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Evaluation of Gas Turbines Efficiency in the Frequency Control Mode Using Experimental Data

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Abstract: *This paper provides experimental results about the efficiency of gas turbines operated in part-load mode. Load frequency control plays a vital role in electric power production as it offers the most important generation control of power plants. In order to participate in frequency control, power stations must change from pre-select mode to the part-load condition. Evaluating the efficiency of the units operated in so-called modes, leads to more precise pricing for participation in frequency control ancillary service market. In this paper, it is considered gas turbines operated in both modes and results are provided. Comparison of experimental results obtained from a real case study shows that the efficiency of the gas turbines has very low decrease in the part-load mode.*

Keywords: Efficiency, frequency control, gas turbine, part-load, pre-select

۱. Introduction

Frequency deviation arises as a result of temporary power variation. In order to maintain the frequency in the target value, controlling of active power generated and/or consumed is necessary. This is provided by frequency control, which is a reserve of certain amount of active power [۱].

To sustain the balance between load and generation, three levels of frequency controls are used: primary, secondary and tertiary frequency control. Primary frequency control is an automatic balance adjustment between load and generation. It is based on frequency variation with response time less than ۳۰ seconds. Speed governor plays an important role in this control. Secondary frequency control ensures the re-establishment of primary control to bring back the frequency to its nominal value and thereby minimizing the power flow imbalance in neighboring control areas. This is slower with a response time of ۱۵ min, which is implemented with Automatic Generation Control (AGC). Tertiary frequency control is done manually through telephone calls or faxes with response time from several minutes to hours [۲].

It has been published lots of paper in the field of frequency control [۳, ٤]. In order to participate in such ancillary service, knowledge of operating costs in such condition is critical to the competitive power market. For this purpose, it is essential to know the effect of frequency control on the operation and condition of equipment of the power plants.

Comprehensive evaluation of the power plants, which are operated in frequency control, is provided in [٥] and it is discussed some of the main affecting factors in costing this ancillary service. In [٦] several methods for the power-reserve pricing of frequency control are presented. In the EPRI report, it is shown a reduction in boiler efficiency due to frequent load adjustments in steam power plants [۷].

High frequency changes for automatic generation control (AGC), can lead to damage to the power generation equipment [۸].

The characteristic of gas turbines operating at part-load conditions is analyzed in [۹-۱۳]. The term “part-load” used in these references is different from used term in the field of frequency control. In mentioned papers, the part-load term is equivalent to conditions, which the unit is delivering any constant MW below its base-load capacity. However, in the field of frequency control it is referred to conditions, which the unit is set to follow the load variations and delivers variable MW in any moments depending on frequency variations.

In this paper, it is discussed about the effect of performance of gas turbines operating in frequency control mode. To provide this ancillary service, units should change their operating condition from pre-select mode to part-load. In order to investigate this problem, it is selected a real case study, a combined cycle power plant with two gas turbines and a steam unit. In order to provide frequency control, the gas turbines are operated in part-load condition.

Evaluation of experimental results for mentioned case study show that the efficiency of gas turbines has very low decrement when they are working in part-load condition compare to working in pre-select mode.

۲. Gas Turbines in Frequency Control Mode

Conventional plants, hydro, gas turbine and thermal power plant are mainly used for primary and secondary frequency control [۱]. Taking into account that the largest portion of the energy produced in the world is thermal, they are one of the most effective alternatives for frequency control. Fig. ۱ represents the total electricity produced in the world from ۱۹۸۰ to ۲۰۰۵ [۱٤].

