The Limitations of an Automatic Generation Control in Stabilizing Power System in the Event of Load Demand Increase

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***Abstract*—The main objective of an Automatic Generation Control (AGC) is to maintain the power system frequency to its nominal value following a disturbance. However, the control action of the AGC is dependable on the availability of spinning reserves. Due to deficiency generation reserve capacity, the system frequency stability can be compromised. The benefits and limitations of an automatic generation control are outlined in this paper. The AGC was developed and implemented on a modified IEEE 14 bus power system network using the DIgSILENT PowerFactory simulation tool. The results indicate that the AGC is only effective in the power system when there are enough spinning reserves. When the generation spinning reserves are depleted, the system frequency can not be maintained at its nominal state following load demand increase.**

***Keywords*—Frequency control, power system stability, Spinning reserves, Automatic Generation Control, Governing system**

I. Introduction

The grid system frequency needs to be maintained as closely as possible to its nominal value to ensure smooth network operation, reliability, and quality supply to the end-users. A stable power system operation can be achieved through an adequate control system considering the uncertainty of load demand forecasting. Frequency control is one of the measures required to ensure that the power system remains stable. Frequency stability can be maintained through two significant control stages such as primary and secondary control. Primary control is performed by the governing system (GOV), while an Automatic Generation Control performs secondary control (AGC) [1], [2], and [3].

An Automatic Generation Control (AGC) is an additional control loop to the speed governing system in ensuring a stable frequency of power systems following a disturbance [4]. The AGC serves two functions: to stabilize power system frequency and maintain tie-line power interchange in the power system [5]–[9].

The benefits of the AGC can only be realized when there are enough spinning reserves [6]. On the other hand, depleting spinning reserves could lead to the failure of the AGC control function, which could be detrimental to the power system grid, resulting in load-shedding activation to safeguard the power system from complete blackouts [10]. Therefore, to avoid or delay the activation of emergency control action, the AGC needs to be adequately configured, and the spinning reserves need to be sufficient to ensure optimal power dispatching is achieved for the grid to remain stable.

II. Automatic Generation Control Overview

Automatic Generation Control uses various control mechanisms and tuning techniques. The various control strategies include classical, modern, and intelligent control strategies. The classical control strategy is still robust and widely used in most AGC configurations [9] and [11]. However, due to the complexity and modernization of the power system network, other configuration methods such as modern and intelligent techniques are also used in the development of the AGC control scheme [12].

The AGC can be designed in two different techniques, such as the centralized and decentralized model. The centralized technique only maintains the system frequency, while the decentralized technique controls the frequency and the tie-line power interchange between neighboring areas [13] and [14]. Fig. 1 illustrates a multi-level control scheme structure where an automatic generator controller is used as the key controller. Within Fig 1, the generator turbine governing system with an integrated system load is orientated at the lower level. The secondary and tertiary controls are positioned at a higher level. Since the governing system is installed on the power plant where the generator is located, it receives all the commands from an external system, such as a communication system situated on tertiary. The responsibility of the governing system is to enable the re-adjustment of the valve's inlet to the turbines of the generator, which will consequently adjust the output power production of the generator. Therefore, the governing system alone will not be as accurate in that function, and hence an additional control loop such as the AGC is required [15].

The power system frequency needs to be maintained within an acceptable operating range. Under normal operating conditions, the acceptable frequency operating range is between 49.5Hz to 50.5Hz [10]. Emergency control is required to protect under or over frequency if the system frequency is not maintained within the normal operating range. Under-frequency load shedding can be implemented as an emergency control strategy when low frequency in the power system is experienced [12]–[14].

