TIE-LINE FREQUENCY BIAS CONTROL OF PV-WIND HYBRID POWER SYSTEM FOR MICRO GRID APPLICATION

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The solar and wind power technologies being well established, penetration of these Renewable Energy Sources (RES) into the grid is increasing progressively. The large scale interconnected PV-Wind hybrid power farms (PVWHPF) are usually located away from the load center depending on the geographical conditions. There by, inter area power dispatch is required in interconnected power system with a proper Tie-line control. The load frequency Control (LFC) of interconnected RES generation is gaining importance in Micro-grid application. A at tie-line frequency bias control of interconnected two-area PVWHPF is investigated in MATLAB, Simulink. The framework of LFC system should be able to handle complex, high degree, wide distribution of load and power generation to ensure the successful operation of LFC by maintaining generation load balance. This paper ad-dress a droop characteristic based at tie-line frequency control to minimize frequency deviation, power exchange over the tie-line. The proposed control demonstrates good tie-line frequency control of interconnected PVWHPF.

Keywords: Two-area, Load Frequency Control, Droop Control, at Tie-line bias control, Hybrid power system, Micro-grid

1. Introduction

Renewable Energy Sources (RES) are rapidly gaining popularity for clean and green generation and 3-phase grid connection is required. An important aspect in grid integration is the optimal power dispatch and grid integration to the existing power system, where efficiency is primary requirement [1]. In the interconnected power system Automatic Generation Control (AGC) plays a vital role in ensuring reliability and power quality of the grid. In large scale systems all the generating units operates at same frequency as they are synchronized to the power system. Any change in load in the system causes frequency deviation in the

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area of change and this change in frequency causes the generators synchronized to the system to act according to the change. The power is transferred through tie-line to compensate the change in load [2]. The Load Frequency Control (LFC) problem has gained much importance because of large capacity and complication in the advanced integrated network. The main goal of LFC is to adjust the power generated by the generators such, that the tie-line power and frequency of the power system are kept within the prescribed limits [3]. Different control strategies of renewable energy generation-based power system, has been proposed and investigated by many researchers in recent years [4, 5, 6, 7, 8].

In LFC technique to minimize the frequency error a PI controller is employed. The PI controller is employed due to its simplicity, easy actualization, cost-effective, rugged and localized behavior of the control strategy [9, 10].

The PI controller reduces the steady state deviation of the frequency to zero, but the dynamic performance of the system is affected. As the dynamic behavior of the system is affected it results in longer settling time of frequency and tie-lime power deviation. In order to overcome the draw backs of conventional controller various controllers were proposed in the literature such as Fuzzy Logic Controller (FLC) [11], Model Predictive Control (MPC) technique, de-centralized co-efficient diagram method (CDM), Adaptive Neuro fuzzy system (ANFIS), effect of Phase Lock Loop (PLL) and frequency measurement on LFC, dual model BAT algorithm based scheduling of PI controllers, Fuzzy gain scheduling of PI, optimal re y algorithm, droop characteristics based controller [12, 13, 14, 15, 16, 17].

The LFC / AGC employed in the interconnected system uses tie-line bias control strategy to maintain scheduled power interchange and frequency. The LFC will regulate the generators connected to the tie-line to maintain stability under different load perturbation in any area of the interconnected system. In general, there are three modes in which interconnected operation can be carried out

- Flat Frequency Control: The control is to obtain a constant frequency. In this type of control, the generators respond to frequency changes only. It cannot have control over the power ow in the interconnected tie-line.
- Flat Tie-line Control: In this method of control implementation the system responds to tie-line changes and changes its generation to maintain the scheduled tie-line interchange. The controller cannot respond to frequency changes.
- Frequency Bias Control: Both the above methods have disadvantages. So, as to overcome it a combined control is used, called the Frequency Bias Control. The controller responds to tie-line power and frequency change in the system and changes generation to maintain the stability of the system.

From the literature it can be observed that no specific research was done towards interconnection of only RES without any storage device or diesel generator set. All the controllers proposed were investigated by using the transfer function derived from the behavior of the actual system. With the above drawback a Tie-Line Frequency Bias Control of Two-Area PV-Wind hybrid.

