Dynamic analysis of the governor control system of a 25 MW Hitachi gas-fired power plant for designing a load shedding system

Alireza Mohammadzadeh-Fakhr-Davoud

Abstract—In this paper, the dynamic response of a governer control system of a 25MW Hitachi gas-fired power plant is studied that was installed by Moham shargh engineering group. In this paper, the block-diagram of the control system is explained completely and then, the behavior of the power plant is examined and analyzed. Also, conventional strategies for load shedding has been investigated and the best strategy that can be implemented and executed in this power plant are proposed. The various load shedding scenarios are considered to determine the suitable scenario for the petrochemical refinery. Grouping the loads and determination of the critical and non-critical loads was selected as operator guide lines. Based on the experiments, frequency-based load shedding is the best strategy for this system.

Keywords: Dynamic analysis, Gas Power Plant, Load shedding, HIACS.

I. Introduction

HITACHI H25 gas power plants use a PLC-based control and monitoring system called HIACS-MULTI and these power plants have been used frequently in Iran [1-3]. Usually, several gas power plants with lower power are used in power plants in refineries. For example, in this case study, three 25 MW power plants were installed and due to the increase in load demand, another unit was added to this set to enhance the system reliability and ease of maintenance. The load required by this refinery is about 25 MW and two power plants are used synchronously to supply the load. The third power plant (which changes periodically) is off and would be started in certain period, according to the operator's decisions. With the increase in demand and installation of the fourth power plant, the problem of load shedding has become more prominent. When some power plants supply a set of loads and for any reason one of the power plants goes out of the grid, it usually takes a long time for the other power plants to make up for the power shortage. The increased demand usually causes a drop in voltage and frequency of the grid and may eventually lead to a total grid outage. To deal with this problem, when a power plant goes out of the grid, the load shedding system disconnects some non-critical loads to maintain grid stability.

This paper examines the dynamic behavior of Hitachi turbines. It should be noted that the power plant information and behavior data, were gathered from the Islamabad West Power Plant, which was supplied and commissioned by Moham Shargh Co. Information about the power plant was received directly from the supplier (Hitachi), and information about the commissioning was obtained from the results of the testing and commissioning of the power plant by the Moham Shargh commissioning team.

Many researches have been executed on load shedding in the literature. For example, an adaptive strategy has been presented in [4], that focuses on remedial action schemes and the protection of power networks with high penetration of renewable energy, while our work concentrates on the direct control of turbines and generators in a Hitachi gas-fired power plant**,** addressing the dynamic behavior and control of the generation equipment itself. The study presented in [5] addresses frequency stability and cyber-physical resilience of modern power systems using CNN-LSTM-based attack detection. Unlike studies that focus on wide-area power system stability under high renewable penetration, such as [6], this work concentrates on the dynamic control of a Hitachi gas-fired power plant, specifically the turbine governor and AVR excitation systems. While previous research addresses network-level frequency stability and oscillation damping, our study deals with local generation equipment dynamics and control performance, providing detailed modeling of turbine and generator behavior under various operating conditions.

This work's novelty lies in its practical, plant-specific integration of detailed dynamic analysis (drawn from manufacturer block diagrams, real commissioning data, and field startup/loading curves from the Islamabad West Power Plant) with a customized, low-cost load-shedding design tailored to the operational realities of multiple parallel Hitachi H25 units in a petrochemical refinery setting.

Unlike many generic studies on under-frequency load shedding (UFLS) or theoretical governor modeling, this paper:

- Explicitly dissects the Hitachi control architecture (acceleration, speed/load, and temperature loops with

Alireza Mohammadzadeh-Fakhr-Davoud is R&D manager in Nick Andshan Energy Co. (Email: newcontrol561@yahoo.com).
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documented delays) and quantifies real-world response characteristics, such as the ~30 seconds per MW dominant delay and ramp rate constraints (e.g., TNR slope of 0.33% per minute).

- Proposes and justifies a power-detection-based scheme using fast digital trip signals (instead of slower/less accurate PLC frequency processing), which addresses the specific inertia and response limitations of these units when one trips while supplying ~17 MW with others.
- Incorporates operator-defined critical vs. non-critical load groupings and scenarios that prevent unnecessary shedding during normal load increases, directly informed by observed dynamics and refinery constraints. This provides actionable engineering guidance and empirical insights for similar isolated or semi-isolated industrial systems, relying on existing facilities without expensive new hardware—something often missing in more abstract papers. The confidentiality note on implementation/testing further underscores its applied value from real deployment experience. If needed, we can expand on quantitative validation (e.g., Fig. 6 frequency response) or compare against broader literature.

