Simultaneous Effect of Temperature and Site Altitude on Generators Output

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Abstract – *The effect of environmental conditions of the site must be considered as one of the most important aspects of designing generators as well as theoretic calculations and considerations. The real amounts which are measurable on the sites under real conditions are usually different from the rated values of the generators. In this paper we exerted this consideration and a typical model of generator produced by Ansaldo Energia was selected and studied. The material of the generator application guide and the measured values on site are used to get related curves of the environmental conditions effect, such as the effect the site altitude and the ambient temperature, on generator rated values. The practical and measured values of this model of generator which has been installed on Parand and Oroumieh sites in Iran are used for verification of the results of this paper and the related error is calculated. We claim this technical research has not been done before with such mentioned considerations and necessities. This paper gives the necessary instruction to evaluate the applicability and the generator characteristic data at different operating conditions (load, voltage, power factor, site and cooling condition). This study enables the designer to evaluate the generator behavior under the customer requirements and environmental conditions as well as to prepare the necessary proposed documentation for the client.*

Keywords: *generator, environmental conditions, site altitude, environment temperature, output power, rated power*

Nomenclature

P	= Output Power of the Generator
P_{rated}	= Rated Output Power of the Generator
k_h	= Site Altitude Correction Factor
k_t	= Environment Temperature Correction Factor
p	= Air Pressure
h	= Site Altitude
T	= Environment Temperature
p_1 to p_3	= Air Pressure Constants
$k_1$to k_4	= Constants in Correction Factors Equations

I. Introduction

While designing generators, we deal with different curves, charts and characteristics. The real amounts which are measurable on the sites under real conditions usually are different from the rated values of the generators. If customer offers different situation from the standard designing conditions, designer should be able to reform these values and adopt them according to the customized conditions. The conditions related to the implementation site which should be considered are as follows: the evaluation of environment temperature which directly affects the temperature of input air, cooling system and the amount of available water and also estimation of the effect of site altitude which refers to the air density [1].

II. Introduction to the Case Study Generator

The study has been done on the generator model TY10546 in the standard voltage of 15.75kV±5% and the frequency of 50Hz±2% according to IEC directions (reference: IEC 60034.3, clause 5, figure 1), indicated in Fig 1.

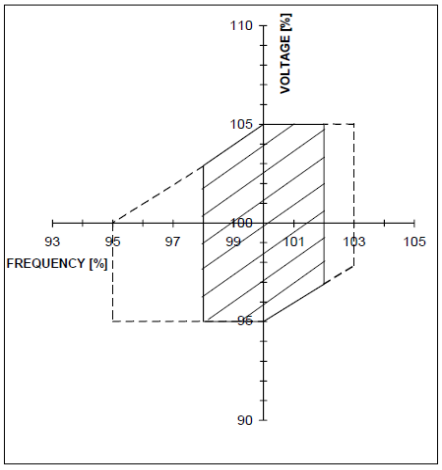

Fig 1. Operation over ranges of voltage and frequency [2]

The standard designing rated voltage value is 15.75kV±5% but the terminal voltage can also be 14.5, 15, 15.75 and 16 kV.

The minimum limitation is 14.5 kV which refers to the machine stability and the maximum limitation is 16 kV which refers to the limitation caused by the maximum electromagnetic induction and class of stator insulation.
This study enables the designer to evaluate the generator behavior under the customer requirements and environmental specification as well as to prepare the necessary proposal documentation for the Client. If costumer offers situation different from the standard designing conditions (the load, voltage, power factor, plant conditions and cooling system), designer should be able to reform these values and adopt them according to the customized conditions. The rated values of electrical and mechanical parameters are 200MVA, 15.75kV, 50Hz, the power factor: 0.8, the efficiency: 98.54 % in rated load, zero site altitude above sea level, the input cold air temperature equal to 40°C and the environment temperature 15°C according to the reference data of the generator. [3]

In the temperatures higher than the environment reference temperature, due to loss increasing, the generator output power decreases and in the lower temperature the generator output will increase according to the generators power limitations [4].

III. Technical Characteristics of Parand Power Plant

The Parand power plant includes six gas turbine units made by Italian company Ansaldo and is constructed in the southwest of Tehran on the 37th km of the Tehran-Saveh Expressway by the second toll station. This plant started its operation in March 2005. The environment conditions of this site have been shown in the table 1.

