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# THE NEEDS AND ENVIRONMENT OF CONTROL CENTRE OPERATORS DURING POWER SYSTEM RESTORATION


Working Group

39.01



August 2002

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## - A BENCHMARK QUESTIONNAIRE SURVEY -

**WORKING GROUP**
**39.01**

by

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# The Needs and Environment of Control Centre Operators during Power System Restoration

# - A Benchmark Questionnaire Survey -

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On the behalf of Cigré WG39-01

## *Abstract*

*This report presents the results of a questionnaire survey on power system restoration, covering operator needs and the changing industry environment. Responses were received from 36 organisations all over the world, and the analyses are presented in two parts:*

- *Part I - Business, which deals with organisational and strategic aspects of restoration, and the influence of market liberalisation on restoration*
- *Part II – Domain, which analyses domain specific issues related to restoration: operator problems in restoration, ideal needs and their current availability, and the gaps*

*The results form a benchmark with regard to many aspects of restoration.*

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# 1 Introduction

Restoration is of key importance to some utilities that experience regular disturbances and blackouts, or a low priority topic in power utilities where serious disturbances occur rarely. However, no power system is 100% reliable, and everyone may, at some time, experience an interruption. Control centre operators are often trained to restore supply to customers with the least risk and as soon as possible, but sometimes not. The lack of experience in restoring the system has been shown in several cases as one of the major reasons for the delayed availability of supply. In addition, operators have to deal with a huge amount of information, which may be inaccurate or contradictory. The liberalised electricity markets add a new dimension to the complexity of restoration implementation from the control centre perspective.

The practice of “sweating the Transmission assets” is putting pressure on the design reliability of transmission systems. In some cases, the investment criteria deliberately assume the equivalent of a certain number of interruptions per year. Thus efficient restoration becomes an imperative.

Therefore, Working Group 01 (System Control & Control Centres) of Cigré Study Committee 39 (Power System Control and Operation) decided to treat the topic of restoration and to realise a survey on current needs of operators in control centres during restoration. The objectives of this survey include:

- Pinpoint the most important issues to be addressed in further developments, which would fill the gap between the current and the desired state in control centres
- Offer a benchmark reference for utilities with respect to restoration
- Provide the opportunity to learn from the practices of others, regarding new developments like market liberalisation or for normal operations practices. This survey is a snapshot in time, but has detected many trends.

In this report, the analyses of the responses are presented under the following major topics:

- Details of respondents (Chapter 2)
- **Part I**
    - Organisational and strategic aspects of restoration (Chapter 3) - This topic covers the definition of interruptions, related performance indicators, restoration philosophies and priorities, involved parties and defining when the system is normal again after restoration.
    - The influence of market liberalisation on restoration (Chapter 4) - This topic covers contracts influencing restoration, interactions with the Market Operator, market and other constraints effecting restoration, costs incurred during restoration and information flows.
    - Conclusions for Business-related analysis (Chapter 5)
- **Part II**
    - Operators’ problems in restoration (Chapter 6) - Operators’ problems in restoration are conveniently classified into the categories of System Control, Information, People and Equipment and analysed.

    - Operators’ needs and gap analyses (Chapter 7) - Operators’ ideal needs for performing efficient restoration are presented in priority sequence. There is a great amount of consensus from all the respondents about the top seven needs. The ideal needs are then compared to actual availability.
    - Conclusions for Domain-related analysis
- Overall conclusions

## 2 Questions and answers

The response to the questionnaire was facilitated by the SC members and was excellent.

The following definitions are used (see also the Appendix):

Restoration: The process of making available electricity supply at the Transmission level supply points after an interruption in supply to customers at one or more supply points (i.e. full or partial black outs).

Customer: Entities either directly connected to the Transmission system (e.g., sub-transmission, distribution, generation, industrial consumers) or buying or receiving transmission services (e.g. retailers, suppliers, Independent Power Producers).

Neighbours: Control centres with which your control centre operators perform direct data exchange and co-ordination *during restoration*. Your control centre neighbours can be “internal”, i.e. under your control or coordination (e.g., regional control centres, power plants) or your peers (e.g., TSOs), and “external”, i.e. superiors or peers (e.g., interconnection or pool members, several TSOs with no ISO within a country).

CAIDI: Customer Average Interruption Duration Index

ISO: independent system operator, with no grid ownership

OTS: operator training simulator

SAIDI: System Average Interruption Duration Index

SAIFI: System Average Interruption Frequency Index

SARI: System Average Restoration Index

TSO: transmission system operator, a combined System Operator/Grid Owner organisation

TTH: Trip to houseload, a condition where a generator is isolated from the system but is running in a stable way, feeding its own auxiliary supplies

VI: vertically integrated organisation.

## 2.1 What we asked

Over and above some general background questions, the survey specifically concentrated on the needs of operators during restoration. Furthermore, specific questions were asked about the impact of a new market environment and possible contractual and liability issues.

The one difficulty experienced, was that just about all transmission organisations are changing, because of the changing environment. All classifications in this paper should be seen in that light.

## 2.2 Who answered

The answers have been received from 36 organisations from all over the world, thus covering a wide range of types and sizes of organisations as well as the economic environments in which they operate. The list of organisations, which returned the completed questionnaire, continent-wise, is listed below. The type of each organisation is also indicated in the list:

- 17 answers from Europe: Czech Republic (CEPS, *TSO*), Finland (Fingrid, *TSO*), Germany (E.ON Netz, *TSO*; RWE Net, *TSO*), Hungary (MAVIR, *VI* in transition to *ISO*), Ireland (ESB, *VI*), Italy (GRTN, *ISO*), The Netherlands (TenneT, *TSO*), Norway (BKK Net and BKK Produksjon, *distribution and generation*; Statnett, *TSO*; Viken Energinett, *distribution*), Portugal (REN, *TSO*), Romania (Transelectrica, *TSO*), Slovenia (ELES, *TSO*), Switzerland (NOK, *TSO*), United Kingdom (National Grid, *TSO*), Yugoslavia (EPS, *VI*)

- 9 from Asia: India (NRLDC of Power Grid, *TSO* and *ISO*), and eight out of ten *vertically integrated* organisations from Japan (Chubu Electric Power, Chugoku Electric Power, Hokkaido Electric Power, Hokuriku Electric Power, Kyushu Electric Power, Shikoku Electric Power, Tohoku Electric Power, Tokyo Electric Power)

- 3 from Africa: Algeria (Sonelgaz, *VI*), Libya (GECOL, *VI*), South Africa (Eskom Transmission, *VI*).

- 3 from North America: Canada (TransÉnergie of Hydro-Québec, *ISO*), US (Northern States Power, *VI* in transition to TSO; PJM Interconnection, *ISO*)

- 2 from Australia: NEMMCO (*ISO*), Western Power (*VI*)

- 2 from Latin America: Brazil (ONS, *ISO*), Venezuela (Opsis, *ISO*)

The above organisations have been classified into four groups with respect to the transmission environment in which they operate, as *mature economy, liberalised industry* (ml) and *traditional industry* (mt), and *developing economy, liberalised industry* (dl) and *traditional industry* (dt). The number of organisations per each of these categories, sorted by their peak load, is shown in Figure 1.