The rest of this paper is organized as follows. Section II presents a detailed analysis of the power plant behavior, including the governor control system block diagram, AVR excitation system, and dynamic response characteristics derived from actual unit startup and loading tests. Section III investigates various load shedding strategies and evaluates their suitability for the studied Hitachi gas-fired power plant, considering the system's dynamic limitations. Section IV describes the proposed load shedding implementation method based on power detection using digital trip signals, along with operator guidelines for critical and non-critical loads. Finally, Section V concludes the paper with key findings and practical recommendations.

II. ANALYSIS POWER PLANT BEHAVIOR

The block diagram of the power plant control system provided by the manufacturer is shown in Fig.1. This figure shows a simplified control architecture for a Hitachi gas-fired power plant turbine, where fuel flow and turbine operation are continuously adjusted to maintain safe and efficient performance. The system combines three major control loops: acceleration control, temperature control, and speed/load control. During startup, the acceleration controller limits how quickly the turbine speed increases to avoid mechanical stress. The speed/load controller regulates turbine output by comparing the desired speed or load setpoint with the actual turbine speed, then adjusting the fuel command accordingly. At higher operating conditions, the temperature controller becomes dominant, using exhaust temperature feedback from thermocouples and radiation shields to prevent turbine overheating. Signals pass through several delay and dynamic blocks (represented by transfer functions such as $1/(1+0.1s)$ and exponential delay terms $e^{-0.1s}$) that model real physical behaviors like combustion delay, fuel system response, compressor discharge dynamics, and exhaust transport delay. The "low value gate" selects the most restrictive command among the control loops, ensuring that protective limits override aggressive fuel demands. Overall, the diagram represents a coordinated feedback control system designed to maintain stable turbine speed, regulate generated power, and protect the gas turbine from thermal and mechanical damage.

Fig.2 represents the Automatic Voltage Regulator (AVR) and excitation control system used in the Hitachi gas-fired

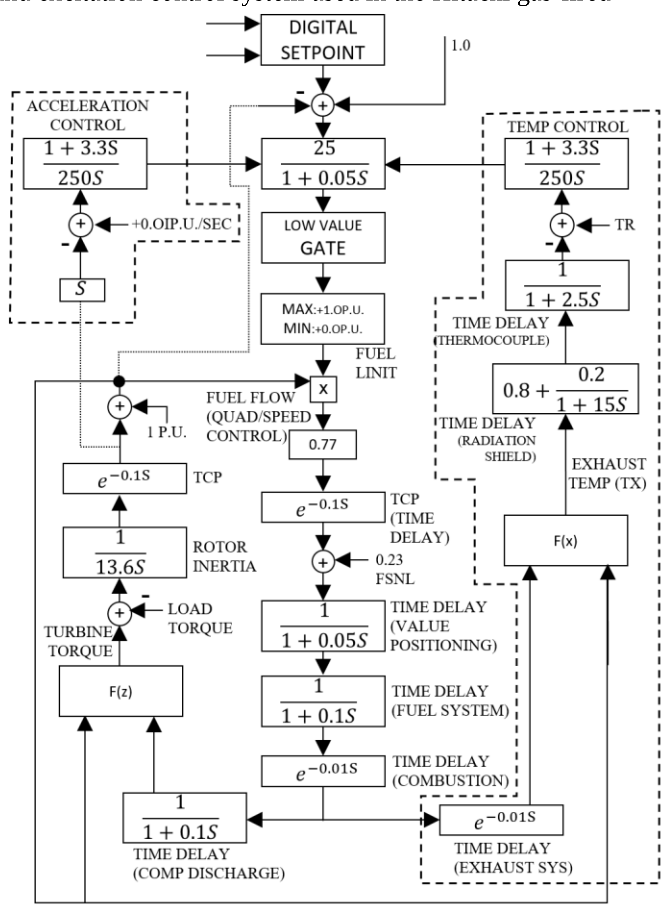

Fig. 1. Power plant control system block diagram

power plant generator. Its purpose is to maintain stable generator terminal voltage and support power-system stability by controlling the generator excitation voltage EFD. The measured terminal voltage Vg first passes through a digital filter to remove noise and measurement fluctuations. The filtered voltage is compared with the AVR reference signal, while auxiliary stabilizing signals from devices such as the Power System Stabilizer (PSS) and reactive current compensation (RCC) are added to improve damping and reactive power behavior. The resulting voltage error is processed by the AVR regulator, which contains proportional and lead-lag compensation blocks that shape the dynamic response and improve stability. Output limiters such as OEL

