COST-BENEFIT ANALYSIS OF RECLOSER PLACEMENT FOR RELIABILITY

J. PRETORIUS* & C.T. GAUNT**
*ESKOM DISTRIBUTION, **UNIVERSITY OF CAPE TOWN

Abstract

Technical network reliability in electrical distribution networks and the improvement thereof will always be part of utilities and the electricity supply industry. One of the key reliability improvement strategies is additional recloser (breaker) installation on medium voltage networks.

The effect of recloser placement on network reliability is investigated. A method of cost-benefit analysis (CBA) is explored, explained and used to analyse the placement of additional reclosers in electrical networks. Costs and benefits are shown to be different when viewed from the perspective of the utility against that of the customer, and this ultimately influence the placement of a newly planned breaker.

Keywords: Cost-Benefit-Analysis; Cost of Energy not Served; Distribution network; Network Reliability; Recloser.

1. INTRODUCTION

In electrical distribution networks, additional breaker (recloser) installations form part of the technical performance improvement strategies of utilities and the electricity supply industry. Traditional breaker placement methods such as using a technical indicator alone, normally SAIDI (System average interruption duration index), are questioned as the importance or load size of the consumer and hence the income to the utility is ignored. A Cost-Benefit Analysis (CBA) is shown to be superior to the use of technical indicator alone when placing additional reclosers, as economic factors are taken into account. CBA results will be shown indicating if a particular installation is beneficial or not. Cost-Benefit Analysis methods may be utilized to determine an optimal position for the placement of additional breakers and to support network planners to motivate projects at financial committees.

2. LITERATURE REVIEW

Traditional placement methods of additional reclosers used by Eskom in a MV distribution network include [1]:

(i) Manual intervention to optimally place reclosers
(ii) The 'top 300' and an adequacy model

(iii) Feeder per-zone analysis.
(iv) Customer segmentation analysis

In all these methods networks are selected by giving priority to larger numbers of customers in the specific region. The last category includes 'the cost of un-served energy' to customers placed in a certain category (segmentation) in terms of exposure to the environment, i.e. lightning density, pollution, etc. The selection of the position of an additional breaker is guided by reducing the number of customers affected in case of network interruptions.

Numerous other methodologies used by world utilities to determine recloser placement exists. A summary of the predominant methods are:

(i) Multiple population genetic algorithms (DG enhanced networks) [2], [3]
(ii) Ant Colony algorithms [4]
(iii) Savings gained (cost of un-served energy) at supply points [5]
(iv) Feeder automation, loop sectionalizing schemes [6]
(v) Priority order by parameters such as the location of fuse failures and faults and customer activities and sensitivity. [7]

Again, the output for the above methods is driven by reducing the number of affected customers during fault conditions in order to improve network reliability. Economic considerations are not the main consideration.

3. RESEARCH METHODOLOGY

A Cost-benefit analysis is a method to finally decide if a particular project or any of its alternatives must be executed or not [8]. The benefits of the next best alternative to a project can also be described as the costs associated to the chosen project. This is because as soon as the decision has been made for the first project to continue, the benefits associated to the alternative are lost. The theory description can thus also be to select to do a project only if its benefits exceed its costs, and not otherwise. A generic Cost benefit analysis can be expressed as:

$$CBA = \frac{Nett\ Benefits\ (B)}{Nett\ Costs\ (C)} \qquad eq. 1$$

Equilibrium is achieved when the total benefits (B) equal the costs (C), when B = C or when B/C = 1 (refer to figure 1).

Projects should be favourable if B > C and not accepted if B < C [9]

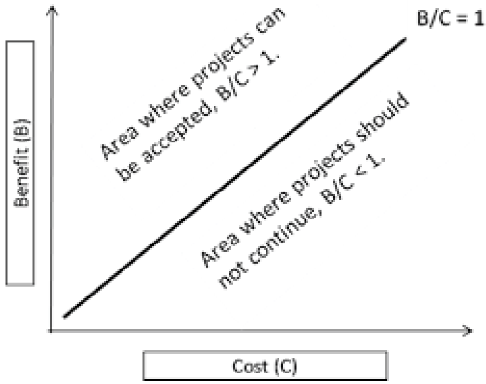

Fig. 1: Generic Cost – Benefit diagram [9]

Projects to install addition reclosers alone cannot reduce the number of network faults - it can only support to sectionalize faults better, to minimize the effected customers and outage duration.

