CHAPTER X

CONCLUSIONS

The developments in power systems have demanded improved protection and often more complex characteristics. Due to the increase in short circuit levels, circuit ratings and complexity of interconnections the reliability of the protective equipments has been emphasized. Shorter operating times have become more essential to preserve system stability as the character and loading approach design limits. The conventional electromechanical relays have reached the stage of almost perfection leaving little potential for further improvements. Experience has shown that the more exacting system requirements can readily be met by resorting to static relays. The rationalisation of basic element designs to meet varied protection requirements has always been difficult with electromechanical relays. Attracted armature, moving coil and induction disc/ cup relays have had some success but flexibility has usually been restricted. On the other hand, new designs of static relays are very flexible, and are so suited to rationalisation that the concept of a range of standardised functional elements with its advantage to both manufacturer and user becomes a practical aim.

Initially the developments in solid state relays were confined to the protection of transmission lines as there

the limitations of electromechanical relays were very much to the fore. The economic considerations led to the development of heavily loaded EHV lines making the existing protection systems more prone to incorrect trippings under heavy loads and swing conditions. A need was therefore felt for a close control of the segments of the distance relay characteristics. This implies an altogether different approach to the application of relays i.e. synthesis of a characteristic dictated by system requirements rather than the earlier method of trying to apply available characteristics, for system protection. This trend is exemplified by the use of solid state relays which can either improve existing functional performance of all protective relays or open up possibilities of new functions as called for by system requirements.

In continuation with this trend developments in solid state relays are reported in the present thesis which fulfil the present day power system requirements. Initially the sine type phase comparators are analysed on a completely general basis. The graphical constructions are presented, both for circular as well as rectilinear pick-up characteristics, to assist in the selection of necessary inputs to the comparator. This comparator has a distinct advantage in providing the characteristics with independent control of the constituent line segments. The unsymmetrical phase comparison limits, obtainable by simple time setting

control of multivibrator circuits, make the comparator more attractive for the application.

The static phase comparators hitherto reported are applied with indirect approach in that the complicated mathematical basis and the associated graphical constructions are necessary to be employed to obtain required inputs to the comparators. A direct and more feasible approach in this regard is developed in the present work employing sequence detection techniques. With this approach a variety of pick-up characteristics can be obtained with sharp discontinuities. The requirement of relatively simple circuitry for functional purpose is an additional advantage.

The hybrid comparator reported in the present thesis is capable of yielding most of the conic characteristics and is free from the requirement of any balancing reference. The comparator makes possible the use of thyristor in the output stage rendering the relay completely static and fast in operation.

The variations in generation and the system loading approaching the design limit call for a significant improvement in the shaping of the distance relay characteristics. A self-adjusting distance relay characteristic appears to contribute to a large extent in this regard. The hybrid comparator reported in the present work yields self-adjusting elliptical characteristic. This

characteristic makes the relay adequately stable during healthy and over load conditions of the system, power swings, external faults and the faults on the other phase or phases. The self-adjusting feature being independent of healthy phase polarisation, the relay is capable of catering for all kinds of faults. Amongst others, the particular advantage of this comparator is in pronounced bulging of the characteristic during internal faults with even low source/line impedance ratios (of the order of 1 to 2.5) .

All static distance relays have lower limit on the amplitude of relaying signals up to which it can serve the purpose of detection of the faulty and abnormal conditions of the system. P-olarisation from healthy phase or phase pair is ,therefore, necessary and, in general,beneficial to directional discrimination against external reverse faults. Owing to the effect of polarisation being that of enlarging the total tripping characteristic for forward faults, in general, it influences discrimination against healthy phase impedance. The amount of influence in this respect depends upon the level of polarisation,fault level at each termination and on the magnitude and direction of power flow at fault onset. The analysis presented in the thesis clearly indicate the effect of polarisation on 2-input and multi-input phase comparators and sequence comparators. It may be observed that the polarisation permits the relays in all the cases to correctly insure the directional property.

Further, in all the cases the reach on the resistance axis of the characteristics remains unaffected for all system conditions. Also, in all the cases the reach on the reactance axis of the characteristics remains unaffected, except for the case of phase to earth fault relays on single infeed line and phase to phase fault relays on double infeed lines employing Multi-input phase comparator. In these cases, the relays are likely to under reach for solid faults at the end of the protected line section when higher level of polarisation (20 percent) is employed. However,the level of polarisation needed for solid state relays is very low (about 2 to 5 percent) the possibility of under reaching of the relays in this regard is remote.

The effect of remote end relay characteristic on the local end and the inherent limitations in the formation of measuring circuits in yielding mixed relaying signals for amplitude or phase comparison call for a significant improvement in the pilot-wire differential protection system. The sine type phase comparator and instantaneous amplitude comparator reported in the present work appears to contribute significantly in this regard. Both the comparators are capable of yielding characteristics with sharp discontinuities and ensure fast operation. The inversion chart reported in the thesis will be found useful in shaping the necessary stable zone.

Novel concepts in protective relaying are always desirable. An important and significant contribution in this regard appears in the application of distance relays in conjunction with pilot-wires. Two schemes of restricted zone protection of short transmission lines, working in this mode, are analysed in detail in the present work. The effects of the complex nature of relaying current distribution factor, attenuation and phase shift of the relayed signals and the power swings on the pick-up characteristic clearly show the short-comings of earlier work. The synthesis of the protective characteristics from these view points is presented in the thesis and relay circuitry in block-schematic form are presented to realise typical pick-up characteristics.

The use of semi-conductor devices as active elements of protective relays offers many advantages over the conventional distance relays such as fast operation, precision, lesser burden on protective transformers, providing novel characteristics etc. The multi-input phase and hybrid comparison techniques for distance relays described in the present work have been developed and tested in the laboratory. Steady state and transient performance of these relays to assess their operating time, transient over-reach and polar characteristics were carried on a dynamic test bench. The results of these testings confirm the theory developed in the main text.

The present work may be extended in the following areas :

The self-adjusting relay reported in the present work yields elliptical characteristic enclosing the origin of the impedance plane. An additional directional unit is therefore incorporated. This could be ameliorated by designing the comparator providing either elliptical characteristic passing through the origin of the impedance plane and terminating in-to mho characteristic during faults, or a self-adjusting directional quadrilateral. The necessary condition of tripping for the former would be :

$$Z_L \leq \frac{K' Z_R \cos(\theta-\phi)}{1- K'' \cos(\theta-\phi)} \qquad \ldots\ (10.1)$$

With $K'' < 1$

The analysis on restricted zone protection of short transmission lines presented in the thesis confines to two machine systems. The analysis may be extended to multi-machine systems.

The present work makes use of semi-conductor devices throughout. The integrated circuits instead could be employed for variety of functions, viz. pulse shaping, integrating, time settings, phase comparisons etc.

The ultimate aim of any engineering research work is in its application to industry and/or system. The theories of various protective relaying systems developed in the present work are confirmed by laboratory tests on the comparator models. The comparators must be subjected to field testing before they could be incorporated in the system protection.