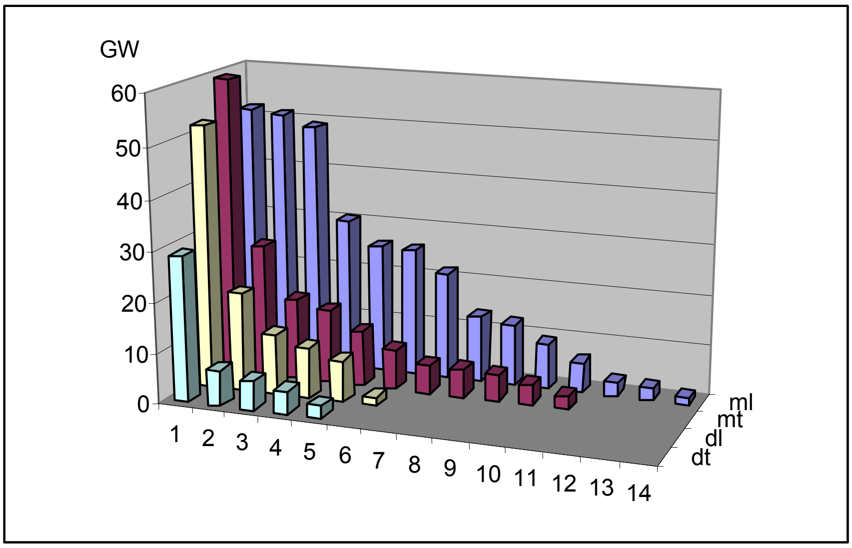


**Figure 1** Number of answers per peak load and per transmission environment

About 2/3 of answers cover mature economies, and 1/3 cover developing ones. With respect to liberalisation status, the response rate was almost the same for both liberalised and traditional industries.

Transmission voltages range from 765kV to 22kV, with all respondents having equipment at 200kV and higher. 92% of the respondents are responsible for a network with voltages of 300 kV and higher, and thus this paper deals primarily with meshed transmission networks rather than radial distribution systems.

# Part I – Business: Organisations, Strategies and Markets

## 3 Organisational and strategic aspects of restoration

### 3.1 Definition of disturbances / interruptions

In order to get a feel of how the different organisations define interruptions, the question asked was how interruptions are reported, i.e. how does Senior Management view interruptions. The responses were varying. Sixteen respondents (44%) use a combination of filters to decide which interruptions are reported to whom and when. (An example of a complex filter is to say that an interruption will be reported if the MWs interrupted exceed “x” (5 MW to 300 MW responses), the duration of the interruption exceeds “y” (14 minutes to 1 hour responses) and the number of customers affected exceeds “z” (5’000 to 50’000).) Fourteen respondents (39%) use a simple MW filter. Some institutional rules exist for reporting interruptions, for example set by DOE, NERC and MAPP in the USA.

The “external” (to Operations) parties to whom the interruptions are reported again vary widely. The relevant ministry in government was the most common answer, with 9 responses (25%). Chief Executives are informed in 3 cases (8%), customer executives in 2 (6%). Direct media liaison is not a control room function with any of the organisations (see also section 4.5 below).

### 3.2 Performance indicators related to restoration

“What gets measured gets done” – the survey tried to get a feel for the performance indicators (PIs) in place around restoration, which drive behaviour.

Most common were:

- Total restoration time (10 responses, 28%), with figures ranging between 14 minutes and 8 hours, depending on the magnitude of the disturbance.

- Field operator response time (6 responses, 17%), varying between 15 minutes and 1 hour.

Other PIs include System Minutes, MWh lost, Number of interruptions, Reporting time, SAIDI, SAIFI, SARI, and CAIDI.

It is clear that no PIs exist in organisations where interruptions are rare.

### 3.3 Restoration philosophies

Respondents were asked to describe their restoration philosophy very briefly, since detailed documents commonly exist. The responses clearly indicate that significant planning and thinking, and sometimes investment, go into these philosophies. Two organisations have their philosophies at a very high level, with no technical detail. For the others, a few basic philosophies exist around what to do first in the case of a major interruption:

- Restoring the backbone system first, using available sources of generation, with or without opening breakers to isolate the “non backbone”, then restoring the remaining system (3 responses, 8 %).

- Restoring loads around black start units or Trip To Houseload (TTH, or trip to auxiliaries) generators first, sometimes in parallel, build up these islands to eventually resynchronise the whole system (18 responses, 50 %).

- Using strong interconnectors / tie lines first to start the restoration process, if available and build up from there (9 responses, 25 %).

Typical major steps mentioned in the summarised philosophies are, with an attempt to arrange these in some time sequence:

- Identify blacked out areas (4 responses, 11 %)

- Check for islands (18 responses, 50 %)

- Identify the causes; verify equipment availability (this may involve getting field staff to site) (6 responses, 17 %)

- Identify sources of available supply (TTH units, black start units, tie lines) (19 responses, 53 %)

- Focus on synchronising TTH units with loads (4 responses, 11 %)

- Start restoration in all islands, pick up priority loads (e.g. nuclear power plants and auxiliary supplies to other generators) and grow balanced islands (17 responses, 47%)

- Or, build up backbone system (3 responses, 8%)

- Synchronise all islands (19 responses, 53%)

- Start with the major cities (2 responses, 6 %)

- Communicate / coordinate with other control centres (5 responses, 14%)

- Restore the DC connections last (1 response, 3 %)

- Restore from the strongest part of the network (1 response, 3 %)

In some cases automatic schemes exist which create balanced islands or break the system up into blocks for parallel or serial restoration (3 responses, 8%)

Although only mentioned in 6 responses, (17%), it is probably generally accepted that the philosophy has to be flexible in its application and adapt to the actual situation.

The state of the transmission environment does not seem to influence the restoration philosophy. Similar responses were received from mature or developing economies and liberalised or traditional industries.

## 3.4 Restoration priorities

Very closely aligned with the philosophy is the matter of priorities in restoration.

The most common (16 respondents, 44%) priority sequence is:

a) Ensure stable supply capacity, via interconnectors or TTH or black start generators, and supply other generators, with nuclear units always the highest priority

b) Restore priority loads, typically defined as hospitals, mines, railways, industries, government institutions, major cities, airports, etc.

The next most common (5 responses, 14%) priority sequence is, with the only real difference being the lower priority of interconnectors:

a) Supply to generators

b) Supply to priority loads

c) Restore interconnectors

Most of these responses came from developing economies (4 out of 5), although the sample size is not big enough to come to a firm conclusion. One would expect that the strength of the interconnectors and of the neighbouring systems would rather dictate where in the priority sequence the restoration of interconnectors will fall.

Eight respondents (22%) simply indicated that loads are restored in priority order. One respondent indicated that heavy industry and traction would be avoided early in restoration.

The issue of "stable supply" as mentioned is probably inherent in all cases and especially where the interruption has also involved generation. That is, generation and load needs to be constantly matched throughout the process.

Again, the state of the transmission environment does not seem to influence restoration priorities. Similar responses were received from mature or developing economies and liberalised or traditional industries.

## 3.5 Who performs restoration?

Decentralisation is common during restoration, but was applied in two significantly different ways.

- 25 respondents (69%) replied that strategies are set at a national or larger geographic area level, and implementation is planned for and executed at a regional or decentralised level.

- 10 respondents (28%) replied that all aspects of transmission-level restoration are handled from one control centre and distribution-level restoration is done in various distribution control centres.

In the large majority of the cases a hierarchy exists, which means that the higher level control centre will provide coordination or even take over some of the functions, depending on the size of the interruption.

