# ENEL'S WAY TO SAIDI

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## *ABSTRACT*

*In most Countries all over the world the quality of service delivered by Distribution Companies to final customers is measured through SAIDI (System Average Duration of Interruption Index). Enel Global Infrastructures and Networks currently operates 11 Distribution Companies (DisCos) in 8 Countries, in Europe and South America, serving around 72 million customers.*

*The diversity of structure, technology, organization, history of each network rises the issue of setting a global and unique strategy for undertaking specific actions at local level to improve the continuity of supply to final customers.*

*The document, addressed to DisCos and Regulators, intents to show an effective and robust method of disaggregation of the SAIDI indicator in a spectrum of control dimensions covering all the aspects of network management, from Capital Allocation to Operations.*

## INTRODUCTION

SAIDI is the worldwide master indicator for measuring the quality of service delivered to final customers, it is expressed with following formula:

$$\boldsymbol{SAIDI = \frac{\sum_{i=1}^{n} t_i \times U_i}{U_t}}$$

Where, $U_i$ is the number of LV customers interrupted during the i-th outage; $t_i$ is the i-th outage duration: $U_t$ is the total number of LV customers served by the Utility; n is the number of long duration outages, in a specific year.

Even if it basically represents the minutes lost per customer in terms of electricity supply, each Regulator has set specific rules to calculate it.

In most cases both planned and unplanned long (>3') interruptions are considered, while, respect the origin of the failures, all the ones under responsibility of the DSO (HV, MV, LV network) are taken into account. Acts of God are generally excluded either deterministic or statistic criteria.

Even if planned interruptions and the unplanned originated in LV and HV network can contribute significantly to SAIDI (see fig 1) indicator and require specific actions, MV network is the field where the highest contribution to SAIDI is present and a large amount of technical alternative solutions are offered to companies to tackle quickly significant and stable improvement, as shown in Fig. 1:

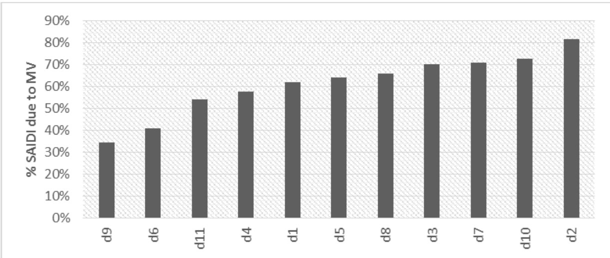


**Fig. 1 – MV contribution to SAIDI values**

This paper focuses on SAIDI originated by unplanned interruptions in MV network and on the approach of Enel regarding the selection of levers to improve reliability and effectiveness of operations.

## DECOMPOSITION OF SAIDI

SAIDI can be split in two indicators, SAIFI and CAIDI:

$$SAIDI = SAIFI \times CAIDI$$

SAIFI is the System Average Interruption Frequency Index and it is expressed with following formula:

$$SAIFI = \frac{\sum_{i=1}^{n} U_i}{U_t}$$

Where, $U_i$ is the number of LV customers interrupted during the i-th outage; $U_t$ is the total number of customers served by the Utility; n, is the number of long duration outages, in a specific year.

SAIFI basically represents the average number of interruptions that the average LV customer experiences in a year.

CAIDI in turn is the Customer Average Interruption Duration Index:

$$CAIDI = \frac{\sum_{i=1}^{n} t_i \times U_i}{\sum_{i=1}^{n} U_i}$$

Where, $U_i$ is the number of LV customers interrupted during the i-th outage; $t_i$ - the outage time of the i-th outage; n, is the number of long duration outages, in a specific year.

CAIDI basically represents how a single interruption, suffered by the customers, lasts on average and is a measure of the overall operational efficiency of the utility.

Following chart shows the value of SAIDI in the different Enel DisCos (d1, d2, ., d11):

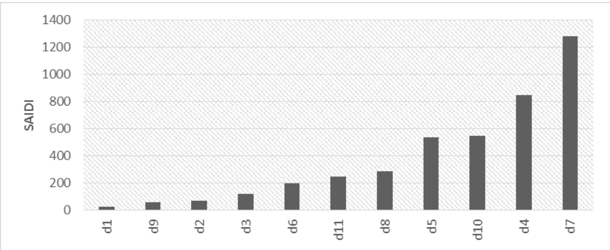


**Fig. 2 – SAIDI values**

Following chart SAIFI/CAIDI shows the positioning of each DiscCo with reference to the year 2018 and enables to identify if the actions for quality improvement should be addressed to the reduction of interruption's frequency (d10) or to their average duration (d4), or both (d7):

