# MODELING OF SIMULTANEOUS FAULT TO RELIABILITY ENHANCEMENT IN DISTRIBUTION SYSTEM

Nemat DEHGHANI
Tampere University of Technology (TUT)
Finland
nemat.dehghani@student.tut.fi

Antti SUPPONEN
TUT- Finland
antti.supponen@tut.fi

Sami REPO
TUT- Finland
sami.repo@tut.fi

## *ABSTRACT*

*The main purpose of an electric power system is to provide electricity from the generation source to the customer point. Security and adequacy are the two most important requirements in power system reliability. As most of the faults that happen in a distribution network are experienced by the customers, improving the security of the distribution side can have a beneficial effect on the entire network. Faults can occur singly, but multiple faults can occur at the same time in many different places in the network. It is these simultaneous faults that can drastically affect the security of a network, and directly decrease its reliability. This paper studied the modelling of simultaneous faults by using the Monte-Carlo (MC) algorithm in a distribution network. This makes it possible to evaluate the effect of the repair time in different situations, and also to model various solutions to enhance the reliability of the network. A real overhead line feeder in a distribution network from a rural electricity distribution company was chosen for modelling the MC algorithm and to study the reliability procedures based on it. The calculations in our simulation model are based on number of the faults and the availability of maintenance and repair crews in the case of simultaneous faults. The algorithm can also be used for calculating the reliability indices in radial and mesh configurations with radially operated feeders.*

## INTRODUCTION

The societies are getting large to compare the past and in same time they are going to be more dependent on electricity. The main task in power system is to supply customers continuously. Electrical companies want to improve the quality and reliability of their system to gain more economical benefit from customers. The financial and regulatory effects of loss of electric service have significant influence on both the utility supplying electric energy and the end users. Just a major outage or blackout in one area can cost millions of euros. Therefore, designing a reliable power supply is a very important issue for power systems long term planning and operation. Modeling the major storm and simultaneous faults is the object of this analyze. Simultaneous faults are modeled by using Monte Carlo simulation (MCS) to analyze the effect on reliability of system.

## SIMULATION MODEL

An actual overhead medium voltage (MV) feeder in a distribution network from a rural distribution company has chosen to use for modeling and study reliability process. Feeder contains 258 buses with total number of 1304 customers including single-family houses, residential building, companies, farms, industry, business, private service, transport and public place. Figure 1 shows the selected total overhead feeder model. The topology of network model is meshed by radially operated. The black point in bus 245 is a switch which works in normal open position and the red points are backup connections possibility. The feeder includes 35 manually controlled switches and 6 remotely controllable switches. Also the fault rate of each section of the network is provided by using a typical fault rate for an overhead line (per 100 km) in Finland [1]. In all 103.42 km length of feeder local geographic coordinate's system and environment information (field, beside a road or forest) of the overhead line is used to get more accurate result.

The next step is to calculate fault rate based on actual distance and also environmental condition. The location of the line directly affects the fault rate in the overhead line. Usually overhead lines are located in three different areas forest, field or roadside with different fault rate which are presented in Table 1.

Repairing time is the time that customer will be out of the service from the moment of fault happens until the situation is back to normal condition, that means reconnecting to the network. However, repairing time is the time that customers are disconnected. Generally different functions affect it like the availability of a repair group, distance to the nearest repair group and climate situation. This is true for those customers which are located within the outage area.

Manual or automatic fault location, isolation and supply restoration may reduce the outage area and duration of customer behind the permanent fault. Switching time plays an important role in decreasing outage time. Two types of switches are remote controlled with switching time of 0.1 hour and manual switch with switching time of one hour. Re-closer also could be good option to increase reliability in a distribution network [2].

