VIRTUAL INERTIA CONTROL STRATEGY TO MITIGATE THE FREQUENCY EXCURSION WITH LARGE PENETRATION OF RENEWABLE ENERGY

A DISSERTATION
SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE AWARD OF THE
DEGREE OF

MASTER OF TECHNOLOGY
IN
POWER SYSTEM

SUBMITTED BY
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UNDER THE SUPERVISION OF

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CANDIDATE'S DECLARATION

I, hereby certify that the Project Dissertation titled "**Virtual inertia control strategy to mitigate the frequency excursion with large penetration of renewable energy"** which is submitted by PRERNA PRIYA, Roll No. 2K21/PSY/05, Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology is a testimony of the project work carried out by the student under our supervision. To the best of our awareness, this work has not been submitted in part or full for any Degree or Diploma to this University or to a different place.

Place: Delhi **PRERNA PRIYA**

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CERTIFICATE

I, hereby certify that the Project Dissertation titled "**Virtual inertia control strategy to mitigate the frequency excursion with large penetration of renewable energy**" which is submitted by **PRERNA PRIYA,** Roll No. **2K21/PSY/05,** Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology is a testimony of the project work carried out by the student under our supervision. To the best of our awareness, this work has not been submitted in part or full for any Degree or Diploma to this University or to a different place.

Place: Delhi

Date:

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ABSTRACT

The introduction of renewable energy (RE) aids in lowering the inertia of the power system. When renewable energy (RE) sources take the place of conventional generators, the system's rotational mass decreases, which poses issues for the system's overall stability, especially at higher integration. For the future power grid, including a virtual inertia (inertial response) in renewable energy will be essential. The artificial inertia, primary, and secondary controllers' frequency response models are shown in state space. The dynamic and static performances of the artificial inertia response model are described, using small-signal (dynamic) and state-space analyses. Under two scenarios—significant solar and wind energy integration and random load demand with RES integration—the impacts of system inertia reduction are examined. To handle interruptions caused by the integration of highly dispersed generators (DG) and renewable energy sources (RES), the virtual inertia constant (KAI), which is necessary for simulating extra inertia output into the system, is maintained at the same value. Poor control value selection can result in instability, a long recovery time, and a larger frequency deviation for virtual inertia control. This research uses the fundamental proportional-integral (PI), which is widely used in industrial systems in real-world applications, to apply virtual inertia control to this issue. This yields the precise virtual inertia constant required to simulate actual inertia power and increase the system's frequency stability.

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LIST OF SYMBOLS

Symbol	Meaning
K_S	Gain of Integral controller
T_g	Governor time constant
T_t	Turbine time constant
R	Governor droop constant
H	Equivalent System inertia constant
T_w	Wind Turbine Time constant
D	System Load Damping coefficient
T_{pv}	Solar panel Time constant
T_{inv}	Inverter time constant
D_{AI}	Virtual inertia damping
K_{AI}	Virtual inertia constant

LIST OF ABBREVIATIONS

Abbreviation	Expansion
AC	Alternating Current
RE	Renewable Energy
SG	Synchronous Generator
SE	Swing Equation
AI	Artificial Inertia
VI	Virtual Inertia
ROCOF	Rate of change of Frequency
PI	Proportional Integral
ESS	Energy Storage System
SA	Single Area
PS	Power System
DG	Distributed Generator

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

A big synchronous generator has an attribute called inertial response that acts to balance out the energy supply as well as demand for electrical power systems. The inertial response contains large synchronous rotating masses [1,2]. All of the grid's synchronous generators masses that rotate experience either a rise in frequency (excess power need) or decreases (power demand) due to the ongoing power imbalance between the mechanical power supply and the electric power demand (excess power demand). To modify the AC frequency, the grid operator must halt the speed shift and restore balance to the system. The Swing Equation, a general equation of motion, is used to simulate the specific motions of each synchronous rotor in the grid, which results in the grid frequency relations with demand and supply [3]. Due to the recent energy crisis, environmental concerns, and economic expansion, the addition of distributed generators (DGs) and renewable energy sources (RESs) into conventional generation is rapidly expanding. System inertia is an important parameter for operators. Inertia is primarily generated by synchronous generators. With the increase of renewable energy, there is an increase in the nonsynchronous machine which results in a reducing trend of inertia [1,4,5].

1.2 FREQUENCY COMPENSATION

A power system's frequency regulation can be loosely split into two phases. The power plant’s frequency controllers have not yet been turned on in the initial Phase. The generators will either absorb or release their kinetic energy to stop the frequency change. Because the inertia dampens the frequency variations, this phase is known as the inertial response [1,5]. In the second phase, the primary control (governor action) and secondary control stabilize the frequency first and return it to the nominal frequency. In the event of significant frequency deviations, additional measures, such as automatic load shedding, may be applied. A connected power system's integrated operation depends on maintaining frequency stability. Usually, various time interval-based responses, such as inertial (stored energy), primary frequency(governor), secondary frequency, and tertiary frequency response, can be used to describe the frequency response of any power system [5,6]. Before the governor response of the synchronous generators begins to respond, inertial response plays a vital role in halting the frequency fall at the initial phase of the unexpected generation-load variation and so aids in preserving frequency stability [9].

1.3 Literature Review

Table 1.1: Summary of Literature Relevant to this Thesis

Reference	**Relevance**	**Test Cases**	**Contributions**	**Comments**
[1]	Power system stability and control	McGraw-Hill ,1994	Provide importance of inertia in Power System	Understand the basic of the Power system, Small signal Analysis
[2]	The relevance of inertia in power system	Elsevier Volume 55 2016	different forms of control to arrest frequency variation which are described in more detail	influence of reduced inertia on frequency.
[3]	Voltage sag ride-through performance of Virtual Synchronous Generator	IEEE 2014	control structure that supports power system stability by imitating a synchronous machine	proper measures can be embedded to eliminate the hazardous consequences of voltage sags.

[4]	A Virtual Synchronous Machine implementation for distributed control of power converters in SmartGrids	Elsevier, Volume 122 2015	The ongoing evolution of the power system towards a “SmartGrid”	A specific VSM implementation
[5]	Real-time simulation of a power system with VSG hardware in the loop	IEEE 2011	The development of such a device started in a pure simulation environment and extends to the practical realization of a VSG.	The VSG then interacts with the simulated power system through a power interface
[6]	Robust Power system Frequency Control	Springer 2014	Provides comprehensive coverage of frequency control simulation, design, and optimization in a wide range of operating conditions	offer solutions to low inertia and damping effect impacts
[7]	Enhanced Virtual Inertia Control Based on Derivative Technique to Emulate Simultaneous Inertia and Damping Properties for Microgrid Frequency Regulation	IEEE 2019	effective methods for improving system inertia and maintaining frequency stability.	the efficiency and robustness of the proposed control technique are compared with the conventional inertia control

[8]	Virtual Inertia: Current Trends and Future Directions	MDPI 2017	Review of the current state-of-the-art of virtual inertia implementation techniques, and explores potential research directions and challenges.	A discussion on the challenges and research directions points out several research needs, especially for systems-level integration of virtual inertia systems.
[9]	Report On Assessment of Inertia in Indian Power System,2019	MNRE 2018	Report about training in POSCO Power.	Having details about training.
[10]	Integrated wind turbine controller with virtual inertia and primary frequency response for grid dynamic frequency support	IET,2017	a de-loading pitch control scheme is proposed to reserve the capacity required for frequency regulation	A three-machine prototype system containing two synchronous generators and a Doubly Fed Induction Generator (DFIG)-based wind turbine with 30% of wind
[11]	A Novel coordination scheme of virtual inertia control and Digital	IET,2019	low system inertia issue could affect the Microgrid stability and resiliency in the situation of uncertainties, thus threatening their dynamic security. Hence, preserving Microgrid dynamic security is one of the important challenges, which is addressed in this study	The simulation results of the studied Microgrid are carried out using MATLAB/Simulink® software to validate the effectiveness of the proposed coordination scheme.

[12]	Protection for Microgrid Dynamic Security Considering High Renewable Energy Penetration	IET,2019	low system inertia issue could affect Microgrid stability and resiliency in the situation of uncertainties, thus threatening their dynamic security. Hence, preserving Microgrid dynamic security is one of the important challenges, which is addressed in this study	The simulation results of the studied microgrid are carried out using MATLAB/Simulink® software to validate the effectiveness of the proposed coordination scheme.
[13]	Power System Analysis	McGraw-Hill, 1998	System inertia	Impact of virtual Inertia
[14]	THE MODELLINGOF ELECTRIC POWER SYSTEMS ON THE STATE SPACE AND CONTROLLING OF OPTIMAL LQR LOAD FREQUENCY	Scopus , 2019	The modelling of electric power systems on the state space and an optimal control system known as Linear Quadratic Regulator (LQR) for designing the load frequency control system	Load frequency control system of electric power system has been developed
[15]	Robust load frequency controller design for hydro power systems	IEEE 2005	This paper presents a new approach for power system load frequency control of a hydro turbine power system by means of a PID controller.	Comparative results of this new load frequency controller and a conventional PI one show the improvement in system damping considerably
[16]	On the use of thermal inertia in building stock to leverage decentralized demand side frequency regulation services	Elsevier 2018	The research presented takes a proactive approach to demand response employing heat	The paper reports on hardware-in-the-loop simulations, testing real

			transfer dynamics	thermal loads within a simulated power network.
[17]	Distributed PI-control with applications to power systems frequency control	IEEE 2014	This paper considers a distributed PI-controller for networked dynamical systems.	Sufficient stability criteria are derived
[18]	A modified whale optimization algorithm-based adaptive fuzzy logic PID controller for load frequency control of autonomous power generation systems	Taylor and Francis 2017	This paper proposes an adaptive fuzzy logic PID (AFPID) controller for load frequency control.	Reduction of 39.13% in error criteria (objective function) compared with WOA-PID controller.
[19]	Challenges and Opportunities of Load Frequency Control in Conventional, Modern and Future Smart Power Systems: A Comprehensive Review	MDPI 2018	This paper presents a comprehensive literature survey on the topic of LFC.	Review Paper
[20]	Enhanced Virtual Inertia Control Based on Derivative Technique to Emulate Simultaneous Inertia and Damping Properties for Microgrid Frequency Regulation	IEEE 2018	The proposed virtual inertia control uses the derivative technique to calculate the derivative of frequency for virtual inertia emulation	the efficiency and robustness of the proposed control technique are compared with the conventional inertia control under a wide range of system operation
[21]	Iterative Method for Tuning Multiloop PID Controllers Based on Single Loop Robustness Specifications in the Frequency .	MDPI 2021	This work proposes an iterative design methodology of multiloop PID controllers for stable .	The methodology uses a frequency response matrix representation of the system .

[22]	Virtual Inertia-Based Inverters for Mitigating Frequency Instability in Grid-Connected Renewable Energy System: A Review	MDPI 2019	This study paper presents a comprehensive review of virtual inertia (VI)-based inverters in modern power systems	Review Paper
[23]	Synthetic-Inertia-Based Modular Multilevel Converter Frequency Control for Improved Micro-Grid Frequency Regulation	IEEE 2019	This paper proposes an MMC synthetic inertia concept that is mainly affected by renewable penetration ratio, SM capacitance and the modulation index of the MMC, with the system constraints determined in the design phase.	The experimental results show that, by proper system parameters design, the frequency deviation and the rate of change of frequency (ROCOF) can be reduced by 13.9% and 18.5%, respectively.
[24]	Frequency dependent strategy for mitigating wind power fluctuations of a doubly-fed induction generator wind turbine based on virtual inertia control and blade pitch angle regulation	Elsevier 2018	This paper presents a new approach to address the issue of the frequency deviations induced by the fluctuating power injected into the grid by doubly-fed induction generator based wind turbines in a weak or isolated power system that is based in a frequency dependent smoothing of the wind power	This algorithm has been devised to reduce the turbine unload requirements, and at the same time, to increase the available kinetic energy in the turbine.
[25]	Conservation Voltage Reduction in Modern Power	MDPI 2023	work offers a thorough analysis of CVR applications,	Concerns with the further utilizing and measuring of

	Systems: Applications, Implementation, Quantification, and AI-Assisted Techniques		implementation, and quantification strategies, including data-driven AI-based methods in PE-based modern grids	CVR impacts in modern power systems are discussed in the future trends section, where new research areas are suggested.
[26]	A cogeneration scheme with biogas and improvement of frequency stability using inertia based control in AC microgrid	IJEEPS 2021	This work is related to the generation of physical inertia through the biogas plant and emulates inertia from the dc-link capacitor to control the rate of change of frequency (ROCOF) under abrupt load change.	A storage system can help to compensate for abrupt frequency change during transient but due to its higher cost and relatively lesser lifetime, these systems can't be relied upon in the long run.
[27]	A gas-thermal inertia-based frequency response strategy considering the suppression of a second frequency dip in an integrated energy system	IDEAS 2023	This study fully exploits the slow-dynamic characteristics in gas-thermal systems of the integrated energy system to provide frequency response.	The frequency response model presented in the paper also offers an opportunity to weigh the frequency response effect against the total economic benefit.
[28]	Synthetic Inertia Based CHB-STATCOM for Dynamic Frequency Control in a High Inverter-Based-Resources Network	IEEE 2022	This work presents a circuit configuration of cascaded H-bridge (CHB) based static synchronous compensator (STATCOM) providing synthetic synchronous inertial support in the future grid with high penetration of inverter-based	the cumulative energy stored in the DC-link capacitors of CHB provides virtual inertial support to minimize the rate of change of frequency (ROCOF)

			resources (IBR).	
[29]	Computational Methods to Mitigate the Effect of High Penetration of Renewable Energy Sources on Power System Frequency Regulation: A Comprehensive Review	SPRINGER, 2022	This paper aims at introducing a comprehensive survey of the effects of the increase in RESs on power system inertia and frequency.	Review Paper
[30]	Hierarchical dual loop voltage and frequency control in stand alone microgrid with priority based intelligent load management	EPSR 2023	The paper presents a hierarchical voltage and frequency control framework for peak and off-peak hours to enhance grid resiliency.	Coordination between the primary and secondary control mechanism is established to enhance the dynamic response of the system during both peak and off-peak hours
[31]	Solar Power Generation Data	Kaggle Report 2022	Report	Report
[32]	Wind Power Generation Data	Kaggle Report 2022	Report	Report
[33]	Self-Adaptive Virtual Inertia Control-Based Fuzzy Logic to Improve Frequency Stability of Microgrid With High Renewable Penetration	IEEE 2019	this paper proposes a self-adaptive virtual inertia control system using fuzzy logic for ensuring stable frequency stabilization, which is required for successful	The proposed control method shows remarkable performance in transient response improvement and fast damping of

			microgrid operation in the presence of high RESs penetration	oscillations, preserving robustness of operation.
[34]	Virtual Inertia Synthesis for a Single-Area Power System	Springer 2020	this chapter explains the dynamic performance and frequency characteristics of a single-area system with the deployment of virtual inertia control in addition to the primary and secondary control	The effects of various parameters over inertia control-based frequency response are emphasized
[35]	Effect of Inertia Constant on Generator Frequency and Rotor Angle	Engineering and Applied Sciences 2018	In this project work, effect of inertia constant of synchronous generator (machine constant) on its frequency and rotor angle is investigated.	The analysis is done by observing how the frequency and rotor angle changes when the inertia constant is varied while keeping all system parameters constant.
[36]	Fast Frequency Control Scheme through Adaptive Virtual Inertia Emulation	IEEE 2018	This paper presents a novel virtual inertia controller for converters in power systems with high share of renewable resources.	The results show a significant improvement in the frequency response compared to an open-loop system, while also preserving drastically more DC-side energy than a non-adaptive controller.
[37]	Effects of Inertia on Dynamic Performance of Wind Turbines	IEEE 2009	In this paper, a simulation model of a wind turbine system has been developed to	The effects of shaft speed on the actual time constant and the power loss due

			study the effects of inertia.	to inertia under varying wind speed conditions.

Some major takeaways from the above-tabulated literature review are:

Table 1.2 Relationship between the rotor speed and moment of Inertia [38]

Power Mismatch	Moment of Inertia (Js)	Rate of change of rotor speed (df/dt)
No mismatch i.e=0	High	Low
No mismatch i.e=0	Low	High
Mismatch	High or Low	Zero

The inertia [H] of the Thermal unit,1800rpm is in the range of [4-10] [38]

Table-1.3 Parameters for the isolated system in different literature review

Reference No.	Parameters									
	Gain of Integral controller, K_S (s)	Time constant of the governor, Tg(s)	Time constant of Turbine, T_t (s)	Droop characteristics, R(Hz/p.u)	Time constant of ESS, T_{inv} (s)	Time constant of Wind Turbine ,T_{W_t} (s)	Solar Time Constant, T_{PV} (s)	Artificial Damping Constant, D_{AI} (p.u./ Hz)	Artificial Inertia Control Droop, R_{AI} (Hz/p.u.)	Artificial inertia constant, K_{AI} (p.u./ Hz)
33	0.05	0.1	0.4	2.4	10	1.5	1.85	-	-	-
34	0.1	0.07	0.37	2.6	1	1.4	1.9	0.3	2.7	0.6
38	0.35,0.25 ,0.40	0.07,0.05 ,0.06	0.38,0.35 ,0.45	3,2.73, 2.81	-	-	-	-	-	-
7	0.2	0.1	0.4	2.4	10	1.4	1.9	1.2	-	1.6
15	0.05	0.1	0.4	2.4	10	1.5	1.85	-	-	0.8
35	-	-	-	-	-	-	-	0.138	-	-
36			3							
37			1.3							

From the Literature review, I have used these parameters for isolated power system.