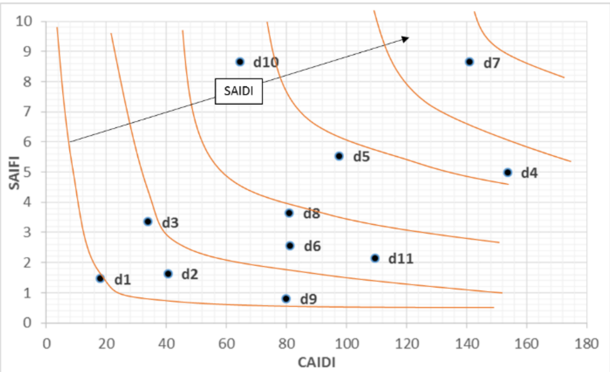


**Fig. 3 – SAIFI/CAIDI matrix**

## DECOMPOSITION OF SAIFI

In order to identify the proper actions to improve the network performance, SAIFI can be decomposed in the product of two indicators, ANICI (Average Number of Interruptions per Customer Index) and FRIC (Frequency Rate Index per Customer):

$$SAIFI = \underbrace{\frac{\sum_{i=1}^{n} U_i}{n}}_{ANICI} \times \underbrace{\frac{n}{U_t}}_{FRIC}$$

Where, $U_i$ is the number of customers interrupted during the i-th outage; $U_t$ is the total number of LV customers served by the Utility, in a year; n, is the number of long duration outages, in a year.

This chart shows the values of SAIFI 2018 for the Enel DisCos (d1, d2,., d11):

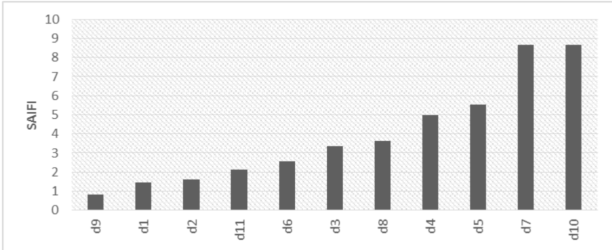


**Fig. 4 – SAIFI values**

ANICI represents the weighted average number of LV customers interrupted after the interventions of the switching devices responsible for protecting the lines (or part it) to which they are connected and is directly dependent on the number of customers protected by the same switching device which allow to operate in less than three minutes (feeder breaker, recloser, fuse, etc.).
As SAIFI normally refers to interruptions that last more than three minutes, if the switching device operate in a shorter time, the interruption is not considered.
This chart shows the values of ANICI 2018 for the Enel DisCos (d1, d2, .., d11):

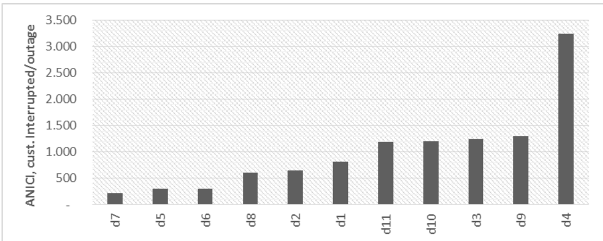


**Fig. 5 – ANICI values**

A higher value of ANICI is the result of a higher number of customers protected by the same switching device as shown in fig. 5 (d4). On the contrary the lower values of d1, d5, d6, d7 are explained by:

- low customer number per MV branch or line (d7)
- presence of widespread fuses (in particular in d5,d6)
- presence of widespread automation (d1),

It is interesting to note that ANICI does not appears to be the main cause of d7 high SAIFI, while the opposite would appear for d10, as well as for d9 and d11.
ANICI is the main driver for the "network automation" action plans: i.e. the installation along the line of automatic switching devices (device able to "see the fault" and to trip in less than three minutes).

In turn FRIC is the interruption rate per customer:

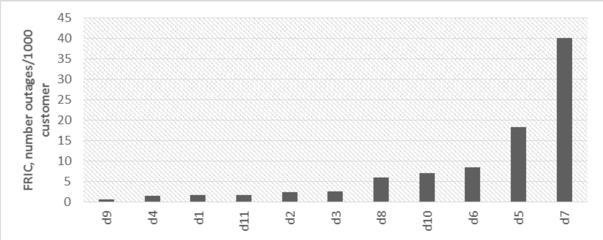


**Fig. 6 – FRIC values**

To convert FRIC to the most familiar "failure rate" (FRIL, number of outages per 100 km of the MV line) it is necessary to introduce the network length for customers served (ALC, average length per customer):

$$FRIC = \underbrace{\frac{n}{\sum_{i=1}^{r} l_i}}_{FRIL} \times \underbrace{\frac{\sum_{i=1}^{r} l_i}{U_t}}_{ALC}$$

Where $l_i$ is the length of i-th MV line; $U_t$ is the total number of LV customers served, in a year; r, is the number of MV lines; n, is the number of long duration outages, in a year.

