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SURVEY OF HYDROGENERATOR FAILURES

**Working Group
A1.10**

October 2009



WG A1.10

Survey of Hydrogenerator Failures

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ISBN: 978-2-85873-079-7

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SURVEY OF HYDROGENERATOR FAILURES

1. INTRODUCTION

Utilities aim for lower maintenance and operational costs. One of the main operational costs is related to generator failures.

The purpose of the survey was to obtain statistical information to help evaluate the risks of the main hydrogenerator failures. The intent was to report information helpful to users and manufacturers in improving unit future reliability.

Therefore, WG A1.10 initiated a worldwide survey to evaluate the incidence of hydrogenerator failures. The survey was limited to failures that produced forced outages of more than 10 days on hydrogenerators rated higher than 10 MVA operating for more than 10 years. To fulfil this goal, in October 2002, the WG prepared a questionnaire that was sent to both manufacturers and users.

In order to evaluate the size of the sample for every company, first part of the questionnaire consisted of questions such as time span covered by the survey (**not less than 10 years**), number of hydrogenerators rated higher than 10 MVA, and lump sum of those hydrogenerators' power.

To evaluate each incident, the second part focused on failure severity (outage and extent of damage), nature of the failure, root causes, type of damage and influence of the monitoring and risk reduction methods on the failure cost reduction.



2. INFORMATION GATHERED

Table 1 summarizes the sources of the information. Sixteen utilities and one manufacturer in five countries replied to the questionnaire.

Table 1: information Sources

Country	No. of companies	No. of hydrogenerators	Total power of hydrogenerators (MVA)	Incidents Reported	
				Number	Total Power (MVA)
Australia	1 (Utility)	31	3.756	1	145
Germany	5 (Utilities)	111	3.785	5	597
Norway	2 (1 Utility+1 Manufacturer)	410	20.000	11	1.343
Spain	4 (Utilities)	409	16.384	37	2.700
Sweden	5 (Utilities)	238	13.317	15	804
		1.199	48.692	69	5.589

A sufficient amount of information has been gathered to obtain a realistic picture.

3. RESULTS OF THE SURVEY

Failures have been considered from different points of view, such as:

3.1 Damage

Damage can be defined as harm or injury to property (a hydrogenerator in our case), resulting in loss of value or the impairment of usefulness.

Four different damage categories have been established: insulation, thermal, mechanical and bearing damage.

Figure 1 shows that insulation damage occurrence accounts for more than half of the sample.

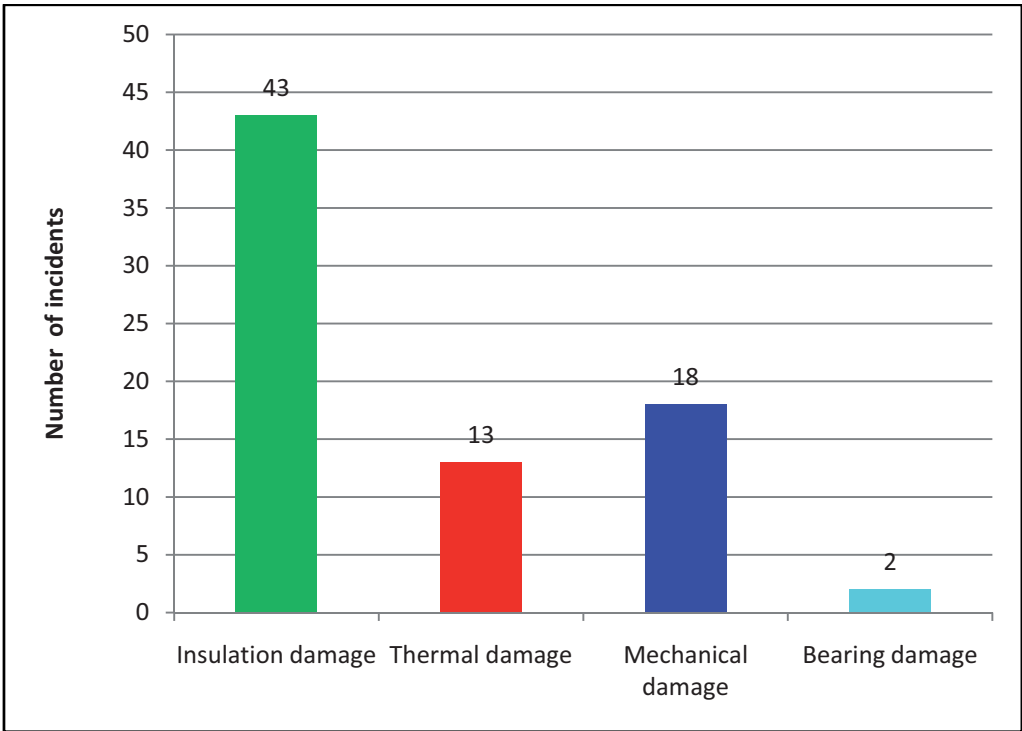


Figure 1: Insulation, thermal, mechanical and bearing damages

On a second classification level, more damage categories have been established. Figures 2 to 5 show their occurrence. It must be highlighted that 40% of the damages are related to stator phase to ground or phase to phase faults and around 12% produce insulation burning.