2. Modeling of Two-area PV-Wind hybrid power system:

The system representation of interconnected Two-area system is shown in Fig. 1. The electrical equivalent of the two-area system in shown in Fig. 2. A tie-line frequency bias control is implemented using droop characteristics technique. The generation will respond to change in frequency of the system and will maintain the frequency of the system at 50 Hz.

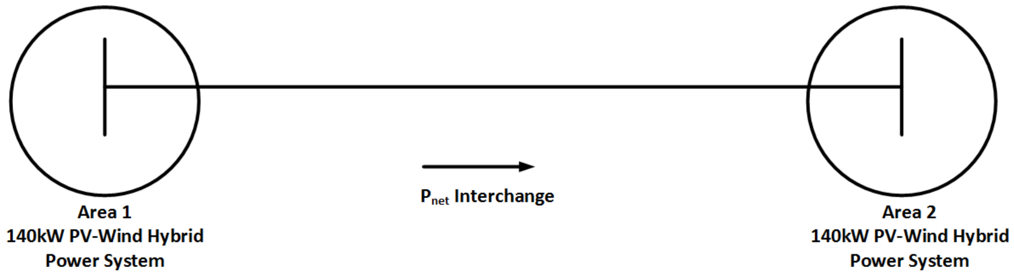

Fig. 1. Block Diagram representation of Two-area system

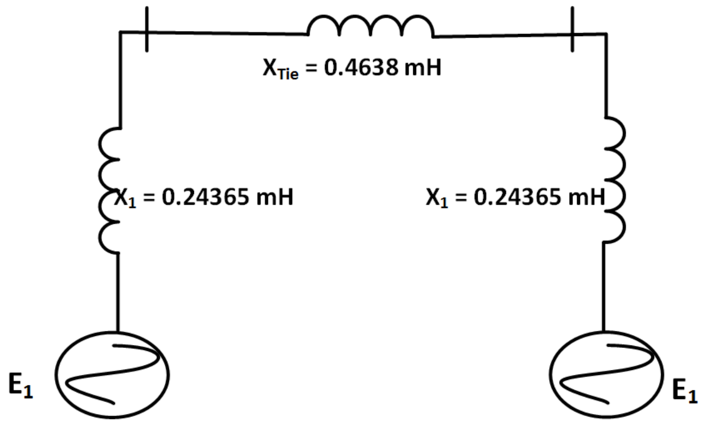

Fig. 2. Electrical equivalent of Two-area system

Under steady-state each area of two-area system shown in Fig. 1 are loaded by 100 kW and an increase in load demand of 80 kW is observed in the area 2. The performance of the controller is analyzed under this condition and the performance is compared with the mathematical analysis of the system.

2.1. Modeling of PV-Wind Hybrid Power System:

The equation-based modeling of PV based generation is taken from [20] and the model-based design of the wind-based generation is taken from [21] and the Fuzzy implementation of the Maximum Power Point Tracking (MPPT) algorithm for PV-Wind hybrid power system is taken from [22]. The element wise representation of PV-wind hybrid power system is shown in Fig. 3.

