Electrical Power and Energy Systems 97 (2018) 120–126

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

# Assessing the contribution of automation to the electric distribution network reliability

Carlos Girón[a], Fco Javier Rodríguez[a,*], Laura Giménez de Urtasum[b], Samuel Borroy[b]

[a] Department of Electronics, University of Alcalá, Campus Universitario, Escuela Politécnica Superior, Alcalá de Henares, Spain
[b] CIRCE Foundation, Zaragoza, Spain

ARTICLE INFO

*Keywords:*
Distribution power network reliability
Communications latency
ASIDI
SAIDI
TIEPI
KPIs

ABSTRACT

Electrical distribution systems have changed significantly in the last years. Todays it is necessary to optimize the quality and quantity of power delivered to customers and to respond to current energy demand. In this sense, electric utilities are involved in network automation processes, supported in information and communication technologies, to improve network efficiency, reliability, security and quality of service. This paper aims to quantify the improvements achieved in the reliability indices with the automation of secondary substation (SS). As this automation process lies in the use of non-ideal communication channels, their latency and availability are considered. In order to complete the analysis from an experimental evaluation, this methodology has been applied to a real distribution network, included in the framework of several research projects developed in EU (European Union). 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 incoming for the strategic development of the distribution networks.

## 1. Introduction

Distribution System Operators (DSOs) should adapt their network operations and business to newly developed technologies and solutions for medium and low voltage grids [1]. Demand management and the increase of the use of distributed generators have emerged as some of the main concerns during the last years in electric power distribution [2]. To address these recent concerns, DSOs have equipped their networks with information and communication technologies in order to improve network efficiency, reliability, security and quality of service [3]. 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.

The automation of secondary substation (SS) is required to facilitate network integration and control of distributed generation, local storage and manageable loads, to ensure and even improve power quality. The rapid restoration of the power supply after outage situations is a key factor in the reliability of the network. Therefore, network automation should allow developing a self-healing system able to restore service as quickly and efficiently as possible [5].

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 DSO due to reliability improvement [6]. In this sense, network automation involving remote-controlled disconnectors and fault passage indicators (FPI) belong to the basic structures in distribution technology, and these devices play an important role in the improvement of reliability [7,8].

Therefore, DSOs have mainly two options to enhance reliability: the first is the installation of an undefined number of these network automation devices and thereafter to check the change in reliability. The second choice is to calculate 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 whether the economical effort necessary to install the network automatic devices is profitable before the real equipment installation is carried out.

* Corresponding author.
*E-mail addresses:* carlos.giron@depeca.uah.es (C. Girón), franciscoj.rodriguez@uah.es (F.J. Rodríguez), lauragdu@fcirce.es (L. Giménez de Urtasum), sborroy@fcirce.es (S. Borroy).

http://dx.doi.org/10.1016/j.ijepes.2017.10.027
Received 22 November 2016; Received in revised form 16 October 2017; Accepted 22 October 2017

On the other hand, communication networks provide necessary infrastructure allowing a DSO to manage these devices from a central location. The communication comprises several important aspects: the communication channels used to transfer information as well as the way to carry it out; the services provided by each resource; and the information technologies [9,10].

In the smart grid environment, heterogeneous communication technologies and architectures are involved. Communication networks should meet specific requirements, i.e., reliability, latency, bandwidth and security, for automation purposes. The election of the communication channels has been dealt with in several previous works. Examples of the use of wireless networks could be found in [11]. The use of Ethernet networks has been presented in various works as [12].

So, the development of smart grids in the distribution domain can be achieved by investing in information and communication technologies (ICT). However, although these technologies already exist, implementing them in the extensive distribution network would be prohibitively expensive. Therefore, the focus must get fed back to determine the optimal level of technology deployment that would achieve these objectives at minimum cost. This is easy to understand thinking about the dimensions of the electric current distribution system for a medium country: about some million kilometers and a huge number of customers. If this one-way system, whose basic function is to provide energy through these lines to customers, adds the bidirectional option generation or storage dispersed case of electric vehicles, then it becomes a more complex and exciting challenge to find balance versus technology investment [13,14].

