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REPORT ON SURVEY TO ESTABLISH PROTECTION PERFORMANCE DURING MAJOR DISTURBANCES

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REPORT ON SURVEY TO ESTABLISH PROTECTION PERFORMANCE DURING MAJOR DISTURBANCES

By
Working Group 09
of
Study Committee 34

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1 INTRODUCTION

Over the past decade the electricity supply industry (ESI) has been subject to dramatic change. This has resulted both from corporate restructuring and technological development. One of the primary drivers in today's ESI is the trend to maximise asset utilisation. A survey, to cover this period of unprecedented restructuring in the ESI, on the behaviour of protection schemes during large system disturbances was deemed a suitable starting point for the work of WG34.09 Optimisation of Protection Performance during System Disturbances. To initiate this activity a questionnaire was prepared and circulated early in 1998.

2 QUESTIONNAIRE

The objectives of the questionnaire were to:

- review significant disturbances which have occurred since 1986 (i.e. where load loss exceeded 1 system-minute or generation loss exceeded 10% peak demand);
- identify and categorise the cause and nature of the disturbances;
- collect user experiences relating to behaviour of protection and control systems during such disturbances.

Country	No. Responses	No. Utilities
Brazil	3	1
Canada	1	1
Czech Rep.	1	1
France	1	1
Germany[1]	1	Various
Ireland	12	1
Italy	1	1
Japan	6	5
Malaysia	1	1
Norway	2	1
Portugal	7	1
South Africa	2	1
Spain	6	3
Sweden[1]	1	Various
Switzerland[1]	1	Various
United Kingdom[1]	1	3
USA[2]	23	21
Totals 17	70	42+

[1]No major disturbances reported
[2]All responses based on NERC records.

Table 1: Response to Questionnaire on Protection Performance

The questionnaire was circulated - mainly through the SC 34 members - to 29 countries. It was composed of five parts dealing with information on different aspects of the disturbance:

- general information on the network and the utility.
- the status of the network prior to the disturbance.

- the disturbance, its cause and development.
- the performance of protection and control during the disturbance.
- the influence of the disturbance on the operational and control philosophy of the utility.

A total of 70 responses were received from over 42 utilities in 17 countries. See Table 1. Apart from 4 countries that recorded no disturbance in excess of the severity levels indicated in the time period concerned, over 60 major incidents were described. Table 1 refers.
The evaluation and analysis of the questionnaire responses attempted to identify common behavioural patterns for the different networks surveyed and to examine the role played by protection equipment in curtailing or exacerbating the disturbance.

3. DETAILS OF DISTURBANCES

3.1 General

Questions 2 and 3 in the Questionnaire dealt with the network data prior to the disturbance and the description of the entire disturbance (date, period, causes, severity, conclusions…). The level of response relating to system data immediately prior to the disturbances was poor. Consequently the available information was inadequate for reaching any particular conclusions. Table 2 indicates the severity of the different disturbances. Many responses did not indicate disturbance severity.

	No. of Disturbances by Region						
Severity	Asia excl. Japan	Japan	North America	South America	Africa	Europe	Total
1			2		2	8	12
2		1	2	3		7	13
3	1					1	2
Total	1	1	4	3	2	16	27

Disturbance severity category as defined by CIGRE SC39 in terms of system minutes:
1-Energy loss between 1 and 9 system minutes. 2- Energy loss between 10 and 99 system minutes.
3-Energy loss between 100 and 999 system minutes.
System minute = system peak demand interrupted for one minute.

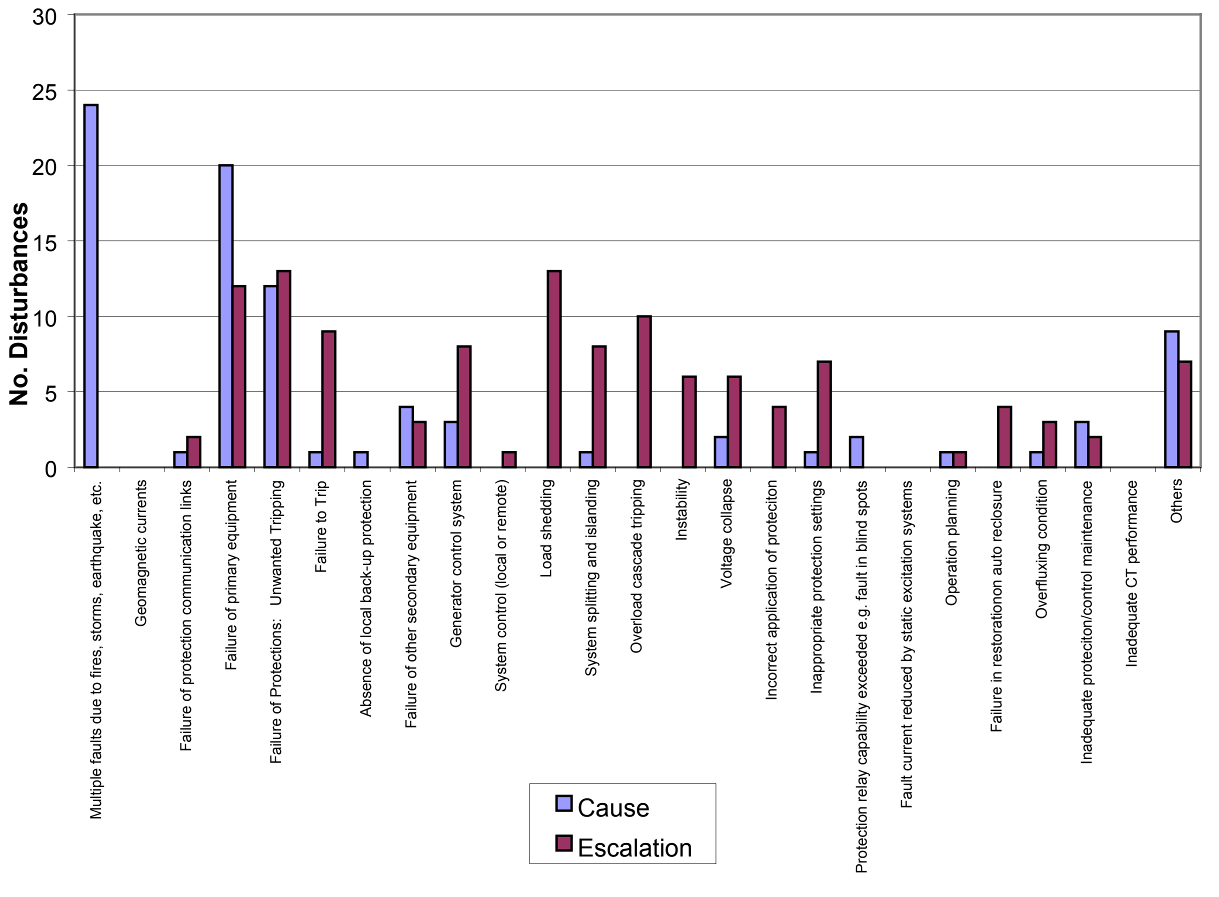
Table 2: Summary of Disturbances – Level of Severity

3.2 Causes of disturbances

The initial causes of the disturbances are shown in Table A1, Appendix A and summarised in Figure 1. The causes of disturbance escalation are also indicated. These allow classification of events in terms of the primary cause of each disturbance and are grouped as follows:

- Multiple faults due to natural events:Vegetation fires, storms, earthquake etc. (24 cases).
- Failure of primary equipment (20 cases).
- Protection maloperation (13 cases).
- Other causes (9 cases)
- Miscellaneous (20).

Figure 1: Immediate Causes and Factors Escalating the Disturbance



3.2.1 Multiple faults due to Fires, Storms, etc…

Twenty four disturbances are linked to such situations. Of these eight disturbances were due to fire, thirteen to storms, two to sabotage, and the last one resulted from an earthquake.

3.2.2 Failure of primary equipment

The failure of primary equipment was the immediate cause of twenty disturbances reported in the survey. Initiating factors were faults on insulator chains, busbars, transformers or directly on lines. These were not linked to an external event (e.g. lightning, fires, etc.) but to internal failure of the equipment that initiated widespread tripping of plant.

3.2.3 Failure of Protection

The cases analysed were those where protection failure or maloperation of a relay either directly caused or escalated the disturbance. Thirteen disturbances were due to protection maloperation. Twelve cases concerned incorrect tripping by protection relays of lines or other electrical plant. Six of these unwanted tripping cases occurred in North America. Some European countries also experienced similar events. Typical is a disturbance that occurred in 1987. It involved a three phase to earth fault on a 220 kV line. The intertripping on the faulted line failed to trip the remote end. The fault was not cleared for 400ms causing a prolonged voltage depression which led to the tripping of two generators. In addition, a distance relay on a generator transformer tripped in error causing the loss of a further 270 MW. This example illustrates both the effects of protection failure to trip and of unwanted tripping. Other disturbances linked to the failure of a protection are similar to these two examples.

In twenty two cases, protection relays were responsible for the evolution of the disturbance either through failure to trip (9 cases) or unwanted tripping (13 cases).

3.2.4 Other Failures

Controllers on generators and their associated prime movers are frequently responsible for generator trips. In four of the nine disturbances reported, the causes were due to problems of this nature. In two cases, human error was the cause. In two further cases, significant imbalance between demand and generation destabilised the system, and in the last case, the fall of a tree on a line caused a trip/lockout at both line terminals. The following are typical examples.

An incident in 1993 occurred when two generators tripped 68 seconds apart. The first was due to boiler control problems. The second occurred because of problems with the automatic voltage regulator (AVR). This resulted in the loss of 439 MW of generation, 310 MW of load and 140MWh of energy. Triggering causes on other disturbances were excitation controls and oil pressure gauges.

Two examples of human error creating disturbances were also reported in Europe. In the first incident an operator initiated a line fault by erroneously closing the busbar isolator of an earthed 400kV line (the circuit breaker was already closed). In the second, an operator dropped a portable earthing rod on a busbar.

The last disturbance reported arose in Japan in July 1987 due to an error in the provision made for demand. The system demand started to increase just after the lunch break at a level considerably higher than expected due to high temperature. The rate of demand increase was also much greater than estimated. Although capacitors were quickly connected to control the rapidly increasing reactive power demand, the total supply of reactive power was insufficient. Voltage collapse ensued resulting in the loss of 1,775 MW of generation, 8,168 MW of load and 10,823 MWh of energy.

3.2.5 Miscellaneous

In the case of twenty responses various reasons were given as the primary cause. The complete list is shown in the Appendix A, Table A1. A few factors arose more than once e.g. secondary equipment failure other than protection (4), inadequate protection maintenance (3), generator control systems (3), protection blind spots (2). There was no particular trend evident from the disparate nature of these responses and it is difficult to draw firm conclusions.

3.3 Conclusions and Lessons Learnt

Thirty three of the questionnaires registered various degrees of significant "lessons learnt". The remainder either made no comment or comments without significance in the wider context. For example actions which address specific defects have no significance in the wider context apart from highlighting how basic errors or deficiencies can either cause or exacerbate system disturbances.

3.3.1 Equipment Settings

There were five references to settings problems which are summarised below.

- System dynamics studies would have been very beneficial in order to optimise AVR settings.
- Periodic reviews of protection scheme application and operation should be undertaken so that there is adequate co-ordination between interconnected systems.
- Special schemes should be reviewed and evaluated to ensure that they remain effective independent of seasons, power transfers or system configurations.
- The remaining two refer to wrongly applied fast timer settings on CB Fail timers and an inappropriate delay between alarm and trip on an overload setting.

3.3.2 Personnel Training

There were six references to staff training. With the exception of one, which recommends training as a result of a fundamental mistake during switching, the others are concerned with staff's ability to deal with a developing system disturbance or its aftermath. The recommended actions for implementation are summarised below.

