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Demand Response of Industrial Boiler for Power System Frequency Regulation

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Abstract: Frequency fluctuation is one of the major issue of power system stability problem. By increasing the spinning reserve is the conventional way to mitigate this problem. Textile industry consume a large amount of electric energy. The industry can privilege its cost by participating in demand side management in power system grid. This paper proposed a demand side resource like industrial boiler to regulate power system frequency. Due to thermal inertia by adjusting the temperature set point of the heater of an industrial boiler, it would able to provide a fast frequency regulation without sacrificing the industrial compliance. The proposed method not only can enhance the frequency regulation during the time of power unbalance, like rapid increase in load of the industry or rapid loss of generation but also reduce the significant proportion of the total cost in textile industry. The effectiveness of the model is verified in several plausible case studies.

Keywords: Demand side response, frequency regulation, responsive load, industrial boiler, turbine governor.

I. INTRODUCTION

A textile industry has required more energy for its production. When the demand is greater than the generation, then the captive generator or quick rental power plant is started. If the quick rental power plant is started the cost increases and the cost increases all the consumers. If the captive generator of a textile industry is started for regulating the frequency, it is cost effective than the quick rental power plant. Every industry has a captive generation which generates 10% energy of their demand. At the peak hour the tariff rate is high. So the captive generator is started and industrial electric boiler regulate the frequency. It is very cost effective because a boiler regulates the frequency by increasing or decreasing the energy consumption. If the demand increases the boiler reduce energy consumption and temperature reduce but not to the threshold level. Energy consumption varied the boiler temperature between 150 to 170℃ and the set point is 160℃. When demand decreases the boiler increase the energy consumption. In these process the boiler regulates the frequency. In this chapter the power system frequency regulation for demand side control is discussed. Frequency fluctuation is a major issue of the power system stability problem. Integration of more renewable energy resources will enhance this problem. A mismatch creates for the power generation and the demand. The mismatch always occurs for the discontinuous nature of the renewable energy [1]. For the mismatch the frequency of inconstancy is occurred.

The total system inertia is inversely proportional to the rate of changing the frequency deviation. The utility of energy for which the generators and the power systems are coupled. This is called the system inertia. For the renewable energy source like wind or solar power, the machine and power system are not coupled directly between them. Therefore, reduce the total system inertia and stability. Normally try to increase the system spinning reserve amount to dealing with this problem, which increases costs [2]. The frequency control is performed the generation side has become more problematic as well as expensive for the expanding needs of renewable energy resources. To mitigate this problem, demand side frequency response will be the alternative way [3]. The spinning reserve is reduced as well as improve the system stability by using demand control strategy [4].

Energy is one of the most important elements of any industrial activity. However, its availability is not unlimited. The global energy crisis and high fuel costs have led to more efforts to save maximum energy. The textile industry holds the record for the lowest energy use efficiency and is one of the most important energy consuming industries. About 34% of the energy is used for spinning, 23% for weaving, 38% for chemical treatment and 5% for various purposes. Electricity dominates spinning, weaving consumption patterns, but thermal energy is very important for chemical processing. Textiles and clothing are part of history, proposing new high-quality materials and techniques that can be used by people in specific locations. The manufacturing and manufacturing process works by converting natural and synthetic fibres into yarn, which is ultimately converted into fibre.

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The fabric then becomes textiles and is eventually used to make the fabric. It's a long process that uses a variety of equipment with the latest technology and trends to make the process as efficient as possible. The textile industry is vast and has spawned many clothing and linen companies. The textile industry requires an uninterrupted supply of hot water and steam. The Boilers manufactures premium boilers for the textile industry that help the textile industry meet fluctuating needs, significantly reduce fuel costs and help improve efficiency and more. Steam boilers play an important role in the production of textiles. Boilers are widely used for pre-treatment, dyeing, printing and finishing etc. It is really important to install reliable boilers for better efficiency and profitability. Steam is a vaporized state of water that is used in many ways. It has thermal energy and can be transferred in many different processes. The Quick Guide to Choose the Best Boiler for the Textile Business will give some insight into the matter. Boilers help the textile industry from start to finish. After ensuring the textile is evenly dyed to your choice, the boiler also plays a role in the printing and finishing of the fabric. Boiler becomes an indispensable equipment in this industry. Therefore, choosing the right type of boiler is becoming more and more important.

At present day the electric boiler is more important than the previous time. Many industries use to start the electric boiler to produce the steam. It is environment friendly because it has no carbon emission and other contamination gas. The electric boiler does not use the fossil fuel like natural gas, coal, oil etc. So the electric boiler is environment friendly. The boiler which used fossil fuel this have the low efficiency because most of the heat energy is useless. But the electric boiler efficiency is maximum because there is no heat loss.

WDR horizontal electric boiler is a kind of high thermal efficiency (99%) and environment protect boiler. The boiler is full automatic boiler; the working life of cartridge heater is about 2000 hours. Application are textile plant, rice mill, food & beverage, laundry, hotel, hospital, school etc. Industrial electric boilers are water containing vessels in which the heat generate with the help of electric heater. Then it is transferred to different pipes connected to different industrial equipment. Steam power is set to run machinery, providing industries with a cost-effective way to power production. The operation of the boiler is not as complicated as one might think. It is a combination of basic science and the latest innovations. Separate parts of the system are located at different points. The heat source and the water tanks are located in different compartments. The metal rods connect to the water tank and are then heated to create steam. The steam is then collected in a dome to condense before being discharged from the boiler. This increases the pressure and the energy generated helps power your manufacturing processes.

