INTERNATIONAL JOURNAL OF RESEARCH, SCIENCE, TECHNOLOGY & MANAGEMENT
E-ISSN: 2455:2240, Volume 7 Issue 1
CONFERENCE PROCEEDINGS: ICEMPS-2017

CONTROL STRATEGY FOR FREQUENCY REGULATION OF MICROGRID USING TYREUS-LUYBEN BASED PID TECHNIQUE

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Abstract- ***In this study deals with an autonomous isolated microgrid comprising both controllable & uncontrollable sources, which are diesel generator (DG), aqua electrolyzer (AE), fuel cell (FC), solar, wind, battery energy storage system (BESS), and fly wheel (FW).***

Power generating sources comprises of solar, wind, DG, FC & energy storage element are BESS, FW, AE . AE generates hydrogen which is used by a FC as fuel. The sudden change in load demand and real power generation deviates the power system frequency. The frequency of the system is controlled by regulating the output power of DG, FC, BESS, FW and power absorbed by AE, by the use of controller. Proportional plus integral plus derivative (PID) is used as controller. Proposed hybrid system's controller gains are tuned by using Tyreus-Luyben (TL). On comparison of the system response of TL method and classical method, the TL based controller gives better results.

Keywords- Tyreus-Luyben, fuel cell, fly wheel, Aqua electrolyzer, frequency and power deviation.

I. INTRODUCTION

In today's era, energy plays the key role for growth and development. And electric energy has become so important that one cannot spend a single day without it. And for most of us it will be really hard even to spend a single hour without the electric energy.Distributed generations (DGs) are small capacity generators which uses renewable energy sources (RES), located at dispersed locations. Distributed energy resources (DERs) are power generating sources in DG. Micro grid is a small capacity power grid formed by the interconnection of DGs.

Operating conditions control the micro grid which is operated in a grid interconnected mode. Since, many small capacity generators giving different power output are embedded in the micro grid, in order to maintain the system stability these small capacity generators are connected together to perform highly coordinated operations. The various types of small scale generation systems used in a micro grid can be basically divided into two groups which are as follows :-

Primary sources comprising of solar and wind energy systems. Secondary sources such as diesel generator, fuel cell, battery and flywheel.

The wind and solar comes under the category of not correctly predictable energy sources in which the power varies with time i.e. (not a constant power source).Thus micro grid have fluctuations in power and frequency. To deal with the problem of balancing of increase in load demand or decrease in power generation secondary sources are used in order to get constant power.

Microgrid contains frequency oscillations due to delay in output characteristics. To maintain minimum frequency deviation and to obtain optimal utilization of secondary resources some proper controllers must be designed.

It is well known that the decrease in frequency deviation is caused due to smaller droop characteristics in the conventional Automatic Generation Control (AGC). But there is need of a frequency bias term in AGC as a secondary controller in order to deal with a larger droop. In the past, trial and error approach has been used to explain the controller gains and frequency bias in the context of AGC for the modeling of microgrid.

For the tuning of conventional PID controller Ziegler and Nichols method has been used. The controller gains once tuned for a given operating point are only suitable for limited operating point changes. Therefore, the use of the conventional PID controller does not meet the requirements of the robust performance. MATLAB illustrates the basics of TL. The conclusions given by TL PID controller to the hybrid-power system and conventional PID controller are then compared. The result concludes that the TL PID controller gives better dynamic performance than fixed gain conventional controller. The TL controller also shows better transient performance for load disturbances.

The paper is described as follows. Section II illustrates proposed hybrid System (microgrid model) and its important parts. Tuning of the PID controller by TL method and comparison with Classical method is shown in Section III. Section IV, explains the results of stimulation and Analysis are demonstrated under various condition. And section V shows the conclusion.

