Increase Productivity and Absorption of Reactive Power for Power Station with Using Static Reactive Power Compensator

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Abstract:

In this article, a new method of reactive power compensation for Synchronous generator power stations by using static reactive power compensator provided. The advantages of this methodis used for control voltage transmission is removing capacitors and reactors power station that their changing great voltage and current transients in the power system. Also using of this compensator will improve automatic voltage regulator function (AVR).

Keyword:

Power production ability, Synchronous generator, Reactive power market, Static compensator of active power

1. Introduction:

Synchronous generators are rotating electrical machines that against of induction machines have the ability to generate and absorb reactive power and can change delivered or received reactive power proportional with required load. But changing reactive power absorption for synchronous generator is done in a certain range in some cases may affect synchronous generator active power output or stability.

In [1] automatic voltage regulating (AVR) for generator is discussed and according to estimate the parameters of the generator model were chosen control values for the AVR. This process called self-regulation for AVR was composedan estimatorsand a PID controller because of long process of estimating have great time constant.

In [2] algorithm based on geometric location for poles (Pole-Placement) and minimal changes (Minimum-Variance) was used for reducing the estimation time constant which was confirmed experimentally. But again the time constant is not decreased more because of estimation procedure. Usually in AVR, stability control or power system stabilizer (PSS)also considered to avoid instability generator that with sampling output current will change voltage reference value of AVR.

In [3] an AVR called digital automatic voltage regulator (DAVR)considered as improves dynamic performance for steady-state. This improve is done by changing PID controllers gain so that can improve terminal voltage and generator stability. In this article gain changing system only changes proportional and integral gain according to weighting effective voltage and current values .So in this case AVR will be answered quicker.

In [4] a static compensator (STATCOM) for generator stability without AVR performance is used and results show faster time response of the system. This article based on contents has been discussed about performance of STATCOM under steady-state operating conditions with changing AVR and finally, their concomitant performance provide stable and adjustable of output voltage for synchronous generator and in the electricity market have more arena to generate reactive power.

2. Construction and operation of synchronous generator

Synchronous generator is composed of a fixed part (stator) and a moving (rotor) that rotor duty is field production and neither stator duty is induction will be responsible. Field generated by the rotor specified by the amount of current through the windings because it is rotating with a certain angular velocity that is called the synchronous angular velocity (w_s) and will create voltage in stator and their effective amount will be calculated from the following expression:

$$E_{rms}=4.44\ N\Phi_m F_s$$

E_{rms} is the effective value of the induced voltage, N is the number of rounds, Φ_m is the rotor flux and F_s is the frequency according with the w_s. Because of the scattering field the induced voltage directly will not receive to terminal. On the other, Stator winding will have little resistance so that model of physical generator totally defined in figure 1.

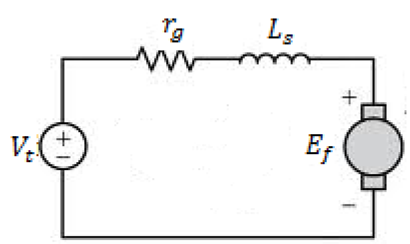

Figure 1.Physical equivalent circuit of synchronous generator

In figure 1 V_t is terminal voltage and E_f is the induced voltage. r_g is the stator winding resistance and L_s is the scattering inductance.

When connecting the generator to the load current will flow in the stator windings, this current will produce the field between the space rotor and stator that called the armature reaction and show the reactance will be series dispersion reactance in the equivalent circuit in figure 1.

Also because of their Large amount compared with the series impedance of the generator, the total impedance of the generator is known as a reactance equivalent which is the sum of dispersion reactance and armature reaction that will show in figure 2.

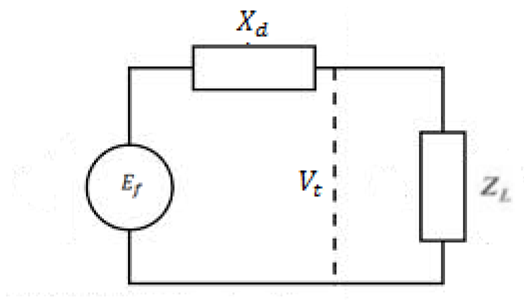

figure 2. Simplified equivalent circuit of synchronous generator with load

X_dIs called generator direct axis reactance. According figure (2) it can draw phasor diagram generator that shows in figure (3).

