Young Researcher Symposium IEEE Benelux Chapter IAS/PES/PESC,
April 24 – 25, 2014, Ghent, Belgium

METHODOLOGY TO DETERMINE THE PERFORMANCE INDICATORS OF ELECTRICAL GRIDS THAT USE BACKUP ELEMENTS

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Abstract. This paper describes a methodology to calculate the performance indices of any electrical grid composed of usual elements (buses, transformers, lines or cables, switches, etc.) and back-up elements. The methodology proposed is aimed to be implemented in computer software, hence, the method makes use of graph theory algorithms to analyse the topology of the input grid and the Monte Carlo method to converge to a solution.

Keywords: Backup, Graph, Grid, Monte Carlo, Reliability.

INTRODUCTION

The reliability problem in electrical grids is a special case of systems reliability. Usually it is not practical to obtain the failure rate of an electrical grid, but to determine the inconvenience of the failures occurred in it, therefore the grid performance indicators are used instead of using reliability factors or mean times to failure.

The method presented here addresses the problem of the improvement of the supply quality in radial or meshed grids by including back-up elements such as batteries or generators.

ASUMPTIONS

1) It is considered a fixed simulation time, usually a very long one, for instance 20 years.
2) As input there is an un-weighted graph (G) which nodes represent the components of the electrical grid that are being considered.
3) Some element might be omitted if they are considered to have full reliability for the study time. This is because in the simulations the elements are grouped into subsystems of elements in series and in parallel (supply paths).
4) The edges of the graph G represent the element-element connections, therefore an edge is not a cable; cables are also nodes.
5) Each element is characterized with a statistical distribution of its failure and recovery times.
6) Each element is characterized with functions that describe their operation cost and their repair or replacement cost.
7) There is a list of generators, and a list of load elements, both are input parameters.
8) Some elements are considered generators and some elements are considered loads, but no element is considered generator and load.
9) The elements considered as back-up are included in the group of generators.
10) Elements like external connections are also considered in the generators group.
11) The elements considered as loads are also characterized by a demand.
12) The back-up elements are considered to have full reliability in the time span where they are used.
13) The losses of the back-up are not considered.
14) There is a penalty value for the energy not delivered. E.g.: 10 €/kWh of non-delivered energy.

THE METHOD

Given a graph where each node is an object that represents a grid element, the list of nodes that are generators and the list of nodes that are loads, the following steps are performed:

1) Obtaining of the supply paths.
2) Simulation of all the elements.
3) Evaluation of the supply paths subjected to the simulation values of the elements that compose the path.
4) Application of the back-up correction.
5) Obtaining of the system performance indicators, adding them to the Monte Carlo average.
6) Repeat steps 2, 3, 4 and 5 until certain level of convergence or certain number of iterations.

THE SUPPLY PATH

A supply path is the series of elements that link a generator and a load (both included). The supply paths needs to be Hamiltonian, this means that the supply paths cannot contain loops. The Hamiltonian paths [1] of a graph can be obtained by using the Breadth-first Search algorithm.

For those readers new to grid reliability, this step is the link between the grid reliability analysis and the mechanical, chemical or nuclear reliability analysis because each supply path is a system that will be simulated independently.

For each pair generator-load, the path logical equation is a set of elements arranged in series (using the AND operator). The set of equations linking several generators with a load are arranged in parallel (using the OR operator).

This will lead in a very long logical equation that includes all the possible ways of getting from a generator to a certain load. There are as many of these equations as loads in the graph.

THE SIMULATION

For the evaluation of the components in the study time span, it could be used an array of n positions determined by the time and the resolution, but since most of the array values would be repeated it is much more efficient to consider those points where an element changes from being operative to being inoperative. This is called event simulation [2], and it is what it has been used for the implementation.

Said this, for every Monte Carlo step, all the components are simulated individually, then, all the logical equations of the supply paths are evaluated for all the events of the elements that compose the path, obtaining the up and down time for every load and thus the unsatisfied demand and the operation and repair/recovery costs considered for the elements (some elements will be present in several paths, so their cost shall be computed only once).

Once all the paths have been evaluated for a certain Monte Carlo step, the grid indicators are calculated and added to the Monte Carlo method average together with the cost, proceeding then to repeat the simulation process for the next Monte Carlo step.