***Table 1** Fault rate based on location [3,4,5]*

| Type of Conductor | Forest | Field | Road side |
|---|---|---|---|
| **Overhead (100km)** | 7 | 2.3 | 1 |
| **Underground(100km)** | 0.79 | 0.78 | 0.82 |

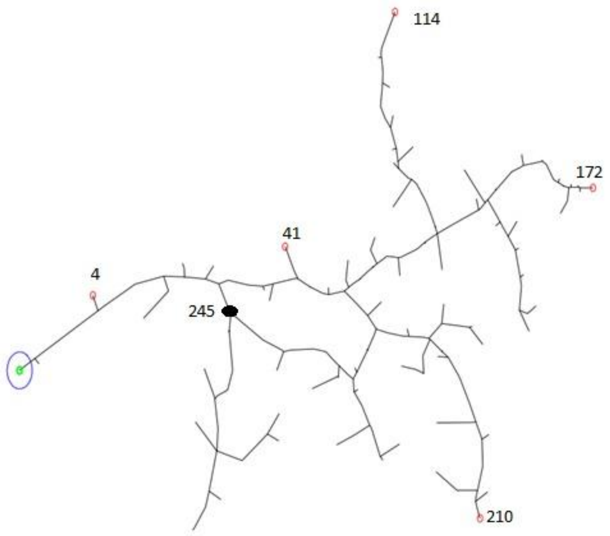


***Figure 1** The selected feeder model from rural company*

## MONTE CARLO SIMULATION (MCS)

Monte Carlo methods are a broad class of computational algorithms that are based on repeated random sampling to gain numerical results. For example by running simulations many times in order to calculate those same probabilities. They are often used on physical and mathematical problems and most are suitable to be applied when it is impossible to obtain a closed-form appearance to apply on deterministic algorithm. MC methods are mainly used in three distinct problems: optimization, numerical integration and generation of samples from a probability distribution. In this case MCS has been applied to generate the fault rate of each node induration of one year and also the required independent repair time for each fault. [6]

## SIMULTANEOUS FAULTS

A number of techniques have been published for fault analyses, but the effects of simultaneous faults have been neglected. It is required that the simultaneous faults are taken into account in the overhead distribution network planning [7] due to tightening reliability requirements of regulators. For example in Finland the maximum outage duration should not exceed 6 h in urban areas and 36 h in rural areas by the end of 2028 [8].
Modeling the simultaneous faults has same procedure when to compare other fault modes. Each part of network has own fault rate that is independent, Table 1. The study of faults in unusual situations like major storms require large amount of statistical data from technical and environment sources, like the type of line, number of customers, fault rate, and geographical date of the location that feeder installed.
Weibull distribution, which has enough flexibility to fit and model the statistical data, has been used to model fault rates. To define the simultaneous faults in each healthy section has same possibility to fail in fault situations at same time as a faulty section. As the fault rates of feeder sections are different the result also will be different and it is depend on the fault location.

### Repairing time

Many functions have effect on repairing time in simultaneous situations. When there is just one fault in the system it is clear to decide what is the right decision to correct it and also reconnecting the customers to the system.
The availability of a repair group has also direct effect on repairing time. When two or more repair groups are available two separate faults will be repaired and reconnected at same time. With limited repair group resources prioritization of faults needs to be done. The highest priority can be nearest fault to repair group, the most important customer, the fault that has less damage and it requires less work to clear it or the fault that may reconnect many customers when repaired. Transport from one fault to other fault may also be counted as repairing time for the second fault and the others.
Monte-Carlo Simulation (MCS) is used to model the repairing time but repairing time is not independent and each fault is affected by the last fault and also can effect on next fault. Generally the repairing time increases based on faults distance and number of simultaneous faults. Standard deviation of repairing time is affected by severity of damage at fault locations (e.g. a tree touching a wire, broken wire or totally damaged line section), weather conditions (e.g. how much there are snow in the fault location), environmental conditions (e.g. how long distance from a nearest road to fault location), etc.

