Frequency Control Of Two Area Thermal Power System With Optimized Facts And SMES Controllers

Sabita Chaine

Abstract: To improve upon the management of limited real power resources, “Flexible AC Transmission systems” devices along with energy storage devices coordinated controllers may be successfully implemented for “Automatic Generation Control” of thermal power system. In this work energy storage devices like “Superconducting Magnetic Energy Storage system” and devices from the FACTs like Thyristor Controlled Phase Shifter, Static Synchronous Series Compensator, are operated together in different combinations in an interconnected two-area Thermal-Thermal system.

Index Terms: Automatic Generation Control; FACTs devices; wind-Thermal; SMES; TCPS; SSSC; CSA.

1 INTRODUCTION

For change in load of the systems, a mismatch occurs between generation and the load. So frequency fluctuation is caused by deficiency or sufficiency of generation. The deterioration and fluctuations in frequency affects consumer’s equipments & power system as a whole in an adverse manner. Therefore, it is necessary to regulate the frequency at its nominal value within a short span of time. To ensure more reliable and stable power system operation, it may be beneficial to introduce energy storage devices to alleviate power fluctuations. When energy storage system (ESS) connected at the output side, it has been shown to reduce the uncertainty, which leads to better scheduling of its generation [1] and beneficial for stabilizing frequency oscillations of power generation during peak load periods. In another similar domain of devices, the benefits of utilizing FACTs devices in overall improvement of power system operation and control has already been established [2-6]. The co-ordination of ESS and FACT devices facilitates extra storage source, permits independent adjustment of certain system variables and therefore makes the system more controllable and secure. The work probes into the optimum utilization of ESS and FACTs devices to enhance controllability of system frequency, with load variation. Energy storage is generally used in various applications. Examples of some primary applications are in traction and transportation systems [7], FACTs devices [8], uninterruptible power supplies (UPS) [9] and many more. Further transient stability is improved [10], by utilizing an ESS integrated FACTs devices. The several types of ESS, such as BESS, SCESS, “flywheel energy storage system” (FESS) [11] and SMES [12], used in power system applications. Among some more prevalent devices in the FACTs family, the use of supplementary control can be applied for devices connected in series with interconnected tie-line power systems to damp the inter-area oscillations and power flow control [13]. Due to sudden dynamic output, series FACTs devices such as TCPS [14], SSSC and thyristor controlled series capacitor (TCSC) [15] are used in power system to reduce the frequency oscillations and tie-line power variations.

In [16, 17], the TCPS utilized in the form of an ancillary service, has been applied for stabilizing the frequency oscillations of an interconnected power system. It is a well established fact that, FACTs devices and fast acting energy storage systems can effectively damp electromechanical oscillations in a power system. To verify the efficacy of different FACTs devices such as TCPS, SSSC and SMES in the problem of AGC, some selected devices are placed in two area thermal power system and their performance may be compared. The paper is organized as follows. Section 2 illustrates the system model, and its main components. Section 3 discusses about the different objective function, methodology and system parameter chosen. The simulation and results are analyzed in section 4. At the end, conclusions are presented in section 5.

2 AGC IN T-T POWER SYSTEM WITH THE PRESENCE OF SMES AND SERIES FACTS DEVICES

Many problems in AGC, within two interconnected areas of power system, have utilized a widely accepted model in Fig. 1. The presence of SMES in the control of frequency in an AGC framework provides rapid control over requirement of deficit or surplus real power, by deriving the same from a large inductor or reactor. As per the need of the power system, the power delivered or recovered from the reactor can be controlled by suitably designed controller dedicated for the SMES given in [18]. A detail overview behind the fundamental physics and some elementary modeling issues already covered in [19].

3 METHODOLOGY AND SYSTEM PARAMETER CHOSEN

The two area thermal (T-T) system data are described in [20]. In this work, both the control areas have been assumed to have identical integral controllers whose gains (K_i, K_d) are denoted as K_t. The actual and per unit value of SMES device are given in [19]. The parameters of the controllers of AGC, SSSC, TCPS and SMES are optimized with the help of the CSA, which has been already established in [19,21] to be giving better performance in optimization. The values of integral of time multiple of square of error (ITSE), settling time (T_s) of both area frequency deviations (∆f_1 and ∆f_2) and ΔP_{Th} among with the minimum damping ratios among all
the system eigenvalues are combined to formulate the objective function \( J \) as given below in equation (1).
\[
J = \omega_1 (\text{ITSE}) + \omega_2 (\Delta f_2)^2 + \omega_3 (\Delta P_{\text{tie}})^2 \tag{1}
\]
\( \omega_1, \omega_2 \) and \( \omega_3 \) are the weighing factors suitably chosen.

\[
\text{ITSE} = \int_0^{T_{\text{sim}}} \left[ (\Delta f_1)^2 + (\Delta f_2)^2 + (\Delta P_{\text{tie}})^2 \right] \, dt
\]

\( x = \) Minimum Damping Ratio (MDR) among all the eigenvalues of the system.

