A Research on Generators with Constant of Active Power and Variation of Excitation Current in Thermal Power Plant

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***Abstract*: This paper presents a method to determine critical points to adjust operating parameters for a thermal generator in case of constant of active power and variation of excitation current. Operating thresholds corresponding to above points are defined by maximum reactive power generating to the power system (positive), zero reactive power and maximum reactive power absorbing from the power system (negative). Curves representing the relation between power factors, angle of electromotive cross force and reactive power are also created in this paper corresponding to above operating points. Due to exactly determining critical points in this case, an algorithm is also proposed to help the controller have correct thresholds to adjust the excitation current for parallel couple of a thermal generator and the power system. This paper also presents a detailed calculation for a thermal generator having 57.5 MW rated active power to illustrate the proposed method. Calculation results showed the meaning of the proposed method to create a full and clear profile for any thermal generator that helps to control and dispatch power systems.**

***Index Terms*— Active power, angle of electromotive force, excitation current, reactive power, thermal generator.**

I. INTRODUCTION

Generators are very important units in thermal power plants and used to work in parallel with power systems. Active power is always generated to the power system while reactive power can be generated to the power system or absorbed from the power system. Corresponding to the demand of electric loads, output power of generators must be adjusted continuously to balance power and hold voltage/frequency stability for power system. By adjusting excitation current, values of active/reactive power can be changed but they are only in allowable ranges [1], [2].

In almost operating modes, value of active power from the generator to the power system is often from minimum value (P_{min}) to maximum value (P_{rated}) while value of reactive power is often from $-Q_{min}$ (the generator absorbs reactive power) to $+Q_{max}$ (the generator generates reactive power) [1], [2]. In the process of adjusting active/reactive power, its power factor is also changed. Value of power thresholds depends on allowable thermal operating condition and the characteristic of each generator. Moreover, electromotive cross force (E_q) is also adjusted in module and angle to ensure instantaneous operating requirements [1].

To hold stability, the difference of angles (δ) between electromotive cross force and voltage of power system is always chosen from 0 to 90^0 [3], [4]. It can help to ensure to extinct the oscillation of above difference in the operating process. The adjustment of δ and E_q makes many operating modes for the generator such as varying active power, generating or absorbing reactive power [1]. The stability problem has been concerned in some researches but they have almost focused on calculating angle limitation [4], [5], [6]. Because pair values at critical points have not been make clear for any generator in previous researches, controllers have not had information about thresholds to limit operating range of parameters.

To have the safe range for generators in thermal power plants, this paper will propose a method to determine critical points that are defined by parameters corresponding to the constant of active power and variation of excitation current. Section II will represent steps to have equations and curves with critical points. Section III will show a case study to make more detailed about the proposed problem. The last section will show some conclusions of this paper.

II. METHOD TO DETERMINE CRITICAL POINTS FOR THERMAL GENERATOR IN CASE OF CONSTANT ACTIVE POWER AND VARIABLE EXCITATION CURRENT

A generator coupled in parallel with the power system is described in Fig. 1. Voltage at the point of common coupling (PCC) is kept at fixed values for both module and angle [1], [2].

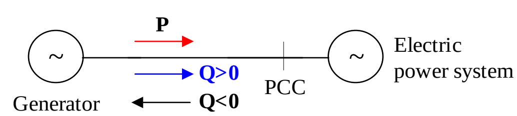

Fig. 1 Parallel couple of the generator and the power system

In Fig. 1, P is instantaneous active power generating from the generator, Q is instantaneous reactive power. If the generator generates reactive power, value of Q will be positive. If the generator absorbs reactive power, value of Q will be negative. Because resistance of the stator winding is very smaller than its reactance, the resistance will be ignored in this research. The equivalent circuit of the system is depicted in Fig. 2.

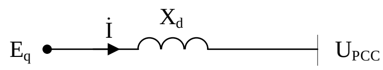

Fig. 2. The equivalent circuit of the system

Quantities in Fig. 2: E_q is electromotive cross force; U_{PCC} is voltage at PCC; X_d is axial reactance of the generator; I is current from the generator to the power system. The relation of above quantities is shown in Fig. 3.

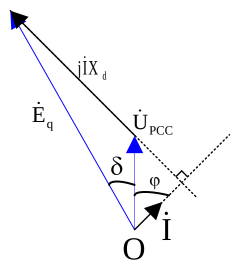

Fig. 3. Relation of quantities

Due to considering the difference of angle between U_{PCC} and E_q, the angle variation of U_{PCC} in real operation does not affect to this research. Value of E_q can be determined by (1) [2], [3]:

$$E_q = \sqrt{(U_{rated}\cos\varphi)^2 + (U_{rated}\sin\varphi + I_{rated}X_d)^2} \quad (1)$$

where: cosφ is power factor; U_{rated} is rated voltage; I_{rated} is rated current.