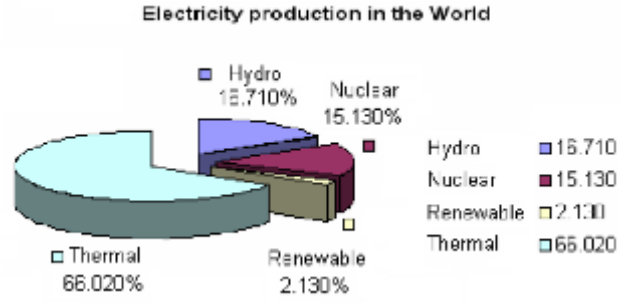

Fig. ۱: Total electricity production in the world from ۱۹۸۰ to ۲۰۰۵ [۱٤]

The gas turbines as fast response units are ideal for improving primary control response of the power system. The speed/load-frequency control is the main control loop during normal operating conditions and the most important for stability study [۱٥]. Gas turbines combined with steam units, well known as Combined Cycle Power Plants (CCPP), are widely used in the worldwide, due to their benefits such as high efficiency, quick construction and low emission [۱٦]. Gas turbines of CCPP are commonly used for different modes of frequency controls, especially for primary and secondary control. Primary, secondary and tertiary frequency controls with respective response times are shown in Fig. ۲ [۱۷].

Effects of different parameters on efficiency of gas turbines are investigated in many researches. As demonstrated it is obvious that the efficiency of gas turbine is increased as the ambient temperature increase [۱۰, ۱۱]. In addition, it is shown that the efficiency increases when the output power is increased near to its rated nominal power [۱۰-۱۲].

In this paper besides the influence of ambient temperature and output power, it has been investigated the effect of operation in frequency control mode on the efficiency of gas turbines. Experimental results for the effect of mentioned parameters on the efficiency of a real CCPP case study are provided in the next subsections. Selected case study consists of ٦×۱۲٥ MW gas units, which are combined with ۳×۱۱۰ MW steam units.

۳. Influence of Temperature on the Efficiency of Gas Turbines

It is obvious that gas turbines have higher efficiency at higher ambient temperatures as demonstrated in [۱۰, ۱۱]. Experimental results for selected CCPP case study confirm this subject, too. The influence of the ambient temperature rise on the efficiency of one of the gas units in several winter days for ۹۸ MW output power is shown in Fig. ۳, which has been fitted with a linear approximation on it.

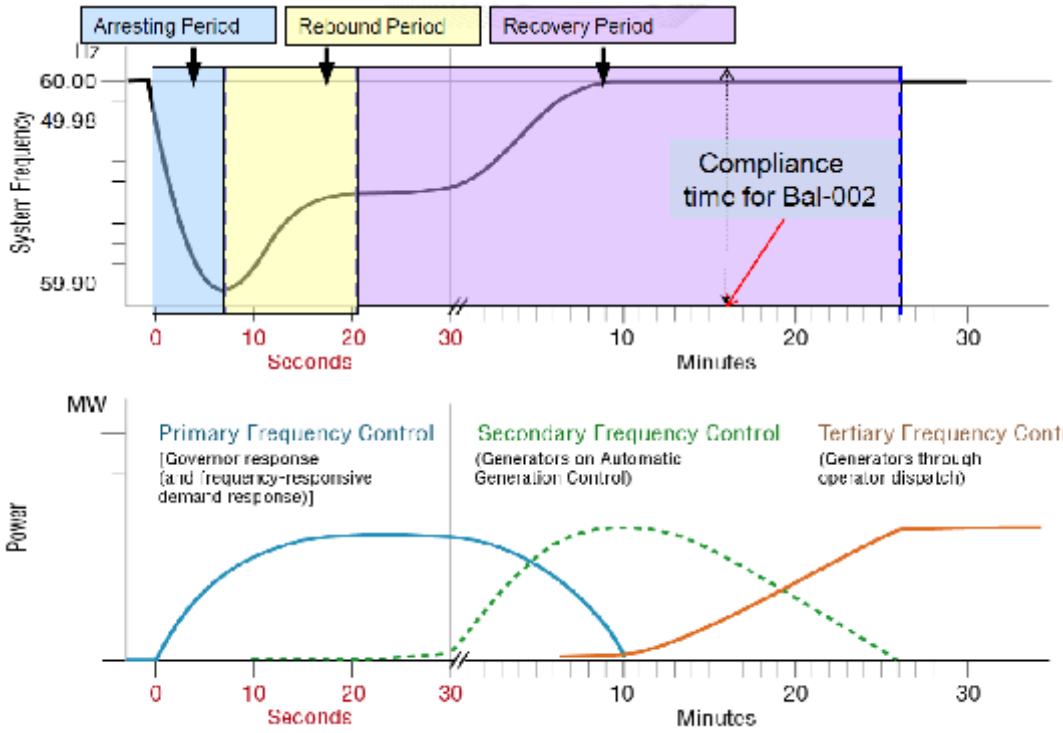

Fig. ۲: Primary, secondary and tertiary frequency controls with respective response times [۱۷]