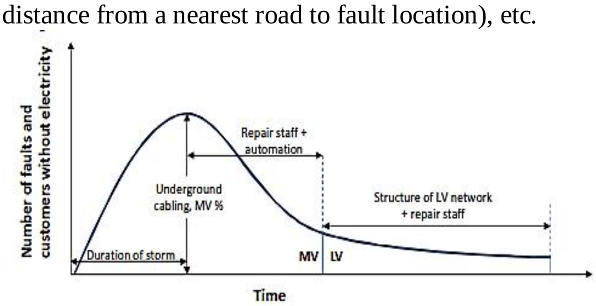


***Figure 2** The situation of customers in MV and LV during the storm and repair time [9]*

Figure 2 shows the aspects that effect on outage time in the major storm situation. The number of faults and customers without electricity is largest during the storm and the very first repairing processes in MV network. The underground cabling rate in MV network has the largest impact on the maximum number of simultaneous faults and customers without electricity. The duration of MV network repairing process is affected by the availability of repair groups and distribution automation. Distribution automation reduces the switching time significantly because unusually high number of switching actions is needed. [9]

### Probability of storms

Most of simultaneous faults happen due to a storm condition but the probability of a storm is low during the one year study. By increasing the simulation duration the possibility of a storm condition is increased during the simulation. Storms are divided in three classifications, class I, class II and class III which probability of major storm class I is each 5 years ,major storm II is each 20 years and major storm class III is each 100 years. The classification and the probability of major storms were taken from the reference [10].

## SIMULATION RESULTS

Monte Carlo simulation (MCS) is always useful for solving problems relating random variables with expected or fixed probability distributions. As the possibility of repairing time is different for each area or dependent on availability of repair personnel therefore the repairing time is also randomly and separately generated for each section based on Weibull distribution and the effect of other faults on each other in term of repairing time takes into account. Weibull distribution has capability to follow different kind of statistical situations. Based on environmental condition each line section has special fault rate which is simulated for one year. To increase the accuracy of simulation total duration of fault for one year is divided on 8760 hours.

The probability of major storm and simultaneous fault condition is not high and the only way to simulate the situation is to increase the duration of study for several years to find a clear view for long term planning of network. In this study the MCS continued for duration of 10, 100, 1000 and 10000 years and the reliability indices and behavior of network compared among simulation periods. To provide the probability density function (PDF), the cumulative form of data should fit in the static data. The merit of PDF is an opportunity to define the probability of reliability indices.

### Distributions of reliability indices

Figure 3 includes the outputs of MCSs (SAIFI) with different number of sequences. The SAIFI has a normal distribution and the required number of sequences is at least 10000. By increasing the number of sequence more than 10000 times the simulation time also will be increased but the final result is quiet same as 10000 sequences. Each sequence represents one year of study and the result for each year is independent. The Table 2 represents the value of reliability indices for probability of 95 %. From this table can be found that by probability of 95 % the value of SAIFI will not exceed from 3.6515. This condition is the same for lowest value of system indices. The red circle in Figure 3 shows that when the number of sequences is 10 which means by less probability, the value of SAIFI is high. It is one of the interesting parts of analyzing SAIFI for modeled network in simultaneous faults condition. As it is clear in the Figure 3 fewer faults has more effect on reliability index of modeled network and the problem could be from the configuration of network.

The distributions of SAIDI and CAIDI are represented in Figures 4 and 5. The value of SAIDI and CAIDI will never exceed from highest and lowest values during the simulation which are represented in Table 2, Figure 4 and 5. For example the minimum value of SAIDI never goes lower than 0.2452 h during the 10000 sequences and the value of CAIDI is same or less than 0.0775 h by probability of 95 % during the simulation.

***Table 2** The value of indices in 95% presents probability*

| Indices | Probability | *Highest value* | *Lowest value* |
|---|---|---|---|
| *SAIFI* | *95 %* | *3.6515* | *2.7034* |
| *SAIDI(h)* | *95 %* | *0.5356* | *0.2452* |
| *CAIDI(h)* | *95 %* | *0.1678* | *0.0775* |