At the end of the Monte Carlo process, the values will have converged providing the most likely values for the indicators and costs.

THE BACK-UP ELEMENTS CORRECTION

As said in the assumptions, all the elements have statistical distributions modelling their behaviour, and the back-up elements are no exception. When all the elements are being simulated the back-up elements are given a list of events with zero failures. Once the path where they belong has been evaluated obtaining the failure and recovery events list, the backup elements will shorten or remove the failure times based on their power and capacity definition. See Figure 1.

The back-up elements can be marked as generators if they are meant to be used in the whole grid, otherwise their effect will be limited to the supply path where they belong; this is up to the modeller. Both possibilities behaviour are shown in the [Example of Supply path obtention].

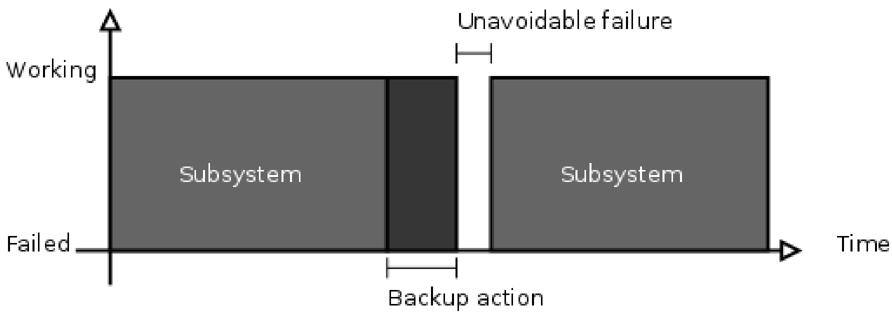

Figure 1: Backup correction of the simulated failure.

EXAMPLE OF SUPPLY PATH OBTENTION

Consider the example grid showed in the Figure 2. For this example the supply paths are being obtained explaining how the back-up elements are modelled.

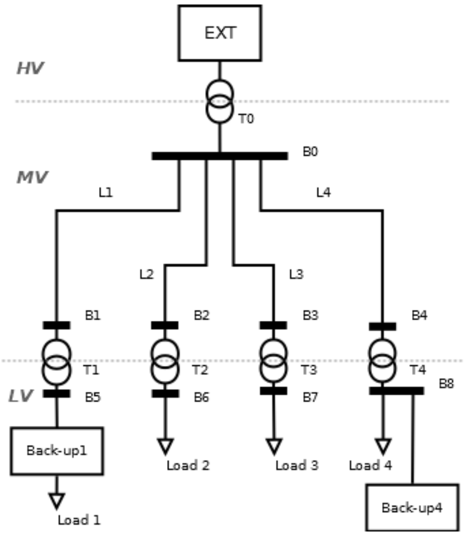

Figure 2: Example grid.

Load list: Load1, Load2, Load3, and Load4.
Sources list: EXT, Back-up4

The supply paths of this sample grid are:

1) (EXT AND T0 AND B0 AND L1 AND B1 AND T1 AND B5 AND Back-up1 AND Load1) OR (Back-up4 AND B8 AND T4 AND B4 AND L4 AND B0 AND L1 AND B1 AND T1 AND B5 AND Back-up1 AND Load1)
2) (EXT AND T0 AND B0 AND L2 AND B2 AND T2 AND B6 AND Load2) OR (Back-up4 AND B8 AND T4 AND B4 AND L4 AND B0 AND L2 AND B2 AND T2 AND B6 AND Load2)
3) (EXT AND T0 AND B0 AND L3 AND B3 AND T3 AND B7 AND Load3) OR (Back-up4 AND B8 AND T4 AND B4 AND L4 AND B0 AND L3 AND B3 AND T3 AND B7 AND Load3)
4) (EXT AND T0 AND B0 AND L4 AND B4 AND T4 AND B8 AND Load4) OR (Back-up4 AND B8 AND T4 AND B4 AND L4 AND B0 AND L4 AND B4 AND T4 AND B8 AND Load4)

STUDY CASE: BACK-UP VS. NO BACK-UP.