Table-1.4 Parameters for the isolated system [33-38,7,15]

Parameter	Value
Gain of Integral controller, K_s(s)	0.1
Governor time constant, T_g(s)	0.08
Turbine time constant, T_t(s)	0.3
Governor droop constant, R(Hz/p.u)	2.5
System inertia constant, H(p.u.s)	4
System Load Damping coefficient, D(p.u/Hz)	1.25
Solar panel Time constant Tpv(s)	1.2
Inverter time constant T_{inv}(s)	10
Artificial inertia damping D_{AI}(p.u/H.z)	0.3
Artificial inertia constant K_{AI} (s)	0.6
Artificial inertia droop constant R_{AI}(Hz/ p.u)	2.7
Wind turbine time constant Tw(s)	0.3

- The studies tabulated above comprise the importance of inertia in Power systems and frequency stability.
- In almost all the above-listed papers, various methods of mimicking the artificial inertia topology are mentioned
- The swing equation-based approach is the most effective way to mimic artificial inertia.

  To ensure synchronization between the artificial inertia control unit and frequency control system, the optimization of the artificial inertia constant/gain is carried out while also taking that into account

CHAPTER 2

IMPACT OF INERTIA IN GRID

2.1 INERTIA RESPONSE

Inertia is the property of matter to resist changes in velocity (speed and/or direction).

The inertial response feature of high-rating synchronous generators, which regularly power the electrical grid, is able to adjust the deviation between power supply as well as demand for energy systems. The precise motions of each individual synchronous rotor in the grid work together to have a combined effect that allows the grid operator to equilibrium the system to halt the speed change. As a result, there is little variation in the grid frequency. The Swing Equation, a general equation of motion, may be used to describe them.

The frequency control procedure of a power system may be roughly divided into two components. During the first phase, the frequency controls for the power plants have not yet been activated. The generators will either absorb or release their kinetic energy to halt the frequency change. The "inertial response" of this phase explains the dampening of frequency changes by inertia. In the second phase, the main control (governor action) first stabilizes the frequency before the secondary control returns it to the normal frequency. Additional methods, including automatic load shedding, may be used when there are significant frequency changes.

2.2 INERTIA POWER

The use of an Artificial inertia control is build on simulating the synchronous generator (SG) swing equation in the control of an inverter [7]. The typical swing equation of the synchronous generator is:

$$P_{mec} - P_{ele} = P_{acc} = \frac{2H}{\omega_0}\frac{d^2\delta}{dt^2} = \frac{2Hd}{\omega_0}\frac{\Delta\omega r}{dt} \qquad (2.2.1)$$

In this equation, ωo is the rotor's maximum allowable angular speed (in rad/s), P_{ele} is the electrical power output, P_{acc} is the acceleration power, H is the inertia constant (in MWs/MVA), is the rotor angle, is the rotor speed, and t the time (s).

$$P_{mec} - P_{ele} = \frac{2Hd}{\omega_0}\frac{\Delta\omega r}{dt} + D\,\frac{\Delta\omega_r}{\omega_0} \qquad (2.2.2)$$

where, D represents the damping coefficient.

The above Equation (2.2.2) could also be written in frequency (Hz) as

$$P_{mec} - P_{ele} = \frac{2Hd}{f_0}\frac{\Delta f_r}{\partial t} + D\,\frac{\Delta f_r}{f_0} \qquad (2.2.3)$$

This decrease in inertia affects the lowest frequency (nadir frequency) and the ROCOF, two variables that are crucial for the activation of system protective mechanisms. The primary frequency profile of identified generation loss events as experienced in the Indian grid is explained below [9]-

1. Date:- 30 October 2018
   Time:- 19:23 PM
   Brief:- Unit #30,40 and 50 of CGPL Mundra tripped due to generator Class-A2 Protection operation

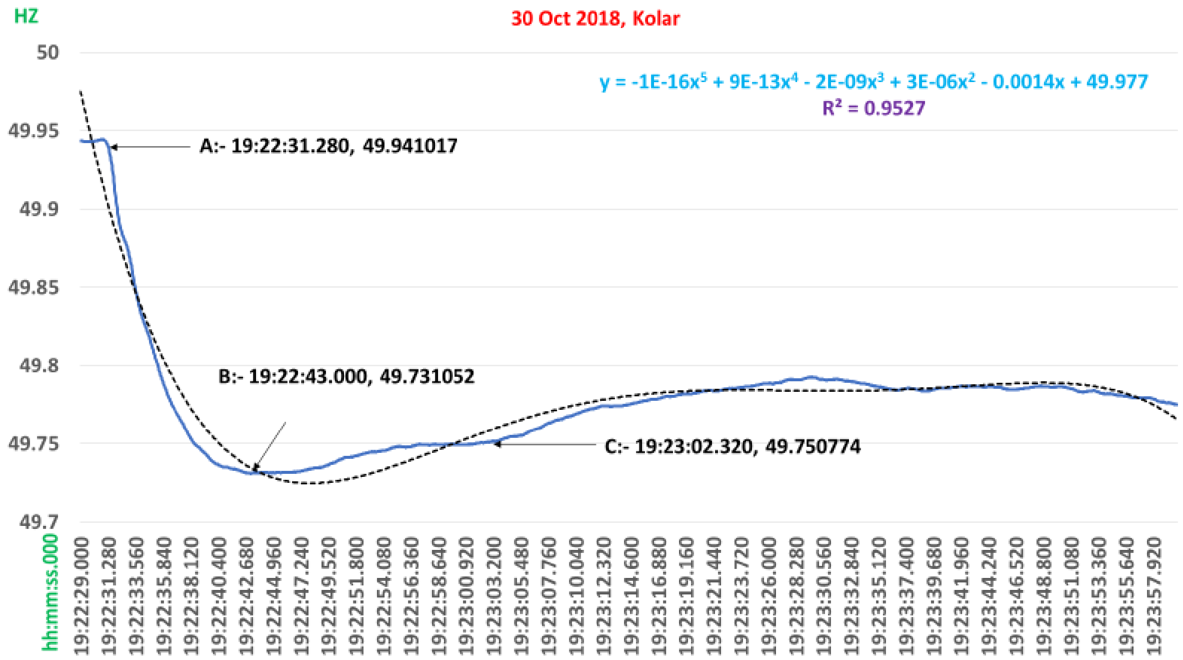

Fig.2.2aFrequency response of the fault at kolar s/s

R^2=0.9527, Constant=49.977, df/dt=0.0014

2. Date:- 06 August 2018

Time:- 13:06 PM

Brief:- 400kV Chakan & 400kV Lonikhand S/S tripped due to operation of busbar protection.

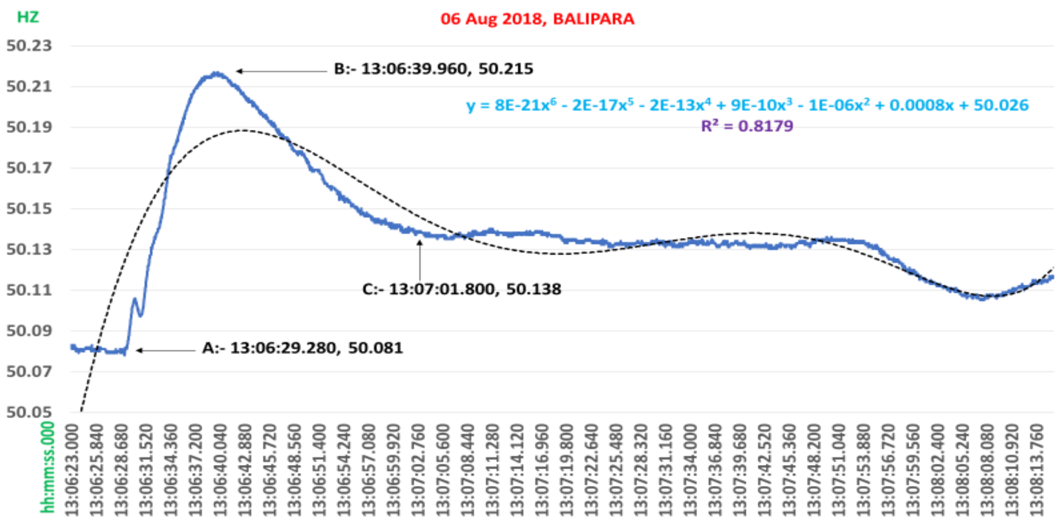

Fig.2.2bFrequency response of the fault at Balipara s/s

R^2=0.8179, Constant=50.026, df/dt=0.0008

3.Date:-10May2018
Time:-06:12AM
Brief:- Generation loss of 900 MW due to tripping of unit I & II

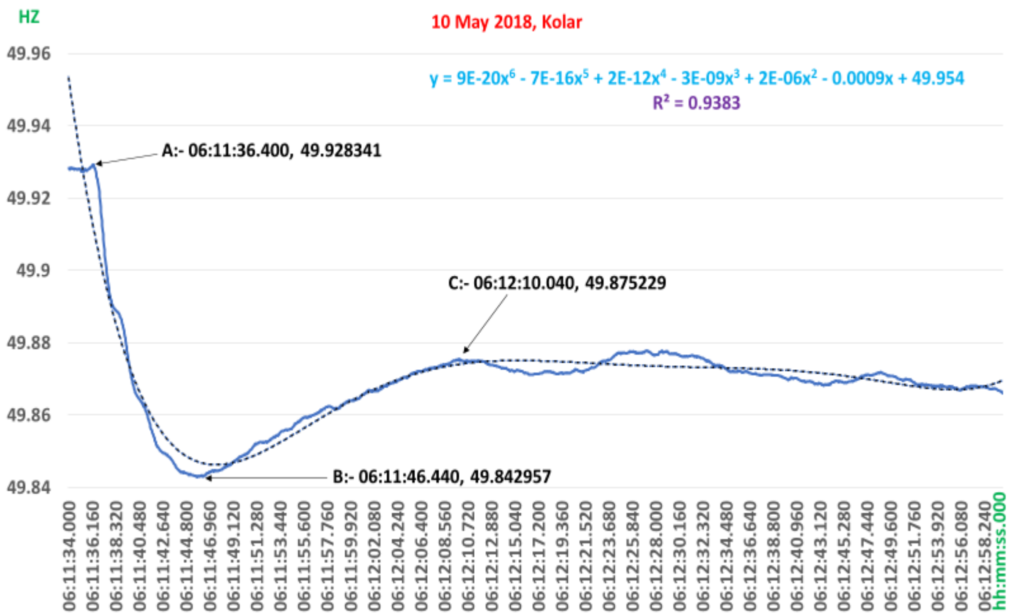

Fig.2.2cFrequency response of the fault at Kolars/s

R^2=0.9383, Constant=49.954, df/dt=0.0009

Where, coefficient of x = df/dt (2.2.4)

R^2 = Correlation between Polynomial and Original Graph

A = Point at which incident happened, Pre-disturbance Frequency.

B = Point of lowest drop in frequency, Nadir Frequency.

C = Point at which frequency stabilized again, Settling Frequency.

The primary frequency response of the Indian grid supplied through the conventional generator is shown in the above graph. The blue dotted curve is the real time curve at the time of the fault, black dotted curve is trajectory of real time curve. The best trajectory that trace the real time primary frequency response curve is polynomial of six degree. It shows from the Indian grid curve due to inertia present on the grid the deviation in frequency variation is less.

CHAPTER 3

SINGLE-AREA POWER SYSTEM

3.1 ARTIFICIAL INERTIA SYNTHESIS AND CONTROL

For the analysis of an isolated single-area power system, using an analogous Eq. 2.2.1. It can be complex to study a multi-generator dynamic characteristics using an identical generator model to undertake frequency stability investigation and examination for a isolated-area power system. The combined model can therefore be utilized as an equivalent frequency analysis model for all of the generators in a single-area power system. The analogous model combines the damping effects of the system loads and generators into a single damping factor or constant. The total inertia constant of all generating units is what is considered to be the corresponding system's inertia Constant [1,9].

Artificial inertia control can be constructed by ESS, Power electronics converter & control mechanism. The power required can be simply as-

$$P_{VI} = K_{AI}\left(\frac{d\Delta f}{dt}\right) + D_{AI}\,(\Delta f) + P_{initial} \quad (3.1)$$

Where, $K_{AI} = \frac{2HP_{conv}}{f_0}$ (3.2)

The rate of change of frequency (R0COF) is denoted by $\frac{d\Delta f}{dt}$ the nominal frequency of the system is denoted by fo, the virtual inertia constant is denoted by K_{AI}, the virtual damping coefficient/constant is denoted by D_{AI}, the nominal power of the inverter unit is denoted by P_{conv}, and the primary power supplied to the inverter is denoted by $P_{initial}$.

The relationship between the nadir point and ROCOF was stated by the equation's first term. It can improve the SG's inertia properties. The second term can mimic the results of SG's damper winding. This phrase will reduce the frequency oscillation of the system following an interruption, accelerating the process of system stability. The last term explains the supplied primary power to the inverter. In a power system, frequency deviation is directly proportional to active power and voltage variation depends on reactive power. The first-order transfer function of an inverter-based battery storage system and the inertia droop characteristic are integrated with the characteristics equation (5) for simulating the dynamic model of virtual inertia control [7,9].

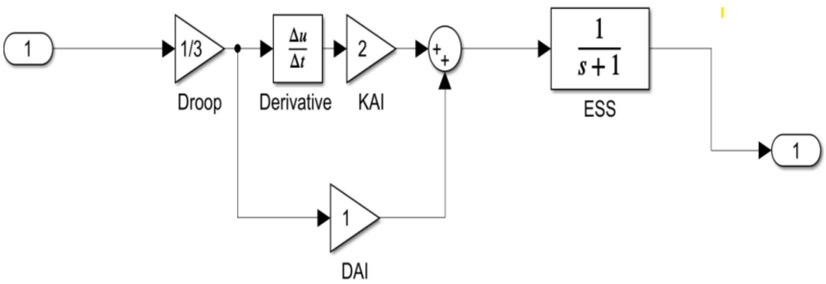

Fig.3.1a Dynamic model of virtual Inertia Power System

Simulink model diagram of isolated system is constructed by using equation-14.

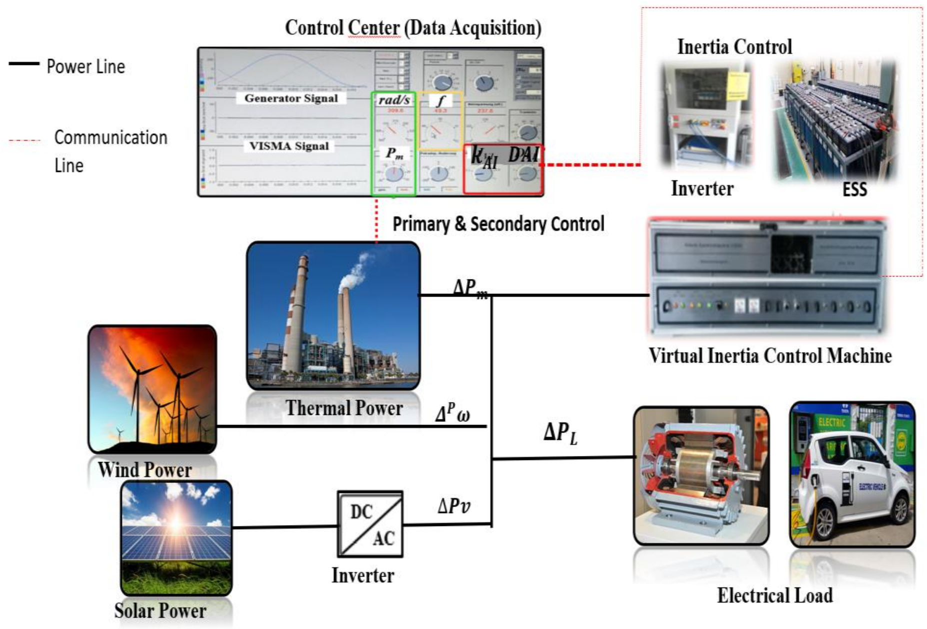

Fig.3.1b Block diagram of Isolated Power System[7,9]

Three generators having different inertia constants, droop at their own MVA rating. The interconnected system is converted p.u at a common base 100 VA rating.

