21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2018 Grid of the Future Symposium

The Definition of Reliability in Light of New Developments in Various Devices and Services Offering Customers and System Operators New Levels of Flexibility—Summary of Technical Brochure 715

P. J. PALERMO*, G. ANCELL (NZL), K. BELL (GBR),
M. MATSUURA (USA), P. SOUTHWELL, (AUS), A. TUOHY (USA), C. RAY (GBR)
PJP Consulting
USA

SUMMARY

In recent years, a number of important changes occurred that affect the understanding and scope of reliability. These include wider recognition of the danger of global climate change, widespread adoption of renewable-energy targets by governments and utilities, decreasing costs of solar photovoltaic panels and wind turbines, and potential cost reductions of energy storage, as well as a range of developments collectively known as the smart-grid. Present worldwide conditions and expected trends show an increased use of customer generation and renewable generation technologies.[1]

From a customer perspective, the historical understanding of reliability may be best expressed as customers expecting nearly uninterrupted electric service for their own health and welfare. Reliability, however, is a wide-ranging concept that includes technical, economic, and socio-political elements. Even within the technical realm, reliability includes planning and operating aspects, as well as, utility-specific and country-specific requirements.

A power system is reliable when both enough facilities have been installed to meet expected customer needs and it is operated so service can continue following reasonable disturbances. Reliability, as understood in the utility industry worldwide, consists of two fundamental concepts: adequacy and security. Reliability, adequacy, and security apply to the entire power system and include all elements of the generation, transmission and distribution systems, and customer facilities that supply or use power, energy, or provide ancillary services.

In recent years, a number of new technologies providing energy, capacity and other grid services have become available. These include wind and solar generation, but also new forms of energy storage, and technologies like smart-grids and the Internet of Things.

1. Working Group C1.27 was formed to address the possible need to change the definition of reliability in light of these changes. This paper summarizes their results as published in Cigré Technical Brochure 715.

* jeff@pjp-consulting.com

It is likely that a large portion of the future generation mix will consist of distributed generation (DG) or distributed energy resources (DER). These resources will displace the conventional generation that traditionally provides frequency response and control, voltage control, and other enabling services.

The need to change the definition of reliability is driven by these developments, the significant rise in user options to self-supply or supply power to the system, and various new technologies that provide new kinds of operating flexibility. An important trend is that customers are actively participating in their electric supply by providing power to serve their own load, and, that this often leads to power flowing out from customers' facilities during many hours of the day. This is a noteworthy change from the historical pattern of one-way power flow from the utilities to their customers.

The developing two-way nature of the power system is raising new issues affecting power system planning and operation. This will likely require unbundling a range of enabling services necessary for system operation that had been provided by a single utility in the past. The revised definitions for reliability recommended here are likely just a first step in revising many of the aspects of planning and operating power systems.

KEYWORDS

Reliability, adequacy, security, renewable generation, energy storage, customer flexibility

The Definition of Reliability in Light of New Developments in Various Devices and Services Offering Customers and System Operators New Levels of Flexibility

Thomas Edison's original power systems (circa 1885) were small stand-alone systems. By the end of the 19^{th} century, small systems began interconnecting. These interconnections reduced costs by allowing more efficient larger generating unit sizes. Interconnecting improved customer reliability by sharing generation reserves among neighboring systems. Thus, these early utilities began incorporating reliability into their development. In the following decades utilities recognized the benefits of further interconnecting and formed power pools and other regional organizations to share reserves and to operate with shared economic dispatch.

Technical Brochure 715 describes the current definitions of reliability, the evolution of variable non-synchronous generation including important example countries, new technologies including digitalization and their effects on reliability, some key uncertainties in future evolutions, and finally the proposed new Cigre definitions for reliability, security and adequacy with some recommendations for further work. This paper presents highlights from the Technical Brochure.

1 Reliability

From a customer perspective, the historical understanding of reliability may be best expressed as customers expecting continuous electric service for their own health and welfare. A power system is reliable when both enough facilities have been installed to meet expected customer needs and it is operated so service can continue following reasonable disturbances.