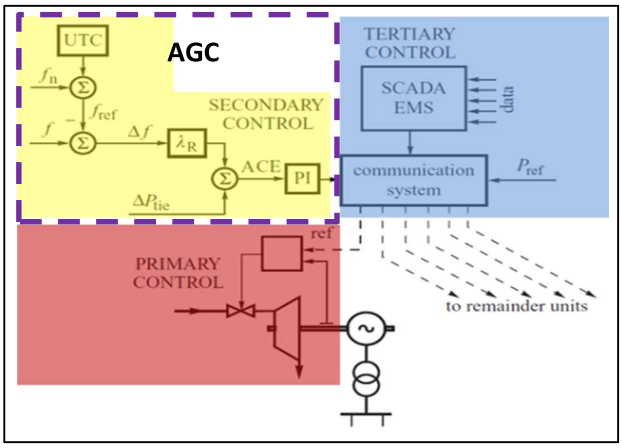

Fig. 1. The application of an automatic generator controller in an integrated control system [11]

However, for over frequency, tripping of generators can be initiated [16], [17]. The emergency control is the last defense mechanism in the power system stability; therefore, improving the response of the AGC and integrating other resources in the power system systems can help mitigate such operations [18].

A. AGC modeling approach

The AGC model and the network used in [7] have been adopted to interrogate the AGC contribution and its limitations in stabilizing the power system. Since the AGC can be configured in a centralized or decentralized model, the decentralized model is regarded as the most effective model as it ensures frequency stability while maintaining power interchange between the areas. The difference between centralized and decentralized automatic generation control is presented in the figures below. Fig. 2 illustrates the configuration of centralized automatic generation control. The tie-line power interchange is not considered in the control process of centralized automatic generation control. Instead, the tie-line power interchange is integrated into the overall control in the decentralized model. Fig. 3 below shows the configuration of a decentralized automatic generation control.

In evaluating the performance of the AGC in the power system grid, a four-area power system network utilized in [9] was considered. The interconnection and segregation of the areas are shown in Fig. 4. The purpose of illustrating these

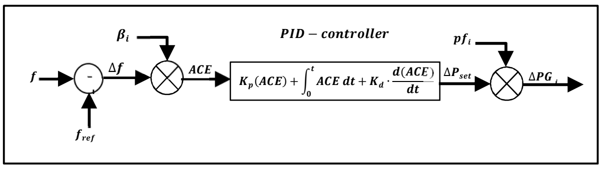

Fig. 2. Centralized automatic generation control block diagram [7]

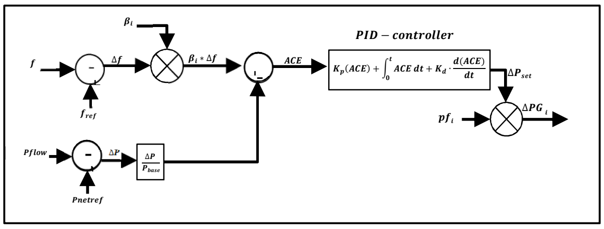

Fig. 3. Decentralized automatic generation control block diagram [7]

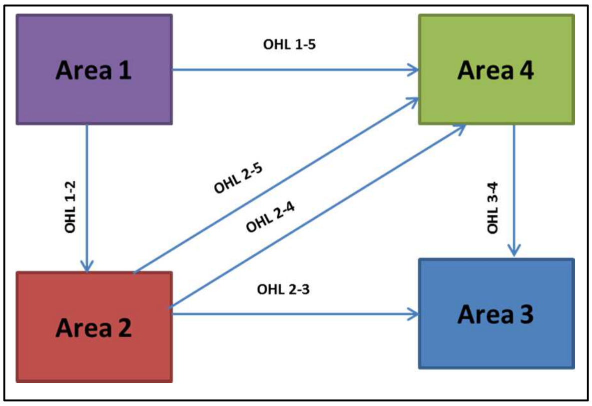

Fig. 4. Power system interconnection configuration

Four areas indicate the interconnection between the areas and the power flow direction. In addition, the power distribution or transfer amongst the areas needs to be controlled to ensure that the areas are not under-supplied or over-supplied. If they are under-supplied, there is a possibility of not meeting the load demand within the area. When they are over-supplied, the power lines can be strained, the loading percentage will increase, and the possibility of overload and activation of feeder protection such as overcurrent conditions is likely to occur [6].

III. Application of Automatic Generation Control and Development using DIgSILENT

The modeling of the AGC on DIgSILENT is achieved by first creating the frame diagram. The purpose of the frame is to define inputs and output assignments. The inputs to the controller to be defined include frequency measurements and the active power flow at the receiving end of the area. These analog signals are sent to the controller and processed for obtaining a desired control output signal. Fig. 5 shows the frame diagram of the AGC for all four areas. Fig. 5(a) shows the frame model for area 1. Area 1 supplies power to the neighboring areas; hence, the power interchange is not considered, as shown in Fig. 4. Fig. 5(b) indicates the signal mapping for area 2, Fig. 5(c) is for area 3, and Fig. 5(d) is for area 4.

