

**International Survey on adoption of resilience within the Electricity Sector**

**CIGRE C4.47 Working Group on Power System Resilience**

**SUMMARY**

In recent years, the impact of natural and man-made hazards on critical infrastructure has resulted in governments, regulators, utilities and other interested parties elevating requirements to enhance the ability of critical infrastructure. In this context, CIGRE C4 has established a technical working group (WG) to provide guidance in an attempt to standardise the approach to adopt resilience thinking in the utility environment. The first duty of the CIGRE C4.47 WG was to conduct an international survey to understand the existing trends of adoption and application of resilience concepts in the electricity sector. This reference paper will describe key observations and unpack the initial thoughts of the WG. Further insight into the survey observations and results can be obtained from the future CIGRE Technical Brochure.

**KEYWORDS**

Resilience; Power System Resilience; CIGRE C4.47 PSR WG

## **1. BACKGROUND**

In recent years, the impact of natural and man-made hazards on critical infrastructures, including electricity, natural gas, water, telecommunications, has resulted in governments, regulators, utilities and other interested stakeholders seeking to formalise a framework to enhance resilience, in particular for electricity infrastructure [1]–[4]. In essence, such formalisation aims at defining strategies to improve the ability of a critical infrastructure to withstand or absorb impacts of hazards, prevent deterioration in service to the point of failure, respond to and recover from disruptions and make adaptations that strive to provide continued essential services under new conditions [5]–[7] & [8].

The planning and operation of the electricity critical infrastructure has been traditionally driven by reliability principles, with the goal to maintain its functionality when exposed to known and frequent disturbances. This has led to the development of well-established network reliability practices and security standards that inform the long-term planning and real-time secure operation of an electricity network [9]–[11].

Therefore, the concept of resilience is receiving increasing attention in the engineering, business and natural science disciplines [12], [13] & [14]. This renewed popularity has led to attempts to define its role and scope within these different communities. In this context, CIGRE has established a working group to provide guidance to these challenges and attempt to set a standardised approach to resilience thinking and practices within the power utility environment [15].

## **2. CIGRE C4.47 WG on Power System Resilience**

The goal of the Power System Resilience Working Group (PSR WG) is to provide a framework to assess resilience thinking that seeks to inform operational and investment decisions. This requires the adoption of resilience concepts, methods and metrics within the decision-making processes, to enhance the anticipation of planning and response to extreme incidents or threats that could result in major and prolonged power interruptions.

## **3. International survey**

The outcome of this international survey will inform and assist the working group to develop resilience definitions, characteristics, metrics, regulatory mechanisms and methodologies to support decision-making during investment and operational resilience initiatives. The survey consisted of five sections intended to provide insights into adoption and application of resilience concepts in the electricity sector.

### **3.1. Survey deliverables**

The results of this survey on the current practices of resilience within the electricity infrastructure will inform and assist the CIGRE C4.47 WG PSR in achieving the goals as stated in the terms of reference and will be shared with all the participating entities.

The working group will develop technical brochures, tutorials, position papers and articles and journal publications to describe the trends on the adoption and application of resilience concepts in the electricity sector.

The initial international survey will inform the enhancement of the next survey before the development of an international power system resilience index that can be utilised to benchmark the maturity of the utility resilience programme.

## 4. OBSERVATIONS AND DISCUSSIONS

This section on the analysis of the survey results consists of the initial thoughts and general observations of the PSR WG. The survey questions focused on five sections to better understand the adoption and application of resilience in the electricity sector.

### 4.1. Section 1: Introduction

The purpose of the section was to understand the profile of the utilities and/or interested parties participating in the international survey. The survey addressed the following themes or questions:

- i. General participant information (Q2)
- ii. Electricity sectors and the role of participants in the survey (Q1, 3, 4 and 6)
- iii. Authority accountable for the resilience programme and coordination (Q5)
- iv. Understanding the extreme threats and disaster scenarios on which electricity utilities focus their efforts (Q6, 7 and 8)

#### 4.1.1. Key observations

The international survey has been distributed to 114 CIGRE members and interested parties, with 29 countries responding. Sixty-one (61) survey results have been successfully returned (53% success rate). Continental representation is illustrated in **Figure 1** below.



**Figure 1:** Continental participation in the international survey

#### 4.1.2. Summary of discussion by C4.47 WG

*The international survey is the first attempt to obtain a better understanding of the existing international trends of the adoption and application of resilience concepts within the electricity infrastructure. This survey will form the basis of a new survey to assist utilities to benchmark their resilience programmes.*

The large participation by interested parties, including educational institutions from outside the utility environment, suggested that resilience concepts in the electricity sector were novel in nature. In the majority of cases the SO is accountable for driving the resilience programme within the utility environment. This is in contrast to the co-ordination of disaster planning, which is almost always the responsibility of a government emergency agency or a regulatory agency.