4. FINDINGS AND DISCUSSION

To use CBA in project evaluations the necessary costs need to be assigned in the CBA.

Cost in respect of the Utility

When a cost-benefit analysis is applied to electrical networks, the cost of the energy not delivered to the customer is a one method of assigning cost to the utility (as revenue is lost) whenever supply is interrupted. The energy that is not delivered due to a planned or fault network interruption is also referred to as the 'un-served energy' or energy not served (ENS) and is measured in kilowatt hour (kWh) [10]:

$$ENS = \int_{T1}^{T2} P(t)$$

$$\approx \sum_{h=i}^{h=i+n} P_h \quad [kWh] \qquad eq.\,2$$

Where Ph is the load averaged in an hour h. The integral can be reduced to an approximate sum of the hourly averaged loadings.

In order to calculate the Cost of Energy not Served (CENS) seen as revenue lost in this study, the following Eskom tariffs were used:

Table 1: Eskom tariffs used in Cost of Energy not Served (CENS) calculations in R/kWh. [12]

Customer Segment	Tariff (R/kWh) vat incl.	Note:
Residential, Ur ban, Pre - paid (PPU)	0.8853	Use up to 600kWh
Residential, Urban, Pre-paid (PPU)	0.9357	Use less than 600kWh, NMD < 100kVA
Residential, Urban, Pre-paid (SPU)	1.4405	Use more than 600kWh, NMD < 100kVA
Small Urban, Agricultural (SPU)	0.7945	Dual and Three phase, NMD > 25kVA
Small Urban, Agricultural (SPU)	0.5759	NMD = 25kVA to 1MVA
Large Urban users, Commercial (LPU)	0.4746	NMD > 1MVA

Note: PPU = Pre Paid Users, SPU = Small Power Users and LPU = Large Power Users.

With the successful installation of the addition breaker, faults should be isolated more effectively and fewer customers should be interrupted. The result should yield a reduction in energy not served (ENS) and hence a reduction in the cost of energy not served (CENS). This can also be expressed as the difference between the CENS before and after the installation (delta).

The cost benefit analysis from the Utility's (CBAu) perspective can be expressed as:

$$CBAu = \frac{Nett\ Benefits}{Nett\ Cost}$$

$$= \frac{Saving\ in\ Cost\ of\ Energy\ Not\ Served\ (CENS)}{Recloser\ project\ cost + \ maintenance\ cost + cost\ of\ failure}$$

$$= \frac{CENS\ before - CENSafter}{Recloser + Maintenance + failure\ costs} \qquad eq. 3$$

The CENS before and after the breaker installation must be evaluated for a set period - at least 1 year data to even out the season effect on network performance. For the installation (project) to prove viable, the equation must yield an answer greater than one, or: CBA > 1. For projects that do not proof to be viable in year one, a pay-back period can be determined for when the CBA becomes attractive after extending the period of evaluation.

Cost in respect of the Customer

From the customer's perspective, the cost benefit analysis specific to a new recloser installation will reduce to a more simple equation. The customer do not carry cost for the installation, so the CBA in respect of the customer (CBAc) will prove acceptable if the customer experience less outages, lower outage durations and thus lower costs after a new installation:

$$\begin{aligned} \boldsymbol{CBAc} &= Benefits\ before - Benefits\ after \\ &= CICbefore - CICafter \qquad eq.\,4 \end{aligned}$$

With CIC the Customer Interruption Cost as experienced by the consumer dependent on the duration of the interruption.

Customer Interruption Costs (CIC) is dependent on factors such as; the customer type, actual load demand at the time of the interruption, the duration of the outage and the specific time of day and year of the interruption [4].

The specific customer costs (R/kW) for each interruption and each customer is different. Calculating the exact cost of an outage involves a considerable amount of data of the customer and of the network which is normally not readily available. Calculating ENS and CIC by using approximate R/kW per duration and customer segment is more realistic for utilities to use.