- Training should inculcate an awareness of the conditions that can cause system oscillations and possibly require remedial actions.
- Additional training for dispatchers in the operation of a "remedial action scheme" and procedures for restoration of the HV and lower voltage systems in a more expeditious manner.
- Training to prepare staff to respond to sudden system frequency, voltage and stability events using simulation techniques where possible which should provide an insight into the response of individual generators.
- Training to improve communication skills of staff likely to be dealing with emergency situations e.g. system operators, maintenance supervisors, etc.
- The preparation of a co-ordinated system restoration plan addressing sectionalisation, intersystem communication and co-ordination of system switching. Ensuring that operational personnel are always trained and capable to efficiently implement such procedures.

The above items clearly have a large degree of overlap and have a common goal of developing staff's skills to manage and minimise major system disturbances.

3.3.3 Telecommunications Facilities and Communication Generally

There were nine references in this category which are summarised below.

- The provision of adequate telecommunications within regions and between interconnected systems to deal with system emergencies is essential.
- The screening and prioritising of incoming phone calls is necessary as continuous call answering diverts staff from essential actions.
- Better staff communication would have been beneficial in many cases to achieve co-ordination of actions during system problems. In one case a specifically provided "hot line" was not used.
- The provision of conferencing facilities would improve speed of decision making.

There were also examples of good practice in communications. These were provision of pre-programmed pager messages, an internet bulletin board and terminals which enabled the event and associated restoration measures to be viewed. This latter feature facilitated the return to service of plant on planned outage.

3.3.4 SCADA

There were five references to SCADA problems. These are summarised below.

- In a number of cases poor SCADA reliability was an aggravating factor.
- Better organisation of SCADA displays would have simplified operator tasks
- Lack of time synchronisation of events reported via SCADA
- Dynamic scheduling for remote generation could be achieved by exchanging real-time operating data

3.3.5 Voltage Related Problems

There were six references to voltage problems: avoiding them, dealing with them and minimising their effects. These are summarised below.

- A major voltage collapse was exacerbated by the action of automatic tap changers trying to re-establish volts beyond the system's capability leading to further loss of generation. Automatic blocking devices have since been installed.
- Two questionnaire responses discussed the effect of motors stalling during voltage dips. This extends the dip well beyond the fault clearance time causing further load related problems and leading to load shedding over and above the designed value for undervoltage. This is particularly problematical with air conditioning motors and there appears to be a need for solutions tailored to the load profile.
- Another response was more concerned with system restoration. This was prolonged by trips of circuit breakers as a result of loss of volts in an area of blackout. More selective use of this (undervoltage or no-volts tripping) is proposed in order to re-establish some of the load more quickly and reduce the number of control actions.
- The remaining two responses dealt with the problem of generating station auxiliaries dropping out due to low volts. In one case solid state contactors and capacitive support for volts were investigated for short term dips. The other referred to a very slow fault clearance resulting in a trip of several units to their house load, only one of which was successful. A design review into voltage dip proofing is ongoing.

3.3.6 Specific Lessons Learnt Which May Have Wider Implications

There were a number of references in questionnaire responses under this category which are summarised below.

- In one case the system disturbance was initiated by a major fire that was spreading rapidly requiring co-ordination between various government and non-government bodies. In cases such as this it was proposed to use a common GIS mapping system on which the transmission lines would be superimposed enabling the supply utility to get first hand information on the path of the fire.
- A controlled islanding scheme was deemed to be very desirable to minimise loss of generation and demand that results from random islanding.
- Credible multiple contingency outages should be considered in the system planning process.
- Circuit switchers in lieu of circuit breakers are not appropriate for items of plant such as shunt capacitors or reactors which are subject to frequent operation.

Analysing the questionnaire responses was impeded by the lack of uniformity in the recording of information by the respondents. Furthermore a lot of questions received no response. For example, the lack of comparable data on generation/load/energy loss prevented analysis of the impact of the disturbances in that context. Nevertheless definite indicators are available from the survey. While the avoidance of large scale disruption is probably impossible during catastrophic natural disasters protection maloperation together with primary plant failure were primary causes in many disturbances (see Figure 1). In terms of escalating the disturbance protection maloperations and other related relaying functions such as inadequate settings, failure of load shedding relays, cascade tripping, etc. played a significant role. Clearly there appears to be considerable scope for improvement in the area of protection and control. Staff training and improved communication skills between personnel when dealing with emergencies were also identified as issues to be addressed.

4. PERFORMANCE OF PROTECTION AND CONTROL

The questionnaire asked for the ranking of performance according to the following criteria:

1 = very unsatisfactory ⟷ 5 = highly satisfactory;
6 = not applicable; 7 = Notes; 8 = no information.

In the initial analysis the responses were grouped into two broad categories: applicable and non-applicable responses. Applicable refers to those responses that indicate a definite result or score (i.e. 1, 2, 3, 4 and 5 in survey). Non-applicable indicate responses which gave no information e.g. No Information, Non Applicable or no response at all to the question. The following analysis concerns applicable responses only and the results are summarised in Appendix A.

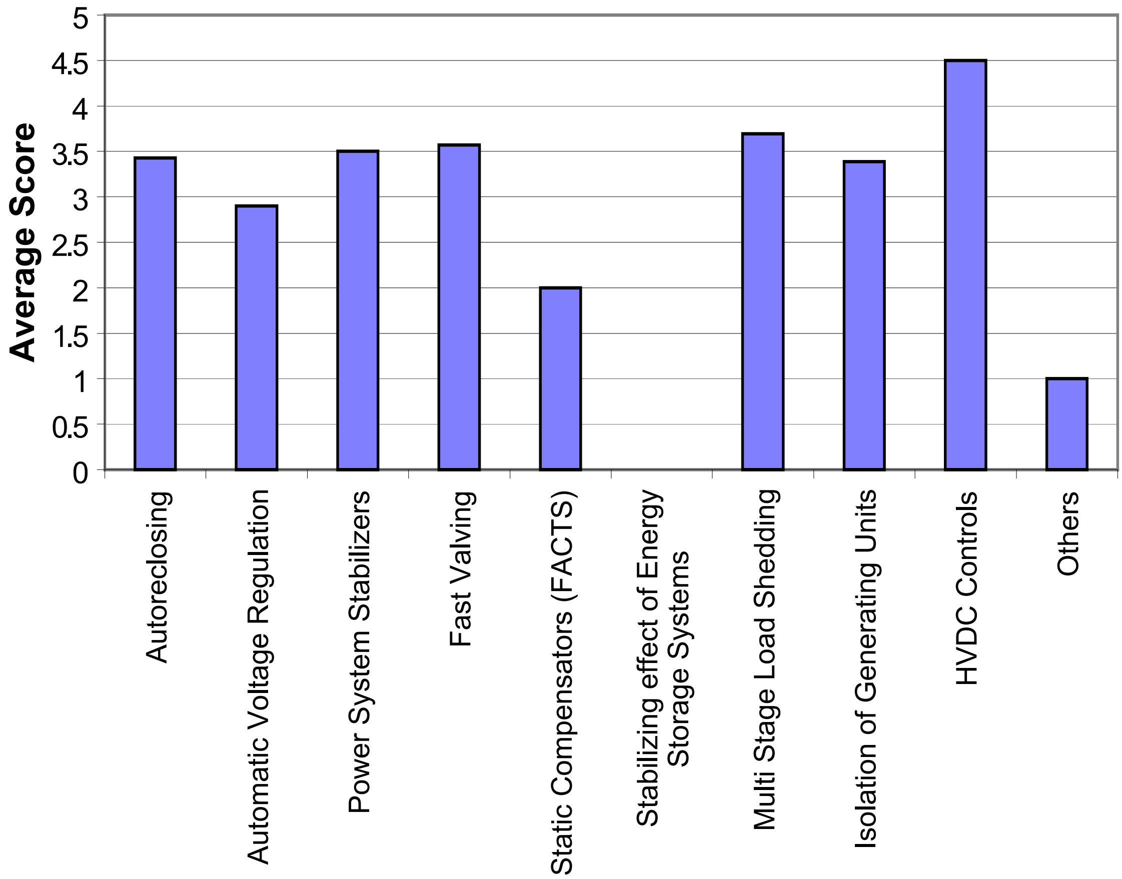
4.1 Evaluation of Power System Dynamic Performance

The various control features should enable the "healthy" plant to ride-through the disturbance caused by the fault and the subsequent tripping of the faulted plant
This is evaluated under the following headings:
Auto-reclosing – Faulted lines are assumed to have been subjected to a transient fault and are re-energised to re-establish the system. This is particularly important under extreme weather conditions when many faults occur over a wide area in a short time-scale.
Automatic Voltage Regulation - The rapid raising of excitation to maintain machine terminal volts to prevent pole slip and loss of generation during faults.
Power System Stabilisers - These should act to counteract system oscillations that frequently arise as a result of faults or routine switching. They usually feed another signal into the AVR which without intervention could exacerbate the oscillation.
Fast Valving - Method of rapidly adjusting steam conditions to match a drop in load.
Static Compensators (FACTS) – The application of power electronics to modify system parameters. This contributes to transient stability and power oscillation damping.
Stabilising Effects of Energy Storage Systems – Provides short term instantaneous energy reserve
Multi-stage Load Shedding – This is a means of rapidly reducing load to match available generation. (It is also scored as a protection function under 4.2).

Isolation of Generating Units – Isolation of generation should either be to reduce a surplus or, after attempting remedial action, to isolate the generator in order to prevent it being damaged by a continuing system problem. This latter case is really a protection function rather than a control function.
HVDC Controls - Ability of HVDC controllers to rapidly respond in regulating power flows and support system stability

Results are detailed in Table A2 of Appendix A and summarised in Figure 2.

Figure 2: Power System Dynamic Performance



4.1.1 Auto-reclosing

Auto-reclosing was the most frequently scored function (23 responses) indicating a general application throughout most networks. Thirteen events were scored as 5 or 4. A number referred to extreme weather when the rapid restoration of circuits was critical and appeared to have been successful. Three were scored at 3, some being basic hardware failures which did not effect the principle of the application. The remaining scored 1or 2 and consisted of:

- One where the situation was made worse (network heavily meshed and application being reviewed).
- One where the reclaim time was a problem because of its long setting.
- Two where there appeared to be basic scheme design problems.

- Three which gave no, or unclear, supporting information

Mean score: 3.4

4.1.2 Automatic Voltage Regulation

Of the ten responses there were three scores of 5. In one case the remaining generation had to survive the loss of two large generators 10 minutes apart while load was reduced and reserve generation was brought on stream. Another case involved slow clearances and islanding. One score of 3 related to a very slow clearance, protection maloperations and consequently power swings leading to voltage depression and overfrequency. The AVR's responded correctly but reverse power conditions caused "trip to house load" schemes to come into play. Basically the AVR can only deal with terminal voltage and the limited success in the particular case was entirely understandable given the duration of the fault. A score of 2 was given to an incident caused by a rapid increase of reactive load that exceeded the available system's capabilty. Application of power capacitors and AVR action were used to reduce the voltage drop but some protection operations exacerbated the situation. There is no indication that the AVR's did not perform to their capabilities rather that high network frequency ultimately resulted in some loss of generation. In the three scores of 1, the AVR action was not in question, rather its co-ordination with over excitation protective devices.

Mean score: 2.9

4.1.3 Power System Stabilisers

Only four responses were received of which two scored 5. In one case there were two controlled curtailments of generation. The other is associated with an AVR score of 1 in 4.1.2 above. This disturbance was a voltage collapse brought about by loss of generation during a high load period. The remaining generation clearly had to cope with this. A score of 3 had no associated explanation. There was little information associated with the score of 1 but generation was lost due to too high a rate of change of frequency.

Mean score: 3.5

4.1.4 Fast Valving

Of the seven responses five had scores of 5 and 4. One of the 5's refers to two tail-connected generators one of which tripped correctly along with its associated line. The other tripped 10 minutes later due to fuel quality. The second score of 5 referred to the successful islanded operation of 12 out of 14 thermal generators. The three scores of 4 refer to generators surviving islanding although in one case the score would appear to be generous as the sets were lost due to high pressure in the burning chambers. A score of 2 is associated with the failure of the fast valving to reduce generation successfully. This resulted in tripping due to low pressure in the burning chambers and poor valving.

