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EXPLOITING OF GENERATOR REACTIVE CAPABILITY

Jasna Dragosavac, Žarko Janda, Jelena Pavlović, Tomislav Gajić, Dušan Arnautović, Bojan Radojičić*
Electrical Engineering Institute Nikola Tesla, University of Belgrade, Belgrade, Serbia
*Steam Power Plant “Nikola Tesla – A”, Obrenovac, Serbia

Abstract: *This paper discusses an improved method to evaluate the net reactive power delivered to a system by a generator. The proper use of available reactive sources, mostly synchronous generators, is of utmost importance for preserving the power network transmission capacities at predefined level. A wide accepted transformer model is used to demonstrate the method. The additional reactive power limits related to generator operation within terminal voltage ±5% band around rated value are taken into account. By taking into account all real influences on generator capability chart, a new way of capability chart presentation is proposed. The main benefit from the proposed evaluation is to achieve the best possible use of generator reactive capability from the system point of view.*

Key Words: ***synchronous generator/ capability curve/ step-up transformer/ reactive power***

1. INTRODUCTION

At deregulated electricity market it is of utmost importance to maintain power transmission capabilities at predefined levels. To achieve that goal, the proper secondary voltage control at transmission connection nodes should be implemented. Furthermore, to achieve the optimal (minimal cost, increased reliability) voltage control of main transmission network nodes it is necessary to deploy the full available generator reactive capability and still maintain the reactive reserve as high as possible, due to transmission security reasons.

Generators produce active power (MW) in accordance with the requirements of an automatic generation control system. The second important generator role is to deliver reactive power to transmission network. Studies show that voltage instability often occurs after key generators reach their reactive capability limit [1] and [2]. Proper reactive power support from generators is crucial in maintaining voltage stability of a transmission grid. The generator capability curve is the key operational document of any generator connected to power transmission network. In newer power plants today, there are computer screens showing the capability curve with an illuminated point indicating the current operating state of the generator. On the other hand, practice shows that the limits of the allowed operation usually do not correspond to the real conditions and performance of a generator [3], [4].

Reactive power is required to provide voltage support for the grid, meet the reactive component of the loads and losses, and enable active power to be transferred across the transmission grid from the generator to the loads. One of the most important reactive resources is from generators connected to the transmission grid. For a given generator rated power factor, the reactive capability is a built-in function of the generator.

In such way, the independent system operator (ISO) is responsible for proper allocation of reactive power sources as well for maintaining the high enough system reactive reserve. To successfully fulfill this task, the generator owners have to be fully aware of the instant generator reactive capability regarding current network conditions at the point of network connection.

Elements affecting the amount of MVArs delivered to the system:

- The rated power factors of generators are usually 0.85 or 0.90. A lower power factor generator has a higher reactive capability at its rated MW generation. In general, a standard 0.90 power factor of generator costs approximately 6% less than a 0.85 power factor of generator.
- The step-up transformer transfer ratio.

2. GENERATOR CAPABILITY CURVE

There are three main factors that affect the amount of reactive power delivered to the system:

- Reactive power taken by station service loads
- Reactive power losses in the step-up transformer
- Generator terminal voltage.

The main operational guide in generator exploitation is the capability curve. The amount of produced VARs is linked to actual MW generator production, but this chart is by the rule defined for rated generator voltage. In practice the generator voltage can significantly vary from rated value. The admissible range for generator voltage under normal exploitation circumstances is ± 5% around rated value. Under some special circumstances it can be raised up to 10% above rated. But, when delivering MVArs to the transmission network via step-up transformer there is additional increase of the generator voltage due to voltage drop across the step-up transformer reactance, according to figure 1.

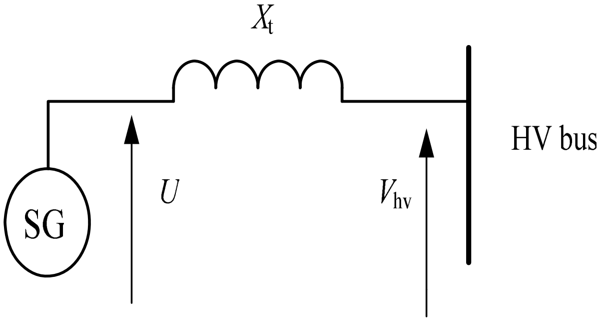

Fig. 1. *Equivalent circuit of the generator connection via step-up transformer to HV bus*

By increasing the generator terminal voltage, the rotor field limit is shrinking, while stator current limit is expanding, if the generator saturation effect is properly taken into account. To calculate these capability curve changes, the saturation of magnetic circuits is carefully calculated. In case study the Potier reactance approach is employed. In any way, the best utilization of the generator reactive capability at rated power can be achieved at rated voltage.

