Load Disturbance Rejection Based PID Controller for Frequency Regulation of a Microgrid

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Abstract- This paper deals with an autonomous isolated microgrid comprising both controllable & uncontrollable sources. Like solar, wind, diesel generator (DG), aqua electrolyzer (AE), fuel cell (FC), battery energy storage system (BESS), and fly wheel (FW) are considered. Solar, wind, DG and FC are power generating source & BESS, FW, AE as energy storage element. The generated hydrogen by an AE is used as fuel for a FC. The power system frequency deviates for the sudden change in load demand and the real power generation. The output power of DG, FC, BESS, FW and power absorbed by AE is regulated by using controller such that frequency of the system is controlled. Controller used is proportional plus integral plus derivative (PID). Load Disturbance Rejection (LDR) is used for tuning of proposed hybrid system’s controller gains. This uses the chien-hornes-resnick (CHR) setting with 20% overshoot.

The system response of LDR method is compared with classical method and the result of LDR based controller gives better response then the classical method.

Keywords- Load disturbance rejection, aqua electrolyzer, fuel cell, fly wheel, frequency and power deviation.

I. INTRODUCTION

In today’s rapidly growing world, energy in any form is of utmost importance. Among the different energy types, electric energy is one of the most important forms of energy and one cannot imagine the life without electric energy in these days. Distributed generations (DGs) are small capacity generators, preferably uses renewable energy sources (RES), located at dispersed locations. The power generating sources in DG are called as distributed energy resources (DERs). These DGs interconnected together to form a power grid of smaller capacity, known as microgrid [1].

The microgrid may operate in an autonomous mode or it can operate in a grid interconnected mode, decided by the operating conditions. Since, the concept of microgrid involves many small capacity generators, may also be with variable power output, connected together necessitates highly coordinated operation among the different units to maintain the system stability [2]-[3].

The various types of small scale generation systems used in a microgrid can be categorized into two groups namely primary sources consisting of solar and wind energy systems and secondary sources such as diesel generator, fuel cell, aqua electrolyzer, battery and flywheel [4]-[6]. The solar and wind fall into the category of not correctly predictable energy sources in which the power varies with time i.e. not a constant power source. This results in power and frequency fluctuations in the microgrid. To overcome this problem secondary sources are used to supply power to balance out the increase in load demand or the reduction in power generation. However due to the delay in the output characteristics of secondary sources, the frequency oscillations are still present in the microgrid [7]-[8]. Hence there is a need of designing proper controllers for secondary sources for optimal utilization of energy and to maintain minimum frequency deviations.

In the conventional Automatic Generation Control (AGC), it is well established that smaller the droop characteristics, lesser will be the frequency deviations. However, if the droop is larger, then there is a requirement for frequency bias term to be included in AGC as a secondary controller. In the past, the modeling of microgrid in the context of AGC has already been explained with controller gains and frequency bias decided through trial and error approach [9].

Method described in Ziegler and Nichols has been used for the tuning of conventional PID controller [11]. 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 [12]. Basics of LDR are illustrated in MATLAB. The results of applying the LDR PID controller to the hybrid-power system are compared to those obtained by the application of a conventional PID controller. Simulated results show that the LDR PID controller provides improved dynamic performance than fixed gain conventional controller. The LDR controller also shows better transient performance for load disturbances [20].

The paper is described as follows. Section II illustrates proposed hybrid System (microgrid model) and its main components. Tuning of the PID controller by LDR method and compared to Classical method is presented in Section III. Section IV, explains the Simulation Results and Analysis are demonstrated under various condition. The conclusion is presented in Section V.
II. PROPOSED HYBRID SYSTEM

In this paper, we have considered a 100% self-sufficient isolated microgrid consisting of wind power source (300 kW), solar power source (300 kW), diesel generator (400 kW), fuel cell (200 kW), aqua-electrolyser (100 kW) and battery (30 kWh). 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. The block diagram of the proposed hybrid system is shown in Fig.1. The system consists of wind power source, Solar power source, diesel generator, fuel cell, battery energy storage system and Fly Wheel. The power supplied 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. The mathematical models with first order transfer functions for fuel cell, aqua electrolyzer, BESS and Fly wheel & Second order for Diesel Generator are shown in this section [13].

![Block Diagram of Hybrid System](image)

**A. Wind Energy (uncontrollable source)**

Usually maximum power point tracking (MPPT) is implemented in wind energy conversion system (WECS). However, because of this WECS loses its power output controllability. Hence, it cannot be used for frequency regulation of microgrid. In order to use WECS for this purpose we 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 do not have a control over the 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)**

Diesel generator can follow the load demand by means of its governor control and speed droop. The governor regulates the fuel input to an engine via a valve mechanism. The engine acts as a turbine and drives the synchronous generator. The governor of the diesel generator can be modelled with a first order transfer function [10], as depicted in (1).

\[
G_{dg}(s) = \frac{1}{1+sT_{dg}}
\]  

(1)

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

\[
G_{tb}(s) = \frac{1}{1+sT_{tb}}
\]  

(2)

Therefore the overall transfer function of a diesel generator will be

\[
G_{d}(s) = \frac{1}{1+sT_{dg}} \times \frac{1}{1+sT_{tb}}
\]  

Where \(T_{dg}, T_{tb}\) 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. One of the 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 microgrid model.

\[
G_{BESS}(s) = \frac{1}{1+sT_{BESS}}
\]  

(4)
Where $T_{RESS}$ 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 in the form of 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, electric current flows through the motor increasing the speed of the flywheel while during discharging current flows out of the system due to generator, which further leads to slowing of the wheel [2].