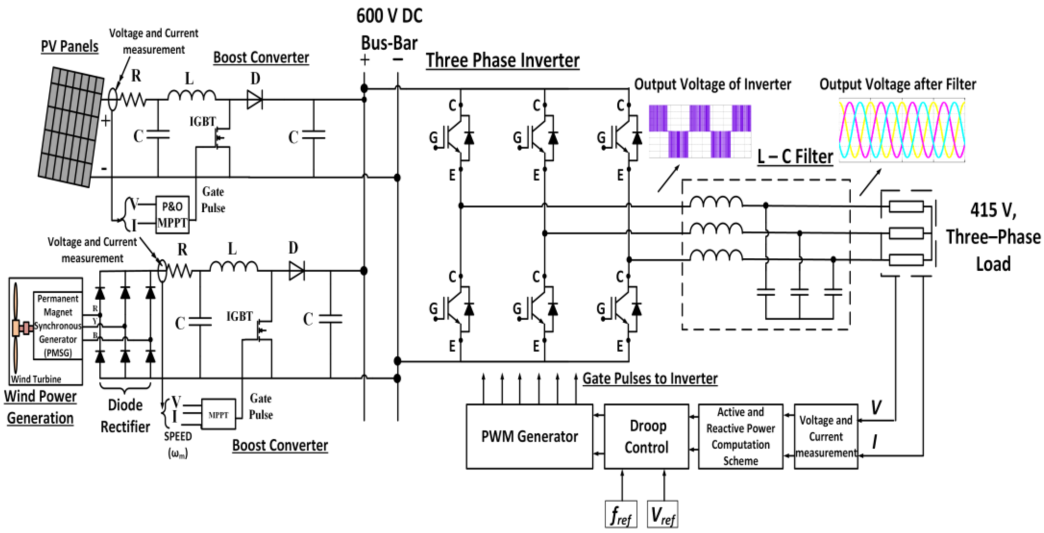

Fig. 3. Element wise representation of hybrid power system

A 100 kW PV generation is implemented using two-diode model of PV cell. The electrical parameters of one PV module are tabulated in Table. 1

Table 1

Electrical Parameters of PV Panel

Maximum Power (W) = 414	Cells per module = 128
Open Circuit Voltage V_{oc} (V) = 85.3	Short Circuit Current I_{sc} (A)=6.09
Voltage at MPP V_{mp} (V) = 72.9	Current at MPP I_{mp} (A) = 5.69

To form a 100 kW PV generation 5 PV panels are connected in series to form a string and such 5 strings are connected in parallel to from array. The simulated Current (I)-Voltage (V) and Power (P)- Voltage (V) characteristics of the PV generation operating under different solar illumination at operating temperature of 25^0C is plotted in Fig. 4. The simulated power characteristics of wind turbine are graphically represented in Fig. 5.

A equation based model of PVWHPS is implemented in the MATLAB, Simulink. The output voltage from the PV and Wind are stepped up to expected level of 600 V DC forming a common DC bus-bar. A Voltage Source Inverter (VSI) is employed to obtain a 415 V AC supply from the 600 V Com-mon DC bus-bar. A droop characteristic based VSI control is employed to control the output frequency and voltage of system as represented in Fig. 1. The block diagram of representation of the Droop characteristics implementation is shown in Fig. 6.

The three-phase line voltage (V_{RY}, V_{YB}, V_{BR}) and Line currents (I_R, I_Y, I_B) are sensed and converted into d-q reference frame of Voltage (V_d, V_q) and Current (I_d, I_q) respectively and further utilized to compute Active and reactive power as (1), (2).