Mean score: 3.57

4.1.5 Static Compensators (FACTS)

Only two responses were received for this function, both scoring 2. One related to the same event as the score of 2 for AVR's in 4.1.2, namely a rapid increase in inductive load. There was reference to application of power capacitors to generate MVARS but no reference to ability to respond to system conditions automatically.

Mean score: 2

4.1.6 Energy Storage Systems: No responses received

4.1.7 Multi Stage Load Shedding

Of fourteen scores received there were seven scores of 5, two of which show the system remaining largely intact and load being orderly reconnected once the situation made it possible. In other cases the load shedding appeared to take place as planned but the situation deteriorated. Clearly there are some occurrences that cannot be planned for and others where the amount of load shed would need to be reviewed. The single score of 4 relates to a relay failure to operate at one location. The single score of 3 arose because the amount of load shed was inadequate for the event. The scores of 2 and 1 are associated with scheme failures and inadequate load shedding provision. In one case delay in implementing manual load shedding was also a factor. These issues can be resolved and correctly designed automatic load shedding schemes remain an essential weapon in reducing load to match available generation.
Mean score 3.6.

4.1.8 Isolation of Generating Units

Of nineteen responses nine scored 4 or 5. In five cases the high score related to reducing generation either automatically or by operator action in order to correct a surplus. The other cases were isolation mainly via protective devices designed to protect the generator. Four were scores of 3. Two of these related to some non-desirable trips for various reasons as well as some stabilisation after islanding. In another case tripping of the generator was incorrect but turned out to be fortuitous. In the final case the loss of generators was by correct protective action as a result of failures in load shedding. The remaining six scored 1. All concerned the tripping of excitation systems due to excessive field/stator currents as a result of system faults.
Mean score: 3.3.

4.1.9 HVDC Controls

Of the four responses three scored a 5 but also referred to some negative effects of the frequency controller. Reference was also made to incorrect hourly schedules. The other scored a 3. Some DC circuits tripped as a result of an earthquake. The other reference is to the action of a frequency controller. It exacerbated the situation by increasing power flows in an attempt to raise frequency in what was an islanded situation. This ultimately resulted in a trip when the DC flow reached 2900MW.
Mean score: 4.5.

4.1.10 Conclusions

The overall mean score was 3.6 and there were sixteen non-applicable responses.
The majority of events (65%) noted no problem with the dynamic performance of the power system. It is obvious from the responses that there is a heavy reliance on traditional forms of control (auto-reclose - 22 responses, multi-stage load shedding - 14, isolation of generating units - 19) to minimise the effects of major system disruption. AVR's got only 10 reponses although they would be expected on all generators and contribute to retaining generation during system faults. Also with a score of 2.9 their performance is less than adequate.
This implies that more modern approaches have not been widely adopted although it has to be said that many of the disturbances were as a result of extreme conditions which are probably outside the ability of systems to cope. Protection failures associated with some disturbances were unacceptably high. Furthermore tripping due to overloads or for other reasons which exacerbate the situation need to be reviewed. Of those incidents

that did experience problems 50% involved undesirable (not necessarily incorrect) operation of generator controls. For example when generation is isolated from large blocks of load the frequency increases and the generator trips due to overfrequency. This event, although not desirable, may have been correct. Other problems were incidents of out of step tripping, line overloading, failures to reclose and some underfrequency schemes that didn't operate correctly. These cases alone rarely caused any significant escalation of the event, but are noted as unsatisfactory performance. In general, with the possible exception of the generator controls issues, the performance of controls were as would have been expected. However it must be remembered that the responses referred to existing settings. Definite potential for improvement exists. Immediate examples are more system specific settings for power swing detection. The temporary adaptation of overload settings to cater for emergency situations would also clearly be beneficial.
More fundamental is the design of some systems which leave areas very weakly connected. Consequently they are susceptible to major disruption as a result of faults.

4.2 Evaluation of Protection Performance

4.2.1 Evaluation

The evaluation of protection performance is given in Table A3 of Appendix A and summarised in Figure 3. The results indicated that protection systems gave satisfactory performance in 50% of events.

For 25% of the events maloperation (i.e. unwanted operation or failure to operate) of protective relaying systems either caused or aggravated the disturbance. This resulted in more plant items being out of service than the initial fault would have required. Several of these "maloperations" however were due to line overloads. In many cases these operations while undesirable were correct based on the relay type used and the settings applied. Most of these unwanted operations occurred on transmission feeder protection (10 maloperations from 22 responses). These were due to a variety of causes: failure to trip due to wiring error, out of step blocking fault clearance, inappropriate settings, low system voltage being the more common causes. See Section 6.1.8 for further details.
Failure of the protective systems to operate correctly for a fault caused 15% of the events. The resulting back-up or remote clearing of faults resulted in multiple circuit outages.
Undesirable, but not necessarily incorrect, operations of protective equipment caused the remaining 10% of the events. For instance a fault on a weak system having a 25-cycle normal back up clearing time (e.g. distance protection, zone 2) resulted in a large voltage depression causing loads to trip off-line on undervoltage. Although not desirable, the operation was correct.

4.2.2 Conclusions

Mean score: 3.9
As indicated by the score the performance is generally good. The most significant impact of relay maloperation related to feeder protection (Score: 2.8). It is worth emphasising also that the scores relate to the impact of protection performance during disturbances. It does not indicate the effectiveness of protection per se. Most relay operations relate to isolated equipment faults or natural events and were outside the scope of this survey.
Two developments which could improve the availability of protection systems were highlighted. Proper preventative maintenance can reduce but not eliminate the number of maloperations and failures to operate. However the upgrading of protective relaying systems to modern numerical designs with self-diagnostics could improve protection availability and hence performance.
The application of distance relaying with adaptive setting facilities has the potential to avoid operation for short duration overload situations. Care should be taken in the settings used which should be carefully co-ordinated with the overload capabilities of the protected plant. This aspect also features elsewhere in the survey results.

4.3 Evaluation of Preventive and Remedial Actions.

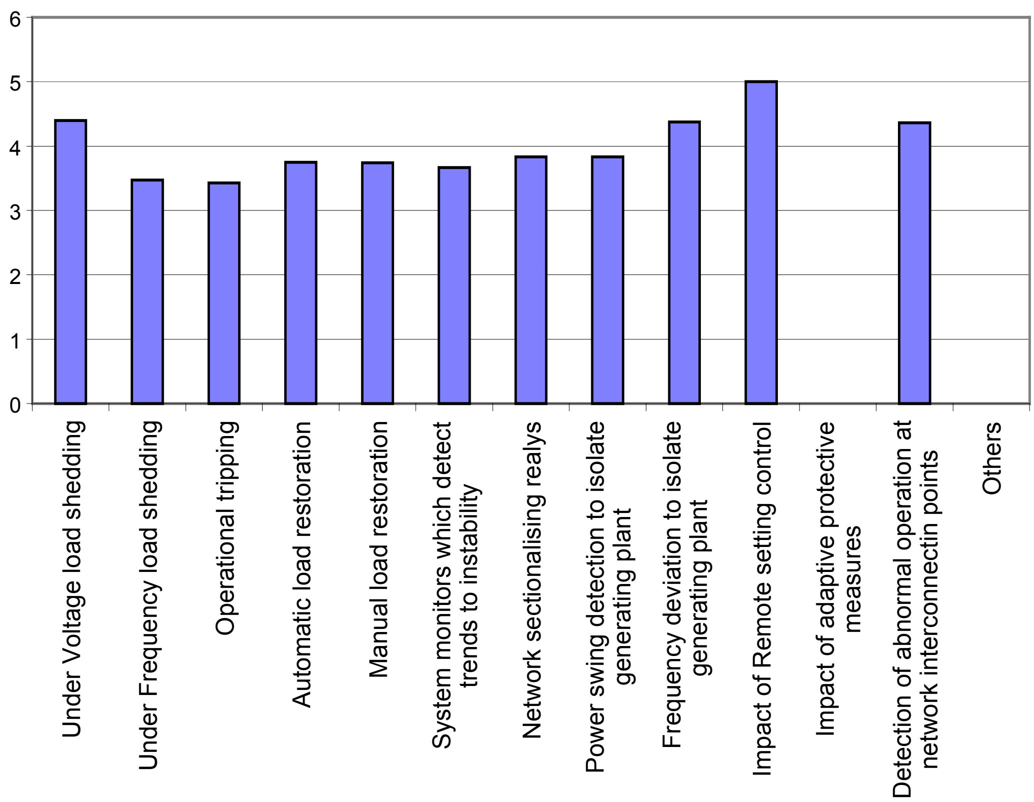
The survey results are shown Table A4 of Appendix A. Figure 4 summarises the findings.

4.3.1 Under voltage load shedding

Of five responses four indicate a highly satisfactory under voltage load shedding performance (two in North America and three in Europe). One of these disturbances occurred in July 1992 in USA. In this case, 550 MW of load were dropped due to under voltage relay action. It was the only remedial action used and it allowed the rapid recovery to normal voltage and the restoration of most load within 30 minutes. Although used by few utilities these cases suggest that under voltage load shedding seems to be very satisfactory. Incidents in Europe resulted in undervoltage tripping of

generator auxiliary loads rather than consumers although consumers were then shed due to insufficient generation. Undervoltage tripping during a WSCC (USA) disturbance mainly related to generating plant also.
Mean score: 4.4

Figure 4: Evaluation of Preventive & Remedial Actions



4.3.2 Under frequency load shedding

Under frequency load shedding schemes are widely applied. Of seventeen responses, 3 categorise this load shedding as "very unsatisfactory" and 8 as "highly satisfactory". One disturbance in North America, in August 1992, illustrated how manual load shedding was not fast enough to prevent generator unit instability. This inability to rapidly load shed caused the disturbance to escalate. Most other disturbances, by contrast, showed the beneficial influence of automatic under frequency activated load shedding. Poor performance of load shedding was usually attributable to defective relays. In one incident none of the under frequency relays operated as planned resulting in an unsustainable system overload. More attention is required to ensure better dependability as these relays perform such a critical function.
Mean score: 3.5.

4.3.3 Operational tripping

There was no particular trend from the seven responses. Experience varied from very satisfactory to very unsatisfactory. During an incident in North America in 1992, operational tripping exacerbated the problem; however in another incident 1995 (also

North America), the operational tripping facilitated a prompt solution without tripping any generator and without interrupting any customer demand. The conclusion appears to be that for operational tripping to be effective a prearranged contingency plan for the switching sequence must be in place. An incident in Europe illustrates how operational tripping performance can impact on the situation. Tripping of an intertie was initiated in accordance with operational procedures but in the particular situation it would have been much better not to trip. The operational tripping criteria were subsequently changed.
Mean score: 3.4.

4.3.4 Automatic load restoration

Automatic load restoration is not widely employed. Of the twelve responses received four were from the ESB, Ireland and four from REN, Portugal i.e. 66% of responses came from two utilities. The remainder were from Spain (3) and Brazil (1). In general the response was satisfactory with only one response indicating very unsatisfactory performance. During one incident in Ireland numerous failures of the automatic frequency restoration (AFR) scheme occurred during a disturbance in 1987. This was due mainly to a batch of faulty auxiliary relays in the AFR control system, not to poor scheme design. These were replaced by a different type of relay and subsequent operation was satisfactory
Mean score: 3.8.

4.3.5 Manual load restoration

Manual restoration is much more common than automatic load restoration. Of twenty three responses, fourteen categorised the manual load restoration as highly satisfactory. Generally manual restoration worked well if reliable system status information and remote control facilities were available on SCADA. Lack of remote control of circuit breakers in unmanned stations significantly affected the rate of restoration in a few incidents.
Mean score: 3.7.