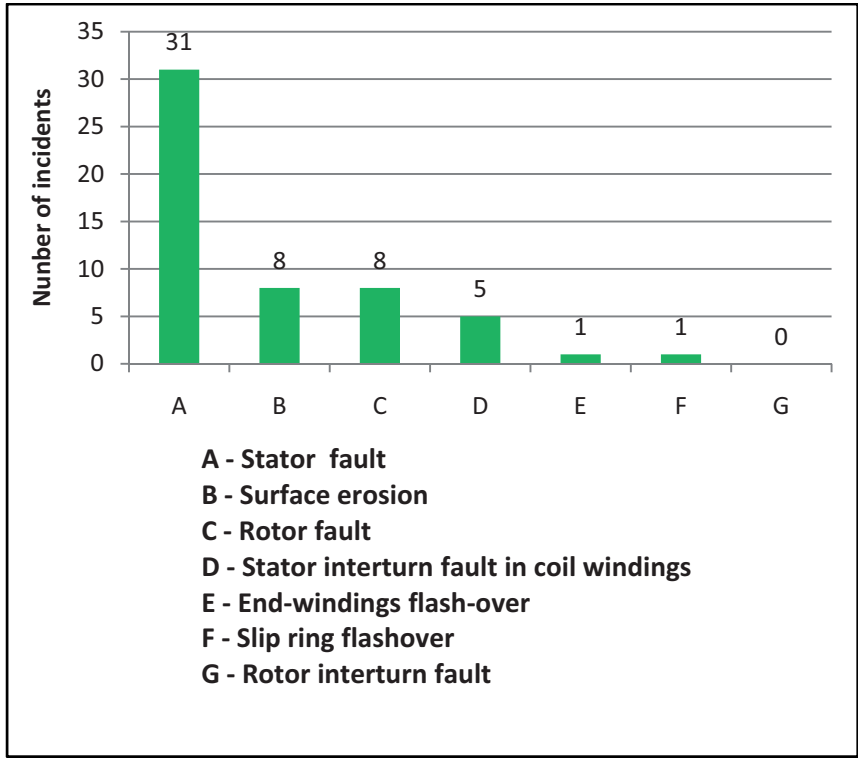


Figure 2: Different Insulation damages considered

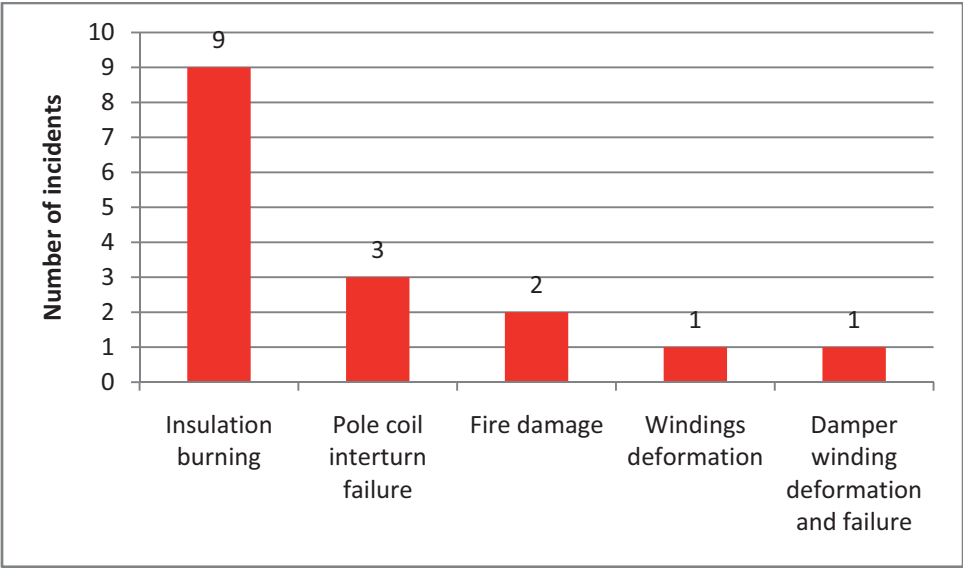


Figure 3: Types of Thermal damages considered

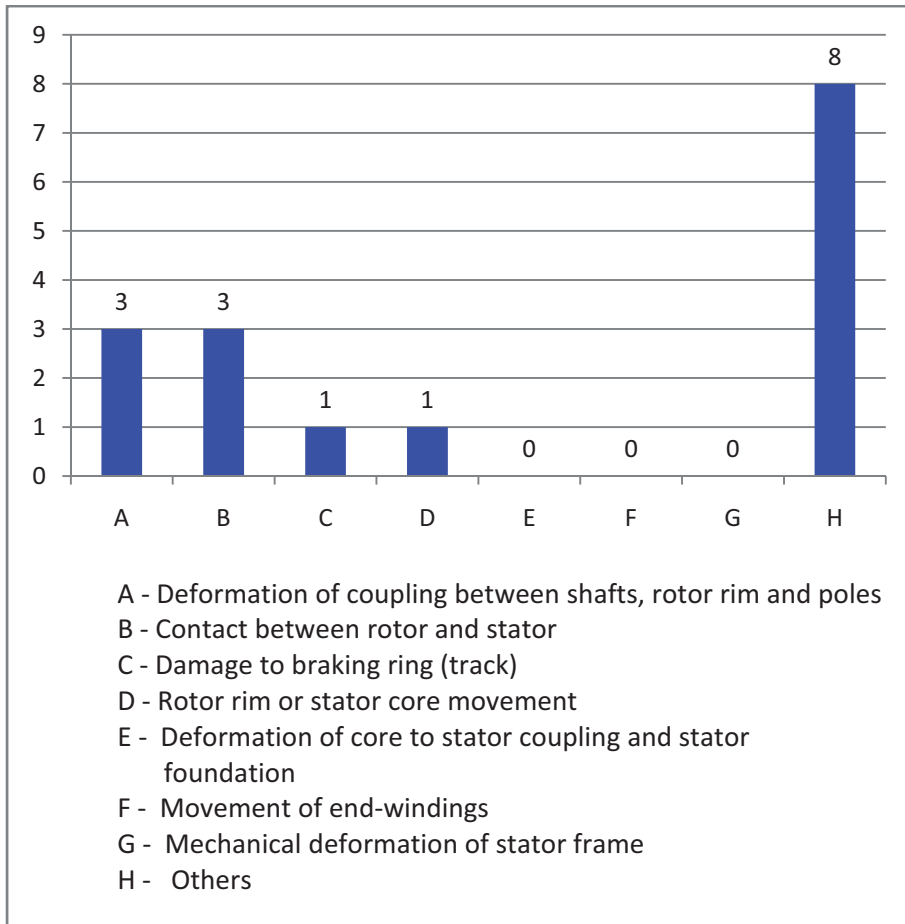


Figure 4: Types of Mechanical damages considered

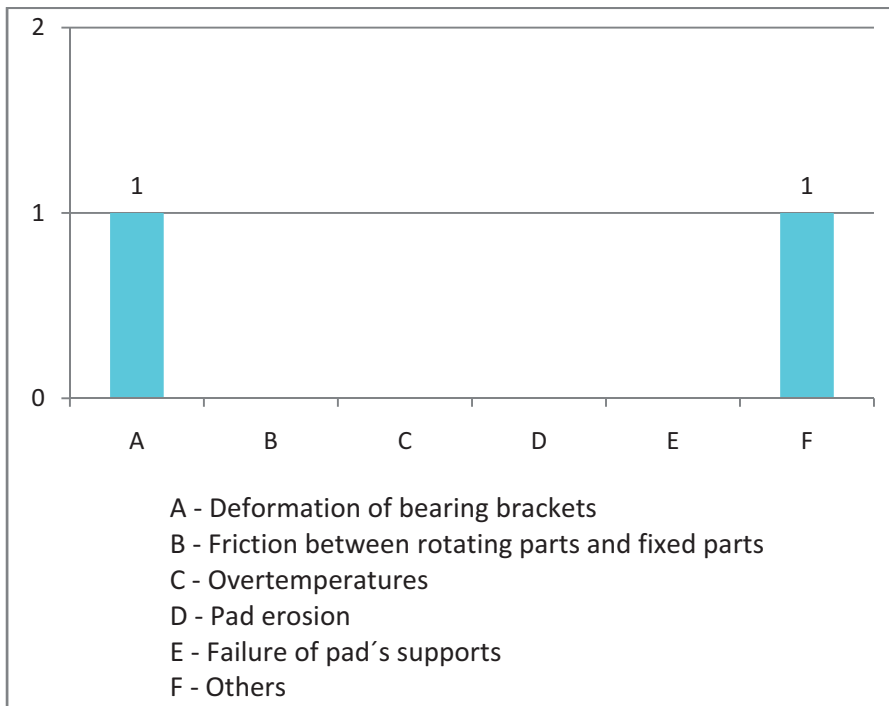


Figure 5: Types of Bearing damages considered

Once the type of damage has been established, we must analyse the causes.

3.2 Failure root cause

In item 3.1 the direct or proximate causes which immediately lead to the failure were discussed. However, these causes often result from another set of causes, which could be called intermediate causes, and these may be the result of yet other causes. When a chain of cause and effect is followed from a known end-state, back to an origin or starting point, the root causes are found. The main purpose of attempting to find root causes is to solve a problem that has actually occurred or to prevent a less serious problem from escalating to an unacceptable level. The basic concept is that solving a problem by addressing root causes is ultimately more effective than merely addressing symptoms or direct causes.

We will identify these root causes by relating them with the resulting damage: insulation, thermal, mechanical and bearing root causes.

Figure 6 shows failure root cause occurrence.

