NOVEL POWER SYSTEM RELIABILITY INDICES CALCULATION METHOD

Andrés HONRUBIA-ESCRIBANO
Fundación CIRCE – Spain
andres.honrubia@uclm.es

Laura GIMÉNEZ DE URTASUN
Fundación CIRCE – Spain
lauragdu@fcirce.es

Samuel BORROY VICENTE
Fundación CIRCE – Spain
sborroy@fcirce.es

Susana MARTÍN ARROYO
Fundación CIRCE – Spain
smartin@fcirce.es

Miguel GARCÍA-GRACIA
Fundación CIRCE – Spain
mggracia@fcirce.es

ABSTRACT

In the last years, with the advent of Smart Grids, several concerns such as demand growth and increase of the use of distributed generators have emerged in electric power systems. Currently, electric utilities are involved in network automation processes, thus implementing advances in information and communication technologies, in order to improve network efficiency, reliability, security and quality of service.

In this sense, this paper presents a novel methodology developed to calculate one of the most commonly used power system reliability indices in the electric field. In order to complete the analysis from an experimental evaluation, this methodology has been applied on a real distribution network, based on the framework of PRICE-RED and DISCERN (EU-FP7) projects. Since the value of this reliability index has a remarkable influence on the revenues of the distribution system operator companies, these results provide a useful methodology for the strategic development of the distribution networks.

Keywords: Smart Grid, power system reliability, ASIDI, TIEPI, KPIs

I. INTRODUCTION

One of the current challenges of Distribution System Operators (DSOs) is to adapt their network operations and business to newly developed technologies and solutions for medium and low voltage grids, [1]. Demand growth and increase of the use of distributed generators have emerged as some of the main concerns during the last years in electric power systems, [2]. To address these recent concerns, DSOs have been implementing advances in information and communication technologies in order to improve network efficiency, reliability, security and quality of service, [3]. In this line, it is important to remark that system reliability is not the same as power quality, [4]. Reliability is associated with sustained and momentary supply interruptions, whereas power quality involves faster electrical disturbances such as voltage fluctuations, abnormal waveforms and harmonic distortions.

A considerable interest in reducing economic losses suffered by power system customers due to reliability events has been identified recently by the electric sector stakeholders. This situation, together with the changing regulation of the power industry, has motivated the definition of reliability based rates or penalties to power distribution companies. According to current regulatory models around the world, such as the Spanish or the Finnish, the investment in the improvement of system reliability is motivated because reliability has a direct effect on the revenues of the DSOs. Specifically, an increase up to 2% of the yearly remuneration without incentives may be given to a Spanish DSO due to the reliability improvement, [5]. In this sense, network automation involving remote-controlled disconnectors and fault passage indicators belong to the basic structures in distribution technology, and these devices play an important role in the improvement of reliability, [6], [7]. Therefore, DSOs have mainly two options to enhance reliability: the first is the installation of an undefined number of these network automation devices and afterwards check the change in reliability. The second choice is to calculate the reliability through the simulation of the effects of this network automation equipment over the modelled DSO network and, consequently, install the appropriate devices in the network. Obviously, the first option may lead to uneconomical results; whereas the second one provides the possibility to assess if the economical effort necessary to install the network automatic devices is profitable before the real equipment installation is carried out.

Under this framework, this paper presents novel methodology developed to calculate one of the most commonly used reliability index in the electric field, which is the Average System Interruption Duration Index (ASIDI). The paper is structured as follows: After this introduction, the most common power system reliability indices are discussed in section II. Section III presents the variability of the reliability indices measured in real networks in several countries depending on the year. The methodology of the ASIDI calculation is detailed in section IV. Section V includes the results obtained by applying the developed methodology on a real distribution network and section VI collects the conclusions.

II. RELIABILITY INDICES: THEORY

Depending on the region or the country where the power system reliability is studied, a wide range of indices area available to be used. The following reliability indices have been identified as the most common and comprehensive performance metrics from Europe and the U.S. state rules, [8]:

- System average interruption frequency index (SAIFI): gives the average number of sustained interruptions per customer per year.
- Momentary average interruption frequency index (MAIFI): similar to SAIFI but related to momentary interruptions.
- System average interruption duration index (SAIDI): provides the average duration of interruptions per customer per year.
- Average system interruption duration index (ASIDI): This indicator measures the average duration of supply interruptions per served energy per year.

As it can be deduced, there are remarkable differences between these indices. SAIDI is representative of the average interruption time but it is not weighted according to the consumption neither the installed power. On the other hand, ASIDI includes the influence of the consumption of the interrupted customer. In addition, in some countries, such as Spain, the installed capacity of the secondary substations is used to weight the ASIDI instead of the served energy, resulting the TIEPI reliability index.