### 3.6 When is the situation normal again after restoration?

There are almost as many variations here as the number of responses received. Many organisations (17, or 47%) use multiple criteria. The following criteria had at least some commonality:

- Voltages, frequency within limits (13 responses, 36%)
- 100% of the load restored (11 responses, 31%)
- The next contingency can be handled (system back to the n-1 state) (4 responses, 11%)
- No islands exist (3 responses, 8%)
- When the customer can take load, i.e. the supply voltage is restored on the busbar (2 responses, 6%)
- Power flows within limits (2 responses, 6%)
- No precise definition exists (yet) (6 responses, 17%)

Other definitions include varying portions of the load restored (75, 80, 85, 90, 95%), interchange within limits, all distribution feeders energised, 80% of generation restored, all power and transmission stations connected to the grid, the Regulator defining the exact point after the fact.

One respondent pointed out the importance of this definition. In a liberalised environment, the market may be suspended due to a severe interruption, and clear criteria should exist for when the suspension can be lifted. Another reason why this definition is important is because many of the performance indicators are based on time.

### 3.7 Discussion: organisational, strategic aspects of restoration

There is obviously no right or wrong in any of the above. Local circumstances, the state of industry evolution, organisational politics and preferences and even country politics play a role. However, some common themes exist, for example:

- A decentralised approach to restoration
- Ensuring stable supply capacity during restoration

It is hoped that these and other information shared above can form benchmarks of best practices.

## 4 The influence of market liberalisation on restoration

In this section, we will explore the specific impact of the changing environment on the restoration process. Responses used are specifically from those organisations that operate, or plan to operate in a liberalised environment. The base used in percentage calculations in this section is limited to 20 organisations.

## 4.1 Contracts covering restoration

Contracts exist on both the input (service acquisition) and output (service delivery) side. Bilateral support agreements exist with neighbours, some of which are contractual.

Five respondents (25%) have input-side contracts with generators to provide black start facilities or with loads to limit consumption. In an additional four cases (20%), these obligations are contained in the Grid Code, in law, or in Regulator documents, which is assumed to also cover the output-side.

Seven respondents (35%) have output-side contracts with interruptible or other industrial loads or nuclear power plants to provide supply within a certain time period and with other customers for the provision of mobile generators.

Although only mentioned by a few respondents, it is assumed that all participants in the major interconnections throughout the world have mutual support rights and obligations.

No respondent mentioned that any of these contracts / agreements constrain the restoration process (see also chapter 7, Q16, in Part II).

## 4.2 Interactions with the Market Operator during or after restoration

It is common to have the System Operator deciding, and communicating with the Market Operator, on power system emergency conditions that could suspend or re-open market operation (7 responses, 35%).

One respondent mentioned that the market is never suspended for an interruption; two mentioned that only a total blackout would cause market suspension, one stated that the market is suspended while Black Start Rules apply.

The Market Operator could be the party coordinating the provision of emergency resources during restoration (2 responses, 10%) and the settlement afterwards, while keeping in mind that the generation picture after restoration may differ from the agreed schedules.

The relationship between the System and Market Operators seems to cover a whole spectrum, from “The Market Operator is an integral part of the restoration” to “It is not possible for the (system) operator to ask for prices when his first priority is to re-build the grid”.

Whether or not these interactions work better when the System and Market Operators form part of the same organisation (3 cases), was not apparent from the responses (see also chapter 7, Q04, in Part II).

## 4.3 Restoration: Market, legal and organisational constraints

Few of these types of constraints seem to exist. Mentioned are:

- Many or different parties involved in the process (4 responses, 20%)
- Technical constraints (e.g. safety, security of supply) (2 responses, 10%)
- Cost (also due to Regulator pressure) (2 responses, 10%)

- Environmental, information confidentiality, lack of training, procedural (NERC) (1 each)

## 4.4 Costs incurred during restoration

Since most respondents answered this question, and not only those in a liberalised environment, percentages are not quoted to prevent confusion.

- In seven cases a system has been implemented where the party causing the costs, or the user of the extra services, pays. An example is a case where the owner of the asset will have to pay if the interruption was caused by its unreliability. This is seen as a significant development and trend in the liberalised environment, and should drive appropriate behaviour.

- In another seven cases the TSO bears the costs.

- In six cases, it is not yet decided or not clear who should pay.

- In another six cases it is simply the vertically integrated utility that bears the cost and thus the end customer ultimately.

- Where there is an ISO, or in the case of one TSO, the market participants bear the costs (4 responses).

- In one case, it is up to the Regulator to decide.

The type of costs incurred includes the use of some ancillary services, e.g. black start, penalties for deviating from schedules as well as additional balancing / regulation usage.

## 4.5 Information issued by the control centre during restoration

The responses here were quite broad, providing a useful overview. Again, most organisations responded to this question so percentages are not given.

Common views on *what* information is issued:

- Instructions to other control centres, generators, interruptible loads and ancillary services providers (6 responses)

- Time of interruption and current status (6 responses)

- The area affected and the magnitude of the interruption (6 responses)

- Expected restoration time and situation / process (5 responses)

- The cause of the interruption / description of the fault (4 responses)

- Weather, reserves, injuries, protection operations, status of interconnectors, etc. (1 response each)

*To whom* is the information sent:

- Management (14 responses)

- The media (10 responses, see below)
- Government institutions, FERC, NERC, the Regulator (5 responses)
- Regional/distribution control centres (5 responses)
- Neighbours (3 responses)
- Market participants (2 responses)
- Regional coordinator (2 responses)
- Customer executives (1 response)
- Affected emergency services (1 response)

*How* is the information exchange managed:

- Pre-defined instructions between control centres and other parties (6 responses)
- Information to the media goes via public relations / information centre / customer relations / management (5 responses)
- A rule that, during the restoration process, control room communication only takes place between the involved parties (3 responses)
- An emergency restoration organisation / system incident centre is created to take care of all communications (2 responses)
- A comprehensive, multi-level, pre-defined process (1 response)
- Put on the internet (intranet) for company employees (1 response)

### 4.6 Assessment of the impact of market liberalisation on restoration

From the above sections, one can conclude that market liberalisation has not created major problems for restoration. In general, complexity increases with new interfaces appearing and relationships become more contractual. A cost element is introduced into the restoration equation and more formal information is exchanged. A number of these details are still being defined. However, responsibilities seem to be clear, no major new liabilities face the System Operator and the information exchange requirements seem to be under control.

All of this means it is impossible to escape the fact that demands on control room operators are increasing.

## 5 Conclusions and recommendations (Part I)

The intent of this section is not to repeat all of the conclusions mentioned in the body of the paper. Rather, a few high level conclusions / recommendations are made.

## 5.1 Organisational, strategic

The trends mentioned can be used as industry benchmarks. These include:

- Total Restoration Time is the most common performance indicator
- The most common restoration philosophy is to restore loads around black start units or Trip To Houseload (TTH, or trip to auxiliaries) generators first, sometimes in parallel, build up these islands to eventually resynchronise the whole system.
- Restoration priorities are, typically, ensuring stable supply capacity and then restoring priority loads.
- A decentralised approach to restoration is quite common.
- Good definitions of when the system is normal, are needed but don't seem to exist yet

## 5.2 The influence of market liberalisation

The liberalisation of the industry has not caused undue problems with restoration. Overall the restoration process is more complex with more demands being placed on control room operators.

