A New Approach for the Improvement of Synchronous Generators' Reactive Power Sharing Using STATCOM in Power Plant

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Abstract
This paper introduces a new technique for the improvement of the reactive power sharing between the synchronous generators in power plants. Through the implementation of STATCOM as a variable reactive power source a smooth regulation of reactive power sharing between the generators can be achieved. A case study for the proposed technique has been undertaken using the data of a real Combined Cycle Power Plant (CCPP). The results are more than encouraging.

Key Words: STATCOM, Reactive Power Control, Synchronous Generators, Capability Curve

I- INTRODUCTION

Recently, there has been a significant interest in reactive power as one of several ancillary services required to ensure system reliability and security. System operators and researchers have been looking for appropriate mechanisms for reactive power provision in the context of deregulation [1].

Reactive power is tightly related to bus voltages throughout a power network. Hence, reactive power services have a significant effect on system security. Insufficient reactive power supply can result in voltage collapse, which has been one of the reasons for some recent major blackouts (e.g. the Canada-US and the Sweden blackouts in 2003). The US-Canada Power System Outage Task Force stated that insufficient reactive power was an issue in that blackout, and recommended strengthening the reactive power and voltage control practices in all North American Electric Reliability Council (NERC) Regions [2].

Nowadays, the Flexible AC Transmission Systems (FACTS) are effectively used in the transmission systems for voltage and reactive power controlling. From the successfully applications of FACTS in power system transmission [3-10], as well as the coordination with Under-Load Tap Changers (ULTC) [11], it can be seen that the implementation of STATCOM in power plants may also be so efficient for regulating and improvement of synchronous generators' reactive power sharing. In this work a new attempt is undertaken, in which the STATCOM implementation in power plants is proposed. The new approach has been tested on a real data of a real Combined Cycle Power Plant.

II- CAPABILITY CURVES OF THE SYNCHRONOUS GENERATORS

The main purposes of the synchronous generators are to supply active power, to provide the primary voltage control of the power system. Also, they bring about, or at least contribute to, the desired reactive power balance in the areas adjacent to the generating stations. A generator absorbs reactive power when being under excited and produces reactive power when being over excited. The reactive power output is continuously controllable through varying the excitation current. The allowable reactive power (absorption or production) is dependent on the active power output as illustrated by the capability curve in Fig. (1). The field winding and stator winding thermal limits are shown.

![Fig. (1): The Synchronous generator capability curves](image)

The rated power factor of generators usually lies within the range 0.8 to 0.95. Generators installed remotely from load centers, usually have a high rated power factor. Generators installed close to load centers usually have a lower rated power factor. In some cases of large steam-turbine generators, the rated power factor may be selected at the lower end of the above range in order to ensure reactive power reserve for severe forced outage conditions of the power system [12]. The
terminal voltage of a large generator is usually allowed to be controlled within a ±5% range around the nominal voltage.

The reactive power dispatch corresponds to the short-term real-time allocation of reactive power to suppliers based on current operating conditions. The system operators are interested in determining the optimal reactive power schedule for all providers based on certain objective that depends on the system operating criteria, such as minimization of total system losses and system laudability to minimize the risk of voltage collapse.

Under certain circumstances, usually arising from critical system conditions, the system operator may request or instruct a generator to increase its reactive power output, which may require a reduction in its active power output. The real and reactive power output from a synchronous generator is limited by the capability of its prime mover.

III- THE PROBLEMS ASSOCIATED WITH REACTIVE POWER SHARING IN SYNCHRONOUS GENERATORS

In power system plants the generators have to share not only the active power, but also the reactive power. Thereby, the outputs of the generators may be either manually or automatically controlled.

In case of manual control, the generator will have fixed output reactive power, whereas the power factor changes with load changing. Accordingly, the output active power of one or more of the generators may be reduced (see \( \theta_1 \) in Fig. (2a)), that they lose the real opportunity in active power sharing. On the other hand, the operating point may reach the capability limit if the power factor is highly improved (see \( \theta_2 \) in Fig. (2a)).

In case of automatic control, the generator responds to the power system requirements holding a fixed active power as shown in Fig. (2b). Thereby, the automatic voltage regulator (AVR) of the synchronous generator tries to maintain the voltage value of the generator terminals. Also, in this kind of control, there is a danger of reaching the capability limits (see \( \theta_1 \) in Fig. (2b)), because the armature and field winding heating limits have to be taken into consideration.

If the generator is working with a leading power factor as in case of absorbing reactive power (case \( \theta_2 \) in Fig. (2b)), the generator may suffer other types of field heating and losses [13].

In the following, a data from a real combined cycle power plant (CCPP) is used for discussion and illustration of the problem of reactive power sharing in synchronous generators. The plant consists of six gas turbine generators each of 140 MVA and three steam turbine generators each of 150 MVA. A simple case containing two gas turbine generators is used in this discussion.

Table (1) introduces the actual measured values for the total power generated, the active power, the reactive power, and the power factor for the two generators. Furthermore, Fig. (3a) illustrates a real snapshot for the capability curve of the two generators. The points GTG1 and GTG2 indicates the two generators operating points.

