SELECTIVE MODAL ANALYSIS OF POWER FLOW OSCILLATION IN LARGE SCALE LONGITUDINAL POWER SYSTEMS

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Abstract

Novel selective modal analysis for the determination of low frequency power flow oscillation behaviour based on eigenvalues with corresponding damping ratio, cumulative damping index, and participation factors is proposed. The power system being investigated consists of three large longitudinally interconnected areas with some weak tie lines. Different modes, such as exciter modes, inter area modes, and local modes of the dominant poles are fully studied to find out the significant level of system damping and other factors producing power flow instability. The nature of the energy exchange between area is determined and strategic power flow stability improvement is developed and tested.

Keywords: Power flow oscillation, longitudinal power systems, inter-area modes, eigenspectrum, stability improvement

1. INTRODUCTION

In large scale longitudinal power systems, large amounts of electric power are transmitted over very long transmission lines covering the entire power areas under consideration. This paper examines power flow oscillation characteristics of three large power areas which are interconnected longitudinally with weak tie lines causing several inter-area modes [1,2]. Power systems of this type have features quite different from radial power systems and commonly found in geographically long islands with relatively low or medium population densities. Power flow stability is a major issue in this kind of systems since any power disturbances may easily lead to sustained power flow oscillations or even power splits which are very detrimental to the goals of maximum power transfers. The effects of the oscillations should be minimized.

For achieving the system secure operation againts any disturbances or transient perturbation, appropriate damping of the power system oscillations between the interconnected power areas is very important. Preventive or corrective remedial actions are necessary to ensure that the systems remain dynamically secure. For example, large interconnected power areas with weak tie-lines or poorly damped are susceptible to low frequency oscillations. Types of remedial actions may include strengthening the tie-lines, and/or using strategic coordination of PSSs and FACTS devices [4, 6, 7]. Improper coordination may cause destabilizing interactions [2,9].

As briefly stated above, large power systems highly utilize available transmission-distribution networks and generators in power stations with large amounts of power interchanged among area control centers and geographical regions. In power system operation and control, the modal properties of the systems can be explored through explicit knowledge of the whole eigen spectrum of the systems [10].

In this paper, the method of selective modal analysis is used where eigenvalues and participation factors computations of the systems are performed to determine the power flow characteristics and stability of the systems [8].

2. TEST SYSTEM AND STABILIZERS

Power System Model

A 54 machines, 118 bus system as shown in Fig. 1 is simulated in this research.

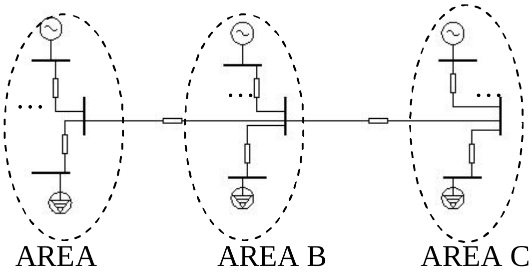

Figure 1. Three areas power system

The generators are represented by two axis model and static exciter model is used for the excitation control. The prime mover and governor dynamics are also taken into consideration.

The main characteristics and features of the test system are as follow:

- Voltage levels: 138 kV and 345 kV
- 166 transmission lines at 138 kV
- 11 transmission lines at 345 kV
- 109 load buses

- Total installed capacity of 44.5 GW and 315 MVAR.

By means of selective modal analysis the test system is divided into 3 major areas with weak tie-lines where low frequency inter-area oscillations are observed.

Series FACTS devices have been recognized as economical and effective means to damp low frequency power system oscillations. In this study, besides PSS, a STATCOM is employed for damping the inter-area oscillations and maintaining voltage stability. Coordinated applications of PSS, FACTS devices, and tie-line strengthening strategies are also considered.

Power System Stabilizer (PSS)

A typical PSS controller is shown in Fig. 2.

