Distribution reliability improvement through optimal location of load break switches in 33 kV network

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Abstract— *Distribution network is responsible for many of the interruptions in an electricity supply system. This is internationally the case due to the more exposed nature of the distribution lines which are mostly of overhead type going through different zones like vegetated areas, coastal areas, urban areas, flat fields and hilly areas. The causes for failure as well as the failure frequency differ from one zone to the other. In Sri Lanka there are 33 kV lines of 25,257 km length spread all over the country going through different landscapes. The lines are all radial and a failure at the beginning of the line lead to supply interruption for all the connected customers. However, a failure towards the end of the line if properly managed would interrupt only a section of the customers.*

This paper presents a method to decide on the best number of load break switches and the optimal location of each of the switches considering nature of the different zones the line is going through and the distribution of the customers. Feeder failure data has been gathered and used to estimate failure rates corresponding to different exposure zones using the least square fit. Failure rates so estimated are used to model the failure behaviour in a given feeder going through a combination of exposure zones. Each feeder is divided into a series of logical sections based on the location of distribution transformers serving customers. If there are n such sections r (≤n) breakers can be located in ${}^{n}C_{r}$ *different ways and for each of such constellations a cost function is evaluated and the System Average Interruption Duration Index (SAIDI) is calculated using number of customers that are isolated by each of the switch and the average restoration time. The total unserved energy can also be calculated. The cost function gives the sum of cost of unserved energy due to interruptions and the cost of breakers on an annual basis. Optimum arrangement can be obtained for given r and known n. By repeating this optimization for all possible r, the global optimum is obtained. This algorithm has been effectively implemented.*

Keywords *—* **Distribution reliability, SAIDI, Load break switches**

I. INTRODUCTION

Distribution network is responsible for many of the interruptions in an electricity supply system. This is internationally the case due to the more exposed nature of the distribution lines which are mostly of overhead type. In Sri Lanka there are 33 kV lines of total length 25,257 km (Ceylon Electricity Board, 2011) spread all over the country going through different landscapes. Customers always prefer interruption free supply as the cost of not having electricity is many times higher than what they have to pay for the electricity. The utility also strives to minimize the interruptions as they are compelled to be within the reliability targets set by the regulator. In some countries penalties are imposed if reliability targets are not met and rewards are due if the utility is well within the target. Different strategies both management and technical are available to improve the distribution reliability.

One such strategy is to allocate switching devices in distribution systems in an optimal manner. Hagnifarm et al. (2003) have highlighted the importance of optimal location of switches in enhancing distribution system performance. Chen et al. (2008) have introduced an immune algorithm based optimization method for the placement of line switches. Alencar et al. (2011) introduced a switch allocation methodology using particle swarm optimization based on fuzzy expert systems.

This paper introduces a new methodology based on crisp logic to locate the optimum number of load break switches located at best positions to achieve cost effective reliability improvements.

First a mathematical model is presented to estimate the failure rates in any segment of a line. Then an algorithm is developed to find out the best number of switches and their optimal location to achieve most cost effective arrangement.

II. RELIABILITY INDICES

A lot of different indices are being used to quantify the supply reliability internationally. In this study we limit to System Average interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI). The two indices together cover the two most important aspects of the reliability which are interruption duration and interruption frequency. Ideal situation would be to have lowest possible values for both indices as long interruptions that seldom occur are equally undesirable as very frequent short interruptions. Sri Lankan Utilities use these indices for quantification of their reliability levels.

SAIDI and SAIFI applicable to an area with *N* customers are defined as given below:

$$SAIDI = \frac{1}{\mathrm{N}} \sum_{i=1}^{N} \begin{pmatrix} Annual\ interruption \\ duration \\ of\ i^{th}\ cusomer \end{pmatrix}$$

$$SAIFI = \frac{1}{\mathrm{N}} \sum_{i=1}^{N} \begin{pmatrix} Annual\ interruption \\ number \\ of\ i^{th}\ cusomer \end{pmatrix}$$

In the Sri Lankan system the 33 kV lines are usually of radial nature. When a fault occurs in a 33 kV line it is isolated by opening the line at a point on the supply side. All the customers beyond the opening point are disconnected and remain disconnected until the fault is cleared or isolated and the opened circuit breaker is reclosed. Each of such incidents contribute to increase the SAIDI and SAIFI indices of the area. Strategically placed load break switches can minimize the number of customers that are interrupted. Further, the fact that such devices can be operated remotely reduces interruption durations as they can be switched on immediately after the fault clearance.