It is observed that the risk landscape highlights the four extreme threats (national blackout, seismic, load shedding and cyberattack) to the electricity infrastructure. While these threats do not occur frequently, the significant adverse impact and consequence to the economy and society require focused attention.

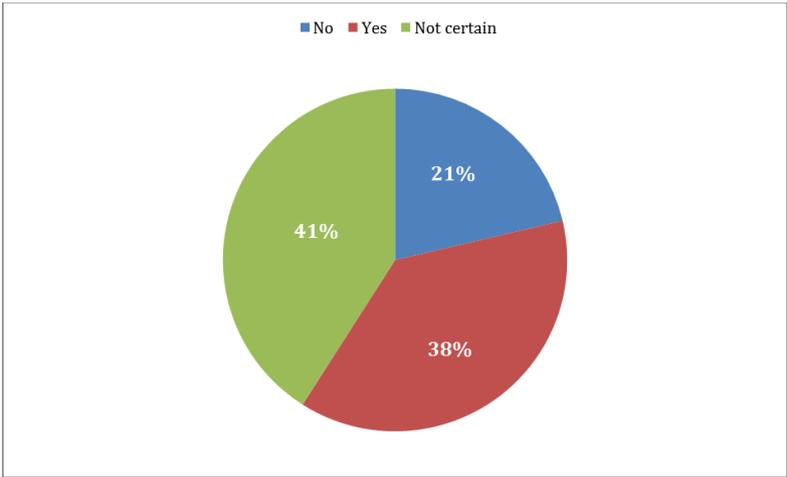
**4.2. Section 2: Definition of resilience**

The purpose of the section was to understand whether or not the concept of resilience had been incorporated in the electricity sector, how it was understood and how it was differentiated from well-established concepts, such as reliability. The survey addressed the following themes or questions:

- i. Distinction between reliability and resilience (Q9 and 10)
- ii. Definition and standard of resilience at utility or country level (Q11 and 12)
- iii. Power system resilience characteristics (Q13)
- iv. System domains considered for boosting resilience (Q14)
- v. Resilience strategies adopted (Q15)
- vi. Resilience goals/objectives adopted (Q16)

**4.2.1. Key observations**

It was evident from 59% of the responses that two distinctive and yet interrelated concepts are recognised within utility decision-making processes. It is envisioned that the C4.47 PSR WG technical brochures will address the complexities of an integrated nature of a power system and the uncertainty of the threats associated with resilience thinking within the utility environment. Furthermore, 38% of the respondents accept their country’s definition for resilience, and it appears that about 21% of the respondents may have established their own resilience definitions. The survey results are illustrated in **Figure 2** below.



**Figure 2:** Results of utilities accepting the general definition

**4.2.2. Summary of discussion by C4.47 WG**

A significant contribution of the C4.47 PSR WG is to create a distinction between reliability and resilience as a concept. This distinction of concepts and a framework within the electricity infrastructure will support and enhance the decision-making process, particularly for preparedness of extreme events.

It is evident that reliability concepts, including standards, have been well entrenched within the DNA of the electricity infrastructure. However, there is a realisation that resilience thinking is required within standards and regulatory frameworks to prepare adequately and respond effectively to extreme incidents or threats.

Given the increasing level of complexity and interactions between sectors, it is critical to move towards a “system-of-systems” thinking and engineering that captures multiple critical infrastructures and their interdependencies with essential services.

The strategies adopted to boost resilience require the application of hybrid approaches and techniques to solve the resilience objectives. The selection of resilience goals/objectives would steer the decision-making process for investment or operational funding allocation. The survey suggests that the existing objectives focus on consequence management and withstanding disruption of the system. These resilience objectives would influence the need for appropriate models, metrics and methodologies to demonstrate the value of resilience.

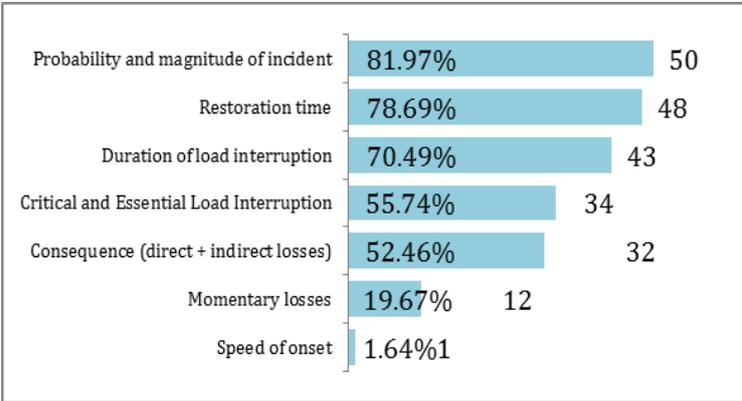
**4.3. Section 3: Methods and metrics**

The purpose of this section was to understand methods and metrics adopted in the electricity sector to inform decision-making and to determine how these were utilised. The survey addressed the following themes or questions:

- i. The techniques utilised to evaluate the risk and vulnerabilities (Q17)
- ii. Reliability indices considered in assessing extreme incidents (Q18 and 19)
- iii. Characteristics applicable to resilience metrics (Q20)

**4.3.1. Key observations**

The majority of the respondents employ a resilience metric that describes the value of resilience by using probability techniques. Secondly, the duration of interruption and restoration time is applicable as resilience metric. However, utilities focus efforts on critical and essential load interruption; therefore resilience metrics should indicate the impact on critical and essential loads. The resilience characteristics applicable for resilience metric are illustrated in **Figure 3** below.



**Figure 3:** Results of the resilience metrics characteristics

**4.3.2. Summary of discussion by C4.47 WG**

The C4.47 PSR WG Task Team 2 will focus their efforts on reviewing and deriving resilience metrics to describe the value of resilience and the fundamental difference to the reliability indices. The traditional reliability metrics evaluate the risks and consequences of a disturbance in a power system due to a set of recognised and credible contingencies (also known as normal criteria contingencies) and ascertain its ability to withstand these contingencies without resulting in system failures. Therefore, the analysis of reliability does not consider, nor is there a need to consider, the interdependency domains under these system disturbances.

It is clear that focusing the efforts on loads of significant importance (mission critical, critical and essential loads) is critical to the resilience efforts when critical infrastructure operation is restored or sustained during an extreme incident or threat.

Resilience assessments focus on the extent of power system failures along with the response, recovery, adaptation and ability to sustain critical system operations in order to achieve resilience objectives.

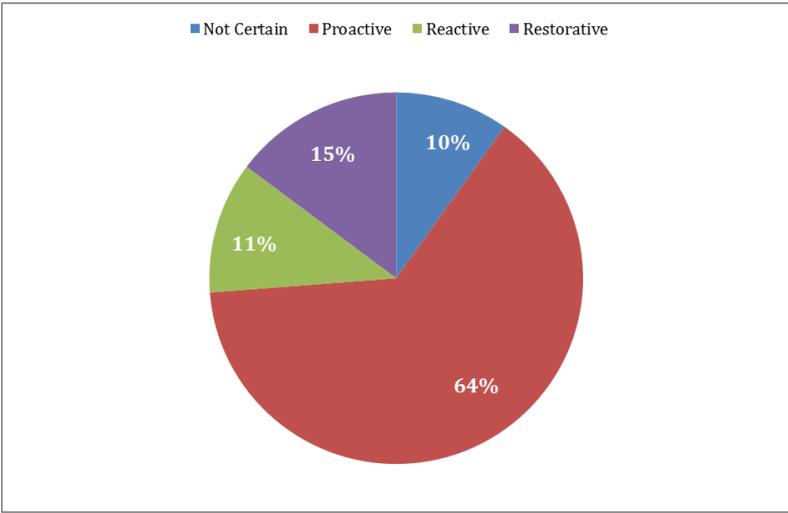
**4.4. Section 4: Boosting resilience**

The purpose of the section was to understand the approach adopted to boost or to enhance the resilience of power system infrastructure. The survey addressed the following themes or questions:

- i. Adoption of resilience as a security obligation (Q21)
- ii. Adopting risk-informed decision-making for extreme incidents (Q22, 23 and 27)
- iii. Operating regimes or plans adopted (Q25)
- iv. Determining resilience techniques and goals adopted (Q26 and 24)

**4.4.1. Key observations**

A number of planning processes were required to respond to, and recover adequately from, incidents, and in 83% of cases, utilities had prepared and compiled emergency response plans. Risk-based decision-making is utilised to inform investments, and more than 44% of the respondents perform these types of analyses. It is evident that in 64% of cases utilities have adopted a proactive approach to extreme incidents or threats. In 64% of cases the technique adopted to evaluate the impact is to map the hazards against the potential impact to electricity infrastructure. The survey results are illustrated in Figure 4 below.