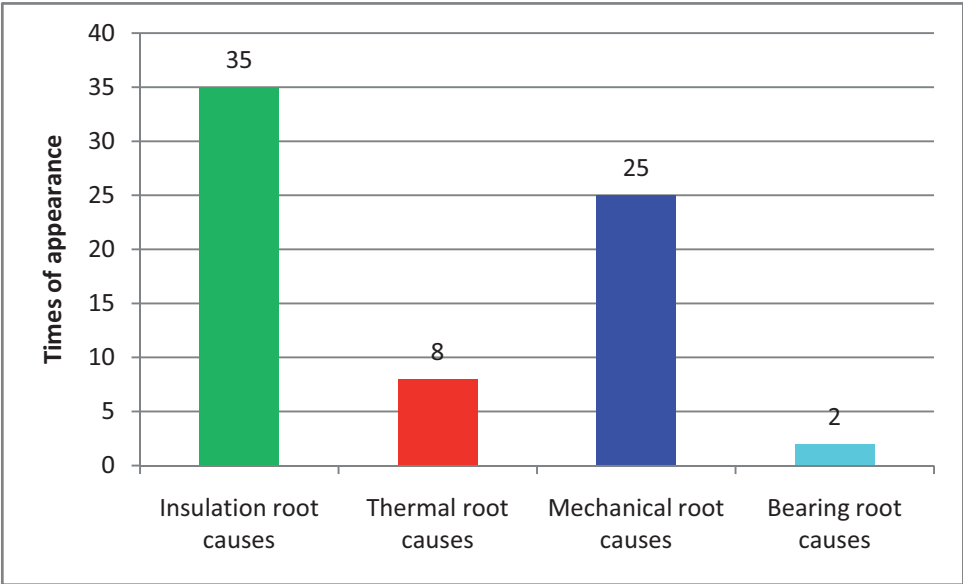


Figure 6: Root causes

If damages and root causes are compared (see figure 7), both align, but the mechanical vs. insulation ratio is higher for root cause occurrence than for damage occurrence. There is a strong relation between insulation root causes and insulation damages, but some insulation damages derive from causes not related with insulation. A similar conclusion can be reached for the other root causes and damages.

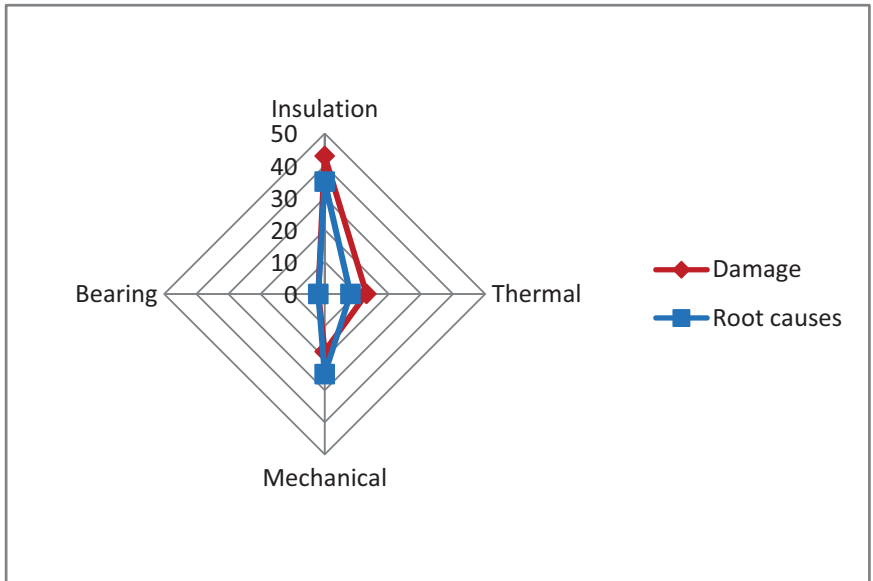


Figure 7: Damage vs. Root causes

On a second classification level, more root cause categories have been established for each of these four. Figures 8 to 11 show their occurrence.