Fig. 6 below illustrates the function block diagram of the AGC for all four interconnected areas. The output signal of the AGC model in Fig. 6 is sent to their respective governing systems for actuate generator output power dispatching. Fig. 6(a) represents the AGC function block for area 1, and area 2 is shown in Fig. 6(b). Area 3 and Area 4 are shown in figures 6(c) and 6(d), respectively.

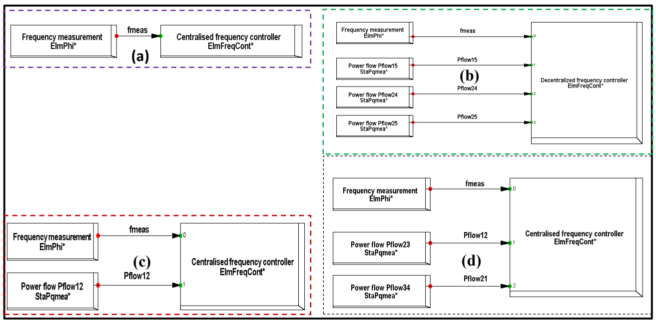

Fig. 5. AGC frame diagram for all areas

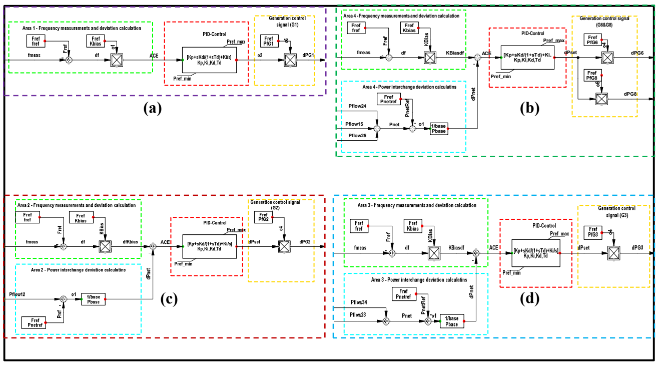

Fig. 6. AGC block diagram for all areas [7].

In order to evaluate the response of the AGC, the modified IEEE 14 bus network was used and modeled using the DIgSILENT software tool. The network model is found in [9], and the network parameters can be found in [19]. In the network, each area has its designated AGC. The AGC parameters were also extracted from [9].

IV. Simulations and Results Analysis

Fig. 8(a) represents the system frequency before and after the implementation of the AGC. Before the AGC was implemented, it can be seen that the governing system could not maintain the system frequency to its nominal state from the inception of the load demand increase. The system frequency fell to 49.32Hz, as shown by the red graph. The AGC was introduced as an additional control loop to the governing system of the generators. The frequency was maintained following a load demand increase to the 9th step (equal to a 9% load demand increase); however, at T=200sec, the AGC started to fail to maintain the system frequency. Following a 15% load demand increase, a new steady-state was reached at 49.64Hz, as indicated by the blue graph within Fig. 8(a).

The tie-line power interchange for area 2 is presented in Fig. 8(b). Before implementing the AGC, the load demand increase resulted in a deviation of the scheduled power interchange of area 2 from -86.81MW to -92.96MW. Therefore, the scheduled power interchange was maintained to the 8th step following a load demand increase when the AGC was implemented. However, after the 8th step, where T=180sec, the AGC failed to maintain the power interchange in area 2. As a result, a new state was reached where the

