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Risk assessment of interruption times affecting domestic and non-domestic electricity customers

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ABSTRACT

Legislation defined to protect domestic and non-domestic customers from long durations of interruptions includes additional requirements to system's reliability-related performance that distribution network operators (DNOs) must consider in planning the operation and maintenance process of power supply systems. DNOs are required to restore the supply to interrupted customers that fall into "unprotected" customer class within a given period of time, otherwise penalties are applied. In order to meet these requirements, comprehensive strategies must be defined based on upfront analyses. Accordingly, this paper proposes a deterministic algorithm for estimating DNOs' risk of experiencing interruptions with durations above imposed targets. Besides the Regulator-defined legislation, security of supply requirements are engaged in the development of the proposed methodology. Failure analysis of network components is used to identify interrupted customers that are grouped into power demand classes such that the duration of interruptions can be addressed following the security of supply requirements. Moreover, the penalty times defined by the Energy Regulator are engaged in the analysis and used as thresholds to quantify the penalty risk that DNOs are exposed to.

The proposed methodology is applied to a typical UK distribution system, whose average reliability performance is also considered in the analysis.

1. Introduction

Reliability performance of power supply systems is nowadays a major priority for distribution network operators (DNOs). Energy Regulators impose annual reliability and continuity of supply targets for the frequency and duration of customer interruptions and, accordingly, penalties or rewards are applied to each DNO based on the achieved performance.

In the UK, DNOs' annual reports submitted to Regulator (The Office of Gas and Electricity Markets, Ofgem) must contain a set of reliability indicators which reflect the network performance. Three system-related metrics [1], namely customer interruption (CI), customer minutes lost (CML) and short interruption (SI), are used to quantify the frequency and duration of long and short interruptions occurred within the supply system. Even though all three metrics are reported to Regulator, targets are only imposed for the CI and CML indices.

In order to avoid penalties for poor reliability performance, DNOs must carefully plan the operation and maintenance process of the power supply systems they manage. However, statistics show that this is not an easy task as 14% of the UK DNOs have recently been penalised for not achieving the targets set up for the CI index, while 50% of the DNOs exceeded the limits imposed for CML [2].

Besides the targets for CI and CML, DNOs must also obey additional requirements related to the duration of long interruptions for customers that are not protected by special contracts/agreements (i.e. residential). This means that for those customers that correspond to unprotected category, DNOs are obliged to restore the supply within a given period of time otherwise penalties are applied [3]. No rewards are however applied in this case and penalties are paid directly to affected customers and not to Regulator.

An efficient planning strategy, which may lead to reported reliability indices below the targets and avoid unprotected customer-related penalties, requires accurate upfront analyses of system's reliability performance. Monte Carlo simulation (MCS) is an effective method that has widely been used in such surveys [4–22]. Detailed network modelling and statistics of failure rates and repair times for all network components are inputs for the MCS technique. The network model and failure rates are used to assess the frequency of the customers interrupted by failure/faults occurred within the system. Moreover, the duration of long interruptions is obtained based on the mean time to repair (MTTR) values of faulted network components, whereas the times corresponding to the protection settings are used to calculate the duration of short interruptions. Once the frequency and duration

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of interruptions are achieved, the reliability indices can further be calculated and different planning strategies can be adopted.

This paper proposes a straightforward methodology for assessing the reliability performance response of power supply systems to targets which are imposed by Regulator to protect domestic and non-domestic customers from extremely long durations of interruptions. For that purpose, a comprehensive database with failure rates and repair times reported for network components operating in the UK, corresponding protection schemes, UK security of supply requirements and Regulator-related legislation are engaged in the reliability analysis.

The risk of having interruptions above the targets is one of the main outputs of the proposed methodology.

2. Security of supply requirements and legislation for customer interruption process

2.1. Security of supply requirements

Power supply systems are designed to meet security of supply requirements during events which lead to interruptions of customer supply. After an interruption, the supply to electricity customers has to be restored within a specified period of time. Therefore time limits are defined as maximum durations required by security of supply legislation to restore at least a minimum group of customers. Considering the design process, the network configuration, protection schemes and repair process of faulted network components are the main features which decide the duration of interruptions.