II. LITERATURE REVIEW

An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

A. Related work

In the high percolation of renewable energy source like as photovoltaic or wind power energy systems, are increasingly replacement of the traditional generators, the total system inertia is reduced. Like as the retrenchment causes the system frequency have undesired variations. Therefore, a virtual synchronous machine (VSM) was raised in [5][6] imitative the primary behaviour of a traditional synchronous generator. A synchronous generator which imitative the primary behaviour of a traditional generator to give a frequency modulation service has been raised in [5]. The normal grid features are approached by the VSM model. The network performance was studied for the various injection level by using the batteries and the super-capacitor. The modulation strategy of the virtual load has been improved in [6] to compensate for the frequency offsets occurred by the uncertainty of the renewable energy sources. Various scenery was considered to test the raised studies. Benchmarking of an IEEE 39 bus is used to an IEEE 39 bus was used to underpin a proposed program. The writers of [7] raised a traditional power system model accompanied by an individual and collaborative DR and the primary model for the frequency control and the tuning purposes. In this proposed power protocol system allows the power operators between these services to take the necessary steps if the frequency deviation is occurred. Above on the other hand the writers of [8] propose a coordinated control system to an inverting micro-grid system which based on the main frequency signal. To the study applied goal to combine ESS and RES, considering the limitations of the source which based on the virtual impedance & slope method. The electricity market is deregulated so the consumer encourage participation in ancillary services of the power to develop the system elasticity. Additionally, to the data centres often leverage the load resiliency to maintain the load generation is balanced. However, the data centre response times are relatively slow, which limits their proficiency to give a real time support. To the alleviate problem, the writers of [8] raised a combined battery to give the fast frequency tuning. The combination was successful to reduce the size of battery required compared to a standalone system, while the writers of [9] presented a study evaluating the financial proficiency of BESS for providing this service. To replace the bulk traditional generator with renewable energy leads to a reduction in inertial mass, jeopardizing the stability of the grid.

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So, the writers of [10] proposed to coordinate the control system for efficient operation of a mixed system consisting of a super-capacitor and a battery for the market of electricity to the ancillary services. Feasibility studies have been conducted to confirm the advantages of such protocol on the traditional measurements. The hybrid super-capacitor and the battery system has been raised in [11] to give the large scale regulatory services. The proposed system goals to reduce the battery usage the ancillary services and raise the cost effectiveness of regulatory services. Furthermore, the authors of [12] used a vanadiumredox series battery based power system model to give a variety of ancillary services focused on the application of frequency support and peak scraping. The frequency law offerings also may be furnished via way of means of right changes to the energy intake of the controllable device [13]. Such as, the writers of [13] proposed a manipulate set of rules for dynamically managed fridges to offer number one frequency manipulate offerings. Similarly, the writers of [14] researched the capacity of the dynamic the capacity managed hundreds of preserve grid frequency inside a selected variety submit an unexpected lack of generation. In the proposed examine shows a big put off the frequency fall much or less reliance on swiftly frequency fall and much less reliance on swiftly captive generators. The version turned into discovered dependable and quicker in reaction as compare to a frequency touchy producing unit. The author [15] investigate the cap-potential variety of common energy which may be supplied via way of means of electric powered water warmers if accurately managed for energy balancing applications. The manipulate method turned into finished via way of means of balancing the temperature set-point and the water drawn. A method to help the frequency and voltage profile of the grid via way of means of the use of a load control together with an electric water heater and electric cars turned into offered in [16]. The availability of home fridges and commercial bitumen tank load to offer frequency reaction offerings turned into investigate in [16]. A coordinate and manipulate method of Inverter based air conditioning is raised in a grid this is ruled via way of means of renewable electricity reasserts to offer number one frequency law [18]. In the number one frequency reaction, the regulating ability is furnished via way of means of balancing the temperature set- point of the air conditioning units. A recuperation approach is likewise raised to repair the preliminary running state of IAC law. The raised examine is resolved via way of means of verify the effectiveness of a six system and two place gadget and a remoted micro-grid. Furthermore, a relatively recent study raised in [18] present a novel thermoelectric dynamics based on dynamic modelling of AC air conditions and GSHP geothermal heat pumps, as well as existing the model of electric water heater to develop the decentralized control response technique to DLC (Direct Load Control) to provide main frequency tuning in hybrid system micro-grid. In addition, the reference [19] suggested electric vehicles to provide more centralized frequency control through the intermediary between the control centre of power system and and power demand taking into account the load demand. The decentralized control has also been proposed to balance the power consumption of the load relative to the network frequency. The response of demand applications in the ultramodern power system has been reconsidered by [20]. The response of demand in the frequency control application has been studied in [21]. The writers conclude a paper by pointing out the demand control application for the future directions. The author of [22] presented an architectural test bed to provide demand response (telemetry monitoring and load triggering) for the frequency carrying application. The writers of [22] expanded previous research by examining potential challenges and novel the frequency control schemes in the modern power systems. This paper expresses a new control system which uses separate large hub heat sinks to provide mains frequency tuning service by the regulating power consumption. The delay controller and its parameters optimized by using the actual genetic algorithm code is incorporated to the system to improve overall response. The document also recommends a highly efficient control scheme that takes into account consumer comfort and the inherent characteristics of the heatsink of limiting the switching cycles and internal temperature. Highlighting the effect of reducing inertia on the frequency behaviour ends research project.

B. Contribution

In paper [23] there discuss about decentralized control method. Fast frequency responses are the main advantages of this paper. But customer comfort level hampered so much. In paper [24] discuss about centralized control method. Main advantages of this paper is frequency stability. But this is too much time consuming and it is not desirable. In paper [18] there discuss about how to reduced power consumption. This is very cost effective technique. But main problem is repeated ON OFF switch, which hamper the customer comfort level. In paper [7] discuss about frequency regulation technique. It gives a fast frequency response. This is the main advantages of this paper. But an additional storage devise needed and it is not cost effective. So, it is a disadvantages of this paper. In paper [25] works on modern power system and there reviewed the potential challenge of frequency regulation. But the given solution is not cost effective. In paper [26] works on industrial heat pump. Main advantages of this paper is its good performance. But this paper has a disadvantage of high energy loss.

This paper proposed a novel technique that works on industrial boiler heater in providing primary frequency regulation service by adjusting the temperature set point and providing good frequency response in short time operation. This work not only fulfil industrial compliance but also gives a cost effective operation and there does not need any storage device.

