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A Reliability and Customer Criticality Based Prioritization Method for Reliability Improvement of Distribution Lines

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SUMMARY

The continuing advances in smart grid technologies has elevated expectations for power system reliability. Reliability improvements oftentimes go well beyond vegetation control and strategically allocated reclosers, encompassing various upgrades that overlap with those of resilience. Optimizing system-wide reliability improvement requires targeting strategic distribution feeders or portions thereof, typically the worst performers of the feeder population. The determination of this target population considers not only simple reliability metrics, but also the impact to critical loads and other important infrastructure. This paper introduces a methodology to prioritize distribution system investment considering two objectives, namely the improvement of system-wide reliability and the continuity of electricity supply to critical infrastructure. Important to note is that the electric utility that developed this method has made continuous improvements and the current methodology differs from the one presented in this paper, although they are in alignment. The utility also made a commitment to revisit and improve it at least every year and the result of each reprioritization will affect projects going forward. The paper presents potential areas of investment adopted industry-wide and how they are being considered in the short term to achieve these objectives.

KEYWORDS

CMI, Critical loads, distribution planning, distribution reliability, SAIDI, SAIFI.

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1. INTRODUCTION

Distribution system reliability has become a very important subject for the past several decades. Utility commissions and energy boards across most jurisdictions are requiring local distribution system operators (DSOs) to provide system availability to an increasingly large portion of time, putting pressure on DSOs to prioritize investment and target the most underserved portions of their system [1]. However, DSOs must take the prioritization of distribution system initiatives beyond simple reliability metric improvement and aim at increasing service availability to critical infrastructure as it has a large impact on social burden and is aligned with recent resilience goals [2].

This paper presents a methodology created by a Caribbean DSO to prioritize distribution feeders for targeted distribution system improvements. The study and proposed strategy were conducted using actual feeder parameters of the system which currently is served in four different supply voltage levels: 13.2kV, 8.32kV, 7.2kV, and 4.16kV, which are about 25%, 15%, 3%, and 55% of the feeders, respectively. This DSO system is currently ranked at the 100th percentile of all the United States territories and states with the highest customer-minute-interruption (CMI). For illustration, Fig. 1 shows the CMI data for each root-cause over a period of 2 years and 3 months and then calculating one-year average values, depicting not only the CMI, but also pinpointing the underlying root causes which are related to the difficulties to control vegetation. Additionally, Fig. 2 illustrates how addressing the worst performing feeders can result in significant improvements, as the worst 10% of them contribute 40% of the total system CMI.

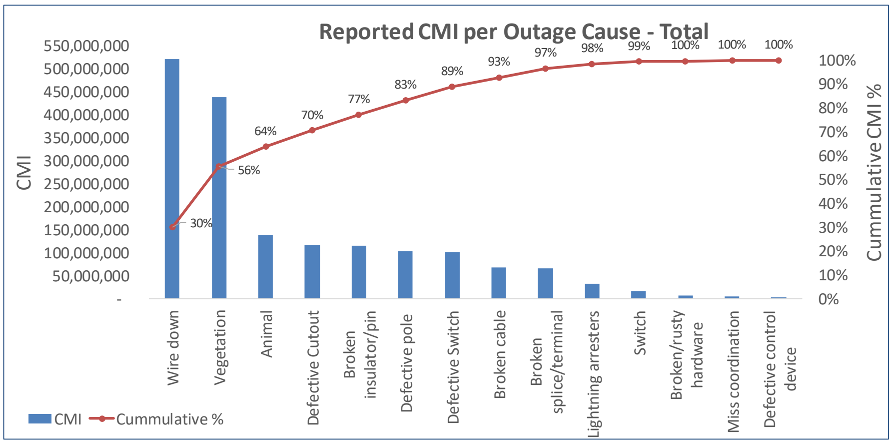


Fig. 1. Reported CMI and root causes averaged over one year.

