The protection of rotating machines

A very large number of electrical machines of a wide range of types and ratings are used in power systems around the world. The vast majority of them have a rotating member, i.e. a rotor and a stator, and both members usually have windings associated with them.

The largest machines are the three-phase alternators used in generating stations. In the UK, many stations have machines which provide 50 Hz voltages of 22 kV (line) and power outputs of 500 MW. Their star-connected output windings, which are mounted in the stator, are thus capable of carrying currents of 15 kA. Their rotor windings, which provide the m.m.f.s needed to set up the magnetic fields, carry direct currents up to 4.24 kA, these being supplied by exciters rated at 2.5 MW. The field windings of these machines are supplied in turn by pilot exciters. The alternators and their exciters are driven by steam turbines supplied by boilers. Associated with such plants are motors which drive pumps, fans and other items including coal pulverizers.

Even larger alternators are now in use. As an example those installed in the Itaipu hydro-electric power station on the Parana River which flows between Brazil and Paraguay are rated at 700 MW. This station contains 18 of these machines, each of which weighs 2700 tonnes.

In an article [1] published in the IEE *Power Engineering Journal* in 1990, Creck described machines rated at 985 MW, 1158 MVA which were being produced at that time by GEC Turbine Generators for the Daya Bay nuclear power station in the People’s Republic of China. These machines are designed to produce voltages of 26 kV (line) at a frequency of 50 Hz, the full-load current of the output windings being 25.7 kA. Their stator and rotor cores are to be hydrogen cooled and water flowing in a closed circuit will cool the stator windings.

It will be appreciated that power units, such as those referred to above, are very complex and it is necessary that their performances are completely monitored at all times to ensure that continuity of supply is maintained and that any faults or breakdowns which may occur do not cause unnecessary consequential damage.

Machines with ratings ranging down from the very high levels quoted above to levels of only a few watts or less are in service and many are produced...
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annually for widely ranging applications. Both three-phase and single-phase a.c. synchronous and induction machines are produced as well as motors suitable for operation from sources of direct voltage or rectifiers. In addition, in recent years, reluctance motors [2] operating from controlled-rectifier banks have been introduced to provide efficient variable-speed drives.

Over the years several forms of protective equipment have been developed to enable the whole range of rotating machines to be protected at cost levels which are acceptable. Clearly cheap devices must be used with small machines, whereas quite costly equipment is justifiable when very large and important plant is to be protected.

In all applications, it is desirable that the most appropriate protective equipment is used and to enable this to be achieved it is necessary that adequate information about the machine to be protected is available when protective schemes or devices are to be selected. As an example, if fuses or relays with inverse time/current characteristics are being considered for use with a particular motor, then it is essential that the magnitude and duration of the current surges which will flow in it during starting periods are known.

A significant factor which should be recognized at this point is that although machines which are to be used as motors may be physically the same as others which are to be used as generators, their protection must take into account the use to which they are to be put.

Motors, clearly, are loads and therefore only their operating characteristics need to be considered when selecting the protective equipment to be used with them. Should time-graded schemes be used, then the protection on the circuits supplying the motors must be set so that the necessary co-ordination will be achieved under all conditions, i.e. the devices on the supply circuits should operate more slowly than those on the motors.

Generators are, of course, sources and therefore the settings of their protective equipment must be such that operation will not occur in the event of faults on the circuits being supplied by them and, in addition, the generators should not suffer consequential damage.

It will be appreciated that it is not possible in this work to provide detailed guidance on the protective arrangements which are most suitable for each of the many types and sizes of machines which may be encountered in practice. In this chapter, therefore, the protective schemes and devices currently available are examined and a number of applications of them are considered, after some details are given of the early relays which were introduced to protect machines.

7.1 HISTORICAL BACKGROUND

When motors, generators and alternators were being produced in the final decades of the last century for installation in power systems the only electrical protective devices available were fuses. Whilst they were suitable for use with