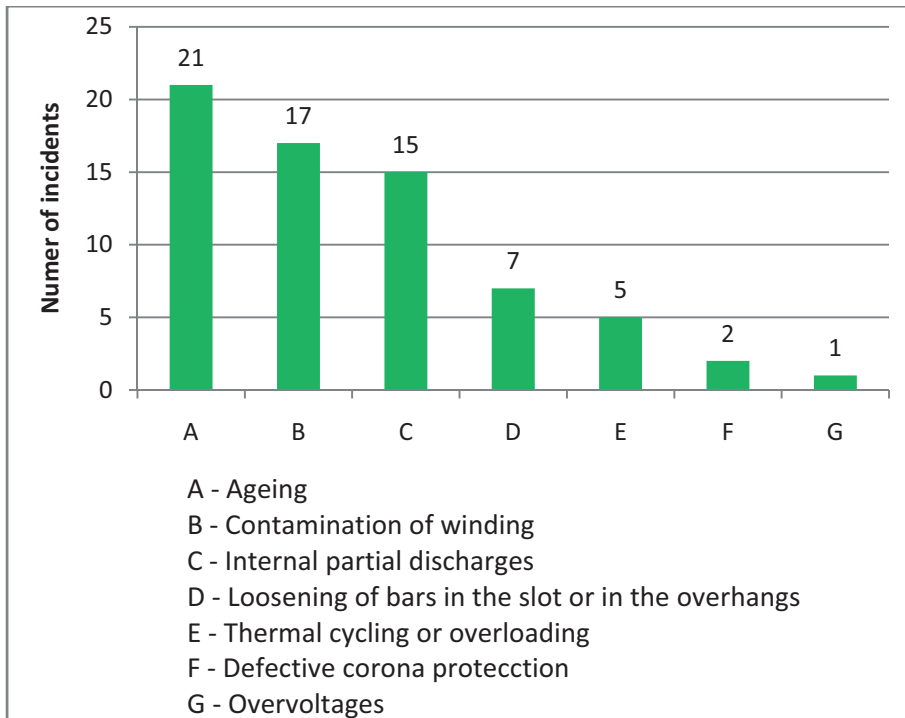


Figure 8: Insulation root causes considered

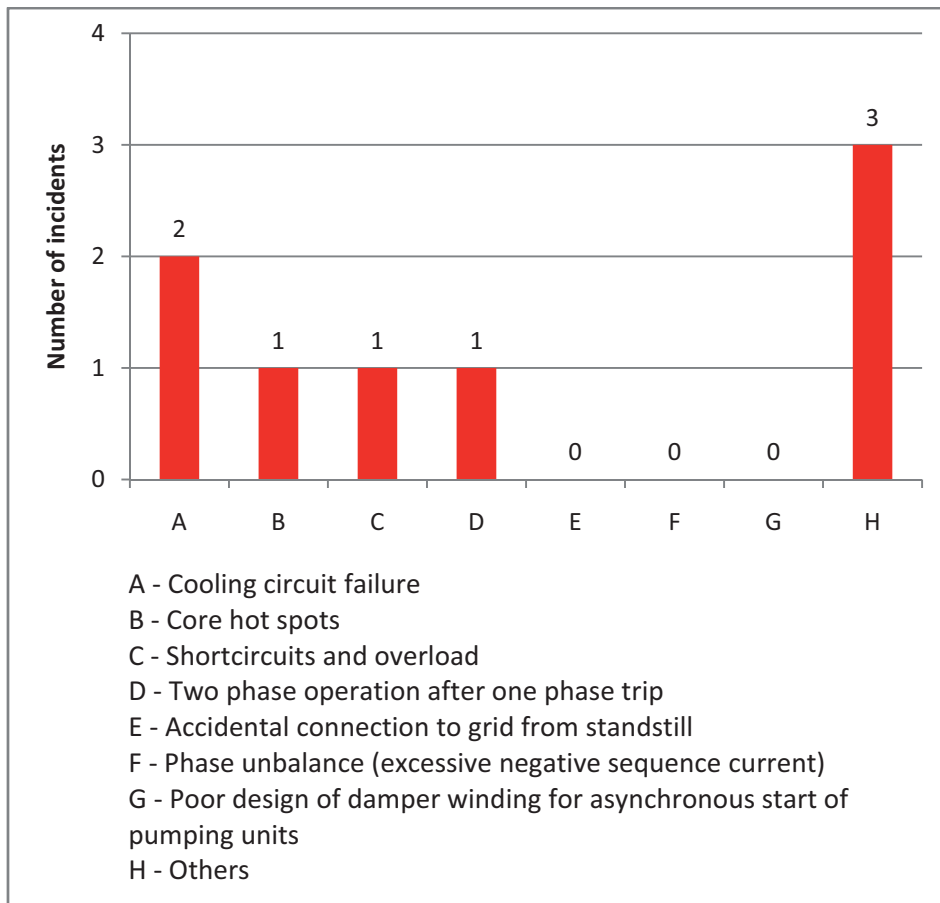


Figure 9: Thermal root causes considered

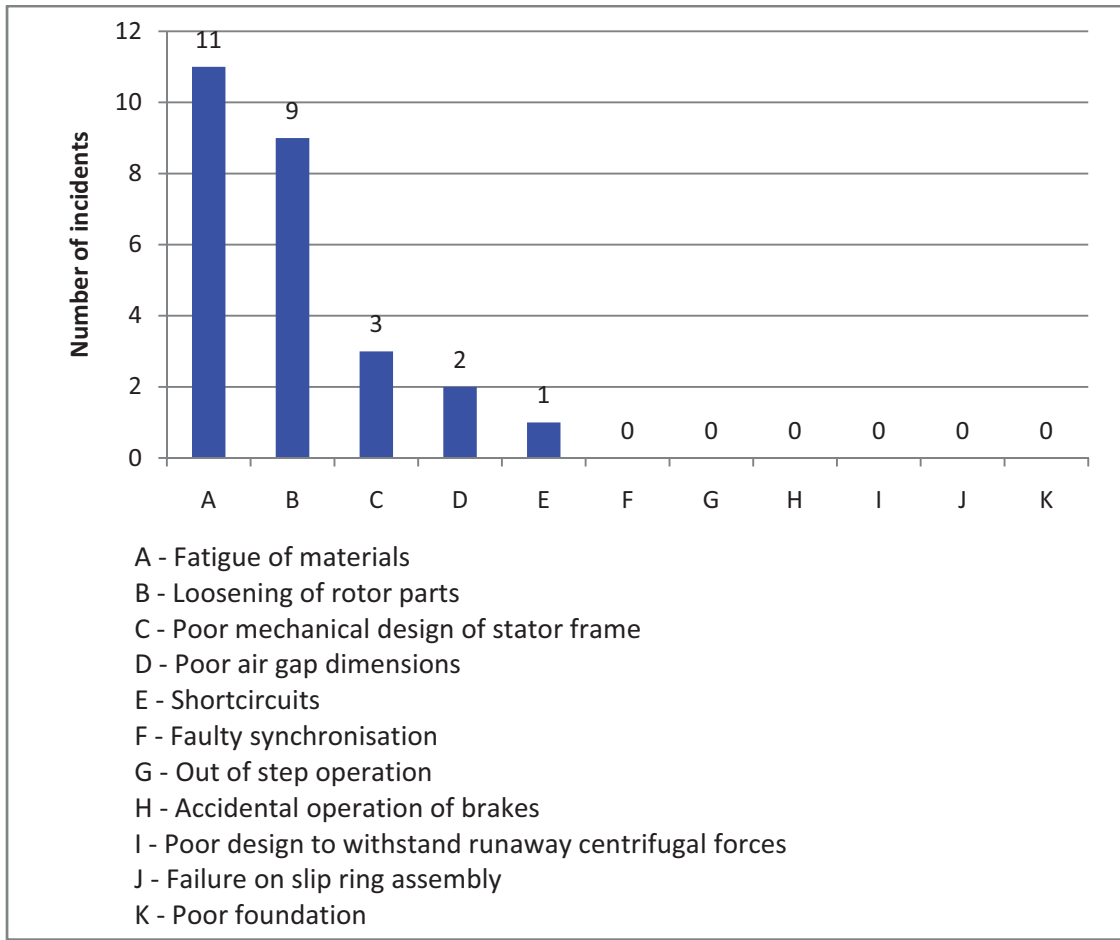


Figure 10: Mechanical root causes considered

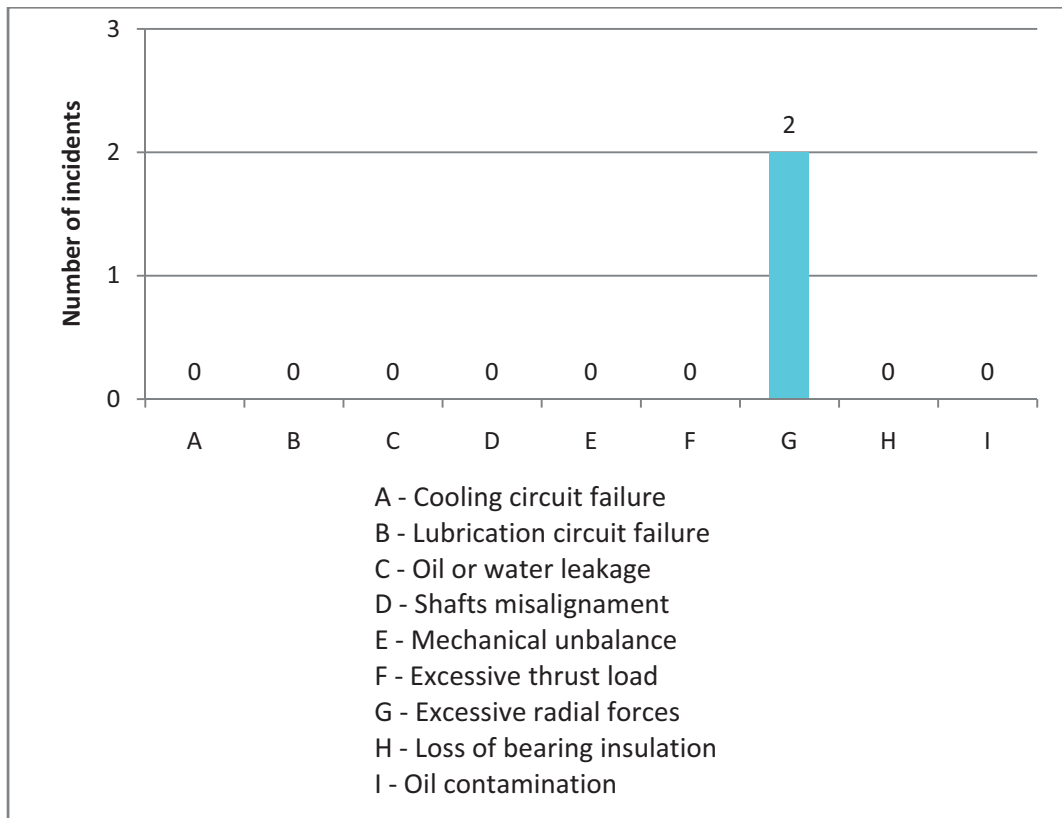


Figure 11: Bearing root causes considered

Three significant insulation root causes predominate: ageing (32.8%), winding contamination (24.3%) and internal partial discharges (24.3%). Somewhat behind are two mechanical root causes: fatigue of materials (15.7%) and loosening of rotor parts (12.8%).



There are two main aspects to bear in mind to observe the severity of a failure: the extent of damage and the outage produced. An infrequent failure that produces a very long outage is as severe as another more common failure which produces shorter outages.

Figure 12 shows the relation between the root cause of failure and the extent of damage. As can be seen, the more destructive failures are those originated by insulation root causes (three incidents with an extent of damage over 30%).