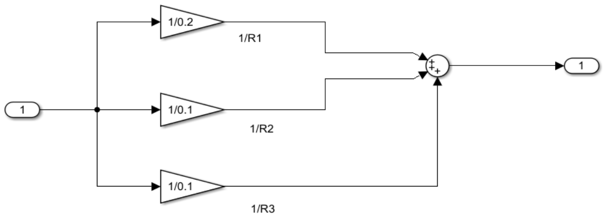

Fig.3.1c Equivalent droop constants of three generators.

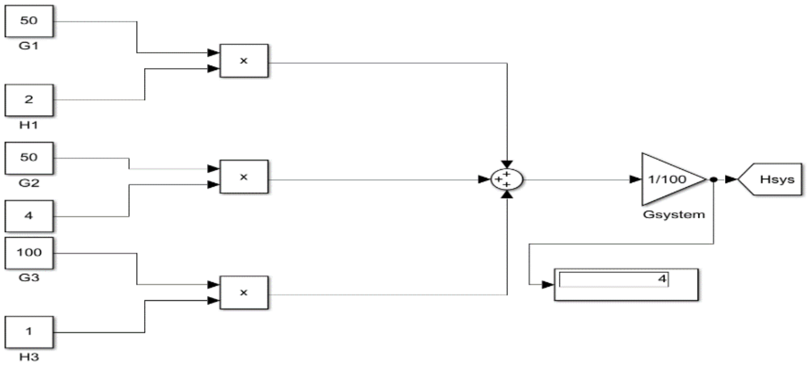

Fig.3.1d Equivalent Inertia constant of three generators.

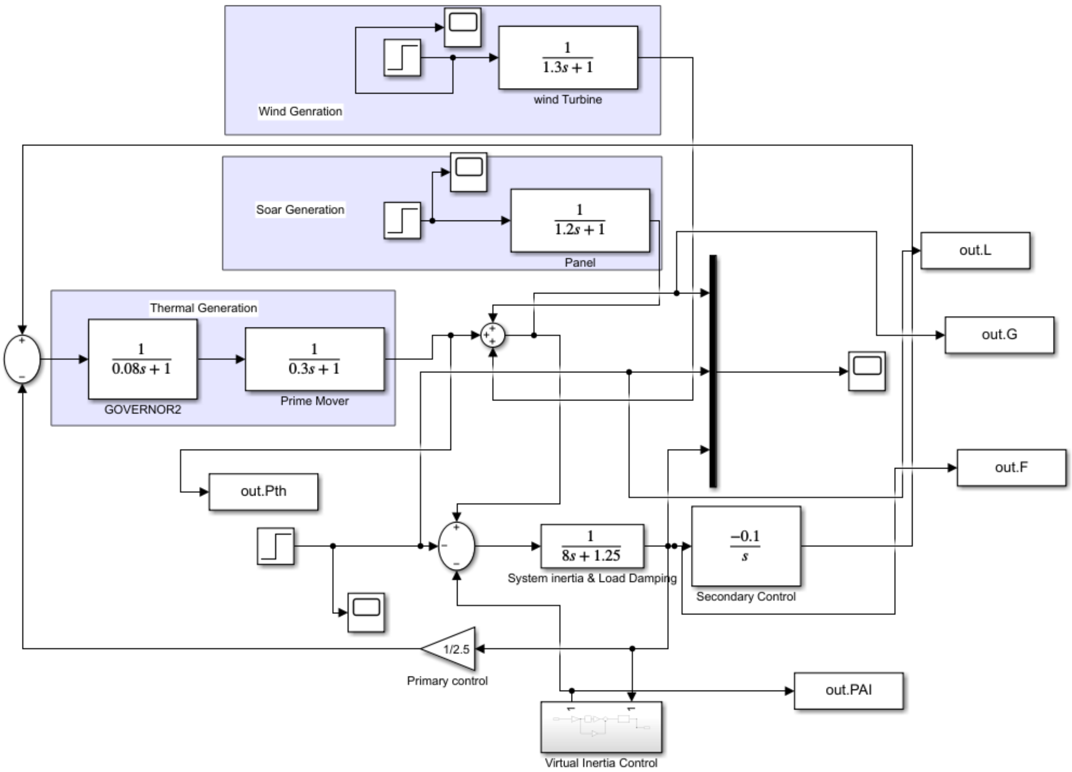

Fig.3.1e Simulink Model of single area Power system.

3.2 CALCULATION

The swing equation (1) linearised into two first-order differential equations-

$$\frac{d\delta}{dt} = \omega_0\omega_r \quad 3.1$$

$$\frac{d\omega}{dt} = \frac{1}{2H}(P_{mec} - P_{ele}) = \frac{1}{M}(P_{mec} - P_{ele}) \quad 3.2$$

As soon as the load changes, the electrical power, mechanical power, frequency, and rotor position will also vary.

$$\frac{d\Delta\delta}{dt} = \omega_0\Delta\omega r$$

$$\frac{\partial\Delta\omega_r}{\partial t} = \frac{1}{M}(\Delta P_{mec} - \Delta P_{ele}) \quad 3.3$$

Taking Laplace Transform; $s\Delta\delta(s) = \omega_0\Delta\omega(s)$

$$s\Delta\omega_r(s) = \frac{1}{M}(\Delta P_{mec}(s) - \Delta P_{ele}(s)) \quad 3.4$$

Some loads are frequency dependent so change in electrical power will be-

$$\Delta P_{ele} = \Delta P_L + D.\Delta\omega_r \quad 3.5$$

Here, generation from solar, wind, and Virtual inertia, so the equation will be-

$$\Delta\omega_r(s) = \frac{1}{2HS+D}(\Delta pmec(s) + \Delta P_{solar}(s) + \Delta P_{wind}(s) + \Delta P_{VI}(s) - \Delta P_L(s)) \quad (3.6)$$

Where,M=2H

The first ordered transfer function of Turbine, Governor, Wind, Solar are used for simulating the dynamic model of single area power system [10].

Turbine -

$$\Delta P_{mec}(s) = \frac{1}{1+sT_t}\Delta P_g(s) \quad 3.7$$

Governor-

$$\Delta Pg(s) = \frac{1}{1+sTg}\left(\Delta P_{ref}(s) - \frac{1}{R}\Delta f(s)\right) \quad 3.8$$

Wind-

$$\Delta P_{\omega}(s) = \frac{1}{1+sT\omega} \qquad \Delta P_{wind}(s) \quad 3.9$$

Solar-

$$\Delta P_{p_v} = \frac{1}{1+sTpv} \quad \Delta P_{solar}(s) \qquad 3.10$$

3.3 STATE SPACE ANALYSIS

For designers and operators, understanding the entire system attribute is made simpler by the state space model. This state space model is helpful for exploring the specifics of power system dynamics and stability.

The system's state space model enables the creation of a controller that utilizes all of the system's state parameter.

The standard form of state matrix[11,12]-

$\dot{x}(t) = A'x(t) + B'u(t)$

$y(t) = C'x(t) + D' u(t)$

$x(t) = State\ vector$

$y(t) = \text{Output vector}$

$x^0 = A'x + B'_1\omega + B'_2 u ,$ 3.11

From the equation (14-19) the state variable as

$x^T = [\ \Delta f\ \Delta P_{mec}\ \ \Delta P_g\ \ \Delta P_{ref}\ \ \Delta P_{VI}\ \ \Delta P_W\ \ \Delta P_{PV}]$ 3.12

$w^T = [\Delta P_{wind}\ \Delta P_{solar}\ \Delta P_L]$ 3.13

$u^T = [\ \frac{dF}{dt}]$ 3.14

Where x^T = output signal; w^T = disturb signal; u^T = input signal. The equation from(14-19) we get;

$$s \cdot \Delta f(s) = \frac{\Delta P_{mec}(s)}{2H} + \frac{\Delta_{Pws}(s)}{2H} + \frac{\Delta P_{Pv(s)}}{2H} + \frac{\Delta P_{v_I}}{2H}(s)\frac{-\Delta P_L(5)}{2H} - \frac{D\Delta f(s)}{2H} \qquad 3.15$$

$$s.\Delta P_{mec}(s) = \frac{\Delta Pg\ (s)}{T_t} - \frac{\Delta\Delta P_{mec}(s)}{T_t} \qquad 3.16$$

$$s.\Delta P_g(s) = -\frac{\Delta f(s)}{RT_g} - \frac{\Delta Pg(s)}{T_g} + \frac{\Delta PC(s)}{T_g} \qquad 3.17$$

$$s.\ \Delta P_{ref}(s) = Ks\Delta f(s) \qquad 3.18$$

$$s\ \Delta P_{AI}(s) = \Delta f(S)\left(\frac{Dv_1}{R_{v_I}TINV}\right) + \Delta f\ (S)\left(\frac{KVI}{R_{v_I}TINV}\right) - \frac{\Delta P_{v_I}}{T_{INV}} \qquad 3.19$$

$$\Delta P_\omega(s) = \frac{\Delta P_{wind}(s)}{T_{\omega T}}\frac{+\Delta P_\omega(s)}{T_{\omega T}} \qquad 3.20$$

$$s.\Delta P_v(s) = \frac{\Delta P_{solar}}{T_{PV}} + \frac{\Delta P_{Pv}(s)}{T_{PV}} \quad 3.21$$

Now, the state equation can be write into the time domain and written in matrix. That we use in MATLAB code for designing load frequency control system that control the power generation.

$$\begin{pmatrix} \Delta f' \\ \Delta Pm' \\ \Delta Pg' \\ \Delta PVI' \\ \Delta P' \\ \Delta Pv' \end{pmatrix} = \underbrace{\begin{pmatrix} -D/2H & 1/2H & 0 & 1/2H & 1/2H & 1/2H \\ 0 & -1/Tt & 1/Tt & 0 & 0 & 0 \\ -1/Rg & 0 & -1/Tg & 0 & 0 & 0 \\ -\frac{DVI}{RVI\ TINV} & 0 & 0 & -1/Tinv & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/Tw & 0 \\ 0 & 0 & 0 & 0 & 0 & -1/Tpv \end{pmatrix}}_{A} \begin{pmatrix} \Delta f \\ \Delta Pm \\ \Delta Pg \\ \Delta PVI \\ \Delta P\omega \\ \Delta Pv \end{pmatrix} + \underbrace{\begin{pmatrix} 0 & 0 & -1/2H \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1/T\omega T & 0 & 0 \\ 0 & 1/Tpv & 0 \end{pmatrix}}_{B} \begin{pmatrix} \Delta Pwind \\ \Delta Psol \\ \Delta Pl \end{pmatrix}$$

$$\begin{pmatrix} \Delta f \end{pmatrix} = \underbrace{\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}}_{C} \begin{pmatrix} \Delta Pg \\ \Delta Pm \\ \Delta P\omega \\ \Delta Ps \\ \Delta P \\ \Delta f \end{pmatrix} + \underbrace{\begin{pmatrix} 0 \end{pmatrix}}_{D}$$

From the matrix we can easily find which variable is dependent upon which parameter.

CHAPTER 4

RENEWABLE ENERGY PENETRATION AND ITS IMPACT ON THE GRID

4.1 EFFECT OF VARIATION OF SOLAR, WIND GENERATION AND LOAD ON THE ISOLATED POWER SYSTEM

A single area power system is shown in Fig. 3.1b uses the Primary control, Secondary control, virtual inertia control method. The MATLAB/Simulink initiatives is used to build the small-signal/dynamic response model. Following are some degraded scenarios of system inertia and load-damping reductions that are added to the examined system in order to verify the effectiveness of the suggested inertia control strategy. Inverter-based RE is not provided inertia to the system, so we use ESS to build Artificial inertia.

4.1.1 Frequency behavior with an increase in load and generation and variation of system Inertia

Adding solar (0.05p.u) and wind (0.05p.u) generation to the system at t=10sec, and the load (0.5p.u) is changed at t=60sec, Before that the system was balanced. The frequency of the system first increases at t=10sec due to a sudden increase in generation in the system, the frequency decreases at t=60sec due to a sudden increase in load and then settles finally at the rated value (Fig-4.1a). To decrease the system inertia of its starting value, this causes a larger overshoot and nadir as the load changes, which necessitates a longer recovery period following the disturbance (fig-4.1b). It is clear that a longer stabilizing period will result in a large rise in the frequency nadir/overshoot of the system due to the reduction in system inertia caused by RESs/DGs penetration. A system operator has less time to respond to disruptions as the ROCOF of the system likewise rises. In a system with a high share of RESs/DGs, these issues would worsen. Under-frequency load-shedding (UFLS) may be necessary to control such low inertia conditions without using virtual inertia control. System instability, generation tripping, cascading outages, and power blackouts could happen in the absence of adequate regulation.

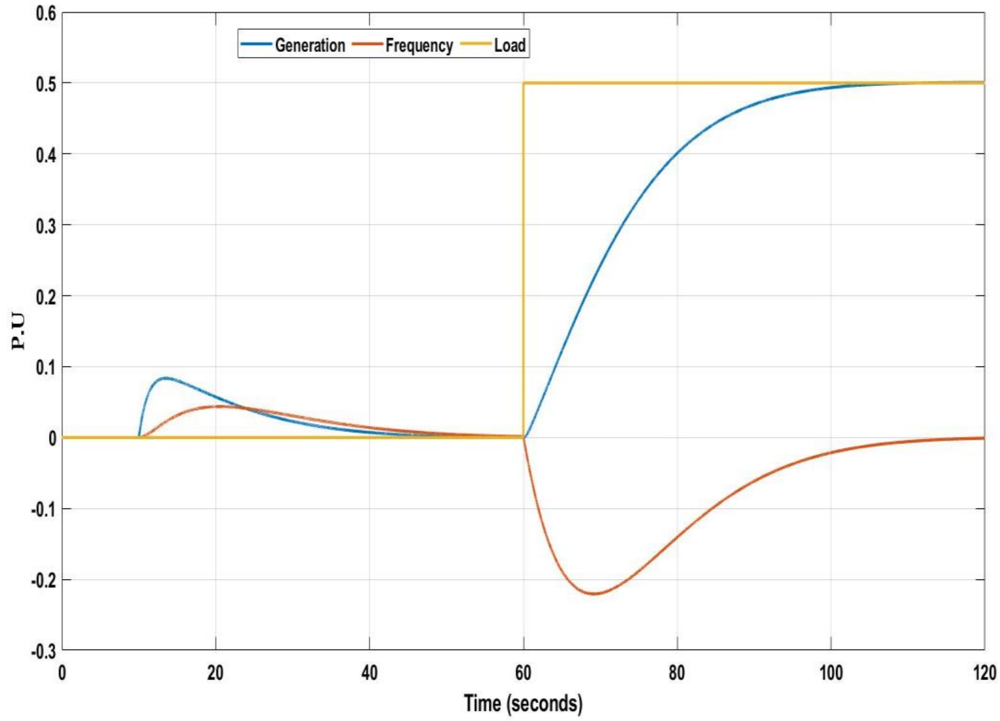

Fig.4.1a Responses of isolated power system with Variation of load and RE.

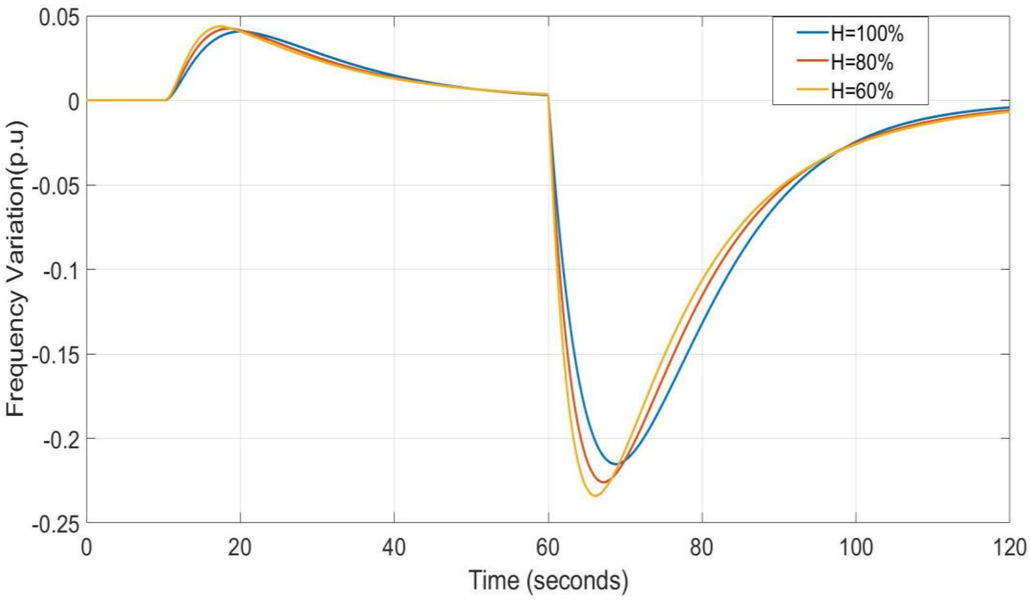

Fig.4.1b Frequency response isolated inertia power system with Variation of System Inertia.