2. PROPOSED HYBRID SYSTEM

A self-sufficient isolated DGS comprising of wind power source(300kW) , solar power source (300 kW), diesel generator (400 kW), fuel cell (200 kW), aqua-electrolyser (100 kW) and battery (30 kWh) has been taken into account in this paper. The total generation from renewable sources and from the controllable sources is equal to 600 kW. The battery is used for supplying power only during transient period.[10]

The block diagram of the presented hybrid system is shown in Fig.1.The system consists of wind power source, Solar power source, diesel generator, fuel cell, aqua electrolyzer, battery energy storage system and Fly Wheel. The power given to the load is the sum of output powers from wind and solar power source, diesel generator, fuel cell, battery energy storage system and fly wheel. The aqua electrolyzer is used to absorb the fluctuations of wind and solar power source and produce the hydrogen gas which is used as input to fuel cell generator. Section [13] shows the mathematical models with first order transfer functions for fuel cell, aqua electrolyzer, BESS and Fly wheel & Second order for Diesel Generator.

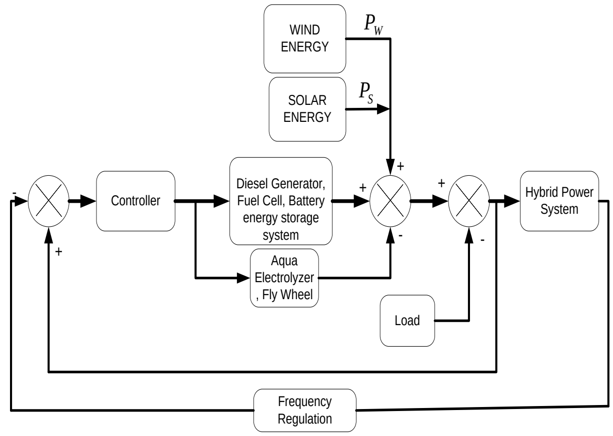


Fig. 1. The block diagram of the microgrid with Primary sources : solar, wind energy system and secondary sources: diesel generators, aqua electrolyzer, fuel cell, battery energy storage system, flywheel and Hybrid power system.

A. *Wind Energy (uncontrollable source)*

Usually maximum power point tracking (MPPT) is implemented in wind energy conversion system (WECS). However, due to this WECS loses its power output controllability. Hence, it cannot be used for frequency regulation of microgrid. To use WECS need to make some modifications in its control loops. Therefore in this paper we have treated the WECS as an uncontrollable source, not participating in frequency control. A constant power strategy is used in this paper [1]-[2].

B. *Solar Energy (uncontrollable source)*

MPPT is also used in case of photovoltaic (PV) systems (as was in the case of WECS). Because of this, we cannot control power output. Hence, in this paper the solar system is treated as an uncontrollable source, not participating in frequency control of the microgrid. A constant power strategy is used in this paper [1]-[2].

C. *Diesel Generator (controllable source)*

Load demand can be followed by the Diesel generator by means of its governor control and speed droop. The governor maintains the fuel input to an engine through a valve mechanism. The engine works like a turbine and moves the synchronous generator. The governor of the diesel generator can be modelled with a first order transfer function [10], as depicted in (1).

$$G_{dg}(s) = \frac{1}{1 + sT_{dg}} \qquad (1)$$

Similarly, the turbine of the diesel generator can be modeled as presented in (2).

$$G_{dt}(s) = \frac{1}{1+sT_{dt}} \qquad (2)$$

Therefore the overall transfer function of a diesel generator will be

$$G_{dgt}(s) = \frac{1}{1+sT_{dg}} \times \frac{1}{1+sT_{dt}} \qquad (3)$$

Where T_{dg} , T_{dt} is the time constant of governor and turbine respectively.

D. Battery energy storage system (controllable source)

It is always an advantage if we are using RES to run power system instead of our conventional energy sources. A problems of using RES in power system operation is the fluctuation occurring in the amount of renewable energy obtained. Just for example, we won't be getting a steady flow of wind over a longer period of time. Similar fluctuation is also observed in case of solar energy(on an bright, sunny day one can expect high amount of solar energy, and on a cloudy day low level of solar energy would be obtained). Our prime objective of using secondary supply is to accommodate load fluctuation or/and primary source fluctuation. So any form of fluctuation in secondary storage is undesirable. Hence we cannot directly use RES as direct secondary supply. However, we all are aware about the advantage of RES over conventional energy sources. So to accommodate RES in the secondary supply side an alternative method called as BESS is used. The power generated from RES is stored inside a battery. This stored power is used to handle the load fluctuation and/or primary source fluctuation situation. From the battery we are able to get constant source of power without any fluctuation and also by this system we are able to use RES effectively.