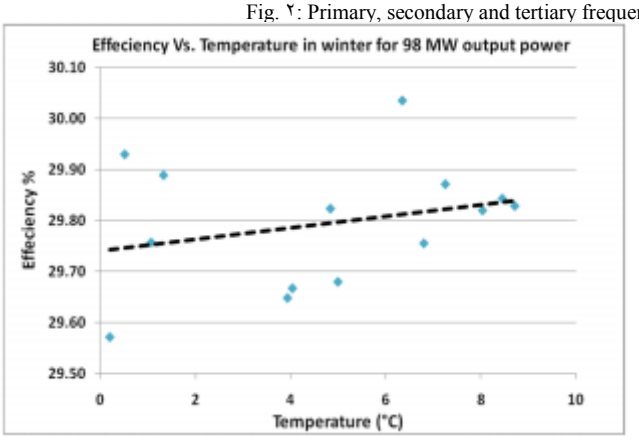

Fig. ۲: Influence of ambient temperature rise on the efficiency of gas turbine

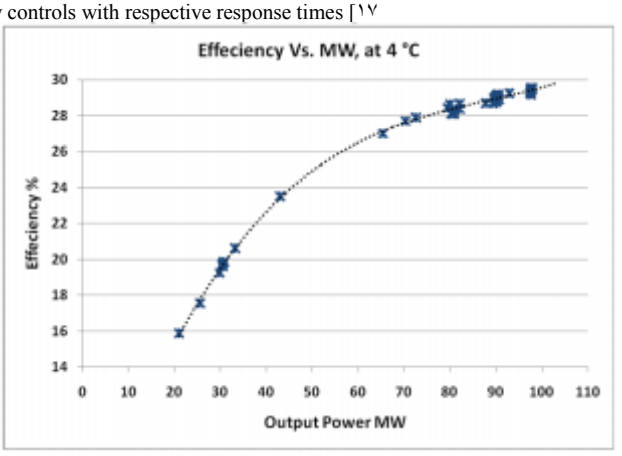

Fig. ۳: Influence of output power on the efficiency of gas turbine for evaluated case study

۲.۲. Influence of Output Power on the Efficiency of Gas Turbines

Similar to the effect of ambient temperature discussed in previous subsection, in this subsection it is investigated the influence of increasing output power on the efficiency of the gas turbines. As expected and indicated in [۱۰-۱۲], the efficiency of gas units will be increased if the output power is increased. Effect of output power on the efficiency is shown in Fig. ٤ for constant temperature ٤ °C; which the data are fitted with a polynomial graph of ۲nd degree (for the evaluated case study).

۲.۳. Influence of Frequency Control on the Efficiency of Gas Turbine

Besides to the temperature and output power, in this paper it is investigated the effect of participating in frequency control ancillary service on the efficiency of gas turbines.

In order to contribute gas turbines to control the frequency of the power system, they are designed with part-load mode. Gas turbines selected to contribute in frequency control must change their operating condition from pre-select to the part-load. In pre-select mode, a variation in frequency has no considerable effect on the output power, so there will be limited to very little variations in output power. But, when part-load mode is selected in order to contribute in frequency control, large

variations in frequency is followed with large variations in output power [۱۸]. Output power for a short period is shown in Fig.s ۵, ۶ for pre-select and part-load modes, respectively.

