Modern thermal power plants (including nuclear power plants) are, in fact, among the biggest world industrial plants and electric energy consumers. Depending on their design, water feeding pumps, drives (steam turbine or electric motors), self consumption of thermal power plants amounts from 4.5% to 8%, respectively. Bearing in mind that typical modern thermal power plant units burning coal have installed capacity of 800 – 900 MW, while nuclear power plant units reach 1500 MW, the self consumption of a two unit nuclear power plant of such capacity amounts to 135 – 240 MW - which is equivalent to the installed capacity of some older thermal power plants.

High voltage (HV) electric motors, which drive large pumps, fans, coal mills, belts, etc., all requirements for thermal power plant operation, account for approximately 80% of self consumption. Therefore, the unit’s capacity has to be large enough – very often more than 1000 kW. Another 20% of thermal power plant self consumption is spent on low voltage motors, lighting, valves drives, etc.

Even if HV motors have high reliability and operational stability (because of relatively simple construction and small number of “weak points”), there is always a risk of unscheduled shutdowns, which may lead to difficulties in electricity generation supply or even to shut down with loss of generation as a consequence. It is obvious that the behaviour of HV motors has a strong influence on electricity generation in power plants, with serious financial consequences. Therefore, it is important to understand whether correlations could be found among work conditions, load, start-stop frequency, maintenance policy or other factors and large HV motor failures.

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Knowledge about the most frequent types of faults and, of course, about the failure causes, may be used in the same way. What is also of great significance is to understand whether and how an initial failure develops, whether failure propagates and how, what consequences rise up (Root cause analyses). Fig. 1 shows a high voltage (HV) motor which drives a large pump.

**Scope of study**

According to WG A1.19 Terms of Reference, it was decided that:
- Induction motors (both squirrel-cage and wound rotortypes) for power station applications, rated more than 800 kW and not less than 1000 V would be included
- Synchronous motors, DC motors, motors for industrial and traction applications would be excluded
- The present investigation would statistically cover the failures occurred during the last 10 years of operation.

This scope was approved by the Cigré Technical Committee.

**Participants**

The study received good contributions from Japan, Brazil and Serbia. France also participated, not by filling out the questionnaire, but by getting its own analyses for HV motors availability. These analyses have been integrated in this report.

**Statistical sample**

A questionnaire was prepared in order to supply the study with statistics data for concerned motor population to be investigated. It includes:
- General data for all motors considered by responders, as motor type, voltage, capacity, work conditions, driven equipment, load, kind of starts, speed regulation, etc.
- Basic data of motors which failed in the last 10 years, including if possible working conditions and data about initial (and possibly propagated) failure
- Neither the names of the power plants nor the names of the motor manufacturers were required in order to maintain responders confidentiality
- Seven power plants with 24 units have been covered by the answered questionnaires: 5 units are nuclear (21%), 10 units burn crude oil (42%), and 9 units burn coal (37%). Total installed capacity of these power is 16,410 MW and total number of installed HV motors is 323.

The number of observed units running in base-load regime is 14 (58%); other 10 units (42%) work in two-shift regime. Regarding HV motors, 219 work at base load (68%), and 104 (32%) work in two-shift regime. Concerning the motorloads:

- 73 HV motors (54%) drive pumps
- 84 HV motors (26%) drive fans
- 58 HV motors (18%) drive coal mills
- 8 HV motors (2%) drive other equipment

All observed motors have direct start (none have soft start), none of them are
equipped with electronic speed regulation (frequency regulation), but 101 out of them (31%) use mechanical speed regulation while 222 HV motors (69%) work without any speed regulation. All observed motors have squirrel cage type rotors, none have wound rotors.

One of the questions prepared to provide good statistical samples was related to HV motors’ load running conditions: 176 motors (54%) operate at less than 90% rated load while 147 HV motors (46%) operate close to the rated load value (more than 90% rated).

Regarding the motors installation conditions, the situation is as follows: 215 (67%) motors are running indoors while 108 motors (33%) are installed outdoors. Motors have been divided by ambient conditions, as follows:

- Dirty working conditions: 56 motors (17%)
- Wet working conditions: 28 motors (9%)
- Combination of wet, dirty and high temperature working conditions: 36 motors (11%)
- High or low temperature working conditions: 2 motors (1%)
- Working under normal conditions: 201 motors (62%)

The majority of the responders declared that the dominant HV motor maintenance policy is “Calendar based maintenance” – 307 motors are maintained in that way (95%), while 16 motors are maintained using running hours as a criterion for maintenance scheduling. However, in all cases, preventive maintenance is applied.

Motor operation and failure records are available for 203 (63%) out of the observed motors. Usually, if present, the failures database is fulfilled by the power plants personnel. Only one power plant (nuclear) reported that the records are kept by motor manufacturer.

The average age of the observed motors is equal to 23 years.

Detailed statistical samples are given in Table 1 – 4.

France motors data – statistic sample

A great contribution came from the major French utility which had sent statistics about their HV motors fleet including two generations of motors. The motors corresponding to coal power stations built before 1975 have a 5,5 kV internal medium voltage grid. Starting from 1976 (700 MW coal power stations) the internal power station HV grid has been set up to 6,6 kV. In 1991 the construction of coal power plants ceased. Also, HV motors of the pressurised water reactor (PWR) nuclear units (900 MW, 1300 MW and 1500 MW) built before 2001 also have a 6,6 kV rated voltage (see Table 5).