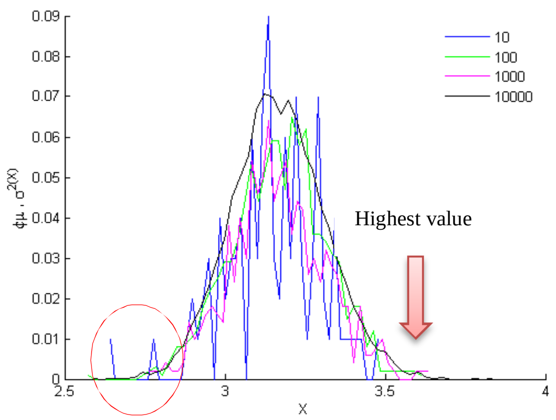


***Figure 3** SAIFI for different number of simulations*

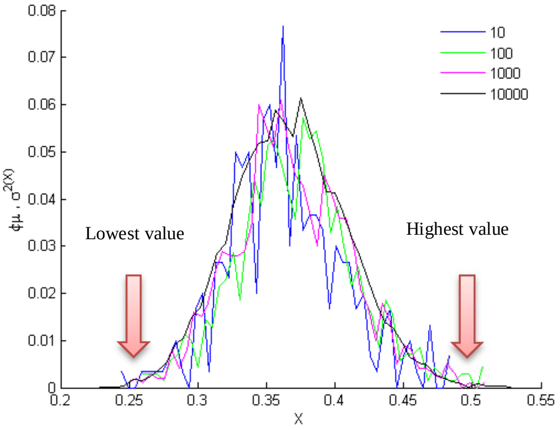


***Figure 4*** *SAIDI for different number of simulations*

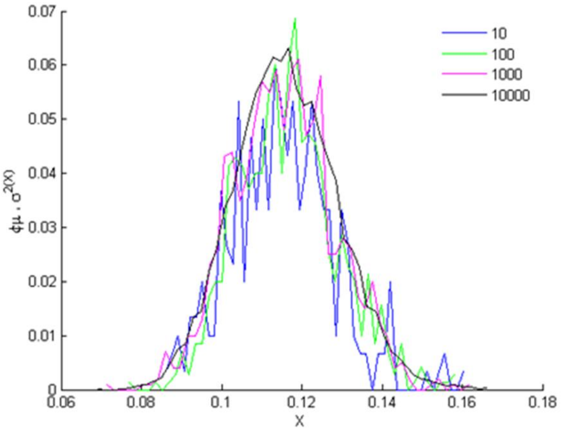


***Figure 5*** *CAIDI for different number of simulations*

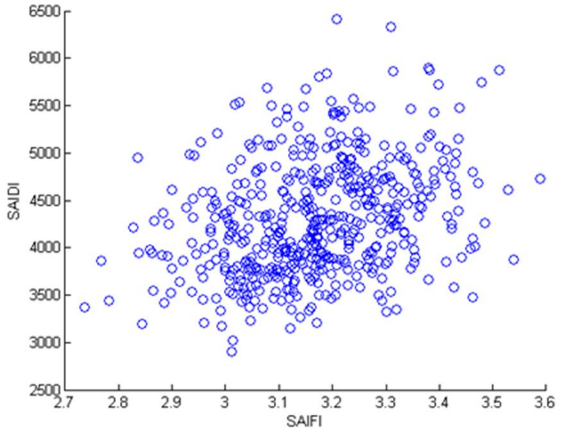


***Figure 6*** *the correlation between SAIFI and SAIDI*

Figure 6 shows the correlation between the values of SAIFI and SAIDI during the simulation. The correlation value is 0.3158 and it is obvious that there is no strict relation between fault frequency (SAIFI) and fault duration (SAIDI), which means in this network it is possible to have low fault rate but still quiet long average outage duration or vice versa that mentioned in description of Figure 3.

## Analysis of network reliability

The fault rate of each line in the modeled network has represented in different color by Figure 7. Green color shows the line sections by fault rate from zero to 1.2120 and the red color indicate the line sections by fault rate from 6.0600 to 7.2720 during the major storm; we can call the red color area the most fault prone area of network which can effect on the average outage of whole network. Based on Figure 1 nodes 114, 210 and 172 have already backup connection possibility from neighbor feeders; one suggestion could be installing remote controlled switches on the mentioned places in Figure 7 to decrease the average outage of network (SAIDI) by increasing the switching time and isolating the rest of network from fault area.