Active power generating to the power system can be calculated by (2) [1-6]:

$$P = \frac{E_q U_{PCC}}{X_d}\sin\delta \quad (2)$$

Reactive power interchanged with the power system can be calculated by (3) [1], [2]:

$$Q = \frac{E_q U_{PCC}}{X_d}\cos\delta - \frac{U_{PCC}^2}{X_d} \quad (3)$$

In real operation, parameters of the generator always change so the generator will have many operating modes. When the excitation current is regulated, E_q will be varied respectively. Due to the purpose of determining critical points to have allowable control area for generator in case of constant reactive power, this research will consider the variation of E_q in module and angle.

Due to the requirement of static stability, value of δ must be from 0^0 to 90^0 to extinct oscillation and have static backup area [1-4]. Vector diagram representing critical points is depicted in Fig. 4.

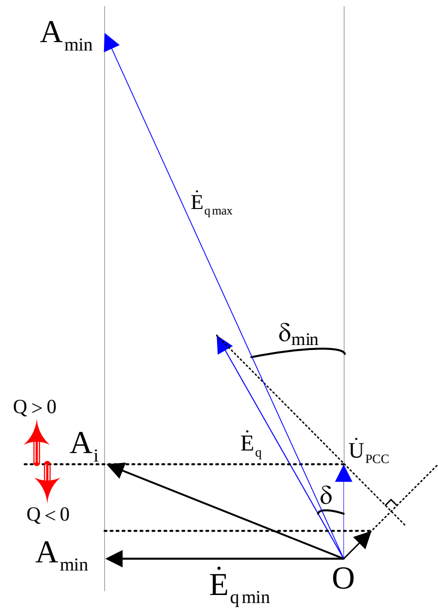

Fig. 4. Vector diagram with critical points

Because P is constant and positive, formula (2) showed sinδ>0. It means that it always exists a minimum value (δ_{min}) that satisfies (4) [1]:

$$\delta > \delta_{min} \quad (4)$$

δ_{min} can be determined from allowable thermal operating condition of rotor and create maximum value for E_q, called E_{qmax} [1]. Value of E_{qmax} can be defined by maximum multiplying factor as formula (5):

$$E_{qmax} = kE_q \quad (5)$$

Combining (5) and (6), value of δ_{min} can be calculated by (6):

$$\delta_{min} = \arcsin\frac{PX_d}{E_{qmax}U_{PCC}} \quad (6)$$

Combining (3) and (6), maximum value of reactive power generating from the generator can be calculated by (7):

$$Q_{max} = \frac{U_{PCC}}{X_d}(E_{qmax}\cos\delta_{min} - U_{PCC}) \quad (7)$$

Combining the limitation of static stability ($\delta=90^0$) and formula (2), value of E_{qmin} and Q_{min} can be calculated by (8) and (9):

$$E_{qmin} = \frac{PX_d}{U_{PCC}} \quad (8)$$

$$Q_{min} = -\frac{U_{PCC}^2}{X} \quad (9)$$

Combining Q=0 and (3), value of E_{qi} (E_q at intermediate state of posisitve and negative value) can be calculated by (10):

$$E_{qi} = \frac{U^2}{\cos\delta_i} \quad (10)$$

Moreover, formula (2) can be rewritten at P=const, Q=0 as (11):

$$P = \frac{E_{qi} U_{PCC}}{X_d} \sin\delta_i \quad (11)$$

Pair values of (E_{qi}, δ_i) will be determined by solving two above equations.

With the above presentation, value of all parameters at critical points can be calculated corresponding to known parameters of the generator and desired active power. The variation of cosφ, δ, and Q are represented in Fig.5.