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), including in the model worst case latency and availability of communication channels. In the literature, few studies focused on the role of automation and communication infrastructures in the probabilistic power system reliability assessment [15].

The paper is structured as follows: after this introduction, the most common power system reliability indices are discussed in Section 2. Section 3 presents the variability of the reliability indices measured in real networks in several countries depending on the year. Section 4 presents channel communications modelling. The methodology of the ASIDI calculation is detailed in Section 5. Section 6 includes the results obtained by applying the developed methodology to a real distribution network and Section 7 collects the conclusions.

## 2. Reliability indices: Definition

Continuity of energy supply is determined by the average number and duration of outages suffered by a user for a period of one year in a given area.

These two parameters are defined as:

a) The outage time equal to the time elapsed between the beginning and the end of the power cut, measured in hours. Total interruption time is the sum of all downtime during a specified period.
b) The number of interruptions. The total number of interruptions is the sum of all interruptions therein during a specified period.

Interruptions can be unexpected or planned; the latter allows the execution of scheduled maintenance work on the network, in which case consumers should be informed in advance by the distribution company, with prior authorisation of the competent authority.

Depending on the region or the country where the power system reliability is studied, a wide range of indices are 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, [16]:

- System average interruption frequency index (SAIFI): Gives the average number of sustained interruptions per customer per year.
- Momentary average interruption frequency index (MAIFI): Like 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 neither weighed according to the consumption nor the installed power. On the other hand, ASIDI includes the influence of the consumption of the interrupted customer. In addition, in some countries, the installed capacity of the SS is used to weigh the ASIDI instead of the served energy, resulting in the TIEPI (Equivalent Interruption Time Related to the Installed Capacity) reliability index.