4.1.2 IMPACT ARTIFICIAL INERTIA CONTROL DROOP'S AND ARTIFICIAL INERTIA CONSTANT

The inverter-based artificial inertia control droop controls the produced power with the required inertia and damping. By reducing frequency variations following the disturbance, the artificial inertia control droop characteristic may also aid to increase system study [11]. Table 1.1 contains the system's control parameters. While the stabilizing time lengthens, the system performs better with less frequency nadir/overshoot when the R_{AI} is decreased (Fig-4.2a).

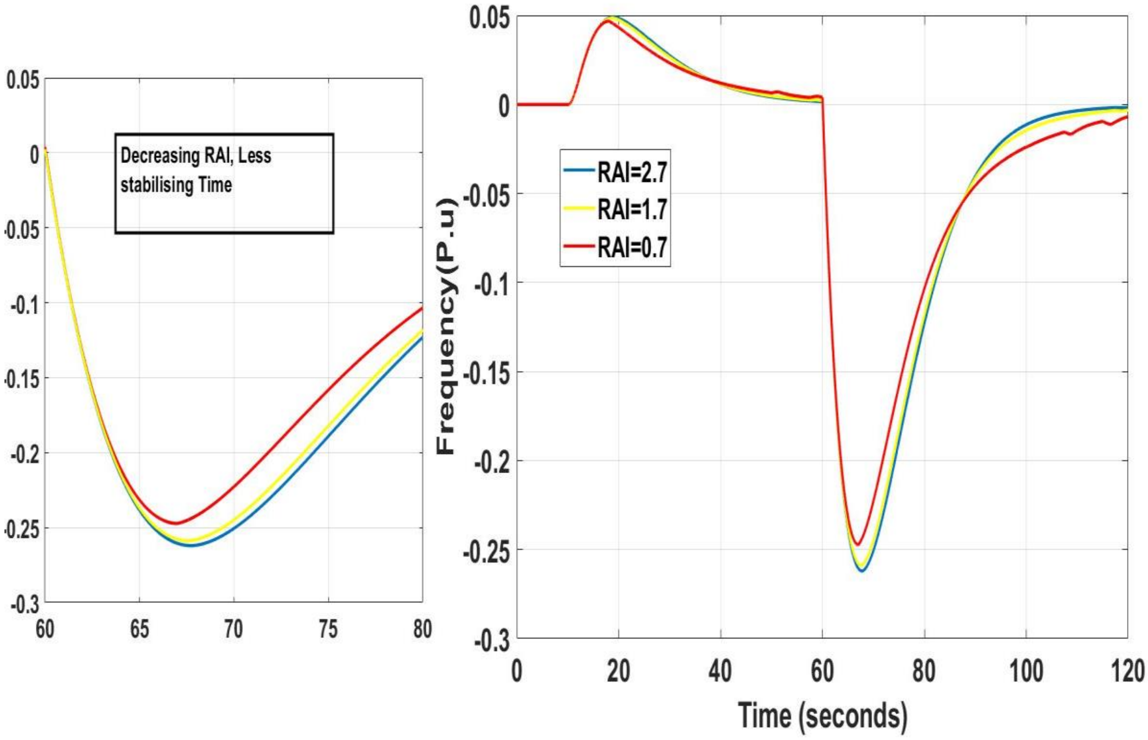

Fig.4.1c Frequency response when the artificial Droop constant varies

The other parameters of the system remain constant, by increasing the inertia constant which led to in decrease of frequency nadir point. Then the system is more stable(fig-4.2b). If the inertia constant value is increased very large value the system frequency needs more time to stabilize. This can be reduced by increasing the value of the virtual damping constant along with the virtual inertia constant.

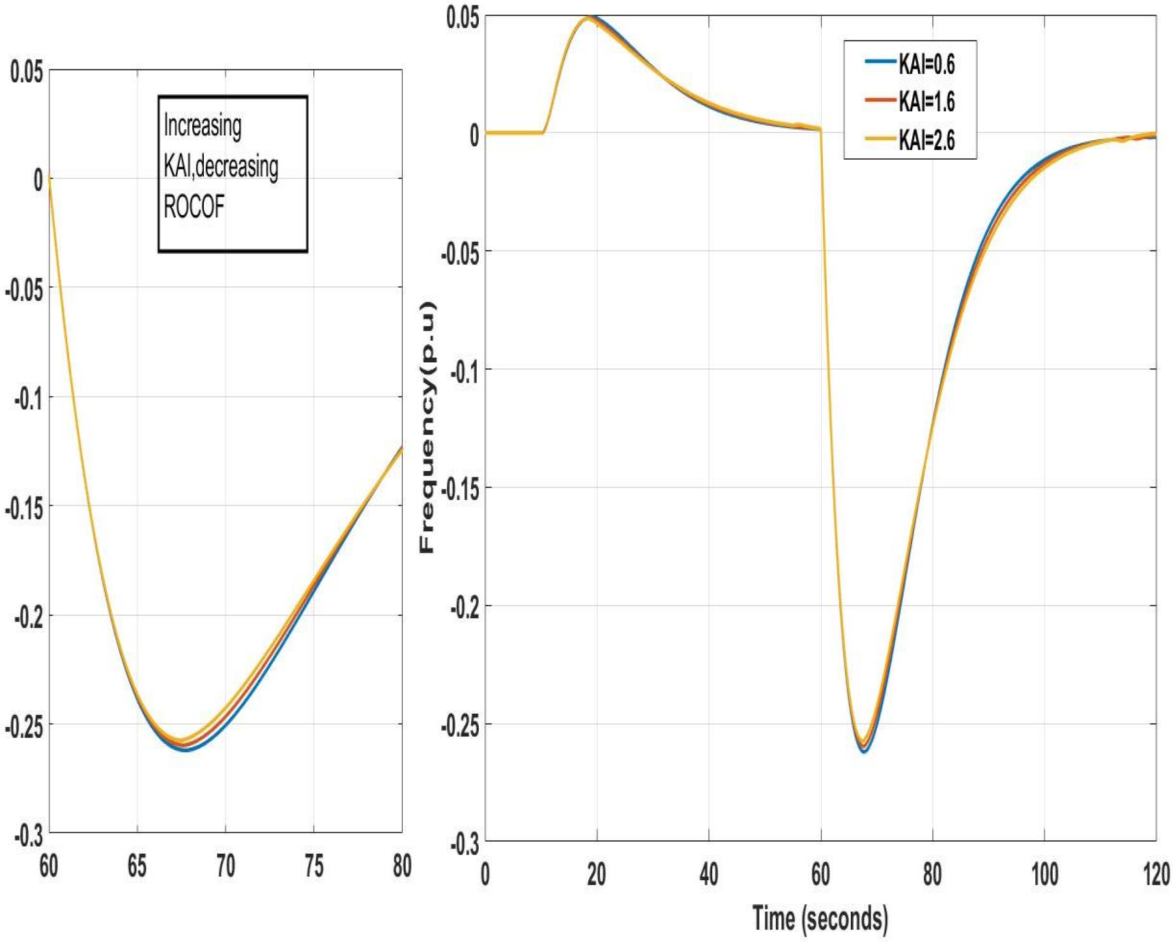

Fig.4.1d Frequency response when the artificial inertia constant varies

4.2 PRACTICAL ISOLATED POWER SYSTEM

For practical analysis of frequency variation, the change in Power data of 24 hours. distributed into four sections.

In each case, we have plotted frequency variation. The load curve remains the same for all the cases.

The actual solar and wind power data is used to simulate the isolated power system. From actual data of solar and wind power data, we are able to calculate power deviation at 15 min intervals.

Table-4.1 Solar Power Deviation [32]

Solar Power Deviation(P.U)	(12 A.M to 6A.M)	(6A.M to 12P.M)	(12P.M to 6 P.M)	(6P.M to12A.M)
1	0	0	0.019606	-0.006736
2	0	0	0.015897	-0.002152
3	0	0.00033	0.022509	-0.001714
4	0	0.00235	-0.01750	-0.000833
5	0	0.00338	0.009185	0
6	0	0.00585	-0.03505	0
7	0	0.00507	0.005623	0
8	0	0.00119	0.009011	0
9	0	-0.0011	0.00241	0
10	0	0.00041	0.016745	0
11	0	0.00826	0.010487	0
12	0	0.01275	-0.050712	0
13	0	0.00392	0.012764	0
14	0	-0.01316	-0.007961	0
15	0	0.02060	-0.001845	0
16	0	-0.01044	0.00759	0
17	0	-0.00781	-0.015021	0
18	0	0.03164	-0.004091	0
19	0	-	0.001645	0

		0.00435		
20	0	0.00612	0.002020	0
21	0	-0.0218	-0.01631	0
22	0	0.00962	-0.00902	0
23	0	0.01405	-0.00326	0
24	0	0.01735	-0.00828	0

Table-4.2 Wind Power Deviation[33]

Wind Power Deviation(P.U)2 24	**(12 A.M to 6A.M)**	**(6A.M to 12P.M)**	**(12P.M to 6 P.M)**	**(6P.M to12A.M)**
1	0	-0.0018	0.02397	0.02019
2	-0.0101	-0.0006	0.003	-0.01996
3	-0.0099	-0.0003	0.003	-0.01001
4	0.07713	-0.0024	-0.011	0.01998
5	-0.0611	-0.0017	0.0091	0.01007
6	0.00357	0.03461	-0.02898	0.01005
7	-0.0477	-0.03751	-0.00991	0.01008
8	-0.001	-0.0017	-0.03831	-0.00997
9	-0.0009	0.06865	0	0.00015
10	0.0006	0.02845	0.07851	0.01015
11	-0.0008	0.0744	-0.01984	-0.03489
12	-0.0008	0.003	-0.00998	0.0008
13	-0.0007	-0.024	0.02003	0.0005
14	-0.001	0.002	0.01014	0.0007
15	0.0002	0.003	-0.01999	0.001
16	-0.0003	-0.008	-0.00998	0.0011
17	-0.0013	-0.013	-0.00983	0.0013

18	-0.0014	-0.018	0.0001	0.0002
19	-0.0012	-0.015	0.01004	0.0006
20	-0.0004	-0.007	0.01016	0.0099
21	-0.0003	-0.008	-0.00988	-0.0092
22	-0.0014	-0.001	-0.0297	0.0007
23	-0.0016	-0.03797	0.00014	-0.0006
24	-0.0015	0.02397	0.01012	0.001

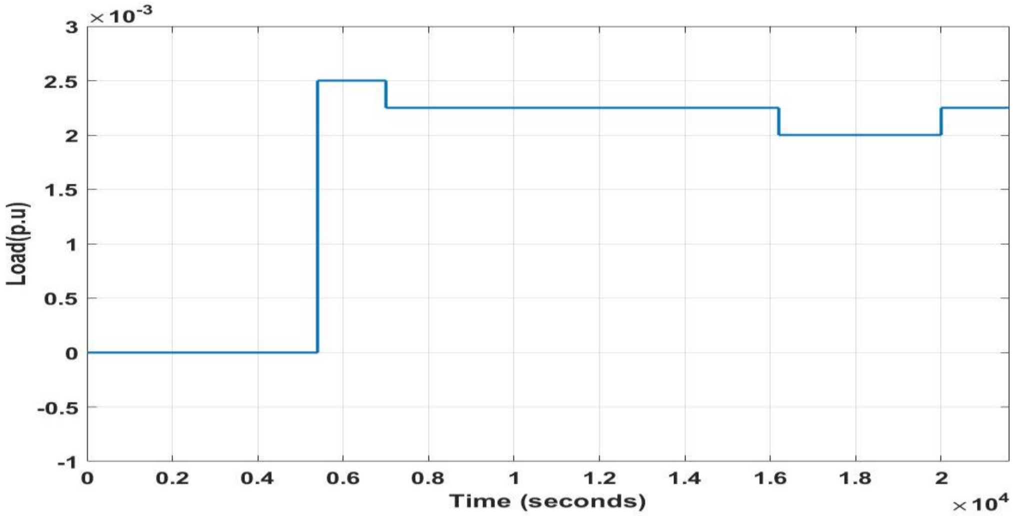

Fig.4.2a Load variation curve of 6 hrs

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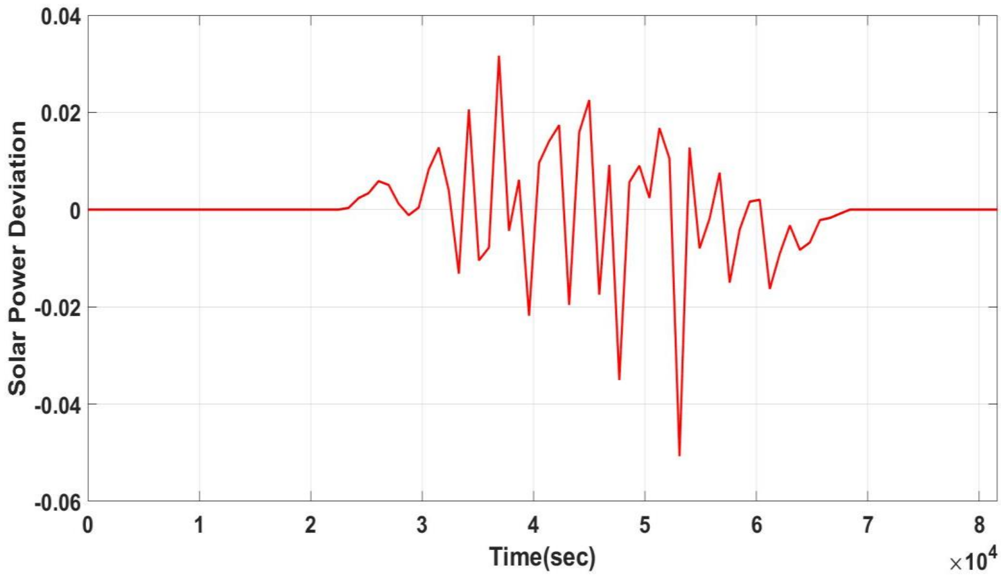

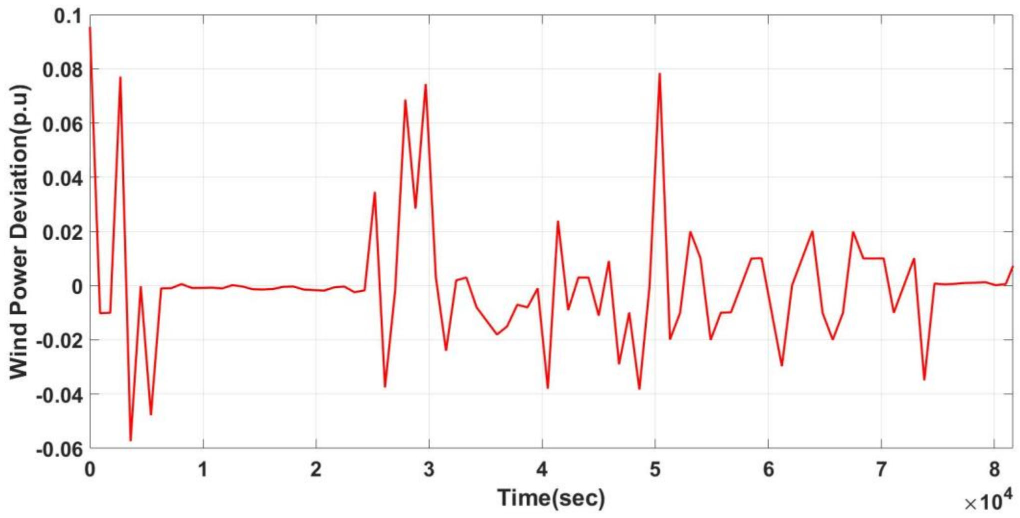

Fig.4.2b Power deviation curve of 24 hours due to variation of solar insolation and wind speed.

4.2.1 Frequency variation due to the renewable energy's irregular nature (ignoring an increase or decrease in load, change i.e $\Delta P_{L=0}$)

In every instance, the power curve displays the power produced by Thermal + with AGC, Solar, Wind, & Thermal without AGC. Every case's power curve is presented so that we can quickly see the frequency variation brought on by RES' inconsistent nature.

4.2.1a- In this instance, we saw the frequency response due to the inconsistent RES of duration (12A.M-6A.M).