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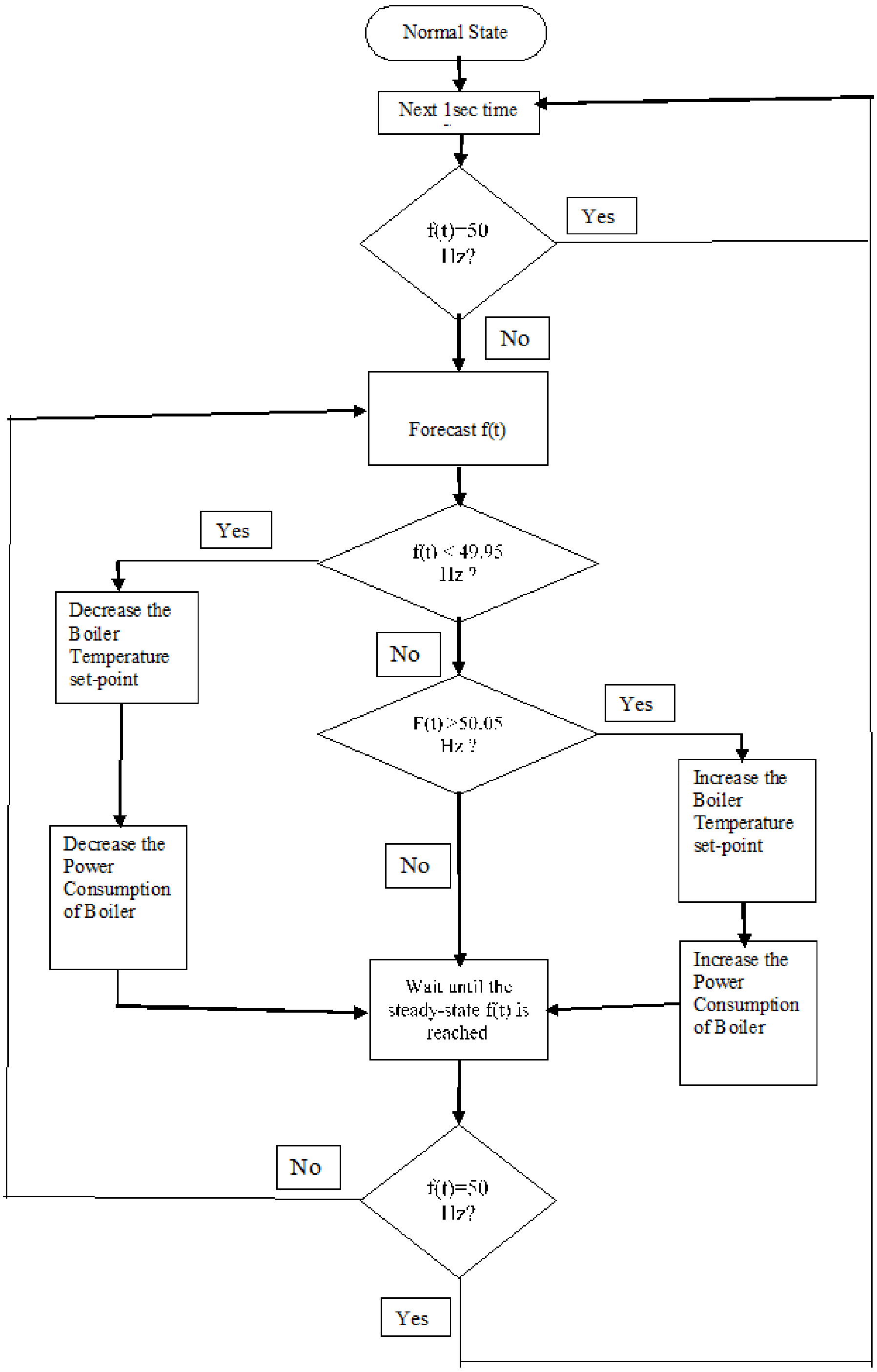
III. RESEARCH METHODOLOGY

This section discusses about all the model subsystem that used in the proposed method. This section mainly focused on the design method and discusses how to design a single area power system model and how to design an Industrial Boiler heating system.

A. Methodology

In this thesis work, firstly design a single area power system model. Then an inside Boiler heating model is designed. Finally, the output of the frequency deviation is used for changing the temperature set point and corresponding improve the frequency variation. The overall process is given in a flow chart:
Recommended font sizes are shown in a flow chart:



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Is the frequency 50Hz? If the answer is yes, the system is stable and the boiler has the temperature set point is 160℃. If the answer is No, then the frequency is forecast or measure. Thus the measured frequency is 49.95 Hz. The answer is yes then the boiler decrease the temperature set point and boiler decrease the power consumption. This process wait until the steady state frequency is reached at 50Hz. If the frequency is 50Hz then the system is in the normal state. normal state. When the frequency is 50.05Hz, the answer is yes then the boiler increase the temperature set point and also increase the power consumption until the frequency reached at the steady state value. Is the frequency 50Hz? The answer is yes then the system is normal state. If the answer is No the frequency is forecast and the flowchart is repeated.

B. Single area Power System Model design

The power system model for the proposed study is shown in Fig. 2. For further detail study a simplified model of the power system can found in paper [44].