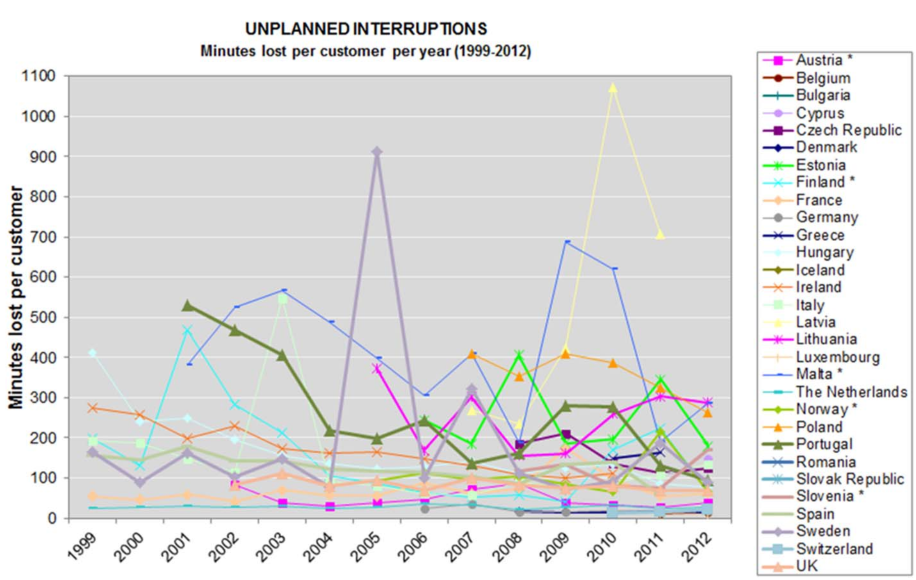


**Fig. 1.** SAIDI and ASIDI values in Europe, from 1999 to 2012.

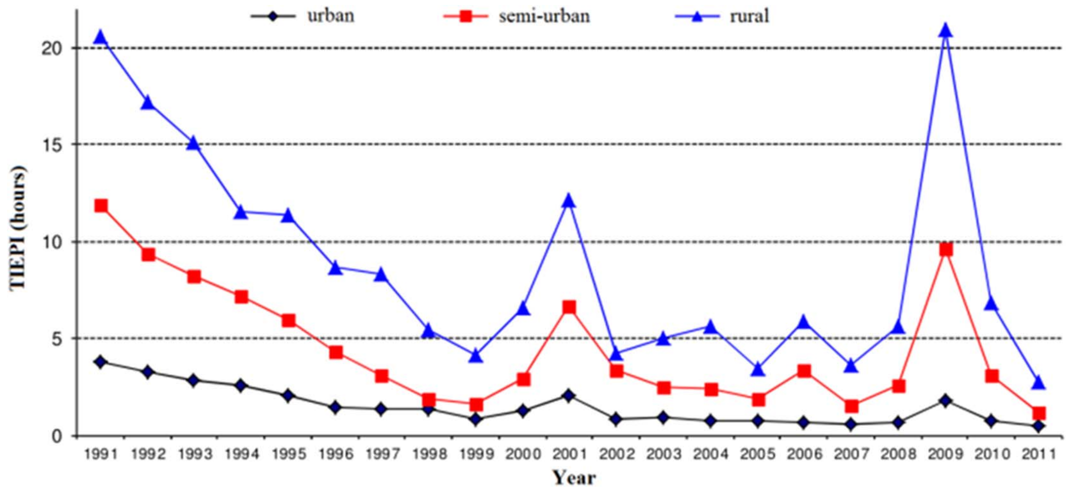


**Fig. 2.** TIEPI value in a region of Spain, from 1991 to 2011.

## 3. Reliability indices: Real values

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

Fig. 1 reviews SAIDI and ASIDI (marked with an asterisk) values, including exceptional events, collected from 1999 to 2012 in several European countries, [17]. 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.

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, Fig. 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.

From Fig. 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 for the largest portion of outages, [16]. In this line, Table 1 highlights the differences of the reliability indices when major events are considered based on real data from California (EEUU), [19]. 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.

| Year | Major events included | | Major events excluded | |
|---|---|---|---|---|
| | 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 |

## 4. Communication modelling

The reliability of the power supply networks is also affected by the communication channels used for detection, signaling and actuation. From communication point of view, the automation of SS can be characterised homogeneously using an average delay along the communication channels, regardless of channel type. However, this method does not consider the unavailability of communication channels or the pseudo-stochastic behaviour of delays.

Mainly, while attending communications, two parameters should be considered: availability and latency. In order to get more accurate values for reliability indices, these two parameters have to be modelled for each type of communication channel.

In this work, to obtain an estimated value for latency and availability in typical communication channels used in distribution networks, a detailed study has been done using a mathematical modelling for low complex communication networks [18] and an empirical model for multi-node communication networks, based on real data captured by distribution networks operators.

Table 2 contains the results of the characterisation of typical communication technologies used in distribution automation.

## 5. Reliability index calculation methodology

As stated above, due to the direct impact of power system reliability over the revenues of the DSOs (highlighted in Section 1), the improvement of reliability indices is highly motivated in the electrical sector. For this reason, network automation devices, such as remote-

**Table 2**
Communications channel parameters.

| | Availability (%) | Average latency (ms) | Latency standard deviation (ms) |
|---|---|---|---|
| GPRS | 99.64% | 847 | 199 |
| 3G | 99.91% | 115 | 34 |
| ADSL | 99.96% | 67 | 3.9 |
| Ethernet/ Fiber | 100% (losses $< 10^{-7}$) | 0.4008 | 2.1 |

controlled disconnectors and FPI play an essential role in the current design of distribution networks. In this line, DSOs have to assess whether 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 consists of the modelling of different fault clearing technology algorithms, including random factor in the analyses. For this modelling, 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.