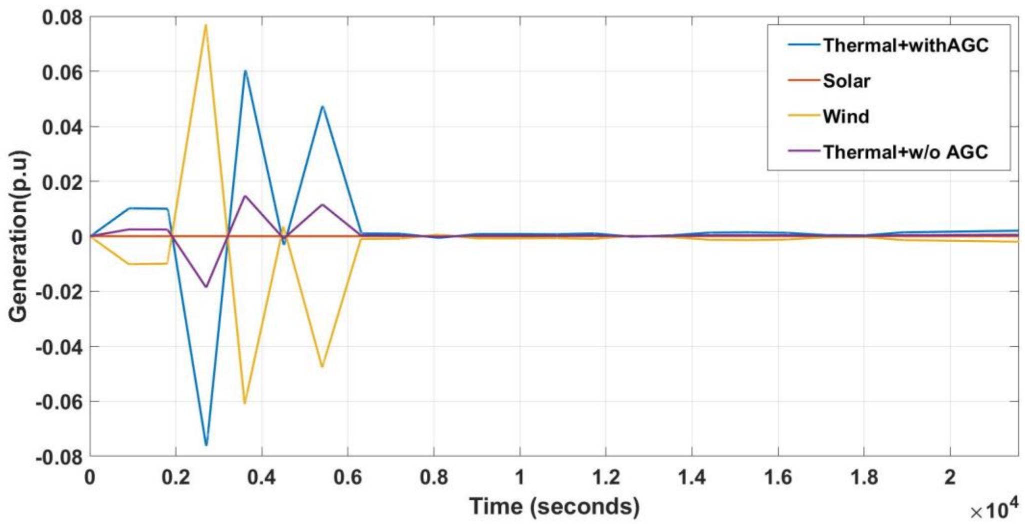

Fig.4.2.1a Power generation from Thermal+ with AGC, Solar, wind &Thermal +w/o AGC

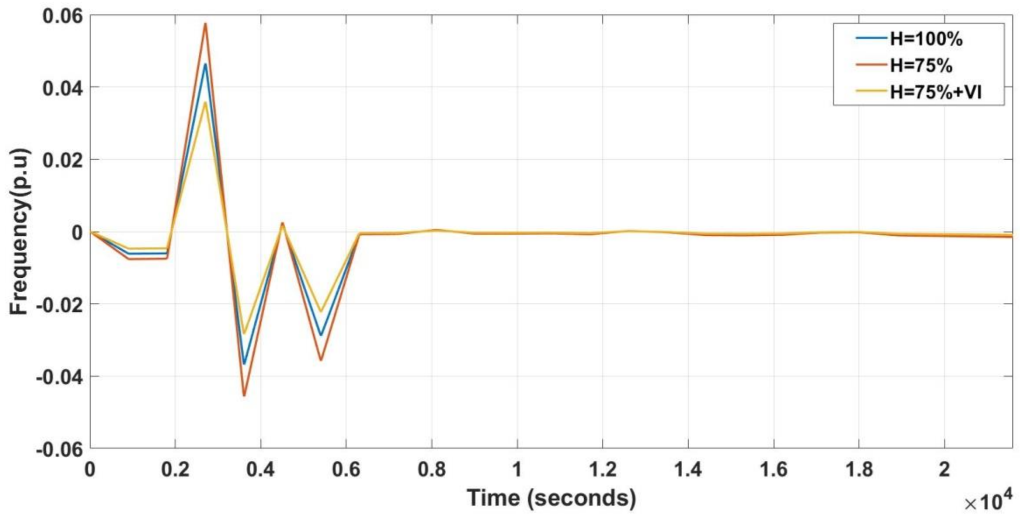

Fig.4.2.1b Frequency variation(Δf) response due to inertia(H) &W/O AGC.

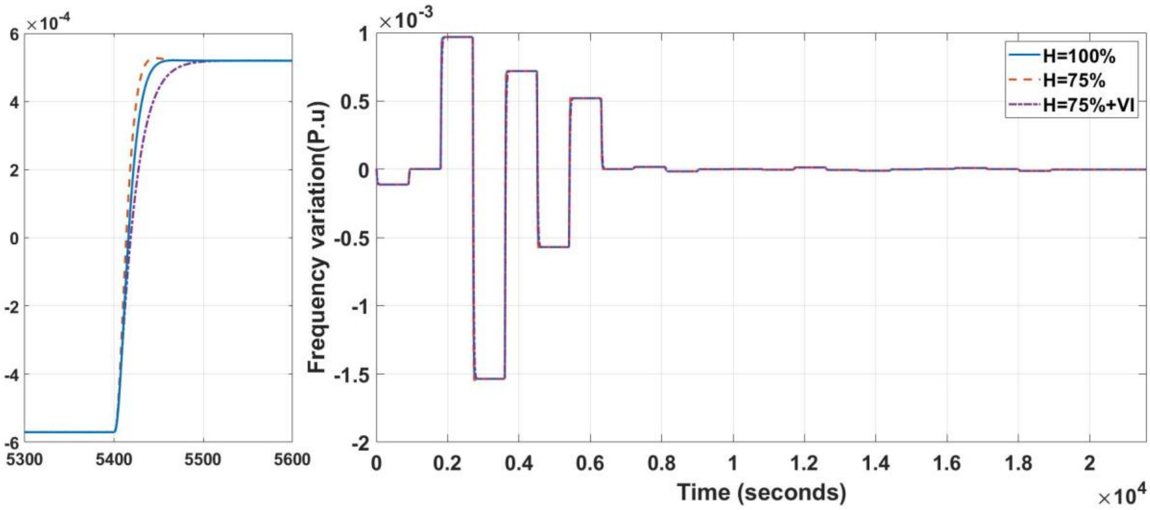

Fig.4.2.1c Frequency variation(Δf) response due to inertia(H) & with AGC.

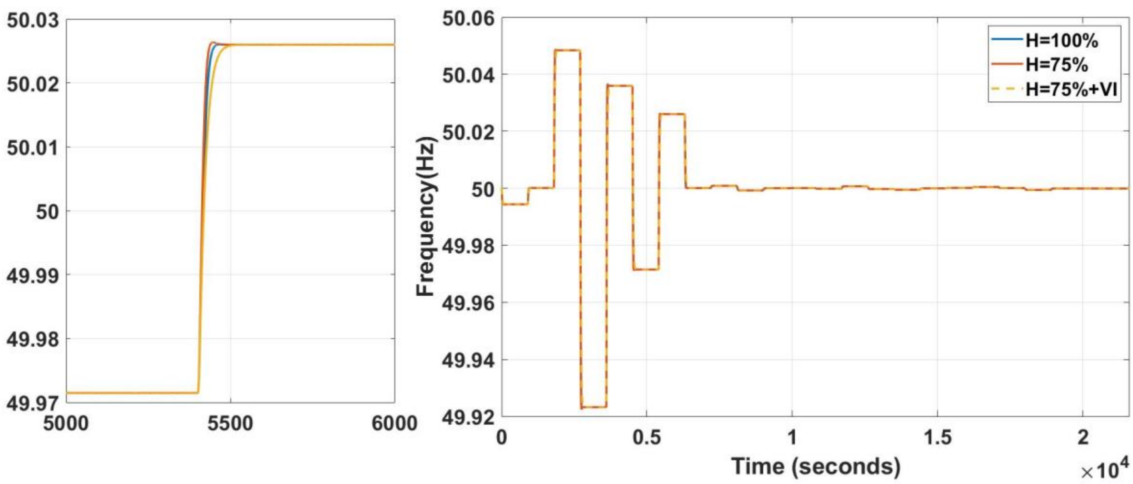

Fig.4.2.1d Frequency response (Hz) with a variation of inertia with AGC.

In this section, we have observed the variation of generation due to wind (solar generation=0). The power generation by the conventional generator is more within AGC. The frequency response is analyzed with a variation of inertia and the presence of virtual inertia. The variation of frequency is less when 75%of thermal generation and RE with Artificial inertia

4.2.1b In this we have observed the frequency response due to the intermittent nature of RES of duration(6A.M-12P.M).

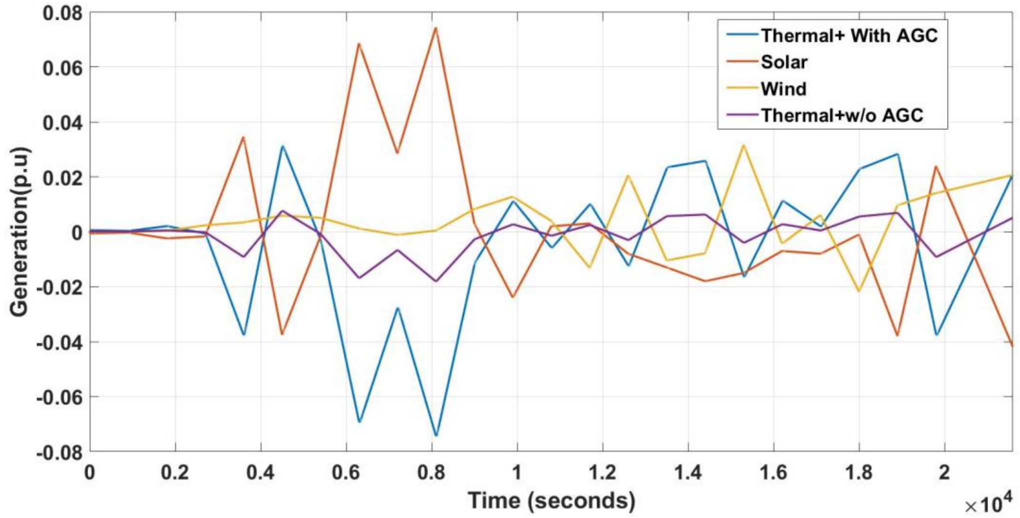

Fig.4.2.1e Power generation from Thermal+ with AGC, Solar, wind &Thermal +w/o AGC

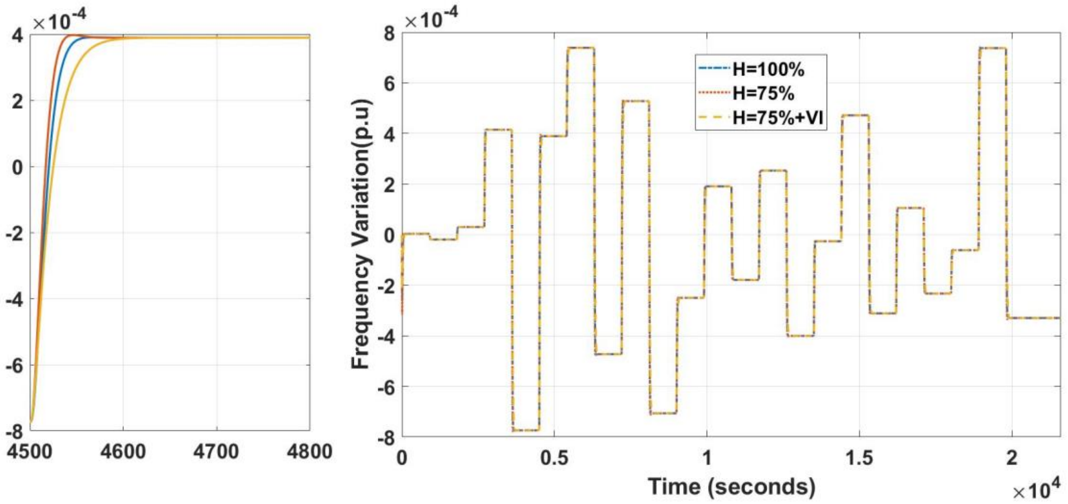

Fig.4.2.1f. Frequency variation(Δf) response due to inertia(H) &with AGC

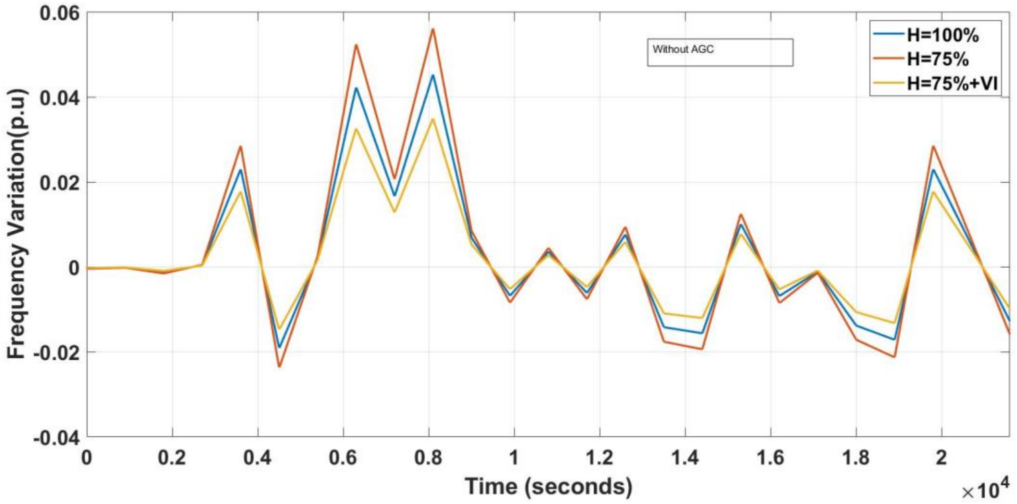

Fig.4.2.1g. Frequency variation(Δf) response due to inertia(H) &W/O AGC.

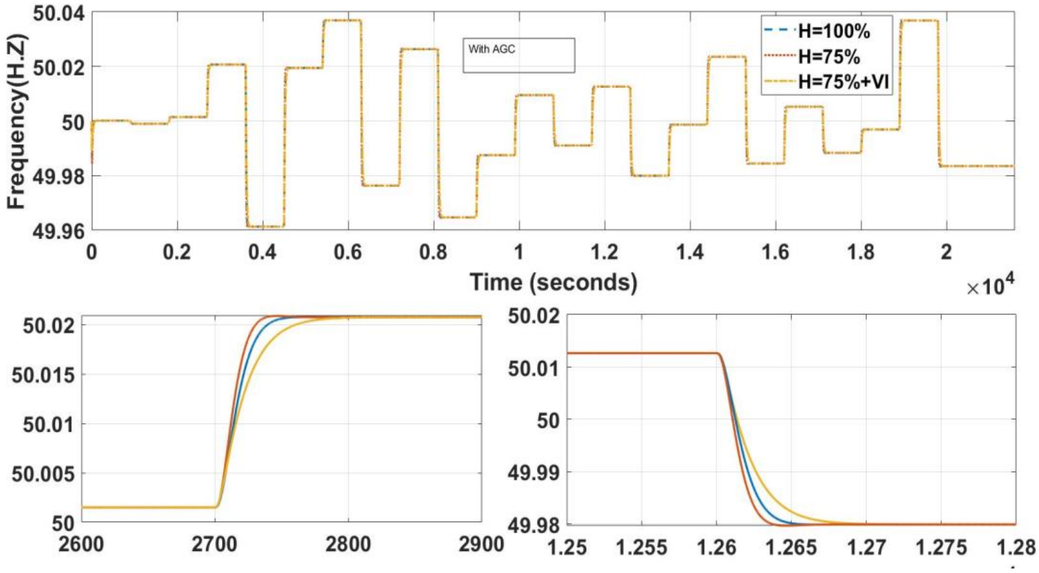

Fig.4.2.1h Frequency response (Hz) with a variation of inertia.

In this section, we observed that at some time there is a wide variation of solar generation. At that instant Thermal generation decrease to balance the system. From Fig.4.2.1h we observed that the frequency variation is less with virtual inertia compare to other scenarios.

4.2.1c In this we have observed the frequency response due to the intermittent nature of RES of duration(12P.M-6P.M).

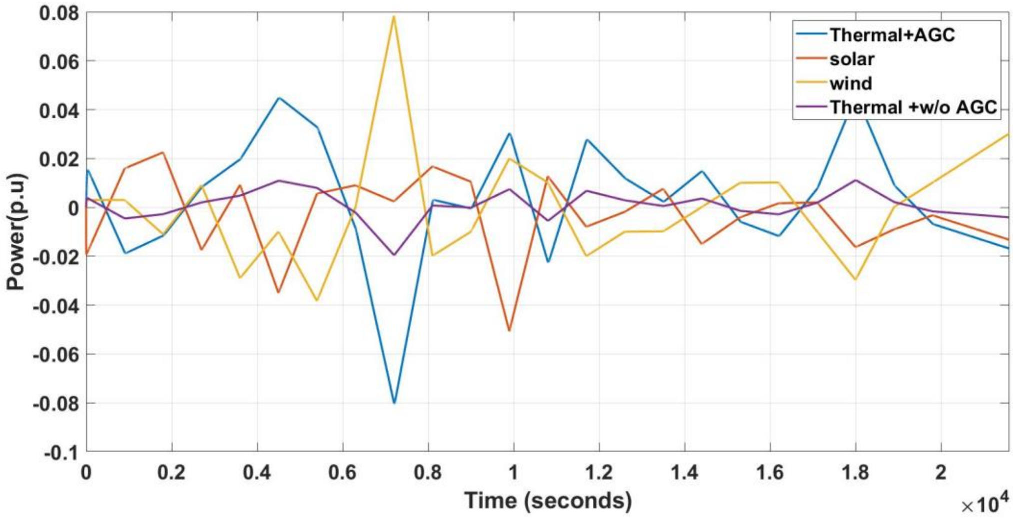

Fig.4.2.1i Power generation from Thermal+ with AGC, Solar, wind &Thermal +w/o AGC

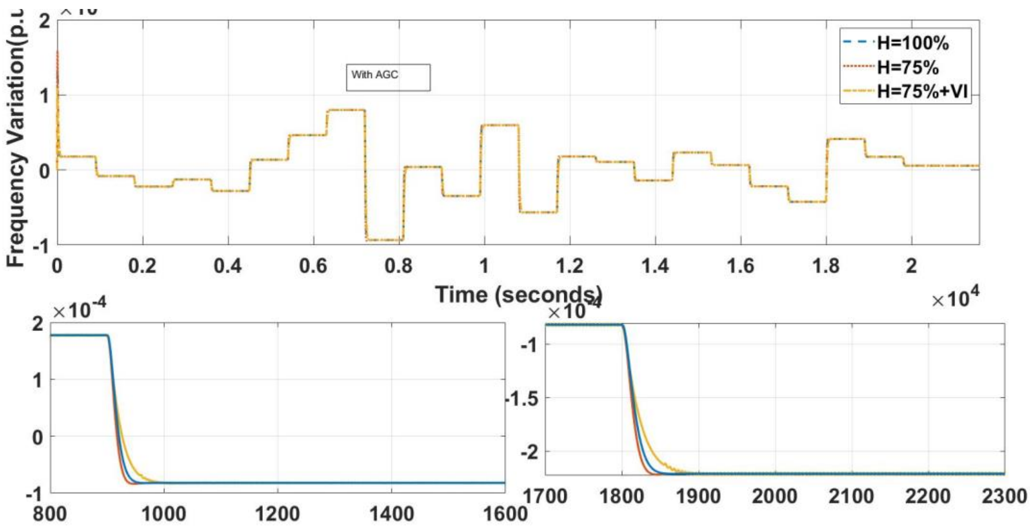

Fig.4.2.1jFrequency variation(Δf) response due to inertia(H) & with AGC.