A reliable electric system operates with few involuntary interruptions of customer service. While it may be easy to develop a historical record of how reliable an electric system has been in the past, it is much more difficult to determine how susceptible that same system will be to outages in the future.

Reliability is a wide-ranging concept that includes technical, economic, and socio-political elements. Even within the technical realm, reliability includes planning and operating aspects, as well as, utility-specific and country-specific needs. The Technical Brochure, however, focusses on the future of reliability in light of new developments offering customers and system operators new levels of flexibility. The goal of the work was to determine if there was a need for a modified or expanded definition of reliability in light of the expected new devices and services.

1.1 Power industry definitions of reliability

In the utility industry, reliability, adequacy and security are more fully elaborated to include necessary additional details. The present Cigre definitions reflect the historical perspective of one-way power delivery from the utility to customers:

> **Reliability**
> **1987:** *A measure of the ability of a bulk power system to deliver electricity to all points of utilization within accepted standards and in the amount desired.*

2002: *Electric system reliability can be addressed by considering two basic and functional aspects of the electric system adequacy and security.*[2]

Reliability, as understood in the utility industry worldwide, consists of two fundamental concepts:

1. **Adequacy**
   The ability of the electric system to supply the aggregate electric power and energy requirements of the customers at all times, taking into account scheduled and unscheduled outages of system facilities.[3]
2. **Security**
   The ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system facilities.[4]

As the North American Electric Reliability Corporation (NERC) put it: "adequacy implies that there are sufficient generation and transmission resources available to meet projected needs plus reserves for contingencies. Security implies that the system will remain intact even after outages or other equipment failures occur."[5]

It is understood that reliability, adequacy, and security apply to the entire power system for steady-state, dynamic, and transient conditions and includes all elements of the generation, transmission and distribution systems, and customer facilities that supply or use power, energy, or provide ancillary services.

Of course, system planners must develop plans that allow the system to be operated securely and operators must develop adequate short-term operating plans. How this understanding of reliability may need to change in the future is the primary subject of this paper.

1.2 The need to change the definition of reliability

In the past, all the elements of electric power system services were supplied by the single integrated utility. This generally meant that large generators supplied power and, together with the bulk transmission system, formed an extensive network of generation, transmission, and customer load connected to distribution systems. The single utility provided not only the power and energy to serve their customers, but also a range of necessary additional services that enabled the power system to operate.

In recent years, a number of important changes occurred that affect the understanding and scope of reliability. These include wider recognition of the danger of global climate change, widespread adoption of renewable-energy targets by governments and utilities, decreasing costs of solar photovoltaic panels and wind turbines, and potential cost reductions of energy storage, as well as a range of developments collectively known as the smart-grid. In addition, more customers are taking steps to supply more of their own energy use from on-site generating sources such as rooftop solar panels.

---

2. Cigre Study Committees 37, 38 and 39, Brochure 198, *CIGRE Glossary of Terms Used in the Electricity Supply Industry*, February 2002, page 8.
3. Ibid., page 4
4. Ibid., page 8
5. U.S. Department of Energy, Secretary of Energy Advisory Board, citing nerc, Maintaining Reliability in a Competitive U.S. Electricity Industry, 29 September 1998, page 6.

The need to change the definition of reliability is driven by the significant rise in user options to self-supply or supply power to the system, and various new technologies that provide new kinds of operating flexibility. Many of these changes and their impact on the power system are discussed in more detail in Technical Brochure 715.

The important trend is that customers are actively participating in their electric supply by providing power to serve their own load, and, that this often leads to power flowing out from customers' facilities during many hours of the day. In addition, communication and control technology advances allow these customers to participate in utility power and ancillary service markets.[6] This is a significant change from the historical pattern of one-way flow of power from the utilities to their customers.

The developing two-way nature of the power system is raising new issues affecting the future of power system planning and operation. This will likely require unbundling a range of services necessary for system operation that had been provided by a single utility in the past. The revised definitions for reliability recommended here are likely just a first step in redefining many of the aspects of planning and operating power systems.