The proposed methodology comprises four use cases of automation deployment that covers the current and expected scenarios in the automation of distribution networks:

- *Use case 1*: Remote control (RC) in feeder circuit breaker as well as in the SS sited in border points (BP) is installed. This scenario is the starting point to evaluate the improvements reached with automation.
- *Use case 2:* FPI are distributed along the line, but without RC; so operations service restoration should be carried out by the crew in the field. This use case is not a real scenario, as the fault passage detectors are always accompanied by remote control. It is used for comparative purposes.
- *Use case 3:* Remote control in the feeder circuit and in the SS sited in frontier points is installed (as in use case 1). Moreover, FPI are distributed along the different lines, including remote control in the breakers related with FPI.
- *Use case 4:* Same as use case 3, adding self-healing algorithms in the management of fault restoration. Also, the FPI equipment includes an algorithm to locate the fault.

For each use case, a procedure for fault clearance and service restoration is defined. According to these procedures and considering the different time intervals, the reliability indices can be obtained, for example ASIDI. Next section shows in detail the typical time intervals.

ASIDI values measured on real networks depend on the events that occur during a year, which have a random characteristic, as emphasised in Section 3. 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. In the proposed methodology, this random characteristic can be reproduced considering 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).

Moreover, although new technologies allow restoration times to decrease significantly, a remarkable concern regarding 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 centre would not be prepared. For this reason, this new methodology considers 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, as can be seen in Fig. 3.The generic fault clearance process and service restoration is shown in Fig. 4.

The number of fault passage detectors and the number of automated and remote-controlled switches are the main parameters to consider in the flowchart. First, the section in which the fault is located is identified and isolated. Next a crew is sent to the line for reparation purposes. The automation provides, relying on communications, a considerable reduction in response time to isolate the fault without having to send a crew to travel across the entire line, but only to the section where the fault is located.

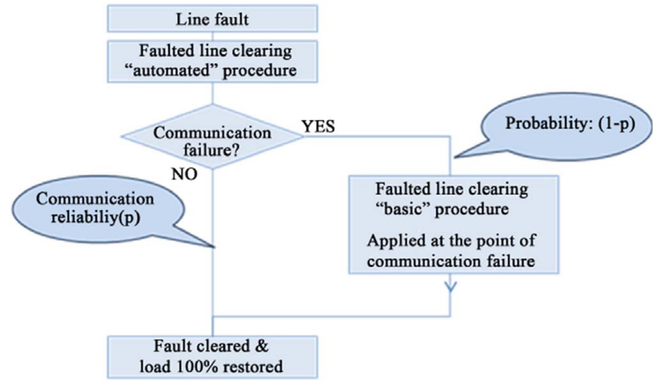


**Fig. 3.** Communication failure in faulted line procedure.

```
    N →Number of fault passage indicators
    D →Fault passage indicator
    S →Section between FPI. S_i is the section
between D_i-1 and D_i
    Line fault
    {
        Feeder circuit breaker detection
        Reclosing
        for i ∈ N
        {
                if (no fault indicator D_i)
                {
                        Reclosing S_i+1 …S_N
                        Crew to S_i
                }
        }
    }
```

**Fig. 4.** Fault clearance process.

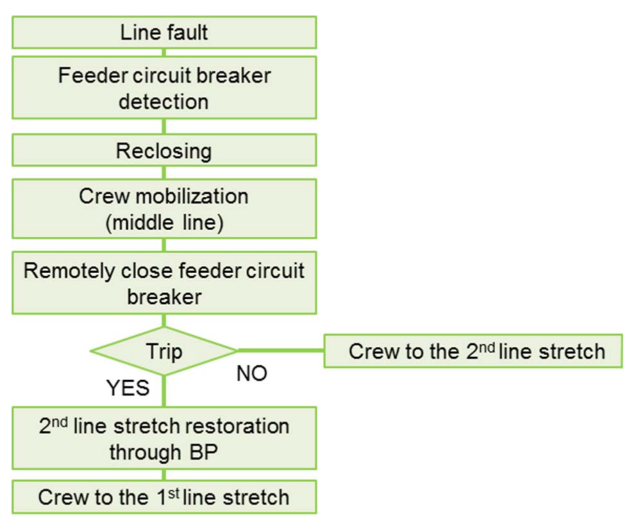


**Fig. 5.** Basic fault clearing procedure, considering permanent fault (reclosing not successfully and subsequent trip).