4.3.6 System monitors which detect trends to instability

Of the six relevant responses, two show system monitors to be very unsatisfactory and four as highly satisfactory. One disturbance in particular illustrates a deficiency experienced with such a system monitor. The alarm for low frequency was the same as the alarm for high frequency leading to incorrect operator action during an emergency situation. This serves to emphasise the desirability of more comprehensive monitoring. It is only useful if it provides unambiguous information to operators.
Mean score: 3.67

4.3.7 Network sectionalising relays

Of six responses four reported very good behaviour while two responded unsatisfactorily. In one of the latter the out-of-step tripping scheme for sectionalising did not operate for various reasons (incorrect philosophy, system dynamic modeling and protection settings) - the most important factor being incorrectly located sectionalising points for the particular incident. Obviously the location of sectionalising points must be carefully chosen based on simulations of system disturbances.
Mean score: 3.8.

4.3.8 Power swing detection to isolate generating plant

Of six responses four behaved very well while two responded poorly. Poor behaviour was due to inappropriate settings. For example in one incident due to incorrect settings of a "house loading" scheme, three generators tripped unnecessarily to house load. As a result of power swing detection two further units unnecessarily shut down. Better coordination of protection setting and control would alleviate such situations
Mean score: 3.8.

4.3.9 Frequency deviation to isolate generating plant

Of eight responses the experience with six was excellent, one was good and one very poor. This approach functioned very well. Mean score: 4.4

4.3.10 Impact of remote setting control

There was only one response which, while indicating a very satisfactory (score: 5) performance, is no indicator of any particular trend.

4.3.11 Impact of adaptive protective measures

There was no response on this question. The lack of response probably indicates that adaptive settings are not yet widely employed.

4.3.12 Detection of abnormal operation at network interconnecting points

The detection performed satisfactorily in ten cases from eleven responses. In 9 cases it behaved excellently while one performance was reasonable and one poor. Therefore this type of detection seems to work well.
Mean score 4.4.

4.3.13 Conclusion

The overall score of 3.8 indicates very satisfactory performance. Furthermore scoring was high for all systems – the lowest, 3.4, applying to operational tripping.

4.4 System Restoration

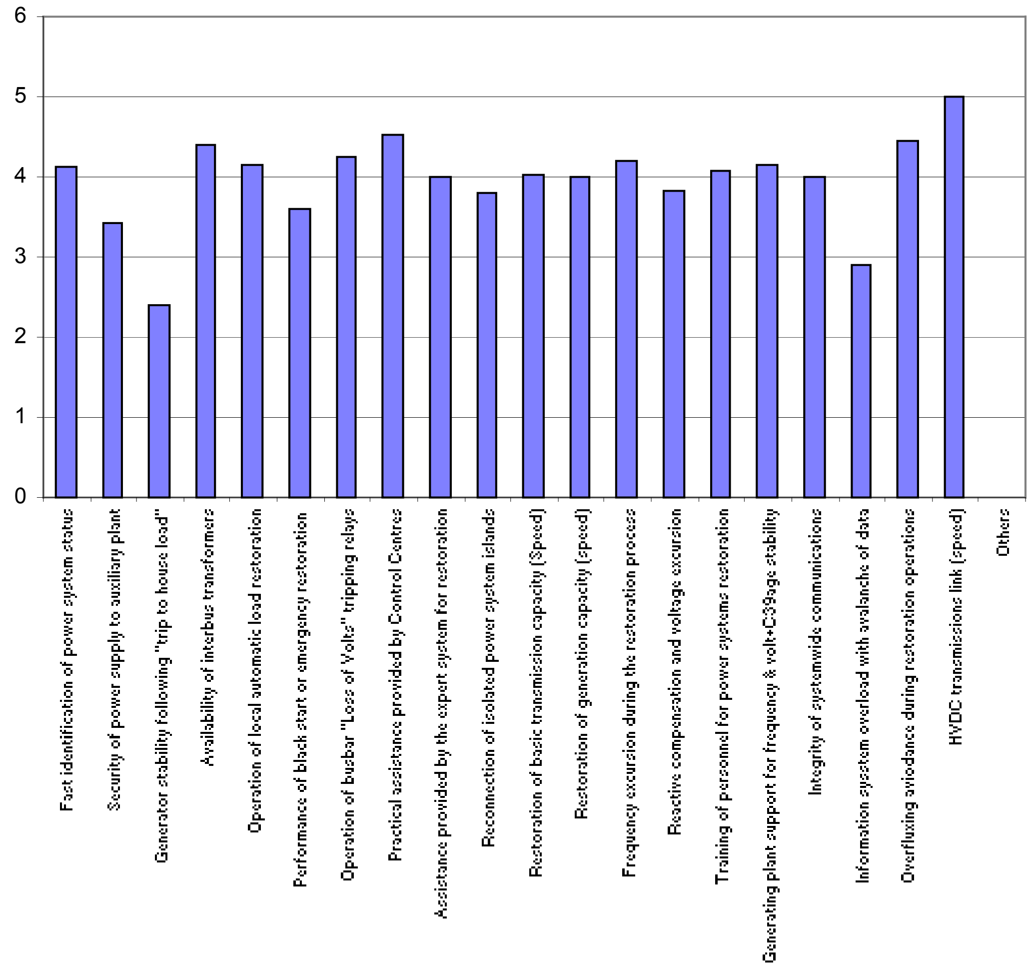
Figure 5 summarises the results. They are illustrated in more detail in Table A5 of Appendix A.

4.4.1 Fast identification of power system status

Of forty one responses twenty three indicated excellent performance, seven were satisfactory, two were average while eight were poor. In most cases, the system status was rapidly detected, facilitating correct reaction and prompt system restoration by operating personnel. In three cases where performance was poor the status identification was too slow. This identification is a major contributory factor to the success of the restoration. In general those power companies that have experienced poor performance recognise the necessity to improve planning in order to achieve better operational response during such disturbances. For example, WSCC in USA are considering the establishing of new criteria to define credible multiple contingency outages that should be considered in the planning process. WSCC also intend establishing new criteria to address risks associated with relay misoperations and how these are to be considered in evaluating the potential risk and impact of multiple contingency outages. As part of this the number of relay misoperations to be considered at one time is being assessed. An

example of poor performance was where it took 26 minutes to characterise the fault following a line short circuit. In the interim two unsuccessful attempts were made to manually reclose the faulted circuit.
Mean score: 4.1.

Figure 5: System Restoration



4.4.2 Security of power supply to auxiliary plant

Of nineteen available responses ten show the security of power supply to auxiliary plant as highly or very satisfactory, four as average and five as poor. The disturbance on an intertie in North America shows how the lack of a secure power supply can increase the severity of an outage. It was due to a forest fire near a substation causing two 500 kV lines to trip. During the disturbance the substation lost all external power. After 15 minutes, the emergency generator failed due to high temperatures. It was subsequently established that emergency loading exceeded the generator capacity. Procedures were implemented to keep loads within the generator's capacity.
Mean score: 3.4.

4.4.3 Ability of generator sets to run following "trip to house load"

Of ten responses only two indicated satisfactory performance; one was reasonable and seven were poor or very unsatisfactory. In general it can be stated that generators frequently failed to trip correctly to house load.

Mean score: 2.4.

4.4.4 Availability of interbus transformers

All five responses indicated satisfactory performance.

Mean score: 4.4.

4.4.5 Operation of local automatic load restoration (excluding fault protection and related autoclosing)

See Subsection 4.3.4 "Evaluation of Preventive and Remedial Actions - Automatic load restoration"

Mean score: 4.1.

4.4.6 Performance of black start or other emergency restoration facilities

Performances of black start or other emergency restoration facilities were highly variable. Indeed, of the five responses each indicated a different level of performance from highly satisfactory to highly unsatisfactory.

Mean score: 3.6.

4.4.7 Operation of busbar "loss of volts" tripping relays

Of five responses three were very satisfactory while one was reasonable. In some cases this system was found to impede system load restoration. For example during a disturbance on one system many substations were equipped with under voltage relays to open all circuit-breakers of a busbar in case of sustained absence of voltage. The intervention of such relays under blackout conditions caused delays in feeder restoration. As a consequence, these under voltage relays were removed so that service restoration after an incident could start from a partially disconnected network (quite similar to the network topology before the incident) instead of an almost completely disconnected network (with hundreds of circuit-breakers awaiting reclosure). While in general the performance was good, in that it did not impede restoration, it is difficult to quantify the benefits it brought.

Mean score: 4.2.

4.4.8 Practical assistance provided by the control centres

This type of assistance seems to work well. Of the twenty six disturbances, where such a service was used, 19 respondents found it highly satisfactory, five found it very satisfactory and four found it average. Problems highlighted during outages in North America were principally those of communication between different centres. Moreover, in one case lack of synchronisation of all event recorders proved a great handicap. The provision of such facilities further enhances the assistance provided by the control centres. Their absence, by contrast, can lead to lack of clarity in the sequencing of events thus reducing the quality of the available information.

Mean score: 4.5.

4.4.9 Practical assistance provided by the expert systems for restoration

See subsection 4.4.5 “Operation of local automatic load restoration” (excluding fault protection relating autoclosing).
Mean score: 4.

4.4.10 Reconnection of isolated power system islands

Of the nineteen applicable responses three categorise the reconnection of isolated power system islands as unsatisfactory, five as average, three as satisfactory, four as very satisfactory and eight as highly satisfactory. It leads to the conclusion that the reconnection of isolated power system islands is often difficult but in general performance meets requirements. For example in North America in 1994 an earthquake triggered an extensive disturbance that separated the power system into five separate electrical islands. Subsequent restoration was hampered by the inability or failure of utilities to determine the connectivity of their own and neighbouring systems. Poor communications between the control centres also hampered the restoration process. An example of defective equipment impeding restoration was illustrated during a disturbance in Europe due to high winds in 1994. At the control substation operators were unable to close the circuit breaker due to a faulty closing mechanism. For this reason load had to be supported by local generators. Load pick-up was further delayed because two capacitor banks were out of service. Elsewhere on the system restoration proceeded well.
Mean score: 3.8.

4.4.11 Restoration of basic transmission capacity (speed)

The survey indicated that restoration of basic transmission capacity progressed quickly. Of the twenty seven responses three were poor, three were average, ten were very satisfactory and eleven were highly satisfactory. Except for problems of communications the restoration of basic transmission capacity was effected in a satisfactory time.
Mean score: 4.

4.4.12 Restoration of generation capacity (speed)

The responses were similar to those for “Transmission Capacity” and concerned many of the same incidents. Indeed the same answers applied to a great extent. The survey response indicated that restoration of generation capacity progressed quickly. Of the twenty five responses three were poor, three were average, ten were very satisfactory and nine were highly satisfactory.
Mean score: 4.

4.4.13 Frequency excursion during the restoration process

Of fifteen responses nine were highly satisfactory, three were satisfactory, one was average and two were poor.
Mean score: 4.2.

4.4.14 Reactive compensation and voltage excursion

Of the thirteen responses six were highly satisfactory, two were very satisfactory, three were average and two were poor.
Mean score: 3.8.

4.4.15 Training of personnel for power systems restoration

Of twenty three answers to this question, three considered the training of personnel as very unsatisfactory, one considered it average, ten as satisfactory, and nine as highly satisfactory. A disturbance in North America in 1994 showed how the wrong action by staff exacerbated the consequences of the disturbance. The catastrophic failure of a current transformer resulted in the loss of several system elements (640 MW of generation, 43 MW of demand). Although adequate reserves were available to handle an incident of this magnitude, the energy co-ordinator did not take prompt action to restore ACE (Area Control Error) to zero following the units' loss. In most other cases however the personnel worked well to restore the system. Training does not seem to be a contributory factor to the extent or severity of the disturbances covered by this survey. Mean score: 4.1.