For certain customer segments the costs escalates as the duration of restoration is prolonged, and for the normal household it is a frustration difficult to translate into a monetary value. For the purpose of this study, CIC values from [11] are used:

Table 2: Customer interruption Costs (CIC) in R/kWh

	Duration of outage				
Sector	**1 min**	**20 min**	**1 hour**	**4 hours**	**8 hours**
Residential	0.00	0.18	1.44	16.20	36.00
Commercial	8.82	106.7	316.3	1495.9	2746.8
Industrial	16.9	42.48	110.3	417.24	797.22
Governance & Institutions	9.27	85.95	186.5	700.02	1384.8
Offices and buildings	193.7	198.5	276.4	619.7	1077.6

Application

A cost-benefit analysis can be used in the evaluation of projects to install additional reclosers and should be able to direct the project planner to:

(i) determine the limit (based on cost) of additional reclosers,
(ii) determine the positioning of a specific recloser,
(iii) decide if the specific project must continue or not.

4.1.1 Case study

For the purpose of this study an 11kV overhead distribution network was selected, the Selosesha – Sandoord (SSO) feeder. Data for the case study was extracted from Eskom's NEPS (Network and Equipment Performance System) for the years 2005 to 2013 and used as in accordance with Eskom standards [13].

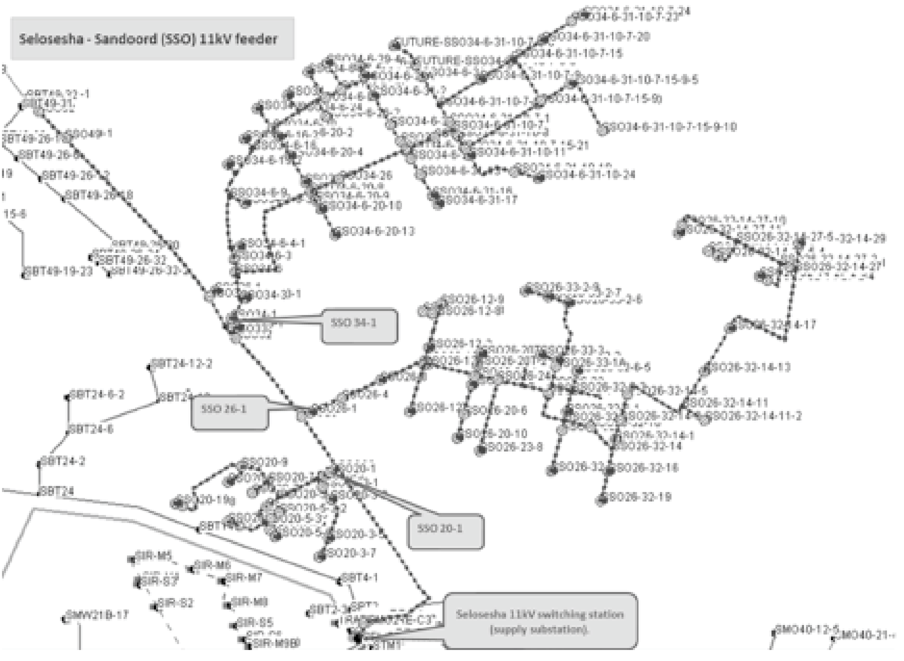

Fig. 2: Geographical layout of the Selosesha – Sandoord 11kV feeder [14]

The SSO feeder has an installed capacity of 7101 kVA, and an average measured load of 2200 kVA measured from 2011 to 2012. There are a total of 5681 customers connected: 5611 pre-paid customers (of which 707 customers are served from spur SSO 20-1), and 70 small power users.

In April 2009 an additional breaker was installed at SSO 20-1. This project will be evaluated using the CBA calculations and 2 years of network interruption data (recordings of all outage times and customers involved) – 1 year prior to the installation and 1 year afterwards.

Note that although the case study comprises of a completed project, the position of a new (planned) breaker can be moved manually on any network with the associated interruption data to calculate the impact on the CBA.

4.1.2 CBA Results

For the installation done on the SSO feeder the benefits of 1 year before, is weighed up against the benefits of 1 year after the installation on 9 April 2009. From the utility's perspective then, using equation 2 and 3:

$$CBA = \frac{CENSbefore - CENSafter}{Recloser\ Cost}$$

Assuming Maintenance and Failure cost to remain constant before and after, so it can be set to zero. The CENS calculations are not shown here as it must be done for each interruption, duration and tariff per customer type using table 1.