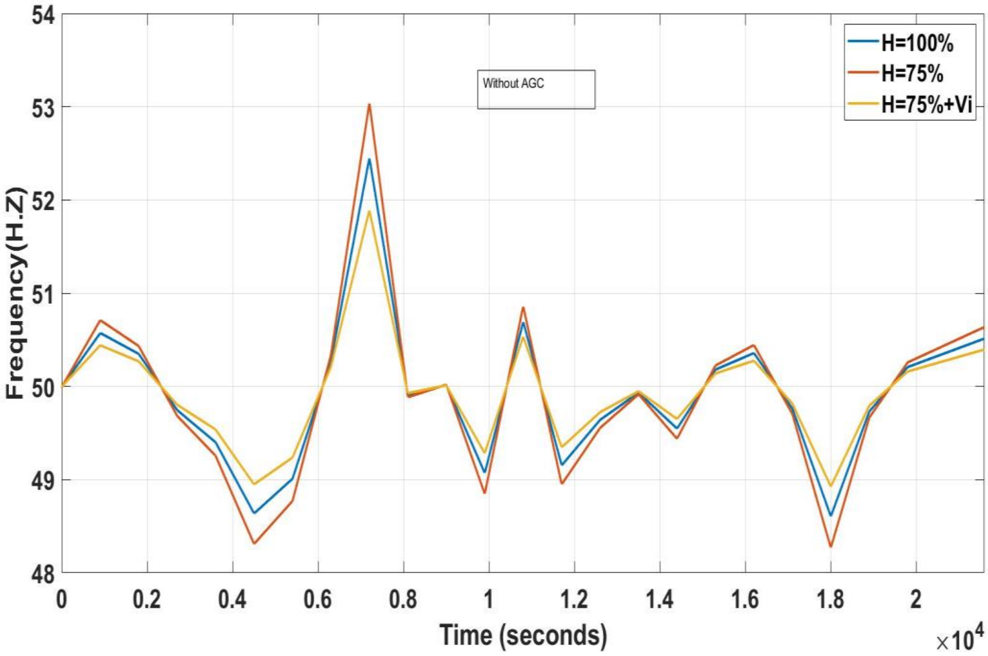

Fig.4.2.1k Frequency variation(Δf) response due to inertia(H) &W/O AGC.

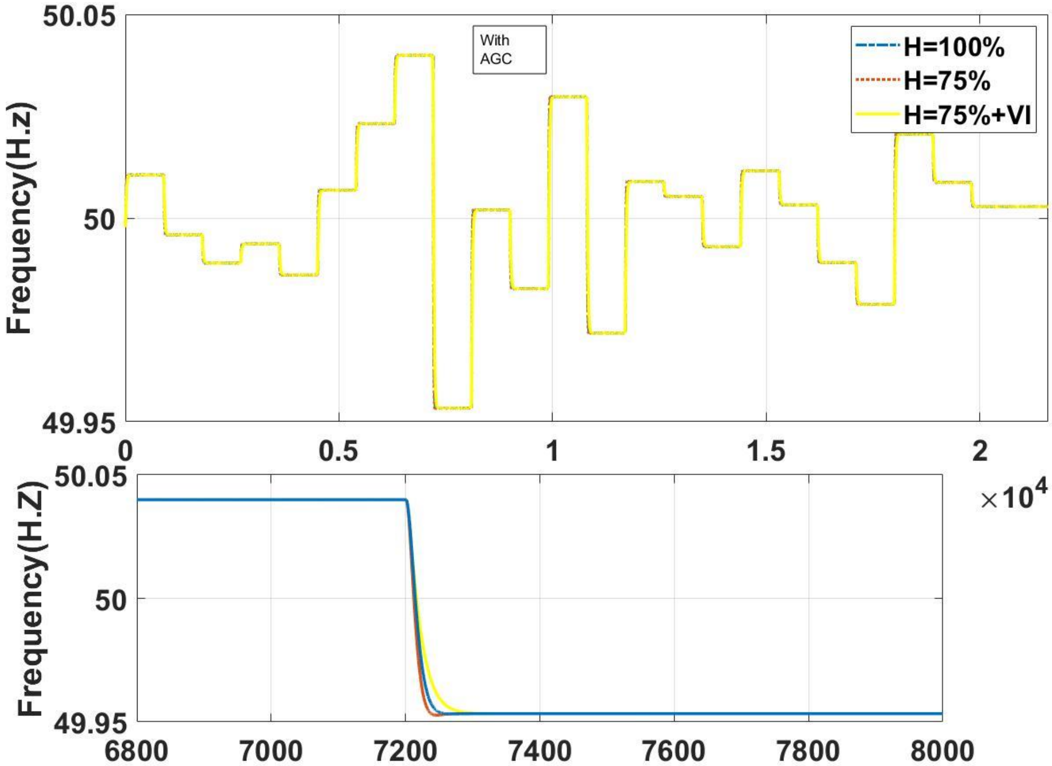

Fig.4.2.1l Frequency response (Hz) with a variation of inertia.

4.2.1d In this we have observed the frequency response due to intermittent nature of RES of duration (6P.M-12A.M).

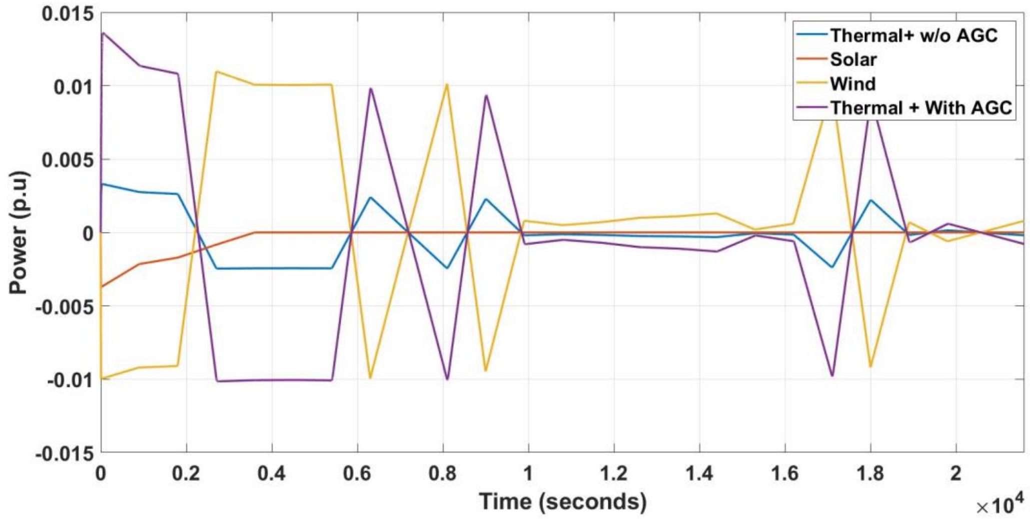

Fig.4.2.1m Power generation from Thermal+ with AGC, Solar, wind &Thermal +w/o AGC

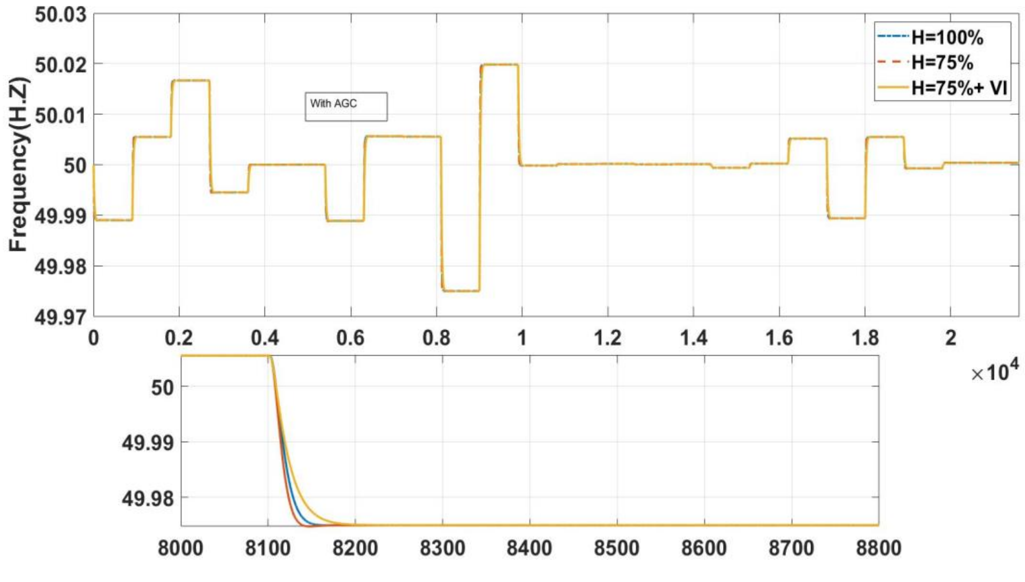

Fig.4.2.1n Frequency response (Hz) with the variation of inertia.

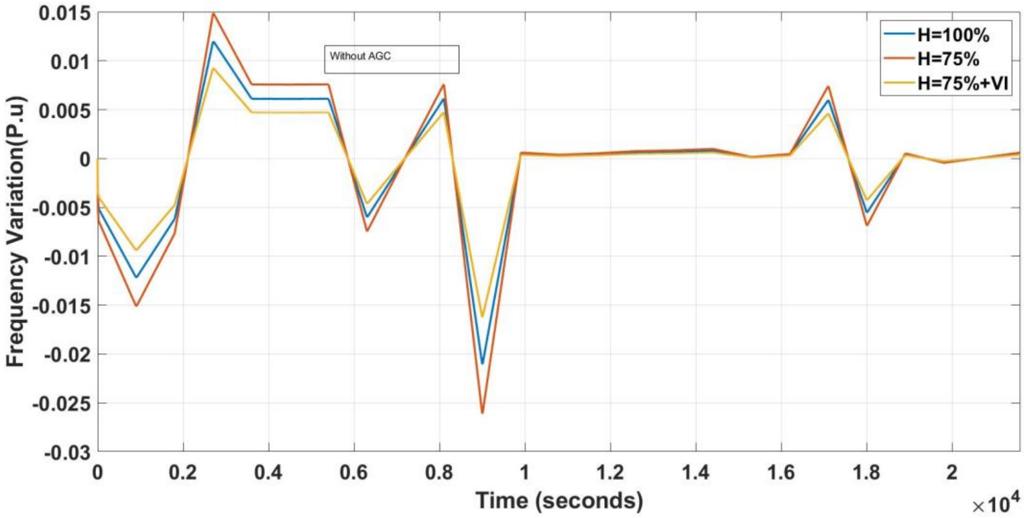

Fig.4.2.1oFrequency variation(Δf) response due to inertia(H) &W/O AGC.

4.2.2 Observation of frequency deviation due to the inconsistent nature of Renewable energy & Load change.

4.2.2a In this we have observed the frequency response due to the inconsistent nature of RES and Load (Fig.4.2a) of duration (12A.M-6P.M).

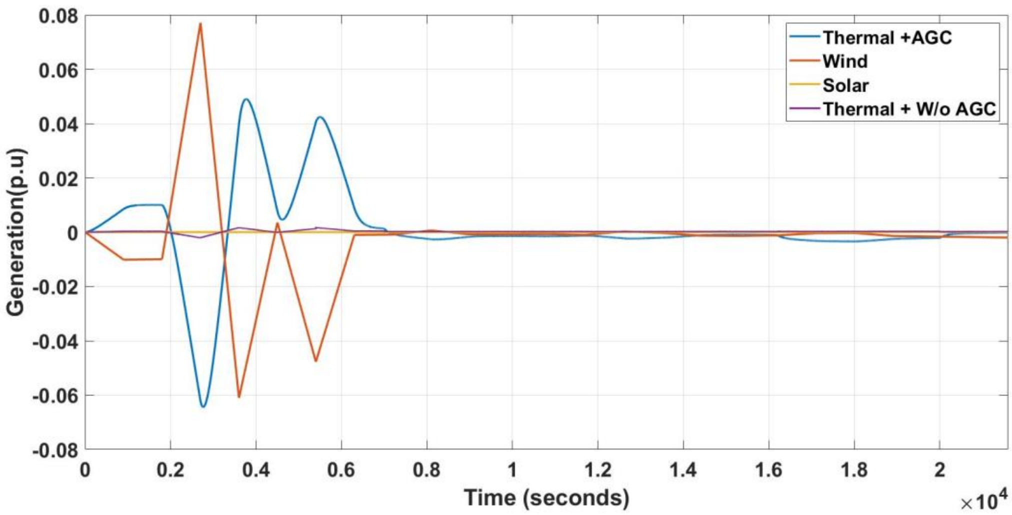

Fig.4.2.2a Power generation from Thermal+ with AGC, Solar, wind &Thermal +w/o AGC

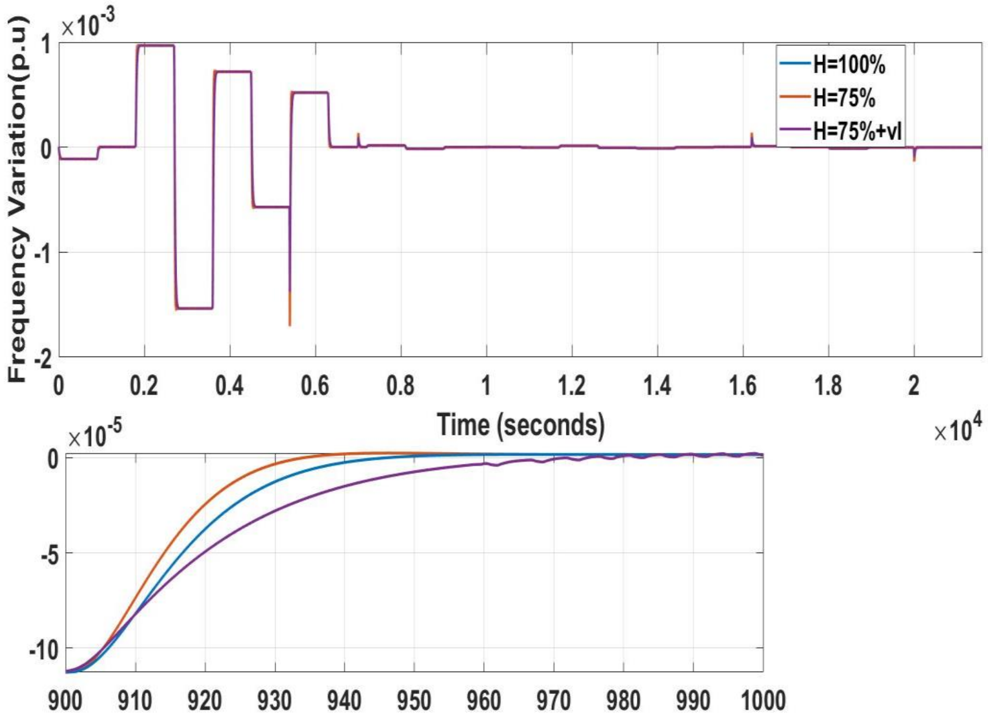

Fig.4.2.2b Frequency variation(Δf) response due to inertia(H) &with AGC

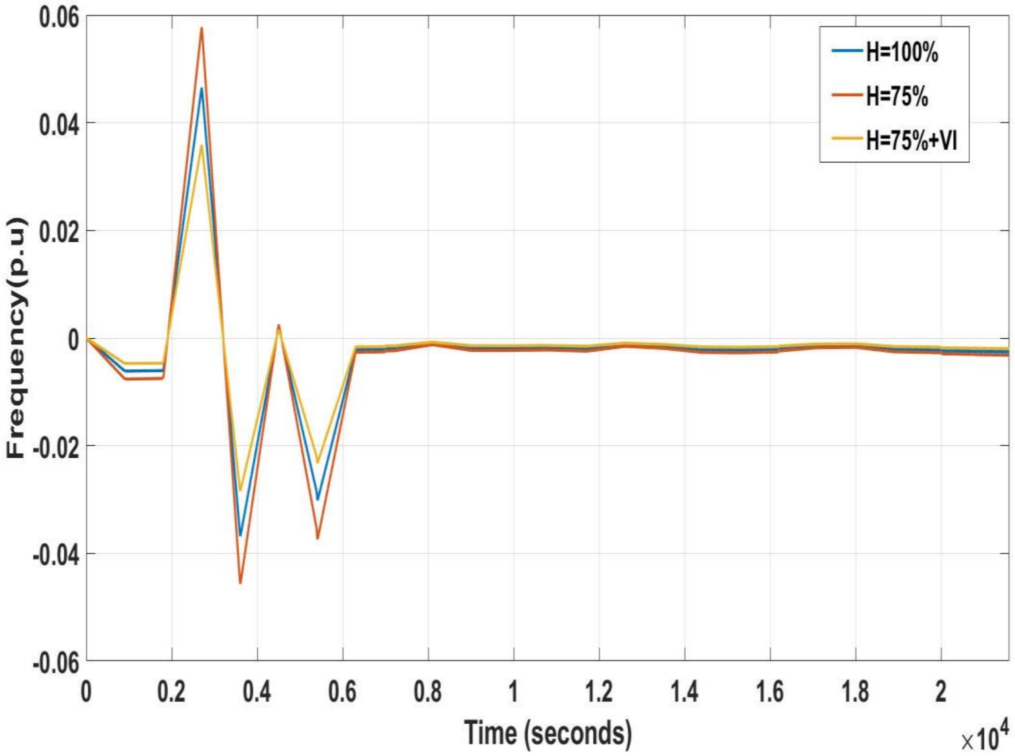

Fig.4.2.2c Frequency variation(Δf) response due to inertia(H) &W/O AGC.

