Frequency Deviation Mitigate For Renewable Energy Power System for Constant Load in MATLAB Simulation

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Abstract: **In this research paper frequency deviation mitigate analysis on Renewable Energy Power System for constant load in MATLAB Simulation for autonomous system. The results of Renewable Energy Power System are analyzed in frequency-domain and also analyzed the changes in generated supply Power. In proposed system included five Wind Turbine Generators (WTG_S), Fuel Generator (FG) and Energy Storage System (ESS). The nature of output power of wind turbine generator is mostly non-linear and this deviation effect on the frequency of the all system and also depends on the sudden change in total generation power , to solve this problem considering renewable energy power system with PID controller with proper control gain. By using PID controller the frequency deviation of the system is alleviated. A simulation approach based on mathematical modelling of Wind Turbine Generator (WTG_S), Fuel Generator (FG) and Energy Storage System (ESS) the system observed in various cases in many operating points and different-different conditions, such as variable (non-linear) wind speed and load disturbances. It can be concluded from all MATLAB simulation results that the power deviation of the system is alleviated.**

Keywords: **Wind Turbine Generator (WTGs), Fuel Generator (FG), Energy Storage System (ESS), System Stability, MATLAB simulation, and Frequency Deviation.**

1. INTRODUCTION

India is a large country and has many rural areas. There is not always grid connection to outlying rural areas and many of these rural areas remain without electricity. These areas are sparsely populated and have a low power demand. However, to encourage economic growth in these rural areas, some form of electricity is needed. During the past several decades, large amount of natural resources of the earth have been unlimitedly consumed, and our living environment has been severely destroyed and polluted.

In recent years the increasing concerns about the limited fossil fuel resources led to the awareness that the amount of energy import should be decreased so as to become less dependent of oil exporting countries. Further, the impact of fossil fuel on the environment, especially the global warming and the harmful effects of carbon emissions have created a new demand for clean and sustainable energy sources. Wind, sea, solar, biomass, geothermal

powers are sustainable energy sources. Among these, wind and solar have the potential to make significant contribution and hence assume great importance [1]

The hybrid generation power system is coming up. The system having an abundantly clean generation strategy can supply power to the load demand. However, if we use wind turbines, the output power is not constant and it varies with wind speed rise and fall. Furthermore, these fluctuations result in frequency variations one existing method to solve these issues is to install batteries which absorb power from wind turbine generators. The other method is to install a dump load which dissipates unpredictable power. Using these methods, the hybrid renewable power energy system generation system can supply almost good quality power. [3]

The use of wind turbines to produce power is not a new idea but the large scale use is. Solar power can also be traced back thousands of years. Earliest uses were for cooking. A hybrid energy system is a system that consist of two or more alternative energy sources (ex: solar and wind). Hybrid energy systems are growing in popularity due to the reliability of standalone solar or wind power sources.

A hybrid energy system can supply AC power or DC power or both, depend upon system designer and requirement of consumer. A hybrid power generation/energy storage system may combine all different kinds of available renewable energy (wind, solar, geothermal, bio mass, tidal, hydro electricity and ocean) related with available energy storage units (flywheel, battery, fuel cell, super capacitor, Superconducting Magnetic Energy Storage (SMES) etc.). The hybrid power generation/energy storage system with suitable control and effective coordination among various subsystems is effectively delivered and supplied the required power to the connected loads. [4]

A typical hybrid generation system relies on power electronic interfacing for functioning and interfacing between different generating units and with the distribution network (in grid connected operation). The hybrid system requires back up protection for the system to make it reliable. Back up protection is provided by the fossil-fuel engine generator and Aqua electrolzer etc.