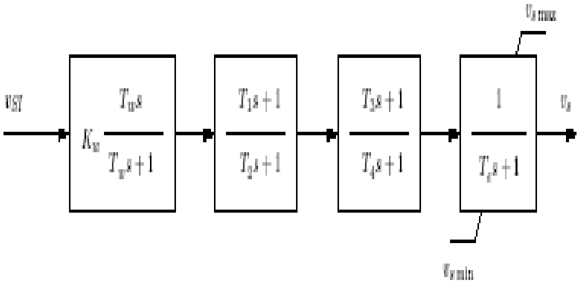

Figure 2. Typical PSS Controller

It works through the excitation system generating additional damping torque proportional to speed change. The main components of the PSS structure are proportional or amplification block, a wash out block and lead lag blocks.

Flexible AC Transmission Systems (FACTS)

Basically series FACTS controller has similar structure as PSS controller. The output of the FACTS device is Vs which represents the controlled variable. In this simulation, a series FACTS controller is employed. By installing FACTS technology on the tie-lines and controlling it to effectively mitigate the inter-area oscillations, the power exchange between power areas can be maintained safely

3. SIMULATION RESULTS and DISCUSSIONS

In this study, the test system eigenspectrums are displayed for 4 different cases. Case-1 corresponds to the original system comprising longitudinally interconnected three power area. Note that in this operating mode, the system is not equipped with PSSs or other FACTS devices. Parallel tie-lines configuration is implemented in case-2 reducing the inter-area reactances. Case-3 considers placement of PSSs at dominant generating machines based on the corresponding participation factors of the system generators. Case-4 refers to the application of STATCOM which can improve the voltage profile at the connection point to the network by injecting or drawing reactive power to or from the network.

Case-1: Original system

Eigenspectrum of the system is shown in Fig. 3 whereas the eigenvalues of the local, interarea, and exciter modes are indicated in Table 1, 2, and 3 respectively.

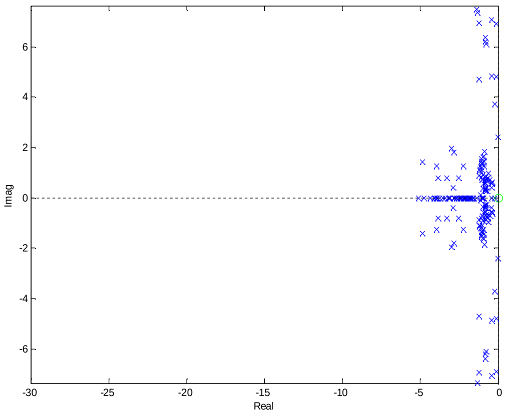

Figure 3. Eigen values of original system

Table 1. Eigenvalue of Local Mode

Most associated state	Real	Imag	f (Hz)
delta_Syn_36, omega_Syn_36	-2.6668	±10.0732	1.6032
delta_Syn_21, omega_Syn_21	-1.5998	±10.1058	1.6084
delta_Syn_26, omega_Syn_26	-1.4558	±10.1196	1.6106
delta_Syn_46, omega_Syn_46	-2.0436	±10.2165	1.626
omega_Syn_21, delta_Syn_21	-1.5968	±10.4119	1.6571
delta_Syn_54, omega_Syn_54	-2.3496	±10.4317	1.6603

Table 2. Eigenvalue of Inter -Area Mode

Most associated state	Real	Imag	f (Hz)
delta_Syn_39, omega_Syn_39	-0.8547	±6.1922	0.98551
delta_Syn_14, omega_Syn_14	-0.80827	±6.3712	1.014
delta_Syn_3, omega_Syn_3	-0.10488	±6.912	1.1001
delta_Syn_49, omega_Syn_49	-1.2182	±6.941	1.1047
omega_Syn_27, delta_Syn_27	-0.57075	±6.9699	1.1093