4.2.2b In this, we have observed the frequency response due to the intermittent nature of RES and Load(Fig.4.2a) of duration(6A.M-12P.M).

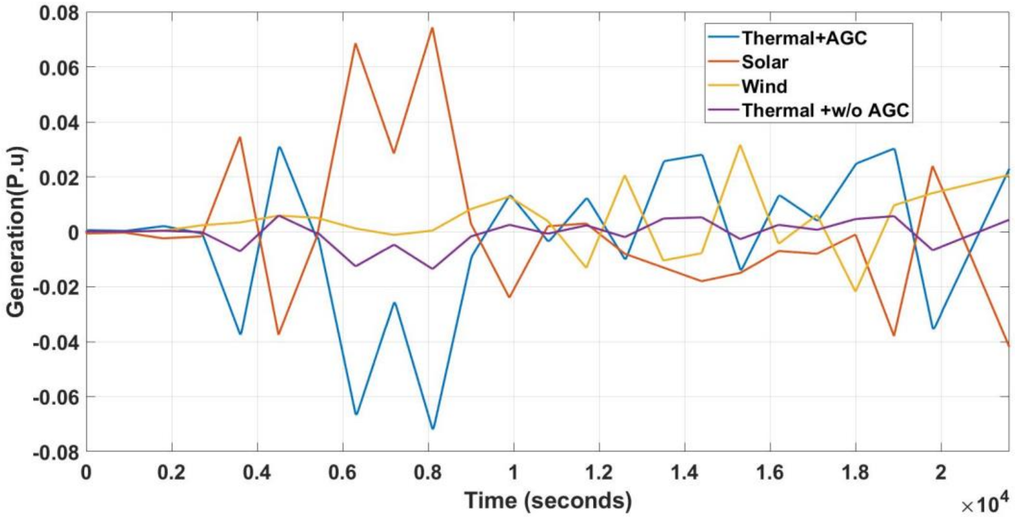

Fig.4.2.2d Power generation from Thermal+ with AGC, Solar, wind &Thermal +w/o AGC

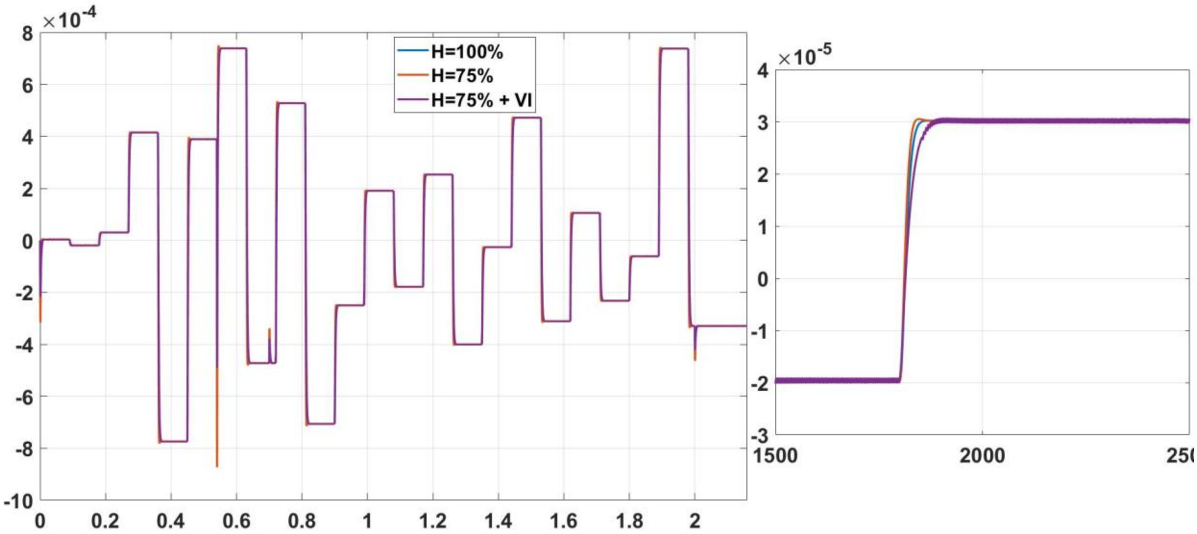

Fig.4.2.2e Frequency variation(Δf) response due to inertia(H) & with AGC.

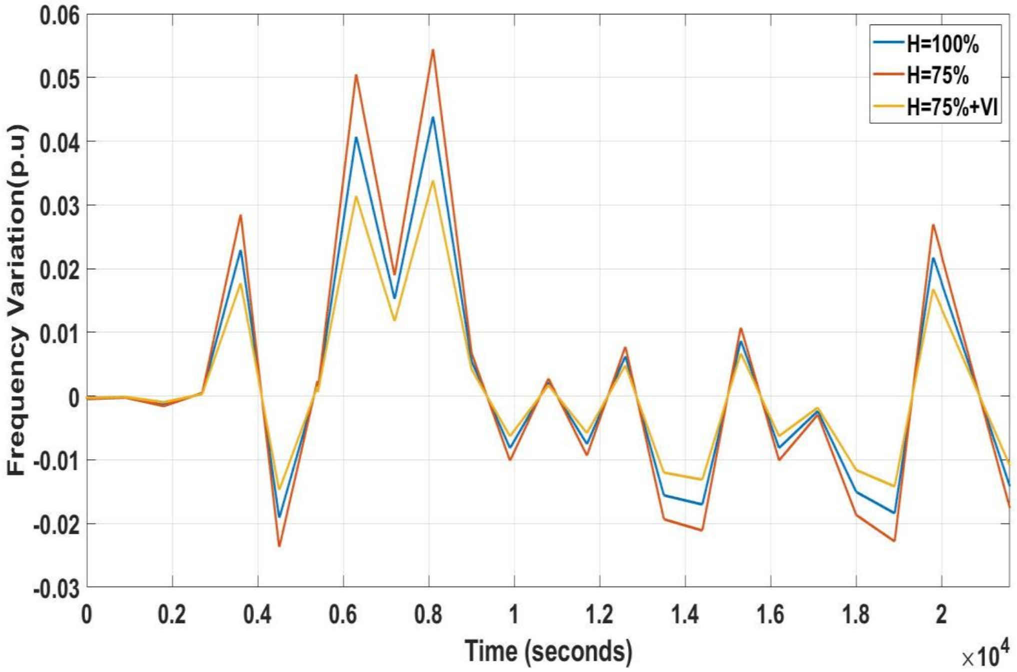

Fig.4.2.2f Frequency variation(Δf) response due to inertia(H) w/o AGC.

4.2.2c In this we have observed the frequency response due to the inconsistent nature of RES and Load(Fig.4.2b) of duration(12P.M-6P.M).

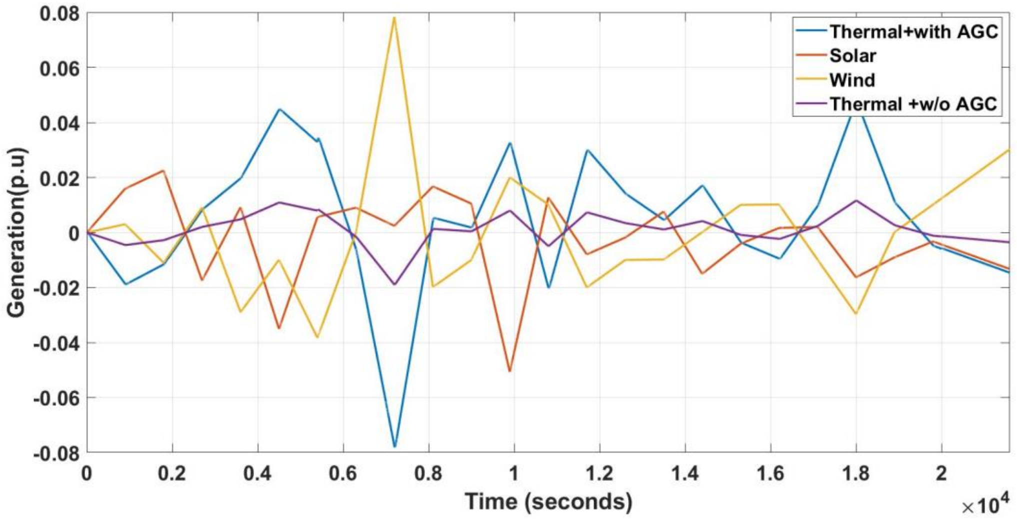

Fig.4.2.2g Power generation from Thermal+ with AGC, Solar, wind &Thermal +w/o AGC

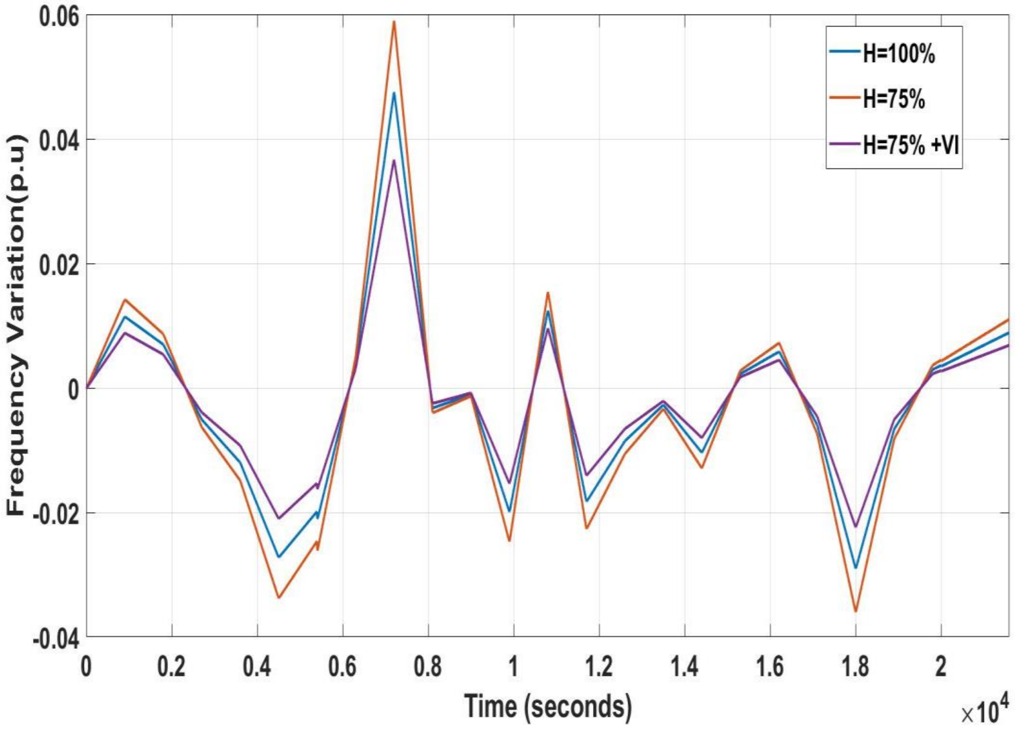

Fig.4.2.2h Frequency variation(Δf) response due to inertia(H) & w/o AGC

4.2.2d In this we have observed the frequency response due to the intermittent nature of RES and Load(Fig.4.2a)of duration(6P.M-12A.M).

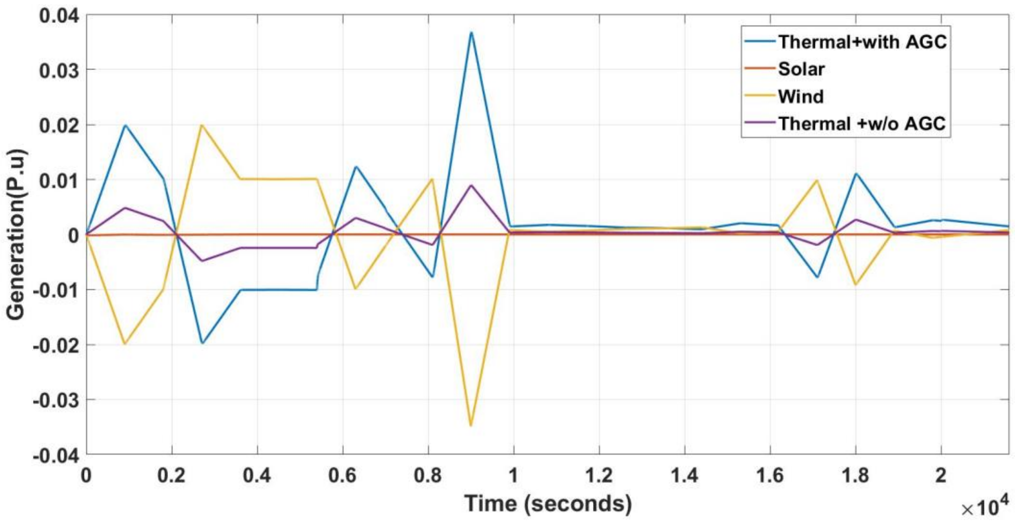

Fig.4.2.2.i Power generation from Thermal+ with AGC, Solar, wind &Thermal +w/o AGC

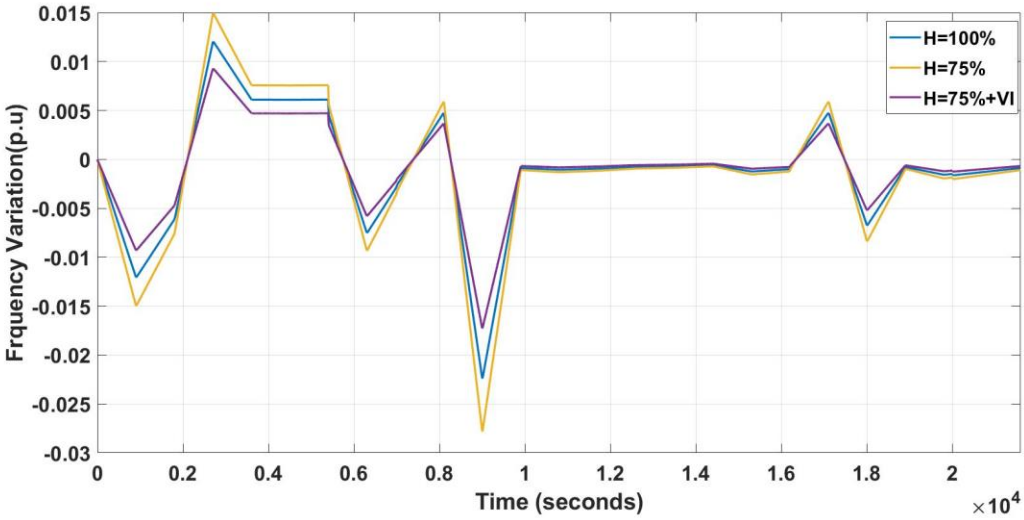

Fig.4.2.2j.Frequency variation(Δf) response due to inertia(H) & w/o AGC.