# Part II – Domain: Problems, Needs and Gaps

## 6 Operator problems in restoration

In the question on problems during restoration and main bottlenecks causing time delays, we gave a few typical restoration problems as examples, but the answers highlighted still many more issues. We have grouped all the highlighted problems into four categories: *Equipment*, *Information*, *System control* and *People*. The number of enumerated problems per response sheet varied from 0 up to 11, and Figure 2 shows the cumulative number of answers per problem class and transmission environment. The following is the summary of most common problems within each of the above problem classes.

**Equipment.** The main reason for delayed restoration seems to be the inability to switch transmission plant rapidly, reported by 23 organisations (64%). The problems are mostly related to the malfunctioning or slow control facilities and malfunctioning breakers.

**Information** related problems also have a major impact on the speed of restoration. The lack of status information was emphasised in 22 answers (61%). The next issue in this category is the large amount of non-selective information (6 answers or 17%).

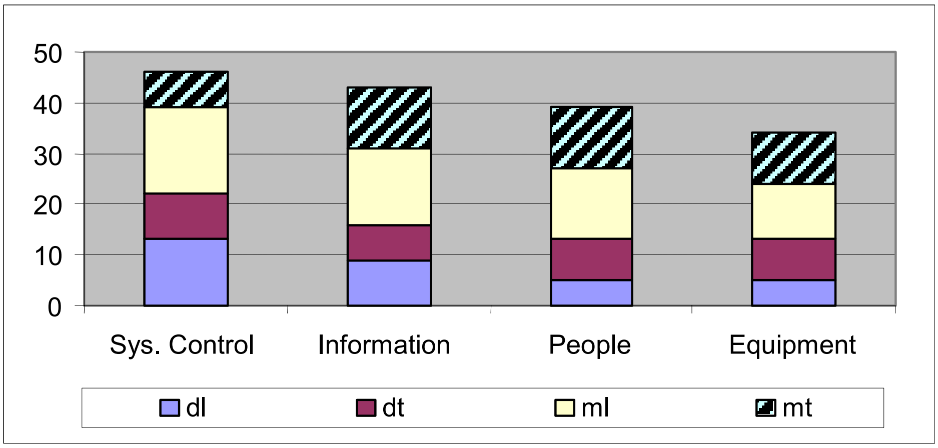


**Figure 2** Cumulative number of answers per problem class and transmission environment

**System control.** The inability to control voltages is the main issue in this category, mentioned 14 times (39%). Next to this is the problem of the shortage of generation (13 answers or 36%), and in particular the location of the black-start and other available production units. The inability to control frequency is an issue for 10 organisations (28%). Synchronisation problems were an issue in 7 answers (19%), and related mainly to the lack of synchronisation facilities.

**People**-related problems were not given as examples in this question, but the organisations mentioned a number of them as additional factors causing delays in restoration. The most significant problems, identified in 13 answers (36%), are those related to co-ordination, such as lack of co-ordination or delays caused by intermediate control centres in the hierarchy. The problems related to *control centre operators* represent 15 answers (40%), and include the lack of experience and training, the stress in the control room, and the inability to quickly process all the incoming information. Ten organisations (28%) addressed *field staff* response time and experience.

## 6.1 Discussion

The answers show that for different organisations, the same problems during restoration have differing importance. To get a better view, Figure 3 shows the relative importance of the factors delaying restoration, per problem group and transmission environment.

- System control problems were mentioned mainly in answers from *developing* economies. This category shows also the widest span in importance level with respect to transmission environment: the most important being in *developing liberalised* (2.17pu), and the least important being in the *mature traditional* environment (0.64pu).

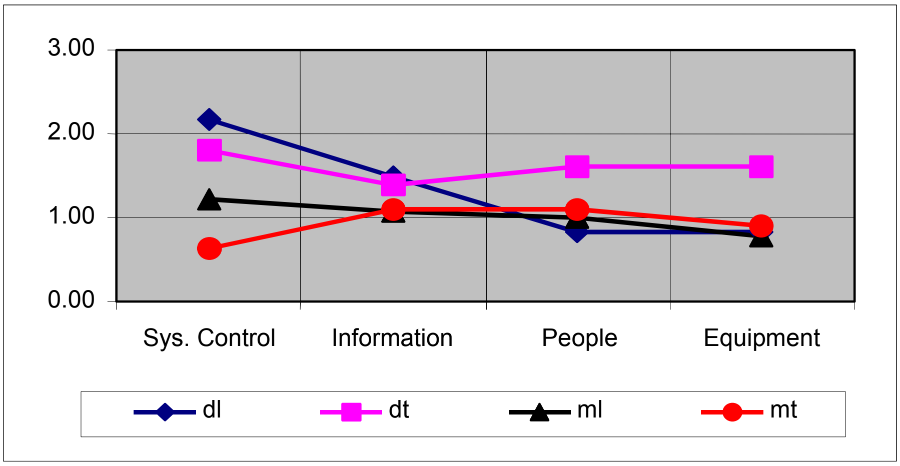


**Figure 3** Relative importance [pu] of problems delaying the restoration, per problem group and transmission environment

- *Traditional* organisations mentioned more people and equipment related problems than the *liberalised* ones, probably due to their inherent characteristics: the "vagueness" of transmission asset ownership and the higher number of hierarchy levels increasing the need for co-ordination.

- The most important problems in *liberalised* industries are those related to system control.

- Information-related problems are given similar importance irrespective of the environment.

Table 1 summarises most relevant problems or factors that lead to delays during the restoration. Although the equipment and information related problems are not striking compared to other groups of problems from Figure 3, the inability to switch transmission lines rapidly and the lack of status information *are* the most frequently mentioned issues causing delays in restoration. They are also the most representative issues, since evenly distributed across all types of environment and organizations.

**Table 1** Most relevant restoration problems

| Restoration problem | | Relevance [pu] |
|---|---|---|
| Equipment: | Transmission switching | 0.66 |
| Information: | Lack of status information | 0.63 |
| System control: | Voltage control | 0.44 |
| System control: | Shortage of generation | 0.43 |
| People: | Coordination | 0.39 |
| System control: | Frequency control | 0.36 |

## 7 Operator needs and their priorities

The questionnaire contained 17 questions concerning the operator needs during the restoration, summarised in Table 2. Organisations were asked to state first what would the operators *ideally* need to perform the restoration tasks most efficiently, then to *prioritise* these needs, and finally to say to what extent the enumerated needs are *actually* available in their control centres.

We will first analyse the *ideal* operator needs during restoration and their priorities. Figure 4 shows the cumulative number of answers (y-axis) per priority (areas), assigned to the needs (questions Q01 through Q17 on x-axis). The needs are prioritised as ***essential***, ***important***, ***nice to have*** and not required.

**Table 2** List of questions on operators needs (RT: real-time)

| | |
|---|---|
| Q01 | RT information on the directly involved part of the network |
| Q02 | RT information on the surrounding / rest of the network |
| Q03 | RT information from neighbouring control centres |
| Q04 | RT information from the market |
| Q05 | RT information regarding generators |
| Q06 | Computer decision support tools |
| Q07 | Other decision support tools |
| Q08 | Remote control facilities |
| Q09 | Operator back up at the site |
| Q10 | Telecommunication |
| Q11 | Training |
| Q12 | Energy support form “internal” neighbours |
| Q13 | Energy support form “external” neighbours |
| Q14 | Access to sources of power with rapid response |
| Q15 | Local substation automation |
| Q16 | Knowledge of contracts |
| Q17 | Other |

The following seven needs are considered as *essential* (highest priority) for restoration by 60% of organisations, and as either *essential* or *important* by as much as 94% of organisations (see section 7.1).

