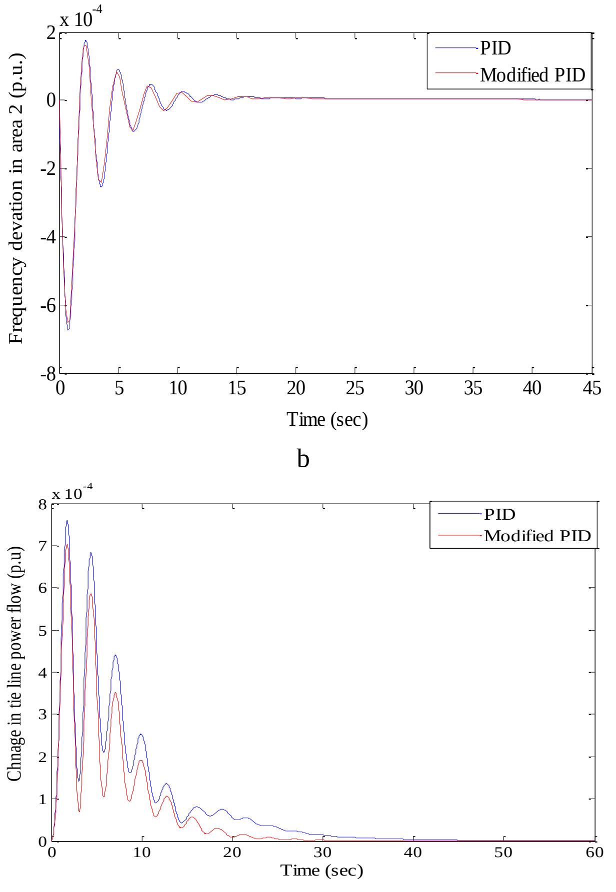


b

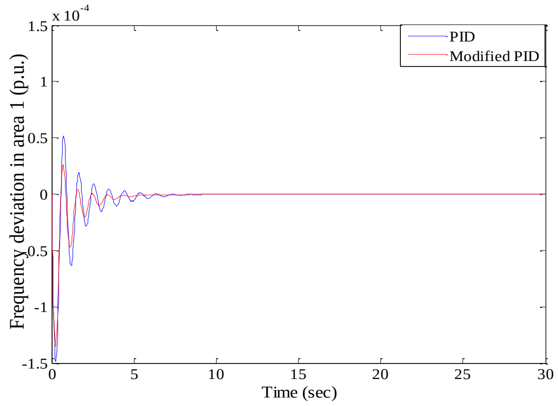
c

Fig. 2. Step response for 1% step load perturbation with WU without frequency control

a DF for area 1

b DF for area 2

c Change in power flow of tie line



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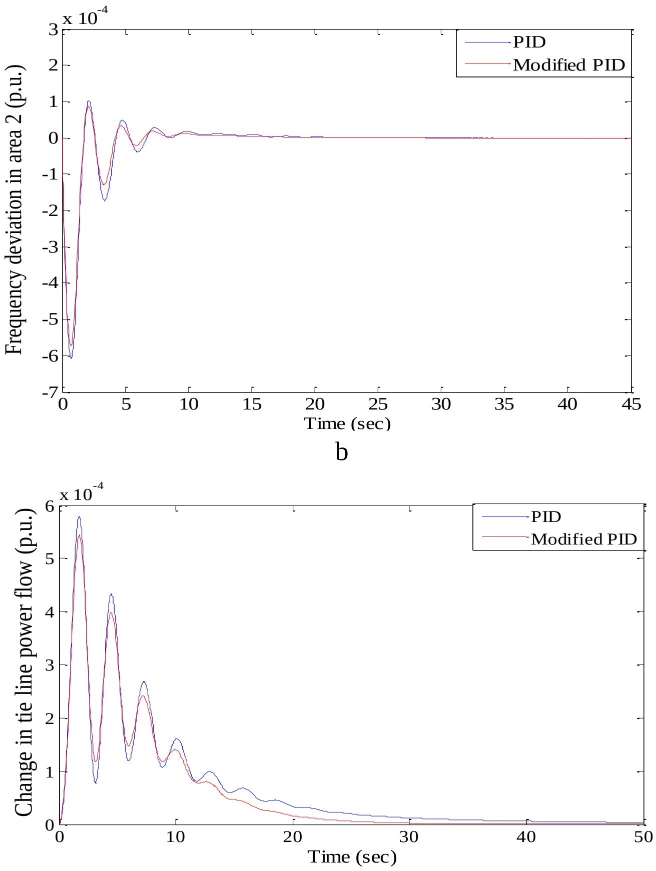