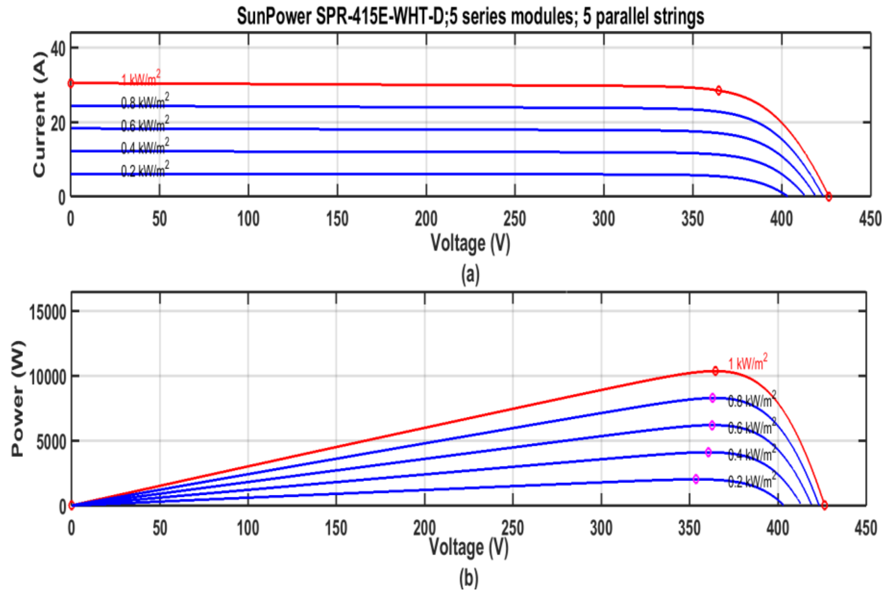

Fig. 4. (a) I-V Characteristics; (b) P-V characteristics

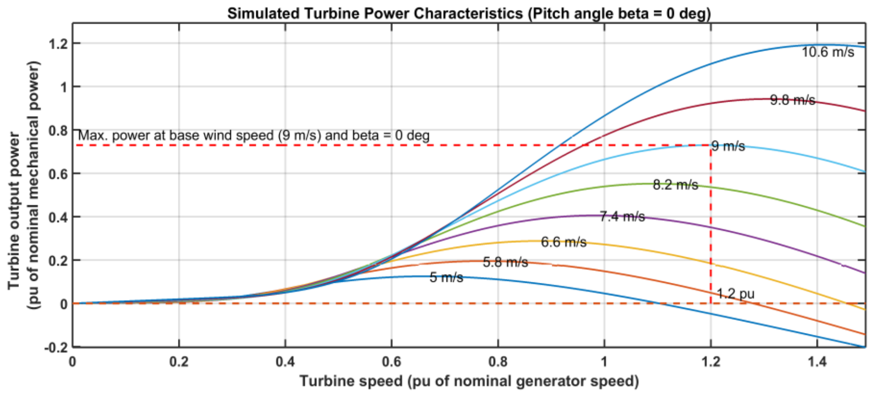

Fig. 5. Power Characteristics of Wind turbine

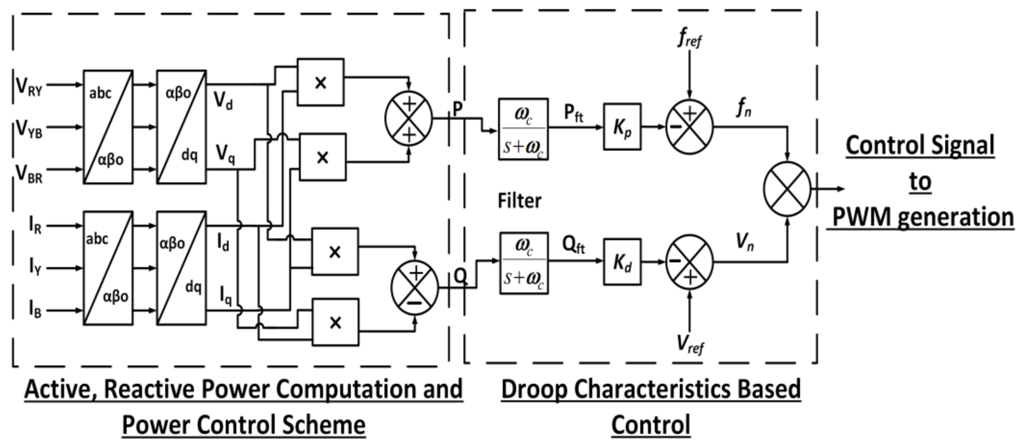

Fig. 6. Block diagram of Droop Characteristics implementation

$$P = V_d I_d + V_q I_q \tag{1}$$

$$Q = V_d I_d - V_q I_q \tag{2}$$

The filtered P_{ft}, Q_{ft} are the active and reactive power respectively which are utilized to calculate control signal to generate nominal frequency f_n, nominal voltage V_n for controlling the output voltage and frequency expressed as (3), (4).

$$f_n = f_{ref} - k_p P_{ft} \tag{3}$$

$$V_n = V_{ref} - k_d Q_{ft} \tag{4}$$

where k_p, k_d are computed as

$$k_p = \frac{\Delta f}{P_{\max}}; k_q = \frac{\Delta V}{Q_{\max}} \tag{5}$$

2.2. Droop Implementation of Inverter control in two-areas:

Area 1: The droop constant R_1 is defined as the ration of change in frequency Δf to the change in output power ΔP of the inverter and is taken

$$R_1 = \frac{\Delta f}{\Delta P} = \frac{0.2}{11} = 0.018 \tag{6}$$

The frequency dependent load constant D_1 is 0.8 i.e. The voltage magnitude of the load starts decreasing when the load reaches 80% of full load. The droop characteristics of the inverter are graphically represented in Fig. 7