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

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

(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. One of the advantages of using fuel cell over conventional generators (like diesel generators) is that the energy produced is very pure and free from pollution. Usually a fuel cell produces 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 form a fuel cell stack. Hydrogen, which is used 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. 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 microgrid model.

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

(6)

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

**G. Aqua electrolyzer (controllable source)**

In order to overcome this drawback 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 expressed by [13] and implemented in microgrid model.

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

(7)

Where $T_{ae}$ time constant of the AE. Since a typical AE consists of several power converters, time constant of the AE is very small [7].

**H. Power and Frequency Deviations**

In a power system consisting of synchronous generator, if the balance between the generation and load demand is not maintained, the frequency deviates depending 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

$$\Delta f = \frac{f_{sw}}{2H} \left[ \Delta P_G - \Delta P_L \right]$$

(8)

Where

$$P_G = P_e + P_A + P_W + P_F - P_w \pm P_{w0} \pm P_{fe}$$

(9)

Generally, the loads are of mixed type like frequency dependant and non-dependant. So speed load characteristics of composite load is approximated by

$$\Delta f = \Delta P_L - D \Delta f$$

(10)

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

$$\Delta P_L = \left( \frac{2H}{f_{sw}} \right) \Delta f$$

(11)

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

$$G_{sw}(s) = \frac{\Delta f}{\Delta P_L - \Delta P_T} = \frac{1}{D + \left( \frac{2H}{f_{sw}} \right)} = \frac{K_p}{1 + sT_p},$$

(12)

Where $K_p$ and $T_p$ are $\sqrt{D}$ and $\left( \frac{2H}{f_{sw}} \right)$, 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].

**III. Tuning Of PID Controller Gain**

The objective of the controllers is to regulate 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 single definition for best tuning that applies to 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 open loop is used as a tuning algorithm with LDR as tuning preference. This method uses the Chien-Hrones-Resnick (CHR) setting with 20% overshoot. It is worth mentioning here that Ziegler-Nichols closed loop cannot be applied to first-order or second-order systems with time delay. If Ziegler-Nichols closed loop is selected for these cases, the tuning algorithm will automatically be switched to Ziegler-Nichols open loop [20].
From the compensator “C” the Values of gains are calculated using

\[ C = K_p + \frac{K_i}{s} + K_d s \]  \hspace{1cm} (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

\[ ITSE = \int_0^t |\Delta f|^2 dt \]  \hspace{1cm} (14)

The results obtained from the LDR 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 LDR METHOD**

| Microgrid Components | \( K_f \) Modified \( K_p \) Modified \( K_i \) Modified \( K_d \) |
|----------------------|-----------------|-----------------|-----------------|-----------------|
| Diesel Generator     | 4               | 0.1025          | 0.0073          | 0.3013          |
| Aqua Electrolyzer    | 0.2             | 1.498           | 4.5399          | 0.1044          |
| Fuel Cell            | 2               | 0.1858          | 0.0464          | 0.156           |
| Battery              | 0.1             | 3.380           | 0.1251          | 0.098           |
| Fly wheel            | 0.1             | 3.380           | 0.1251          | 0.098           |

**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 is the different 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.](image)

**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 20 sec.( Time Domain Analysis).**

Due to 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 due to the sudden change in the Renewable energy sources power and load demand and the PID controller is used to control 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 LDR technique and are given in Table 1 & table 2 respectively. In the set of graphs shown in figure.8 the left axis is indicating classical method and right axis is indicating right axis.
And it can be observed in the graphs shown in fig. 3, that transient time taken by LDR method is much better 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 right axis.
we got a transient period of 35 sec-50 sec for frequency there is a mismatch in supply and demand therefore to transient time taken by classical method. And it can be observed in the graphs shown in FigA that transient time taken by LDR method is much better than deviation using LDR based PID Controller. The results control as compared to that of 165 sec-200 sec using classical is required in the Renewable energy power generation system.

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 presents a new approach to reduce frequency deviation using LDR based PID Controller. The results obtained by this method are promising and are much more superior to the classical method [13]. By using LDR method we got a transient period of 35 sec-50 sec for frequency control as compared to that of 165 sec-200 sec using classical method.

V. CONCLUSION

And it can be observed in the graphs shown in Fig4 that transient time taken by LDR method is much better than transient time taken by classical method.

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