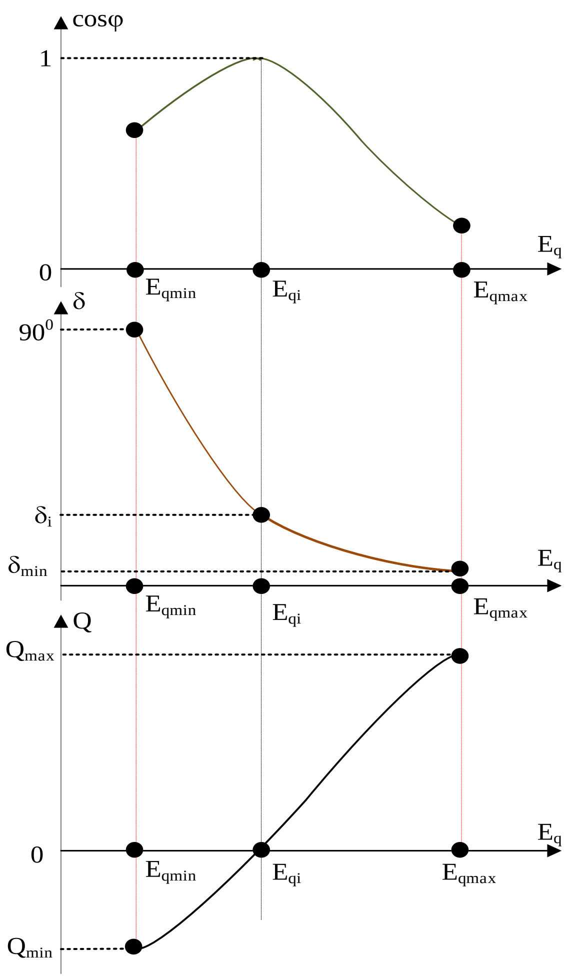

Fig. 5. The variation of cosφ, δ, and Q

By using above formulas and curves, each operating state of the generator can be defined exactly. Corresponding to the requirement of Q (positive, zero, or negative), the controller will calculate suitable angle to decide control signal that help to regulate the excitation current as shown in the proposed algorithm in Fig. 6.

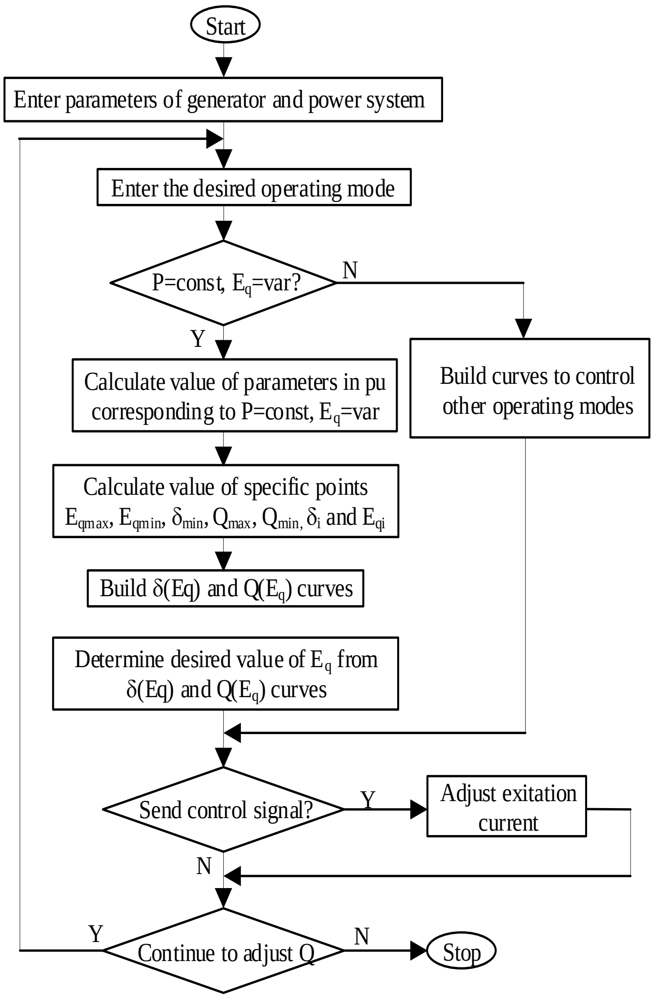

Fig. 6. Algorithm to operate system at generator side

III. RESULTS FOR A CASE STUDY

Consider a system as described in Fig. 1. Parameters of the generator is shown in Table 1.

Table I: Parameters of the Generator

Type	Parameters	Value	Unit
P_{rated}	Rated active power	57.5	MW
I_{rated}	Rated current	3720	A
U_{rated}	Rated voltage	10500	V
cosφ	Power factor	0.85	
X_d	Axial reactance	185.6	%
k	Maximum multiplying factor	1.1	

Step 1: Choose base unit

U_{base}=U_{rated} and S_{base}=100 MVA.

Step 2: Calculate quantities in base unit

Voltage of the generator in base unit: U_{rated*}=1 pu;

Current of the generator in base unit: I_{rated*}=0.5249 pu;

Power of the generator in base unit:: P_*=0.575 pu;

Reactance of the generator in base unit: X_d=1.856 pu;

Value of E_q in base unit:

$$E_{q*} = \sqrt{0.85^2 + \left(0.528 + 0.6765 \times 1.856\right)^2} = 1.9747\,\text{pu}\cdot$$