In hybrid system the frequency deviates for sudden changes in load or generation or the both. The controllers (PI or PD or PID) are installed before the sources to alleviate this frequency deviation. Various optimization approaches, such as, Genetic Algorithm (GA), Particle Swam Optimization (PSO), Artificial Neural Network (ANN), are applied to optimize the gains of the controllers used in automatic generation control. All types of controllers are used with the hybrid system with proper control gain to alleviate the frequency deviation in the system. [5-6]

II. CONFIGURATION OF SYSTEM WITH TRANSFER FUNCTION

The following section will describe the different components of proposed system. It can consist of following components are - Wind Turbine Generator (WTGs), Fuel Generator (FG), Energy Storage System (ESS), Power modulator (PM),Constant Electrical Load (EL). It needs to be noted that apart from the component operation frequency deviation and power differences are an important consideration in the proposed system. The Configuration of Renewable Energy Power System in Time Domain MATLAB Simulation is shown in fig. 1. The generation subsystem comprises of four WTGs, and an FG. The storage subsystem ESS is connected to the electrical load side. The study is conducted for WTG, FG and ESS which required suitable power converter for exchanging energy with the AC/ DC system. The ESS is assumed to have enough capacity to store surplus energy generated by generating subsystems. When the load demand increases, the ESS can release enough energy to connect within a short time. The FG is standing by generator that may automatically start up to deliver power to the system only when the total power generated by the generating subsystem is insufficient even if the ESS may have enough storage energy [2].

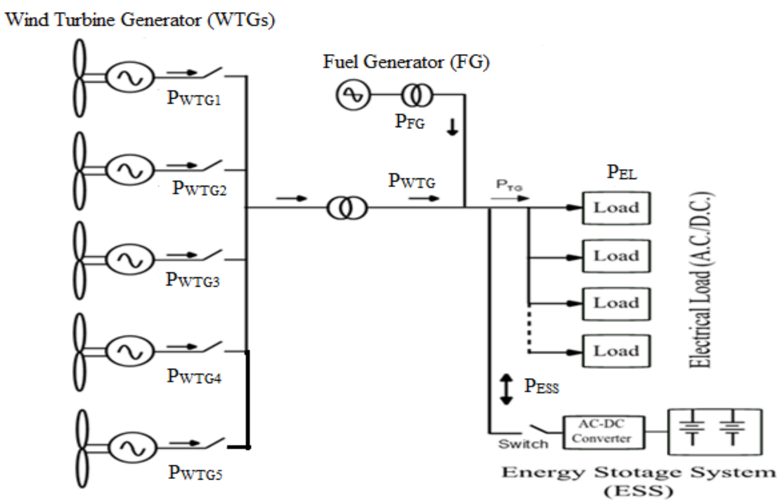

Figure.1: Block Diagram of system developed diagram

The net power generation P_{TG} is shown in fig. 1 is determined by:-

1. A part of output power from with WTGs (P_{WTG})

2. The output power of FG (P_{FG})

3. The exchanging power of ESS (P_{ESS})

The expression for P_{TG} is given by

$$P_{TG} = \left(\sum_{i=1}^{5} P_{WTGi}\right) + P_{FG} \pm P_{ESS} \qquad 1$$

To precisely simulate the dynamic behaviours of practical WTGs, FG, ESS, etc. should employ high-order mathematical models with nonlinearity. These high order models may include associated power conditioners and controllers. For large-scale power system simulations, however, simplified models or transfer functions are generally employed. Hence, the power losses and controllers are not considered in the two cases of this paper. The mathematical modeling for wind speed model and various power generation / energy storage subsystems such as WTGs, FG, ESS, CELP

A) Wind Speed for Proposed System:

The generated power of the Wind Turbine Generator (WTG) depends on wind speed $V_{WS.}$ The wind is modelled as the algebraic sum of base wind speed, gust wind speed, ramp wind speed, and noise wind speed. The associated equations for different wind-speed components are given below [3]

The base wind-speed component can be expressed by

$$V_{WB} = C_B \qquad 2$$

Where C_B is the constant and its value always depend upon the climatic condition of located side when the Wind Turbine Generator (WTG) is operating.

The Gust of wind-speed component can be expressed by

$$V_{WG} = \begin{Bmatrix} 0, & t < T_{1G} \\ V_{cos,} & T_{1G} < t < T_{1G} + T_G \\ 0, & T_{1G} + T_G < t \end{Bmatrix} \qquad 3$$

Where

$$V_{cos} = \frac{MAX(G)}{2}\left\{1 - \cos 2\pi\left[\left(\frac{t}{T_G}\right) - \left(\frac{T_{1G}}{T_G}\right)\right]\right\}$$

T_G is the gust of wind period, T_{1G} the starting time of Gust of wind, and MAX (G) is peak of the gust wind. The gust of wind speed is the usual (1 − cosine) gust of wind used in wind studies.