This generic procedure, should be particularized for each or the proposed use cases. For example, Fig. 5 shows a flowchart related to the use case 1 clearing procedure. In this scenario, the only information that the control centre has in order to restore the service is the feeder circuit breaker trip. Therefore, the clearing of the fault must be done searching using the crews for the fault in the whole line. This situation implies that the time for load restoration increases significantly.

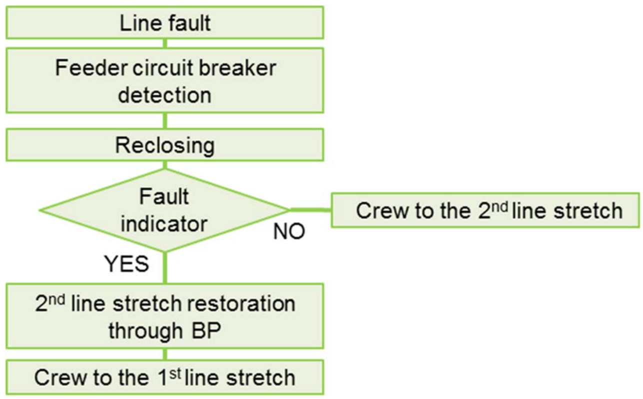


**Fig. 6.** Fault clearing procedure with FPI, considering permanent fault (reclosing not successfully and subsequent trip).

In Fig. 6, the use case 3 fault clearing procedure can be seen, corresponding to a protection system with a FPI installed in the middle of the line. In this scenario, once received the first trip communication, the control centre receives the state of the FPI, and knows whether the crew has to be sent to the first or second line stretch.

Furthermore, a fault locator technology was also considered in use case 4. 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 fault restoration and automation level of the grid, considerable differences on the restoration time are found.

## 6. Results

This section presents the results obtained by applying the developed methodology in a real distribution network shown in Fig. 7. As can be seen, in this medium voltage network, radial operation is implemented,

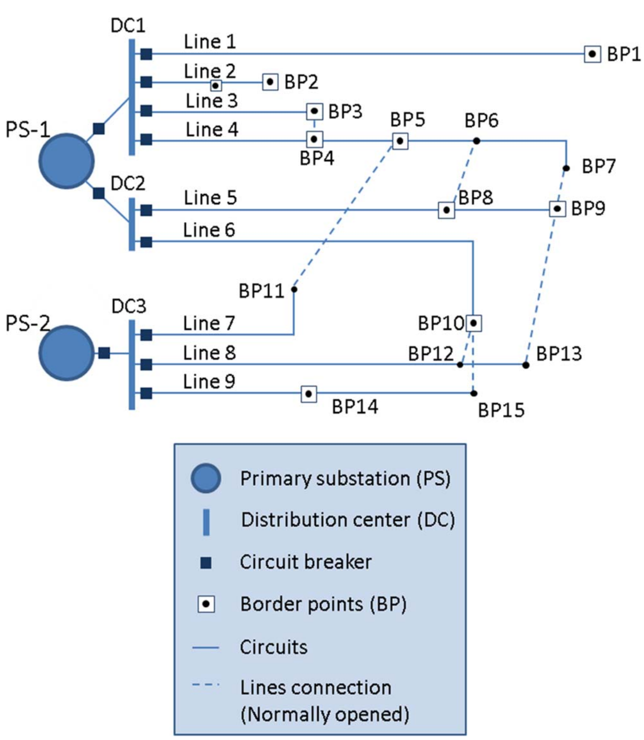


**Fig. 7.** Distribution network under test.

with border points with other lines of the same voltage level or reflexing centre connected to the same voltage level. Both systems provide support for service restoration in case of failure.