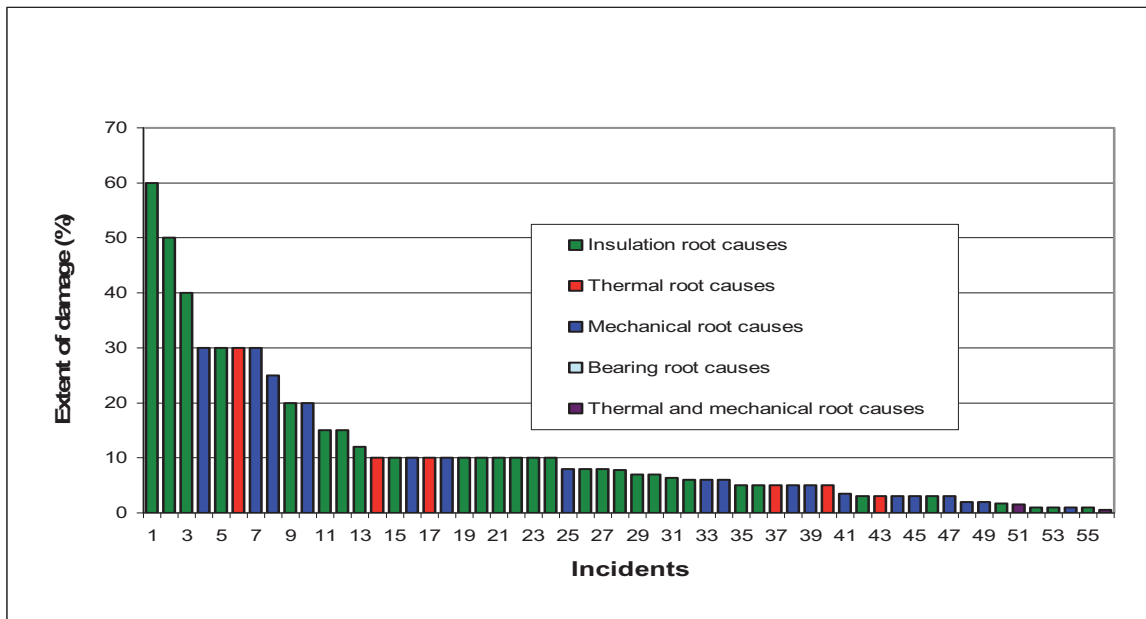


Figure 12: Distribution of the incidents by root cause of the failure and the extent of damage

Figure 13 shows the relation between the root cause of failure and the outage. In only one incident the outage was more than 200 days (due to mechanical root causes), but for eighteen incidents (25%) the outage was more than 100 days and for forty one incidents (60%) the outage was more than 50 days.

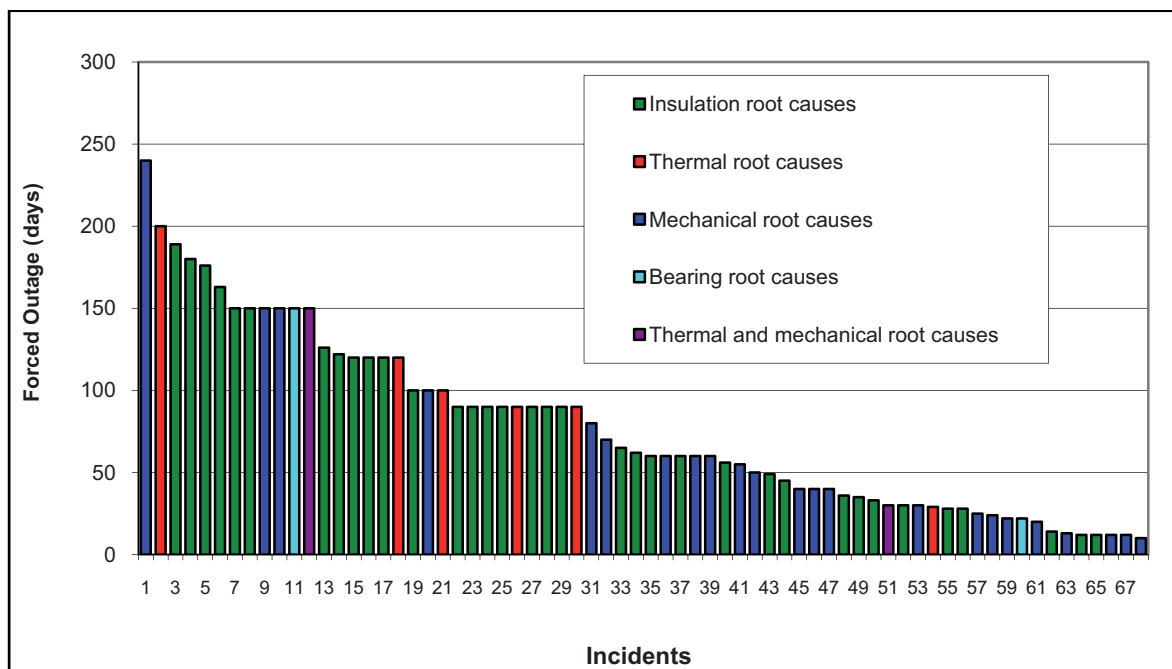


Figure 13: Distribution of the incidents by root cause of failure and outage

3.3 Nature of the failure

Now that we are aware of the failure occurrence, severity and their causes, we shall concentrate on how to prevent those root causes.

Figure 14 shows the nature of failure. Material weakness comprises 50% of the occurrence, followed by design weakness with 27.9%.

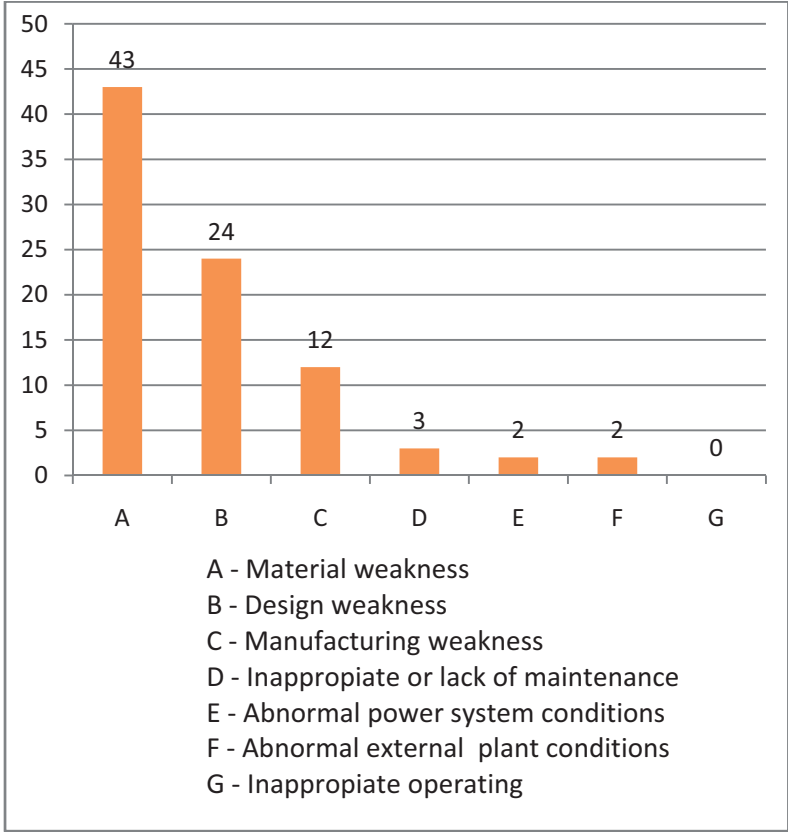


Figure 14: Nature of failure considered

User intervention figures in only 8% of the cases and manufacturers are at fault for the remaining 92%.

It must be said that almost all the responses were from utilities and only one was from a manufacturer. Therefore, it is perfectly understandable that the results of this survey strongly imply manufacturers for problem origins.

Furthermore, the average age (in years) and the average run hours were calculated for the three most important types of failure considered (see table 2).

Table 2: Most important types of failure considered

Types of failure	AGE average (years)	Run average (hours)
Material weakness	30.4	130,567
Design weakness	28.8	126,222
Manufacturing weakness	23.1	56,567

The scores shown in figure 14 are not consistent with the results of table 2. Material weakness is a type of failure observed in 63.24% of the failures but at same time the age average for that type of failure is 30.4 years and the run average is 130.567 hours. If material failure was present in so many failures we would expect a failure to appear in the early years of operation.