III. RELIABILITY INDICES: REAL VALUES

After the introduction and the discussion of the different reliability indices, this section shows several real examples of reliability indices measured in different networks along the years.

Figure 1 reviews SAIDI and ASIDI (marked with an asterisk) values, including exceptional events, collected from 1999 to 2012 in several European countries, [9]. Reliability indices in Europe show a wide range of values depending on the country and the year. A general trend to reduce SAIDI values along the years is observed in most of the countries. However, some other countries, such as France or The Netherlands, present a constant horizontal SAIDI value.

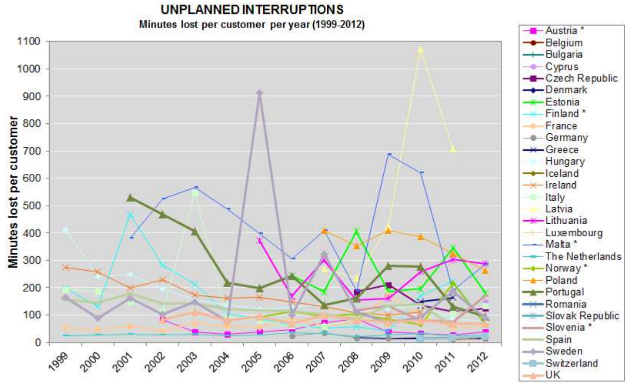

Figure 1. SAIDI and ASIDI values in Europe, from 1999 to 2012.

One problem with reporting average data for a country, or even for a specific DSO within a country, is that it does not address whether the served area is urban, semi-urban or rural. Nevertheless, downtown areas tend to be wired with underground cable networks, which are more reliable and costly than radial overhead networks found in semi-urban and rural areas. In this line, Figure 2 shows the variation of the TIEPI in a region of Spain according to the type of network considered during several years. It is proven that the worst reliability values correspond with rural areas, whereas the best indices are associated with urban networks, being semi-urban networks in the middle.

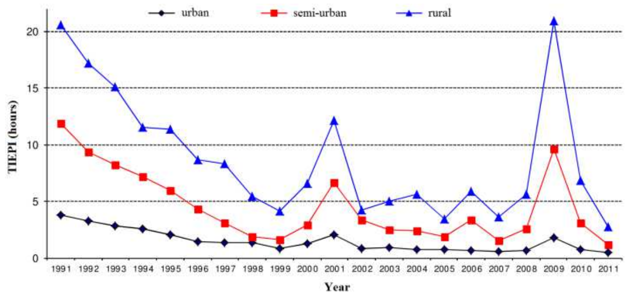

Figure 2. TIEPI value in a region of Spain, from 1991 to 2011.

From Figure 2, a constant improvement of the TIEPI is also observed along the years, although two exceptional situations are detected in 2001 and 2009. Bad weather was the main cause of the fall in reliability in 2001; whereas the Klaus cyclone (wind gusts of the order of 200 km/h) caused the largest peaks in 2009. Actually, major events (some types of natural phenomenon such as large storms) are responsible of the largest portion of outages, [8]. In this line, Table 1 highlights the differences of the reliability indices when major events are considered based on real data from California (EEUU), [10]. In this table, a major event is identified when the event is caused by earthquake, fire or storms of sufficient intensity to give rise to a state of emergency being declared by the government. As it may be deduced, during the year 2013 no major events were recorded.

Therefore, it is important to remark that local weather conditions have a serious influence over the power system reliability.

Table 1. SAIDI and SAIFI values in California (EEUU), from 2004 to 2013.

	Major events included		Major events excluded	
YEAR	SAIDI	SAIFI	SAIDI	SAIFI
2004	181.7	1.277	181.5	1.277
2005	210.9	1.352	157.7	1.222
2006	251.0	1.534	136.5	1.137
2007	138.6	1.117	138.6	1.117
2008	377.8	1.428	150.3	1.155
2009	192.8	1.203	149.8	1.099
2010	220.0	1.251	153.4	1.066
2011	243.9	1.115	215.5	1.085
2012	122.3	1.010	122.3	1.010
2013	102.4	0.915	102.4	0.915

IV. RELIABILITY INDEX CALCULATION METHODOLOGY

Nowadays, due to the direct impact of power system reliability over the revenues of the DSOs (highlighted in section I), the improvement of reliability indices is highly motivated in the electrical sector. For this reason, network automation devices, such as remote-controlled disconnectors and fault passage indicators play an essential role in the current design of distribution networks. In this line, DSOs have to assess if the economical effort necessary to install the network automation devices is profitable before the real equipment installation is carried out. The way to evaluate this approach is addressed in the present work.