(Over Excitation Limiter) and UEL (Under Excitation Limiter) prevent unsafe operating conditions by constraining excitation demand within allowable limits. The signal then enters a PWM power converter model that represents the thyristor-based excitation system dynamics. Additional feedback loops and saturation/nonlinear limiter blocks model exciter response, field current constraints, and magnetic saturation effects. Then, the system produces the excitation field voltage EFD, which controls the generator rotor magnetic field and therefore regulates terminal voltage, reactive power output, and overall power-system stability. However, since the excitation system is used to regulate and control the reactive load of the power plant, and in the load shedding system calculations we are

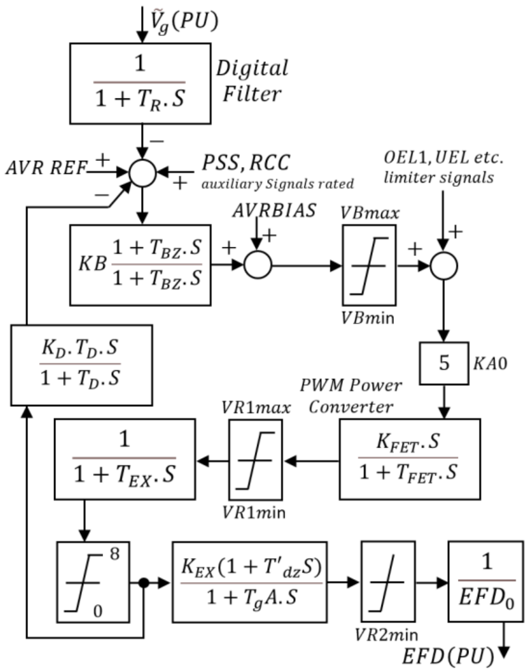

Fig. 2. AVR excitation block diagram

directly faced with the generated active power, the excitation system does not play a large role in the load shedding program and our focus will be on the turbine control system and the generated active load.

In the following, we will use the unit startup diagrams for the dynamic analysis of the turbine. We will divide this section into two parts. First, we will examine the unit startup diagram until reaching the full speed no-load point, abbreviated as FSNL, and then the unit loading diagram.

Fig. 3 shows the unit startup diagram. It can be seen that when there is no load on the turbine and the main breaker connecting the power plant to the grid is open, the system response speed is fast. As can be seen in Fig.3, the speed set point is initially set to 4850 rpm and after the turbine accelerates, it reaches a speed of 5100 rpm with a gentle slope. The turbine accelerates from low speeds to 4850 rpm with high acceleration and then from this point it reaches a speed of 5100 rpm, which is the nominal speed of the turbine, in a controlled manner.

Fig. 4 shows the unit loading diagram. First, a small step, i.e. from 1.8 MW to 2.5 MW, is given to the turbine. It is observed that the system has a delay in response to the set point and there is a time difference between the set point and the amount of active power generated. On the other hand, these two curves move with the same slope. Therefore, it can be concluded that the control system has a high speed and the time difference (delay in the system) is due to the turbine dynamics. It is observed that when AVR and generator dynamics are added to the system, the delay and inertia in the system increase. Another important point in this diagram is that the system set point cannot be applied in a stepwise manner. In fact, to prevent the system from being hit, each change in the set point is applied to the system with a specific and calculable slope. According to the manufacturer's documents, this slope is defined as follows for the Hitachi power plant: The number called TNR is defined as 100 percent at zero load (the generator breaker is open) and 104 percent at a load of 25 MW. It is worth noting that the system droop is 4%. The movement from 100 to 104 is at a slope of 0.33% per minute. Therefore, reaching the rated load takes about 12 minutes.

Fig.5 shows the unit loading diagram at base load. In this diagram, the time to reach the base load, which is 19.96 MW due to environmental conditions, is about 8 minutes and 30 seconds. In this diagram, the system delay is better defined. As stated, the turbine has a time-varying system and also has a small uncertainty and it is not possible to state a specific value for the system delay with certainty. This is also mentioned in the block diagram provided by the manufacturer. However, the dominant delay for the turbine response time to the command is about 30 seconds per megawatt. That is, regardless of the time of trip detection and issuing the load increase command, the turbine dynamics reach the set point value with this delay. It is noteworthy that in this system, the turbine, AVR and generator blocks are presented as a single system and the separation of different parts is avoided. In addition to increasing the complexity of the discussion, it also distracts us from the main purpose of this discussion, which is to examine the dynamics of the entire system.

III. Considering Various Load Shedding Scenarios

It is generally customary for the load shedding sequence to be as follows [12,13,15,16,17]:

a) Frequency detection: With a frequency drop, loads are disconnected in 4 stages in order of priority [7-9].

b) Power detection: With a drop in generated power, important and heavy loads are disconnected in order of priority [10,14].

c) Voltage detection: With a drop in voltage, all loads are disconnected and the power plant remains on without load [10,14,15,18].