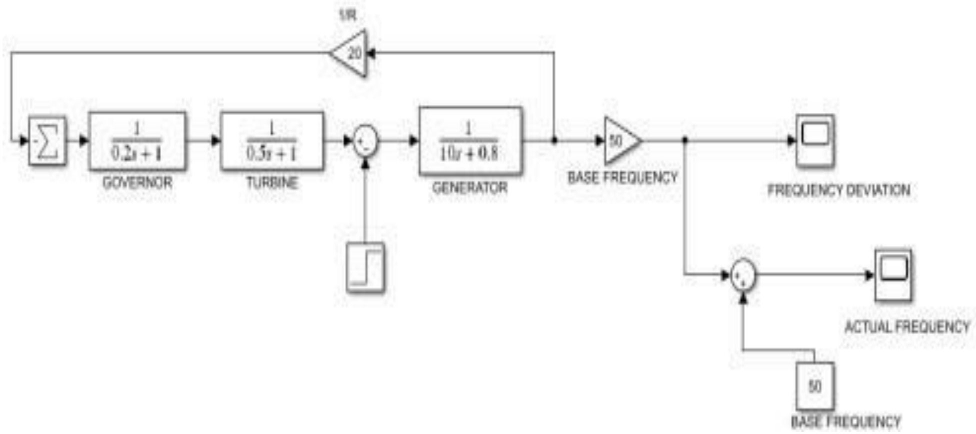

Fig. 2 Single area power system model design

C. Generator Model

The rotor dynamics of a synchronous machine are described by the swing equation shown Eq. 1

$$\Delta Pg(t) - \Delta Pd(t) = 2H\frac{d\Delta f(t)}{dt} + D\Delta f(t) \qquad (1)$$

From Eq. 1, the block diagram of a generator is shown in Fig. 3

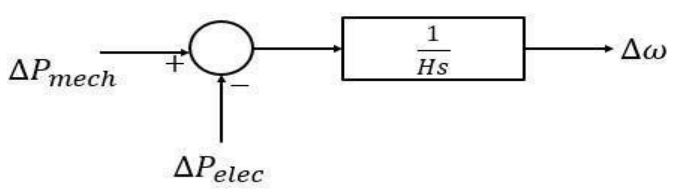

Fig. 3 Block diagram of generator

Where, H, ΔPm, ΔPe, and Δδ are inertia constants, change in mechanical power input, change in electrical power output, and change in power angle of synchronous machine respectively.

D. Prime Mover Model

Energy generation in a prime mover is through the burning of fuels like coal, gas or nuclear fuel. The non-reheat steam turbine can be approximated with a single time constant τT. The transfer function of the simplest prime mover model is given in Eq. 2

$G_p(s) = \Delta P_m(s)/\Delta P_v(s) = 1/(1 + s\tau)$ (2)

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Here, $\Delta P_V(s)$ is the change according to the position of a steam valve and $\Delta P_m(s)$ shows the change of output mechanical power.

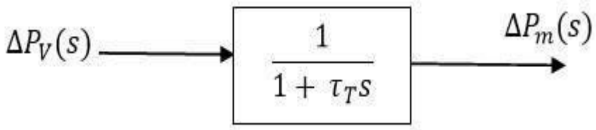

Fig. 4 Prime mover model

E. Governor Model

Governor is used to sense the speed change and adjust the turbine mechanical input to achieve a new steady state point of operation in order to create any mismatch between total generated power and connected demand. The speed characteristic of a governor is given in Eq. 3

$\Delta Pg(s) = \Delta P_{ref}\,(s) - \Delta\Omega(s)\,/R$ (3)

Here, R is used for government speed regulation. For the linear relationship and for the governor time constant τ_g is given in Eq. 4

$$\Delta P_v(s) = \frac{\Delta P_g(s)}{1+s\tau_g} \quad (4)$$

The governor model is shown in Fig. 5

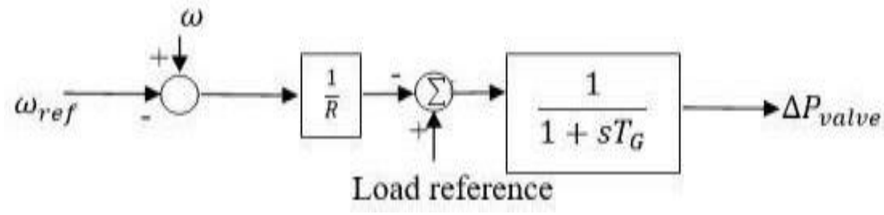

Fig. 5 Governor model

Speed regulation (R) is the ratio of per unit change in speed to the per unit change in generated power. The slope of the line in Fig. 6 is the speed of regulation R. From zero to full load, the speed regulation of the governor becomes 5-6 percent.

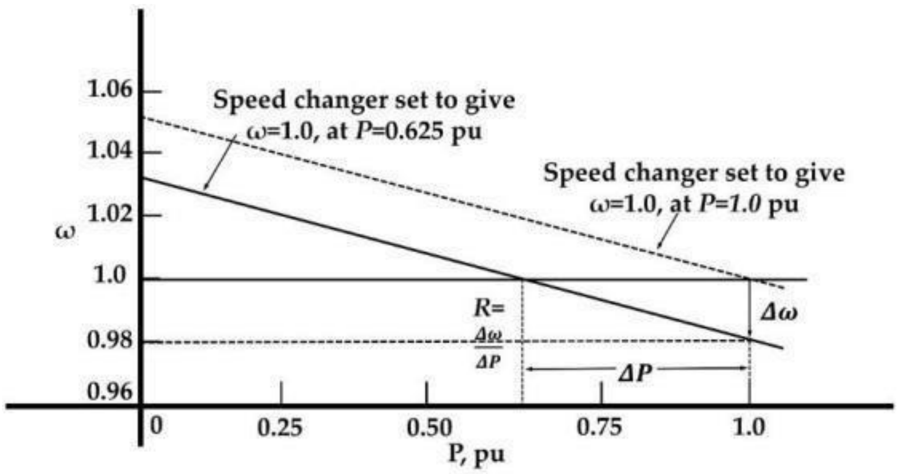

Fig. 6 Steady state speed characteristics of the governor

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F. Inside Boiler Heating System design

Boiler heating system generally depends on heater component model, thermostat heating model, boiler heat gains and heat loss model. These individual systems model are design in MATLAB Simulink and various Boiler heating components design model are discussed.

G. Heater Component Model

For modelling heater component some things must be takes to concern.

i. Measured the current boiler temperature and control signal from the thermostat as input signal
ii. Heat gain can be calculated from the heat gain equation.
iii. Output of heat gain are taken only when the control signal is on condition.