The developed methodology is based on the modelling of the different fault clearing technology algorithms considered at the analyses. For this reason, the different time intervals needed by each step of the whole process of restoring the electric service after a fault occurrence are taken into account. The time intervals considered in this methodology have been obtained from real measurements carried out in several distribution networks operated by different electricity distribution companies.

At Figure 3 an example of a simplified basic fault clearing procedure can be seen. At this use case, the only information that the control center has in order to restore the service is the feeder circuit breaker trip. Therefore the clearing of the fault has to be done searching using the crews for the fault at the whole line. This situation implies that the time for load restoration increases significantly.

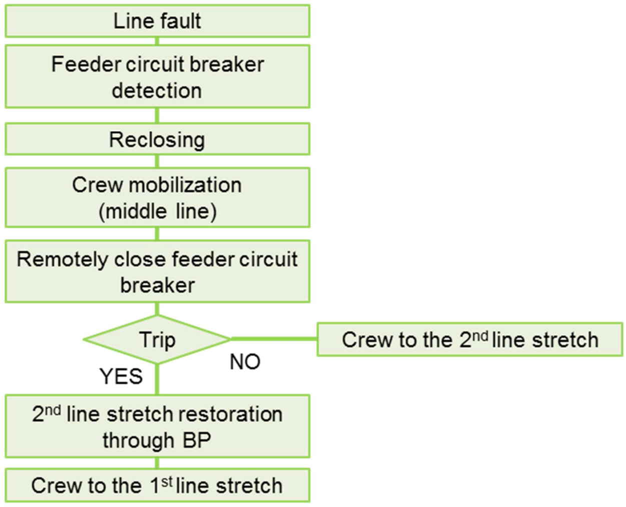

Figure 3. Basic fault clearing procedure, considering permanent fault (reclosing not successfully and subsequent trip).

At Figure 4 another example of a simplified fault clearing procedure can be seen, corresponding to a protection system with a fault passage indicator installed in the middle of the line. At this use case, once received the first trip communication, the control center receives the state of the fault passage indicator, and knows whether the crew has to be sent to the first or second line stretch.

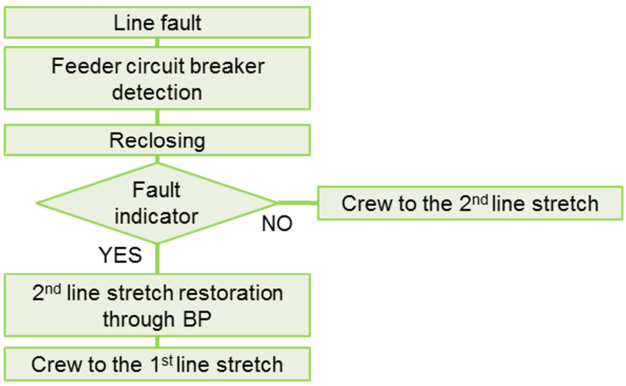

Figure 4. Fault clearing procedure with fault passage indicator, considering permanent fault (reclosing not successfully and subsequent trip).

Furthermore, a fault locator technology was also considered in the developed methodology. This implies that the installed device calculates directly the point where the fault has occurred, allowing the restoration of the load at the not-affected area, and to send the crew directly to the faulted point.

Depending on both the used technology for the fault restoration and the automation level of the grid, considerable differences on the restoration time are found.

ASIDI values measured on real networks depend on the events that occur during a year, which have a random characteristic, as it was emphasized in section III. Commonly ASIDI values published by DSOs are measured referring to large networks, where the random factor is diluted. However, when testing a new restoration technology at a demo-site grid, the random effect of fault events is not compensated and therefore the ASIDI values measured at those grids cannot be directly compared. At the developed methodology for simulations in the present work, this random characteristic can be reproduced. Actually, this effect is considered by taking into account different fault rates according to the line length, type of feeder (urban, semi-urban and rural) and the type of cable (overhead line or underground installation).

New technologies allow restoration times to decrease significantly, although a remarkable concern to its installation resides on the possibility of their failure, which would bring the system back to the basic fault clearing procedures for which the control center would not be prepared for. For this reason, this new methodology takes into account the possibility of failure of the installed devices as well, and the need to restore the system with the backup protection, considering the probability values of these events.

V. RESULTS

This section presents the results obtained by applying the developed methodology in a real distribution network. The results of the methodology can be directly compared, as they refer to the same grid, with the same conditions, and the only differences are the technology used, and the deployment level.