- **Q01: Need for real-time information on the directly involved part of the network.** Most answers included the fault information, the involved part of the network, sequence of events, equipment condition, indications, measurements, and loads lost.

- **Q10: Need for telecommunications.** Most frequently mentioned were SCADA, mobile phones, radio, and dedicated public networks.

- **Q05: Need for real-time information on generators.** Most of the answers mentioned black-start capability, restart/resynchronisation times (ready to resynchronise in time x, must be synchronised before time y), and unavailability due to maintenance or failure.

- **Q02: Need for real-time information on the rest of the network.** Most frequently mentioned were indications, measurements, status of generating plants, level of generating and regulating reserves, circuit breaker lock out, abnormal loading and violation limits for power flows and voltages in the transmission network.

▪ **Q08: Need for remote control facilities.** Most of answers included switching devices, tap changers, black-start units, and load (interruptible, customer and industrial; frequency and voltage load shedding).

▪ **Q14: Need for access to sources of power with rapid response.** Most answers included hydro (pumped storage) plants, gas plants, interruptible loads and compensation devices.

▪ **Q11: Need for training.** Most answers contained restoration training on an operator training simulator, restoration drills (internally and with neighbours; starting of black-start units, build up a blacked out grid; team and individual), theoretical courses, and field training in power plants, substations and control centres.

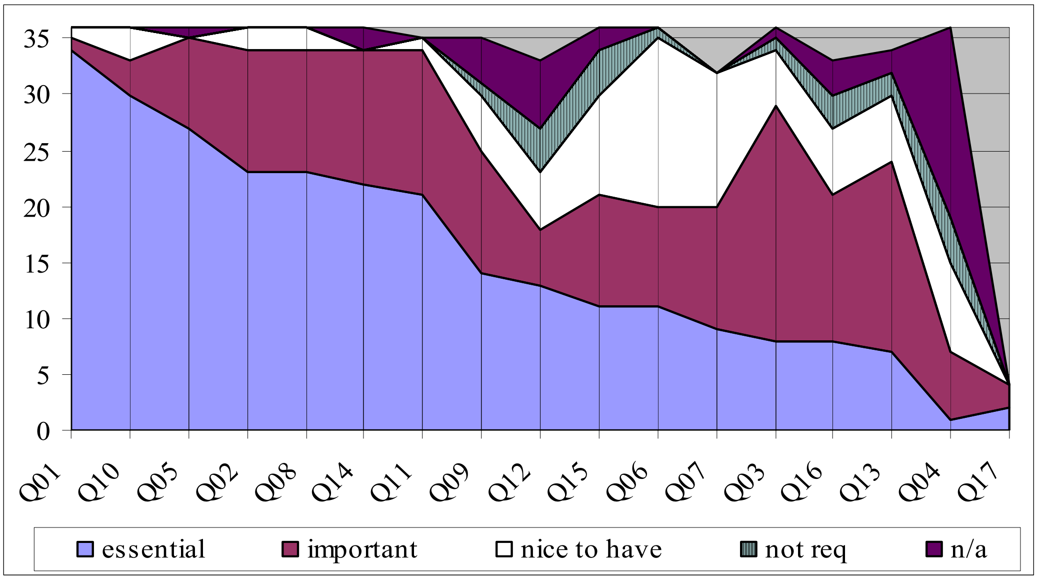


**Figure 4** Needs during restoration, sorted by "essential"

While still referring to Figure 4, the next eight needs qualified *either as essential or important* by more than 50% of organisations.

▪ **Q09: Need for operator back up at the site.** Where applicable, this has been tagged as essential in 47%, and as important in 37% of answers. Most frequently mentioned requirements were the response time of field operators to get to the site, and the appropriate skill level. The response time ranges from 5min-2h for generating plants (mostly 30min), and from 5min-3h for substations (mostly 1h).

▪ **Q12&Q13: Need for energy support from internal and external neighbours.** 28% of organisations do not need energy support from *internal* neighbours, while this number is much smaller for *external* support (11%). Of those who need *internal* support, 57% consider it as essential, and 22% as important, while the proportion is inverse in the case of *external* support. The most frequently mentioned requirements for information from *external* neighbours were the quantity of available cranking power and its location, constraints, and extra charges for emergency power. The need for internal or external energy support heavily depends on the configuration and the type of the network, and sometimes on the restoration philosophy (see also sections 3.3 and 3.4 in Part I).

▪ **Q15: Need for local substation automation.** This need was tagged explicitly as not required by six TSOs/ISOs. For the others, the priorities are evenly distributed. The most frequently mentioned functions of local substation automation included coordinated load shedding, opening of all breakers in the event of the busbar voltage going to zero (automatic or initiated from control centre), and automatic operation of intelligent devices. The comments to this question reflect the differences in the perception of, and the confidence in “intelligent” devices or systems, performing tasks, which can have a major impact on network security.

- **Q06: Need for computer-based decision support tools.** This question inspired the most imaginative answers, and a detailed analysis would require a chapter on its own. Due to the space limits, we will mention only the most relevant (numerous) topics, which are undoubtedly intelligent alarming and on-line restoration guidance tools. *Intelligent alarming* should point to the problem, analyse what happened, and predict the network behaviour via simulation. *On-line restoration guidance tools* should be an interactive, context-driven decision support system, capable of elaborating on the re-energising path and providing the most effective sequence of actions or detailed actions. The solutions should be a function of what happened, and should take into account the operational status before failure, the status of the parts of the network directly involved, and inherent characteristics of the network itself. Interestingly enough, there was a single explicit answer “not required” by a European TSO, otherwise all the organisations rated this need as either essential (32%), important (26%) or nice to have (42%).

- **Q07: Need for other (non-computer-based) decision support tools.** Those that provided an answer rated this need in proportion 3:3:4 as essential, important or nice to have. Most of answers included priority customer lists, restoration plans, instructions or procedures and checklists or guides for reporting.

- **Q03: Need for real-time information from neighbouring control centres.** The needs that apply to *both internal and external neighbours* in most cases were current status of the neighbouring network, energising path capacity and available power reserves, indications, measurements, circuit breaker lock out, abnormal loading, or any near abnormal condition in neighbouring control areas. With respect to *internal* neighbours, TSOs, ISOs or main control centres of traditional organisations need a verbal report of the incident, obstacles that may prevent restoration, the timeframes involved, information on islands in regional networks, and customers affected. As for *external* neighbours, most often emphasised were emergency assistance capabilities, interchange transactions, and additional risks on interconnections. Note that the real-time information from neighbours is considered as *essential* by only 24% of organisations, which are mainly TSOs (or their equivalents), but is ranked as *important* by 62%. This probably goes along with what has been identified as one of important problems for operators during restoration, namely, the selective handling of vast amounts of information.

- **Q16: Need for knowledge of contracts.** Applicable mostly where the industry is liberalised, this topic has been rated as essential, important or nice to have during restoration in proportion 3:5:2. The knowledge most often required included operating manuals, the Grid Code or equivalent, potential liability issues, communication procedures with external neighbouring control centres and contracts or mutual assistance agreements with them. A combined comment from two organisations is worth noting here: “It should be mandatory for operators to know all the system constraints, both technical and contractual ones, in advance - no reading during restoration” (see also sections 4.1 and 4.2 in Part I).

Finally, for completeness, a discussion on the last two questions follows.