\( T_s = \) Settling time. \( T_s = T_{s1} + T_{s2} + T_{s\Delta \text{P}_{\text{tie}}} \)

4 SIMULATION AND RESULTS

The model of AGC system is developed in MATLAB/SIMULINK to obtain dynamic response for a step load perturbation (SLP). As an interconnected power system is subjected to load disturbances, system frequency may get disturbed and oscillating, affecting the dynamic performance. To compensate for such load disturbances and stabilize the area frequency oscillations, the dynamic power flow control of SSSC or TCPS in coordination with SMES are examined in this work. A coordinated operation of SMES in both the areas, is also studied in a comparative manner. The effectiveness of frequency controllers are guaranteed by analyzing the transient performance of the system with varying load. The gains (\( K \)) of integral controller in AGC loop, SMES (\( K_{\text{SMES}}, K_{\text{SM}} \)), TCPS (\( K_{\text{TCPS}}, T_{\text{TCPS}} \)) and SSSC (\( K_{\text{SSSC}}, T_f \) and \( T_d \)) are optimized in different cases with the help of CSA. At the outset, for the sake of obtaining the objective functions \( J \), the real power loads (\( P_d \)) of the 1st control area is perturbed by 1 % SLP. Optimum system response for a SLP and the impacts of SMES and TCPS, SSSC in that regard, have been explored and discussed in the following section. Three specific cases are examined as follows;

TCPS-SMES: In this case, the SMES is placed in area 1 and area 2, with load is perturbed in area 1. Further, a TCPS is placed in the connected tie-line between the two areas.

SMES-SSSC: In this case, an SMES is placed in the 1st area along with an SSSC operating in the tie-line.

SMES–SMES: In this case, the SMES is placed in both the areas, without the presence of TCPS in the tie-line.

The optimized gains, their corresponding values of objective function, for three different cases of operation including no SMES or TCPS, are elucidated in Table 1. It may be seen that, the optimized value of \( J \), obtained for SMES-SMES has the least value compared to the other cases, and therefore the dynamic performance for the same should be the best among them. The dynamic responses for the SMES–SMES coordinated operation against SMES-TCPS coordination is shown comparatively in Fig. 2. The results depict relative advantage of investing in two numbers of SMES compared to an SMES operating with TCPS in the tie-line. The optimized controller parameters and objective function values are depicted in Tables 2. The dynamic responses of the systems with the SMES–SMES and SSSC–SMES coordinated operation are depicted in Fig. 3 after 1 % SLP in area 1. The results clearly indicate that the coordination of SMES–SMES and SSSC–SMES can be effectively employed to suppress the oscillations in area frequencies and the tie-line power exchange under load disturbance Keeping the respective

<table>
<thead>
<tr>
<th>Controller parameters</th>
<th>Controller parameters</th>
<th>Optimized value of J</th>
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<tbody>
<tr>
<td>( K )</td>
<td>( K_{\text{SMES}} )</td>
<td>( K_{\text{SM}} )</td>
</tr>
<tr>
<td>TCPS-SMES(1*)</td>
<td>-1.665</td>
<td>47.122</td>
</tr>
<tr>
<td>TCPS-SMES(2*)</td>
<td>-2.041</td>
<td>26.885</td>
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![Graph showing dynamic response of systems](image-url)
Fig. 3. $\Delta f_1$, $\Delta f_2$ and $\Delta P_{tie}$ in T-T system with SMES and SSSC for 1% SLP in area-1.
5 CONCLUSION
The thermal power plants operate with large numbers of operational constraints, particularly in an integrated system. The level of real and reactive power reserve with only contribution from rotor inertia of generators provides a very small margin of maneuverability in system operation. The use of ESS and FACTS devices solves the problem to a large extent particularly in larger interconnected system. The SMES–SMES scheme offers the least undershoot and overshoot in frequency deviations and tie-line power exchanges as compared to SSSC–SMES controller and TCPS–SMES controller. However, as far as coordinated operation of SMES with FACTs devices is concerned, SSSC is a preferred option compared to the TCPS, due to better dynamic performance.

REFERENCES

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<table>
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<tr>
<th>Controller</th>
<th>Controller parameters</th>
<th>Optimized value of J</th>
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<tbody>
<tr>
<td>SMES(1st)-SSSC</td>
<td>K_I: 1.7399, K_SMES: 50.8156, K_id: 22.2465, T_3: 5.7902, T_I: 32.2239, K_SMES: 1.6682</td>
<td>41.7909</td>
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<tr>
<th>Performance Indices</th>
<th>Different FACT devices with SMES.</th>
<th>T-T</th>
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<tr>
<td></td>
<td>TCPS-SMES</td>
<td>SSSC-SMES</td>
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<tr>
<td>ISE</td>
<td>7.4383x10^4</td>
<td>8.4152x10^4</td>
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<td>ITSE</td>
<td>0.0015</td>
<td>9.7620x10^3</td>
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<td>IAE</td>
<td>0.0097</td>
<td>0.0634</td>
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<td>0.1193</td>
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<td>T_f (sec)</td>
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<td>A_f1</td>
<td>14.71</td>
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<td></td>
<td>-30.3751</td>
<td>-7.80 ± 10.10i</td>
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<tr>
<td></td>
<td>-3.82 ± 3.95i</td>
<td>-3.3333</td>
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