Classes of supply are defined in [23] based on group demand ranges, for which the duration of interruptions is imposed so that the minimum demand can be met. An example of how customers' supply is restored within different periods of time is presented in Table 1.

Six classes of supply (A to F) are defined on group demand (GD) ranges for which the maximum durations of interruptions and minimum demand that has to be met are specified. For example, if a group of customers with the power demand between 1 MW and 12 MW is interrupted, the supply must be restored to most of the customers in three hours' time. For the remaining interrupted customers within that group, the power supply can be restored in accordance with the duration necessary to repair the faulted component which affected the customers (i.e. in repair time/MTTR).

2.2. Legislation for DNOs supplying customers without interruptions-related contracts

The UK Regulator specifies additional requirements for the duration of customer interruptions in order to protect domestic/residential and non-domestic customers from excessively long interruption events. These requirements are introduced to protect those categories of customers that have no special contracts or agreements with DNOs regarding the duration of interruptions. The Electricity Standard of Performance Regulations [3] is the main UK statutory instrument which indicates the maximum admissible durations of interruptions for up to 5000 customers and more than 5000 customers. Table 2 presents these interruption time limits together with the corresponding penalties DNOs will pay directly to the customers (not to the Regulator), if supply is not restored within the specified period of time.

Table 1
UK security of supply requirements for interrupted customers [23].

Class of supply	Range of group demand (GD)	Minimum demands to be met after first circuit outage
A	GD $\leqslant$ 1 MW	In repair time: GD
B	1 MW < GD $\leqslant$ 12 MW	(a) Within 3 h: GD-1 MW (b) In repair time: GD
C	12 MW < GD $\leqslant$ 60 MW	(a) Within 15 min: min{GD-12 MW; 2/3 GD} (b) Within 3 h: GD
D	60 MW < GD $\leqslant$ 300 MW	(a) Immediately: GD-up to 20 MW (b) Within 3 h: GD
E	300 MW < GD $\leqslant$ 1500 MW	Immediately: GD
F	GD > 1500 MW	According to transmission license security standard

3. Reliability analysis

Analytical methods and simulation techniques can be employed to assess the reliability performance of power supply systems [9]. Analytical methods use mathematical models, which represent the analysed system in probability calculations of different states of the system and provide numerical solutions for reliability metrics. The outputs of the analytical methods are restricted to mean values and standard deviations, whereas the simulation procedures provide additional output results in the form of probability distributions of considered reliability parameters.

Inverse Transform method, also known as Monte Carlo simulation [10,24–27], is adopted in this paper to address the interruption process of electricity customers. The first step of the MCS procedure is to identify physical parts of the analysed system and collect information on their electrical and mechanical parameters necessary for reliability analysis. Then, a comprehensive database with failure/fault rates and mean repair times for all network components within the system should be created as in Table 3.

A random generator is used to assign random variables to an inverse distribution function in order to convert the failure rates and repair times into system states based on the operating and failure stages of individual network component. The operating and failure states of the system are determined from the corresponding component failure rates, whereas the repair times provide the duration of the failure states of the system.

In this paper, the standard assumption that the initial conditions of component failure rates and repair times are exponentially distributed is considered, although other distributions such as Gamma, Weibull or Rayleigh can also be adopted [10]. The outputs of the reliability assessment procedure are expressed as frequency and duration of short and long interruptions, which can be further used to calculate the reliability indices that DNOs report to Regulator. The main steps of the MCS procedure are summarised in Fig. 1.

4. Deterministic algorithm for customer interruption risk assessment

DNOs' risk of being penalised due to durations of interruptions above the threshold of 18 h for up to 5000 customers and 24 h for more than 5000 customers has also consequences on the CML targets that DNOs must meet annually for the overall system reliability performance. This means that if the duration of interruptions is reduced for individual groups of customers in accordance with the thresholds given in Table 2, the system-related index CML will be decreased and thus the targets for the latter are more likely to be met.

This paper proposes a deterministic algorithm for estimating DNOs' risk of being penalised when the time requirements specified for domestic and non-domestic customers are considered as