4.4.16 Contribution of generating plant to rapid achievement of frequency and voltage stability

Of nineteen answers to this question, two considered the contribution of generating plant as unsatisfactory, three as poor, four as very satisfactory, and ten as highly satisfactory. Mean score: 4.2

4.4.17 Integrity of systemwide communications

Of twenty three responses relating to the integrity of system-wide communications, four showed system-wide communication as unsatisfactory, two as average, five as satisfactory and twelve as highly satisfactory i.e. the performance of communication systems is regarded as very satisfactory.
Mean score: 4.

4.4.18 Information system overloaded with avalanche of data

Only nine responses were received so a generalised interpretation is difficult. Of these three were satisfactory; two were average while four were poor. It would seem that this is an area deserving of considerable assessment. A European experience illustrates the problem. During a disturbance in 1994 the control system became overloaded with an avalanche of data and had to be restarted by the operator, thus losing all data. Saturation of the telephone network delayed communication and coordination between the main control centre and a local control centre. It was subsequently recommended to increase the reliability of SCADA. During an earlier disturbance in 1986 the avalanche of data left the frequency regulating system (which shareed a common platform with the telecontrol system) inoperative for 30 seconds. After this time, it recovered and operated normally.
Mean score: 2.9.

4.4.19 Avoidance of overfluxing during restoration operations

Only nine responses were received so a generalised interpretation was difficult. Of these five were highly satisfactory; three were satisfactory and one was average. It would not seem to be an area of any great concern which is surprising given the large voltage fluctuations that can occur during large disturbances and subsequent restoration.
Mean score: 4.4.

4.4.20 HVDC transmission link (speed)

Very little information was received on this theme i.e. two responses. Both indicated excellent performance.

Mean score: 5.

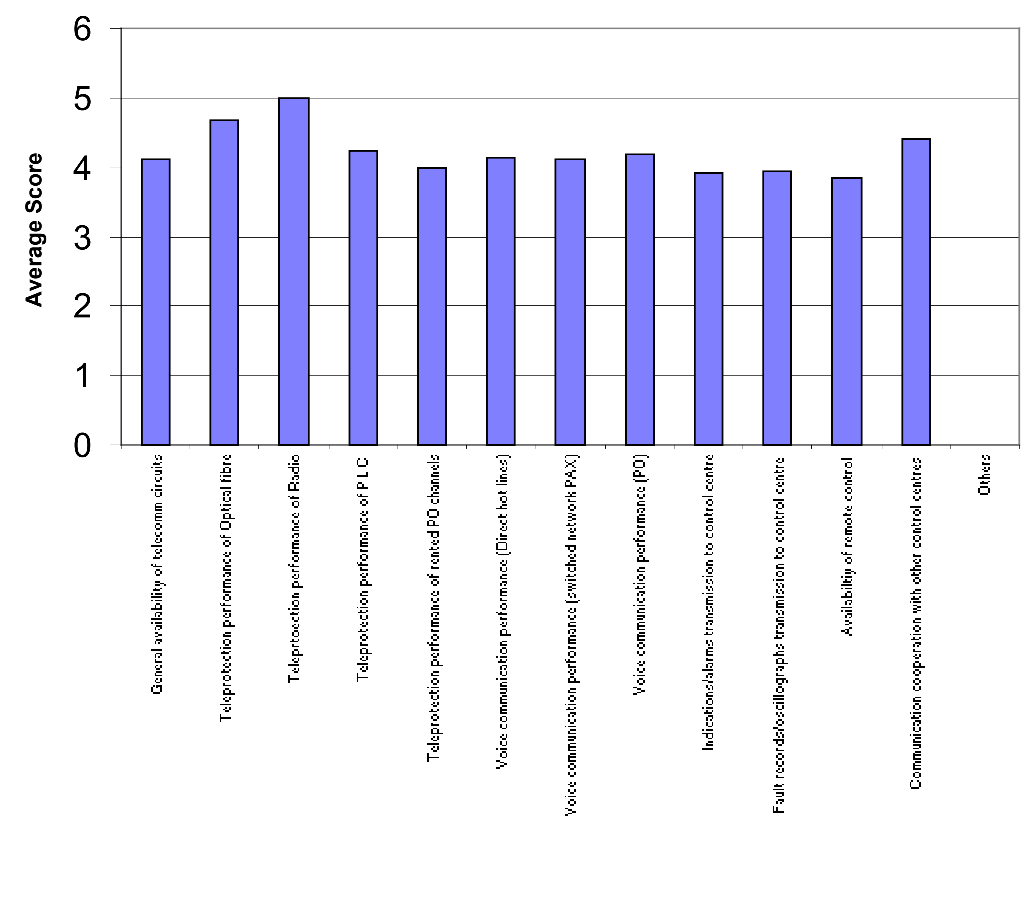
4.4.21 Conclusion

With an overall score of 3.98 performance was very good. The weakest functionality related to overloading of the information or SCADA systems. The current trend to restructuring with the rationalising of control centres together with the proliferation of numerical data collection devices will make this situation even worse in future. Automated intelligent systems to manage and prioritise data are required urgently for decision making support to system operators.

4.5 Telecommunications Performance

The evaluation is divided into two sections. The first establishes the telecommunication media in use and how they are used. The second evaluates and ranks performance. There are scores for teleprotection as well as for voice, data and control functions under the various headings. The results are summarised in Figure 6 and a more detailed evaluation is illustrated in Table A6 of Appendix A.

Figure 6: Evaluation of Telecomms Systems



4.5.1 Types of Telecommunication(TE) and Teleprotection (TP) provided

Unfortunately the amount of information in the replies varied considerably. From a total of sixty two responses, thirty two gave no information. The most widely used medium was power line carrier (PLC) which confers immunity to the oft depicted "telecomm cloud". The latter is a feature of leased public telecommunication lines which have been used extensively in some countries and where transfer between different media can occur. In this context it is assumed that usage, as identified under the various headings, implies direct control of that medium and consequently it is immune to problems on public facilities. There was widespread usage of metallic pilots and microwave with some utilities moving heavily into fiber optic usage. Satellite usage was minimal. Responses indicated widespread usage of PUTT, POTT and acceleration. Intertripping was less widely used while blocking schemes and weak infeed echo had limited usage.

4.5.2 Telecommunication & Teleprotection Performance

General availability of telecomms scored quite high during the disturbances but unfortunately there was only one response (5) for rented public lines. Teleprotections demand availability of communications just before, during and immediately after fault inception. Other users are mainly interested in mass data transfer and are not too concerned by interruptions measured in fractions of a second.

PLC scored consistently high (5 and 4) but there were cases where teleprotection usage was indicated but only general availability was scored. There was no explanation for the two scores of 1. The general evidence for this medium indicated good performance.

There were five responses for fiber optic, two of 5 and one of 4. While one would have expected this medium to perform well the sample was small. Some of the fiber optic usage identified was likely to have been for non-teleprotection facilities. Radio scored very well but evaluation was based on only four responses.

4.5.3 Performance of other Media

a) Voice Communication on Direct Connections: This generally scored high. Scores of 3 and 1 were due to loss of power supplies (reference to loss of SCADA power supplies were assumed to include voice supplies) and saturation respectively. Two scores of 2 were not explained.

b) Voice Communication Using Switched Networks: This generally scored well. The lower scores were associated with the same events as in a) above and for the same reasons.

c) Voice Communication Public Operator: In this category again the performance was quite good. The exceptions were scores of 1 (the same event as above which seems to have saturated all voice communication) and 3 (no information given).

d) Data to Control Centre (Indications & Alarms): The previously mentioned saturation effects produced a score of 1 and another score of 1 appeared with no reason being given. There were four scores of 3 due to the previously mentioned loss of SCADA power supplies and two unexplained. The remaining scores of 4 and 5 again indicate a good performance.

e) Data to Control Centre (Fault records): This was largely in line with d) i.e. good performance

f) Availability of Remote Control: A score of 2 with no explanation and a score of 3 were due to loss of power supplies. Three 4's and two 5's indicated that generally usage of the facility was reasonably successful.

g) Communication between Control Centres: Apart from two scores of 3 all scores were of 4 and 5 indicating good performance.

4.5.4 Conclusion

In general teleprotection scoring was high – average score: 4.2. It was predominantly PLC with limited but high scoring for both fiber optic and radio with a single score for public links. Clearly even scores of 4 may be unacceptable when fast clearance of faults can mean the difference between serious system shut down and its ability to remain largely intact. Fibre optical communications within the control of the utility should provide a secure option and is likely to be more widely used in future.
Voice communication, control and data gathering in the aftermath of major system disruption enables remedial actions to be prompt and also facilitate post fault analysis. The scores over the range of categories involved were quite varied and there was room for improvement. The degree of control over the communication facilities provided is influenced by the performance of rented facilities. Interference by the disturbance itself as well as system capacity were factors also.

4.6 New Relaying and Control Systems

The number of responses (9) was small and generally indicated a satisfactory performance (five responses scored 4 and 5) with self-monitoring facilities on numerical relays. Results are detailed in Appendix A, Table A7. Mean score: 4.8

4.7 Disturbance Analysis and Assessment

For immediate analysis, 5 to 20 minutes were the norm. One case took 45 minutes and another one 150 minutes. Complete analysis required 3 to 30 days with one case taking 45 days and another one year. There was a 50/50 split on the issues of sharing data and analysis changing protection philosophies.
Most responses noted appropriate coverage by Sequence of Event Recorder (SER) equipment on the EHV/HV systems.
Less coverage was noted for System Disturbance Recorders (SDR); however, this equipment can generally provide data for larger areas. Time tagging of SERs and SDRs was the exception not the rule
The results to the questions related to alarms were mixed and inconclusive.
Minimal use of on-line analysis was noted.
In general companies noted that the performance of this equipment was satisfactory based on their expectations.

4.8 Monitoring of Power System Performance

A large number were either not applicable or no information was supplied. Portugal appeared to have reasonably extensive monitoring which generally scored a “4” in the survey response. Mean score for power system monitoring performance during the disturbance: 3.79. The results are detailed in Appendix A, Table A8.
The transfer of SER records from substations via SCADA to the control centres made them more accessible although this depended on good communications media. Investment in disturbance and event recorders to enable effective post fault analysis

would appear to have some way to go. However, the advantages were clear and widely accepted.

5 PERFORMANCE OF SPECIAL SYSTEMS

5.1 Evaluation of FACTS during the Disturbance

General conclusions are not possible as the responses related to three disturbances only: in Canada and South Africa. As indicated in Appendix A, Table A9 performance was very good for most functions. However in Canada poor performance was experienced with FACTS protection, harmonic behaviour and interaction with other power system controllers. Furthermore support given to voltage profile and the impact of remote control were found to be only moderately successful. In South Africa performance was excellent.

5.2 Evaluation of HVDC Links during the Disturbance

Five responses were received and evaluation details are shown in AppendixA, Table A10. Two responses were from North America, two from Japan and one from Europe. As the number of responses was so low general conclusions were difficult. However the high mean score of 4.4 reflects the fact that overall performance was excellent except for a poor response of HVDC protection during one of the North American disturbances.

6. CONCLUSIONS AND SUMMARY

6.1 Evaluation

The following criteria were adopted to identify the areas of poor performance by protection and control devices during large disturbances:

- To ensure a representative sample, only questions that received 10 or more responses were considered (total of 63 questionnaires).
- Only those questions where 40% or more of responses scored 3 (average) or less were considered

On this basis and considering also the evaluation of NERC questionnaires, the following areas of poor performance were identified:

- Autoreclosing
- Under frequency load shedding
- Automatic voltage regulation
- Manual load restoration
- Security of power supply to auxiliary plant
- Reconnection of isolated power system islands
- Information system overloaded with data avalanche
- Feeder protection maloperation

The reasons for poor performance as evident from each disturbance are described in the following together with the relevant explanation if available.

6.1.1 Autoreclosing

Of the auto-reclose responses 45% scored 3 or lower. Unfortunately little information is available but the following cases illustrate some difficulties that can arise.