The ramp wind-speed component can be expressed by

$$V_{WR} = \begin{Bmatrix} 0, & t < T_{1R} \\ Vramp, & T_{1R} < t < T_{2R} \\ 0, & T_{2R} < t \end{Bmatrix} \qquad 4$$

Where

$$V_{ramp} = MAX(R)\left[1 - \left(\frac{(t - T_{2R})}{(T_{1R} - T_{2R})}\right)\right]$$

MAX(R) is the ramp maximum, T_{1R} the ramp start time, T_{2R} the ramp maximum time. The values of MAX(R) are select depend up on the simulations time.

The noise wind-speed component can be expressed by

$$V_{WN} = 2\sum_{i=1}^{N} \sqrt{S_V(\omega_i)\Delta\omega}\, \cos(\omega_i t + \phi_i) \qquad 5$$

Where

$$\omega_i = (i - 0.5)\Delta\omega,$$

ϕ_i a random variable with uniform probability density on the interval $0 - 2\pi$, and

$$S_V(\omega_i) = \frac{2K_N F^2|\omega_i|}{\pi^2\left[1 + \left(\frac{F\omega_i}{\mu\pi}\right)^2\right]^{4/3}}$$

is the spectral density function, ($K_N = 0.004$) the surface drag coefficient, (F= 2000) the turbulence scale, and μ the mean wind speed at reference height of 7.5, 4.5, and 15 m, respectively. Various studies use N = 50 and $\Delta\omega = 0.5 - 2.0$ rad/sec to obtain excellent results.

According to the aforementioned four wind-speed components, the employed wind-speed model is defined by [3]

$$V_{WS} = V_{WB} + V_{WG} + V_{WR} + V_{WN} \qquad 6$$

B) WTG's Output Power:

The wind turbine is characterized by non-dimensional curves of power coefficient *Cp* as a function of both tip speed ratio λ and blade pitch angle β. The tip speed ratio, which is defined as the ratio of the speed at the blade tip to the wind speed, can be expressed by

$$\lambda = \frac{R_{blade} \times \omega_{blade}}{V_{WS}} \qquad 7$$

Where R_{blade} (= 23.5 m) is the radius of blades and ω_{blade} (= 3.14 rad/sec) is the rotational speed of blades. The rotational speed of blades is depending upon the wind speed, and radius of blade depends upon wind turbine. So that power of co-efficient and tip speed ratio is not a fix quantity but a variable quantity. The expression for equation (4.19) of C_P is also approximating as a function of λ and β is given by [7 and 10]

$$C_p = (0.44 - 0.0167\beta) sin\left[\frac{\pi(\lambda - 3)}{15 - 0.3\beta}\right] - 0.0184(\lambda - 3)\beta \qquad 8$$

The output power of WTGs is

$$P_{WTG} = \frac{1}{2}\rho A_{RS} {V_{WS}}^3 C_p$$

Where

ρ (= 1.25 kg/m3) is the air density,

A_{RS} (= 1735 m2) is the swept area of blades,

C_p is the Power Co-efficient, V_{WS} is the Velocity of wind speed.

C) Transfer Functions of Various Generation Subsystems:

The transfer functions of the WTG, FG, and ESS shown in Fig. 1 are, respectively, represented by a first-order lag as given later [8, 9 and 11]

$$(T.F)_{WTG_S}(s) = \frac{K_{WTG}}{1 + sT_{WTG}} = \frac{\Delta P_{WTGK}}{\Delta P_{MWT}} \qquad 9$$

$$(T.F)_{FG}(s) = \frac{K_{FG}}{1 + sT_{FG}} = \frac{\Delta P_{FG}}{F_f} \qquad 10$$

$$(T.F)_{ESS}(s) = \frac{K_{ESS}}{1 + sT_{ESS}} = \frac{\Delta P_{ESS}}{F_D} \qquad 11$$

D) Power Differences:

We must control the supply power so as to meet the required load demand since the output power of wind turbine generators fluctuates with wind speed. To maintain a stable operation for proposed system, the total power generation must be effectively controlled and properly dispatched to meet the constant electrical load power of the connected loads. This power control strategy is determined by the difference between constant electrical load power P_{EL} and total generation power P_{TG} as follows [3]

$$P_D = P_{EL} - P_{TG} \qquad 12$$

E) Frequency Deviation:

In power systems, the frequency Deviation depends on the total generation power either it deficit or exceed and similarly depend on electrical load power, either it is increase or decrease. The frequency deviation of power system F_d is represented as follows [11]

$$F_D = \frac{P_D}{G} \quad 13$$

Where P_D is power deference between total generation power to electrical load power, and G is the system frequency constant. The expressions is valid under ideal conditions, in actual practice, there will be a delay in the frequency characteristics and, hence, the above equation is modified as

$$F_D = \frac{P_D}{G(1+Ts)} = \frac{P_D}{Ms+D} \quad 14$$

Where is the frequency characteristic time constant, is the load damping constant, and is the inertia constant. In this study, is chosen as 0.2 and is 0.012

III. TWO STUDIED CASES OF THE PROPOSED SYSTEM

The better understandings of frequency deviation in this proposed system I will be make two studies cases

A) Case-I WTG_1, WTG_2, WTG_3, WTG_4 and WTG_5 are connected to the system with Constant Electrical load

B) Case-III WTG_1, WTG_2, WTG_3, WTG_4 and WTG_5 are connected to the system with PID Controller and Constant electrical load

A) Case-I:

The block diagram of this studied case is shown in Figure 2. This case assumed that WTG1, WTG2, WTG3, WTG4 and WTG5 are connected to the system with a constant electrical load at different times, FG and ESS is also connected. The power generated from WTG1, WTG2, WTG3, WTG4 and WTG5 is combined with FG power to supply a constant electrical load power to the system. At time duration 0s to 250s, the value of electrical load power is closer to match the value of total generated power so that, the ESS neither stored nor released the power in the system. But in the duration 250s to 300s the total generated power is higher to the electrical load power, there is a surplus of power, so that ESS starts its working. The total generated power of this case can be expressed by

$$P_{TG} = \left(\sum_{i=1}^{5} P_{WTGi}\right) + P_{FG} \pm P_{ESS} \quad 15$$

Where i^{th} is the number of WTG_i connected to the studied system

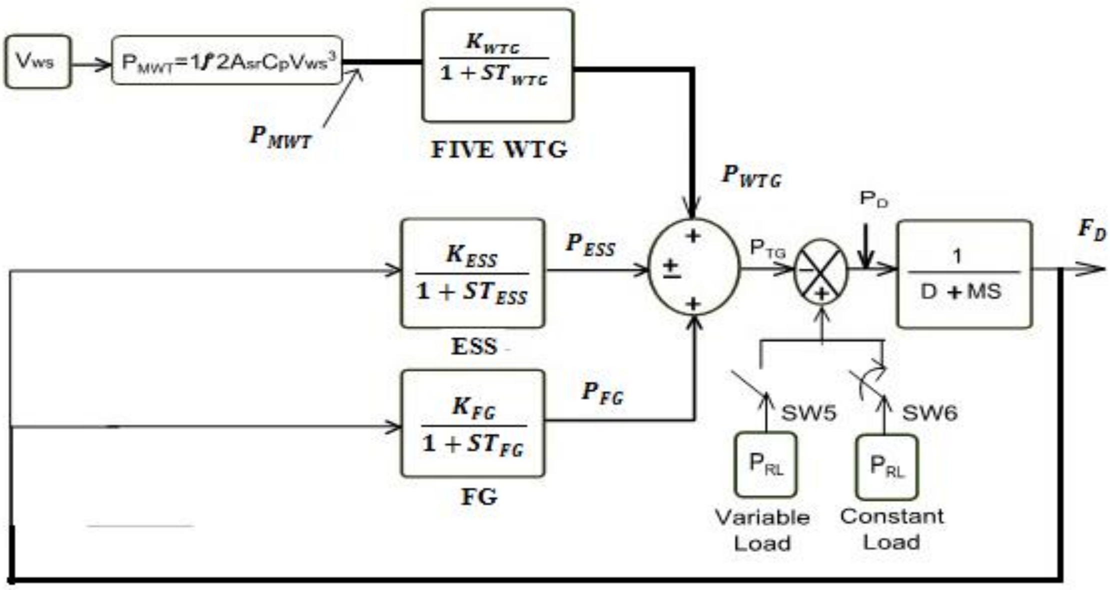

Figure.2: Block Diagram of CASE-I

B) Case-II:

The block diagram of this studied case is shown in Figure 3. This case assumed that WTG1, WTG2, WTG3, WTG4 and WTG5 are connected to the system at different times, FG and ESS is also connected with PID controller. The power generated from WTG1, WTG2, WTG3, WTG4 and WTG5 is combined with FG power and ESS to supply electrical load power to the system. At time duration 0s to 250s, ESS release the stored Power and remaining time duration it stored the power. At duration 250s to 300s the total generated power is higher to the references load power, there is a surplus of power, so that ESS starts its working. The total generated power of this case can be expressed by

$$P_{TG} = \left(\sum_{i=1}^{5} P_{WTGi}\right) + P_{FG} \pm P_{ESS} \qquad 16$$

Where i^{th} is the number of WTG_i connected to the studied system

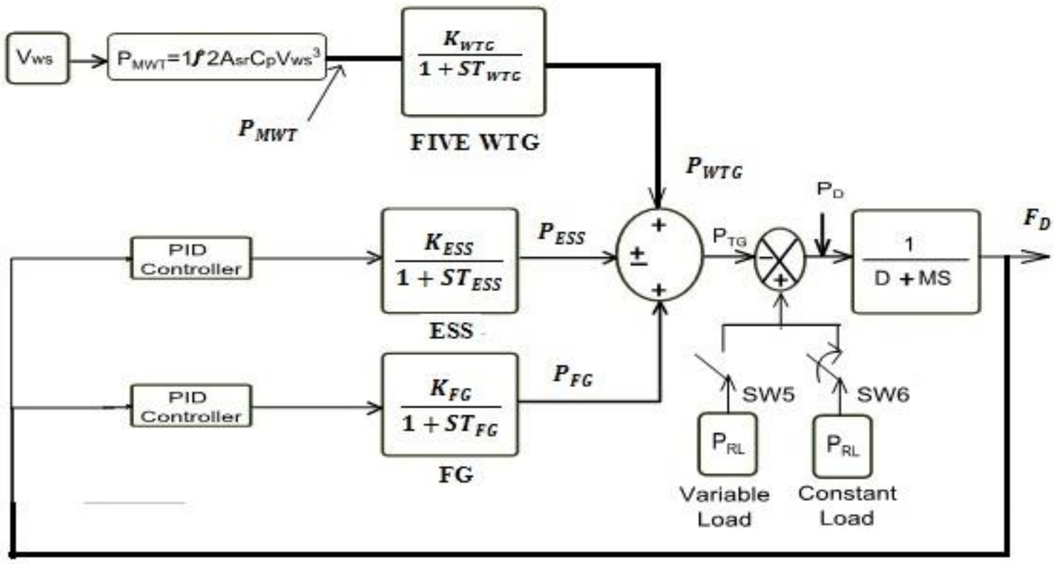

Figure.3: Block Diagram of CASE-II

IV. TIME DOMAIN MATLAB SIMULATION RESULTS

In this time domain simulation model, time domain simulated responses of the studied proposed system under various operating points and different disturbance conditions are carried out. In this case all quantities in the plot are in per unit (P.U) except that velocity of wind speed (V_{WS}) is in meter per second (m/s).

In studied case V_{WS} is set to be 6.5 m/s. The total electrical load power in the studied case is assumed to be P_{EL} =1.5p.u duration of 0s to 300s under this condition electrical load is constant. To deeply examine the effect of power of wind turbine generator and as well as total power generation, to create sudden drop in wind speed (6.5 m/s to 1.5 m/s) and sudden rise in wind speed (1.5 m/s to 9.5 m/s) of V_{WS} properly applied to the studied system at specified time.