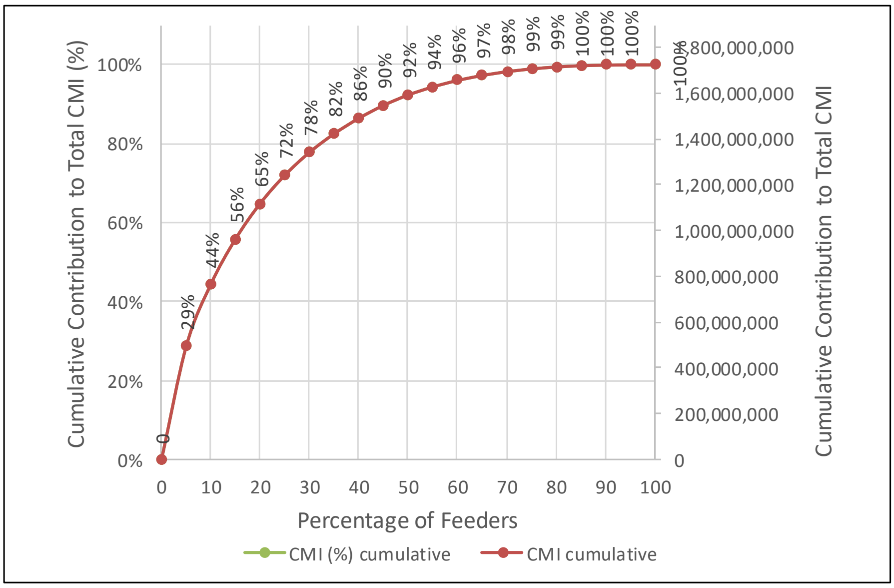
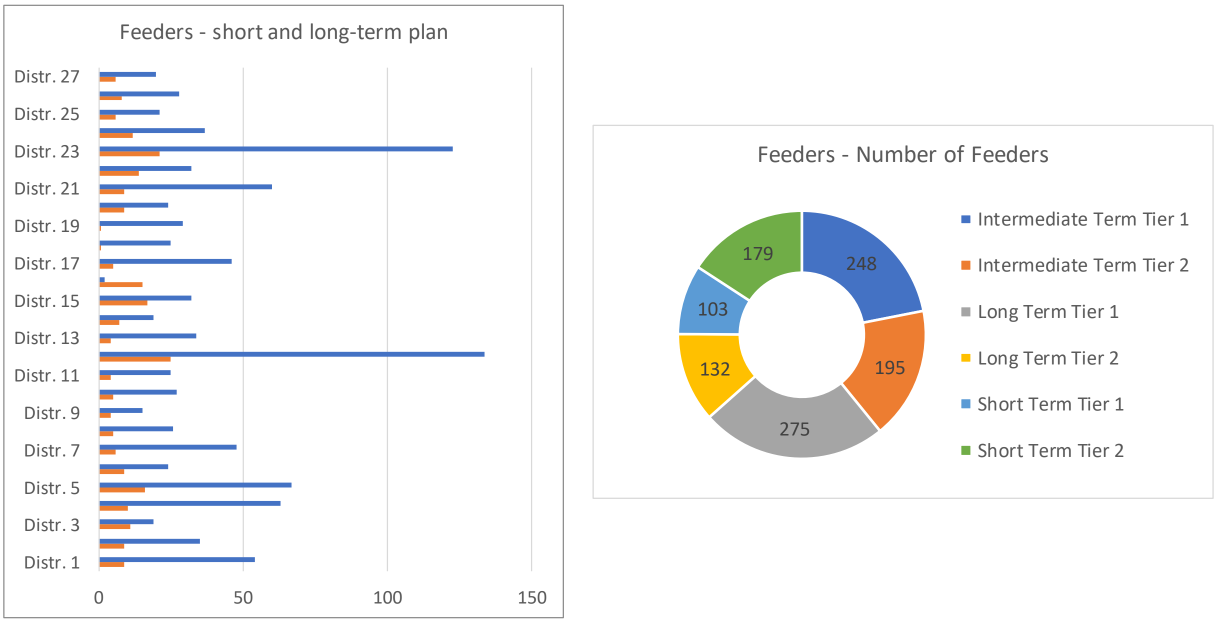


Fig. 2. Cumulative CMI and feeder distribution.

2. FORMER PRIORITIZATION

In its first prioritization exercise conducted prior to the DSO taking over the system operations, the distribution facility owner interviewed all its municipalities to create improvement strategies. For this prioritization, it used input from the district offices and assigned importance somewhat evenly among the various districts. The main driver was to both receive an opinion of each district manager and to capture service to important customers. The intention was also to consider the infrastructure health, but data was collected based on field knowledge of each district office in isolation from each other. Fig. 3a shows the feeder count for the short-, intermediate- and long-term time horizons. It displays correlation between the two bar charts, illustrating the previous philosophy of a proportional approach, i.e., weighting district needs somewhat equally among all districts. Fig. 3b shows the total number of feeders broken down by prioritization, i.e., short, intermediate, and long-term tiers 1 and 2. A new strategy was required to more adequately captured reliability and customer criticality.



a. b.

