DETERMINATION OF ASSET CRITICALITY: A PRACTICAL METHOD FOR USE IN RISK-BASED INVESTMENT PLANNING

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ABSTRACT

This paper describes the underlying methodology used in Condition-Based Risk Management (CBRM) to determine asset criticality. This methodology has been designed to be highly practical, enabling network operators to rapidly determine the criticality of many tens of thousands of assets, particularly when the available data is limited or incomplete. This methodology enables network owners and operators to target network investment towards the most beneficial parts of the network, providing a powerful tool for resource allocation and prioritisation.

INTRODUCTION

Risk-based methodologies such as CBRM [1] have become increasingly commonplace in distribution network system planning and development. In particular, the concept of asset "health indices" [2] is now well established and is used by utilities and regulators around the world.

As described in previous papers [3] [4], risk-based investment programmes generally require the risk associated with each asset to be quantified. However, it may be impractical to determine the consequence of failure for individual assets in large populations. The concept of "criticality" or relative asset importance has therefore been developed to enable network operators to rapidly calculate relative risk values across large numbers of assets.

The presented methodology explains how the severity of the consequences associated with an event or failure can be estimated by taking into account known factors such as the physical location of the asset, the function performed by the asset, the accessibility of the asset for repair and the cost of replacement. The methodology also enables relevant subjective data from other sources to be included. Once established, these factors can be derived from the asset population in an efficient and consistent manner, enabling the rapid calculation of individual asset criticality.

Example calculations will be presented, together with a discussion of the lessons learned in developing the presented methodology. It is hoped that this will provide valuable insight for network owners and operators who are considering the development or deployment of similar risk based processes.

CATEGORISATION OF CONSEQUENCES

The risk associated with the failure of any asset is a function of the probability of failure and the consequences of failure.

For electricity network assets there are a range of possible consequences. For example there may be network performance, safety, financial and environmental consequences. It is important to recognise that the criticality of an individual asset may be different in each of these categories. For example, an asset may have very high network performance consequences, even though it is located in a safe and secure environment. Conversely, the physical location of an asset may result in significant safety-related consequences arising from a failure.

In CBRM, the overall consequence is built up from four specific categories, these having been previously identified as capturing the key issues affecting transmission and distribution businesses investment planning. These are listed in Table 1 together with their typical units of measurement.

Table 1 Consequence Categories used in CBRM

Category	Units of measurement
Network performance	• Loss of system capacity (in MWh) • Number of SAIDI minutes
Safety	• Number of fatalities • Number of major injuries • Number of minor injuries
Financial	• Cost of repairs including collateral damage and site clean up • Cost of replacement
Environmental	• Volume of oil spilled • Volume of SF6 lost • Number of fires with significant smoke / pollution • Volume of waste created • Scale of disturbance (traffic / noise)

Other consequence categories that may be of particular interest to a network business could include reputation, regulatory and legal. The choice of which consequence categories to include in the estimation of criticality should reflect the priorities of the utility concerned. However, the four categories used in CBRM are proposed as a useful starting point to determine asset criticality.

CRITICALITY AND RISK

It is generally recognised that physically similar assets within an electrical network do not necessarily have equal importance, in that the consequences of asset failure are many and varied. Criticality is a comparative measure of consequence. It can be used as a tool to highlight the differences between assets and scenarios.

Many network operators have developed processes or policies either to determine the relative importance of assets, or at the very least to identify those few that are the most critical.

The CBRM process combines criticality with an average consequence to estimate the likely consequence of the failure of a specific asset. Criticality is used to give relative context to a failure, based on each asset's circumstances.

METHODOLOGY

The determination of asset criticality requires consideration of the potential consequences should the asset fail.

As the consequences of failure are multi-dimensional, the first stage in developing a criticality process is to define and categorise the consequences, as discussed previously. The categories are important as they define the units for the calculation and enable values to be assigned. In the next step, a consistent framework of contributing factors is constructed and populated to evaluate asset criticality.

The following basic methodology can be applied to each consequence category in turn. If consequence categories are to be subsequently combined into a single measure of criticality, they must ultimately be expressed in the same units (e.g. monetary value).

Each individual asset can be assessed by combining the various factors that define the consequences in each category. This can be described as follows:

$$consequences_{i,j} = \prod_{k=1}^{p} cf_{i,j,k}$$

where, for consequence category j:
$consequences_{i,j}$ = consequences of failure of asset i
$cf_{i,j,k}$ = consequence factor k of asset i
p = number of consequence factors

The consequence categories used in CBRM are:

Network performance

Network criticality factors are determined on the basis of which circuits supply which crucial customers, whether they are supplied by single or multi feeders, N-1 criteria, restoration methods and capacity limitations on alternative supplies.

