5. CONCLUSIONS

5.1 Conclusions

The HVDC transmission system has been analyzed by analyzing three performance indices by stability harmonic performance, control and protection performance.

Stability Analysis

Sequence impedance networks are developed for interconnected system wherein the HVDC link is embedded in the network. All sequence impedance networks i.e. positive, negative and zero is developed. Mathematical results are validated with the system data.

It is concluded that

- The parameters of the DC link, the resistance, result in positive damping
- Positive damping effect is predominating at low DC power level
- This effect contributes in damping oscillations during fault in the AC network
- There is a decrease in first swing overshoot of the rotor angle of the nearby generator
- Impact of DC power level on electrical damping is observed. Less destabilization exits as the DC power is reduced. As the DC power \( P_{dc} \) increases, the damping is of large negative values
- No considerable effect is observed in case of remote generators

Through analysis, it is shown that the overall system stability is enhanced significantly with the HVDC link in the transmission system.

Harmonic Analysis

The observations are enlisted as:

In HVDC system during the operation of converters, characteristic and non-characteristic harmonics are generated. The harmonics flow through the plant and utility power system resulting in voltage distortion and power losses. They also interact with power factor correction capacitor banks leading to equipment failures. Practically it is possible that harmonic levels are almost crossing the acceptable limits for particular season, at particular time of the day and/or for a typical system load pattern and the fact remain unnoticed.

For measurement of harmonics, in Chandrapur–Padghe HVDC link, both measuring methods viz. filter current measurement and capacitive currents in the CVT measurement, were applied for measurements of harmonics. It has been verified that they give the same results.
The filter current measurements can be performed indoors in the control room and thus is comparatively safer and so is proposed to be used for continuous measurement of harmonics. The CT output, if provided through a harmonic analyzer, detail harmonic analysis is continuously available. A program ‘Filter Performance Analysis’ (FPA) is developed.

The results of analysis provide

- The magnitude of harmonic of every order
- Values of performance indices like Individual harmonic distortion (IHD), total harmonic distortion (THD) etc.

Along with measuring and data storing

- An alert is provided to the operating engineers in the control room regarding any of the parameters (IHD, THD etc.) exceeding the desired limit
- An appropriate massage regarding filter performance

Field measurement results show that

- IHD for every order harmonics is observed to be less than limiting value of 1%
- Rest of the performance parameters are within the specified limits- THD less than 4%
- 5th and 11th harmonics are repeatedly occurring
- Stray capacitances inherent to HVDC converters have resulted in occurrence of triplen harmonics. In particular, odd triplen harmonics are occurring during ground modes of HVDC operations. Presence of triplen harmonics provides information regarding probable voltage unbalance

Thus with minor additions in the set up, existing facilities can be explored for continuous recording and analysis of harmonics as well as filter performance. With such available records it is possible to analyze the trends in harmonic variations with variations in AC-DC network conditions.

**Control and protection system**

The proportional gain of modulation controller of the existing system is set to a particular value. The gain magnitude is suitable for normal system operation. If it is increased, results in sluggish normal operation and reduction results in underdamped system. For having a ‘situation-appropriate-gain-controller’ an adaptive gain controller is
proposed. When the disturbances are appearing, the proposed adaptive controller offers optimized proportional gain thereby critically damping the oscillations. This enhances the applicability of HVDC link.

The expert system, ‘HVDC Fault Localization’, developed helps the engineers for fault diagnosis and localization. On the basis of system symptoms the component and the fault type is diagnosed. In case of DC line fault, the fault location is identified with the resolution of 2 kms.

5.2 Future Scope
Methodology of detail stability analysis of AC grid with HVDC link is developed. Assessment considering FACTS and STATCOM devices is essential. The control and protection system is too complicated. For operating engineers, there are human limitations while considering combined effect of every action undertaken during maintenance. There are rare occasions of maintenance during monopolar operations led to complete tripping. Such an occurrence is never desired. The expert system developed is a prototype. It can be further extended to include every manual action during maintenance and system response to it. Such an expert system will be a full-fledge operational guide for utilities and electrical power supply companies.

5.3 Applications
In future there can be structural changes in the present HVDC link and connected AC network. The system parameters will obviously vary. The effect of these parameter variations can be analyzed in detail with the help of methodology developed in the thesis.

System load and parameters vary time to time in a day, season to season in the year. For all such probable states, continuous record of harmonics will be available. The leading corrective measures results in reduction in harmonics and thus reduction in component deterioration. The expert system provides exact location of the fault. This facilitates corrective measures.

The overall effect is
- Reduction in pole tripping occurrences
- Reduction in outage timings