Regarding the parameters of different communication channels, the network under test is characterised as shown in Table 3, using raw data obtained from utilities. These raw data include latency and losses in communication channels.

**Table 3**
Communication parameters of network under test.

| Line | Average delay (ms) | Availability |
|---|---|---|
| Line 1 | 324,942 | 0.996 |
| Line 2 | 260,649 | 0.998 |
| Line 3 | 145,928 | 0.999 |
| Line 4 | 186,549 | 0.998 |
| Line 5 | 646,840 | 0.996 |
| Line 6 | 645,096 | 0.998 |
| Line 7 | 1.177,474 | 0.966 |
| Line 8 | 555,595 | 0.996 |
| Line 9 | 420,719 | 0.997 |

Moreover, in each of the above described use cases, three different levels of technology deployment have been considered: 10%, 15% and 20%; except for use case 1 that represents the degree of deployment the network currently possesses. Additionally, it is also considered an elementary use case that has neither remote control nor FPI (Table 4).

In order to calculate the reliability index, it is necessary to take into account three different steps and their corresponding duration: (1) fault detection, (2) fault location and (3) service restoration. Going into these three steps, it is possible to analyse several elements affecting the response time.

Table 5 shows the typical response time related to the activities involved in fault detection and location, according to the information provided by several DSOs. All these activities should be considered independently of the automation level.

Some activities, such as "Detection of fault by feeder circuit breaker", "Feeder circuit opening" and "detection of the trigger signal in the Control Centre (CC)" are required in both processes: fault detection and location.

Similarly, Table 6 lists the response time of events involved in the service restoration process. The crew actuation time is estimated for different line lengths.

The reliability index ASIDI has been calculated for the above explained use cases, considering three communications scenarios: (1) communication networks with deterministic behaviour, considering 40 ms fixed latency and 100% availability; (2) communication networks with variable latency, and (3) actual availability less than 100% (named ASIDI-1, ASIDI-2 and ASIDI-3 in Table 7).

Table 7 shows a comparison of ASIDI values for each use case, including the influence of communication latency and availability. As can be seen, increasing the automation level implies a greater influence of

**Table 4**
Use case description.

| Use case | Deployment level |
|---|---|
| Basic | – |
| Use case 1 | – |
| Use case 2 – Only FPI | 10% |
| | 15% |
| | 20% |
| Use case 3 – Remote control and FPI | 10% |
| | 15% |
| | 20% |
| Use case 4 – Remote control, FPI and self-healing | 10% |
| | 15% |
| | 20% |

**Table 5**
Activities involved in both, fault detection and location and their respective response time.

| Activities | T (ms) |
|---|---|
| Detection of fault by feeder circuit breaker | 30 |
| Feeder circuit breaker opening | 60 |
| Re-closing | 3000 |
| Sending alarm signal to control centre | 1500 |
| Delay in trigger signal in control centre | 10 |
| Timeout after a fault location manoeuvre | 150 |
| Sending opening/closing signal to switches, breakers, etc. | 40 |
| Opening switches: 1st and 2nd manoeuvre, border point and distribution centre | 80 |
| Circuit breaker closing | 40 |
| Confirmation of closing/opening circuit breaker | 20 |

**Table 6**
Activities involved in service restoration and their respective response time.

| Activities | T (ms) |
|---|---|
| Control centre staff warns crew | 180,000 |
| Automatic warning crew (only for automated processes) | 100 |
| Crew actuation time | |
| Whole line | 5,400,000 |
| Short line | 3,600,000 |
| Midline | 2,700,000 |
| Third line | 1,800,000 |
| Fourth line | 1,350,000 |

communication, worsening the ASIDI values when actual communication variables are taken into account. These results are more accurate than those presented in [20].

The results of the proposed methodology can be directly compared, as they refer to the same grid, with the same conditions. The only differences are the technology used, and the deployment level.

In Fig. 8, the results of the comparison with the results in the five use cases, relating to different fault restoring technologies can be seen.