Safety

In order to assess the safety criticality of assets, it is necessary to consider the relative likelihood of an injury occurring should the asset fail. Typically, this would include factors such as the insulation medium of the asset, its construction (e.g. certified to withstand internal arc), the likelihood of personnel being present and the proximity of the asset to the public.

Financial

The direct financial consequences of a failure may be recorded historically (and can often be estimated with a reasonable degree of confidence). The capital cost is usually dependent on the nameplate rating and operational costs are primarily driven by location and the complexity of repair.

Environmental

A variety of environmental consequences may result from asset failure, some of which are listed in Table 1. In order to determine criticality factors on a comparable basis, these consequences are all expressed as equivalent tonnes of CO_2. Additional criticality factors can include the insulation medium (oil, SF_6, vacuum, air) and the proximity to a significant watercourse or other environmentally sensitive feature.

PRACTICAL APPLICATION

The consequence categories described above provide a good starting point for the accurate determination of criticality. However, it is recognised that the necessary data to drive this process may not always be easily available.

Nevertheless, engineering judgement and expertise can often be used to build on the available raw data to provide an improved estimate of potential consequences. It is also important to recognise that within a specific group of similar assets, the data requirements may not be as onerous as they first appear. For example, within a population of SF_6-insulated medium-voltage distribution switchgear, the safety, financial and environmental criticality of each asset may be broadly similar. There is therefore only a requirement to determine the average consequences of a failure in these categories. Exceptional assets (with unusually high or low criticality) can be manually identified and scored accordingly if necessary, considerably reducing the data collection requirements.

The most significant differentiator between assets is usually the network performance criticality. It is therefore important to have a robust methodology to determine this value.

Unfortunately, the ever-changing connectivity within a large electrical network can present a number of challenges to the direct determination of network criticality. While modern asset management databases usually hold extensive information on what the asset *is*, it is what the asset *does* that is the primary driver of criticality. It is therefore often necessary to develop simple rules to enable the network criticality to be derived from the available information.

The CBRM process uses separate and distinct methods to determine network criticality, depending on the function of the asset. The two methods described here will cover *distribution assets* (with no redundancy) and *transmission assets* (with n-1 or better redundancy).

Distribution network criticality

For assets with no redundancy, the effect on the network of asset failure is primarily loss of supply. Utility network reliability is usually measured in terms of Customer Interruptions and Customer Minutes Lost. If the average interruption duration following asset failure is known, the main factor in determining network consequence is therefore the number of connected customers, as illustrated in Figure 1.

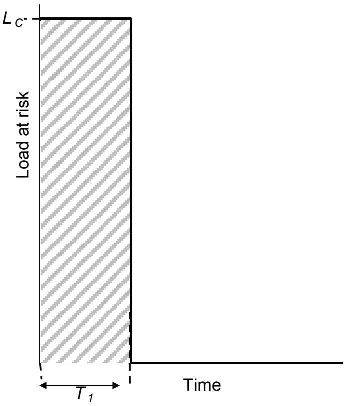

Figure 1 Determination of network performance consequences for distribution assets

$$cf_{i,customer} = L_{C,i} \times T_1$$

where:

$cf_{i,customer}$ = consequence factor for asset *i*

$L_{C,i}$ = customer load fed directly via asset *i* (MVA)

T_1 = average time to restore supply (hours)

Then to improve accuracy, additional factors can be included to reflect variations in expected interruption duration or differences in the classification of customers (according to the local regulatory regime). For example, consider a second asset that has the same number of customers but is twice the circuit length. It is reasonable to expect that the longer feeder will take longer to restore. Engineering judgement could be used to estimate how much longer the outage is expected to be. The additional consequence factor would be an arbitrary function:

$$cf_{i,length} = f\{length\}$$

After reviewing asset data it is possible to methodically apply engineering judgement to asset populations with a clear audit trail that makes explicit any underling assumptions.

Transmission network criticality

For assets with redundancy, the consequence of asset failure is primarily loss of capability. Network performance criticality can be expressed in terms of the load at risk, which is a function of capacity, load and time, as depicted in Figure 2.