Table 3. Eigenvalue of Exiter Mode

Most associated state	Real	Imag	f (Hz)
e1q_Syn_39, vf_Exc_39	-0.8760	±1.8524	0.29482
vf_Exc_51, e1q_Syn_51	-2.9945	±1.9724	0.31392
delta_Syn_11, omega_Syn_11	-0.0442	±2.3518	0.3743
omega_Syn_27, delta_Syn_27	-0.1902	±3.6723	0.58446

The interarea modes indicate very low damping with frequency of power flow oscillation around 1.1 Hz representing a poorly damped system. Pole placement approach is required to drag the complex conjugate poles away from the imaginary axis

Case-2: System With Parallel Tie-Lines

Fig. 4 indicates the eigenspectrum of the system with lower reactances of the inter-area lines. Various operational modes are shown in Table 4, 5, and 6.

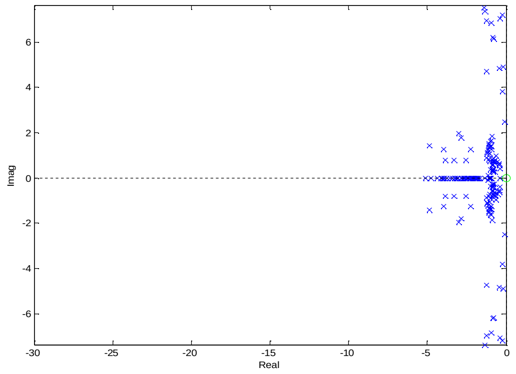

Figure 4. Eigenvalues of the system with tie-line strengthened

Tabel 4. Eigenvalues of Local Mode

Most associated state	Real	Imag	f (Hz)
delta_Syn_28, omega_Syn_28	-1.3273	±10.556	1.68
omega_Syn_54, delta_Syn_54	-2.3498	±10.4166	1.6579
delta_Syn_21, omega_Syn_21	-1.5291	±10.2803	1.6362
delta_Syn_46, omega_Syn_46	-2.0436	±10.2168	1.626
delta_Syn_21, omega_Syn_21	-1.6398	±10.1892	1.6217
delta_Syn_36, omega_Syn_36	-2.6728	±10.0653	1.6019

Tabel 5. Eigenvalues of Inter- Area Mode

Most associated state	Real	Imag	f (Hz)
omega_Syn_11, delta_Syn_11	-0.1841	±4.9074	0.78103
delta_Syn_40, omega_Syn_40	-0.4451	±4.8469	0.7714
vf_Exc_30, e1q_Syn_30	-1.2459	±4.7209	0.75136
delta_Syn_11, omega_Syn_11	-0.2117	±3.8235	0.60853

Tabel 6. Eigenvalues of Exciter Mode

Most associated state	Real	Imag	f (Hz)
omega_Syn_11, delta_Syn_11	-0.1841	±4.9074	0.78103
delta_Syn_40, omega_Syn_40	-0.4451	±4.8469	0.7714
vf_Exc_30, e1q_Syn_30	-1.2459	±4.7209	0.75136
delta_Syn_11, omega_Syn_11	-0.2117	±3.8235	0.60853
omega_Syn_11, delta_Syn_11	-0.0562	±2.4873	0.39586
delta_Syn_36, omega_Syn_36	-2.6728	±10.0653	1.6019

Reducing the interarea reactances show some improvement. Left shiftings of some dominant poles are observed. Combination with series FACTS seems to be better.

Case-3: PSSs are installed at dominant generators

The eigenspectrum and the operational modes are shown in Fig. 5, Table 7, 8, and 9 respectively.