The technical characteristics of the main parts of Parand plant are shown in the table 2.

Table 1. The environment conditions of Parand site

Subject	Charachteristics
Place	Kilometer 30th in Tehran-Saveh Freeway
area	1 km square
Site altitude above sea level	1190 m(equal to the Pressure 0.8885 bar)
The average of maximum temperature	22.7 ºC
The minimum temperature	−10ºC
The maximum humidity	40.8%
The maximum wind speed	100 km/hr

IV. The Estimation of the Site Altitude Effect on the Generator Output

In the air cooling turbo-generators the cooling process is done by the transfer of the heat through the input cold air. The decrease of air density due to altitude effect causes the decrease of heat transfer.

Thus the maximum output power of the generator must be modified by a factor. To consider the effect of site altitude of the power plant on the generator rated output power, the generator power should be derived from the following formula:

$$P = k_h P_{rated} \qquad (1)$$

In order to achieve a factor for correction of the generator power on the base of altitude, first it is necessary to consider how the altitude would affect the air pressure. The influence diagram of altitude and the air pressure is almost linear and it is shown in the figure 2 [5].

Table 2. The technical characteristics of the main parts of Parand plant

Subject	Characteristics
Plant type	Gas Turbin
Turbine Maniufactorer	Ansaldo
Turbin Type	V94.2
The number of turbin vane rows	4
Rated Power	157/5MW
Number of units	6
Gas consuming rate of a unit at base-load	50000 Nm3/hr
Compressor type	axial
number of compressor vane rows	16

We used MATLAB software curve fitting toolbox to achieve the factor of the effect of altitude and air pressure (the pressure unit is Bar in this formula):

$$p = p_1 h^2 + p_2 h + p_3 \qquad (2)$$

$$p_1 = 3.272 \times 10^{-9}$$

$$p_2 = -1.193 \times 10^{-4}$$

$$p_3 = 1.011$$

Note that in the altitude of zero above sea level the factor of altitude effect is equal to 1. The Parand site is in the altitude of 1190 meters above sea level and as in the reference temperature of 15 degrees for the environment the factor of environment temperature effect on the rated generator output is considered as 1, the amount of output power difference from the rated power of this plant which is 157.5 MW, is only considered through the altitude effect (as the registered output power in a certain day of 9th of April 2006 was 135.28MW in the average day temperature of 15 degrees) and the factor of altitude effect for the Parand plant would be equal to 0.8627.

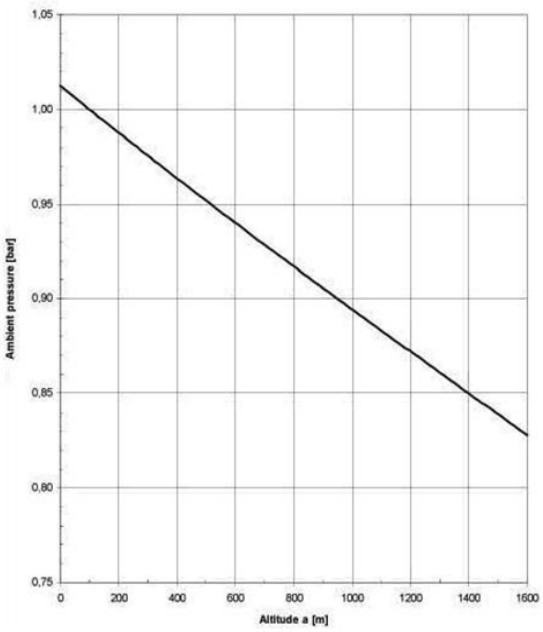

Fig 2. The Effect of the altitude on the air pressure

According to the above values and as we know that for instance in 1st of May 2008 the conditions in Uroumieh plant is as follows: the temperature of 15 ºC with the same generator units and the altitude of 1313 meters above sea level, and the output power of 132.3 MW and the factor of altitude effect for the Uroumieh plant would be equal to 0.8490, now we can conclude the figure 3 and the formula 3 which shows the relation between air pressure and the factor of altitude effect (with MATLAB) [6]:

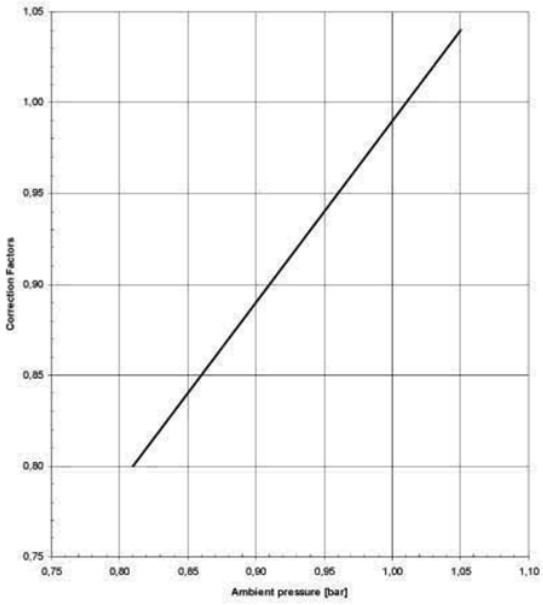

Fig 3. The factor of altitude effect on the generator output

$$k_h = k_1 p^3 + k_2 p^2 + k_3 p + k_4 \qquad (3)$$

Where k_1, k_2, k_3 and k_4 can be achieved by the following formulas:

$$k_1 = -0.2815$$

$$k_2 = 0.7761$$

$$k_3 = 0.2948$$

$$k_4 = 0.2005$$

V. The Estimation of Temperature Effect on the Generator Output

Turbine-generator combination has various mechanical and electrical parts. In many reports, the effect of aging on different mechanical parts of the turbogenerators is reported [7]-[9]. The most important limitation factor in the capability curves is the heating problem of the armature and excitation currents [10]. As mentioned in several reports, it is clear that the fouling in the cooling system of the water-cooled generators, limits the flow of the electric current in the windings due to exceeding thermal limits. Fouling has two important effects on the cooling process: first effect is due to flow restriction caused by fouling and second is due to heat transfer defects caused by fouling layer in the skin of the tubes[11].

To estimate the effect of environment temperature on the output power of Ansaldo made generator model TY10546 it is necessary to keep the generator output power for one year duration. Therefore one of this paper purposes is estimation of the ability of the generator for providing the forecasted load for the specified sites and

also considering this point that for better forecasting, the generators should be studied in their primary operation year and before its depreciation. The output power of this generator in Parand site was studied in 2006.

For considering the temperature effect on the generator rated output the generator power in rated conditions will be calculated by the following formula (formula 4):

$$P = k_t P_{rated} \quad (4)$$

After achieving the generator output data in rated conditions, the diagram of the effect of temperature would be shown as the figure 4 [5].

Since the generator output is equal to its rated value in the reference environment temperature 15ºC, the factor of environment temperature, k_t must be considered equal to 1 in this temperature. In the temperatures less or more than rated power of this plant units, the appropriate factor will be calculated according to the figure 5.

Note that the altitude of Parand plant above sea level is 1190 meters and this affects the generator output power. The amount of the influence of the site altitude on this generator output power in rated situation has been achieved by means of the registered data of 9th April of 2006 (in this day the average temperature was 15 degrees therefore the factor of environment temperature was equal to 1).

The rated output was 135.28MW. Thus the amount of the effect of the site altitude on this generator output power in rated situation would be 0.8627.

According to the figure 5 and by use of MATLAB for the higher temperatures (higher than zero) we can conclude the following formula (No. 5):

$$k_t = k_1 T^3 + k_2 T^2 + k_3 T + k_4 \quad \text{for } T \rangle 0^\circ C \quad (5)$$
$$k_1 = -4.518 \times 10^{-7}$$
$$k_2 = 2.614 \times 10^{-5}$$
$$k_3 = -6.581 \times 10^{-3}$$
$$k_4 = 1.097$$