Similar reasoning could be applied to design weakness, but in the case of manufacturing weakness this line of argument weakens.

Nevertheless, manufacturers are responsible for possible hidden defects. Around 6% of the failures observed occurred during the first four years of operation, with an average force outage of 65 days.

Once the generators are delivered and commissioned, and the guarantee is over, the responsibility for machines fall on users, and they have two ways of reducing the risk of failure.

3.4 Risk reduction methods

On one hand, risk reduction methods can be adopted, in order to minimize root causes.

Figures 15 to 18 show influence of the risk reduction methods on root causes. Some of these root causes (bearing and thermal ones) are low sensitive to the risk reduction methods (marginal help is around or higher than significant help). But insulation and mechanical root causes are very sensitive to some of the reduction methods such as:

- major refurbishment
- improved maintenance techniques

for insulation root causes and:

- improved quality control during design, manufacture and assembly
- increase design requirements
- major refurbishment

for mechanical root causes.

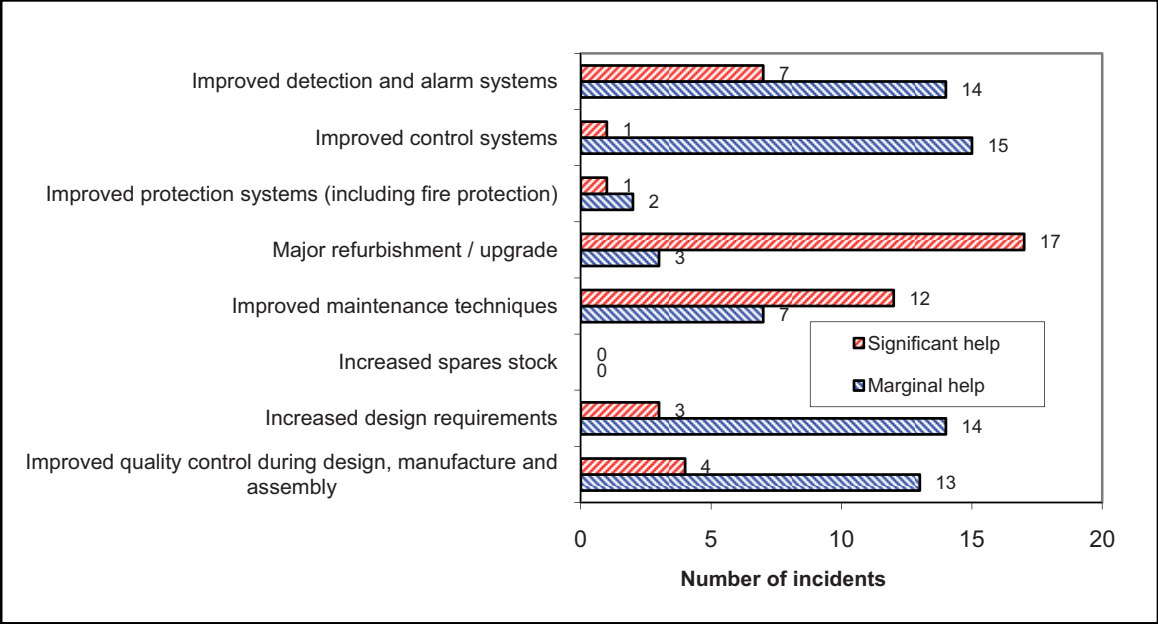


Figure 15: Influence of risk reduction methods on the insulation root causes

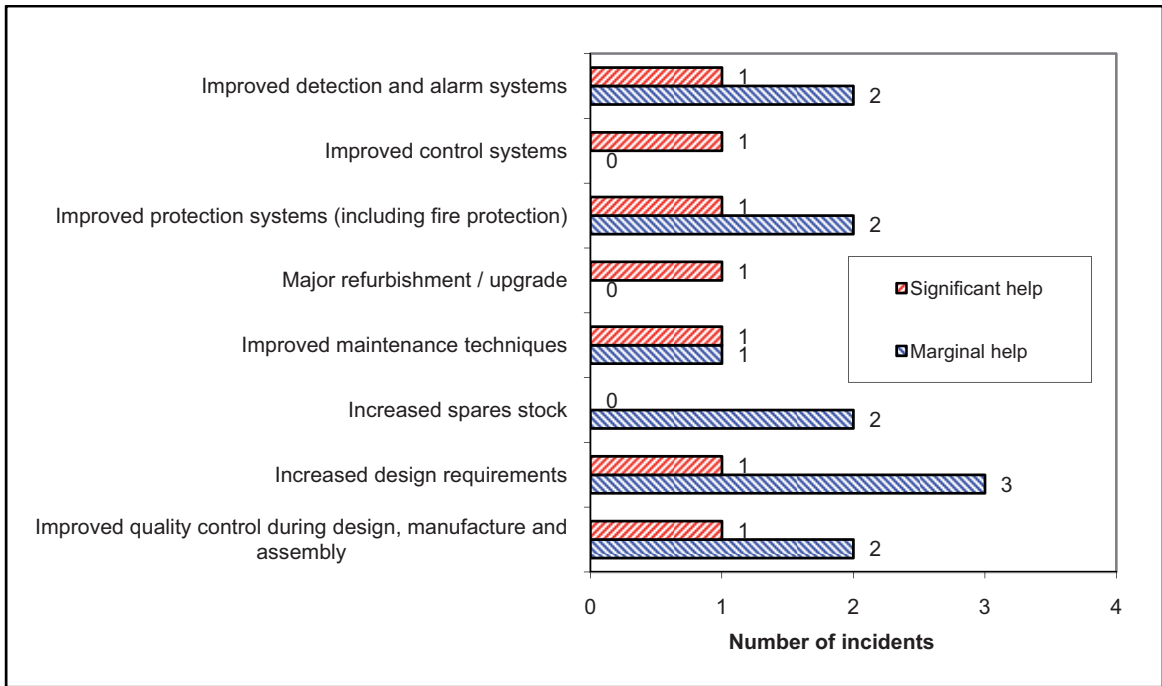