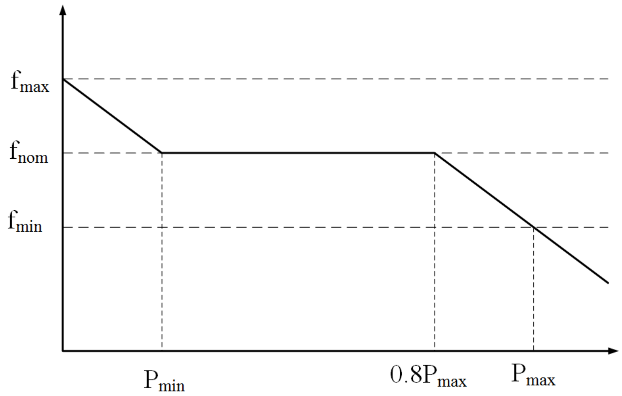

Fig. 7. Droop Characteristics of Inverter in area 1

Area 2: The droop constant R2 is defined as the ratio of change in frequency f to the change in output power P of the inverter and is taken as

$$R_2 = \frac{\Delta f}{\Delta P} = \frac{0.2}{5} = 0.04 \tag{7}$$

The frequency dependent load constant D_2 is 1 i.e. The voltage magnitude of the load starts decreasing when the load reaches 100% of full load. The droop characteristics of the inverter are graphically represented in Fig. 8

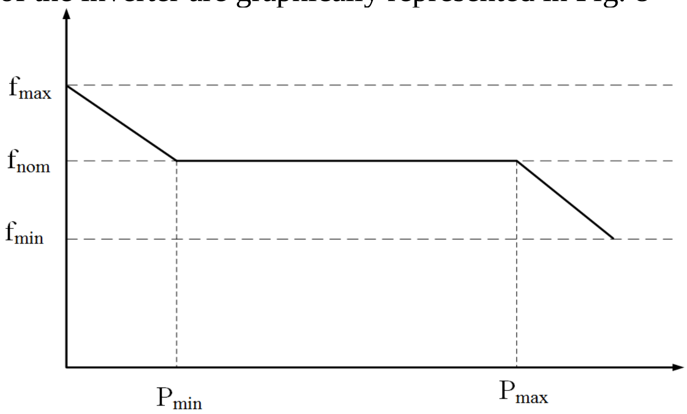

Fig. 8. Droop Characteristics of Inverter in area 2

3. Mathematical Analysis:

A tie-line frequency bias control is implemented using droop characteristics technique. The generation will respond to change in load demand of the system and will maintain the frequency and tie-line power interchange of the system with in the permissible limits. The system frequency to be maintained is 50 Hz and the scheduled tie-line interchange is 40 kW. Under steady-state condition of the system, each area in the system shown in Fig. 1 are loaded by 100 kW each respectively and a sudden increase in load demand of 80 kW is observed in the area-2. The performance of the controller is analyzed un-der this condition and the performance is computed with the mathematical analysis of the system. Further the mathematical analysis of the system is compared with the Simulation results to validate the simulation model.

Considering base KVA to be 500 KVA, Change in load

$$\Delta P_{L2} = \frac{80}{500} = 0.16\, pu \quad (8)$$

$$\Delta\omega = -\frac{0.16}{\beta_1 + \beta_2} \quad (9)$$

where,

$$\beta_1 = \frac{1}{R_1} + D_1 = 56.35 \quad (10)$$

$$\beta_2 = \frac{2}{R_2} + D_2 = 26 \quad (11)$$

$$\Delta\omega = -\frac{0.16}{56.35 + 26} = -1.9429 \times 10^{-3} \quad (12)$$

Change in frequency due to change in load in area 2 is

$$\Delta f = 50 - (1.9429 \times 10^{-3} \times 50) = 49.9029\ Hz \quad (13)$$

$$\Delta P_{12} = \frac{\Delta P_{L1}\beta_2}{\beta_1 + \beta_2} = -0.10927\ pu = 54.634\, kW \quad (14)$$

Change in generation of area 1

$$\Delta P_{m1} = -\frac{\Delta\omega}{R_1} = -0.1084\, pu = -54.2\, kW \quad (15)$$

Change in generation of area 2

$$\Delta P_{m2} = -\frac{\Delta\omega}{R_2} = 0.04878\ pu = 24.39\, kW \quad (16)$$