For the three last use cases: FPI, FPI + RC and self-healing, different deployment levels have been considered (at 10%, 15% and 20% of the SS). Furthermore, bars' shadow shows the value of the reliability index when the communication failure possibility and variable latency are considered. From Fig. 8, a considerable reduction of the ASIDI value when the remote control is included in the network has been found out. However, although increasing the automation deployment level improves the ASIDI values, this improvement does not follow a linear relationship with the deployment level. So, values above 20% are not justified, as they imply a large investment for a little improvement.

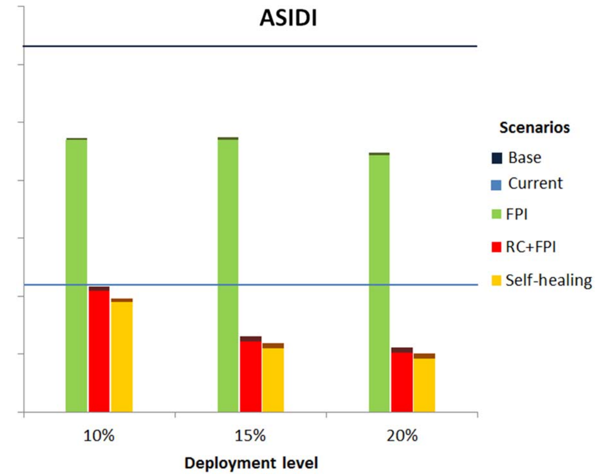


**Fig. 8.** Results obtained applying the developed methodology on a real distribution network.

## 7. 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. Additionally, 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 use cases with both different deployment levels and technologies have been considered. The effects of these scenarios over the ASIDI values have been investigated.

According to the values of ASIDI obtained, it can be concluded that in all cases, delays and failures in the communications system involve a higher value of ASIDI. It is important to note that the negative effects of delays and availability of communications on ASIDI decrease with increase in the automation deployment.

Finally, it is important to remark that although the methodology has been applied over a particular grid with the deployment of some proposed technologies, it can also be used in future assessments for different grid, technologies and other DSOs.

## Acknowledgments

The authors would like to express their appreciation to Iberdrola Distribución and Unión Fenosa Distribución for contributing valuable comments under the PRICE-RED and DISCERN projects framework.

This work has been partially supported by the Spanish Ministry of

**Table 7**
Comparison of ASIDI values (in minutes) for each use case considering three communications scenarios: ASIDI-1: communication networks with deterministic behaviour, a 40 ms fixed latency and a 100% availability; ASIDI-2: communication networks with variable latency, and ASIDI-3: variable latency and actual availability less than 100% Column $\Delta_{2\text{-}1}$ (%) shows the relative variation of ASIDI comparing scenario 2 and 1. Similarly, column $\Delta_{3\text{-}1}$ (%) shows the relative variation of ASIDI comparing scenario 3 and 1.

| Use case | ASIDI-1 (min) | ASIDI-2 (min) | $\Delta_{2\text{-}1}$ (%) | ASIDI-3 (min) | $\Delta_{3\text{-}1}$ (%) |
|---|---|---|---|---|---|
| 1: Base. 10% | 58.2 | | | 59.1 | 1.55% |
| 2: FPI: 10% deployment | 104.8 | 108.1 | 3.15% | 108.2 | 3.24% |
| 2: FPI: 15% deployment | 104.1 | 107.5 | 3.27% | 107.5 | 3.27% |
| 2: FPI: 20% deployment | 100.6 | 105.0 | 4.37% | 105.0 | 4.37% |
| 3: RC + FPI: 10% deployment | 36.5 | 43.2 | 18.36% | 44.4 | 21.64% |
| 3: RC + FPI: 15% deployment | 28.3 | 32.9 | 16.25% | 34.1 | 20.49% |
| 3: RC + FPI: 20% deployment | 24.9 | 27.9 | 12.05% | 29.3 | 17.67% |
| 4: Self-healing: 10% deployment | 32.5 | 38.4 | 18.15% | 39.7 | 22.15% |
| 4: Self-healing: 15% deployment | 24.9 | 28.9 | 16.06% | 30.2 | 21.29% |
| 4: Self-healing: 20% deployment | 22.1 | 24.8 | 12.22% | 26.2 | 18.55% |

Economy and Competitiveness under the PRICE-RED project (IPT-2011-1504-920000) and Region of Madrid under PRICAM project (S2013/ICE-2933).