Figure 16: Influence of risk reduction methods on thermal root causes

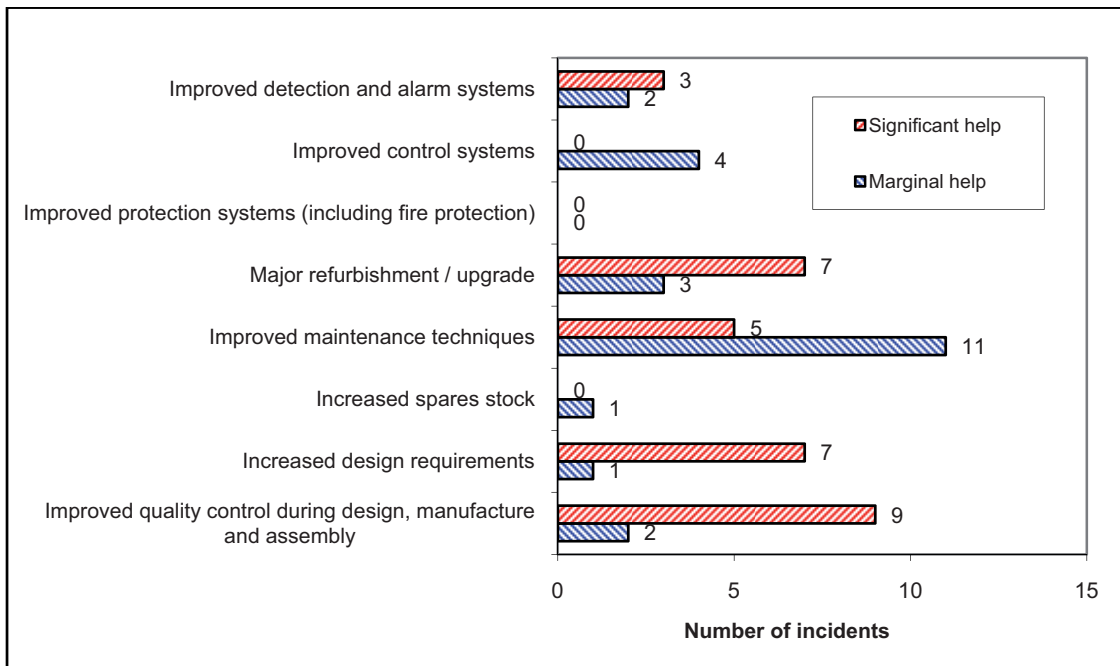


Figure 17: Influence of risk reduction methods on mechanical root causes

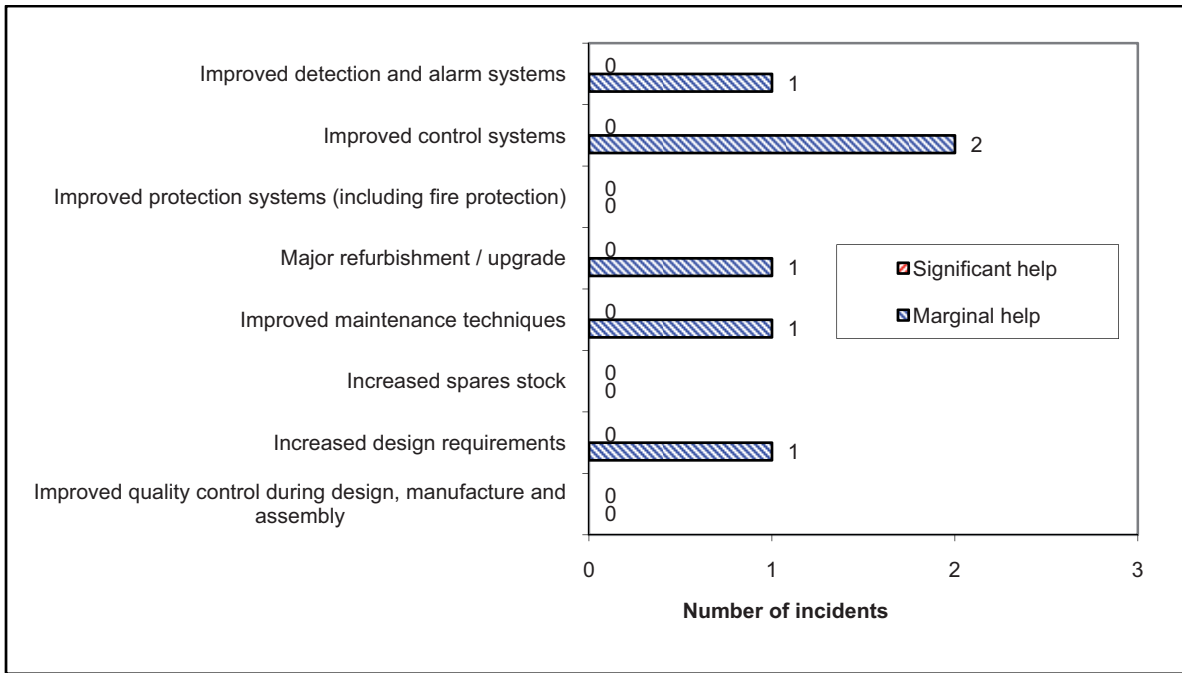


Figure 18: Influence of risk reduction methods on bearing root causes

It should be noted that mechanical root causes are likely to be related to manufacturing process, and insulation root causes are related to ageing and degradation, in a one-way process. Maintenance techniques can slow down this process but only a major refurbishment will recover initial or even higher performances.

Utilities try to delay high-cost refurbishments and at the same time, manage a low failure occurrence. Condition monitoring is the tool used for utilities to achieve this.

3.5 Condition monitoring

Figures 19 to 22 show influence of the condition monitoring methods on root causes. It is surprising that vibration monitoring (stator/core, end windings and bearings) has a lot of influence on insulation root causes. Partial discharge monitoring is another well known method highly appreciated and, day by day, becoming more present in power plants.

On the contrary, vibration monitoring (stator/core, end windings and bearings) has a marginal influence on mechanical root causes. This reinforces the idea that mechanical root causes have to be tackled by manufacturers.