Change in load in area 2 due to drop in frequency is

$$-\Delta\omega D_2 = -1.9512 \times 10^{-3}\ pu = -0.9756\ kW \quad (17)$$

Change in generation of the system

$$\Delta P_{m1} + \Delta P_{m2} = 54.2 + 24.39 = 78.59\, kW \quad (18)$$

Change in load = *80 – 0.78048 – 0.9756 = 78.24 kW*

4. Simulation Results:

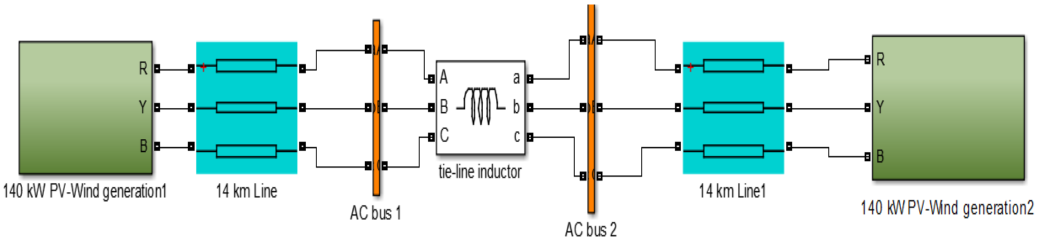

Fig. 9. Simulink Implementation of two-area system

The Simulink implementation of the two-area system is shown in Fig. 9. The inverter output line voltage without and with filtering is graphically represented in Fig. 10. The output voltage, current and power of area 1 are graphically represented in Fig. 11, Fig. 12 and Fig. 13.