Each power generation and distribution network, designs and implements its own specific scenario depending on factors such as following [11]:

a) Type of power generation system (gas, diesel, steam, etc).
b) Number and capacity of generation.
c) Volume of supplied loads.
d) Sensitivity of the network and consumers to the frequency and voltage of supply.

Therefore, first, we refer to Table I which shows the time required for power generation

TABLE I
REQUIRED TIME FOR PROVIDING LOADS

no	Load (MW)	Time (Sec)
1	1	18
2	4	85
3	7	160

In this case, there is no frequency detection capability because the PLC system does not have the accuracy and speed to convert analog frequency values to digital and execute the corresponding logic, as well as the use of time filters to detect the decreasing frequency trend.

There are protective relays to detect frequency drops and issue trip breaker commands in the event of a sharp decrease/increase in frequency, which is related to the topic of network protection. Also, voltage detection in the event of a network voltage drop is used to issue trip breaker commands and disconnect the power plant from the network to prevent damage to the power plant and other equipment. Therefore, the most appropriate option is power detection. In this case, we will face two options:

a) Production loss due to the tripping of an active power plant.
b) Increased consumption due to the introduction of a heavy load into the network.

The load details are described as follows:

- Step 1, 10% ± 1% of total demand is shed. The load type is mostly lighting areas.
- Step 2, 10% ± 1% of total demand is shed. The load types are residential areas.
- Step 3, 10% ± 1% of total demand is shed. The load types are HVAC areas.
- Step 4, 10% ± 1% of total demand is shed. The load types are small industrial areas.
- Step 5, 10% ± 1% of total demand is shed. The load types are densely industrial areas.
- OFF 1, 25% of total demand is shed. The load types large industrial areas, but not critical loads.
- OFF 2, 25% of total demand is shed. The load types are remaining areas.

In the case of the first option, we consider a situation where two power plants with a capacity of 10 and 7 MW are responsible for supplying 17 MW of power. If the 7 MW power plant trips, the second power plant is unable to supply power in a short time and the entire network must be prevented from shutting down by load shedding. Therefore, it is more appropriate not to use analog signals and use digital signals to increase the speed of the system. (It is worth noting that analog power generation signals transmit the amount of power generated numerically. Also, the power plant trip signal transmits the power plant status digitally in terms of active operation or trip.) If load shedding does not occur, the time required to supply 7 MW of power is about 180 seconds and the probability of the voltage drop protection relay or frequency protection and grid shutdown is very high.

In the second case, when a heavy load (about 1 MW) is connected to the grid, the frequency or voltage may drop and it may take some time for the generation network to stabilize. At this time, load shedding procedures should not be run and the governor control system should be allowed to stabilize the network.

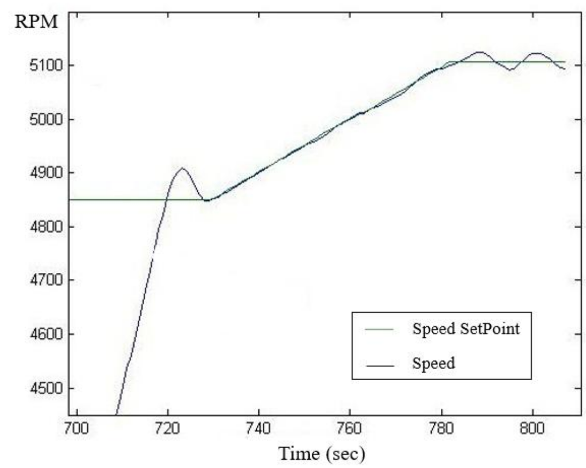

Fig. 3. Power plant run up time

IV. Load Shedding Implementation

The method of implementing load shedding, taking into account the above-mentioned issues, is defined as follows:

a) Load shedding should not be implemented when new load enters the network and the frequency or voltage drops, and the power plant should be allowed to stabilize the network with excess generation. Otherwise, by creating continuous changes in the power network, the network becomes unstable and as soon as the slightest fluctuation in voltage or frequency occurs, the loads are tripped and the operation is disrupted.

b) Load shedding should be activated when a power plant trips and we suddenly encounter a decrease in production and prevent a total blackout. In this case, speed of operation is very important. To increase the speed of operation, a digital signal is received from each power plant as a trip. If the active power plant issues this signal, we remove the amount of production from the unimportant loads so that the important loads remain on.