Statistics done for the decade 2001 – 2010
include the entire HV motor of fleet of the PWR nuclear power stations consisting of more than 2000 motors. The fossil power plants are now using less than 1000 HV motors, as some power plants are out of service, and the majority are running at a rated voltage of 5.5 kV. For these units, few motors are wound rotor type (water feeding pumps, flue gas fans). In some cases synchronous motors are used. The motors have horizontal or vertical axis and speed range between 400 rpm and 3000 rpm. Installed capacities are from several hundred to 9 MW, but the majority of the motors have a rated power less than 1 MW.

HV motors failure rate

The number of failures reported by the responders of WG A1.19 was equal to 11, during an observation period of 5 years and on a sample of 323 HV motors. It gives a failure rate of approximately 0.7 %.

The major French utility statistics is done for several period intervals. For the period before 2000 the failure rate is assessed somewhere between 1 and 1.5% for this period the failure rate value is calculated on the base of an aged motor population (majority of motors built during the 70's). Statistics done for the decade from 2001 up to 2010, including all HV motors of the nuclear fleet (built since early 70s until middle of 90s) indicates a global failure rate of 0.7%, a value similar to the one resulting from the WG A1.19 responders. This value is calculated for a population of more than 2000, 6.6 kV motors.

Large HV motors failures origin

From the total number of failures reported by WG A1.19 responders it is not possible to draw completely reliable conclusions. Therefore, the major French utility statistics were considered.

The major French utility analysis was done for the period 2000 – 2010 where slightly more than 1000 events, over almost 2000 HV motors installed in Nuclear Power Plants, were reported. Detailed overview of the reported events is given in Fig. 2.

The reported events can be classified by their origin as:
- Mechanical
- Electrical
- Environmental
- Human
- Periodical controls and visits
- Accessory equipment
- Other

The majority of the reported events (74%) for the major French utility fleet have a mechanical origin. Only a small part of the listed events has induced a motor failure. The average number of failures reported each year is between 10 and 20. Seventy (74%) of these failures have a mechanical cause. On the contrary, data collected from WG A1.19 responders show that the majority of the failures have an electrical cause (7 out of 11 reported failures, which represents 64%, generally caused by stator winding faults).

Probably the main reason for this different situation is the severity of French Utility specifications for HV motors. According to the major French utility analysis, these mechanical issues generally represent bearing failures due wear or bad lubrication.

Another type of reported event was represented by the internal leakages (lubricants into the cooling fluid). Other reports deal with alignment or mechanical clearances and other mechanical items (screws, bolts, etc.). Only about 10% of the total number of the reported failures had an electrical cause. In some cases abnormally high temperatures levels for stator winding were reported (3%). Generally, these high temperature alarms were noticed during the hot season but could be also induced by overload conditions or mechanical issues. Another 9% of events that have been reported were due to an external cause, like failure of sensors, protection, or command system.

Another family represented concerns the events encountered during periodical controls (6%). In general, this category consists in minor problems (like detection of wear, corrosion, obstruction of vent ducts, small oil leakages) not inducing a system failure. Fig. 3 gives statistics in graphic form.

Mechanical origin failures

Problems with inadequate lubrication led to 31% mechanical origin failures. Another
7% were related to mis-alignment (with vibrations as a consequence), internal leakage of grease, oil or cooling liquids led to 5% failures, 2% of faults arose because of internal ventilation (cooling) problems, while 16% of faults had other reasons.

In Fig. 4 statistics of mechanical origin for HV motors failures are shown.

Electric origin failures
Statistics of electrical origin HV motor failures show that 35% of the events are representing stator winding insulation failures: inter-turn failures, phase to ground or phase to phase short-circuits. Some incidents (25%) were related to cables crimping or connection problems. Other 14% of the incidents were represented by cable insulation failures, mainly due to aging phenomena. High inrush current problems were reported in 11% of the electric origin events. Generally, this problem could be related to a wrong set-up of the over current protections, when ratio between start and rated current was higher than it had been foreseen. Finally, some insulation problems were identified for the connection boxes, heating resistances and bearing insulation. Statistics are given in Fig. 5.

Conclusions
High voltage (HV) electric motors in conventional thermal and nuclear power plants are very important and influential on electricity generation performances. In spite of their high reliability and operational stability, there is always the risk of unscheduled shutdowns of some HV motors, which may lead to electricity generation reduction, or even break off, with loss of electricity generation as a consequence.

The knowledge about average HV motor failure rates level may be used as a criterion for power plants engineers to make a decision whether or not some changes in maintenance policy have to be undertaken.

In this context the large amount of data supplied by France could provide some guidance. Although the data received was not sufficient to establish some correlations among large HV motors failures and work conditions, load, start-stop frequency, or other factors, some conclusions in principle, may be drawn.

probably the most important conclusion may be that power plants owners rather look for motors with better availability than for efficiency. It can be seen through calendar based maintenance as a dominant maintenance policy, and the relatively relaxed work load (more than a half of the HV motors work loaded less than 90%). However, an increase in efficiency of HV motors should also be considered in future designs as their energy consumption affects the energy balance of power plants.

The average age of the observed motors (approx. 23 years) and still low failure rate (less than 1%) testify that expected working life may be more than 40 years, which qualify HV asynchronous squirrel cage motors as very reliable equipment.

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