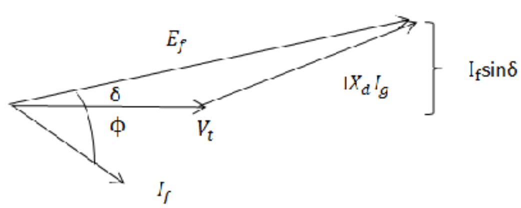

Figure 3.Phasor diagram of synchronous generator

Respectively δ and φ are called power factor angle and load angle.

Output power generator is obtained under relationship:

$$P=V_t I_g \cos j$$

According to figure 3 can be rewritten:

$$P = \frac{V_t}{X_d} V_d I_g \cos j = \frac{V_t E_f}{X_d} \sin d$$

Regard to sign of CP that specificin figure 3 shows $E_f$sin δ is always constant that can be considered as constant power line. Since according to figure 4 reactive power axis is perpendicular to constant power axis and according to the following expression it starts from end of theV_t. The curve of synchronous generator power can drew according figure 4.

$$Q = \frac{V_t E_f}{X_d} \cos d - \frac{{V_t}^2}{X_d}$$

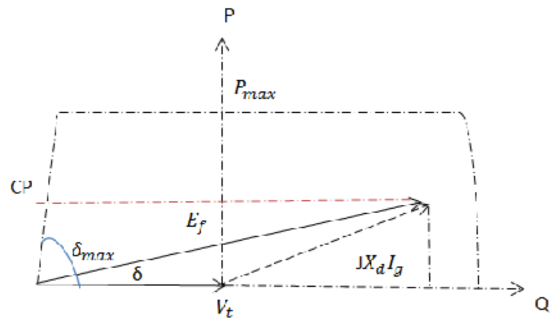

Figure 4. Curve of synchronous generator power

The above figure shows three levels for synchronous generator:

1. Restrictions of E_fIncreasing ($E_{f(max)}$):

Because of enhancing E_f is rotor windings current (excitation current) and have bearing for current increasing in certain extends and also $E_f$values accordingly to a certain extent, it will have ability to increase.

2. Restrictions of power increasing:

This limitation is due to the power of mechanical turbine from specific value due to conditions which arises, cannot produce more power.

3. Restrictions of load angel (δ_{max}):

In accordance with Curves in figure 5 and equation (3) if the load angle (because of the capacitive network) exceeds of 90 degrees, power curve is dropped and imported in unstable area. So for supplying of generator stability, load angle before reaching 90 degrees will be limited.

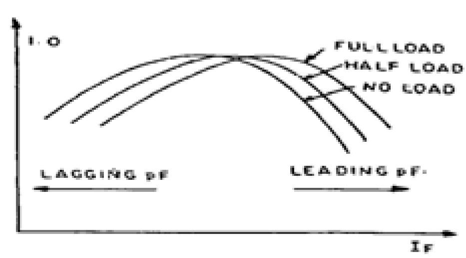

Figure 5.Synchronous generator powercurve according toload angles

Now according to mentioned for the generator can cover times changing and also don't entrance to region of instability performance, AVR will control rotor current. But these restrictions can reduce generator efficiency in the electricity market. For example, suppose that in figure 6, generator is operating point at A. Now if for network requirements or more profits (based on the national dispatching) produce additional reactive power so working point will Reach to point B And to produce more reactive power have to produce lower active power, indeed for supply reactive power for network doesn't have opportunity for produce active power same previous.

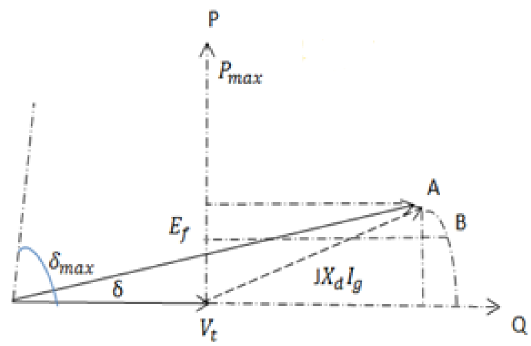

Figure 6.Operating point changing for increase the production of reactive power

At absorb reactive power also restriction load angle will not allow to absorption more reactive power. On the other, with reaching the boundary load angle range, generator stability also will be in danger of collapse.