- **Q04: Need for real-time information from the market** has been explicitly tagged as not applicable or not required by 58% of the respondents. Only 20% of organisations consider this type of information as important or essential during the restoration. The comment of an ISO explains the best the results obtained: "During major interruptions, the focus is on retaining system security, not on economics. However, to the extent that economics will facilitate the maintenance of or the return to a secure system, then market processes can and will be done" (see also section 4.2 in Part I).

- **Q17: Other needs**, dealing mainly with communications and islanding, have been identified by only four organisations, and since this is not representative enough, they will not be considered further in the discussions.

## 7.1 Commonalties, differences

Figure 5 shows the relative number of answers per transmission environment, in which the needs have been tagged as either *essential* or *important*. There follows some discussion on commonalties and differences (greater than 20%) for this overall trend.

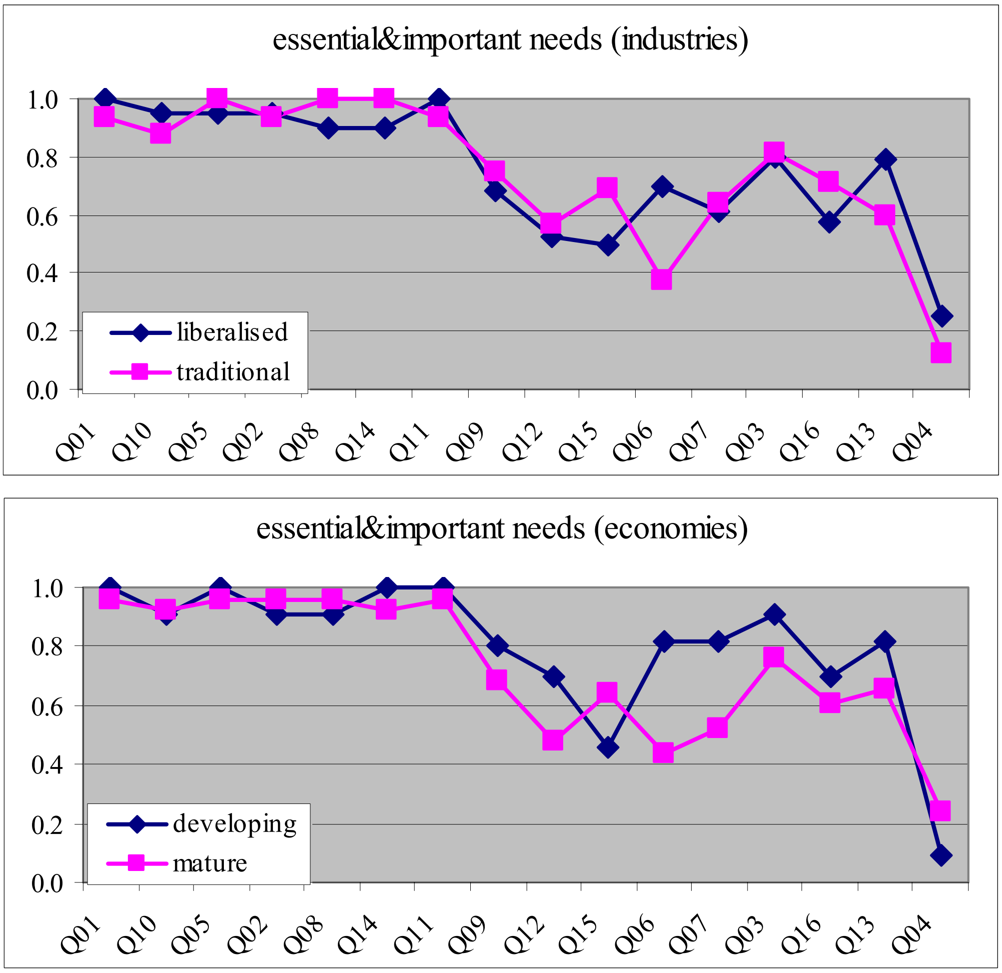


**Figure 5** Distribution of "essential & important" needs

- (Upper figure) Industry liberalisation does not appear to influence the needs of operators during restoration. The only significant difference between *liberalised* and *traditional* industries (38% and 70%, respectively) shows up in the need for computer-based decision support tools (Q06). The difference comes mainly from vertically integrated organisations in *mature* economies, where in 9 out of 11 answers, these tools have been marked as “nice to have”. (Are their environments less demanding?)

- (Lower figure) The needs for computer-based and other decision support tools (Q06, Q07) are given very high priority by 82% of organisations from *developing*, against 44% (Q06) and 52% (Q07) of those from *mature* economies. The reason is probably that in developing environments the operators face the restoration issue much more often, and thus have a greater requirement for decision support tools.

It is obvious from Figure 5 that there is almost a perfect match in trends for the first seven needs, and this holds true for more than 90% of organisations, irrespective of their environment. This means that there is a general agreement on essential and important needs in restoration. However, when considering a narrower criterion (i.e., *essential* needs only), priorities change somewhat with the environment. These differences are discussed below, with the help of Figure 6, which shows the relative number of answers for *essential* needs only.