With a Recloser cost (including installation) to be set at R230 000, the output values are:

CENS-before = R284 190 ; CENS-after = R61 121 and
CBA = 0.97

As the CBA is close to unity, the breaker installation cost is almost recovered in the first year after the installation. A simple payback period (Ps) to recover the project cost can be calculated by:

Payback period Ps = R230 000/R223 069
= 1.03 years

With R223 069 the yearly saving (R284 190 – R61 121)

If the term is longer than 3 years, the yearly saving should be discounted to the present value of money. The discounted payback period can be calculated by: [15].

$$Discounted\ payback\ \boldsymbol{P_d} = \frac{log_{10}[\frac{1}{(1 - P_s(r-1))}]}{log_{10}(r)} \quad eq. 5$$

With Ps the simple payback method, and r the cost of capital, including inflation and opportunity cost.

From the above CBA calculations, many variables can be altered to see the impact on the CBA. The average load can be varied (low and high load conditions) to simulate a coincidence factor – the division of the average load by the installed capacity. This will impact the CENS calculations and ultimately the CBA.

The position of the recloser can also be varied, by manipulating the number of customers protected by the breaker in the interruption data recordings.

4.1.3 CBA results using a second method

A second method to do the CBA, is to do the before and after CENS calculations on the same set of interruptions. This calls for manual manipulation of the recorded interruption data but is manageable using a calculation spreadsheet. The data is duplicated, and on the second set (after breaker installation) the data is altered to show affected customers as if a new installation existed. Fault locations are important in this method as it must be indicated which breaker would have operated with and without the new proposed recloser.

Using the same inputs as in 5.2, and the same set of outage data before and after the breaker installation, the outputs are:

CENS-before = R136 810; CENS-after = R61 121 and
CBA = 0.33

Note, the CENS-after remains the same as this is the data set that was used. The CENS-before is calculated ignoring the existence of the new breaker and altering the number of affected customers with their applicable customer segments and tariffs.

In this case the CBA do not prove to be favourable, although a real monetary saving of R75 688 was achieved. Using equation 5, the payback period for this project will be:

Pd = 3.65 years

with Ps = 3.04 and r = 8.4% (Eskom weighted cost of Capital 2013/14) – use as 1.084% to replace r in eg.5.

The load coincidence factor can be increased to simulate high load conditions. This will increase the CENS calculations and produce a higher CBA value.

The number of customers beyond the new installation can also be varied – if a high number of customers is protected from a fault during each fault, the CENS after will be low resulting in a high (favourable) CBA.

4.1.4 CBA results in respect of the Customer

When calculating a CBA in respect of the customer, the analysis can be done for a specific single customer or for a set of combined customers. As before, the CBA is a function of the selected location; the part of the network and the associated customers selected for the analysis will determine the benefits before and after any intervention.

If the assumption is made that the customer has no direct costs (the utility pays for the new recloser project), then the CBA reduces to equation 4.

For the same case study, using the CIC in table 2 and using the interruption data for 1 year before and 1 year after, the outputs are:

CIC-before = R 13 722 112 and CIC-after = R 3 627 080.

In this case study Small Power Users (SPU's) are situated predominantly on spur 26 and 34 of the SSO feeder. When the new recloser was installed on SSO 20-1 it immediately protected SPU customers from interruptions from faults that occurred downwards from spur 20. The costs that SPU's experience in terms of R/kWh is much higher than PPU's especially in prolonged outages. The project is highly attractive already in year 1 in respect of the customer.

4.1.5 CBA in respect of the customer with initial cost

It can be argued that the costs incurred by the customers on the day (planned interruption) to install the new breaker, can be seen as the Customer initial Cost in the CBA equation. Equation 4 can then be divided by this cost to give a CBA result:

Customer initial Cost = R 1 730 535,
CIC-before = R 11 991 577 and
CIC-after = R 3 627 080 with
CBA = 4.83

Note the CIC-before reduced with the Customer initial cost of R1.7M, as the cost is now seen as the denominator in the CBA, and not part of the CIC. The project remains highly feasible as the CIC-after has reduced significantly.