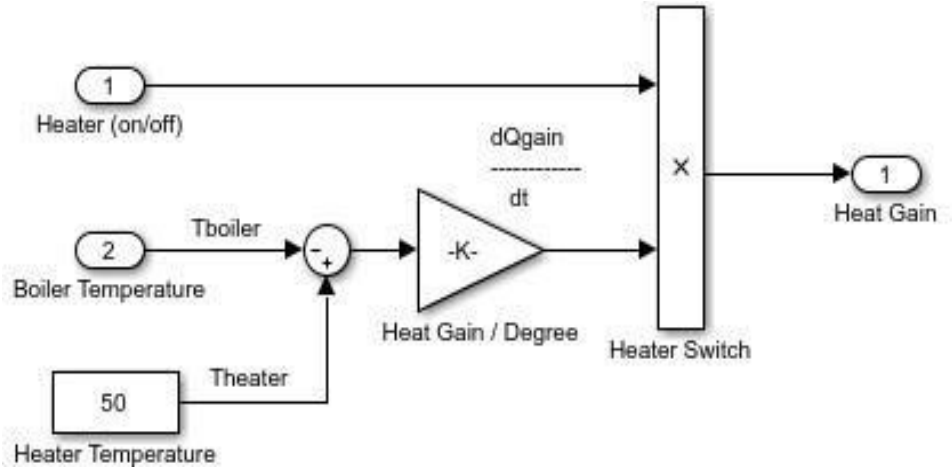

Fig. 7 Heater component model

H. Thermostat Component Model

For modelling thermostat component some things must be takes to concern.

i. Control signal output is "0" when the inside temperature is above the set point and Control signal output is "1" when the inside temperature is below the set point
ii. The allowable temperature hysteresis of the set point in +2°C to -2°C in order to avoid repeated switching The thermostat subsystem Simulink model is given in Fig. 8

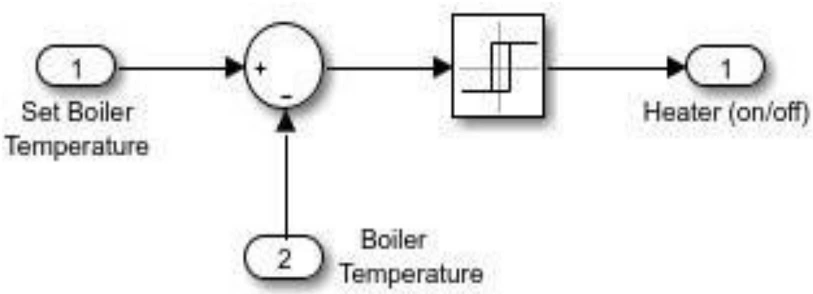

Fig. 8 Thermostat subsystem Simulink model.

Here, in the relay block temperature hysteresis is flexible up to +2°C to -2°C, which is further changeable with the industry compliance.

I. Boiler Component Model

For designing a boiler component model uses the heat flow from the heater and outside temperature for the input signal. By using this input signal, boiler components compute the amount of heat loss through the wall. In order to design boiler subsystem, use the changing the inside temperature equation and rate of the heat loss equation. The model of boiler component is given in Fig. 9.

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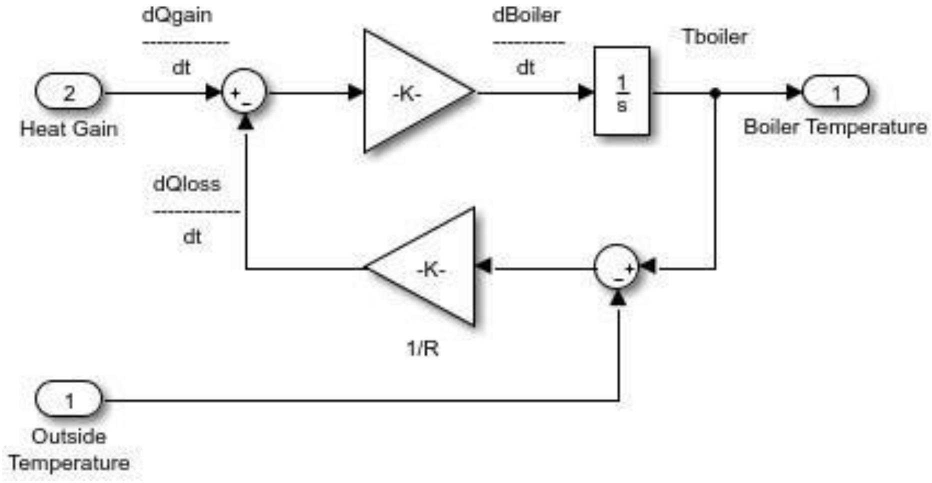

Fig. 9 Boiler component model

J. Integrate Thermostat and Heater Components

In order to simulate the integrated thermostat and heater subsystem there need an additional constant block to set the temperature of the thermostat and a sine wave block for generating a temperature of the outside of the electric boiler.

K. Boiler Heating Model

By combining all the subsystem of thermostat, heater and boiler components, an additional signal is needed for changing the outside temperature. For this purpose, a sine wave block is used. After simulating the system, can easily observe the effect of outside temperature and thermostat setting on inside temperature.

L. Temperature Set Point changing model

When any power unbalance occurs on the system, then line frequency will change from its nominal value. If positive unbalance occurs, i.e. power generation exceed from connected load, then line frequency will increase from nominal frequency(50Hz). But if negative unbalance occurs, i.e. the connected loads exceed from power generation, then line frequency will decrease from the nominal frequency(50Hz).

When the deviation of frequency is positive, then the corresponding temperature set point will increase and vice versa. Changing the temperature set point will be evaluated by the Eq. 5

$$T_{newsetpoint} = T_{oldsetpoint} + K\Delta f \qquad (5)$$

Here, K is the sensitivity factor. For this work, K= 7 °C/Hz.

By using this technique, amount of power consumption of the Industrial Boiler can be controlled. This is very useful method for improving frequency deviation in Industry area and increase the frequency regulation reserve.