III. MODELLING FAILURE RATES

Distribution lines run through different landscapes and the causes for failures and thus also the failure frequencies are landscape dependant. As an example a feeder running through a paddy field is more exposed to lightning whereas a similar feeder running through thick jungle fails mostly due to disturbances caused by vegetation or wild animals. On the other hand failure characteristics are identical for feeder sections passing through same type of landscape. Many practical 33 kV feeders are relatively long and pass through different landscapes. Such landscapes are named exposure zones. This study uses data related to feeders in the North Central Province of Sri Lanka. Following different exposure zones are identified and related causes for failures are given below:

Thick jungle: Here the most of the failures are caused by way leaves and animals.

General vegetation: Here the causes are similar to those in the thick jungle but occur at a lower intensity.

Coconut plantations: Here too the causes are similar to those in the previous zones but the intensity is different.

Paddy fields: Lightning is mostly responsible for the failures in this zone.

Urban areas: Interventions by public such as vehicular accidents, vandalism and fires contribute to failures in this zone. Lightning and way leaves also contribute.

Semi urban areas: Here the causes of failure are similar to those in urban areas but occur at a different intensity.

In other provinces of Sri Lanka further zones such as coastal areas, tea plantations and mountain areas can be identified. The method developed in this paper is a generalized method and is applicable to any number of different zones.

Let us assume that there are *m* different exposure zones. If there are *m* distinct zones, *e*ach of the zones can be characterized by a constant failure rate λ_i (i = 1 ... m) failure per km per year. Failure rates in different zones are not directly available but information about the failure rates corresponding to individual feeders is available. Using data for *n (n>m)* different feeders zone specific failure rates can be obtained using a least square fit. Let as assume that a total length of L_{ji} of the j^{th} *(j=1...n)* feeder runs through exposure zone type *i*. If the total length of the feeder *j* is given by L_j we can write following equations for each of the n feeders:

$$L_j = \sum_{i=0}^{m} \mathrm{L_{ji}}$$

$$\lambda_j L_j = \sum_{i=0}^{m} \lambda_i \mathrm{L_{ji}}$$

Depending on the data availability *n* can be an arbitrary number larger than *m* leading to an over determined system of linear equations. Therefore, linear least square method is used to find the best approximation for the zone specific failure rates.

In this study 33 kV network in North Central Province (NCP) is used for validation of the method. Using actual failure rates and different exposure zones related to 16 feeders in NCP following zone specific failure rates have been obtained and given in Table 1. For this purpose feeder specific failure rates in the years 2009 and 2010 are used.

Exposure zone	Failure rate Failures/km per year
Thick Jungle	0.4512
General vegetation	0.3609
Coconut plantation	0.0107
Paddy fields	0.3927
Urban areas	0.2528
Semi urban areas	0.4079

Table 1. Zone specific failure rates in North Central Province

The highest levels of failures are observed in the thick jungle mainly due to heavy vegetation, tall trees and animal activity. The fact that such zones are not continuously observed by the public and utility personnel also contribute to increased failure frequency. Coconut plantations are less prune to failures as the coconut trees do not branch out and old trees are fell by the owners for timber usage before they can cause any harm. These results also confirm that 33 kV lines passing through coconut plantations have reduced exposure to lightening attacks. On the other hand, lines passing through paddy fields are well exposed to lightning and have comparatively high failure rates. General vegetation areas where more human activity and fewer trees are present have failure rates lower than those in the thick jungle. Urban areas have the least disturbance from vegetation and big animals like apes and show reduced failure rates. Semi urban areas are areas with comparatively low population density and accordingly higher vegetation levels compared to urban areas.

After obtaining zone specific failure rates it is possible to estimate the failure rate of any selected section of a line taking into account how that particular section is exposed to different landscapes. With this model it is possible to estimate the SAIDI and SAIFI values for any constellation of load break switches placed along a line.

IV. LOCATION OF SWITCHES AND OPTIMIZATION

All 16, 33kV feeders in NCP start from one of the three grid substations, old Anuradhapura, new Anuradhapura and Habarana. Feeders run radially outwards from the grid substation for long distances. Seven out of the 16 feeders are longer than 200 km the longest being the feeder from old Anurdhapura to Medawachchiya measuring 440 km. Long feeders branch out making spur lines. Distribution transformers are either connected to the main line directly or to a spur. Ideal location for the LBS would be just prior to the spur or the distribution transformer on the supply side of the radial feeder. Such positioning would facilitate isolation of the spur or the transformer for maintenance work and would have easy access and visibility. In this paper all the locations in a feeder satisfying the above conditions are identified as candidate locations.

