# 6
# CONCLUSIONS

The concept of protection aspects of series compensated transmission lines has been studied in detail in this work. Three techniques, towards possible solution for the problem of malfunctioning / overreach of distance relays when applied for protection of series compensated lines, are worked out and proposed in the work. The suggested techniques are tested by extensive simulation studies. The concluding remarks of the work are summarized as per following:

## 6.1 CONCLUSIONS:

1. Increased transmittable power, improved system stability, reduced transmission losses, improved voltage profiles and more flexible power flow control are techno-economical reasons behind installing Series Capacitors on long transmission lines. Series Capacitors and their over voltage protection device (typically Metal Oxide Varistors, MOVs), in spite of their beneficial effects on the power system performance, introduce additional problems and make operating conditions unfavorable for the protective relays that makes use of conventional techniques. During a power system fault the nonlinear behavior of series capacitor arrangement, the rapidly changing characteristic of circuit impedance, and the high frequency noise generated from the nonlinear protective devices of the compensation capacitors affects the voltage and current signals and thus creates the problems with distance relay's functionality.

2. Sub-synchronous resonance, Voltage reversals, Current reversals, Over reach, System Transients and Negative reach are well known problems introduced by series capacitor compensation. Over reach of the distance relays in their first zone of protection (up to 225% of set zone, in worst scenario), is undoubtedly the worst problem introduced by Series Capacitor Compensation.

3. The Series Capacitor & MOV bank acts as a "fault current stabilizer": for larger currents the capacitive reactance is smaller while the resistance is larger – this reduces the current as compared with a fully compensated circuit; for smaller currents the capacitive reactance is larger – this reduces the net impedance and increases the current as compared with a non-compensated circuit. As a result, the fault current versus fault location characteristic is flatter for series-compensated lines compared to non-compensated lines.

4. In the protection of series capacitors, the use of Metal Oxide Varistors (MOV) has become common practice. These devices protect the capacitors by ensuring that the voltage across the capacitor does not exceed a certain threshold as might occur during a high current fault. When the voltage is below the threshold, the device has very high resistance. However when the voltage exceeds the level set for the device, its resistance drops very quickly and acts to short the terminals of the capacitor in order to protect the dielectric from the damaging effects of a flashover. The device however can cause problems due to its highly non-linear nature. The resistance of this device will vary as the voltage on the capacitor terminals varies. There is however a positive side effect to all of this. When the MOV does operate (Considering that not all faults will induce a current level sufficient to pass the MOV voltage threshold and activate the device), it creates a frequency signature which can be positively identified. When there is operation of an MOV, it is obvious that a series capacitor was part of the fault loop since only fault current would cause an MOV to operate and clip the voltage waveforms seen by the relay. Based on the same, A Fast Fourier Transform (FFT) based technique which can be used to identify the presence of the capacitor in the fault loop in post fault scenario by identifying specific frequency signatures in voltage signals at relaying bus is proposed. The accuracy of the proposed scheme, during its performance evaluation on large number of fault simulations based test data sets, found to be 91%.

5. Wavelet Transforms have been successfully applied in a wide variety of research areas. The scaling property of the selected wavelet function to be used in decomposing the signal will assure the ability of the MRA (Multi Resolution Analysis) technique to detect any transient event and localize it in the time and

frequency domains. Selecting ortho-normal wavelets, multi-resolution analysis will have the ability to distribute the energy of the distorted signal in terms of the expansion coefficients of the wavelet domain. Therefore, both the expansion approximated and detail coefficients will give an indication about the energy content of the distorted signal in certain time and frequency bands. This feature can be used to classify different power system protection related problems. From the other side, the energy of the wavelet coefficients can be combined with the localization property to give a measure of the transient events like initiation of any fault. The small values of the expansion coefficients will give us an indication about the resolution levels that contains low energy of the transient signal and hence can be ignored for data compression purposes. This can reduce the large volume of transient's data to a manageable size. It will provide a higher quality of information about the transient events to be analyzed by power system engineers. Furthermore, the expansion coefficients of the highest resolution levels can be ignored for de-noising purposes. Hence, property like multi-resolution signal decomposition of Wavelet Transforms is utilized to detect, localize and classify different types of power system faults associated with series compensated transmission lines and using the same this work proposes two schemes as per following:

(a) Nowadays the trend is to locate faults quickly, reliably and, if possible, without human intervention. This is made directly possible by utilizing fault generated signals. A fault produces a wide spectrum of signals that contains information about the fault distance. These signals are the power frequency component and the transients. The transients can be used in fault detection, classification and location for both repair and protection purposes instead of the power frequency component. This is possible because the fault transients develop much faster and are less dependent on network configuration than the power frequency component. A Current Differential Pilot Relaying (CDPR) based unit protection scheme is proposed (which utilizes fault generated high frequency transient signals) in this work for detection, discrimination, classification of faults for series compensated transmission line. Wavelet Transform is used as signal processing tool where Instead of directly comparing the currents captured from CTs, "fault spikes" are used as a control variable so that the influence of line

capacitance will be reduced. Also, the proposed technique does not require an accurate replica of the primary current; the purpose of CT in this approach is to provide enough strength for detecting jumps. As a result, this novel approach has high degree of sensitivity than conventional CDPR (Current Differential Pilot Relaying). The accuracy of the proposed scheme, during its performance evaluation on large number of fault simulations based test data sets, found to be 96%.

(b) The bus-bar of the power system is always connected to many power system equipments. In case of bus-bar its impedance to earth is mainly determined by these equipment's capacitance and capacitive coupling to earth. Hence when dealing with fault-generated high-frequency signals which is traveling along the line the bus-bar stray capacitance (between bus-bar and earth) offers these signals low impedance path due to which a large amount of generated high frequency signals (ranging from 50KHz-100 KHz) is directed to earth. On the other hand, the lower frequency signals (in the range of 1 KHz -3KHz) are not affected by bus-bar stray capacitance. Based on this criterion, a non-unit protection scheme for detection, discrimination and classification of the fault for series compensated transmission line is worked and proposed in this work. The accuracy of the proposed scheme, during its performance evaluation on large number of fault simulations based test data sets, found to be 99%.

## 6.2 FUTURE SCOPE:

1 All the suggested techniques of the work are tested through large number of test data sets generated using MATLAB. The performance of suggested schemes can be verified through the other competent software's available in the market for power system transient analysis studies like, PSCAD, ATP-EMTP, EMTDC, etc... , in order to verify robustness of the proposed techniques.

2 All the suggested techniques of the work are tested through simulation studies, using large number of test data sets generated using MATLAB, they need to be tested for their performance accuracies in real time through Real Time Digital Simulators (RTDS).

3 Presently almost all the work being done in the area is focusing on the information available at the remote end/ends of the line in order to work towards the possible solution of problem of overreach experienced by distance relays when applied for protection of series compensated transmission lines. Efforts shall be done to collect the local information available at the location of the MOV-Capacitor bank set up (which is at middle of the line), and then analyzing it at remote ends. This may lead to more accurate and viable solution to the problem.