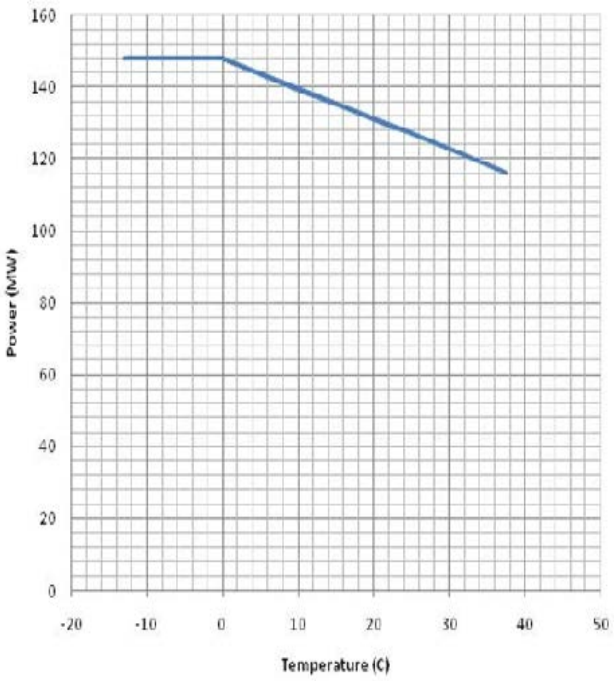

Fig 4. The effect of environment temperature on the generator output

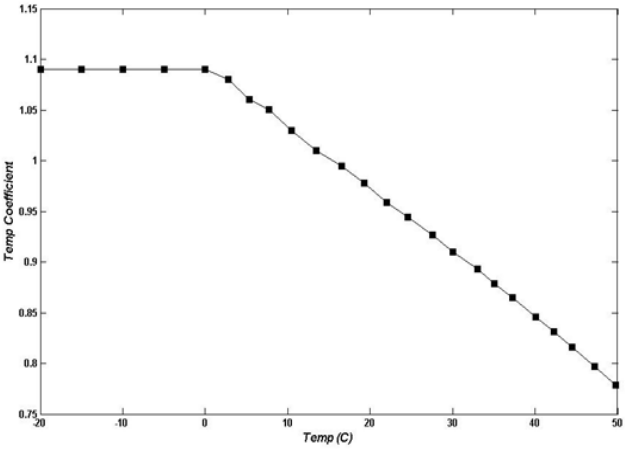

Fig 5. The factor of environment temperature effect on generator output power

For the temperatures lower than zero the factor of the environment temperature effect is 1.09 according to the formula 6.

$$k_t = 1.09 \quad \text{for } T \leq 0^\circ C \quad (6)$$

It must be noticed that the above results are according to the power limitations diagram and through consideration of the limits which prevent the production of power more than a certain value [6].

VI. Simultaneous Effect of Temperature and Altitude on Generators Output

Now that we have the calculated values of the factors

k_h and k_t, we can calculate the output power of the generator in the rated conditions [6].

$$P = k_h k_t P_{rated} \quad (7)$$

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VII. Verification of the Results

In order to verify the accuracy of the achieved results and to check them with the real registered data, we used the related available data of this generator model in Parand and Uroumieh plants in 2008. The related data and the results of this paper are shown in the table 3 and table 4.

According to the table 3, the results of this paper formulas and methods in comparison with the real condition, have the maximum error of 5.5 % which is an acceptable error and it shows that the proposed function for the effect of environment temperature on the generator output power, can be useful for the necessary forecasting in designing and selecting the appropriate generator and also expanding or establishing power plant units [6].

Table 3. Verification of the results for Parand Plant in 2008

SEASON	Spring	Summer	Fall	Winter
The average temperature in the season (ºC)	23	30	14	7
Rated Power (MW)	157.5	157.5	157.5	157.5
The calculated Power (MW)	128.67	122.82	136.11	142
The real registered Power (MW)	128	121	132	140
The error for the power (%)	0.52	1.5	3.11	1.42

Table 4. Verification of the results for Uroumieh Plant in 2008

SEASON	Spring	Summer	Fall	Winter
The average temperature in the season (ºC)	16	23	9	2
Rated Power (MW)	157.5	157.5	157.5	157.5
The calculated Power (MW)	132.31	126.62	138.06	144
The real registered Power (MW)	128	120	132	131
The error for the power (%)	3.36	5.51	4.59	2.12

VIII. Conclusion

The subject of generator designing still needs a lot discussion and investigation and besides the theoretic issues and the mathematical calculations one should consider more points. Different factors and the available limits causes the generator parameters in the site situations differ from its rated values. One of the most important conditions in sites is the evaluation of the environment temperature which directly affects the temperature of the input cold air, cooling system generally and the available water amount. In higher temperature (more than the base environment temperature which is 15°C) the generator has less output power due to the loss increasing. And the output power of the generator will increase to a certain value.

It must be mentioned that the generator power in lower temperature cannot reach more than 1.09 of its rated power and this is because of the limits of the generator output power according to the power circle diagram. Also we could conclude and show that the generator power will decrease by increasing the altitude because the air pressure is lower in higher site altitude.

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