IV. RESULT AND ANALYSIS

In this section, the simulation results of the power system frequency regulation of an industry are shown and analysed for different cases. This model is implemented in MATLAB/Simulink. The system parameters are given in Table 2. Different types of cases are simulated without feedback system and with feedback system. These results show how boiler heater temperature set-point changing with the frequency deviation can support frequency regulation in an industrial power system.

CASE FORMATION

The load in the power system is an uncertain quantity that varies continuously. The gradual increment or decrement of load does not hamper the system's stability. But sudden load change in large quantities causes disturbance in the system frequency. Though automatic generation control system responds to the change in the load and changes generation according to the load. Automatic generation control system balance between generation and load and thus restore the system frequency to the nominal value. The nominal frequency is 50 Hz.

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In case 1, a sudden load increment of 0.3 p.u. in Textile Industry Area. The effect of temperature set-point changing feedback path is shown in the results section and analysed. When a generating unit fails, the load supplied by the unit creates a burden on the remaining generating unit in the power system. As a consequence, the other generating units face sudden load increments and frequency deviation occurs in other regions. A large frequency deviation may cause complete system failure or a blackout.

In case 2, a sudden load decrement of 0.3 p.u. in Textile Industry Area. The effect of temperature set-point changing feedback path is shown in the results section and analysed.

The summary of the formulated cases is given in Table 1

Table 1: Case summary

Case-1	Suddenly a load increment of 0.3 p.u. in Industry Area
Case-2	Suddenly a load decrement of 0.3 p.u. in Industry Area

The values of different parameters of the single area power system model are given in Table 2

Table 2: System Data of the single area power system model

Parameter Name	**Value**
Inertia constant, H	10
Turbine time constant, Tt	0.5
Governor time constant, Tt	0.2
Governor speed regulation, R	0.05
Load damping constant, D	0.8
Thermal conductivity of Aluminium Alloy, k	45 W/m.K
Thermal Resistivity, r	1/k
Thermal resistance, R	D/k.A
Diameter, d	1.3 m
Height, h	3.5 m
Thickness, t	50 mm
Surface Area $A = 2\pi rh + 2\pi r^2$	16.95 m^2

CASE-1 SUDDEN LOAD INCREMENT OF 0.3 P.U. IN INDUSTRIAL AREA

A sudden load increment of 0.3 p.u. in Industry causes a large frequency decrement in Industry Area power system. This frequency decrement is for the imbalance between generation and load. The frequency is decreased due to sudden load increment. The large under frequency may activate the relay used for under-frequency load shedding unnecessarily. After participating the electric boiler in frequency regulation, consumed power of boiler is reduced and corresponding frequency deviation is improved.

Frequency in Industrial Area

The green colour curve in Fig. 10 indicates frequency in Industry Area without Electric Boiler participation in frequency regulation and the pink colour curve indicates the frequency in Industry Area with the participation of Electric Boiler in regulating frequency. The frequency is 48.60 Hz without feedback. After the participation of Industrial boiler to regulate the frequency, the frequency is improved to 49.05 Hz.

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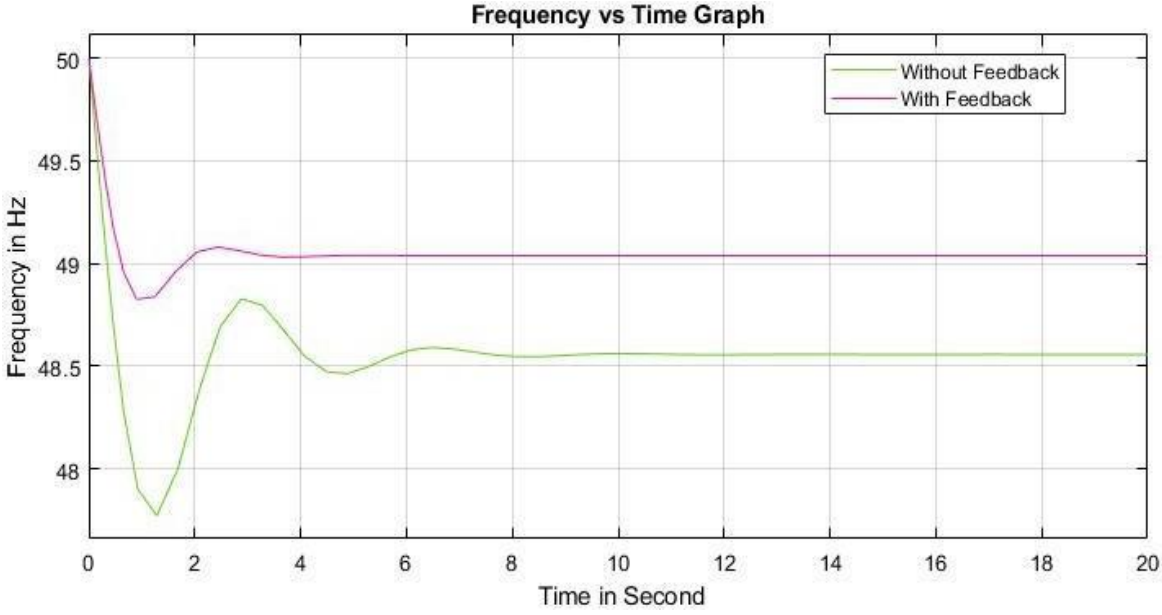

Fig. 10 Frequency profile for with and without feedback system

Here, the frequency improvement with feedback system is 0.45Hz. without feedback system the settling time is 6.76sec which is very high. If the feedback system is used the settling time is minimized and the value is 2.93 sec. The rise time is 0.41 sec without feedback system and using feedback the rise time is 0.43 sec. The percentage of overshoot is improved in the feedback system. Without feedback the overshoot value is 2.97% and with feedback system the overshoot is minimized and the value is 1.96%.

Power supplied by the Industrial Boiler

Fig. 11 shows the power supplied by the Industrial Boiler due to sudden load increase of 0.3 p.u. The consumed power of electric boiler is decreased by 0.03 p.u. after the participation in frequency regulation.