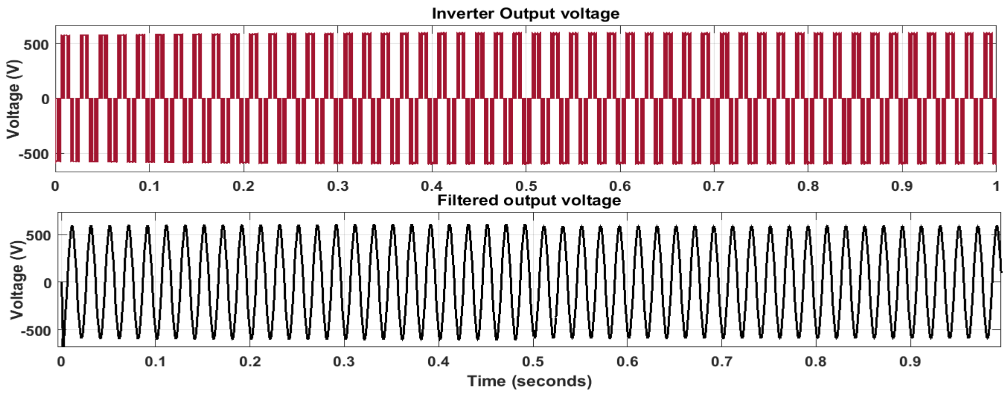

Fig. 10. Inverter output voltage

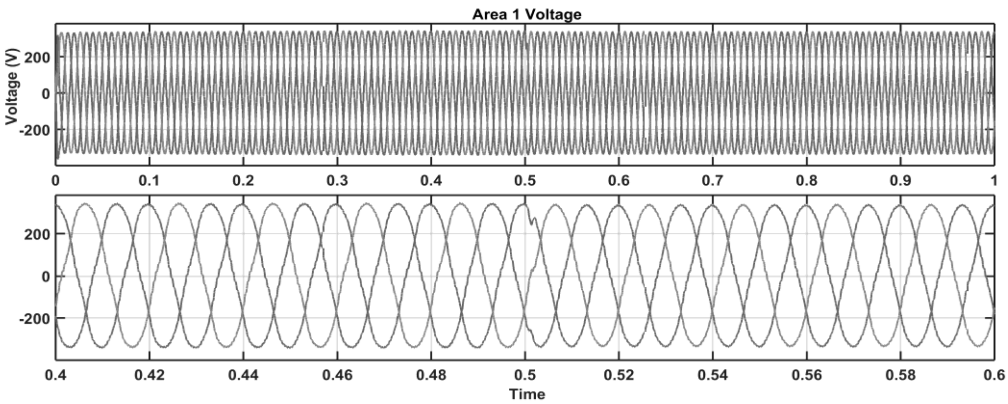

Fig. 11. Simulated Voltage of area 1

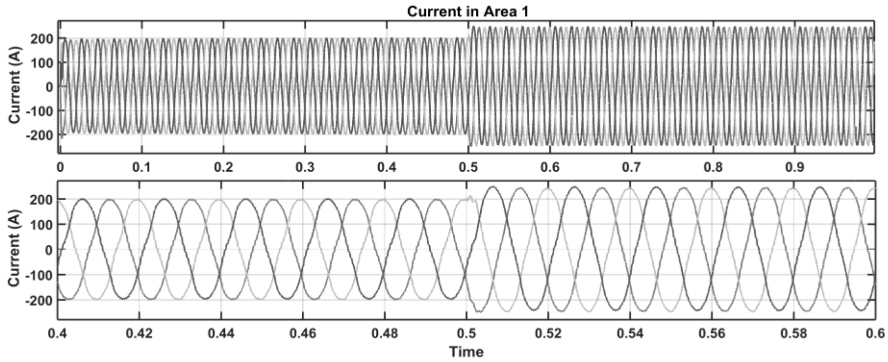

Fig. 12. Simulated Current of area 1

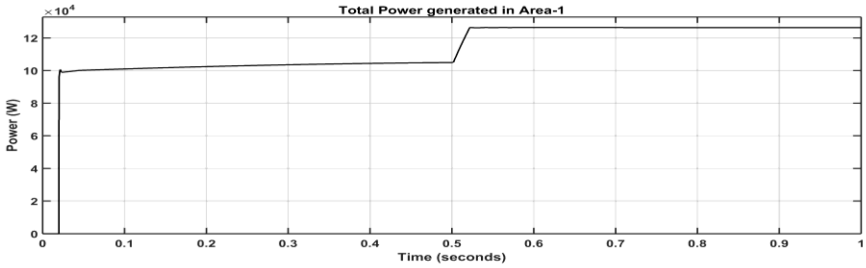

Fig. 13. Power generated in area 1

The output voltage, current and power of area 2 are graphically represented in Fig. 14 and Fig. 15. Tie-line Voltage, current and power interchange are graphically represented in Fig. 16, Fig. 17. The frequency of the system is plotted in Fig. 18.

A tie-line frequency bias control of interconnected PV-Wind hybrid power system was presented. The performance analysis of the droop characteristics implementation is being investigated under load change in one area. A comparative study of the mathematical and simulation analysis is tabulated in Table 2. It can be comprehended that the controller action is as desired.