The transfer function model of battery energy storage system expressed by first order as [2] [14-16] and implemented in DGS model.

$$G_{BESS}(s) = \frac{1}{1+sT_{BESS}} \qquad (4)$$

Where T_{BESS} is time constant of battery energy storage system.

E. Fly Wheel (controllable source)

A flywheel is an electromechanical storage system, as energy can be converted between both electrical and mechanical form. In this system energy is stored as kinetic energy of a rotating body (rotor). The rotor used is normally made up of steel or resin/glass or resin/carbon-fiber. During charging, the flyover gains speed due to flow of electric current through the motor while during discharging current flows out of the system due to generator, which further leads to reduced speed of the wheel [2].

The flywheel is modeled as a first order equation (5) and implemented in DGS model.

$$G_{fw}(s) = \frac{1}{1+sT_{fw}} \qquad (5)$$

Where T_{fw} is the time constant of fly wheel.

F. Fuel cell (controllable source)

Power is produced in an fuel cell by the help of an electrochemical reaction between hydrogen and oxygen. Benefits of using fuel cell over conventional generators (like diesel generators) are that the energy produced is very pure and free from pollution. Usually a fuel cell generates a very small voltage which is not sufficient to meet our needs. In order to create large enough voltage, the cells are arranged in series-parallel combination to make a fuel cell stack. Hydrogen, which helps in for power generation in fuel cell, is an expensive source as compared to other conventional energy sources. This is the only drawback of fuel cell[G]. Normally a fuel cell generator has a higher order model and also non-linearity. However during low frequency domain analysis we can be consider it to have a first order lag transfer function model given as [13] and implemented in DGS model.

$$G_{fc}(s) = \frac{1}{1+sT_{fc}} \qquad (6)$$

Where T_{fc} is time constant of fuel cell.

G. Aqua electrolyzer (controllable source)

In order to solve this problem we use aqua electrolyzer that produces hydrogen. Hydrogen is produces in aqua electrolyzer by method of "electrolysis of water" for which electric current is obtained from the power system. The transfer function model of aqua electrolyzer can be explained by [13] and implemented in microgrid model.

$$G_{ae}(s) = \frac{1}{1+sT_{ae}} \quad (7)$$

Where T_{ae} time constant of the AE. Since a typical AE contains several power converters, AE has little time constant. [7].

H. Power and Frequency Deviations

In a power system comprising of synchronous generator, if the balance between the generation and load demand is not maintained, the frequency deviates based on the domination of generation or load [17]-[19]. The power deviation is the difference between the power generation PG and the power demand PL. From the swing equation of a synchronous machine, the generator mathematical model can be written as

$$\Delta f = \frac{f_{sys}}{2Hs}[\Delta P_G - \Delta P_e] \quad (8)$$

Where

$$P_G = P_W + P_S + P_{dgt} + P_{fc} - P_{ae} \pm P_{bess} \pm P_{fw} \quad (9)$$

The loads types are frequency dependant and non-dependant.So speed load characteristics of composite load is approximated by

$$\Delta P_e = \Delta P_L + D\Delta f \quad (10)$$

Where the first term of (18) is the non-frequency dependent part of the load and the second term

$$\Delta P_G - \Delta P_L = \left(\frac{2H}{f_{sys}} s + D\right)\Delta f \quad (11)$$

Therefore the transfer function for system frequency variation to per unit power deviation is given by (20)

$$G_{sys}(s) = \frac{\Delta f}{\Delta P_G - \Delta P_L} = \frac{1}{D + (2H/f_{sys})s} = \frac{K_{ps}}{1+sT_{ps}} \quad (12)$$

Where K_{ps} and T_{ps} are $1/D$ and $(2H/f_{sys})$, respectively. It is to be noted here that (8) is valid only when there is a synchronous machine in the microgrid. Therefore the researchers should be careful in using (12) for simulating the microgrid [10].