c) The power plant operator has to define important and non-important loads. When the load shedding executed, the shutdown command is given to the non-important loads simultaneously. The amount of power generated by the power

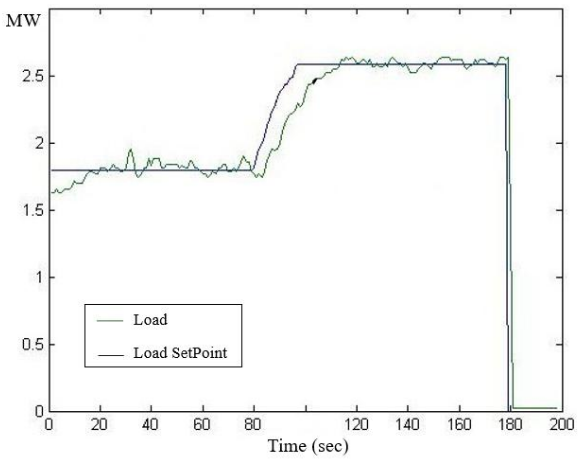

Fig. 4. Power plant loading curve

plant is received online from the power meters.

If a normal shutdown command is issued, the load is reduced with a gentle slope, and the power plant increases its load, and the network balance is maintained, and load shedding is not executed. In the event of a trip in the power plant or the breaker opens, load shedding is executed.

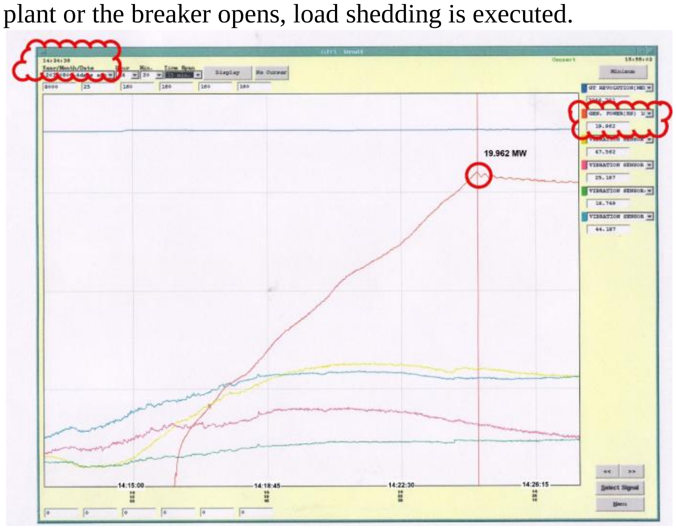

Fig. 5. power plant loading curve in base load

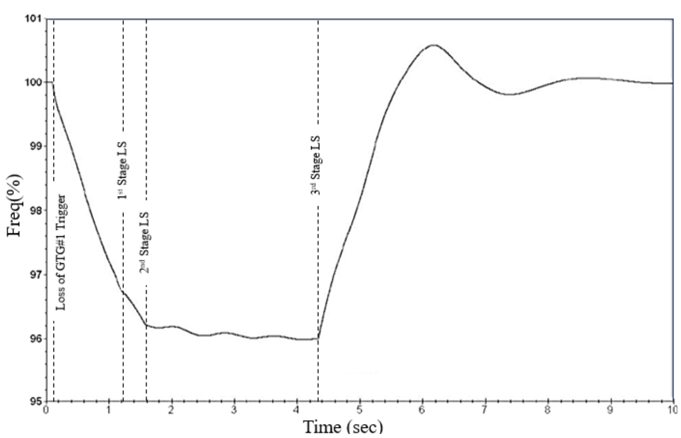

Fig. 6. Fequency response of system in load shedding

V. CONCLUSION

Choosing a load shedding strategy in refineries is of great importance. Failure to choose the right method may cause the refinery to shut down and incur huge losses. In this article, using accurate data from the Hitachi power plant, a load shedding scenario was developed and designed based on the needs, requirements, and existing conditions. In this plan, using all available facilities and without additional costs such as purchasing modern and expensive devices, and relying only on the existing power plant facilities, a load shedding system was designed and built.

The method of implementing the load shedding system in question and the method of testing this system are considered confidential information of Moham Shargh Company.

VI. ACKNOWLEDGEMENT

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Alireza Mohammadzadeh-Fakhr-Davoud (1977) was born in Mashhad, Iran, on Dec 9, 2001856. He graduated from the KNTU university of technology in Control. His employment experience included faculty member in ARI, senior software engineer in NEDA Group, R&D manager in Nick Andshan Energy Co. His special fields of interest included control system, such as gas turbine control system. Due to his shining work in REY power plant control system, Nick Andishan Energy company improved to knowledged-based Co.

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