b

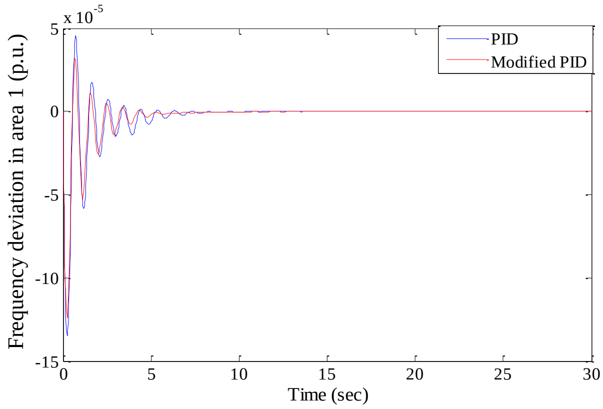
c

Fig. 3. Step response for 1% step load perturbation with WU with C-I

a DF for area 1

b DF for area 2

c Change in power flow of tie line



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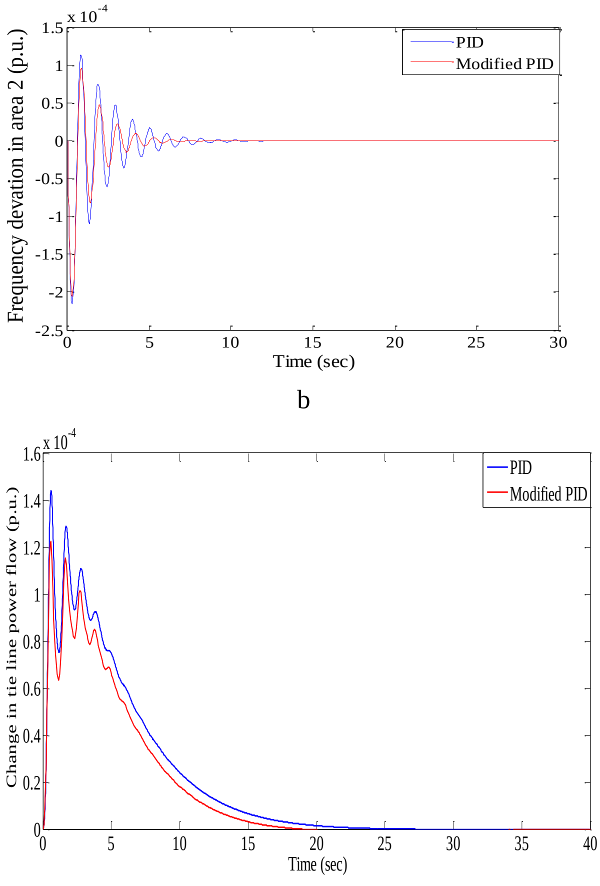

b

c

Fig. 4. Step response for 1% step load perturbation with WU with C-D
a DF for area 1
b DF for area 2
c Change in power flow of tie line