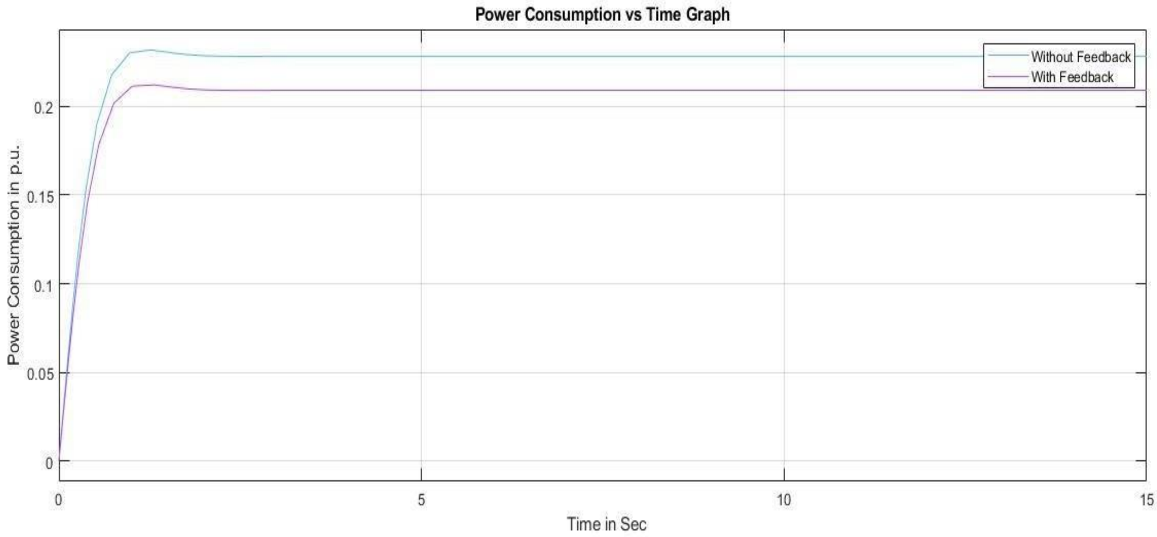

Fig. 11 Per unit power profile by the boiler with and without feedback system

By reducing the power consumption of electric boiler from 0.23 p.u. to 0.21 p.u. frequency deviation is regulated.

Result Analysis

This section shows the results both for feedback system and without feedback system. In Table 3 the time response characteristics is given

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Table 3: Time response characteristics when sudden load increment of 0.3 p.u.

Metric	Without Feedback	With Feedback
Frequency (Hz)	48.60	49.05
Settling Time (sec)	6.76	2.93
Rise Time (sec)	0.41	0.43
% Overshoot	2.97	1.96
Settling Max (Hz)	48.82	49.08
Settling Min (Hz)	47.77	48.83
Consume Power (p.u.)	0.23	0.20
Boiler Temperature (°C)	160	152.30

When the power unbalanced is negative, i.e. demand is greater than supply power, line frequency is decreased. Here, time characteristics are different for feedback and without feedback system. Without using the feedback, frequency is 48.60 Hz but by using the feedback frequency is improved and the value is 49.05 Hz. The frequency improvement with feedback system is 0.45Hz. without feedback system the settling time is 6.76sec which is very high. If the feedback system is used the settling time is minimized and the value is 2.93 sec. The rise time is 0.41 sec without feedback system and using feedback the rise time is 0.43 sec. The percentage of overshoot is improved in the feedback system. Without feedback the overshoot value is 2.97% and with feedback system the overshoot is minimized and the value is 1.96%. By reducing the power consumption of electric boiler from 0.23 p.u. to 0.21

p.u. frequency deviation is regulated. After regulating the frequency, boiler temperature decrease from 160 °C to 152.30 °C. This value is in between 150-170°C and does not hampered the industrial compliance. Thus this feedback system improved the deviation in the frequency and increase the system stability.

CASE-2 SUDDEN LOAD DECREMENT OF 0.3 P.U. IN INDUSTRIAL AREA

A sudden load decrement of 0.3 p.u. in Industry causes a large frequency decrement in Industry Area power system. This frequency increment is for the imbalance between generation and load. The frequency is increased due to sudden load decrement. The large over frequency may activate the relay used for over-frequency load shedding unnecessarily. After participating the electric boiler in frequency regulation, consumed power of boiler is increased and corresponding frequency deviation is improved.

Frequency in Industrial Area

The red colour curve in Fig. 12 indicates frequency in Industry Area without Electric Boiler participation in frequency regulation and the brown colour curve indicates the frequency in Industry Area with the participation of Electric Boiler in regulating frequency. The frequency is 51.24 Hz without feedback. After the participation of Industrial boiler to regulate the frequency, the frequency is improved to 50.80 Hz.