In one European case, on a highly meshed network with high fault level some line protections maloperated immediately while others operated due to power swings as the original flashover at a distribution transformer and subsequent fire had not been cleared. While auto-reclose should not have been initiated from any back-up protection operation there is some suggestion that this may have occurred. There were also some design considerations in reclosing a highly meshed system with a lot of local generation. Dead line charge should normally be at the end remote from a generating station but this will be difficult to attain on such a system. Furthermore the high fault current will exacerbate the situation if the fault is persistent.

In another incident the only question related to the selected time for the reclaim timer. During storm conditions faults can re-occur within this time causing unnecessary lockout if the setting is too long. Consequently more serious consideration may be required when selecting the reclaim time setting.

6.1.2 Under frequency load shedding

In at least six disturbances the situation was exacerbated by the failure of the load shedding scheme. Reasons were either defective relays (failure to trip) or a load shedding programme that did non disconnect sufficient load. Another issue is the ineffectiveness of underfrequency relays in heavily interconnected systems. In isolation they may not succeed in shedding sufficient load to preserve the system. Unless the system control and protection schemes are organised to split the network into islands, frequency will not decline even when local overloads are very high. Consequently cascade tripping by protection relays (typically due to overcurrents) will take place before the frequency relays can operate.

The main conclusion from the survey however was that properly designed schemes with well maintained, high quality hardware are successful in limiting the effects and extent of major disturbances.

6.1.3 Automatic voltage regulation

Generally the AVR's performed to their capabilities. The negative impact of AVR action mainly arose due to its poor co-ordination with over excitation protective devices or network protection devices.

6.1.4 Manual load restoration

In some cases staff failed to make correct decisions based on the available information. Also unmanned substations were often restored following delays in operational staff arriving on site. Automated response seems much more promising in rapidly restoring the system.

6.1.4 Isolation of generator units

In almost half the cases (48%) the score was less than 3. Six of the low scores can be categorised as generator or system related relay failures causing initial loss of generation where the response to this loss was not effective. In some cases the problems were due to basic failures but others related to gas turbine shutdown or islanding with subsequent shutdown. The harmonisation of load shedding with available generation can improve the situation. Furthermore all possible measures should be taken to prevent unnecessary generator loss. Another score related to more catastrophic events when generators had to be tripped to prevent their being damaged. Clearly in these circumstances remaining connected and supplying house-load is the desired outcome. Such schemes are problematical to design as due to the voltage depressions which frequently accompany system disturbances the auxiliaries encounter problems which further exacerbate the situation.

6.1.5 Security of power supply to auxiliary plant

Seven responses indicated that the non-availability of power supplies when required inhibited restoration. Obviously more attention must be given to the design and maintenance of such systems so that they are capable of meeting emergency demands.

6.1.6 Reconnection of isolated power system islands

Reconnection proved difficult in at least nine of the cases reported. Reasons were poor communication between control centres or failure by utilities to determine the readiness of subsystems for reconnection. This suggests that more extensive modeling of different emergency scenarios would be beneficial.

6.1.7 Information system overloaded with data avalanche

In many cases data received, though large in volume, was of dubious benefit because it did not yield useful information to operators. The situation is likely to deteriorate with the wider use of numerical control and monitoring systems unless some form of automated decision making is introduced. While only four responses were received on the use of expert systems for analysis of alarms, indications, etc. all were scored highly satisfactory (5).

6.1.8 Feeder protection maloperation

The relaying failures that caused or escalated disturbances broadly relate to protections that failed to operate or performed unwanted operations. It is illustrative to mention some examples of both:

- On a line equipped with duplicate protections both failed during line fault; adjacent line was incorrectly tripped by its protection; widespread operation of remote back-up protection led to system islanding.
- Failure of breaker to open during fault on capacitor bank followed by failure of associated breaker fail protection resulted in extensive operation of remote protection.
- Failure of transformer protection during a transformer fault coupled with failure of a phase comparison relay resulted in multiple tripping by back-up relays.
- Poor settings resulted in distance relay not clearing a low level ground fault; persistence of fault caused multiple tripping of transformer ground fault protections leading to system blackout.
- Maloperation of a phase comparison relay tripped a line on three occasions during external faults leading to cascade tripping and loss of generation and transmission plant.
- On a 345kV line equipped with duplicate protections one failed during line fault; back-up protection was erroneously left switched to test position following maintenance; four 230kV lines tripped on remote back-up; widespread operation of

transformer earth fault protection cleared the fault but resulted in significant load loss.

- Slow sequential clearance of a 3 terminal line fault caused remote relays to trip with significant load loss.
- Slow clearance of capacitor bank fault resulted in remote back-up tripping of generator intertie; on four other circuits tripping occurred due to an incorrectly wired switch-on-to-fault function; significant load loss resulted.
- Incorrect line protection operation during adjacent line fault triggered overloading and cascade tripping of lines and transformers.
- Teleprotection signalling incorrectly tripped major generation intertie resulting in power oscillations and generation reduction.
- Multiple operation of protections occurred to avoid overloading; operation was correct as designed but not optimal in context of curtailing disturbance.

In those cases where failure to trip was the malfunction the provision of reliable duplicate or local back-up protection would have been beneficial. Unwanted operations generally occurred due to hardware defects or incorrect setting. The solution here is more rigorous attention to relay maintenance and setting procedures. Also underlined are the limitations of using back-up protection to prevent circuit overloading.

6.2 General Summary

The majority of the sixty plus events that were reviewed arose from multiple faults due to natural events or to the catastrophic failure of primary plant i.e. the majority of events resulted from the loss of multiple network elements during normal operation of the system. The optimum solutions to these events would be the construction of multiple redundant facilities to protect against multiple contingencies or to build generation sources closer to the loads. Both these options are not usually feasible from a resource or economic standpoint. However improved protection and control systems would considerably reduce the impact of such events.

Approximately 15% of disturbances were caused by second contingencies resulting from unwanted protection operations or failure to operate for the initial event. While protection performance was reasonably good (overall score 3.8) there was a significant number of maloperations of feeder protection (average score 2.8). Maloperation was usually due to a hardware failure rather than to a fundamental design deficiency. In many of these multiple contingency cases, Special Protection Schemes are already in place to shed large amounts of load and/or generation in an effort to stabilize the systems. Nevertheless more attention to the selection and application of relay settings, including adaptive features, will reduce unwanted operations while increased relay availability through better maintenance or self-diagnostics will avoid failures to trip. The survey confirms that fast clearance of faults, particularly on busbars, is vital to a system's ability to ride through disturbances. Duplication of protection systems and the installation of circuit breaker fail provision is essential on critical busbars and on high voltage lines since back up operation times often resulted in system splitting and cascading. The application of adaptive protection schemes to cater for transient conditions without tripping on power swings, overloads, etc., appear to promise significant benefits. This will be more easily realised with the widespread use of numerical relays. As mentioned a number of times in this report it would avoid instances where relay operation while correct was undesirable

There were several instances of generator controls (e.g. AVRs) failing to operate satisfactorily resulting in multiple unit losses that were unrecoverable from a system standpoint. Better coordination between generator and network control/protection schemes would be beneficial. Dynamic system studies should be used to evaluate these functions.

The response of control and protection devices to declining voltage should be evaluated with a view to optimal coordination e.g. transformer tap change control, motor protection, network undervoltage relay, etc.

The remaining events were in general caused by events so catastrophic (earthquakes, extreme loads, multiple unit tripping, etc.) that no reasonable preventative actions could have been foreseen.

In the area of disturbance monitoring, time synchronisation of equipment was not widely used and could potentially be a great advantage in analysing major disturbances.

Also the prioritising of incoming signals, alarms and telephone calls to control centres would be beneficial. Developments in intelligent devices and knowledge based systems should assist this process.

Finally credible multiple contingency events should be considered in the planning process and simulation training for control staff should include all aspects of disturbance response scenarios.

APPENDIX A: TABLES SUMMARISING RESPONSES

Question 3.5: Function/Malfunction causing or escalating the Disturbance	Cause =1 Escalation =2	
	1	2
Multiple faults due to fires, storms, earthquake, etc.	24	0
Geomagnetic currents	0	0
Failure of protection communication links	1	2
Failure of primary equipment	20	12
Failure of Protections: Unwanted Tripping	12	13
Failure to Trip	1	9
Absence of local back-up protection	1	0
Failure of other secondary equipment	4	3
Generator control system	3	8
System control (local or remote)	0	1
Load shedding	0	13
System splitting and islanding	1	8
Overload cascade tripping	0	10
Instability	0	6
Voltage collapse	2	6
Incorrect application of protection	0	4
Inappropriate protection settings	1	7
Protection relay capability exceeded e.g. fault in blind spots	2	0
Fault current reduced by static excitation systems	0	0
Operation planning	1	1
Failure in restoration or auto reclosure	0	4
Overfluxing condition	1	3
Inadequate protection/control maintenance	3	2
Inadequate CT performance	0	0
Others (please specify)	9	7
Total	**86**	**119**

Table A1: Immediate Causes and Factors Escalating the Disturbance

Question 4.1 Evaluation of Power System Dynamic Performance	Scoring based on total applicable responses						
	1	**2**	**3**	**4**	**5**	**Total**	**Avg.**
Autoreclosing	5	2	3	5	8	23	3.43
Automatic Voltage Regulation	3	1	3	0	3	10	2.9
Power System Stabilizers	1	0	1	0	2	4	3.5
Fast Valving	1	1	0	3	2	7	3.57
Static Compensators (FACTS)	0	2	0	0	0	2	2
Stabilizing effect of Energy Storage Systems	0	0	0	0	0	0	0
Multi-stage Load Shedding	1	4	1	1	7	14	3.69
Isolation of Generating Units	5	0	4	1	8	19	3.39
HVDC Controls	0	0	1	0	3	4	4.5
Others	1	0	0	0	0	1	1
TOTAL	**17**	**9**	**12**	**9**	**33**	**80**	**3.4**

Table A2: Power System Dynamic Performance

Question 4.2: Evaluation of Protection Performance	Scoring based on total applicable responses						
	1	**2**	**3**	**4**	**5**	**Total**	**Avg.**
Transmission line/cable protection operation due to overload	2	3	0	3	19	27	4.26
Transmission line/cable protection operation due to power swings	3	0	1	0	9	13	3.92
Transmission line/cable protection maloperation for other reasons	10	1	2	2	7	22	2.77
Transformer protection operation due to power swings	2	0	0	0	6	8	4
Underfrequency and df/dt type relays	2	3	0	8	5	18	3.61
Undervoltage load shedding relays	3	1	0	0	4	8	3.13
Bus zone protection	2	0	0	0	7	9	4.11
CB fail protection	2	0	0	1	3	6	3.5
Special protection schemes	1	0	0	0	3	4	4
Out of step protection tripping	2	0	1	0	5	8	3.75
Protection to prevent voltage collapse	0	0	0	0	1	1	5
Overfluxing protection	1	0	0	2	1	4	3.5
Shaft torsional stressing protections	0	0	0	0	0	0	0
Harmonization of generator and network protection and control	1	1	3	4	8	17	4
Overall protection coordination	0	1	2	6	20	29	4.55
Local back-up protection performance	3	0	0	0	9	12	4
Remote back-up protection performance	2	1	2	2	8	15	3.87
Protection against asynchronous resonance	0	0	0	0	2	2	5
Others	1	0	0	0	0	1	1
TOTAL	**37**	**11**	**11**	**28**	**117**	**204**	**3.87**