![Fig. (2): Schematic diagram for the synchronous Generator control methods](image)

**Table (1): Practical Operating Points of Two Generators**

<table>
<thead>
<tr>
<th>MVA</th>
<th>MW</th>
<th>MVAR</th>
<th>Cos ( \theta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTG1</td>
<td>117.7</td>
<td>105.9</td>
<td>51.4</td>
</tr>
<tr>
<td>GTG2</td>
<td>116.5</td>
<td>110</td>
<td>38.5</td>
</tr>
</tbody>
</table>

Because GTG1 is more loaded with reactive power than GTG2, the operator has to reduce the excitation current to avoid the increase of heating by GTG1. This is done by turning to manual control and adjusting for the required reactive power. In this case, if GTG1 is manually adjusted to 30 MVAR, the generator GTG2 output reactive power will increase to the value of 64 MVAR as illustrated in the snapshot illustrated in Fig. (3b).
This new value of GTG2 reactive power may lead to another heating problems as GTG1 or it may reach capability limit. It is thus clearly seen that a new concept has to be found to release the whole generators from excess or less reactive power loadings. To this extent, the implementation of STATCOM, as a fast and variable reactive power source, is suggested to be the solution of the problems associated with reactive power sharing in power plants.

IV- IMPLEMENTATION OF STATCOM FOR IMPROVEMENT OF REACTIVE POWER SHARING IN SYNCHRONOUS GENERATORS

Fig. (4) illustrates the schematic diagram for the proposed technique for implementation of the STATCOM. The STATCOM is proposed to share the output reactive power of the synchronous generators (produced or absorbed) by connecting it on the same bus.

A simplified reactive power control loop can be used to adjust the STATCOM voltage setpoint. Thereby, the STATCOM has to lead the generators to an optimal and/or acceptable output reactive power within the capability curve of the generator.

The proposed controller is used to control the total amount of the reactive power of the generators. Fig. (5) shows the control scheme which calculates the summation of the reactive power of all generators on the bus \( Q_1, Q_2, ..., Q_n \) and compared it with the reference reactive \( Q_{ref} \). The controller provides a proportion path with gain \( G_{ss} \) and a feed forward path with transfer function \( G_{FF} \) for fast response to large change or sudden events. The output of the gain and the feed forward path are then combined and inputted to an integrator. The integrator output is clamped by a pair of fixed limits represents the STATCOM available maximum and minimum ratings \( \pm Q_{STATCOM} \). The output of the controller is the required STATCOM reactive power \( Q_{op} \). This output reactive power is used through the STATCOM controller to determine the STATCOM voltage set point.
The proposed technique can be verified using an ATPDraw model equivalent to Fig. (4). The two synchronous generators, mentioned in Table (1), (each 140 MVA, 10.5 kV) are modeled with their turbines and AVRs [14]. The two connecting transformers (each 150 MVA, 10.5/220 kV) are modeled using XFMR saturated model. The 12-pulse STATCOM detailed model given in [15] is used in this study. The model is manipulated to adjust the required rating for the implemented STATCOM. The model consists of two six-pulse converters, step-up intermediate transformer, a voltage regulator, a fundamental and positive sequence voltage calculator, a gate pulse generator, and a synchronizing unit.

For the case given in Table (1), the STATCOM is implemented with a rating of ±60 MVAR. The STATCOM shares the synchronous generators producing the reactive power demand. The resulting operating points of the system are given in Table (2). It is clear that the STATCOM has reduced the reactive power of the generators, improved the power factor, and consequently lowered the losses.

Many test cases have been carried out to ensure the validation of the proposed approach especially at the critical operating points. Table (3) presents a sample test case using the computer model. In this case, the STATCOM implementation resulted in operating points as given in Table (4).

From Table (2) and Table (4), it is clearly seen that the STATCOM implementation has not only improved the reactive power sharing, but also improved the power factor drastically. This saves the generators from critical operation near the capability limits and reduces the losses.

V- CONCLUSION

In this paper a new strategy for implementation of STATCOM in power plants for the improvement of synchronous generators' reactive power sharing has been introduced. The problem associated with reactive power sharing which may lead to reach the capability limits including heating limits have been introduced and discussed on the hand of a real power plant system.

The proposed approach of implementing STATCOM in the power plant has shown that the generators will not only be released from excess or less reactive power, but also will operate within a safe operation conditions. Thereby, a remarkable increase of the power factor of the generators has been reached consequently to a power loss decrease.

| Table (2): Resulting Operating Points for Case of Table(1) With ±60 MVAR STATCOM Implementation |
| MVA | MW | MVAR | Cos θ  |
| GTG1 | 117.7 | 105.9 | 38.1 | 0.928 |
| GTG2 | 116.5 | 110.0 | 24.3 | 0.983 |
| STATCOM | | | 27.6 MVAR |

| Table (3): Critical Operating Point Case |
| MVA | MW | MVAR | Cos θ  |
| GTG1 | 140.7 | 127.5 | 59.6 | 0.906 |
| GTG2 | 137.6 | 129.4 | 46.8 | 0.940 |

| Table (4): Resulting Operating Points for Critical Case of Table(3) With ±60 MVAR STATCOM Implementation |
| MVA | MW | MVAR | Cos θ  |
| GTG1 | 132.7 | 127.5 | 36.8 | 0.960 |
| GTG2 | 132.5 | 129.4 | 28.2 | 0.976 |
| STATCOM | | | 41.5 MVAR |

VI- REFERENCES