In CBA calculations in respect of the customer variables such as the load coincidence factor, number of affected (protected) customers etc. may also be varied to test the impact on the CBA result.

The position of the new recloser can moved in the same way as in respect of the utility – adjusting the recorded outage data (affected customers with CIC costs) accordingly.

5. CONCLUSION AND FURTHER RESEARCH

A simple numeric or algorithm placement of a recloser is not necessarily effective or cost beneficial. An overview of the recorded network faults and placing the recloser manually is effective as then the recloser can be placed to function in a network section where faults are probable.

Cost Benefit Analysis studies done in this study suggests that using a technical indicator such as SAIDI alone is not an appropriate measure to direct an electrical utility. Utilities should not drive down customer numbers (additional reclosers, split of networks etc.) while the type and size of the customer is neglected. The importance of small and large power users, such as industrial and commercial consumers must be considered as CBA calculations proved that the revenue generated (or lost) by them is significant.

CBA assessments and the corresponding payback period for each initiative will give a clear indication of the financial (economical) validity and support better project prioritization.

6. ACKNOWLEDGEMENT

Funding and support to this study was supplied by Eskom Distribution and is appreciated. The support from and knowledge of Professor Trevor Gaunt (Electrical Engineering UCT) played a significant role in the completion of this work and is appreciated.

7. REFERENCES

[1] Eskom Distribution Performance Care Group, meeting minutes and decision logs 2010 – 2013.

[2] Li, Z., Yuqin, X., Zengping, W. (2008), 'Research on Optimization of Recloser Placement of DG-enhanced Distribution Networks', DRPT2008, 6-9 April 2008, Nanjing China, pp. 1-3.

[3] Zou, K., Keerthipala, W.W.L., Perera, S. (2007), 'SAIDI minimization of a remote Distribution feeder', AUPEC 2007, pp. 342-346.

[4] Wang, L., Singh, C. (2008), 'Reliability-Constrained Optimum Recloser Placement in Distributed Generation Using Ant Colony System Algorithm', IEEE Journal, volume 38 Issue 6, pp. 757-764.

[5] Jamali, S., Shateri, H. (2005), 'Optimal sitting of Recloser and Sectionalizers to Reduce Non-Distributed Energy', IEEE journal June 2005, pp. 3-7.

[6] Taylor, T., Fahey, T., Royster, T., Engler, D. (2008), 'New Recloser Functionality Enhances Feeder Automation', IEEE journal 2008, pp. 1-8.

[7] Nosaki, S., Fernandes, F. A., Torrezan, R. (1997), 'Optimization in the application of Reclosers', CIRED, 14th International Conference on Electricity Distribution, CIRED publication Vol. 4, issue no.4, pp. 18/1 – 18/6.

[8] Layard, R., Glaister, S. (1994), 'Cost-benefit analysis', Cambridge University Press, second edition, 1994, pp 1-56.

[9] Van Harte, M. (2008), 'Development of Regional Reliability Hurdle Rate for South Africa', MSc Thesis, University of Cape Town, August 2008.

[10] Kjolle, G. H., Samdal, K., Singh, B., Kvitastein. O. A. (2008), 'Customer Costs Related to Interruptions and Voltage Problems: Methodology and Results.', IEEE Transactions on Power Systems, Vol.23 issue no.3, August 2008, pp 1030 - 1038.

[11] Billinton, R., Wangdee, W. (2005), 'Approximate Methods for Event-Based Customer Interruption Cost Evaluation', IEEE Transactions on Power Systems, Vol.20 issue no.2, May 2005, pp. 1103 – 1110.

[12] Eskom Tariffs and Charges Booklet 2013/14.

[13] Nunes, N., Chatterton, B. G. (2010), 'Eskom DST 34-1188: Distribution Network Performance Definition Standard', July 2010.

[14] Eskom Smallworld geographical database, April 2013.

[15] Ross, S. A., Westerfield, R. W., Jordan, B. D., Firer, C. (1996), 'Fundamentals of Corporate Finance', Irwin publishers, First South African edition, p106-152.