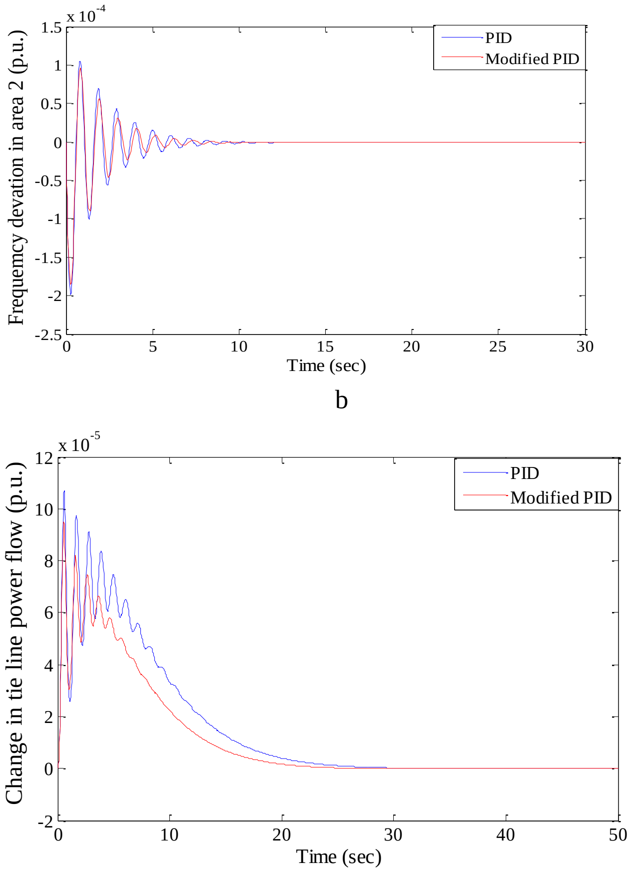

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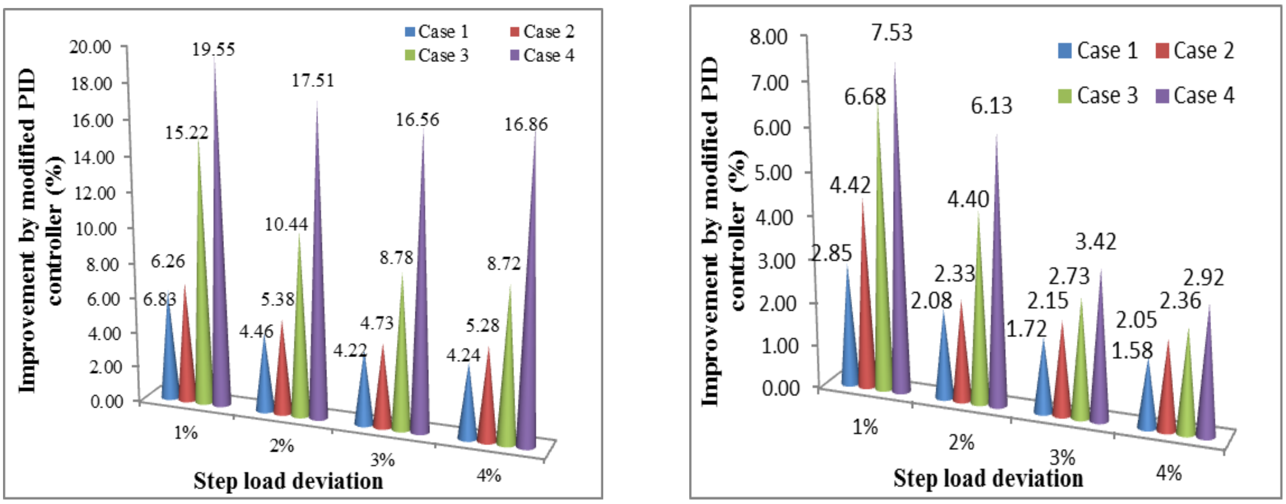
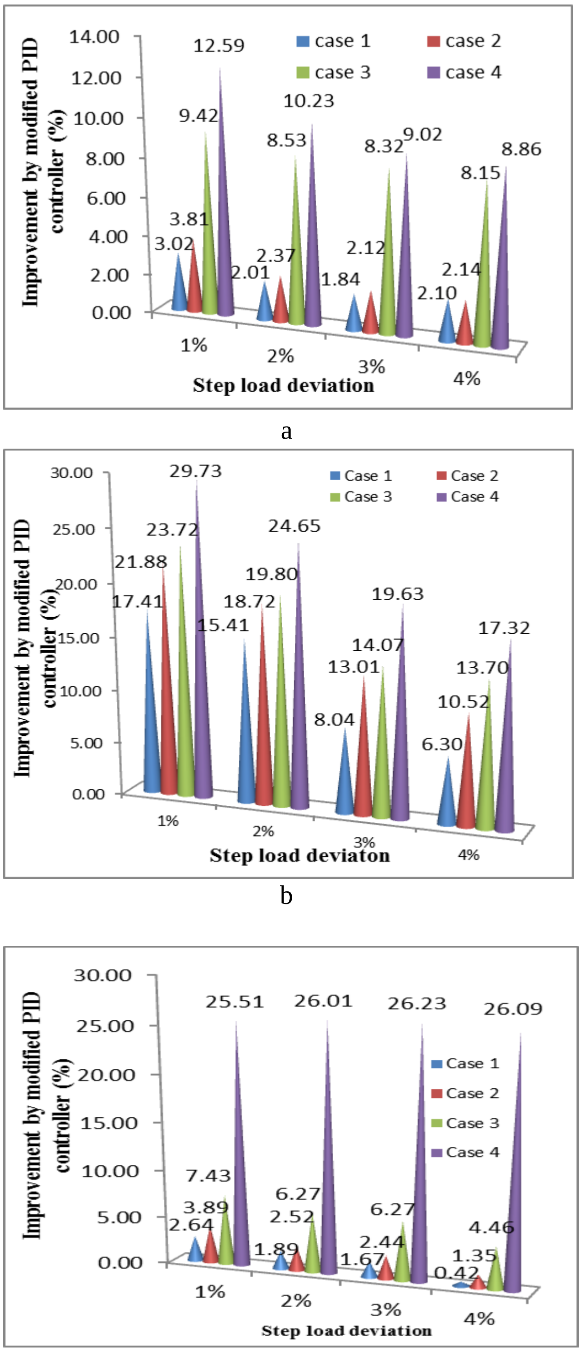
Fig. 5. Step response for 1% step load perturbation with WU with C-P
a DF for area 1
b DF for area 2
c Change in power flow of tie line