1.3 Implementation—planning and operating criteria

In everyday terms, risk is the likelihood that something will happen that causes damage, injury, or loss. Stating this a bit more analytically, risk is the combination of the likelihood that something will happen and the consequences if it does.[7] In electric power-system reliability, risk is the likelihood that an operating event will reduce the reliability of the power system to the point that the consequences are unacceptable.

Utilities translate *events* into *contingencies,* and *acceptable consequences* into *acceptable performance.* In the context of the power system reliability, risk has two parts: the *chance* that a future event will jeopardize reliability, and the *consequences* once that event happens. In its broadest power system definition, a contingency is an event that could occur in the future that should (or must) be prepared for.

System planners use reliability criteria to judge the acceptability of various plans and options. The criteria are tests or measures of system performance used to balance cost and reliability. Reliability planning criteria and indices are used to guide investments that balance system supply and load, and provide an adequate transmission system. They are used in both operating and planning electric power systems—but they are different in important ways that are not discussed here.

System planning criteria have three parts:

1. The conditions and assumptions being considered—e.g. load level, generation scenario, conditions on the transmission system, escalation, costs, etc.;

---

6. In recent years the US Federal Energy Regulatory Commission (FERC) has ordered various changes that require small and large generators to provide some of these enabling services: Order 827 requires wind generators to provide reactive power; Order 828 requires newly interconnecting small generating facilities (<20 MW) to ride-through abnormal frequency and voltage events; Order 841 removed barriers to participation of electric storage resources in the capacity, energy, and ancillary service markets; and Order 842 requires all newly interconnecting generating facilities, large and small, synchronous and non-synchronous, to install, maintain, and operate equipment capable of providing primary frequency response.

7. Adapted from, NERC, Reliability Concepts, 12 December 2007, pages 10 and 17.

2. The manner used to test if the assumed conditions will perform acceptably—e.g. loss of generation, transmission, system faults, fuel shortages, etc.; and
3. The measure of acceptable performance—e.g. component loading, voltages, stability limits, allowable loss of customer load, probability measures, etc.

In system planning, there are two broad categories—generation and transmission (including distribution). Different characteristics and history led to these two being treated differently (and independently).

Changes to the definitions of reliability, adequacy, and security recommended here will be implemented in revised planning and operating criteria and standards. These will, no doubt, present challenges to markets, system planners, system operators, transmission owners, distribution owners and of course customers, generators and market operators, because of their differing practices and histories.

2 Current worldwide conditions

A major driver for this review of reliability was the increasing penetration of renewable variable non-synchronous (VNS) generation that performs differently from traditional thermal generation. In addition, solar generation is well suited for distributed generation, which requires distribution and transmission systems to be considered in an integrated way.

The impact of VNS generators on the power system is closely related to their combined percentage of system size, the existing characteristics of the power system and the control capability of the system. Several systems were reviewed with this in mind—China, continental United States, Hawaii, Germany, Ireland, and Australia. These systems provide useful case studies where the VNS generation's impact on electricity system reliability, security and adequacy is significant as summarized in Table 1, below.

Table 1: Summary of 2015 worldwide VNS generation conditions

System	Generating capacity (MW)	Wind (MW)	Solar (MW)	Comments
China	1,260,000	129,000	35,800	The best wind resources are far from load centers
USA	1,250,000	75,000	28,000	Percentages vary widely across the country
Hawaii	1,800	202	574	Percentages vary widely among the six Hawaiian Islands (some have very high penetration levels.)
Germany	192,000	35,000	34,000	Wind and solar deliver about 20% of energy
Ireland	10,300	3,100	<5	About half of wind is distribution-connected
Australia†	48,000	3,600	3,810	Most solar is rooftop, connected in distribution systems
South Australia	4,940	1,473	700	During light load, nearly all generation from wind and solar

† The figures include only those for the eastern interconnected systems from Queensland through to South Australia

3 New technologies impacting reliability

In recent years, a number of new technologies providing energy, capacity and other grid services have become available. These include wind and solar generation, but also new forms of energy storage, and technologies such as smart-grids and the Internet of Things.