Based on the foregoing,although the production or absorption reactive power that can even by passive elements of power system such as capacitors and inductors doesn't require primary mechanical power (unlike the active power) but their changes can lead to instability or divestment opportunities to production power in power station. Therefore it must take measures for compensated effects of changes.

3. Structure and function of STATCOM:

Static compensator (STATCOM) is connected an inverter to a capacitor or battery at DC side and to the power network in at the AC side. Figure 7 shows the schema of this equipment.

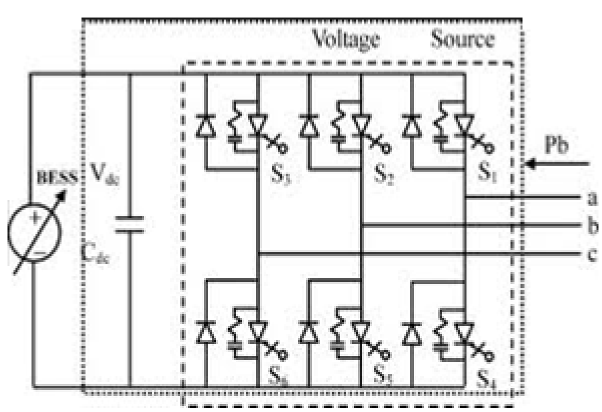

Figure 7.STATCOM compensation scheme

Capacitor $C_{dc}$is responsible for feeding of inverter and by using the process of switching IGBT for output of this equipment which is connected to the power system creates AC voltage. $V_i$andV_{net}respectively are voltage produced by the inverter and network voltage and Rf and Lf are resistance and inductance of filter. For Controllable switching time of IGBT in inverter, voltage $V_i$can be consider in three type, backward fuzzy,forward fuzzy and same fuzzy that compared with the voltage V_{net}shows in Figure 8.

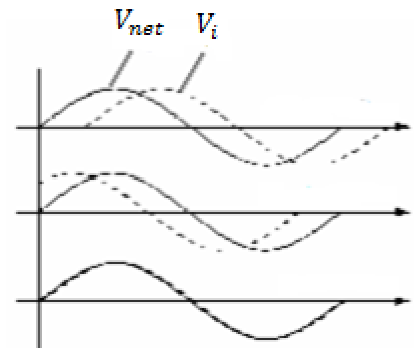

Figure 8.$V_i$andV_{net}voltages condition

On the basis of figure 8 when the voltage compensator and network are coherent there will be no flow between two systems.But based on phasor diagram of figure 9 for backward fuzzy mode,capacitive current is injected into the network and for forward fuzzy mode inductive current is drawn from the network.

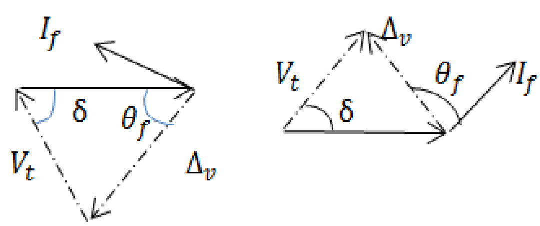

Figure 9. Compensator diagram

So contrary to capacitors and inductors that controlled discrete reactive current value, this equipment can control continuously. Under these conditions transient states will reduce for switching.

4. Control scheme suggested

For synchronous generator reactive power control by AVR, there are restrictions according to diagram 4.

Generally there are parallel capacitor banks or reactors at generator terminal that can improve the ability to generate or absorb reactive power to the system. In addition, transformer after generator

(Transformer unit) can also control the amount of reactive power by changing tap. But due to these elements entrance for several step in circuit and make the transition which may be cause for errors in the power system. But based on the descriptions in the previous section fixed compensator (STATCOM) have continuous and satisfactory performance that could be a safe alternative for capacitor banks and adjacent reactors. But both performance of STATCOM and AVR should be control with a simultaneously system shown to figure 10.