3. TUNING OF PID CONTROLLER GAIN

The objective of the controllers is to maintain the power output of secondary sources, to minimize the frequency deviation by generating appropriate control signals and hence to enhance the performance of the microgrid. In the presence of many secondary sources there is a chance of adverse interaction between their regulators which leads to deterioration of frequency stability of the microgrid. So far there is no one method for best tuning that satisfies all loops. Therefore, to avoid the adverse interaction there is a need of appropriate tuning of the individual PID controller [13].

In this paper SISO toolbox is used for PID tuning(PID controller is used because there is a need to improve both transient and steady state response).To generate this compensator Ziegler-Nichols Close loop is used as a tuning algorithm with TL as tuning preference.

From the compensator "C" the Values of gains are calculated using

$$C = K_p + \frac{K_i}{S} + K_d S \quad (13)$$

Where K_p =Proportional gain,
K_i =Integral gain, K_d =Derivative gain

And The Frequency bias is selected at which ITSE (Integral time square error) is minimum [13] and given by

$$ITSE = \int_0^t t|\Delta f|^2 dt \quad (14)$$

The results obtained from the TL method are compared with classical method and it is found that proposed method gives the better response over the classical method.

TABLE I

TUNING OF PID CONTROLLER GAINS ACCORDING TO CLASSICAL METHOD

Microgrid Components	Frequency Regulation K_f	K_p	K_i	K_d
Diesel Generator	4	0.0397	0.0756	3.3084
Aqua Electrolyzer	0.2	0.35	0.03	0.07
Fuel Cell	2	0.1220	0.2154	3.1608
Battery	0.1	0.4188	0.01666	0.01
Fly wheel	0.1	0.3654	0.01666	0.01

TABLE II

TUNING OF PID CONTROLLER GAINS ACCORDING TO TL METHOD

Microgrid Components	K_f	Modified K_p	Modified K_i	Modified K_d
Diesel Generator	4	0.1095	0.0069	0.2995
Aqua Electrolyzer	0.2	1.501	5.0389	0.0992
Fuel Cell	2	0.1948	0.0472	0.261
Battery	0.1	3.385	0.1299	0.100
Fly wheel	0.1	3.385	0.1299	0.100

IV. SIMULATION ANALYSIS

The Detailed block diagram of the microgrid is shown in Fig.2. and its implementation in MATLAB/SIMULINK. The analysis was carried out by running the system for 80 sec. During this time the system was put under power variation in load as well as in sources. Before creating disturbance in all the cases, constant wind power supply of approximately 0.3 pu. solar power supply of 0.3 pu. and a load demand of 0.6 pu. are considered. The time period shown in some plots differ from the simulation time since in those cases the system is settling before the simulation time [13].

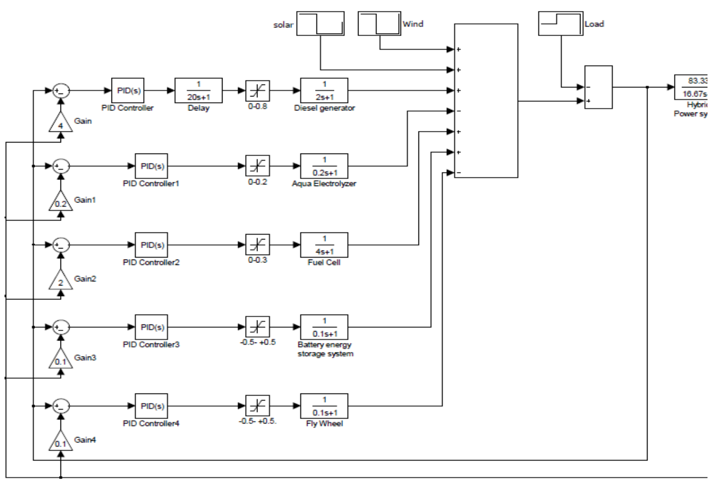
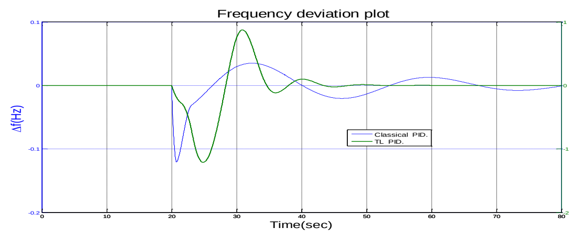