At Figure 5 the results of the comparison with five different fault restoring technologies can be seen:

- Base technology: without any automation equipment. In this case, the ASIDI value is equal to 130 min.
- Current technology: the same technology as the grid for which the study is done.
- Fault passage indicators (FPI) technology.
- FPI technology combined with remote control (RC).
- Self-healing technology.

For the three last technologies: FPI, FPI+RC and self-healing, different deployment levels have been considered (at 10%, 15% and 20% of the secondary substations). Furthermore, bars' shadow shows the value of the reliability index when the communication failure possibility is considered. From Figure 5, a considerable reduction of the ASIDI value when the remote control is included in the network has been found out.

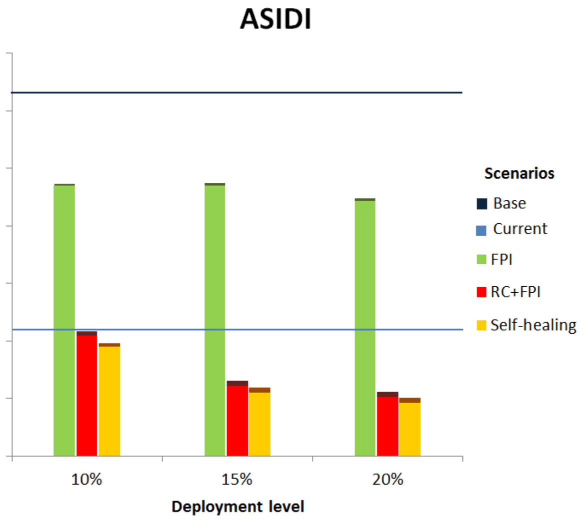

Figure 5. Results obtained applying the developed methodology on a real distribution network.

VI. CONCLUSIONS

This paper has presented a useful tool for the strategic development of the distribution networks, based on a commonly used reliability index. Actually, this reliability parameter has a considerable influence over the economic viability of the DSOs. In addition, most common power system reliability indices have been reviewed, together with a discussion related to real reliability values recorded in different types of networks.

The developed methodology has been applied over a real network, where several scenarios with both different deployment levels and technologies have been considered. The effects of these scenarios over the ASIDI values have been investigated.

Finally, it is important to remark that the methodology has been applied over a particular grid and the particular proposed technologies. Future assessments should be used considering both the costs related to each scenario and further benefits from each deployment, which will be different for each grid and specific DSO.

Acknowledgments

The authors would like to express their appreciation to Iberdrola Distribución and Unión Fenosa Distribución contributing with valuable comments under the PRICE-RED and DISCERN projects framework.
This work has been partially supported by the Spanish Ministry of Economy and Competitiveness under the PRICE-RED project (IPT-2011-1504-920000).
The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007–2013) under grant agreement No. 308913.

REFERENCES

[1] M. Gaudó; R. González; S. Borroy; L. Giménez de Urtasun; S. Martín; M. García-Gracia, 2014, "Smart grid technologies evaluation through KPIs", *Proceedings CIRED Conference*.

[2] H.B. Khalil; N. Abas, 2014, "Smart grids: An approach to integrate the renewable energies and efficiently manage the energy system of Pakistan", *Proceedings International Conference on Computing, Communication and Networking Technologies.* 1-7.

[3] S. Carrillo; F.J. Leiva; G. Petretto; G. Gigliucci; A. Honrubia; L. Giménez de Urtasun; A. Alonso; M. García-Gracia, 2014, "Assessment of the power curve flattening method: An approach to Smart Grids", *Proceedings CIRED Conference*.

[4] T.H. Ortmeyer; J.A. Reeves; Hou Daqing; P. McGrath, 2010, "Evaluation of Sustained and Momentary Interruption Impacts in Reliability-Based Distribution System Design", *IEEE Transactions on Power Delivery*, vol.25, 3133-3138.

[5] Royal Decree 1048/2013, 2013, "Metodología para el cálculo de la retribución de la actividad de distribución de energía eléctrica", *Spanish Ministry of Industry, Energy and Tourism*.

[6] H. Falaghi; M.R. Haghifam; M.R. Osoulitabrizi, 2005, "Fault indicators effects on distribution reliability indices", *Proceedings CIRED Conference*.

[7] J. Haakana; J. Lassila; T. Kaipia; J. Partanen, 2010, "Comparison of Reliability Indices From the Perspective of Network Automation Devices", *IEEE Transactions on Power Delivery*, vol.25, 1547-1555.

[8] Galvin Electricity Initiative, 2011, "Electricity Reliability: Problems, Progress and Policy Solutions".

[9] Council of European Energy Regulators, 2014, "CEER Benchmarking Report 5.1 on the Continuity of Electricity Supply Data update".

[10] Pacific and Gas Electric Company, 2014, "2013 Annual Electric Reliability Report".