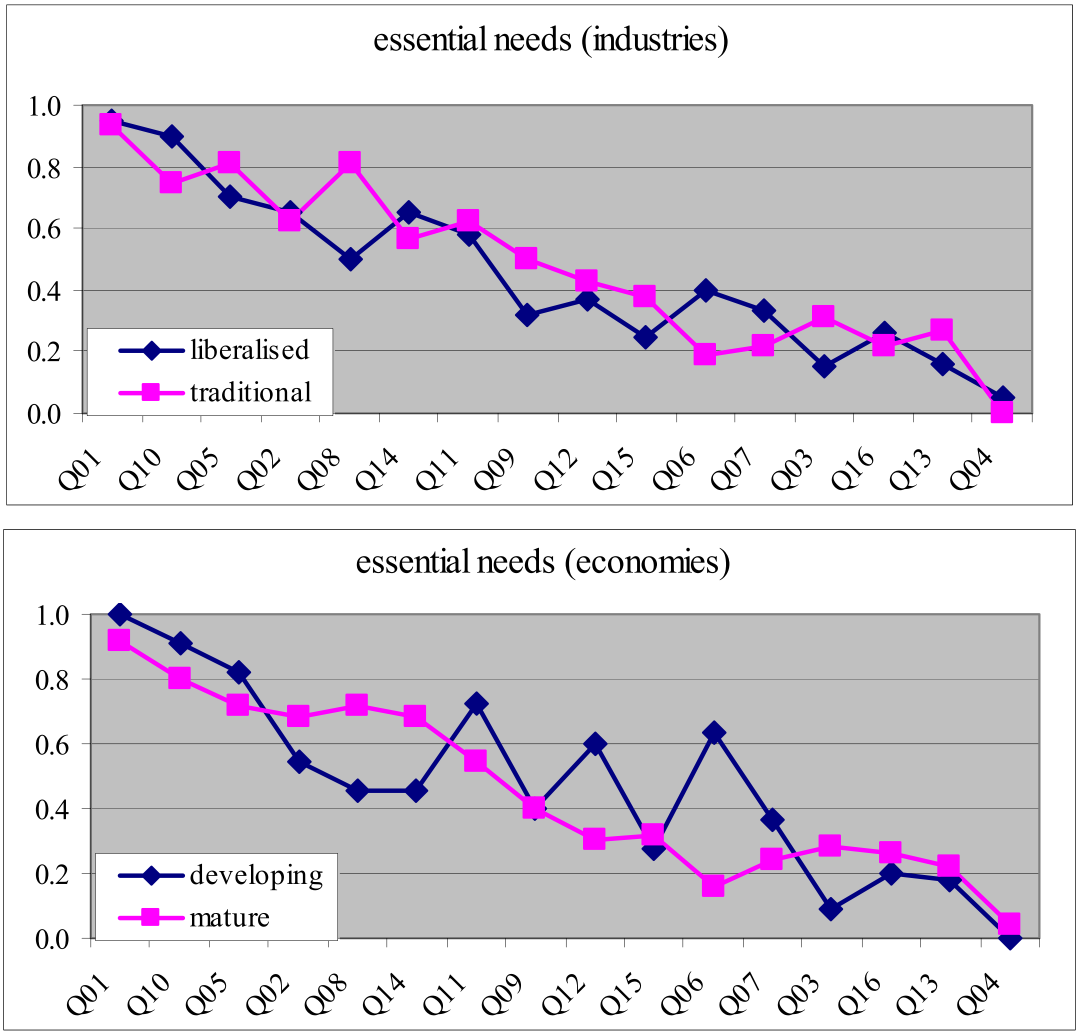


**Figure 6** Distribution of “essential” needs

- Real-time information on the directly involved part of the network (Q01) is the most important need, irrespective of the transmission environment.

- In *liberalised* industries (upper figure), the needs for remote control facilities (Q08) and operator back up at the site (Q09) have somewhat lower priority as essential needs, than in *traditional* industries (since a number of ISOs have no responsibility for direct control of the network devices and no ownership of transmission assets).

- On the contrary, the *liberalised* industries give higher priority to computer-based decision support tools (Q06) than *traditional* ones: 40% and 19%, respectively.

The patterns of *essential* needs have the greatest mismatches when comparing how the organisations from different economies prioritise them (lower figure):

- The needs for remote control facilities (Q08) and sources of power with rapid response (Q14) seem to have much higher priority in organisations from *mature* economies (70%), as compared to those from *developing* ones (45%). One of the reasons may be that the latter organisations simply have less remote control facilities, and therefore cannot rely on them.

- On the other hand, the needs for training (Q11) and for computer-based decision support tools (Q06) are considered as essential by 73% (Q11), and 64% (Q06) of respondents from *developing* economies, while their importance is somewhat smaller for organisations from *mature* economies. They rated these aspects as essential, important, and nice to have, respectively in proportions 5:4:1 for training, and 2:3:5 for computer-based decision support tools. This trend shows once more that more frequent power supply interruptions in developing economies result in higher need for training and software tools that can help operators in preparing for, or during restoration.

## 8 Gap analysis

Up to now, we enumerated and discussed the *ideal* operator needs and their importance during restoration. Here we focus on the actual availability or realisation level of these in control centres. To produce Figure 7, the actual availability levels, represented with bars, have been superimposed on the prioritised needs from Figure 4. Note that the number of answers for some needs is smaller than that in Figure 4. This is because the response rate to the current needs' *availabilities* was somewhat smaller than the one for needs' *priorities*, and all the comparative analyses in this section could be done only for the organisations that provided both the priority and availability values.

The overall trend already shows that for most of the high priority needs (the first seven), the availability trend follows the ideal needs' priority trend. The ideal needs for restoration are *almost* fully satisfied (i.e., availability level over 80%) with some minor exceptions for access to sources of power with rapid response (Q14), remote control facilities (Q08) and training (Q11). These gaps result from complete unavailability reported by some organisations.

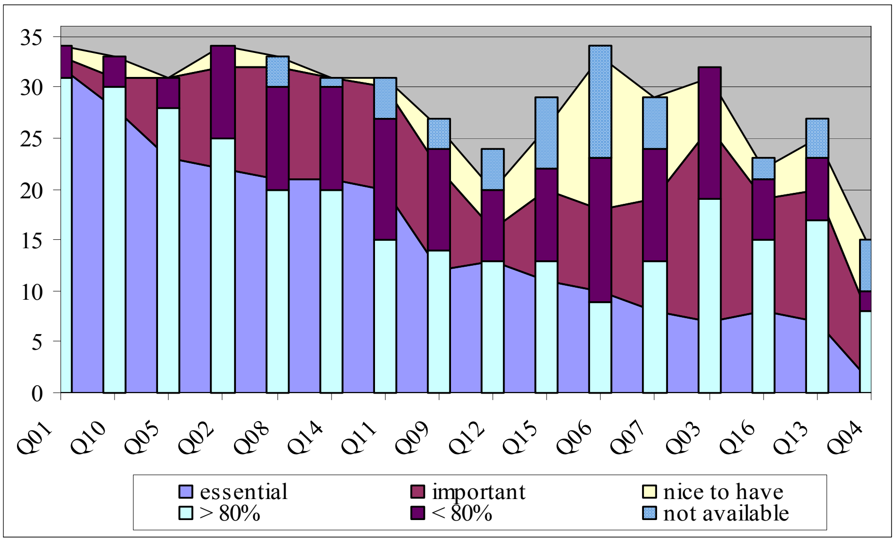


**Figure 7** Global trend for currently satisfied restoration needs in control centres

Table 3 shows average gaps between the needs and their actual availability, per need's priority and transmission environment. The gaps are calculated as the difference to 100% availability.

**Table 3** Average gaps [%] between ideal needs during restoration and 100% availability

| | | | | | | economy | | industry | |
|---|---|---|---|---|---|---|---|---|---|
| | dl | dt | ml | Mt | **avg** | dev | mat | lib | trd |
| ess | -22 | -18 | -13 | -7 | **-15** | -20 | -10 | -18 | -12 |
| ess&imp | -25 | -29 | -17 | -16 | **-22** | -27 | -16 | -21 | -22 |
| imp | -41 | -43 | -27 | -27 | **-35** | -42 | -27 | -34 | -35 |
| nth | -97 | -80 | -54 | -70 | **-75** | -89 | -62 | -76 | -75 |
| **avg** | **-54** | **-47** | **-31** | **-35** | **-42** | **-50** | **-33** | **-42** | **-41** |

- The first obvious difference in availability levels is, as expected, with respect to economy type. The organisations from *developing* economies have gaps 1.4-2 times those of *mature* economies, for the needs of all priorities. It is worth noting that the biggest difference (factor 2) is for *essential* needs.

- The average availability for *nice to have* needs is quite low (25%). It is interesting to note that the extreme values here come from *liberalised* industries: the organisations from *mature* economies have as much as one half of these low priority requirements satisfied (54% gap) while those from developing economies have almost none (97% gap).

- The average gaps in actual availability of all needs during restoration increase (15%, 35%, 75%), as the priorities of needs decrease (essential, important, nice to have, respectively). For those in *mature* economies, the average availability of ideal needs is about 2/3, against only 1/2 for those in *developing* economies.

We will now focus on the most important gaps for *essential* needs with the help of Figure 8, which shows the distribution of significant average gaps, per transmission environment type, only for those organisations that ranked the needs as *essential*.