A) MATLAB Simulation Result Analysis of Case-I:

The MATLAB Simulink diagram and simulation result diagram of this studied case is shown in Figure 4 (a), whose simulation result analyzed, under various operating condition are respectively in the following section

- **Base Case** During 0s < t < 200s, specific time domain MATLAB simulation responses, the average wind speed V_{WS} is around 6.5m/s and the total power generated by WTG_{1to5}, is 1.0p.u. If value of generated power is less than to the electrical load power than FG is automatically connected to the system at t = 0s to supply power of around 0.5p.u. There is no surplus power generated because of low power generation that's why ESS did not store any power, due to power differences between generated power and electrical power the system frequency deviation varied around 0 to 2.0p.u.

- **Sudden Fall Wind Speed** During 200s < t < 250s, V_{WS} suddenly drops to 1.5 m/s at t = 200 s, value of total power generated by wind turbine is decrease to approximately zero. The FG starts up to generated power whose value is varied around 1.5p.u. There is no surplus power generated because of low power generation that's why ESS did not store any power. The power differences between generated power and electrical load power are slightly different as compare to the base case so that the value of system frequency deviation is slightly high around 0 to 4.5p.u.

- **Sudden Rise Wind Speed** When 250s < t < 300s, V_{WS} suddenly rises to around 9.5 m/s at t = 250s to make total power generated higher than 1.0p.u to 3.0p.u. Here Total power generation is higher than the electrical load power so that the surplus power is occurred. Due to this surplus power FG power is become exactly zero or say to instantaneously shutdown, at that time ESS stored the surplus power of the system. After the all got the Frequency Deviation value in excessive amount around 250p.u as compare to the previous values. Due to this frequency deviation is harmful to our system.

MATLAB Simulation Result of Case –I:

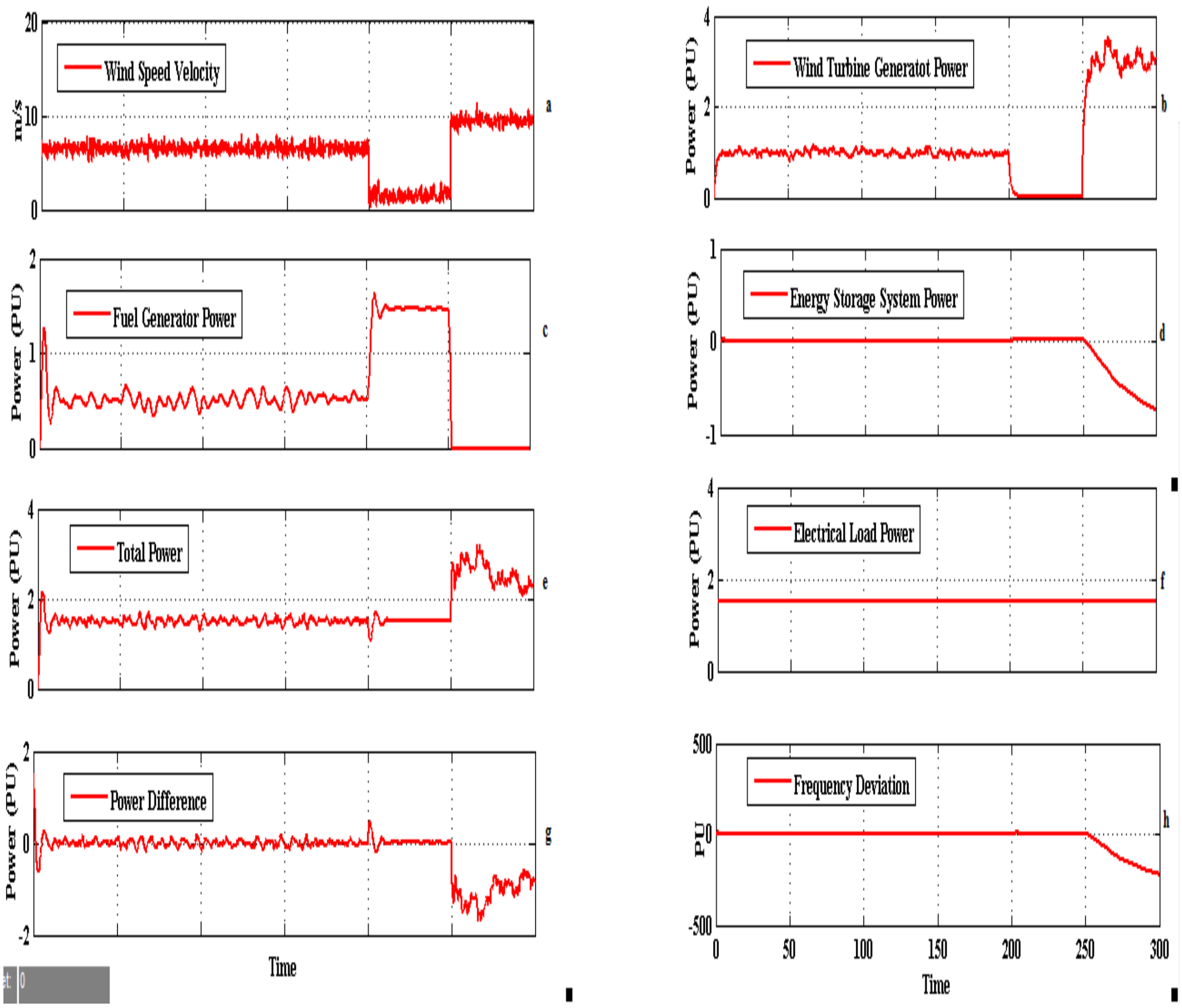

Figure 4 (a)

B) MATLAB Simulation Result Analysis of Case-II

The MATLAB Simulink diagram and simulation result diagram of this studied case is shown in figure 5 (a) and Figure 5 (b) , whose simulation result analyzed, under various operating condition are respectively in the following section

- **Base Case** During 0s < t < 200s, specific time domain MATLAB simulation responses, the average wind speed V_{WS} is around 6.5m/s and the total power generated by WTG_{1to5} is 1.0p.u. If value of generated power is less than to the electrical load power than FG is automatically connected to the system at t = 0s to supply power of around 0.5p.u. At that time the ESS is approximately zero. Because of PID controller is connected to the system with proper control. There is no surplus power generated so that the system frequency deviation is zero, because of the PID controller with connecting proper PID gain, the value of gain is find out by using hit and trial method.

- **Sudden Drop of Wind Speed** During 200s < t < 250s, V_{WS} suddenly drops to 1.5 m/s at t = 200 s, value of total power $P_{WTG1to5}$ decrease to zero. Since electrical load power is still kept at 1.5p.u, the FG starts up to generated P_{FG} and ESS release power whose value is varied around 1.45p.u and 0.05 respectively. There is no surplus power generated so that the system frequency deviation is zero, because of the PID controller with connecting proper PID gain.

- **Sudden Rise of Wind Speed** When 250s < t < 300s, V_{WS} suddenly rises to around 9.5 m/s at t = 250s to make total power of $P_{WTG1to5,}$ is 3.0p.u. Total power generation of $WTG_{1to5,}$ is higher than the electrical load power so that the surplus power is occurred. Due to this surplus power FG power is become exactly zero, at that time ESS stored the surplus power of the system. The system frequency deviation is mitigated as compare to case-I because of using PID controller with proper gain value.

MATLAB Simulation Result of Case –II:

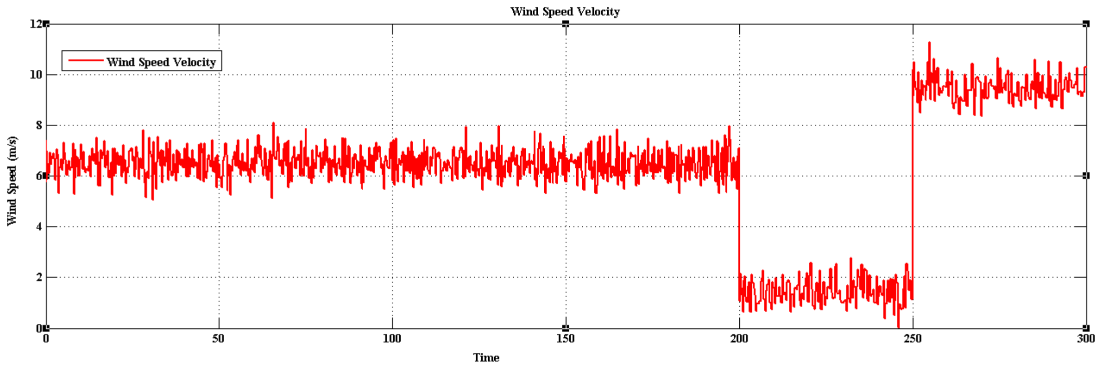

Figure 5 (a)