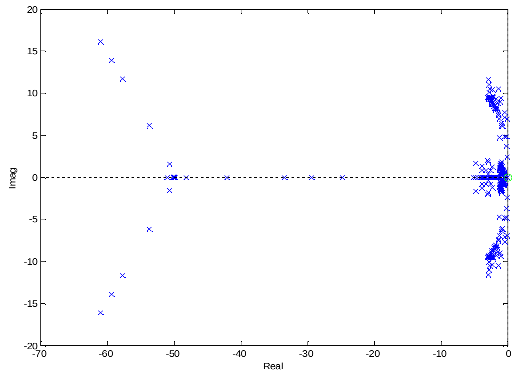

Figure 5. Eigen values of system with PSS

Tabel 7. Eigenvalues of Local Mode

Most associated state	Real	Imag	f (Hz)
omega_Syn_41, delta_Syn_41	-2	±10	1.5434
delta_Syn_6, omega_Syn_6	-2	±10	1.5248
omega_Syn_22, delta_Syn_22	-3	±10	1.5219
delta_Syn_16, omega_Syn_16	-3	±10	1.514
omega_Syn_31, delta_Syn_31	-3	±10	1.5133
omega_Syn_43, delta_Syn_43	-3	±9	1.5113

Tabel 8. Eigenvalues of Inter- Area Mode

Most associated state	Real	Imag	f (Hz)
delta_Syn_11, omega_Syn_11	0	±2.4128	0.38401
vf_Exc_51, e1q_Syn_51	-3	±1.9716	0.31379
e1q_Syn_39, vf_Exc_39	-1	±1.8525	0.29483
e1q_Syn_1, vf_Exc_1	-3	±1.7939	0.28551

Tabel 9. Eigenvalues of Inter Mode

Most associated state	Real	Imag	f (Hz)
vf_Exc_40, e1q_Syn_40	-1	±1.3922	**0.22158**
e1q_Syn_19, vf_Exc_19	-1	±1.3676	**0.21766**
e1q_Syn_44, vf_Exc_44	-1	±1.3597	**0.2164**
vf_Exc_21, e1d_Syn_21	-4	±1.3448	0.21403

Compared with other cases, case-3 has indicated quite different eigenspectrums, better power flow improvement is observed. Installations of PSSs at generators 21, 26, 36, 46, and 54 provide higher damping and lower frequency of oscillation (0.3 Hz).

Case-4: STATCOM is installed at bus 64 (tie-line end)

Simulation reveals that the eigenspectrum is practically unchanged (See Fig. 6). Installation of STATCOM does not show any significant effect on the power flow pattern, but improvement in voltage stability is observed.

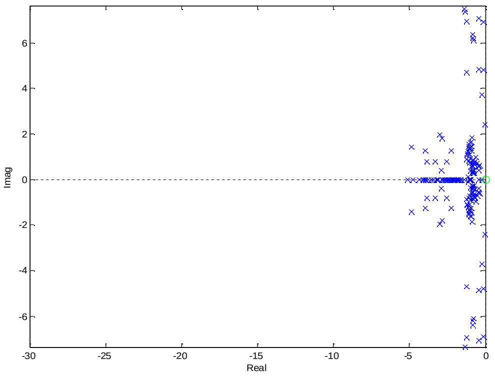

Figure 6. Eigenvalues of system with 1 STATCOM at bus 64

4. CONCLUSIONS

A longitudinal multiarea system with weak tie-lines exhibits a highly oscillatory power flows in the forms of low frequency power flow oscillations as depicted in the eigenspectrum where large number of eigenvalues are concentrated in the region close to the imaginary axis.

Reducing the interarea reactances by connecting parallel tie-lines between power areas will bring the power areas closer and shifts some of the eigenvalues to the left, thus improving the power flow stability to some degree.

Proper installations of PSSs at the dominant machines based on the maximum participation factors of the generators have shown a noticeable improvement to the power flow stability indicating proper phase lag compensation between the exciter input and the generating unit electrical torque.

A STATCOM is basically a shunts FACTS device. In this study, simulation shows that the application of this device has little effects on the damping control but improves significantly the voltage profile and maintains the steady state voltage.

5. REFERENCES

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