Step 3: Calculate E_{qmax} and E_{qmin}

$$E_{q\max} = 1.1 \times 1.9747 = 2.1;$$

$$E_{q\min} = \frac{0.575 \times 1}{1.85} = 1.06\cdot$$

Step 4: Calculate δ_{min}

$$\delta_{\min} = \arcsin\frac{0.575 \times 1.85}{2.1 \times 1} = 30.43^0\cdot$$

Step 5: Calculate Q_{max} and Q_{min}

$$Q_{\max} = \frac{1}{1.75}(2.1 \times \cos 30.43 - 1) = 0.46;$$

$$Q_{\min} = -\frac{1^2}{1.85} = -0.292\cdot$$

Step 6: Calculate δ_i and E_{qi}

$$\begin{cases} E_{qi}\cos\delta_i = 1 \\ E_{qi}\sin\delta_i = 0.75 \times 1.85 \end{cases} \Leftrightarrow \begin{cases} E_{qi} = 1.426\,\text{pu} \\ \delta_i = 46.86^0 \end{cases}.$$

Calculation results for the considering generator are shown in Table 2.

Table II: Calculation Results

δ	δ_{min}=30.43^0	δ_i=46.86^0	δ=90^0
E_q	2.1 pu	1.4 pu	1.06 pu
Q	0.46 pu (16.39 MVAr)	0 pu (0 MVAr)	-0.292 pu (-10.41 MVAr)

Using results in Table 2, δ(E_q) and Q(E_q) curves in this case study are shown in Fig. 6. Simulation curves showed the visual suggests about adaptive range that can be adjusted corresponding to the requirement. When the generator must be absorbed reactive power, E_q can be regulated from 1.06 pu to 1.4 pu. When the generator must be generated reactive power, E_q can be regulated from 1.4 pu to 2.1 pu. It means that, reactive power from the generator will be zero if E_q=1.4 pu. Furthermore, required values for E_q andδ, called E_{qr} và δ_{qr}, corresponding to any required value of Q also can be determined by using curves in Fig. 6. It shows the meaning of formulas and the proposed algorithm in section II.

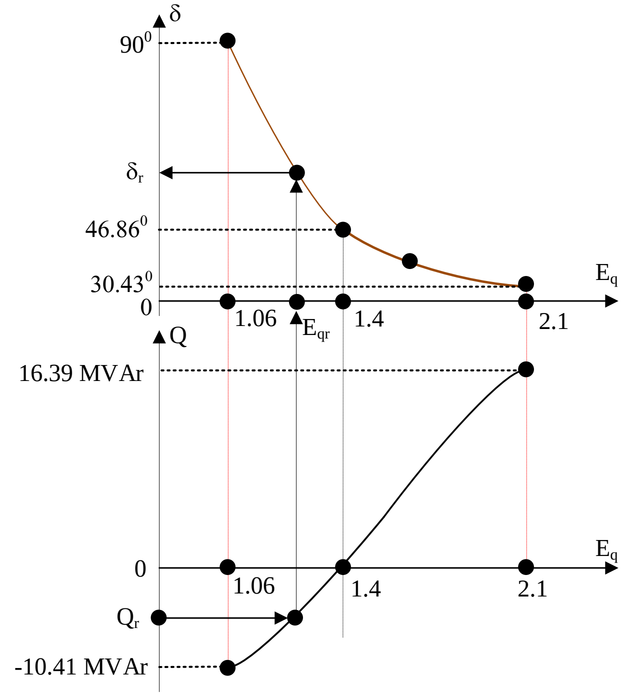

Fig. 6. δ(E_q) and Q(E_q) curves in the considering case study

IV. CONCLUSIONS

This paper presented a method to determine critical points to limit operating range for a generator in case of constant of active power and variation of excitation current. They showed thresholds for maximum reactive power generating from the generator, absorbing from the power system, or without generating/absorbing (zero reactive power). To have pair values at the critical points, formulas and curves were created in this paper to make clear about the quantities. Moreover, an algorithm was proposed to have general idea about the method with control signal corresponding to any requirement.

Calculation results for a case study of 57.5 MW rated active power showed the meaning of proposed method that provide exact information about critical points. The match ofδ, E_q and Q was represented by δ(E_q) and Q(E_q) curves for above generator. Calculation process showed the allowable range of δ is from 30.43^0 to 90^0 and the allowable range of Q are from -10.41 MVAr to 16.39 MVAr. If the generator must be absorbed or generated amount of reactive power as requirement, the controller can interpolate values of E_q and δ from curves to have information about control signal and regulate suitable value of excitation current.

Achieved issues of this paper will help to create optimal range for thermal generators. In cases of changing the structure such as adding transformer and transmission line into the system, the proposed method will help to provide all critical points similar to the calculated case study. However, it needs to have more deeply about other operating modes for generators to meet many requirements of dispatchers. This work will be make more detailed in the future.

ACKNOWLEDGMENTS

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