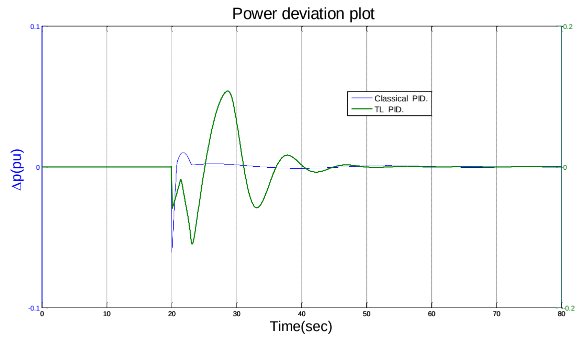
Fig.2: The SIMULINK block Diagram of the microgrid in MATLAB.

CASE 1: The load is increased from 0.6 pu. to 0.66 pu. and the wind(0.3 pu.) and solar power(0.3 pu.) sources are kept constant for the time period of 10 sec.(Time Domain Analysis).

Because of the load variation the microgrid elements(i.e. secondary sources) are giving their dynamic performance and are shown in fig.(3).In the transient period the BESS and fly wheel are supplying the power in such a manner that when BESS is supplying power, fly wheel is charging and vice versa. The fluctuation in the power System frequency is the result of sudden change in the Renewable energy sources power and load demand and the PID controller handles the frequency deviation. The output of system components is automatically adjusted to corresponding value to minimize the error in supply demand and the frequency deviation. The gain values of PID controller obtained through classical and TL technique and are given in Table-1 & Table-II respectively. In the set of graphs shown in figure.8 the left axis is indicating classical method and right axis is indicating TL method.



(a)



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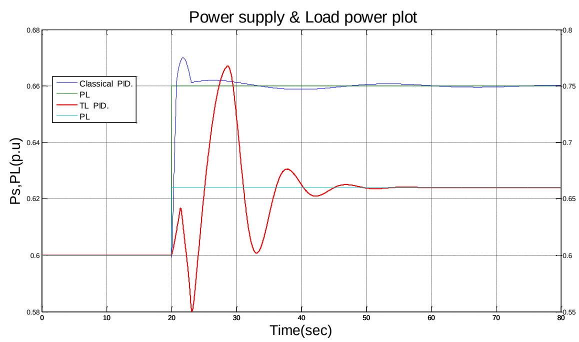
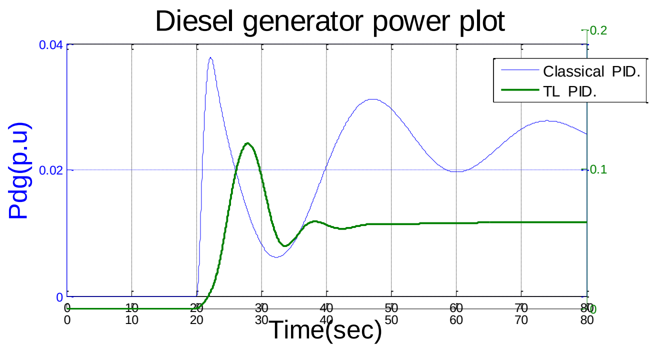
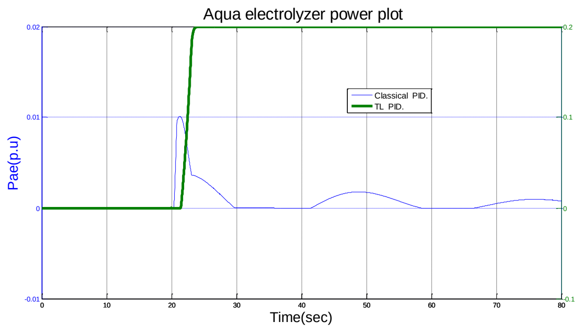