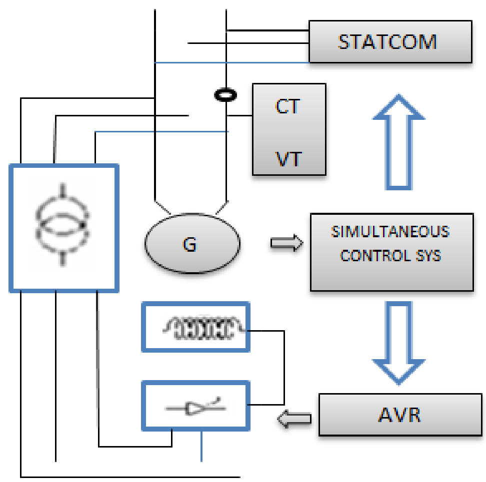

Figure 10. Overview of the simultaneous control system STATCOM and AVR

It is clear at figure 10, Simultaneous control system receives generator output voltage and current and according to amount of reactive power demand or delivery can command both the AVR and the STATCOM. Main assumption for simultaneous system is when startup time of generator and connection to the network all commands send to AVR, so that STATCOM performance is blocked in this condition. After connecting the generator to the network in the normal operating mode the rotor is determined by AVR is constant. If the system demand reactive power for generator is as far as the maximum voltage induced doesn't reach to$E_{f(max)}$, Simultaneous control system commands to the AVR and STATCOM does not have any command. If both of equipment do compensated together their controlling will be harder and both copper losses due to the flow current will be more. Therefore simultaneous control system only sends permission to increase the current for AVR, and then exceed current for AVR go up, AVR blocked the current and STATCOM is to compensate the circuit. Otherwise firstly AVR was reduced when the load angle reached to maximum. AVR current decreasing will be blocked and STATCOM is absorbing reactive power into the circuit.

The only point that remains in the control process is embedding constant in a state of voltage injected by the STATCOM when AVR is just compensation for reactive power. In other words, the voltage changing before voltage compensation by AVR and injection voltage value must match the network voltage conditions so that don't flow current into network.

Therefore, voltage magnitude and angle of network while AVR performance must be equal with magnitude and angle of injection voltage By STATCOM in this action is performed by equipment called a phase locked loop (PLL) .Phase locked loop (PLL) can detect phasor of network voltage which switching of inverter must be in such a way that injection voltage has also the same magnitude and the same phase. And while the AVR perform, Simultaneous control system is adjusted the inverter output voltage so that STATCOM has not the current exchange in network. In addition, while AVR cannot change the excitation current, STATCOM do angle changing so that PLL can measure it. Not that when the STATCOM has compensated task ,not only the phase changing even magnitude changing depicted phasor diagram in Figure 9 can also be responder for demand or delivery reactive power but should apparent power value of STATCOM always be considered.

Figure 11 is shown at a constant voltage difference can produce current with greater or lower phase.

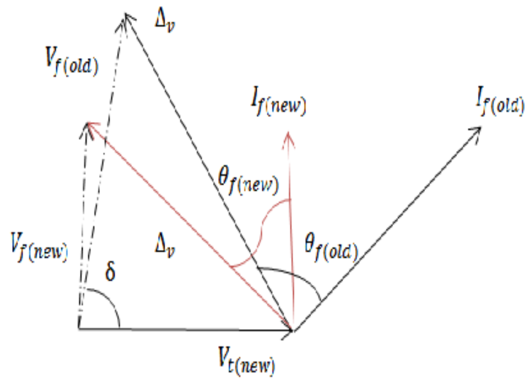

Figure 11. Current Angle changes based on injected voltage magnitude changing by the STATCOM

5. Result

Due to the continuous generation and absorption of reactive power by static compensator (STATCOM), this paper presents an algorithm for how they are controlled by the system. Also to reduce total system losses, control system in a particular state only intern one of the equipment for reactive power control (STATCOM and AVR) in circuit. Also, for the performance of the AVR with voltage increases or decreases, STATCOM doesn’t enter into circuit automatically; PLL coordinates angle and magnitude for STATCOM with network. This has led to increasing margin of safety for reactive power generated which also can improve the stability of the synchronous generator and also can eliminate undesirability transient conditions that make elements such as capacitors or shunt reactor during the performance.

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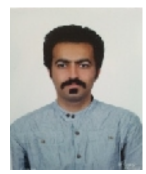

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