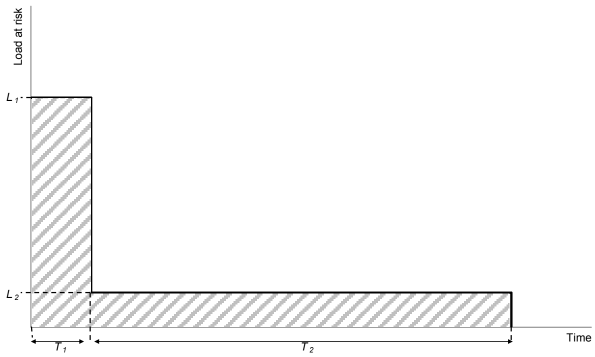

Figure 2 Determination of network performance consequences for transmission assets

$$cf_{i,network} = L_{1,i} \times T_1 + L_{2,i} \times (T_2 - T_1)$$

Where:

$cf_{i,network}$ = network consequence factor for asset *i*

$L_{1,i}$ = capacity associated with asset *i* (MVA)

$L_{2,i}$ = average load on asset *i* (MVA)

T_1 = load transfer time (hours)

T_2 = asset repair or replacement time (hours)

Rules can then be developed to determine $L_{1,i}$ based on the substation configuration. For example, for a typical transmission substation, $L_{1,i}$ for incoming circuit breakers may be defined as the sum of the load on (or firm capacity of) the substation, divided by the number of bus sections. Additional factors can then be included, as per the previous example.

EXAMPLE CALCULATION

In the following example, the network criticality of an incoming transformer circuit breaker will be determined for the example three-busbar substation shown in Figure 3.

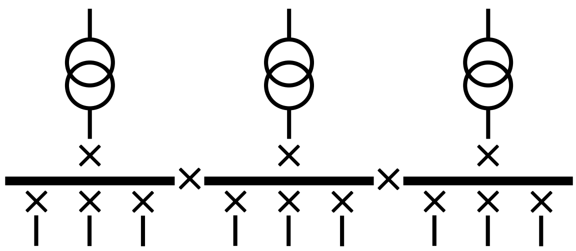

Figure 3 Example substation layout

In this case, the firm capacity of the substation is known to be 22.5 MVA, spread across three busbars. The average load on each transformer is known to be 5 MVA (L_2=5). In the event of a serious transformer circuit breaker failure requiring a busbar outage, the time to transfer the load off the busbar is estimated to be 1 hour (T_1=1). The repair time for the failed circuit breaker is estimated to be 24 hours (T_2=24).

Given the above:

$L_1 = 22.5 \div 3 = 7.5$

$cf_{network} \quad = \quad 7.5 \times 1 + 5 \times (24 - 1) = 122.5$

Other consequence factors can then be derived as described previously. If no other consequence factors are to be taken into account, the network consequences are therefore 122.5MVAh of lost capability.

APPLICATION TO RISK-BASED INVESTMENT PLANNING

The described process for the direct determination of consequences is useful for identifying investment priorities. However, the use of arbitrary factors and functions inevitably introduces the risk of systematic bias and inaccuracy. To make robust investment decisions, it is essential to calibrate and validate the results against real-world values. This can be most readily achieved by using historical information to determine the average consequences of failures within the asset group and then correcting (or normalising) the individual asset consequences to match this value.

The average consequences in category *j* of an asset failure are given by:

$$\overline{consequences}_j = \frac{total\_consequences}{N}$$

Where *N* is the number of historical events. The value of *total_consequences* should be derived from historical records. Where such information is not available, the average consequences can be obtained from published industry average figures, with the obvious caution that such figures may not accurately represent the assets being analysed.

Normalisation can then be applied to the previously determined consequences, and expressed as relative measure of criticality as follows:

$$criticality_{i,j} \quad = \quad \frac{n \cdot consequences_{i,j}}{total\_consequences_j}$$

where:

$criticality_{i,j}$ = criticality of asset *i* in category *j*

n = total number of assets

The corrected consequences in category *j* of an individual asset *i* are given by:

$$consequences\_corr_{i,j} \quad = \quad criticality_{i,j} \times \overline{consequences}_j$$

The corrected consequences can now be used to directly drive and assess asset investment decisions, with increased confidence that systematic errors have been minimised. This forms the basis of the risk-based investment planning process used by CBRM.

CONCLUSIONS

It is clear that a robust methodology for the determination of asset criticality is a pre-requisite for efficient risk-based investment planning. Nevertheless, there are relatively few published techniques for the practical determination of asset criticality, particularly when the available data is limited or incomplete. This paper has described one such approach that has been widely deployed as part of CBRM methodology.

It is hoped that the applicability of this approach to a wide range of asset types within a common risk framework will enable and encourage further development in this area. It is intended that, through the application of a suite of methodologies, it will be possible to prioritise investment across the whole spectrum of asset types, which should help to ensure the maximum benefit to be realised from all network investment.

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