Table A3: Protection Performance

Question 4.3: Preventive & Remedial Actions	Scoring based on total applicable responses						
	1	2	3	4	5	Total	Avg.
Under Voltage load shedding	0	1	0	0	4	5	4.4
Under Frequency load shedding	3	4	0	2	8	17	3.47
Operational tripping	1	2	0	1	3	7	3.43
Automatic load restoration	1	2	1	3	5	12	3.75
Manual load restoration	2	2	5	5	9	23	3.74
System monitors which detect trends to instability	2	0	0	0	4	6	3.67
Network sectionalising relays	1	1	0	0	4	6	3.83
Power swing detection to isolate generating plant	1	1	0	0	4	6	3.83
Frequency deviation to isolate generating plant	1	0	0	1	6	8	4.38
Impact of remote setting control	0	0	0	0	1	1	5
Impact of adaptive protective measures	0	0	0	0	0	0	0
Detection of abnormal operation at network interconnecting points	1	0	1	1	8	11	4.36
Others	0	0	0	0	0	0	0
TOTAL	**13**	**13**	**7**	**13**	**56**	**102**	**3.84**

Table A4: Preventive & Remedial Actions

Question 4.4: System Restoration	Scoring based on total applicable responses						
	1	2	3	4	5	Total	Avg
Fast identification of power system status	4	3	2	7	25	41	4.12
Security of power supply to auxiliary plant	4	1	4	3	7	19	3.42
Ability of generator sets to run following "trip to house load"	3	4	1	0	2	10	2.4
Availability of interbus transformers	0	0	1	1	3	5	4.4
Operation of local automatic load restoration	0	0	2	2	3	7	4.14
Performance of black start or emergency restoration facilities	0	1	1	2	1	5	3.6
Operation of busbar "Loss of Volts" tripping relays	0	0	1	1	2	4	4.25
Practical assistance provided by the Control Centres	0	0	4	5	19	28	4.54
Practical assistance provided by the expert system for restoration	0	0	1	1	1	3	4
Reconnection of isolated power system islands	1	2	5	3	8	19	3.79
Restoration of basic transmission capacity (Speed)	1	2	3	10	11	27	4.04
Restoration of generation capacity (speed)	0	3	3	10	9	25	4
Frequency excursion during the restoration process	1	1	1	3	9	15	4.2
Reactive compensation and voltage excursion	0	2	3	2	5	12	3.83
Training of personnel for power systems restoration	1	2	1	10	10	24	4.08
Contribution of generating plant to rapid achievement of frequency and voltage stability	0	2	3	4	10	19	4.16
Integrity of systemwide communications	2	2	2	5	12	23	4
Information sysstem overload with avalanche of data	1	3	2	2	1	9	2.89
Aviodance of overfluxing during restoration operations	0	0	1	3	5	9	4.44
HVDC transmissions link (speed)	0	0	0	0	2	2	5
Others	0	0	0	0	0	0	0
TOTAL	**18**	**28**	**41**	**74**	**145**	**306**	**3.98**

Table A5: System Restoration

Question 4.7.2 Evaluations of Telecomms. Systems	Scoring based on total applicable responses						
	1	2	3	4	5	Total	Avg.
General availability of telecomm circuits during the disturbance	1	2	2	12	12	29	4.1
Teleprotection performance of Optical fibre communication medium	0	0	0	1	2	3	4.67
Teleprotection performance of Radio communication medium	0	0	0	0	5	5	5
Teleprotection performance of P L C communication medium	2	1	1	3	14	21	4.24
Teleprotection performance of rented PO channels	1	0	0	0	3	4	4
Voice communication performance (Direct connections hot lines)	1	0	2	5	7	15	4.13
Voice communication performance (switched network PAX)	1	1	1	5	8	16	4.13
Voice communication performance (PO)	1	0	1	3	6	11	4.18
Data transmission to control centre (indications and alarms)	2	0	5	11	9	27	3.93
Data transmission to control centre (fault records/oscillographs)	1	0	4	11	6	22	3.95
Availabiltiy of remote control and remote device setting	0	1	1	3	2	7	3.86
Communication cooperation with other control centres	0	0	2	11	12	25	4.4
Others	0	0	0	0	0	0	0
TOTAL	**10**	**5**	**19**	**65**	**86**	**185**	**4.15**

Table A6: Evaluations of Telecomms. Systems

Question 4.8 New Relaying & Control Systems	Scoring based on total applicable responses						
	1	**2**	**3**	**4**	**5**	**Total**	**Avg.**
Impact of remote setting control	0	0	0	0	0	0	0
Impact of adaptive protection	0	0	0	0	0	0	0
Impact of self monitoring in numerical protection	0	0	0	2	3	5	4.6
Use of expert systems by control function to analyse alarms, indications, other system data, etc. and produce summary report	0	0	0	0	3	3	5
Use of expert systems by protection function to perform in-depth analysis based on disturbance recordings, relay models, etc.	0	0	0	0	1	1	5
TOTAL	**0**	**0**	**0**	**2**	**7**	**9**	**4.78**

Table A7: New Relaying & Control Systems

Question 4.10: Power System Performance	Scoring based on total applicable responses							
	1	**2**	**3**	**4**	**5**	**Total**	**Avg.**	
Power system monitoring evaluation	1	1	3	16	3	24	3.79	
% of EHV/HV Ccts. (x%) equipped	**10**	**20**	**30**	**40**	**50**	**75**	**100**	**Total**
No responses having SER on x% of EHV/HV Ccts.	1	2	0	1	1	7	20	32
No responses having SDR on x% of EHV/HV Ccts.	0	1	0	1	0	5	1	8
No responses having SER with time tagging on x% of Ccts.	1	1	7	11	3	3	7	33
No responses having SDR with time tagging on x% of Ccts.	7	7	2	0	2	9	1	28
Alarms to System CC Yes								18
No								14
Selected Alarms to System CC Yes								25
No								7
Analysis by on-line systems Yes								9
No								23

Table A8: Power System Performance

Question 4.5.2 FACTS Performance	Scoring based on total applicable responses						
	1	**2**	**3**	**4**	**5**	**Total**	**Avg.**
FACTS protection operation during disturbance	1	0	0	0	2	3	3.67
FACTS control operation before disturbance	0	0	0	0	1	1	5
FACTS control operation during disturbance	0	0	0	0	1	1	5
FACTS control operation after disturbance	0	0	0	0	1	1	5
Damping of power oscillations	0	0	0	0	0	0	0
Increase in power and voltage stability limits	0	0	1	0	0	1	3
System voltage profile support	0	0	1	0	0	1	3
Impact of remote control setting facilities	0	0	0	0	0	0	0
Impact of local adaptive control operations	0	0	0	0	0	0	0
Network protection tripping due to FACTS control operations	0	0	0	0	1	1	5
Network protection tripping due to measuring criteria being affected by FACTS component	0	0	0	0	1	1	5
Network protection tripping for other FACTS related reasons	0	0	0	0	1	1	5
Harmonic behaviour	1	0	0	0	0	1	1
Interaction with other power system controllers (e.g. PSS)	1	0	0	0	0	1	1
Others	0	0	0	0	0	0	0
TOTAL	**2**	**0**	**2**	**0**	**8**	**13**	**4**

Table A9: FACTS Performance

Question 4.6.2 HVDC Performance	Scoring based on total applicable responses						
	1	**2**	**3**	**4**	**5**	**Total**	**Avg.**
HVDC protection during disturbance	1	0	0	0	3	4	4
HVDC control operation before disturbance	0	0	0	0	5	5	5
HVDC control operation during disturbance	0	0	0	1	4	5	4.8
HVDC control operation after disturbance	0	0	0	0	5	5	5
Damping of power oscillations	0	0	0	0	1	1	5
Increase in power and voltage stability limits	0	0	1	0	1	2	4
System voltage profile support	0	0	0	0	1	1	5
Impact of remote control setting facilities	0	0	0	0	0	0	0
Impact of local adaptive control operations	0	0	0	0	0	0	0
Network protection tripping due to HVDC control operations	0	0	0	0	0	0	0
Network protection tripping due to measuring criteria being affected by HVDC component	0	0	0	0	0	0	0
Network protection tripping for other HVDC related reasons	0	0	0	0	0	0	0
Harmonic behaviour	1	0	0	0	1	2	3
Interaton with other power system controllers(e.g. PSS)	1	0	0	0	1	2	3
Others	0	0	0	0	0	0	0
TOTAL	**3**	**0**	**1**	**1**	**22**	**27**	**4.44**

Table A10: HVDC Performance

APPENDIX B:
SURVEY QUESTIONNAIRE

QUESTIONNAIRE ON PROTECTION PERFORMANCE DURING MAJOR DISTURBANCES

By

Study Committee 34
Working Group 09

INTRODUCTION

1. Background

Over the past decade the electricity supply industry (ESI) has been subject to dramatic change. Worldwide the trend is to restructure vertically integrated utilities catering for generation, transmission and distribution (or various combinations thereof) into smaller "unbundled" companies. Furthermore, centralised price regulation is in many countries being replaced by a regulatory regime more attuned to the market forces prevailing in the electricity market. The resulting coming on stream of generation capacity dictated by unit cost rather than system load growth has implications for the performance of transmission systems.

During the same period rapid advances have taken place in the field of power system control, substation control and protection relaying.

All of these developments are encouraging the trend to maximise asset utilisation and to substitute on-line monitoring techniques for the more traditional preventive maintenance test methods. It is of interest to determine the performance of protection during major system disturbances during this period.

2. Objective of the Questionnaire

The objectives of this questionnaire are to:

- review significant disturbances which have occurred since 1986;
- identify and categorise the cause and nature of the disturbances;
- categorise relay response and to identify maloperations or failures.

Based on the information obtained from the Questionnaire subsequent work will concentrate on analysing the results with a view to formulating a programme of further investigations and studies of methods of improving protection performance.

2. **Definition of Major Disturbance**

Working Group 39.05 of CIGRE defines power system disturbances in terms of unsupplied energy during the event (MW-Minutes) divided by the annual system peak load (MW) and measured in system-minutes. A further consideration is the performance of the power system following sudden loss of generation. For the purpose of this Questionnaire a major disturbance is defined as Plant failure or Operator intervention which results in the loss of:

- supplied energy exceeding 1 system-minute (e.g. this equates to the loss of 300 MW for 10 minutes on a system whose annual system peak is 3,000 MW).

<u>or</u>

- Generation equal to 10% of system peak demand.

2. **Return of Questionnaire**

Please return the completed questionnaire not later than 30 January, 1998 to:

Michael J. Mackey,
Convenor CIGRE WG 34.09,
ESB International,
Stephen Court,
18- 21 St. Stephens Green,
Dublin 2,
Ireland.

Phone +353-1-7038343
Fax +353-1-6615359

QUESTIONNAIRE

Please replicate this and following sheets for each disturbance.

1.1 Utility and Contact

- Name of Company ____
- Country ____
- Name of Contact Person:____
- Address:____

____
____

- Phone: ____
- Telefax:____
- E-mail: ____

1.2 General Network Data at 31 December, 1996.

- Installed Generation Capacity: ________MW
- Peak Load: ________MW
- Energy Demand: ________GWH
- Transmission Lines (Voltage, Circuit Length):

_______kV, ___________km _______kV, ___________km
_______kV, ___________km _______kV, ___________km

- Transmission Cables (Voltage, Route Length):

_______kV, ___________km _______kV, ___________km
_______kV, ___________km _______kV, ___________km

2. Network Data immediately prior to the Disturbance

- Active Load: _______ MW
- Reactive load: _______ MVAr

3. Power System Disturbance __________________________ (day/month/year)

3.1.1 Disturbance occurred during:

peak load period___, valley load period___, during period of intermediate load___.
Indicate with "X".

3.1.2 Interruption of Supply

Generation: _____ MW Load: _____MW Energy _____ MWh

3.2 Summarise Initial Cause of Disturbance

3.3 Network Section relevant to the disturbance: Insert sketch or attach summary network diagram. Show nodes and interconnecting lines, cables with relevant kV level. Show generation, capacitor banks (including series capacitors) and network sectionalising.