Fig. 3. Feeders identified for improvement (a) on a per-district basis and (b) timeframe.

3. REVISED PRIORITIZATION

The proposed prioritization method was intended to not only incorporate field knowledge, but also to encompass a score related to reliability and customer criticality.

3.1 Reliability Contribution

Raw data containing reliability metrics (CMI and CI data by distribution feeder) were used to study 1,057 feeders. While the DSO operates about 1,400 feeders, this total number includes spare breakers and out-of-service feeders. More importantly, there are feeders that are operational but have not experienced any outages. If a feeder has not experienced outages but it serves critical customers, however, it is counted in the 1,057 record. Hence, 1,057 feeders are the total number of in-service feeders that have experienced outages and/or serve critical customers.

A. Feeder Construction Characteristics

Multiple attributes of each feeder, such as total length, length per voltage level, underground and overhead length, total number of customers, critical customers served, etc. were gathered to provide a holistic view of all the feeder population. A summary of OH and UG mileage of these 1,057 feeders is provided in Table 1.

Table 1. Summary of OH and UG miles for the 1,057 feeders and Customer Count

kV	13.2	8.32	7.2	4.16	Total	Customers
OH miles	2,553	3,673	414	6,497	13,154	1,459,132
UG miles	2,459	346	60	434	3,299	

B. Available Reliability Data

The baseline yearly SAIDI and SAIFI values used in the analysis were obtained by adding up the feeder CMI and CI data for each root-cause over a period of 2 years and 3 months and then calculating one-year average values. The baseline SAIDI and SAIFI values for the distribution system are shown in Table 2.

Table 2. System SAIDI and SAIFI values for the Distribution System

SAIDI	SAIFI
1,083	7.1

CMI as the Reliability Index

CMI was chosen as the reliability index to measure system reliability and target the feeder groups for improvement.

C. Customer Criticality Contribution

The conventional approach merely identified whether a feeder served critical or priority customers. To better account for the importance of a feeder, an index is proposed to capture customer criticality globally on a per-feeder basis. The index is being introduced as Customer Criticality Index of a feeder, or CCI. To calculate this index, the weighting factors proposed in Table 3 are used. In this allocation, for example, hospitals and critical water treatment plants receive the highest importance.

Table 3. Proposed Critical Load Weighting Factors

Type of Load	WF_i
Hospital	5
Storm water pumps	5
Critical water supply/treatment	5
AAA Facilities	5
Shelter/Town centers	5
Police/Army	3
Fire station	3
Communication facilities	3
Airport	1
Seaport	1

The index CCI of feeder *f* is then calculated as:

$$CCI_f = \sum_{i=1}^{n} WF_i, \tag{1}$$

where *n* is the total number of critical customers served by a feeder, and WF_i is the weighting factor presented in Table III. Hence, each feeder will have an associated CCI.

D. New Prioritization Approach

To allow prioritization of each feeder for various investment programs, as well as for their scheduling, the following approach was adopted. First, we ranked each feeder *f* per CMI in vector *CMIV* as follows:

$$CMIV = rank(CMI_f), \tag{2}$$

where the function *rank* will rank every feeder CMI in ascending order. Second, each feeder f is ranked by CCI in a similar fashion, in vector *CCIV*:

$$CCIV = rank(CCI_f), \tag{3}$$

where a CCI_f is calculated using (1). Then, each feeder receives a weighted score as:

$$Score_f = w_{CMI} \times CMIV(f) + w_{CCI} \times CCIV(f), \tag{4}$$

where w_{CMI} and w_{CCI} are the weighting factors allocated to the importance of CMI and CCI, respectively. They are intended to rank each feeder to account for the need to:

- Improve overall system reliability (target feeders that are greatest contributors to system CMI)
- Improve reliability of critical customers (target feeders that are greatest contributors to system CCI)

The recommended combination of weights to meet both objectives was:

- $w_{CMI} = 70\%$
- $w_{CCI} = 30\%$

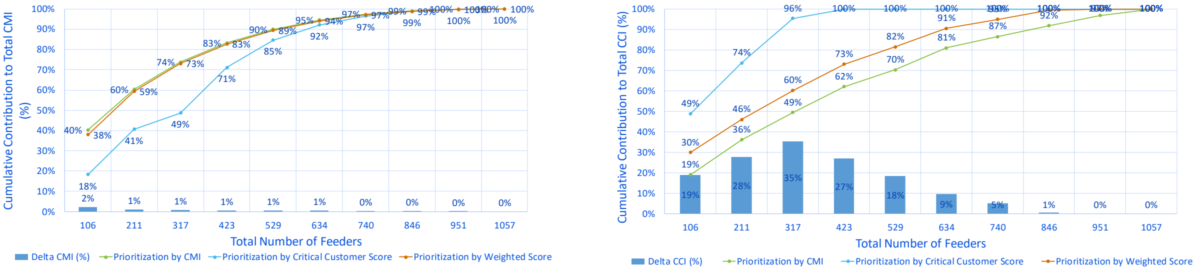
E. Sensitivity Analysis

The CMI and CCI weighting were defined somewhat arbitrarily because it is important to address the worst performing feeders first. To ensure this was a sensible choice, a sensitivity analysis was conducted and is represented in Fig. 4. Fig. 4a shows the cumulative contribution to total CMI for three curves: the feeders prioritized by CMI, by CCI, and by the proposed approach. This approach favors reliability as the curves between the proposed approach and that of CMI are very close to overlapping. It also allows to visualize that:

- The worst 10% feeders identified using the proposed approach contribute to about 38% of total system CMI
- If feeders were prioritized by CMI contribution only, then the worst 10% feeders would contribute to about 40% of total system CMI.

Fig. 4b shows the cumulative contribution to total CCI for the same three curves. While favoring reliability, this analysis reveals the approach does have a very positive impact on CCI as well. It also allows to visualize that:

- The worst 10% feeders identified using the proposed approach contribute to about 30% of total system CCI.
- If feeders were prioritized by CCI contribution only, then the worst 10% feeders would contribute to about 49% of total system CCI.



a. b.

Fig. 4. Sensitivity analysis of the three appraches and its impact on system metrics, (a) CMI and (b) CCI.

Correlation Between the two Approaches

A correlation analysis was conducted to compare both approaches and verify how the new direction would affect the overall prioritization. Fig. 5 shows the categories for worst 10% feeders prioritized using the proposed weighted rank approach. It suggests that most feeders (87%) fall in the top 3 priority categories (Short Term Tier 1, Short Term Tier 2 and Intermediate Term Tier 1). These results show a somewhat weak, but reasonable correlation between the two datasets, considering the fact the traditional method lacked analytical support.

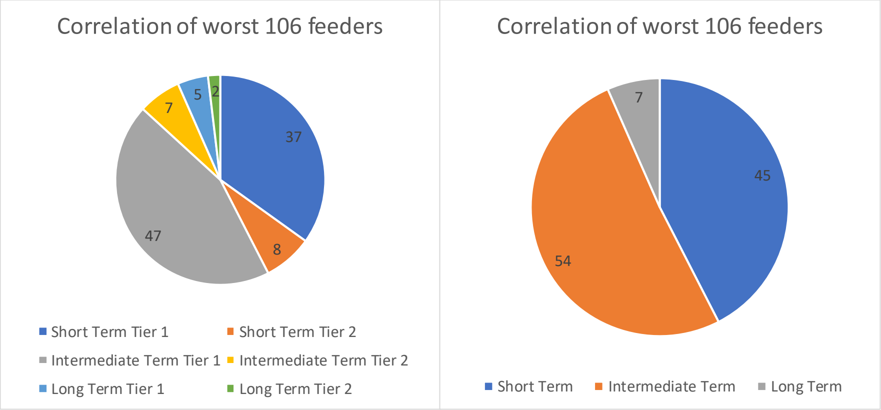


Fig. 5. Correlation between both approaches.

3. POTENTIAL RELIABILITY IMPROVEMENT MEASURES

The DSO is considering several programs to repair the distribution system and improve its performance. Some of them are discussed in more detail in [3]-[4].

Uncertainty in Available Data

The root-causes provided per each category, i.e. distribution or substation and transmission, were in part generalized. For example, “wire down” contributes to around 16% of total CMI reported in the averaged data, which is the highest contribution among all root-causes. However, wire down can be the result of different sub-causes, which are not available in the original dataset. Similarly, around 8% of total CMI is identified as “no cause reported”.

Targetted Undergrounding or Tree-Wiring

The objective of this program is to underground or install tree-wire on selected overhead sections of worst-performing feeders, specifically those that serve critical customers. Worst-performing feeders have been identified and prioritized in the previous section. These results show that, for instance, the 10% worst-performing feeders (106 feeders) contribute to approximately 38% of total CMI, therefore, targeting investments to these feeders is expected to yield the greatest benefit-cost ratio, i.e., programs implemented in these feeders are likely to be cost-effective. Undergrounding and tree-wiring have been targeted to selected worst-performing feeders. Since undergrounding is a more expensive solution, it has been reserved for feeders within this group that have the highest CMI contribution and the most critical customers (e.g., hospitals), while tree-wiring has been targeted to the remaining feeders of this group.