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] Gaudó M, González R, Borroy S, Giménez de Urtasun L, Martín S, García-Gracia M. Smart grid technologies evaluation through KPIs. Proceedings CIRED Conference. 2014.
[2] Khalil HB, Abas N. 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. 2014. p. 1–7.
[3] Carrillo S, Leiva FJ, Petretto G, Gigliucci G, Honrubia A, Giménez de Urtasun L, et al. Assessment of the power curve flattening method: An approach to Smart Grids. Proceedings CIRED Conference. 2014.
[4] Ortmeyer TH, Reeves JA, Daqing Hou, McGrath P. Evaluation of sustained and momentary interruption impacts in reliability-based distribution system design. IEEE Trans Power Delivery 2010;25:3133–8.
[5] Heydt GT. The Next Generation of Power Distribution Systems. IEEE Trans Smart Grid 2010;1(3).
[6] Royal Decree 1048/2013. Metodología para el cálculo de la retribución de la actividad de distribución de energía eléctrica. Spanish Ministry of Industry, Energy and Tourism; 2013.
[7] Falaghi H, Haghifam MR, Osoulitabrizi MR. Fault indicators effects on distribution reliability indices. Proceedings CIRED Conference. 2005.
[8] Haakana J, Lassila J, Kaipia T, Partanen J. Comparison of reliability indices from the perspective of network automation devices. IEEE Trans Power Delivery 2010;25:1547–55.
[9] Timbus A, Larsson M, Yuen C. Active Management of Distributed Energy Resources Using Standardized Communications and Modern Information Technologies". IEEE Trans on Ind Electron 2009;56(10):4029–37.
[10] Zou Q, Qin L. Integrated Communications in Smart Distribution Grid. International Conference on Power System Technology (POWERCON), China, October 24–28. 2010. p. 1–6.
[11] Feng Z, Yuexia Z. Study on smart grid communications system based on new generation wireless technology. International Conference on Electronics, Communications and Control (ICECC), China. 2011. p. 1673–8.
[12] Miao X, Chen X. Research on IPv6 transition evolvement and security architecture of smart distribution grid data communication system. International Conference on Electricity Distribution (CICED), China. 2010. p. 1–5.
[13] Popovic DH, Greatbanks JA, Begovic M, Pregelj A. Placement of distributed generators and reclosers for distribution network security and reliability. Int J Electr Power Energy Syst 2005;27(5-6):398–408. june-July.
[14] Costa Paulo Moisés, Matos Manual A. Assessing the contribution of microgrids to the reliability of distribution networks. Electric Power Syst Res 2009;79(2):382–9.
[15] Aminifar F, Fotuhi-Firuzabad M, Shahidehpour M, Safdarian A. Impact of WAMS malfunction on Power Systems Reliability Assessment. IEEE Trans Smart Grid September 2012;3(3).
[16] Galvin Electricity Initiative. Electricity Reliability: Problems, Progress and Policy Solutions; 2011.
[17] Council of European Energy Regulators. CEER Benchmarking Report 5.1 on the Continuity of Electricity Supply Data update; 2014.
[18] Stahlhut Jonathan William, James Browne T, Thomas Heydt G, Vittal Vijay. Latency viewed as a stochastic process and its impact on wide area power system control signals. IEEE Trans Power Syst 2008;23(1).
[19] Pacific and Gas Electric Company. 2013 Annual Electric Reliability Report; 2014.
[20] Kounev V, Levesque M, Tipper D, Gomes T. On smart grid communications reliability. Design of Reliable Communication Networks (DRCN), 2015 11th International Conference on the. March 2015.