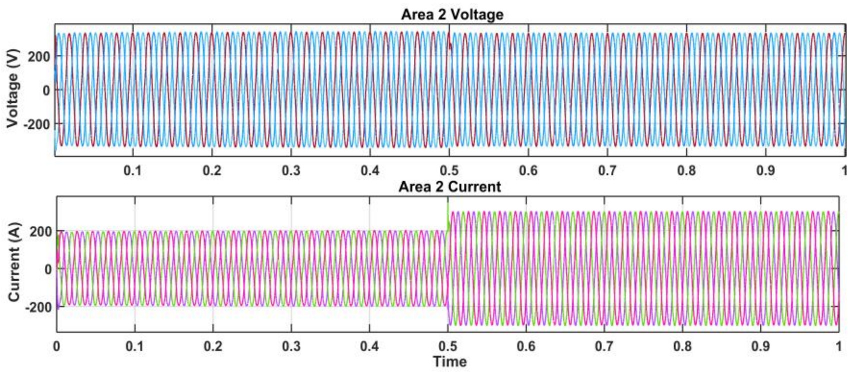

Fig. 14. Simulated Voltage and current of area 2

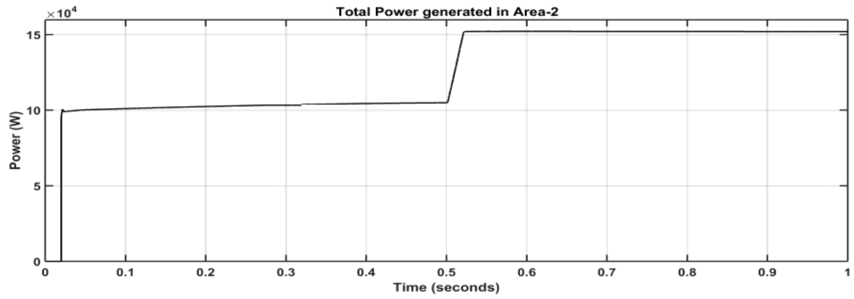

Fig. 15. power generated in area 2

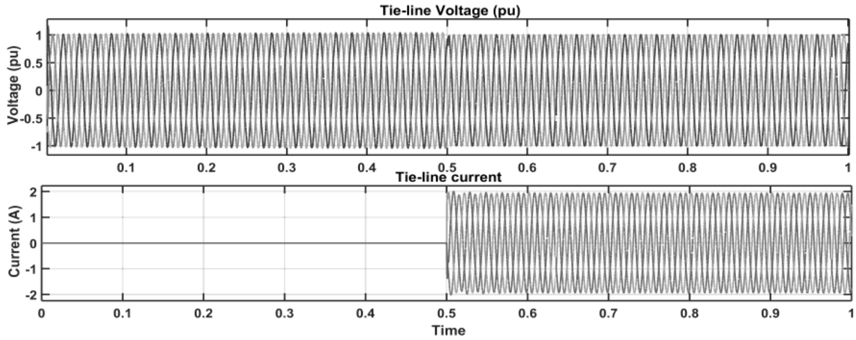

Fig. 16. Simulated Voltage and current of tie-line

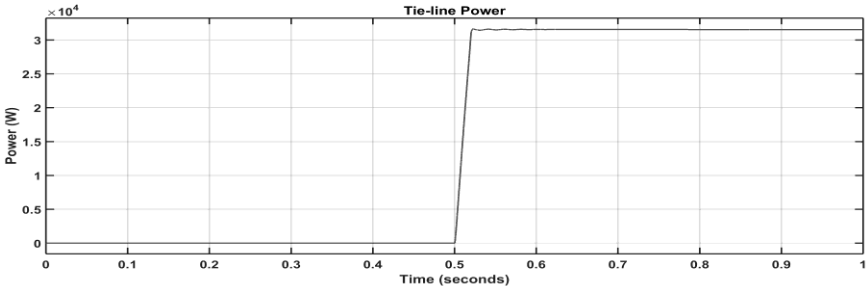

Fig. 17. Tie-line Power interchange

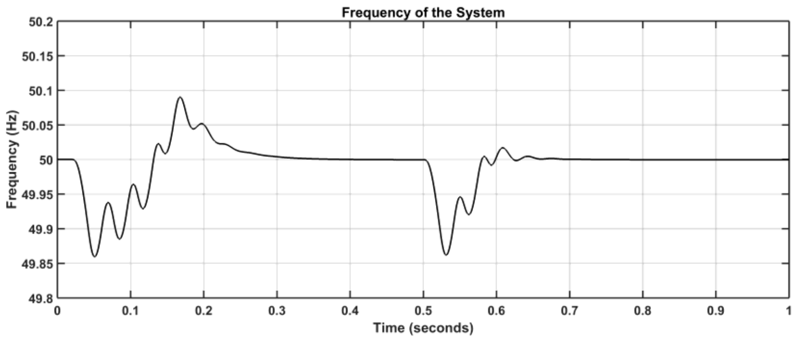

Fig. 18. Frequency of the system

Table 2.

A Comparative analysis of mathematical and simulation of two-area system

Parameter	Mathematical Analysis	Simulation Analysis
Change in Frequency (Hz)	49.9024	49.9409
Power Interchange (kW)	54.634	52.11
Change in Generation in Area 1 (kW)	54.2	52.89
Change in Generation in Area 2 (kW)	24.39	25.4
Decrease in load in Area 2 (kW) due to change in frequency	0.9756	0.97145
Change in Generation (kW)	78.59	78.29
Change in load (kW)	78.24	78.23

5. Conclusions

In this paper a tie-line frequency bias control of two-area interconnected PV-Wind hybrid power system (PVWHPS) for Micro-grid application is presented. Each area consists of 140 kW PVWHPS, the equation-based implementation of hybrid power system was modeled in MATLAB, Simulink with droop characteristics-based Load frequency controller respectively. The performance of the tie-line frequency bias controller is investigated under change in load in area-2. It can be comprehended that the tie-line controller was able to maintain the system frequency and tie line power interchange in permissible limits i.e. 50 2% Hz and 40 kW respectively. The proposed droop characteristics-based Load Frequency Control for a PVWHPS without any energy storage device exhibits an appropriate tie-line power interchange by maintaining the system voltage and frequency at desired level under system disturbances. The simulation results demonstrate satisfactory operation of the tie-line controller and the settling time of frequency is about 0.15 Sec without any steady state error and tie-line power interchange of 33kW. The simulated results are validated with the mathematical analysis of the system for the change in load in area-2. The mathematical and simulation study validates the satisfactory action of tie-line frequency bias controller.

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