As the first step in calculating the reactive power due to rotor field limit, according to [5], the non-saturated value of field emf is calculated,

$$E_f = \sqrt{(U + X_d I \sin(\phi))^2 + (X_d I \cos(\phi))^2}\ , \quad (1)$$

and corresponding field current is determined by air-gap magnetization line. Generator terminal voltage is designated as U, generator armature current is I, generator load power angle is ϕ and non-saturate direct axis reactance is X_d. As the second step, the Potier emf is calculated according to,

$$E_p = \sqrt{(U + X_p I \sin(\phi))^2 + (X_p I \cos(\phi))^2}\ , \quad (2)$$

so the field current correction term is found from curve shown in Figure 2. The used simplified calculation of synchronous machine field current is based on reference [5]. In such way it is possible to take into account the generator saturation when calculating reactive power rotor field limit curve. In order to simplify calculations the air gap curve is subtracted from the inverse magnetization curve and resulting curve is shown in Figure 2. That curve is approximated as

$$I_f = A\left(e^{BE_f} - 1\right) + C\left(e^{DE_f} - 1\right). \quad (3)$$

The fitting procedure for curve expressed with (3) is done using least square method, and the derived coefficient values had proved to lead to very useful results.

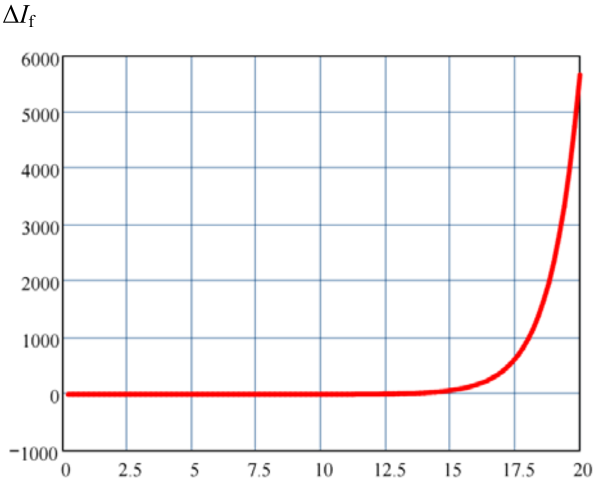

Fig. 2. *The field current correction value in A versus Potier emf in kV (horizontal), for case study generator*

Variable generator voltage is affecting the capability curve, as it is shown in figure 3. So it is necessary to improve the generator capability curve calculation in such way that it can be efficiently used with varying high voltage bus voltage.

The main reason is that the capability curve has to be used on direct and obvious manner. So derived improved generator capability curve then can be projected on computer screen in plant control room.

3. CASE STUDY

The case study is performed on synchronous generator at steam power plant, rated at 308 MW, 367 MVA, 15 kV and with rated field current 3840 A. The generator capability curve is the basic generator exploitation tool, and it is defined for rated voltage. The actual generator terminal voltage is related to HV bus voltage and reactive power,

$$\frac{Q}{V_{hv}} = \frac{U - V_{hv}}{X_t}, \quad (4)$$

where all variables are in pu. Transformer reactance is designated as X_t while HV bus voltage is V_{hv}. The base value for HV bus voltage is 235 kV.

But, taking into account step-up transformer reactance of 0.1335 pu it is possible to get more useful capability curves, shown in figures 4 and 5. It is important to notice that the step-up transformer of the case study power unit is not equipped with tap changer, so the transformer transfer ratio is constant during operation.

It is easily possible to take into account the transformer transfer ratio change, but there is no such step up transformers in Serbian power generating plants, at present moment.

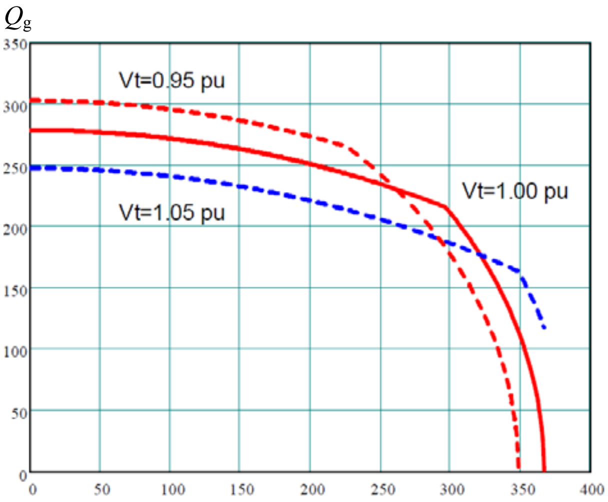

Fig. 3. *Generator reactive power in MVAr versus active power in MW(horizontal) at different terminal voltages. Central trace correspond to 1 pu voltage*

Terminal voltage influence is completely compensated and generator reactive limits are clearly defined in terms of high voltage level. The maximal reactive capability curves of generator under consideration are shown in Figure 4. Horizontal lines shown in Figure 4 correspond to the generator terminal overvoltage limit for continuous operation, in this case set to be 1.05. By using the proposed reactive capability curves it is possible to get direct insight into available reactive power margin.