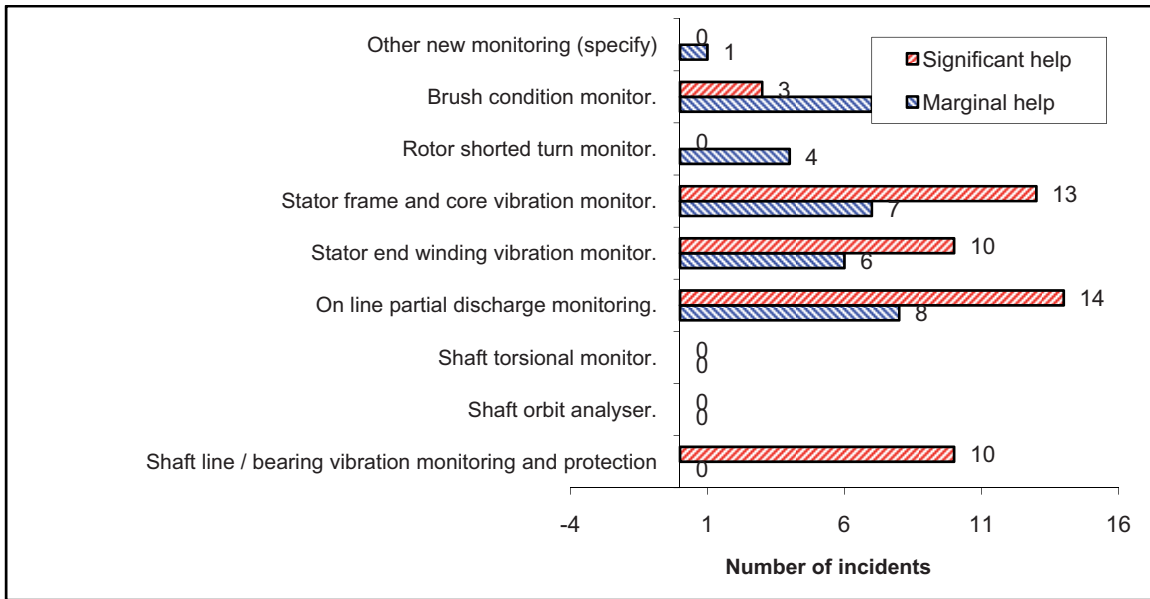


Figure 19: Influence of condition monitoring methods on insulation root causes

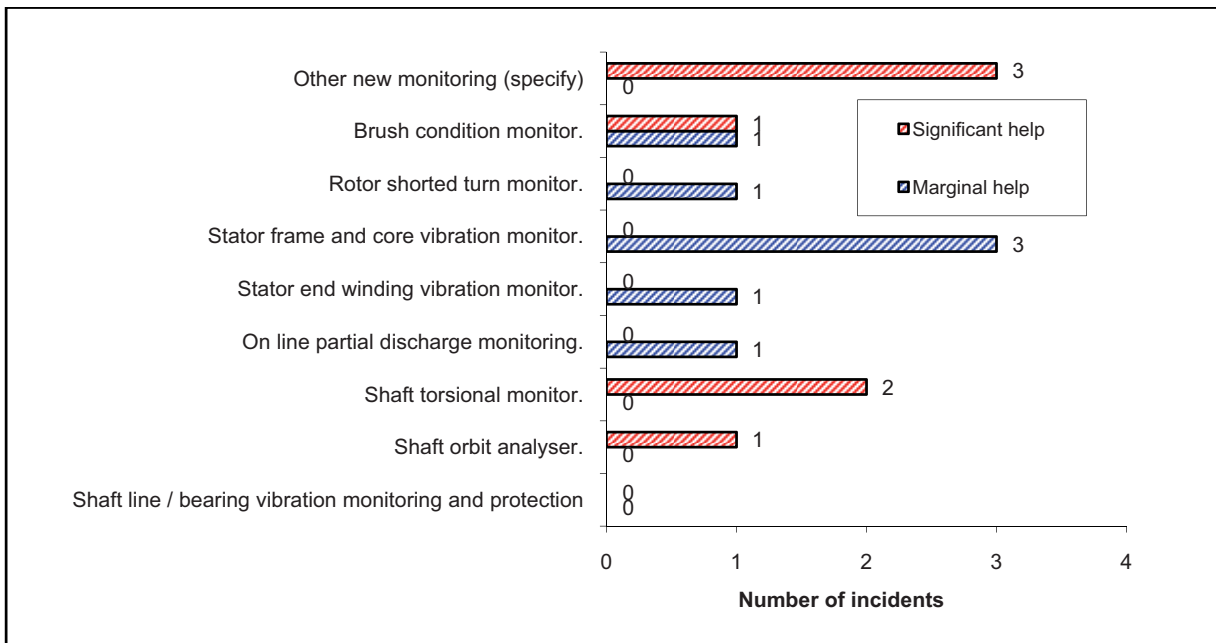


Figure 20: Influence of condition monitoring methods on thermal root causes

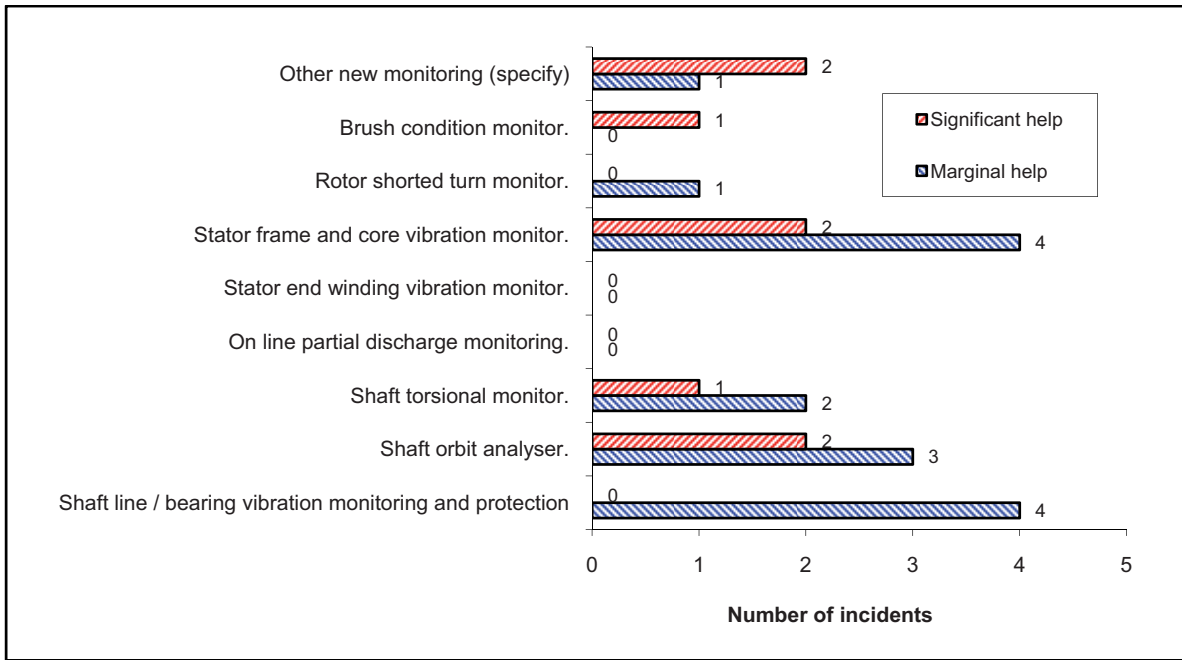


Figure 21: Influence of condition monitoring methods on mechanical root causes

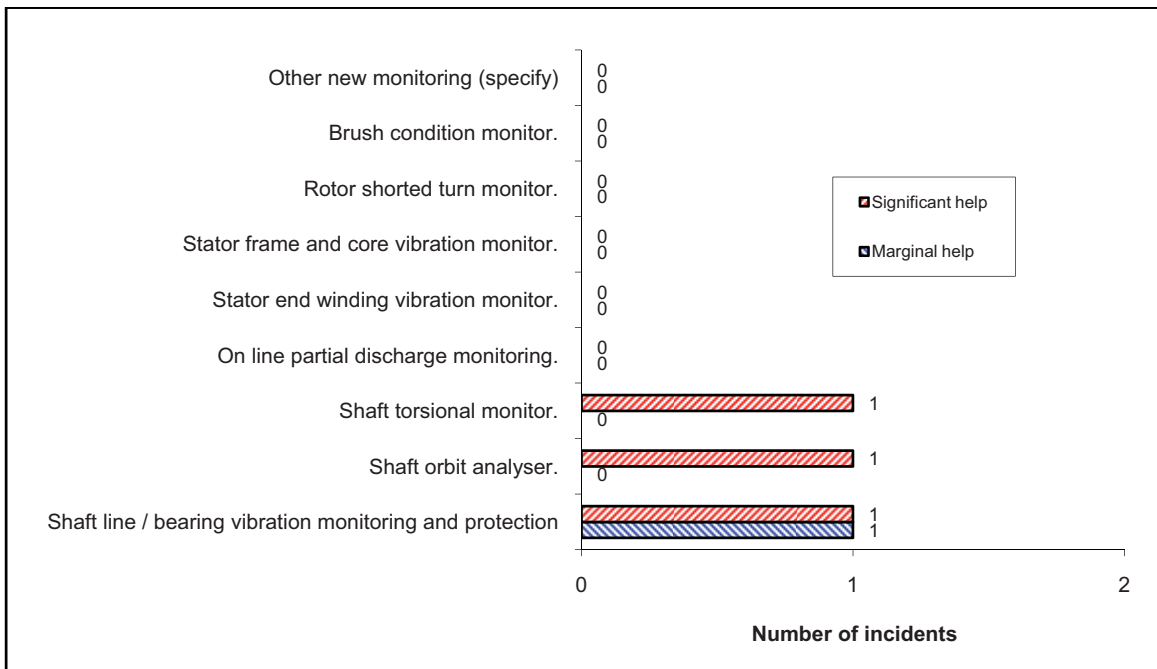


Figure 22: Influence of condition monitoring methods on bearing root causes

The new monitoring methods specified in the responses are:

- End-winding flux monitoring
- Air-gap monitoring
- Detection of hot spots by cooling air analysis

although the latter is not a monitoring method.

Unfortunately, not all the new monitoring methods were specified in the positive responses.

4. CONCLUSION

The results of this survey show that insulation damages are the most frequent failures (57%) and those that produce the greatest extent of damage (in some cases above 30%).



The failure root causes distribution is similar to the damage one, but some of the insulation failures originate in mechanical root causes.

Another important aspect to observe the severity of a failure is the outage produced. The cost of a small but very frequent failure can be similar to another more unusual but more destructive one. It should be borne in mind that the severity (extent of damage and outage) of a mechanical, thermal or bearing failure can be as important as that of an insulation failure.

Insulation failure root causes seem to be more evolutionary and time sensitive than others (mechanical, thermal and bearing). Therefore, the responsibility for reducing these latter root causes falls mainly upon manufacturers (accurate design, high quality standards, etc.) on one hand, and on the other hand, responsibility for hydrogenerator condition assessment falls upon users (partial discharges monitoring and vibration monitoring are the most valuable) as it is vital to foresee future failure occurrence to plan adequate corrective measures. Unfortunately, although condition monitoring methods remain a very effective means of dealing with insulation failure root causes, they are less effective with the other causes.