a

b

Fig. 6. Percentage enhancement obtained by modified PID controller in change in power flow of tie line
a Overshoot
b Settling time



a

b

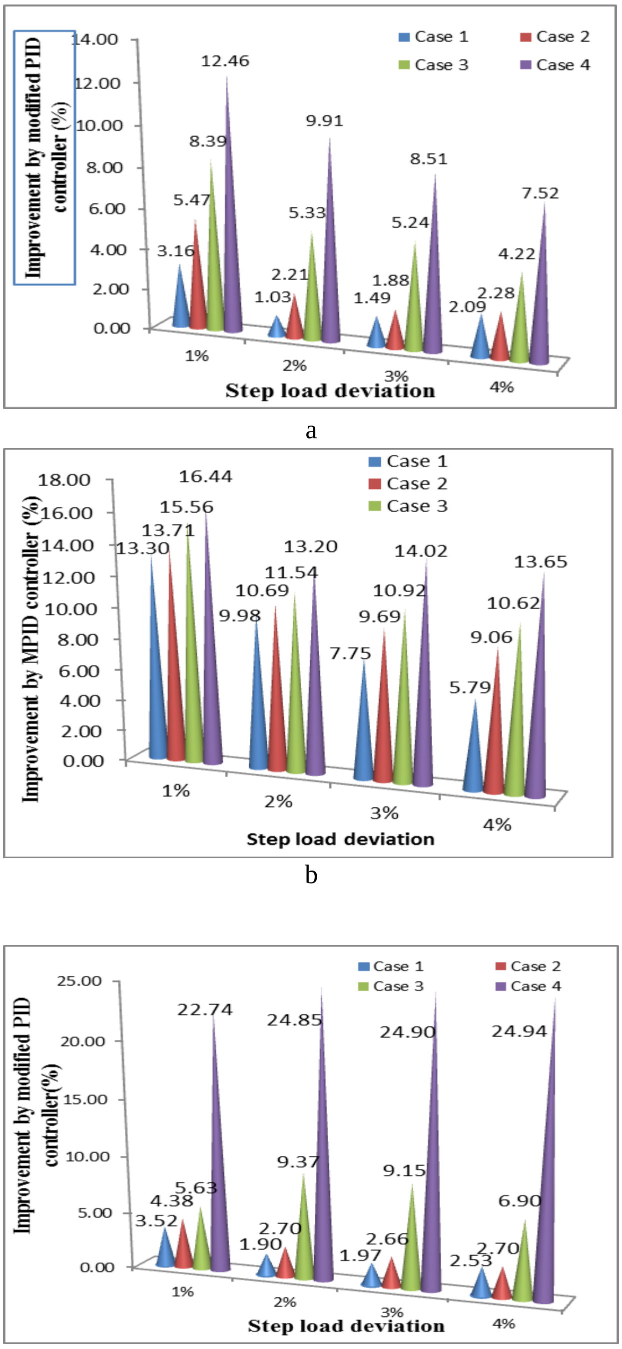
c

Fig. 7.Percentage enhancement obtained by modified PID controller for DF of area 1

a Amplitude of first peak

b Overshoot

c Settling time



a

b

c

Fig. 8.*Percentage enhancement obtained by modified PID controller for DF of area 2*

a Amplitude of first peak

b Overshoot

c Settling time

VIII. CONCLUSIONS

This paper has implemented modified PID controller for TP incorporating WU with various frequency control techniques for 1%, 2%, 3% , and 4% step load perturbation and compared its performance with conventional PID controller. Additionally, frequency control techniques of wind turbine like C-I, C-D, and C-P have been examined with conventional PID and modified PID controller. Proposed controllers has substantially reduced the amplitude of peak, overshoot, and time of settling of deviations in frequency for both area and power flow in tie line with all four cases and has made the frequency and power regulation faster. Furthermore, improvement in performance indices of time domain analysis for different cases shows the feasibility, suitability, and the productiveness of the modified PID controller.

Moreover, the simulation outcomes are inferred that the performance of suggested controller has enhanced with C-P by producing slightest value of all three parameters. Therefore, the modified PID controller gives superior performance in comparison to conventional PID controller for TP including DFIG based WU that is the chief contribution of this work. Also, it is open the possibility of taking frequency support as a ancillary services from WU and that will enhanced the benefit of the WU.

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