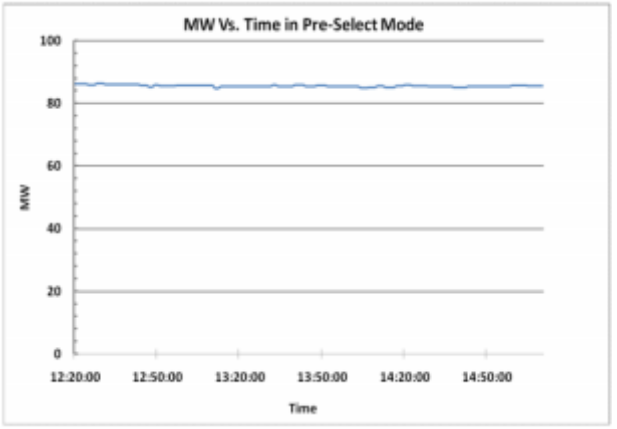

Fig. ٤: MW variations in pre-select mode

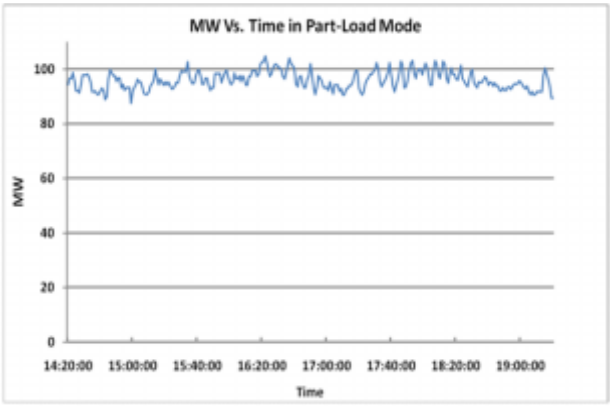

Fig. ٥: MW variations in part-load mode

As described and shown in previous Fig.s, it is clear that in the part-load operation, the output power has more changes compare to the pre-select mode.

When units are operated in part-load mode to contribute in frequency control, one of the major challenges is variation of efficiency. In order to study the influence of part-load mode on the efficiency of gas turbines, a period of seven consecutive days which the gas turbine is operated in both part-load and pre-select mode is considered. The hourly efficiencies are calculated and results are presented in Fig. ۷, which consists of efficiency for both modes for considered period of study.

Evaluation results show that operating in part-load mode leads to very low change in the efficiency, such that as shown in Fig. ۷, the curves of efficiency in part-load and pre-select modes nearly overlap with each other. In other words, there isn't considerable difference between the efficiency o the gas turbine in part-load mode and pre-select condition. This conclusion is result of a short period study consist of seven consecutive days with data which are sampled every one minute. It is obvious that precise and exact conclusions could be concluded only when wide range of data within very long periods is available. Just in this conditions, it is available to reach to comprehensive results which could be generalized to all circumstances.

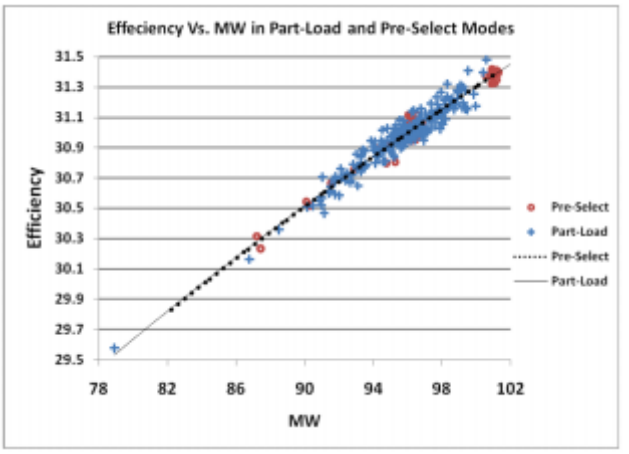

Fig. ٦: Influence of part-load and pre-select modes on the efficiency of gas turbines

۳. Conclusion

This paper studies the effect of participation in frequency control ancillary service on the efficiency of gas turbines. Gas turbines are widely used in order to regulate the system frequency, especially in primary frequency control. In this paper, a real evaluation of efficiency of gas turbines, which are operated in part-load mode, is provided. Evaluation is based on the experimental data that are gathered in seven days from a real combined cycle power plant. Evaluating experimental data for given period, shows that contributing in frequency control, has very low influence on the efficiency of gas turbines. In other words, operation in both pre-select and part-load mode, nearly results to similar efficiencies. This conclusion is an important result for better pricing of frequency control ancillary service.

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