The effects of system inertia reduction are examined under two scenarios that include extensive solar, and wind energy integration and random load demand with RES integration. The frequency response is analyzed in three scenarios: a) when inertia (H=100%), b) inertia(H=75%), and c) inertia (H=75%+Virtual inertia). When the system is having AGC we have observed the variation frequency is within 1% of 50Hz with virtual inertia and without AGC the variation frequency is within 4% of 50H.Z. From each case curve, the frequency deviation is less when the system is having virtual inertia. Along with the system is less oscillating and smaller nadir when the system is having virtual inertia.

CHAPTER 5

ARTIFICIAL INERTIA-BASED FREQUENCY MITIGATION FOR NON-AGC ISOLATED SYSTEM USING SECONDARY CONTROLLER

5.1 INTRODUCTION

In the isolated power system, I have used solar generation, wind generation, and Thermal Power generation. For improving the Frequency stability we have inertia control (thermal) primary control(governor); secondary control (AGC), and Artificial inertia control (ESS based). In the previous chapter, we observed the frequency variation when the system has 75% of H (Thermal generation) and Artificial Inertia without AGC is within 4% of 50Hz. The Artificial inertia constant (K_{AI}) which is used to model the developed required inertia into the system, is a constant value.

A poor choice of the artificial inertia control parameter can result in instability, a longer recovery time, and a greater frequency deviation. This chapter discusses a design solution to address this issue to assist the artificial inertia unit in choosing the best virtual inertia constant for simulating the necessary inertia power against numerous variations in loads, generations, system inertia, and damping[16,17]

5.2 ACTION OF SECONDARY CONTROLLER

a) **Proportional Action**- According to the error signal, it produces a response that acts.

$$C\ (t)\ \ \varepsilon(t) \qquad 5.2.1$$

$$C(t)= K_c\, \varepsilon(t)+C_s \qquad 5.2.2$$

Where, K_c is the proportional gain of the controller C_s is the controller-biased signal (i.e controller output at zero error). ε(t) is error signal & C(t) is output. A proportional controller is described by the value of its proportional gain. The ability to offer minimal control variables when the control error is modest, minimizing unnecessary control efforts, is the proportional controller's main feature.

Integrating a single proportional controller has the disadvantage of producing a steady-state inaccuracy[18,19]

The proportional gain Kc or, alternatively, the proportional band (PB), where

$$PB = \frac{100}{k_C} \qquad 5.2.3$$

is used to define a proportional controller.

b) **Integral Action**- Its actuating output signal is related to the integral of the error. The historical significance of the control error corresponds to the integral control[19,20].

$$C\ (t)\ \propto \int_0^t \varepsilon(t) \qquad 5.2.4$$

$$C\ (t) = \text{Kc} \int_0^t \varepsilon(t)\ \ \text{Cs} \qquad 5.2.5$$

Where T_I is the time constant and reset time in minutes, the reset time is an adjustable parameter and it sometimes referred to minute per repeat, usually it varies in the range 0.1min< T_I<50min.

In contrast to a pure proportional controller, the use of a proportional operation in conjunction with an integral operation (i.e., a PI controller) fixes a number of concerns with the oscillating behavior and the error in the steady state.

$$C\ (t) = \text{Kc}\ \varepsilon(\text{t}) + \frac{\text{Kc}}{T_I}\int_0^t \varepsilon(t)\ \ + \text{Cs} \qquad 5.2.6$$

Each minute, the essential control action repeated the reaction. The amount of time the controller needs to repeat the first proportional action changes in the result is known as the reset time. As long as there is an error in the process results, the integral action induces the controller's result to alter. So even a minor inaccuracy can be eliminated by such a controller [20,21].

5.3 INTEGRAL WINDUP

As long as there is a non-zero error, the integral term of the PI controller seems to be continuously changing. Provided sufficient time, the open mistake cannot be quickly eliminated because they create larger integral terms, which in turn cause the control action to continue growing until it reaches saturation. Integral windup is the term for this occurrence, which takes place during manual operational changes such as shutdown, changeover, etc.[18,22]. Once the process returned back to automated control, the control action will continue to be saturated, resulting in a substantial overshoot.

5.4 DESIGN SPECIFICATION OF SECONDARY CONTROLLER

In this part, An entirely novel modular artificial inertia control system is synthesized and suggested. The primary purpose of artificial inertia control, or the simulation of inertia power, can be utilized by the PI controller. The artificial inertia constant (K_{AI}) and ROCOF decide how much inertia power is emulated [23,24]. A poor choice of the virtual inertia control parameter may produce instability, a longer recovery time, and a greater frequency deviation. To mimic the necessary inertia power, the K_{AI} must be able to adapt to a variety of disturbances (such as changes in RESs/DGs, loads, system inertia, and damping) without affecting the equilibrium of the overall system. The combination of a proportional process along together with an integral process (i.e., a PI controller) addresses a variety of issues with the oscillatory behavior and the amount of error in the steady-state compared to a pure proportional controller [28,29]. The PI controller can take a role in the parameters tuning process by determining a suitable amount of K_{AI} for adjusting to a variety of events. The design of a modified PI controller is depicted in Figure 5.4.1. with an artificial inertia control's dynamic framework.

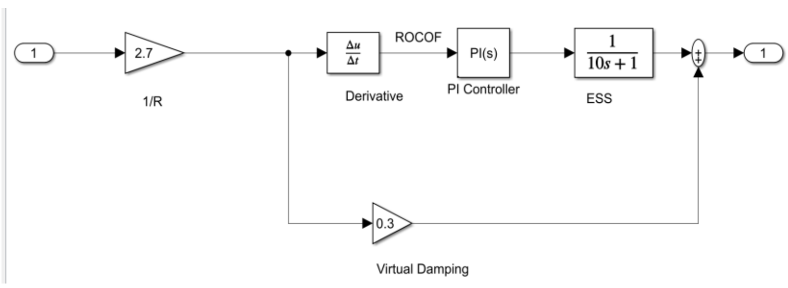

Fig.5.4a Remodel structure of Virtual Inertia Power System using PI controller

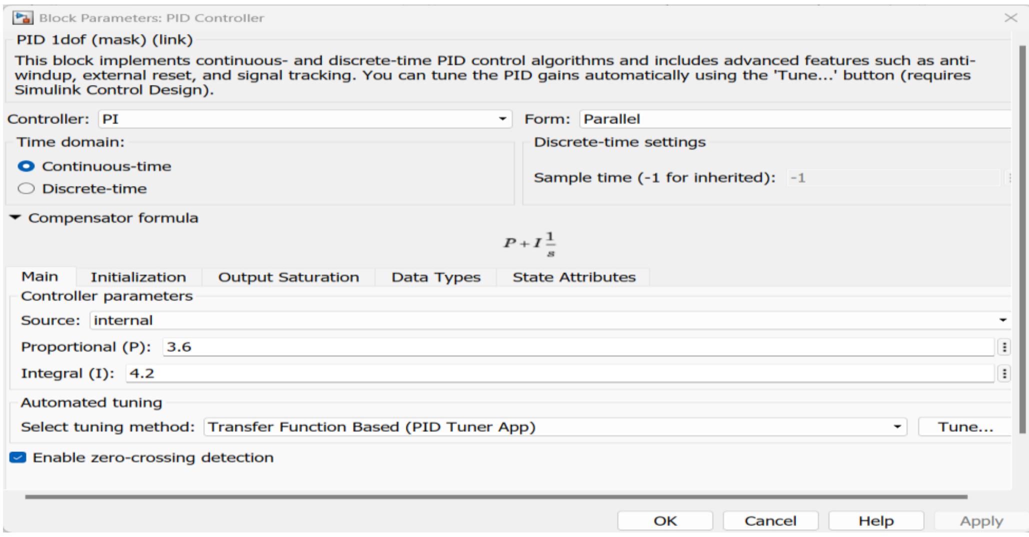

Fig.5.4b Interfaces in MATLAB for configuring the PI controller

5.4.1 In this we have observed the frequency response due to intermittent nature of RES and Load of duration (12A.M-6A.M).

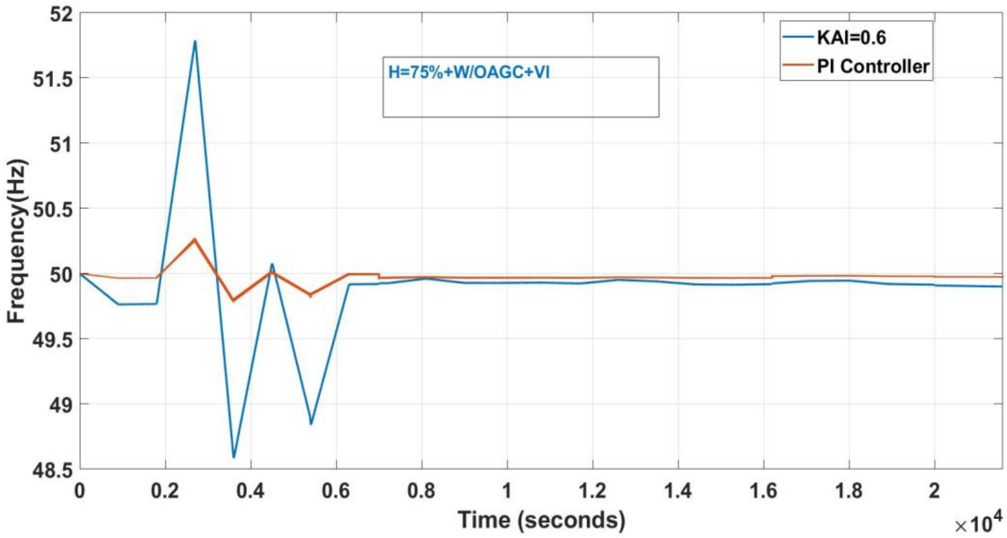

Fig.5.4c Frequency response with PI controller +without AGC

5.4.2 In this we have observed the frequency response due to intermittent nature of RES and Load(Fig.4.) of duration(6A.M-12P.M).

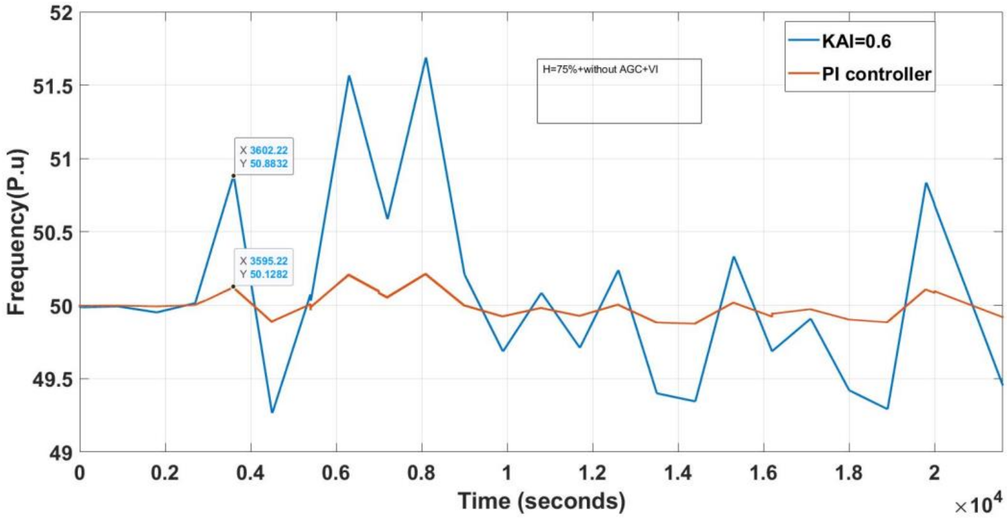

Fig.5.4d Frequency response with PI controller +without AGC

5.4.3 In this we have observed the frequency response due to the intermittent nature of RES and Load(Fig.4.) of duration(12P.M-6P.M).

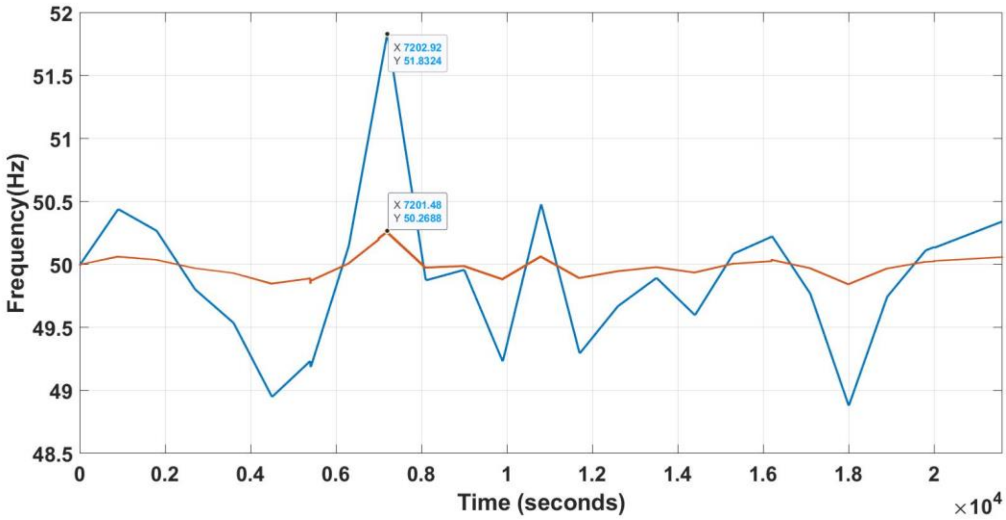

Fig.5.4e response with PI controller +without AGC

5.4.4 In this we have observed the frequency response due to intermittent nature of RES and Load(Fig.4. of duration(6P.M-12A.M).

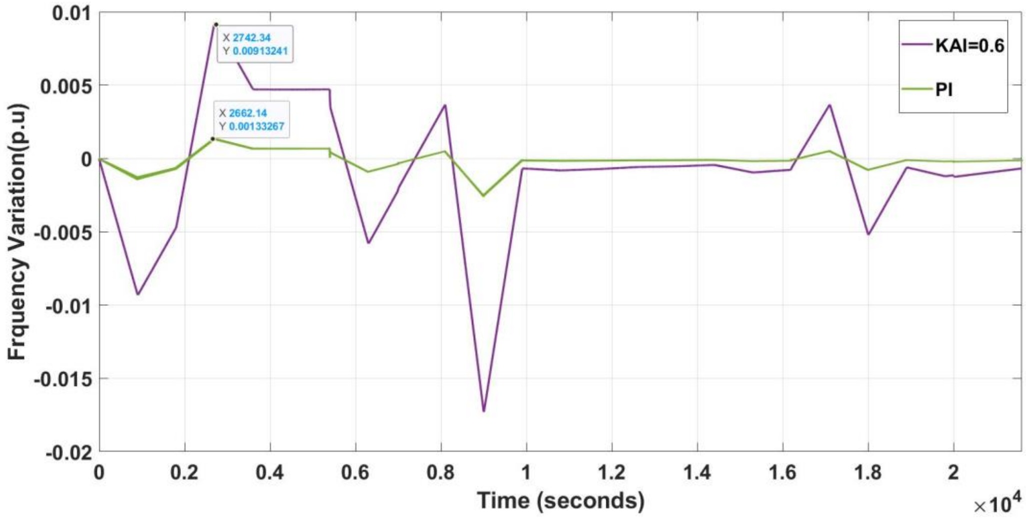

Fig.5.4f Frequency response with PI controller +without AGC

In the previous chapter, we observed the frequency variation when the system has 75% of H (Thermal generation) and Artificial Inertia without AGC is within 4% of 50Hz. By using PI controller we are able to limit the variation of Frequency without AGC within 1%.

CONCLUSIONS

- As resources are limited and consumption is increasing, the only option left is to fully switch to renewable sources. But there are a few limitations in the renewable system behavior compared to synchronous generator.
- The inertia of the system is decreased by embracing renewable energy, so virtual inertia is the ultimate key to sustainable development.
- We discuss the fundamental notions and concepts of inertia power compensation as they relate to frequency regulation. The study is done on the single-area power system's frequency-responsive process.
- The virtual inertia response model's dynamic and static performances are explained in terms of small-signal and state-space representations. Inverter based energy is not provided inertia so we use ESS to simulate Artificial Inertia
- Results from simulations are used to validate this task. Last but not least, the implications of several inherent characteristics affecting the system frequency response with regard to Virtual inertia is highlighted.
- The effects of system inertia reduction are examined under two scenarios that include extensive solar, and wind energy integration and random load demand with RES integration.

  When the system is having AGC we have observed the variation frequency is within 1% of 50Hz with virtual inertia and without AGC the variation frequency is within 4% of 50H.Z. By using PI controller we are able to limit the variation of Frequency without AGC within 1%.

FUTURE SCOPE

The frequency response could be improved by using different controller optimization techniques. We can also use different type of controller. Just as virtual constant is replaced with PI controller to minimize the deviation of frequency. The model can also be simulated for Interconnected Power System. To observe the tie-line power deviation and effect of one area load imbalance, generation imbalance to another area system.

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