Most renewable generation such as wind and solar cannot be fully dispatched; it must be used when available and where the output depends on the weather. If communication and control is available, it can be dispatched-down if required, but there is often a large opportunity cost in doing so because the marginal cost of the resource is effectively zero.

Several characteristics of wind and solar generation lead to changes in system operation and planning:

- **Variability:** The output of wind and solar generation varies over timeframes of seconds, minutes, hours, days and seasons. This can complicate integrating these resources into plans and operation. The fact that weather varies across these time frames requires additional resources to be available to provide power and energy when needed.
- **Uncertainty:** Wind and solar generation output, as well as being variable, also poses challenges in terms of predicting how that variability will occur; again, this occurs over the same multiple time frames, from seconds to seasons. As weather cannot be perfectly predicted, the output of these resources is also only partly predictable.
- **Inverter Interface:** Most modern wind plants, and all solar plants, interface with the power system using inverters to convert from DC to AC. They are naturally decoupled from system frequency and do not inherently respond to a frequency disturbance, unless explicitly controlled to do so. These enabling service must be provided from other sources.
- **Other characteristics:** Much of the wind power is located in wind farms far from load centers and thus may not provide support to remote loads, and will require significant transmission build-out to access the resource.

It is likely that a large portion of the future generation mix will consist of 'DG or DER. (DER may also refer to storage or demand side -technologies.) These resources will displace the large generation that traditionally provides frequency response and control, voltage control, and other enabling services. While some of these services could potentially be provided by DG and DER, others may be harder to utilize.

Energy storage's primary use has been to store energy during periods when energy demand and/or costs/prices are low, and release it when demand and/or costs/prices are high. Energy storage, mainly in the form of pumped hydro storage, has been used to provide this kind of arbitrage for decades.

Batteries being installed today are usually energy limited (typically less than 2 hours of energy at maximum output). Thus, they can only make limited contributions to resource adequacy. Batteries are, however, ideally suited for many other reliability services. For example, their quick and accurate response can allow them to contribute to frequency regulation and spinning reserve. Considerable research is being undertaken to improve battery performance and it is believed this will lead to major improvements in output at lower cost.

Electric vehicles (EVs) have been under development for many years. Today, a small percentage of the vehicle fleet consists of EVs, but falling battery costs, efforts on the part of many manufacturers to increase production of electric vehicles and government incentives for manufacturing and purchasing EVs has led to an expected increase in deploying EVs.

Demand-side options do not come from a single technology; instead they are a group of technologies capable of altering end-user electricity demand (whether residential, commercial or industrial) in response to a signal or incentive. They can take the form of a particular technology performing a defined function (e.g. air conditioners available for direct utility control), or can take the form of price programs or customer aggregators who bid into markets or provide system operators certain defined functionality.

Demand response—where operators of wholesale markets pay electricity consumers for commitments not to use power at certain times—can provide many of the same services as described for storage, and thus offer similar benefits to reliability. As with storage, the value of such services is expected to increase in the future, and, thus, such resources are expected to make up an increasingly significant part of power systems.

Smart grid generally refers to digital communications and control capabilities added to the transmission and distribution networks that allow the grid to automatically react to changes in generation, consumption and local contingencies. These use digital technologies to improve some aspect of power system operations; this may allow for greater visibility of what is happening on the system, more flexibility in system topology, or greater ability to sense and respond to failures on the system.

4 Impact of changing key variables

The most significant future variable change would be the wide availability of economically-priced energy storage. However, the impact of widespread energy storage, and other related technologies on utility planning, operation, financial/business models, and on system reliability, is subject to a number of assumptions and variables that are not yet fully known.

How these technologies are operated will depend in part on who is operating them, and the problem they are being used to manage, or the benefit they are trying to provide. An important unknown regarding the wide uptake of energy storage, or other related technologies is whether there will be numerous small installations distributed throughout low-voltage networks, a smaller number of large installations at transmission levels, or some combination.