For a selected feeder there are many such candidate locations. However, it is not economically viable to position an LBS at each and every candidate location. Too many switches will be a burden to the utility whereas too few switches will increase the SAIDI and SAIFI to unbearable levels. Thus there is an optimum number of switches positioned in such a way leading to the best customer satisfaction at a bearable cost from the utility point of view. If a feeder has *n* candidate locations and *r* switches are to be utilized there are $^{n}C_{r}$ different ways to position the switches. As *r* can take any integer value between *0* and *n* there are exactly 2^n different constellations.

In order to find the optimum number of switches and the related best locations a cost function is defined adding the annual cost of the switches (Ceylon Electricity Board, 2011) and the estimated cost of the unserved energy.

Annual cost of a switch is calculated by equally distributing the life time cost of a switch including initial cost and the maintenance cost over its expected life time. Current market prices are used for this purpose.

In order to calculate the cost of unserved energy the SAIDI value is estimated for each of the constellation of switches. For this the zone specific failure rates obtained using the method described in Section II is used. Data related to the number of customers affected by each failure and the average repair times and average hourly consumption are available. Cost of unserved energy figure published in the CEB long term generation plan (Ceylon Electricity Board, 2010) is used. CEB has estimated this value by inflating the cost of unserved energy published in 2003 (Nexant SARI/Energy, 2003). The published figure corresponds to the national average encompassing all categories of customers. However, majority of the customers served by the feeders under study are rural and sub urban domestic customers. No attempt has been made to adjust the national figure to match the customer cross section in the area under consideration.

This cost function does no incorporate SAIFI value and thus ignores the impact of the number of the interruptions considering only the total interruption duration. This is justified by the fact that short interruptions do not impose severe problems to the rural domestic customers while they could be highly disturbing for the urban and industrial customers.

For each of the constellations of switches the overall cost function can be calculated and they display a clear minimum point as shown in Fig. 3. The minimum point corresponds to the optimal switch configuration. Fig. 3 also shows the costs separated for utility and the customers. The utility cost increases with the increasing number of switches whereas the cost of unserved energy decreases due to the reduction in SAIDI as depicted in Fig. 1.

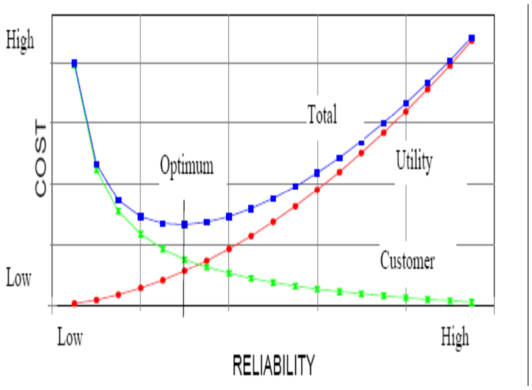

Fig 1. Optimal solution leading to lowest overall cost

V. CONCLUSION

A method to model 33 kV feeders considering how the feeder is passing through different landscapes exposing it to different causes of failures is developed. This model is effectively used to estimate the SAIDI and SAIFI figures corresponding to any given constellation of LBS switches. An algorithm to obtain the optimal number of switches for a given feeder and how the switches could be best located to minimize the overall cost is developed. Comparison of this algorithm with the fuzzy logic based algorithms developed by Alenca et al would bring more insights. Implementation of this method is to be promoted at provincial level and effective implementation of the same will bring in cost effective reliability improvements and better quality of service.

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REFERENCES

Ceylon Electricity Board, (2011). *Statistical Digest 2011*, Ceylon Electricity Board, Sri Lanka, 2011.

Alencar T, Rodrigues A and Silva M da G (2011). “Switches allocation in distribution network using particle swarm optimiztion based on fuzzy expert systems”, 17th Power System Computation Conference, Sweden, August 2011.

Chen CS, Lin CH and Hung JCCW (2008). ”Optimal Placement of Line Switches for Distribution Automatic System using Immune Algorithm”, IEEE Transactions on Power Systems, Vol. 21, August 2008.

Ceylon Electricity Board, (2011). Price List of Materials *2011*, Ceylon Electricity Board.

Ceylon Electricity Board, (2010). *Long Term Generation Plan 2010*, Ceylon Electricity Board.

Nexant SARI/Energyey (2003). *Economic Impact of Poor Power Quality on Industry; Review of studies, sri Lanka*, Nexant SARI/Energy.

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