3.4 Stages of Disturbance Development (Provide brief summary including Sequence of Events Record [SER] if available and list damage to primary plant)

3.5 Main significant factors in causing and spreading the disturbance.

Insert “X”, for as many items as apply, in the appropriate column to indicate whether the item was a primary cause or simply a factor that caused it to escalate. Clarify in “Notes”as appropriate

	Cause	Escalation
Multiple faults due to storms, earthquake,etc.		
Geomagnetic currents		
Failure of protection communication links		
Failure of Primary Equipment		
Failure of Protections: Unwanted Tripping		
Failure to Trip		
Absence of local back-up protection		
Failure of other Secondary Equipment		
Generator Control System		
System Control (Local or Remote)		
Load shedding		
System splitting and islanding		
Overload Cascade tripping		
Instability		
Voltage Collapse		
Incorrect application of protection		
Inappropriate protection settings		
Protection relay capability exceeded e.g fault in blind spots		
Fault current reduced by static excitation systems		
Operation planning		
Failure in restoration on autoreclosure		
Overfluxing condition		
Inadequate protection/control maintenance		
Inadequate CT performance		
Others (please specify)		

Notes

3.6 System (or Supply) Restoration (indicate sequence of events)

3.7 Conclusions and Lessons Learnt

4. Performance of Protection and Control during this Disturbance

In the following tables please grade performance by placing an ”X” in the appropriate column (Column 1,2,3,4 or 5) against each item. Colums 6,7 and 8 give additional information. If performance is poor (i.e. grading ≤ 3) indicate under notes the reasons for this and the particular component(s) which performed poorly e.g.in 4.2 failure of distance relay to trip; unwanted trip by transformer Buchholz relay; etc. The objective is to establish the overall performance of the particular protection or control system e.g.in 4.1 an AVR in a number of locations may have operated correctly but one unit elsewhere failed to respond as intended causing or exacerbating the disturbance; this would merit a 1 or 2 but the notes should be used to indicate the correct performance at a number of locations.

4.1 Evaluation of Power System Dynamic Performance

Grade each item in the columns: 1 = very unsatisfactory; 5 = highly satisfactory;
6 = not applicable; 7 = Notes; 8 = no information.

	1	2	3	4	5	6	7	8
Autoreclosing								
Automatic Voltage Regulation								
Power System Stabilizers								
Fast Valving								
Static Compensators (FACTS)								
Stabilizing effect of Energy Storage Systems								
Multi Stage Load Shedding								
Isolation of Generating Units								
HVDC Controls								
Others								

Notes

4.2 Evaluation of Protection Performance

Grade each item in the columns: 1 = very unsatisfactory; 5 = highly satisfactory; e.g. 1 would be failure to trip or unwanted trip while 5 would be completely correct protection scheme operation; 2,3,4 would represent increasing levels of partially correct behaviour;
6 = not applicable; 7 = Notes; 8 = no information.

	1	2	3	4	5	6	7	8
Transmission line/cable protection operation due to overload								
Transmission line/cable protection operation due to power swings								
Transmission line/cable protection maloperation for other reasons (state reasons)								
Transformer protection operation due to power swings								
Underfrequency and df/dt type relays								
Undervoltage load shedding relays								
Bus zone protection								
CB Fail protection								
Special protection schemes (indicate in “Notes” the scheme operating principles and function)								
Out of step protection tripping								
Protection to prevent voltage collapse								
Overfluxing protection								
Shaft torsional stressing protections								
Harmonization of generator and network protection and control								
Overall protection coordination								
Local back-up protection performance								
Remote back-up protection performance								
Protection against asynchronous resonance								
Others:								

Notes

4.3 Evaluation of preventative and remedial actions

Grade each item in the columns: 1 = very unsatisfactory; 5 = highly satisfactory; 6 = not applicable; 7 = Notes; 8 = no information.

	1	2	3	4	5	6	7	8
Under voltage load shedding								
Under frequency load shedding								
Operational tripping								
Automatic load restoration								
Manual load restoration								
System monitors which detect trends to instability								
Network sectionalising relays								
Power swing detection to isolate generating plant								
Frequency deviation to isolate generating plant								
Impact of remote setting control								
Impact of adaptive protective measures								
Detection of abnormal operation at network interconnecting points								
Others								

Notes

4.4 System Restoration

Grade each item in the columns: 1 = very unsatisfactory; 5 = highly satisfactory;
6 = not applicable; 7 = Notes; 8 = no information.

	1	2	3	4	5	6	7	8
Fast identification of power system status								
Security of power supply to auxiliary plant								
Ability of generator sets to run following "trip to house load"								
Availability of interbus transformers								
Operation of local automatic load restoration (excluding fault protection related autoclosing)								
Performance of black start or other emergency restoration facilities								
Operation of busbar "Loss of Volts" tripping relays								
Practical assistance provided by the Control Centers								
Practical assistance provided by the expert systems for restoration								
Reconnection of isolated power system islands								
Restoration of basic transmission capacity (speed)								
Restoration of generation capacity (speed)								
Frequency excursion during the restoration process								
Reactive compensation and voltage excursion								
Training of personnel for power systems restoration								
Contribution of generating plant to rapid achievement of frequency and voltage stability								
Integrity of systemwide communications								
Information system overloaded with avalanche of data								
Avoidance of overfluxing during restoration operations								
HVDC transmission link (speed)								
Others:								

Notes

4.5 Evaluation of FACTS during the Disturbance

4.5.1 Types of FACTS components provided on or adjacent to the network affected by the disturbance:

Type of FACTS component	yes	no	adjacent
SVC (Static Var Compensator)			
TCSC (Thyristor Controlled Series Compensation)			
PAR (Phase Angle Regulator)			
SSC (Static Synchronous Condenser)			
UPFC (Unified Power Flow Controller)			
Other :			

4.5.2 Performance Evaluation

Grade each item in the columns: 1 = very unsatisfactory; 5 = highly satisfactory;
6 = not applicable; 7 = Notes; 8 = no information.

	1	2	3	4	5	6	7	8
FACTS protection operation during disturbance								
FACTS control operation before disturbance								
FACTS control operation during disturbance								
FACTS control operation after disturbance								
Damping of power oscillations								
Increase in power and voltage stability limits								
System voltage profile support								
Impact of remote control setting facilities								
Impact of local adaptive control operations								
Network protection tripping due to FACTS control operations								
Network protection tripping due to measuring criteria being affected by FACTS component								
Network protection tripping for other FACTS related reasons (please specify)								
Harmonic behaviour								
Interaction with other power system controllers (e.g. PSS)								
Others:								

Notes

4.6 Evaluation of HVDC Links during the Disturbance

4.6.1 Types of HVDC components provided on or adjacent to the network affected by the disturbance:

Type of HVDC component	yes	no	adjacent
Monopolar			
Bipolar			
Back-to-Back			
Point-to-Point Line			
Point-to-Point Cable			
Inverter constant gamma			
Inverter constant voltage			
Voltage/frequency modulation for stability			
Countermeasures against repetitive commutation failure			
Other :			

4.6.2 Performance Evaluation

Grade each item in the columns: 1 = very unsatisfactory; 5 = highly satisfactory; 6 = not applicable; 7 = Notes; 8 = no information.

	1	2	3	4	5	6	7	8
HVDC protection operation during disturbance								
HVDC control operation before disturbance								
HVDC control operation during disturbance								
HVDC control operation after disturbance								
Damping of power oscillations								
Increase in power and voltage stability limits								
System voltage profile support								
Impact of remote control setting facilities								
Impact of local adaptive control operations								
Network protection tripping due to HVDC control operations								
Network protection tripping due to measuring criteria being affected by HVDC component								
Network protection tripping for other HVDC related reasons (please specify)								
Harmonic behaviour								
Interaction with other power system controllers (e.g. PSS)								
Others:								

Notes

4.7 Telecommunications Performance

4.7.1 Types of Telecommunication (TE) and teleprotection (TP) systems provided. Indicate with “X” under “yes/no”whether the scheme is provided or not. In the “Comment” column for each TE state the extent to which each telecomm medium is employed (e.g. as percentage of total telecomm system) and for each TP state the telecomm channel employed for that type of scheme (if more than one telecomm medium employed indicate percentage of each).

Type	yes	no	Comment
TE: Power Line Carrier			
TE: Leased Public Telecomm lines			
TE: Microwave Links			
TE: Satellite Links			
TE: Fibre optic cable			
TE: Metallic pilotwires			
TE: Other			
TP: Direct intertripping			
TP: Permissive underreach transfer trip (PUTT)			
TP: Permissive overreach transfer trip (POTT)			
TP: Zone acceleration			
TP: Blocking scheme			
TP: Weak end infeed echoing			
TP: Other			

4.7.2 Evaluation of Telecommunication System during the Disturbance

Grade each item in the columns: 1 = very unsatisfactory 5 = highly satisfactory; e.g. 1 would be carrier/radio/PO-line/etc. send failure, receive failure or unwanted signal, 5 would be completely correct telecommunication scheme operation; 2,3,4 should represent increasing levels of partially correct behaviour;
6 = not applicable; 7 = Notes; 8 = no information.

	1	2	3	4	5	6	7	8
General availability of telecommunication circuits during the disturbance[1]								
Teleprotection performance of Optical fibre communication medium								
Teleprotection performance of Radio communication medium								
Teleprotection performance of Power Line Carrier communication medium								
Teleprotection performance of rented PO channels								
Voice communication performance (Direct connections - hot lines)								
Voice communication performance (switched network - PAX)								
Voice communication performance (PO)								
Data transmission to control centre (indications and alarms)								
Data transmission to control centre (fault records/oscillographs)								
Availability of remote control and remote device setting								
Communication cooperation with other control centres								
Others:								

[1)] Please indicate in "Notes" the proportion of telecomms. circuits that failed or otherwise became unavailable due to the disturbance.

Notes

4.8 Evaluation of New Relaying and Control Systems

Please list in "Notes" below:

- the adaptive techniques which are employed;
- additional features which you intend to employ;
- type of expert systems employed;
- any expanded role proposed for expert systems.

Grade each item in the following columns: 1 = very unsatisfactory;
5 = highly satisfactory; 6 = not applicable; 7 = Notes; 8 = no information.

	1	2	3	4	5	6	7	8
Impact of remote setting control								
Impact of adaptive protection								
Impact of self monitoring in numerical protection								
Use of expert systems by control function to analyse alarms, indications,other system data,etc. and produce summary report								
Use of expert systems by protection function to perform in-depth analysis based on disturbance recordings, relay models,etc.								

Notes

4.9 Disturbance Analysis and Assessment

Protection and monitoring control information used (elaborate in "Notes" if necessary):

____

____

Indicate the time taken for urgent immediate analysis ______ Minutes
Indicate the time taken for complete analysis and conclusions ______ Days

	Yes	No
Was information on protection/control/monitoring exchanged with other involved utilities.		
Did analysis change protection operation philosophy (e.g.whether 2 main protections or main/back-up employed, setting/discrimination policy, etc.)		

Notes

4.10 Monitoring of Power System Performance
Insert "X" in appropriate column

	10	20	30	40	50	75	100
% age of EHV/HVcircuits equipped with SER[1]							
% age of circuits equipped with SDR[2]							
% age of SERs with synchronised time tagging							
% age of SDRs with synchronised time tagging							

Were alarms/signals in general transmitted to the system control centre ?	YES	NO
Were selected alarms/signals only transmitted to the system control centre ?	YES	NO
Were on-line systems used to analyse alarms/signals ?	YES	NO

[1] SER = Sequence of Event Recorder
[2] SDR = System Disturbance Recorder (Oscillograph)

Grade power system monitoring according to the following 1 = very unsatisfactory;
5 = highly satisfactory; 6 = not applicable; 7 = Notes; 8 = no information.

1	2	3	4	5	6	7	8

Notes

5. General

	Yes	No
Did the disturbance necessitate any changes in operating or design philosophy?[1]		
Do you have a philosophy on the relative importance of avoiding equipment damage vis-a-vis allowing a network disturbance to impact on customers?[1]		

[1] Attach additional sheets to expand response as required