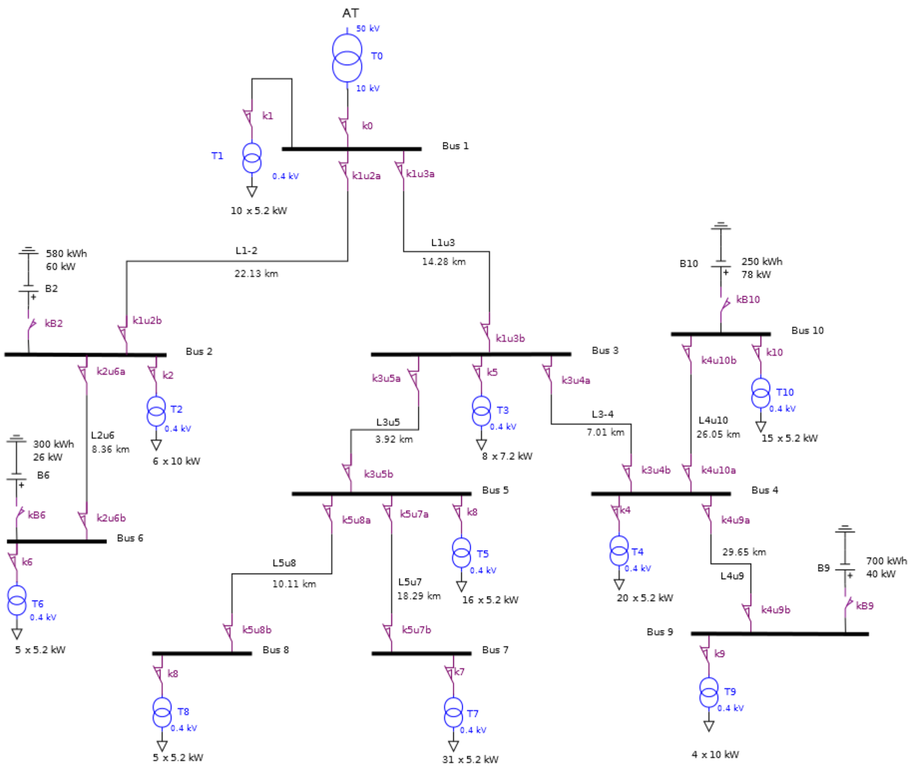

Figure 3: 10 bus grid of the practical case.

The grid of the Figure 3 include four back-up elements (Batteries) in the buses which load present a bigger amount of unsupplied power for the case of using no back-up.

The simulation results of this grid are going to be compared with the simulation results of the same grid but without any back-up element. Unfortunately, giving the whole grid definition would take more paged than the allowed in this paper, and the value of giving such definition data is limited.

The study time is 20 years, and the penalty cost is considered constant and equal to 10 €.

Energy not supplied (ENS)	Grid with back-up [kWh]	Grid without back-up [kWh]
Load 1	0	24.5
Load 2	0	3,113.9
Load 3	0	66.8
Load 4	25.9	93.3
Load 5	128.6	95.4
Load 6	0	1,633.4
Load 7	1,272.0	118.6
Load 8	31.4	170.4
Load 9	0	3,184.0
Load 10	0	1,760.6
Total	**1457.9**	**10260.9**

Table 1: Stochastic results for a 2000 iteration Monte Carlo simulation

	Without Back-up	With Back-up
ENS [kWh]	10260.9	1457.9
Penalty €	102609	14579
Relative investment €	0	2745000
module of the penalty-relative investment vector	102609	2745038.72
SAIFI (Interruptions/Customer)	0.9999	0.9995
SAIDI (Interruption h/Customer)	0.0744	11.4742
CAIDI (h Interrupted to customers/Interruption)	1.5558	94.9734
ASAI	0.9999	0.9999
ASUI	4.25E-07	6.55E-05

Table 2: Comparative table between the two grids (with and without back-up)

The inclusion of backup in the critical spots of the grid reduces the penalty around a 700% but the cost of doing it is prohibitive (considering the use of three sets of batteries during the 20 year period).

CONCLUSIONS

This kind of reliability studies are not complete unless they are coupled to a grid load flow simulation that reveals a more accurate picture of the not supplied loads and the loses, however, this is a good average approximation of what the values are.

This model was developed for the comparison of several scenarios, and to show the weaknesses or strengths of several storage locations and strategies.

The method relies in two general purpose algorithms like the Breadth-first search and the Monte Carlo method, both are well known and examples of them can be easily found in the internet.

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