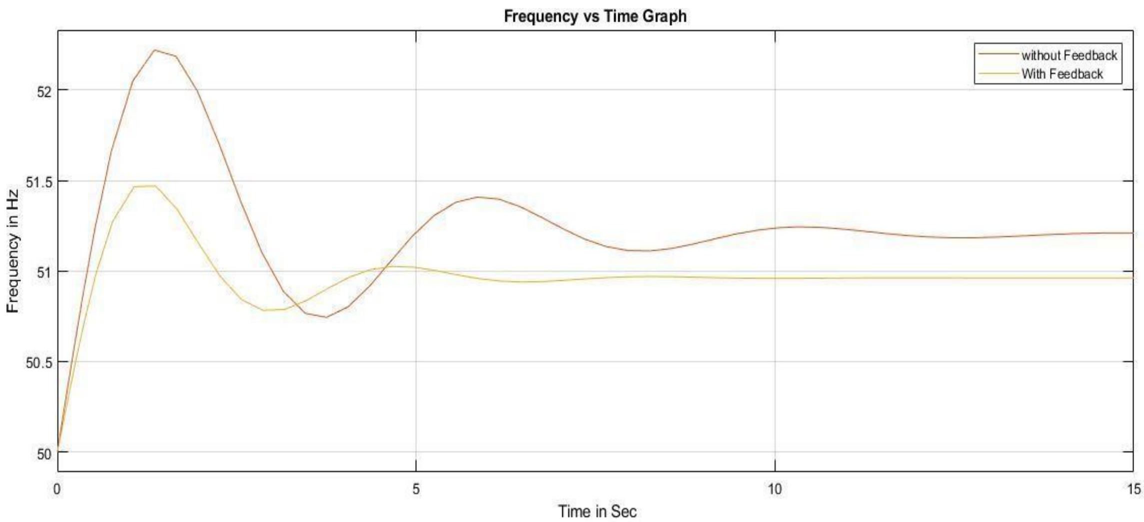

Fig. 12 Frequency profile for with and without feedback system

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Here, the frequency improvement with feedback system is 0.44 Hz. without feedback system the settling time is 12.96 sec which is very high. If the feedback system is used the settling time is minimized and the value is 6.81 sec. The rise time is 0.40 sec without feedback system and using feedback the rise time is 0.41 sec. The percentage of overshoot is improved in the feedback system. Without feedback the overshoot value is 1.97% and with feedback system the overshoot is minimized and the value is 0.99%.

Power supplied by the Industrial Boiler

Fig. 13 shows the power supplied by the Industrial Boiler due to sudden load decrease of 0.3 p.u. The consumed power of electric boiler is increased by 0.03 p.u. after the participation in frequency regulation

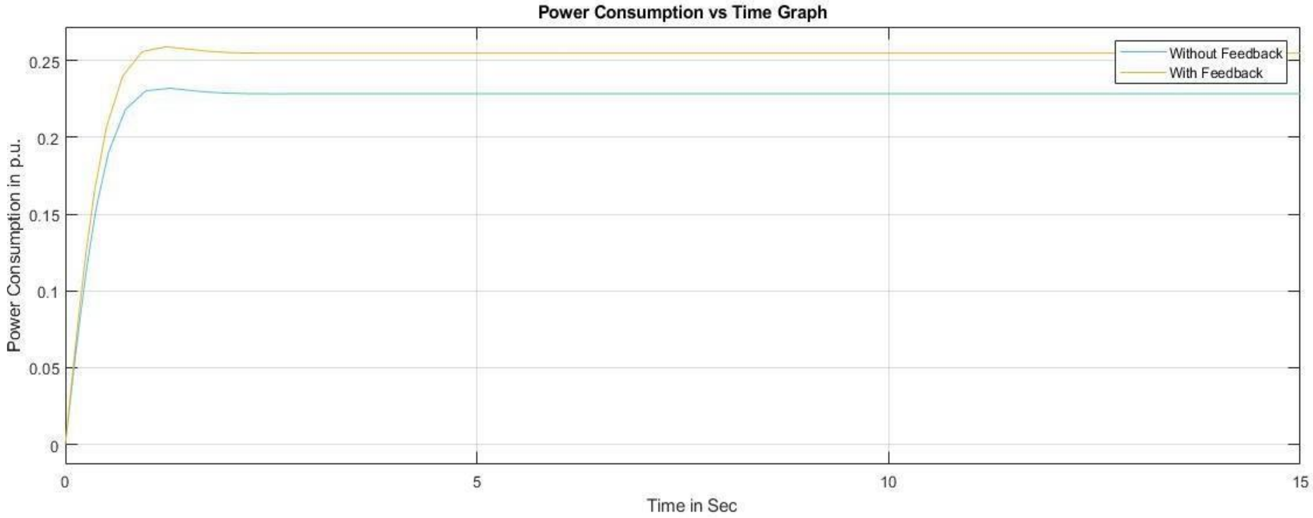

Fig. 13 Per unit power profile by the boiler with and without feedback system

Result Analysis

This section shows the results both for feedback system and without feedback system. In Table 4 the time response characteristics is given.

Table 4: Time response characteristics when sudden load decrement of 0.3 p.u.

Metric	Without Feedback	With Feedback
Frequency (Hz)	51.24	50.80
Settling Time (sec)	12.96	6.81
Rise Time (sec)	0.40	0.42
% Overshoot	1.97	0.99
Settling Max (Hz)	52.22	51.46
Settling Min (Hz)	50.74	50.78
Consume Power (p.u.)	0.23	0.26
Boiler Temperature (°C)	160	168.50

When the power unbalanced is positive, i.e. supply power is greater than demand, line frequency is increased. Here, time characteristics are different for feedback and without feedback system. Without using the feedback, frequency is 51.24 Hz but by using the feedback frequency is improved and the value is 50.80 Hz. The frequency improvement with feedback system is 0.44 Hz. without feedback system the settling time is 12.96 sec which is very high. If the feedback system is used the settling time is minimized and the value is 6.81 sec. The rise time is 0.40 sec without feedback system and using feedback the rise time is 0.41 sec. The percentage of overshoot is improved in the feedback system. Without feedback the overshoot value is 1.97% and with feedback system the overshoot is minimized and the value is 0.99%. By increasing the power consumption of electric boiler from 0.23 p.u. to 0.26 p.u. frequency deviation is regulated. After regulating the frequency, boiler temperature increase from 160 °C to 168.50 °C. This value is in between 150-170°C and does not hampered the industrial compliance. Thus this feedback system improved the deviation in the frequency and increase the system stability.

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V. CONCLUSION

The frequency regulation is very important for an industry. At peak hour the tariff rate is high. So the industry uses their captive generation which generates 10% of their maximum loads demand. An industry has various types of motors which are frequency responsive loads.

Frequency's allowable range 48.8- 51.2Hz. If the frequency changes from this level, then the frequency responsive loads will damage. So frequency regulation is an important factor of an industry. At the peak hour time, the frequency deviation can regulate by using the electric boiler. This paper proposed a novel method to regulate textile industry frequency at the time of power unbalance. When positive unbalance occurs, then the frequency is increases, which increase the boiler temperature by the using of feedback path and regulate the frequency deviation and vice versa.

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