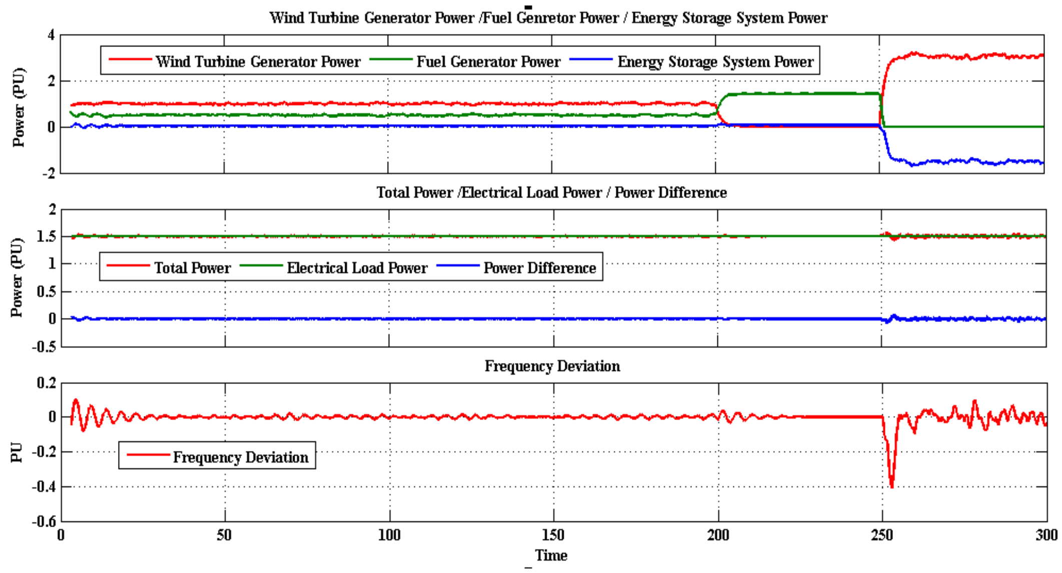

Figure 5 (b)

V. CONCLUSION

This Paper has presented the MATLAB simulation for frequency deviation mitigate of Renewable Energy power System. The studied system contains five Wind Turbine Generator (WTGs), Fuel Generator (FG) and Energy Storage System (ESS). The required power of the system is generated by the Wind Turbine Generator (WTGs) through power converters. The employed mathematical model for the WTGs, FG and ESS are represented by first-order transfer function to simplify the tasks of Renewable Energy Power System simulation. To studied the important performance of the Renewable Energy Power System, models for wind speed, mechanical power of Wind Turbine Generator (WTGs) is properly selected to simulate.

In Proposed system MATLAB simulations two cases are studied in various Operating Conditions at different specific time such as base case, sudden wind speed fall and sudden wind speed increase

The frequency deviation mitigate of Renewable Energy power System uses five Wind Turbine Generators (WTGs). The output power of Wind Turbine Generator (WTGs) is mostly in fluctuating nature because of wind speeds and this effect the system frequency. The one of the existing method used in this dissertation is battery power storage system is used to mitigate the above problem which stored and release the excess or insufficient power of the system respectively.

The controllers are also used to mitigate same problem but in better way It can be concluded from the MATLAB simulation results which is observed in various cases that the power generation from the electrical wind turbine, fuel generator and energy storage system, this full-fill or balance the electrical load power demand according to its changes. The frequency deviation of the proposed system is properly controlled within a range by the use of controller with proper control gain. We have proposed this Renewable Energy Power System for un-electrified small villages and as well as Small Island.

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