**Figure 4:** Results of the utility approach to protect against extreme events

**4.4.2. Summary of discussion by C4.47 WG**

*The accountability of setting the regulatory and legislative obligations are normally prescribed by a government body. Encouraging utilities to plan for, and respond to, extreme incidents or threats is currently addressed in codes/rules/standards, which may need to be amended or modernised by including resilience requirements based on best practices.*

*An extreme incident can be considered as an electricity disaster scenario that impacts on the well-being of electricity infrastructure and its continued capability to deliver power and energy to customers. It highlights the importance of assessing the resilience of the electricity infrastructure under a variety of hazards and evaluating proposed resilience strategies to anticipate, prepare, absorb, adapt, rapid recovery, sustainment of critical system operation and learn following extreme incidents. The adoption of resilience thinking would assist power system planning and operating engineers and investment and/or security planners to assess power system resilience enhancements for prudent investment strategies to safeguard and safeguard against extreme events.*

*The nature of these extreme incidents or threats requires co-ordinated planning and integration of plans with different response partners or affected sectors within and outside the electricity sector. Therefore, the effectiveness of the response and recovery process is enhanced by the quality of planning and integration of plans across the sectors within a region, state, province or country.*

**4.5. Section 5: Quality regulation**

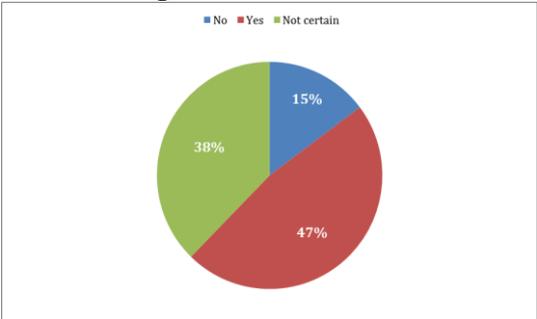
The purpose of this section was to gain insight into the regulatory framework adopted to encourage and incentivise the boosting of the resilience of power system infrastructure. The survey addressed the following themes or questions:

- i. Regulatory framework adopted to encourage utilities to consider extreme incidents (Q28)*
- ii. Participants’ opinions on the effectiveness of a regulatory mechanism (Q29, 30 and 31)*
- iii. Protection of the electricity sector as critical infrastructure (Q32)*
- iv. Interest in the proposed power system resilience index (Q33)*

**4.5.1. Key observations**

This is evident; with 61% of the responders highlighting that the energy regulator obligates electricity utilities to consider extreme incidents within the grid codes. However, about 36% of the cases suggest that regulatory ruling should be mandatory, and quality of service incentive schemes only make up around 28% of the responses.

The responders in 47% of the cases indicate that there should be a definition on the requirement for protection of critical infrastructure, while 38% of the responders are not certain. Furthermore, only 15% of the responders are not certain if a definition has been established. The survey results are illustrated in **Figure 5** below.



It is reassuring and encouraging to report that 82% of the responders expressed interest in participating in the next survey for a proposed Power System Resilience Index from this WG.

**Figure 5:** Results of the adopted definition for the protection of critical infrastructure

#### **4.5.2. Summary of discussion by C4.47 WG**

*Energy regulators require effective mechanisms to encourage utilities to adopt appropriate resilience strategies to influence the planning, design and operation before, during and after extreme incidents.*

*The enforcement of this with more defined mechanisms to demonstrate the value of resilience would require utilities to categorise investments and operating decision-making on resilience in the future.*

*The interdependence of critical infrastructure on essential services during extreme incidents would require the introduction of a specific definition of resilience specific to electricity infrastructure to set the boundaries for decision-making.*

*The high interest in defining an index or a set of indices to measure the approaches adopted by utilities demonstrate the novel nature of the resilience within the electricity sector.*

### **5. CONCLUDING REMARKS**

This survey is the first attempt to obtain a better understanding of the existing international trends and practices on the adoption of resilience thinking within the electricity sector. It has been recognised that the adoption and application of resilience engineering in the electricity sector is novel in nature and crucial in driving the efforts towards minimising the risk exposure of power systems to extreme events.

It is evident that the results of this survey provide critical insights into the current practices, needs and challenges related to the emerging concept of resilience in the electricity sector, which are expected to be very beneficial to utilities and stakeholders worldwide. This survey will also assist the CIGRE C4.47 PSR WG in directing the focus of Task Teams 2 and 3 towards practical issues in order to maximise the impact and contributions to existing resilience practices and support the adoption and application of resilience thinking within the electricity sector. The future key findings of the working group will be disseminated in the form of technical brochures, tutorials, reference papers and conference and journal publications.

This international survey will also serve as the basis for the next survey by the C4.47 PSR WG on defining a power system resilience index that can be utilised to benchmark the maturity of the utility resilience programme of a utility. It is reassuring and indeed a pleasure to see that 82% of the responders to this survey have agreed to respond to the power system resilience index survey to be conducted in the near future by this Working Group.

The future CIGRE Technical Brochure will provide a high-level analysis of the survey responses against the key focus areas for C4.47 Power System Resilience WG according to the approved terms of reference.

### **6. ACKNOWLEDGMENT**

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