(c)



(d)



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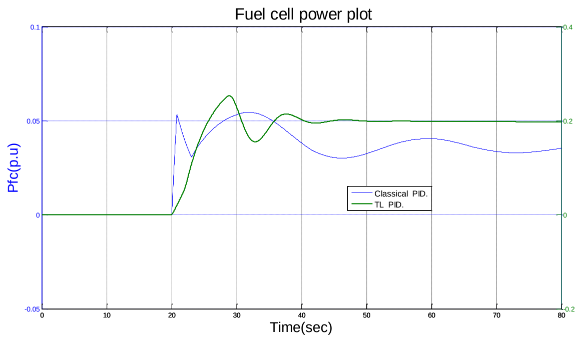

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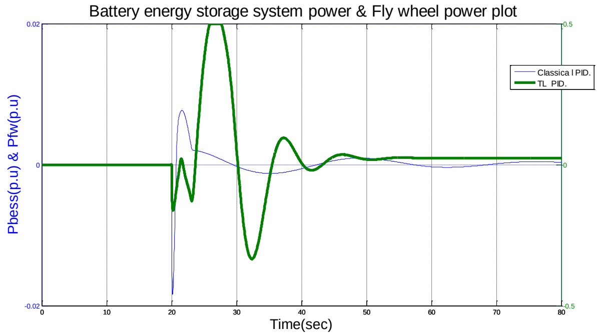


(g)

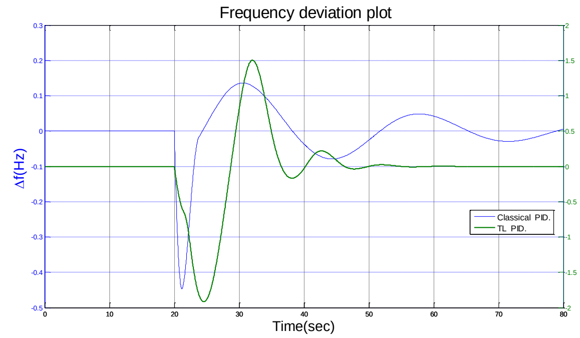
Fig. 3 Simulation results of proposed system Case 1: (a) Frequency deviation of power systems Δf (b) Error in power supply and demand (c)Deviation in supply and load (d) Power supply form diesel generator P_{dg} (e) Aqua electrolyzer P_{ae} (f) Fuel cell P_{fc} (g) Battery P_{bess} & Flywheel P_{fw}

And it can be observed in the graphs shown in fig.3. that transient time taken by TL method is more useful than transient time taken by classical method.

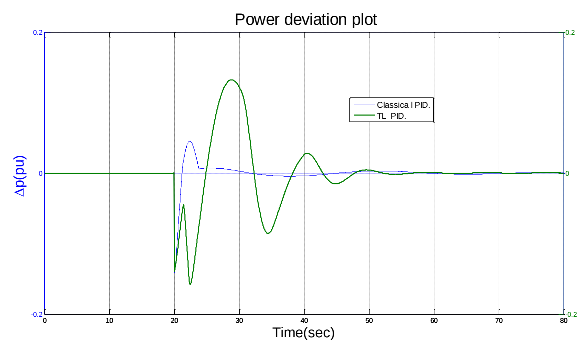
CASE 2: The load is increased from 0.6 to 0.68 pu. Wind and solar power sources are decreased from 0.28 pu. And 0.26 pu. Respectively at 20 sec. (Time Domain Analysis)

In this study, we consider supply and load both are vary simultaneously. Simulation results are shown in Fig.4 (a)-(f).

In the set of graphs shown in figure.4 the left axis is indicating classical method and right axis is indicating TL method.