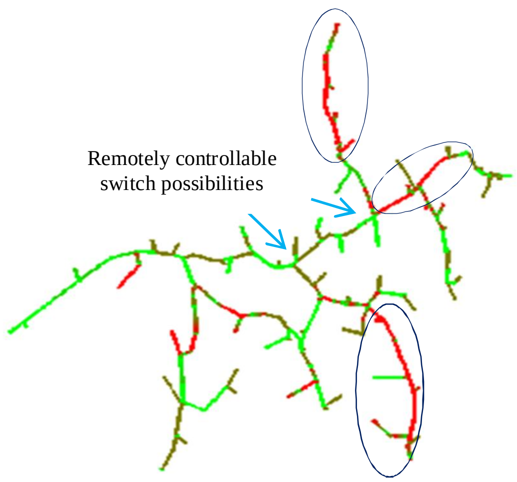


***Figure 7*** *fault frequencies of each line section*

## DISCUSSION

The MCS could be utilized in network planning by using the output of simulation for optimization and allocation study to find the best place for investing to decrease the switching time or decrease the outage time or both. The weakness (vulnerability) of power lines in the weather based condition like major storm or other unexpected condition should be count in quality and ability assessment. The main challenges are the possibility of fall tree on the line, dependency or independency of the generation, communication and shipping during unusual condition or renovation. In the smart grids topology network this dependency will be increase. This is point out by decreasing the duration of repair time or fault clearance and reconnection time [11]. The reliability of network for each company is linked to the environment condition and also network structure aspects, the most important impact factor of environment is storm weather that is intensely related to the duration of outage SAIDI [12], and therefore the major storm condition should be count for long time planning study.

## REFERENCES


[1] S. Repo, J. Antikainen, P. Verho, P. Järventausta " Network Topology Considerations When Connecting a Wind Farm into Distribution Network" Tampere University of Technology, Nordic wind power conference, NWPC'2007, 1-2 NOVEMBER 2007, Roskilde, Denmark.

[2] N.Dehghani , R.Dashti "Optimization of Re-closer Placement to Improve Reliability by Genetic Algorithm" - Energy and Power Engineering, 2011, 3, 508-512 doi:10.4236/epe.2011.34061 Published Online September 2011. www.scirp.org/journal/epe

[3] J.Antikainen, S.Repo, P.Järventausta, P.Verho "Interruption Costs Management in Distribution Network by Intentional Islanding based on Mobile Stand-by Generation Units" Nordic Electricity Distribution and Asset Management Conference, Norway 2008.

[4] J. Pylvanainen, Jouni, P. Verho, J. Jarvinen, S. Kunttu, J. Sarsama, "Advanced failure rate and distribution network reliability modelling as part of network planning software" 18th International Conference and Exhibition on Electricity Distribution, 2005. CIRED 2005.

[5] M. Lehtonen, "Fault rates of Different Types of Medium Voltage Power Lines," Nordac 2010 – Nordic Distribution and Asset Management Conference, Aalborg, Denmark 2010.

[6] R. Billinton and R.N.Allan , Reliability Evaluation of Power Systems , Plenum Press, New York, 1996

[7] C. Pothisarn and A. Ngaopitakkul "Study of Characteristics for Simultaneous Faults in Underground Distribution System" King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand, Advances in Mathematical and Computational Methods, ISSN: 2160-0635 ,Volume 1, Number 2, December, 2011

[8] http://www.finlex.fi/fi/laki/alkup/2013/20130588, available on January 2015

[9] J.Lassila , T.Kaipia , J. Haakana, J.Partanen " Emerging reliability requirements for Distribution System in extreme weather conditions " CIRED 22nd International Conference on Electricity Distribution, Stockholm, 10-13 June 2013

[10] Jyrki Landstedt , Petter Holmström ," Electric Power Systems Blackouts and the Rescue Services: the Case of Finland" Emergency Services College of Finland and State Provincial Office of Western Finland, CIVPRO Working Paper 2007:1, University of Helsinki ,Finland

[11] G.Kjolle, R. H.Kyte , M. Tapper, K.Hänninen "major storms-main causes,consequences and crisis management " CIRED 22nd International Conference on Electricity Distribution, Stockholm, 10-13 June 2013

[12] T. Mohar , L.Valencic, D.Batic "Reliability Impact factor analysis for distribution in Slovenia" CIRED 22nd International Conference on Electricity Distribution, Stockholm, 10-13 June 2013