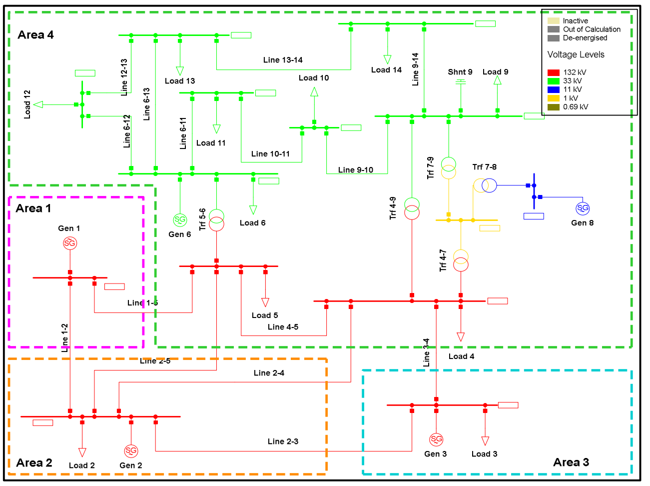

Fig. 7. Four area-modified IEEE 14 bus network [7].

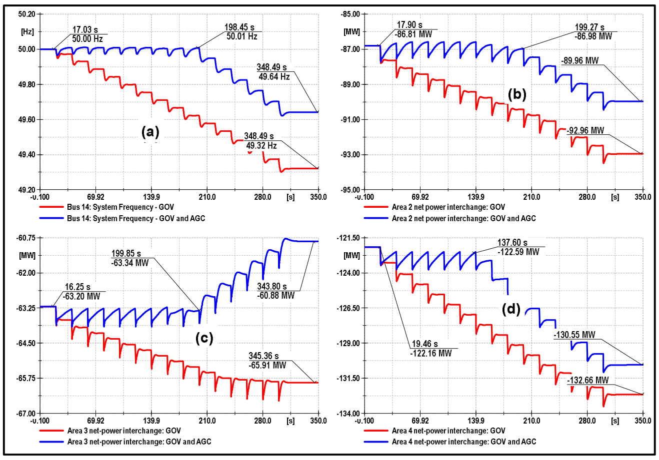

Fig. 8. System frequency and Tie-line Power Interchange following 15% load demand increase contingency

power interchange was recorded as -89.96MW after the 15% load demand increase.

In area 3, shown in Fig. 8(c), AGC maintained the power interchange as close as possible to the scheduled amount until the 9th step at T=200sec following a load demand increase. As the load demand increased, the power interchange in area 3 increased to -60.88MW after the 15% load demand increased.

Fig. 8(d) illustrates the net tie-line power interchange for area 4. The AGC implementation has supported the power interchange to be maintained close to its scheduled value of -122.16MW. However, T=140s (7% load demand increase), the AGC started to fail to maintain the power interchange. As the results of a continued load demand increase, a new state of the power interchange, being -130.55 at area 4, was reached. Area 4 is the most vulnerable compared to other areas; therefore, a critical security supply to the load. As a result, area 4 loses its stability and healthiness quicker than other areas. At the 7th step of the load demand increase, area 4 was already unstable while other areas were still stable at this power demand level. According to Ohms law, the increase in load demand affects the bus bar voltages because of its inverse proportionality. Hence, when the load demand increases, the bus bar voltages to which the system loads are connected start to decrease. Fig. 9(a) illustrates the response of bus bar 14 load demand increase, the illustration of this bus bar was considered the most affected bus bar in the network. After the load demand increase, bus 14 voltage has dropped from 0.99 to 0.98pu. This voltage is still within the acceptable tolerance. However, if the load demand increases, voltage instabilities could be experienced.

The results also show that the AGC does not contribute to grid voltage control. The voltage measure at bus 14 during the GOV response is the same as when the AGC was implemented.

Fig. 9(b) shows the impact of load demand increase on spinning reserve capacity. It can be noted that the total spinning reserves started to decline when the load demand increased. However, during the control action of the governing system, the spinning reserves were left at 8.53MW. This is due to the governing system utilizing the spinning reserves based on its droop characteristics; hence they were not entirely depleted following a load demand increase.