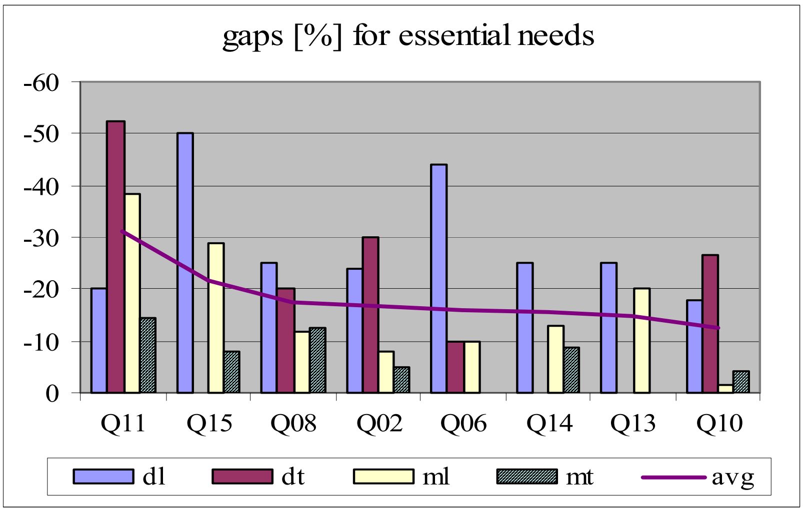


**Figure 8** To which extent the *essential* needs during restoration are *not* satisfied

- The most important unavailability for *essential* needs is in organisations from *developing liberalised*, and the highest availability, in those from *mature traditional* environments.

- The largest average unavailability (31%) is in the need for training (Q11), and mostly in organisations operating in *developing traditional* and *mature liberalised* environments (other organisations mainly ranked the need for training as *important* or *nice to have*, rather than *essential*).

- Then follows local substation automation (Q15, 22%), mainly in liberalised industries; then, remote control facilities and information from the surrounding network (Q08 and Q02, respectively, both 17%); and, computer-based decision support tools (Q06) and access to sources of power with rapid response (Q14), both showing an average gap of 16%, mainly in developing liberalised organisations.

- It is worth noting that the *vertically integrated* organisations from *developing* economies have quite high unavailability not only with respect to training (which is the general trend here), but also for some more basic functions, namely, 30% unavailability in the information on the surrounding network (Q02) and in telecommunications (Q10).

To conclude this section, Figure 9 shows the average unavailability of needs, irrespective of their priority, i.e., for all the organisations that ranked the needs in question as *essential*, *important* or *nice to have*.

- The overall average trend for unavailability of needs is much higher that the one for essential needs only (as in Figure 8). The difference is introduced by high unavailability of needs ranked as *nice to have*.

- The unavailabilities are more evenly distributed per type of transmission environment here (*overall*), than in the case of *essential* needs only.

▪ The first four *overall* largest unavailabilities (Figure 9) are similar to the *essential* ones (Figure 8). The exception is in local substation automation (Q15) and computer-based decision support tools (Q06), which have their positions swapped.

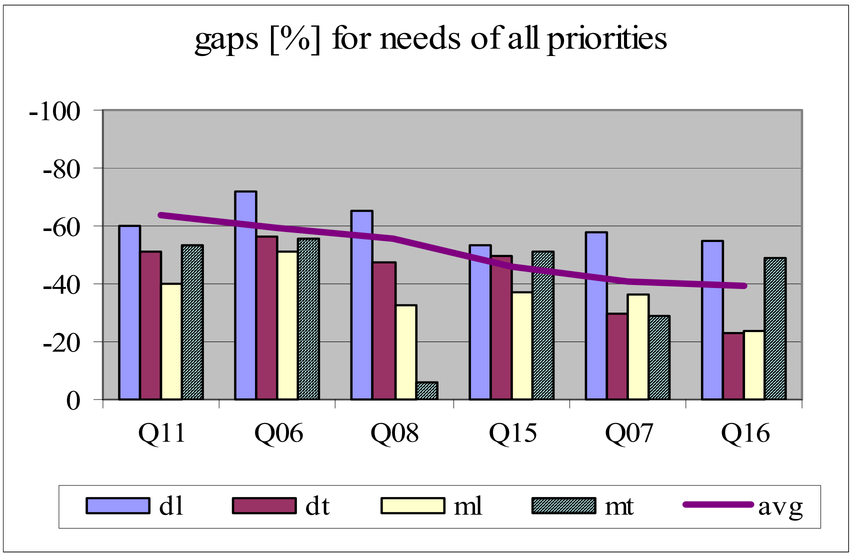


**Figure 9** Average unavailability of needs of all priorities

The need for tools and training is of course accentuated by the fact that many operators get very little practical experience in restoration, due to the reliability of the networks. One respondent mentioned that no interruption of any significance has occurred in the last 10 years. On the other hand, there are cases, especially in the developing economies, where countries black out regularly, (at least once a year) and those operators become very skilled at fast restoration, achieving a total country restoration in perhaps 20-30min.

# 9 Conclusions (Part II)

The inability to switch transmission lines rapidly and the lack of status information are the most frequent causes of delays in restoration. They are evenly distributed across all the different transmission environments and organisations System control problems (voltage and frequency control, shortage of generation) are most relevant in *developing* economies and problems related to co-ordination are the main problems in *traditional* industries.

There is a general agreement (for 94% of respondents) on *essential* and *important* needs during restoration. They are real-time information on the directly involved part and the rest of the network, and on generators; telecommunications; access to sources of power with rapid response; remote control facilities and training.

The main differences in priorities exist for training, and decision support tools. They are given much higher priority in *developing* economies than in *mature* ones, due to more frequent restorations. Also, *liberalised* industries rate these tools as higher priority than *traditional* organisations, due to the increased complexity in the environment.

The organisations from *developing* economies have overall unavailability of needs 1.4-2 times those of *mature* economies (2 being for *essential* needs).

The average unavailability for all needs increases as the priorities of needs decrease. For organisations in *mature* economies, the average actual availability of ideal needs is about 2/3, against only one half for those in *developing* economies.

For *essential* needs, the largest unavailability (31%) is for training. Then follows local substation automation, remote control facilities and information from the surrounding network and computer-based decision support tools.

The average overall unavailabilities are the following: training, computer-based decision support tools, remote control facilities, local substation automation and non-computer-based decision support tools.

## 10 In overview

If we had to emphasise one conclusion, it is the common need for operator training. This implies an organisational commitment, the provision of the required resources and the development of training tools. The other needs, gaps and important factors are quite clear from the paper and are now benchmarked in terms of common (and probably best) practise. Possible response strategies are in the hands of transmission organisations or system developers.


## Acknowledgement

Many thanks to organisations that answered the questionnaire, as well as to Gerhard Krost (WG39-03), Antonio Diu (WG39-04) and WG39-01 members for comments for both the questionnaire and this paper.


## Appendix: Performance Indicator definitions

CAIDI: Customer Average Interruption Duration Index gives the average interruption duration (minutes)

$$= \frac{\text{Total duration of interruptions p.a. (min)}}{\text{Total number of interruptions}}$$

SAIDI: System Average Interruption Duration Index gives the average interruption duration per supply point per year (minutes)

$$= \frac{\text{Total duration of interruptions p.a. (min)}}{\text{Number of supply points}}$$

SAIFI: System Average Interruption Frequency Index gives the average number of interruptions per supply point per year

$$= \frac{\text{Total number of interruptions p.a.}}{\text{Number of supply points}}$$

SARI: System Average Restoration Index is the average of the set of restoration times observed for all the incidents occurred during a certain time period (note: for one incident, there may be more than one restoration time, since this is measured at each supply point).

$$= \frac{\text{Total recorder restoration times p.a.}}{\text{Number of incidents in all supply points}}$$

Publié par le CIGRÉ
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*Published by CIGRE*
*21, rue d'Artois*
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