Reactive power margin is related to relative reactive load of single SG, which is defined as

$$K = \frac{Q_{\text{actual}} - Q_{\min}}{Q_{\max} - Q_{\min}}, \tag{5}$$

where $Q_{\max}$ and $Q_{\min}$ values are derived from real capability curve and correspond to the actual voltage and active power. All generating units supporting the same HV bus voltage should be equally loaded with reactive power, in relative manner according to (5). In such way the voltage support ability of generators connected to same HV bus is maximized, in the case of major transmission network disturbances.

The proposed curves also can be recalculated for generator voltage limit of 1.1 pu and used in emergency cases.

To be able to fully deploy the reactive power reserve, the attention should be paid to the capacitive reactive power limit. Also the influence of the generator terminal voltage to the auxiliary medium voltage bus, supplying the auxiliary power unit equipments, has to be taken into account.

Similar analysis is performed regarding lower limit of generator voltage, i.e. 0.95 pu. The practical underexitation stability limit is defined by expression (6),

$$Q_{cap} = \frac{P}{\tan(\delta_{\lim})} - \frac{U^2}{X_d}, \tag{6}$$

where P is the active power in pu, and $\delta_{\lim}$ is the interior generator power angle, arbitrarily chosen to be 70° in this case. In practice, the preffered value for power angle stability limit $\delta_{\lim}$ usually vary between 70° and 65° for turbogenerators.

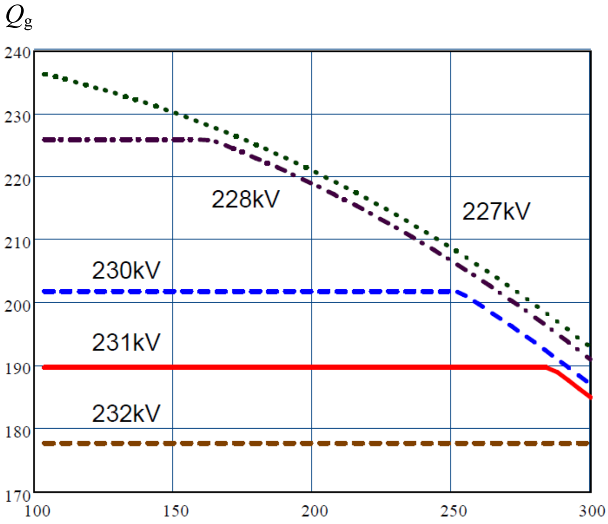

Fig. 4. *Available reactive capability in MVAr versus active power in MW(horizontal) regarding HV bus voltage. Maximal generator terminal voltage is set to 1.05 pu*

Also, it is easy to proof that saturation is not influencing significantly the synchronous machine in underexitation operating area. The same calculation approach as described in this paper previously for field current derivation, is used to check the saturation influence to practical underexitation reactive power limit.

By taking into account all that facts, the underexitation limits for different HV bus voltages are calculated and shown in Figure 5. Horizontal lines shown in Figure 5 correspond to the generator terminal undervoltage limit for continuous operation, in this case set to be 0.95.

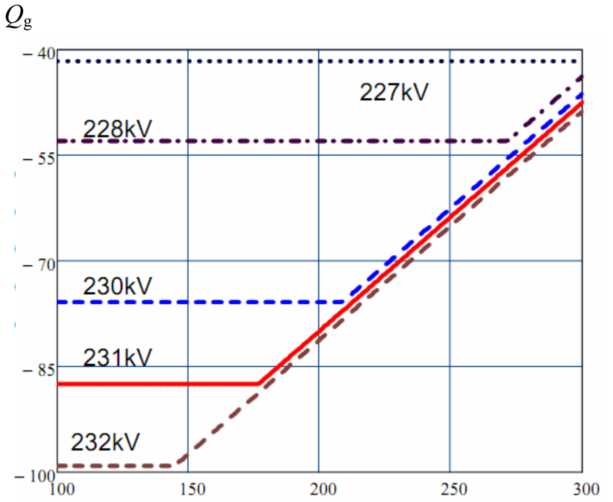

Fig. 5. *Available capacitive reactive capability in MVAr versus active power in MW (horizontal)regarding HV bus voltage. Minimal generator terminal voltage is set to 0.95 pu voltage*

By implementing the proposed capability curves, related to the HV bus voltage and generator terminal voltage limits as imput parameters, it is possible to drive the generator operating point in an optimal way from reactive power utilisation point of view.

4. CONCLUSIONS

An advanced generator capability curve is proposed, taking into account step-up transformer reactance and HV bus voltage. So calculated capability curves express the reactive power limits on direct and obvious manner.

At deregulated electricity market it is important to maintain power transmission capabilities by the proper secondary voltage control at transmission nodes, what is possible only by appropriate reactive power injection.

To ensure the proper reactive power injection just at the critical moment, it is necessary to keep the reactive power reserve at its maximum. In power plants there are computer screens showing the capability curve with an illuminated point indicating the current operating state of the generator. A capability curve shown at screen should be as proposed in this paper, in order to enable fully utilisation of reactive power of generators supporting the same HV bus.

A case study results presented demonstrate the feasibility of the proposed generator capability curves.

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