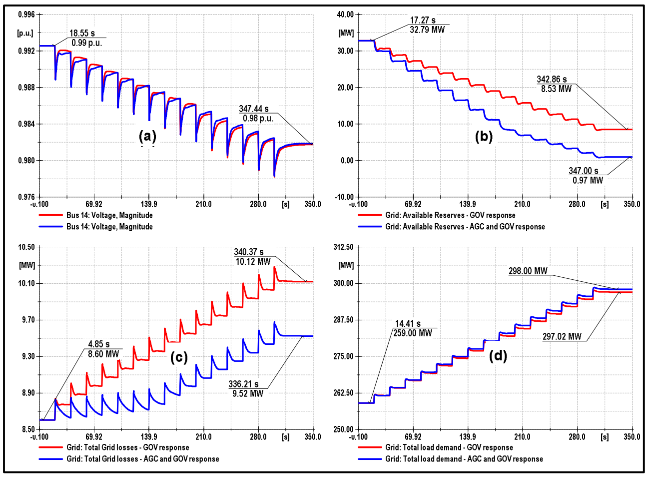

Fig. 9. Bus 14 voltage, spinning reserves, grid losses, and total load demand following 15% load demand increase

When the AGC was activated, the spinning reserves were almost depleted to 0.97MW, as shown in Fig. 9(b).

The benefit of having the AGC in the power system grid is observed in Fig. 9(c), where the power losses following a load demand increase were improved from 10.12MW to 9.52MW. Fig. 9(d) indicates the load demand increase before and after the implementation of AGC.

The power system grid needs to be adequately maintained, and its optimization will result in improved efficiency. In addition, straining the power system generator can reduce its life span. Fig. 10 illustrates the heatmap of the network following a load demand increase. The thermal loading is between 81.8% and 96.7%, generator 3 being the most loaded. The impact of thermal loading, as mentioned, can reduce the expected life span of the generator, the efficiency can also drop. In addition, constant tripping of the generator due to thermal loading can also be experienced.

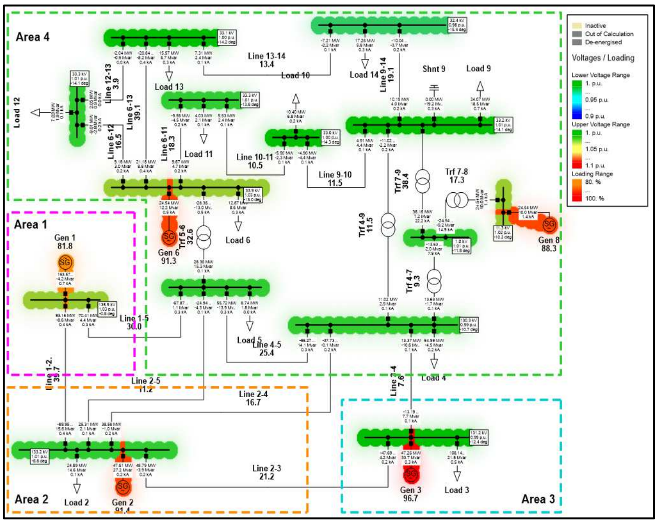

Fig. 10. The modified IEEE 14 bus network heatmap following a load demand increase

V. Conclusion and Future Work

Power system stability is part of the day-to-day activity to all the utility custodians and those responsible for the smooth operation of the power system, such as system operators. Therefore, various control and monitoring strategies are explored every day. Therefore, it is essential to understand what each component within the sphere of control and operation can provide to enable and ensure the stability of the network grid.

Automatic generation control has been interrogated, its contribution to the power system is noticeable. However, a significant contribution of this control strategy could be realized more in a power system where there are enough generation reserves. Therefore, it has been realized that when there are not enough generation reserves in the power system, the contribution of the AGC to power system stability could be marginalized. It has been noticed that the AGC fails to maintain the power system frequency, the generation reserves are depleted. The AGC does not support voltage control as it is primarily for optimal active power dispatching.

Therefore a new control approach is required to deal with the drawback of the AGC. The AGC is mainly configured as an additional control loop to the governing system of the synchronous generator. Considering the restriction and prohibitory measures to mitigate the use of fossil fuel generators, which negatively impact the environment, has drawn more attention in an exploration of using distributed energy resources as an alternative supply. Therefore utilization of wind turbine generators and the photovoltaic system as an alternative source of supply to stabilize the power system grid can be considered in future work. However, these energy resources need to be adequately integrated into the power system grid to avoid any impact leading to power system instability. Therefore a control system that will allow smooth integration into the grid needs to be studied.

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