(a)



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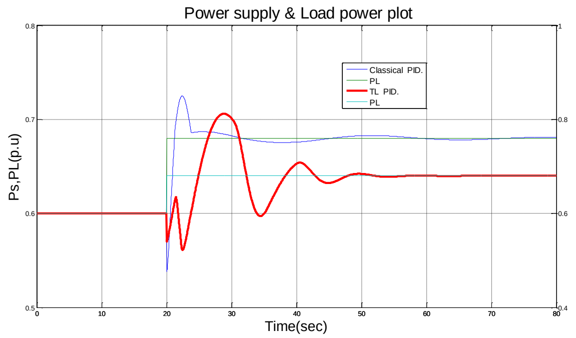

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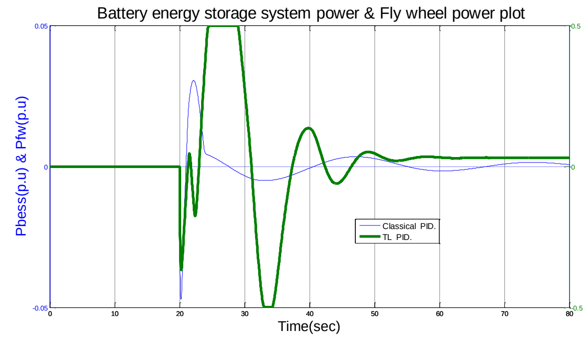

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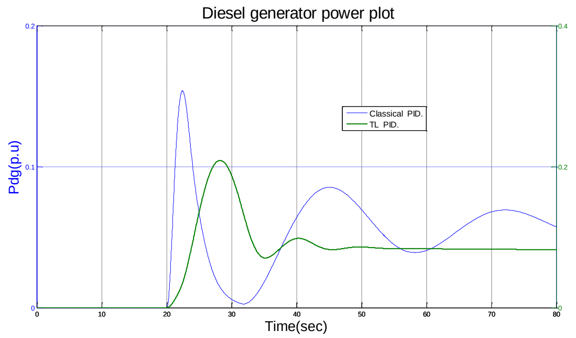

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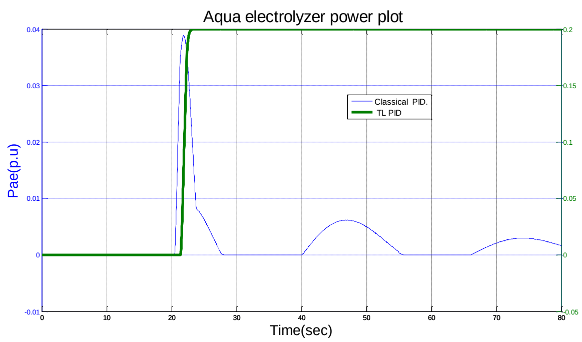

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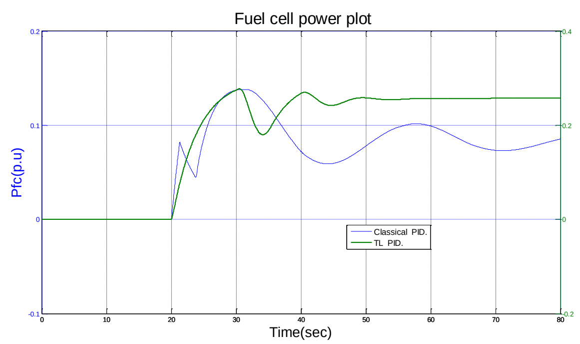

(f)

Fig. 4 Simulation results of proposed system Case 2: (a) Frequency deviation of power systems Δf (b) Error in power supply and demand (c)Deviation in supply and load (d) Power supply form diesel generator P_{dg} (e) Aqua electrolyzer P_{ae} (f) Fuel cell P_{fc} (g) Battery P_{bess} & Flywheel P_{fw}

And it can be observed in the graphs shown in fig.4 that transient time taken by TL method is much better than transient time taken by classical method.

4. CONCLUSION

When load and power sources (wind, solar) vary then there is a mismatch in supply and demand therefore to eliminate this mismatch automatic generation control system is required in the Renewable energy power generation system.

This paper provides a new dimension on how to reduce frequency deviation using TL based PID Controller. The results obtained by this method are promising and are much more superior to the classical method. By using TL method we got a transient period of 30 sec-40 sec for frequency control as compared to that of 165 sec-200 sec using classical method.

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