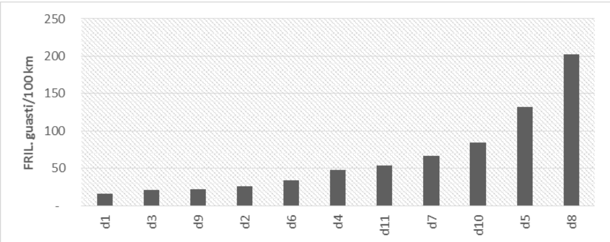


**Fig. 7 – FRIL values**

ALC represents how much network is needed to supply in average each single LV customer: areas less densely populated or rural/dispersed in general have higher ALC.

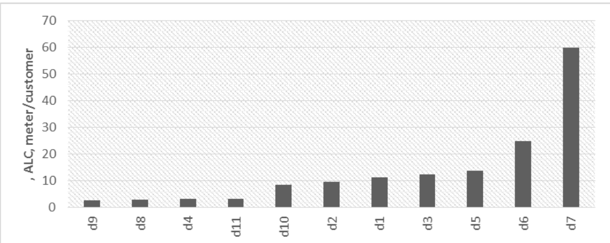


**Fig. 8 – ALC values**

In case of d8, for instance, the high value of FRIL is compensated by the reduced number of ALC, due to reduced length of the lines.

The absolute outstanding d7 has at the same time an extension of 60 km of MV network for 1000 customers and pretty high MV failure rate of 67 (the fourth worse, preceded by d10, d5 and d8).

It is evident that even for grids with disadvantageous ALC values the SAIFI can be improved working on the FRIL side of the SAIFI. In fact the winning strategy reached this year by d7 was to focus on the maintenance of the most critical lines: the goodness of such actions are confirmed by above mentioned analysis.

## DECOMPOSITION OF CAIDI

CAIDI too can be disaggregated in sub-components, relevant to the intermediate times needed to restore the service: in particular separated CAIDI contributions can be calculated for each phase of the total recovery time.

Let's consider an outage involving Ui LV customers interrupted at an instant t=0.

CAIDI can be disaggregated based on the times needed to select the fault, eventually with remote control, to alert the field force, for the logistic, to repair the line, see figure below:

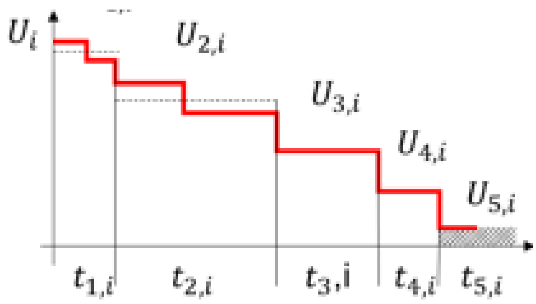


**Fig. 9 – CAIDI decomposition**

Talking about CAIDI we have to consider the following phases each of which requires time to be accomplished:

- Remote selection (RS): the switchgears (or the breakers) installed on the MV feeders are remotely (or automatically) operated by the Control Center. In this phase a high amount of customers not directly affected by the failure can be recovered, as shown below.
- Alert time (AL): after the phase of remote control field crews have to be alerted and addressed.
- Logistic time (LT): is the phase between the alert to the field crews and the time to the first switch to be operated manually, it could take hours depending on several factors;
- Manual selection (MS): under the strict overlooking of Control Center, the crew operates the switches until the fault is localized, recovering at the same time the customers not directly affected by the fault;
- Failure repair time (RT): time to repair the failure affecting customers.

It is widely known the importance of the remote control points (RCP), since they enable the reduction of the time to detect the failure, restoring power to the customers not affected.

Following chart shows for each Enel the correlation between CAIDI and the “remote control points (RCP) pitch” (N. LV customers / N MV remote controls) achieved:

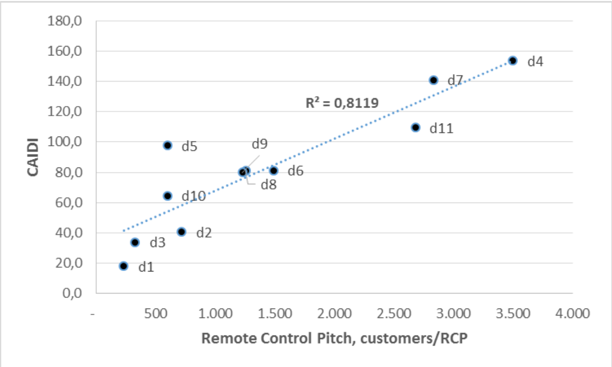


**Fig. 10 – CAIDI vs. RCP pitch**

The correlation is very high and explains about 81% of the duration. The high CAIDI values of d4, d7 and d11 are thus well explained, by the scarcity of RCP.
Remote control and automation have been the pillars of Enel strategy to improve SAIDI indicators in an efficient and quick way, since the early 2000’s.
The different level of RCP pitch is basically determined by the time the DiSco is under Enel I&N management but also by the attitude of the local Regulator in terms of the quality of service improvement and regulation.
The chart in Fig. 10 shows also the significant margins for improvement, regardless of remote control points, which can be achieved, in particular at d5 compared to the regression line; d2, which despite having a remote control pitch still high (equal to 677) has a low CAIDI of 42 min.
In addition to recommending to continue with the remote control rollout plans (ensuring in the meantime the full operation of remote control points already installed) in the Countries with high RCP pitch it is absolutely necessary, among the immediate actions, to reduce the fault selection time, providing appropriate procedures and stringent SLAs for the manual selection phase (either with internal personnel or contractors).
Finally, we must consider the importance of all the actions that can be implemented at Control Centres level, at cost close to zero (optimization of network set-ups, first remote control manoeuvre time, priority criteria for manoeuvres in case of simultaneous failures, availability of remote controls and other control devices).
Finally, CAIDI is influenced by network redundancy and in particular the availability of a second way to supply power to the customer (n-1, Structural Criticality Index, etc.) e.g. via neighbouring feeders that can give alternative feeding, reducing the number of customers affected by the repair time.

The CAIDI decomposition of every single phase or at least of the most critical ones, helps to understand the critical points of the process and to solve them.

Finally following framework recollects the elements of SAIDI decomposition end the relationships among them:

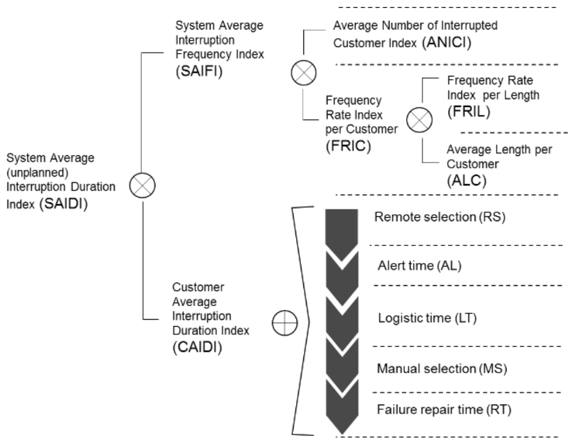


**Fig. 11 – Enel framework of SAIDI**

## LINES OF ACTION ENVISAGED

As highlighted by the Framework, to improve SAIDI, it is possible to act on various levers.

ANICI can be improved acting on:

- Optimal placement of automatic switching devices along the feeders and on laterals
- Protections proper setting and coordination;

FRIC can be improved acting on:

- Network reinforcements (i.e. replace bare overhead conductors with covered conductors i.e. covered conductors/spacer cable/aerial cables, under-grounding overhead lines, reinforcement of poles, etc.)
- Adoption of digital inspections (use of cloud-based and AI-enabled image recognition technologies to automatically identify visible grid elements and detect potential spots that require maintenance e.g. rusty parts, weak connections, use LIDAR to track the changes of the surrounding civil constructions in order to monitor that the safety distances from our electricity lines are kept)
- On condition maintenance (vegetation management, RCS, TLC, prompt repair of defects)
- Advanced network automation implementation with the use of digital technologies to prompt detect/isolate faults and reconfigure the distribution network and minimize the customers impacted (self-healing).

- Insulation coordination optimization;

To reduce CAIDI it is needed to reduce the intermediate times. Thus it is possible to intervene in such a manner:

- Remote selection (RS):
  - Remotely controlled switchgears (RCS)
  - Operating Center efficiency (tools, training)
- Alert time (AL)
  - Early field force warning
  - Response time of contractors (SLA, etc.)
- Logistic time (LT)
  - Route optimization and advanced work assignment
  - Fault passage indicators
- Manual selection (MS)
  - Manual sectionalizing faulty trunk local procedures
- Failure repair time (RT)
  - N-1 redundancy of the network, repair & emergency generators use
  - Local procedures of work assignment and working practice

Above described framework, based on the decomposition of the SAIDI, allows to highlight the values of different levers to enhance the overall reliability of the distribution system.

## CONCLUSIONS

Enel's approach to the quality of service, based on a structured model, highlights the key dimensions for the improvement of network reliability (SAIDI framework).
The structured decomposition of SAIDI in sub-indicators enables to address the decision making process to find out the best mix of actions for each typology of network.
Moreover it is possible to evaluate in advance the marginal effectiveness of each single action on the SAIDI indicator, giving priority to those that can deliver the highest benefit.
Finally, this approach enables to set a global framework to evaluate single network performances and define customized improvement plans at Country's level.

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