It is unclear what level of central control, if any, will be available in future for storage systems, and other new technologies. This contrasts with the visibility and control that network and central system operators have over major generation and loads today. This level of information and control is important for current strategies for assessing, managing and planning power system reliability.

5 Conclusions

Present worldwide conditions and expected trends show an increased use of customer generation and renewable generation technologies by individual customers, independent developers, and utilities. In addition, there are potential new developments in communication and information processing that should accelerate these trends. And, a new wave of innovations associated with inexpensive storage technologies may be just over the horizon

Technical Brochure 715 identified a number of challenges resulting from the increasing penetration of wind and solar generation. While large power systems in the North America, Europe, China, India, the Middle East, South America and elsewhere are rapidly increasing their percentage of renewable generation, major issues with high penetration levels have not occurred, however, because these systems are so large. It is the smaller power systems with high renewable penetration levels that are in the forefront of developing new solutions. These smaller, isolated, or weakly interconnected systems provide useful examples for the larger power systems to follow in the future. Examples are provided in the report from Hawaii, Ireland and South Australia.

All the identified trends point to increased customer participation as suppliers in utility markets and operation. The definitions of reliability, adequacy, and security must be revised to reflect these changes.

5.1 The new definition of reliability

The present Cigre definitions of reliability, adequacy, and security reflect the historical perspective of one-way power delivery from the utility to customers, in particular, the definitions of 1987 and 2002. The WG concluded that, from today's perspective, the 2002 definition of reliability was more of an introduction than an actual definition, and, so, chose to modify the 1987 definition. The reasoning and justification for the changes can be found in Technical Brochure 715. Additions are marked in red and underlined and deletions are shown with strike-through.:

> ***Reliability***
> *A measure of the ability of a ~~bulk~~ power system to deliver electricity to all points of ~~utilization~~ consumption and receive electricity from all points of supply within accepted standards and in the amount desired.*

5.2 The new definition of adequacy

The recommended changes to the definition of adequacy that recognizes the new two-way nature of power flow in power systems, are:

> ***Adequacy***
> *A measure of the ability of a power ~~the electric~~ system to meet ~~supply~~ the ~~aggregate~~ electric power and energy requirements of its ~~the~~ customers within acceptable technical limits ~~at all times~~, taking into account scheduled and unscheduled outages of system ~~facilities~~ components.*

Where:

- ***Power system*** *includes all elements of the generation, transmission and distribution systems, and customer facilities that supply or use power and energy, or provide ancillary services;*
- ***Customers*** *include all parties that supply power and energy or ancillary services, as well as those who consume them;*
- ***Requirements of customers*** *include their basic power and energy needs, and agreed use of customers' ability to vary power supply, adjust demand and provide ancillary services;*
- ***Acceptable technical limits and scheduled and unscheduled outages*** *are those specified in the applicable planning criteria and standards; and*
- ***System components*** *include all elements of the supply, delivery and utilization systems regardless of ownership or control.*

With this definition, a residential consumer with rooftop PV and energy storage might be a typical residential consumer for many hours of the year, but would sometimes sell power and energy to the system, while at other times use the storage to provide peak-load shaving, voltage control, frequency regulation, spinning reserve, or other services. The power system should be adequate to meet all these needs.

5.3 The new definition of security

The WG, in cooperation with Study Committee C2, concluded that the definition of security should be changed to recognize the two-way nature of power flow and customer flexibility:

> ***Security***
> *The ability of the power ~~electric~~ system to withstand ~~sudden~~ disturbances ~~such as.~~*

Where:

- ***Power system*** *includes all elements of the generation, transmission and distribution systems, and customer facilities that supply or use power and energy, or provide ancillary services;*
- ***Ability to withstand*** *will vary depending on specific disturbances and applicable criteria or standards, and includes agreed use of customers' ability to vary power supply, adjust demand and provide ancillary services; and*
- ***Disturbances*** *include electric short circuits, unanticipated loss of system facilities, or other rapid changes such as in wind or solar generation.*

This definition explicitly gives both an obligation and flexibility in maintaining system security. The obligation is to fully meet customer requirements, while the flexibility is to use the various forms of flexibility offered by customers.