Pole and Conductor Replacement

The objective of this program is replacing poles and structures (crossarms, insulation, hardware, conductors, etc.) identified as being at-risk during assessments. This program is intended to reduce failure rates by addressing multiple root-causes besides defective poles, including wire down which is the main contributor (it represents about 16%) to total CMI, broken insulators, and others. This program should also target worst-performing feeders.

Vegetation Management

Vegetation is the second largest contributor to total CMI, it represents about 14% of total distribution CMI. The objective of this program is implementing tree trimming and other vegetation management strategies (e.g., tree trimming, pruning, application of herbicide, etc.) on overhead lines of worst-performing feeders to reduce associated fault rates.

Animal Guards

Results from the historical reliability analysis show that the animal root-cause contributes to about 4.3% of total distribution CMI. Therefore, the objective of this program is installing animal guards to prevent potential faults due to wildlife and reduce respective fault rates. This is an inexpensive and most-cost effective program and should also target worst-performing feeders.

Underground Cable Replacement

This program is intended to replace selected underground cable sections of worst-performing feeders. This program is expected to address root-causes affecting underground assets, specifically broken cable and broken splices and terminals and reduce respective fault rates.

Mid-Line Reclosers

This program is intended to address a variety of root-causes, such as wire down, vegetation, weather, etc. and improve reliability (reduce CMI, CI, SAIDI and SAIFI) by limiting the number of customers impacted by faults, as well as by allowing temporary faults to self-extinguish via reclosing operations. This program consists of installing one or two mid-circuit smart reclosers (with microprocessor-based controllers and the remote monitoring and control capabilities) on selected worst-performing feeders.

Fault Current Indicators (FCI)

The objective of this program is installing remotely monitored FCI in strategic locations of worst performing feeders to improve the outage management and restoration process, specifically by decreasing the time required to detect and locate faults. The overall effect of FCI deployment is reducing CMI and SAIDI by improving response time. FCI does not impact CI, therefore, they do not improve SAIFI.

Targetting Root-Causes

Based on the limited granularity of the available data and the categorization of root-causes, the available programs are studied so, to the extent possible, best target the main root-causes contributing to more CMI and CI. Among distribution root-causes, the root-causes contributing to more than around 1% of total CMI were targeted by available programs. A summary of the assumptions on how distribution root-causes were targeted is provided here:

- Some programs target OH lines, and hence can reduce the CMI contribution of causes that directly impact OH lines. Pole replacement, undergrounding and tree-wiring, and vegetation management are in this category.
- The “Animal Guards” program reduces the CMI caused by the “Animals” root-cause.
- Reclosers help reduce the CMI and CI of more root-causes.
- FCI improve outage management and restoration by reducing mainly the time required to detect and locate faults. FCI reduce the total duration of service interruptions for distribution root-causes, therefore, they only improve SAIDI; they do not have any effect on SAIFI.

Programs Targetting the Same Root Cause

An individual root-cause may be targeted by different programs. For instance, both pole replacement and reclosers can help mitigate the wire down root-cause. In this example scenario, the two programs are considered hand in hand to mitigate this root-cause, and hence their mutual impact is considered in the assumptions with the objective to avoid double counting potential benefits. Moreover, some programs modify key feeder features, this change must be considered when estimating reliability benefits of other programs whose effectiveness is a function of these features. For instance, if part of a feeder is undergrounded, its total OH mileage must be reduced accordingly before estimating benefits for the vegetation management program.

4. CONCLUSIONS

This paper presents a prioritization strategy to implement distribution system improvements and improve reliability indices as well as reduce social burden by improving the continuity of supply to critical infrastructure. The method:

- Is reliant on reliability metrics as well as location of critical infrastructure.
- Provides a reasonable balance between the two objectives, namely improvement of CMI as well as of customer criticality index.
- Provides insight on the distribution circuits necessitating improvements and allows the DSO to direct investment in the most effective way.

The paper also discussed potential improvement initiatives that are likely to be effective measures. As a disclaimer, the utility that developed this method has continuously improved it and the current methodology, which although aligned with the method presented in this paper, is not identical. The utility also made a commitment to revisit and improve it at least every year and the result of each reprioritization will affect projects going forward.

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