# DISTRIBUTED GENERATION PLACEMENT IN DISTRIBUTIVE SUBSTATIONS ANALYSIS USING MARKOV CHAIN MONTE CARLO MODEL CONSIDERING RELIABILITY OF POWER SUPPLY

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**Abstract**: *Proper operation of the power substations is of great importance for power network reliability, stability and uninterrupted power supply. Distributed generation (DG) provides higher reliability in power supply, but still, there are contingencies in the electric power production and supply process, which lead to outages in power supply. In this paper, a method for substations' reliability estimation with distributed generation is presented based on Markov Chain Monte Carlo (MCMC) method. The method considers the possible substation operation states and using random number generator in MATLAB, it simulates faults and calculates the substations' reliability. The method is demonstrated on two cases of 110/35 kV substations, each consisting of two transformers and distributed generator, analysing the best placement for the distributed generation.*

**Keywords:** *Power substations, Distributed generation, Markov Chain Monte Carlo, Reliability*

## 1. Introduction

The progress of the technology initiates the development of the power systems in order enhancement of the quality of life in modern society. Therefore, the need for uninterrupted and quality power supply increases continuously. The power network reliability, i.e. the capability for normal system operation and power supply for the consumers at any time, defines one country's economic and technological development.

The implementation of distributed generation (DG) with storage system, into the distributive network, enhances the reliability of supply, providing the electrical energy needed in conditions of islanded work due to power system outages. However, the substations as part of the power system are infrastructures where the electric power is transformed from one voltage rate to another, and as such, they are objects closest to the consumers and electric power generation facilities. Therefore, the substations, as complex systems that are expected to work with high quality and reliability, have the most important role in the power supply process. The faults that occur in the substations and cause power supply interruption can affect the installed equipment and may cause equipment damages.

The distribution system is part of the power network which is the most prone to failures and disturbances due to contingency, such as equipment failures, human errors or weather-related issues. The implementation of the distributed generation improves the reliability of distribution systems, providing backup power supply during outages. Usually, the distributed generators are renewable energy sources (RES), designed to cater the power consumption to residential consumers or small communities. However, their dependency on the weather conditions aggravates their island work and therefore grid-connected distributive generators are a better solution.

The optimal DG placement requires analysis of the power network where the DG should be connected. It is necessary to know the voltage variations and the technical limits of the installed equipment (rated voltage, current and power). Also, whether the type of DG installed, the uncertainties of load variations have to be taken into considerations. If the DG is a RES generator the uncertainties

of the weather conditions should be considered.

Modelling the uncertainties can be done with many deterministic and probabilistic mathematical models. The application of Monte Carlo Simulations for quantitative analysis of uncertain input data has been proven to provide manageable results for further analysis and decision-making processes.

In this paper, an analysis for the best placement of distributed generators is made, considering the reliability of supply. The analysis is based on Markov Chain Monte Carlo (MCMC) method for reliability estimation of distribution substations with implemented distributed generator on the consumers' side. The purpose of the method is to estimate the reliability of a technical solution in the designing process. The model considers normal operation and fault states of the system caused by different states of the installed equipment, evaluating the probability of occurrence of different scenarios which lead to an interruption in power supply.

The test examples review two different technical solutions, considering equal unavailability rates of the equipment in both cases. The test example is simulated in MATLAB, using a random number generator.

## 2. Related work

The power network constantly spreads due to the growth of the communities and upgrades with new equipment following the latest technology. Finding a method that estimates the reliability of power networks and takes into account all contingencies, is a challenge. In this chapter, the literature that analyses the network reliability of complex systems with distributed generation based on Markov Chain and Monte Carlo Simulation is reviewed.

In [1], Monte Carlo Simulation technique is used for optimal DG placement. The presented approach analyses implementation of two types of DG, conventional and wind farm. The approach proposed is tested on 15-bus and 33-bus radial distribution systems. The results show the best location (bus) to connect the DG for the two of the examples. Also, the application of Monte Carlo Simulation is justified.

In [2], an integrated approach for evaluation of the impact of distributed energy resources (DERs) have on the reliability performance of power networks. The case study is a power network based on a typical urban MV and LV networks in the UK. The potential benefits of the local renewable generation, demand-manageable loads and coordinated energy storage are analysed. The time-variation of electricity demand profiles and failure rates of network components are simulated using conventional MCMC method.

In [3] low and high penetration of distributed energy generators impact on the reliability of distribution system with is investigated. The analysis is made using DGs mathematical modeling and Monte Carlo simulation methods. Also, a Monte Carlo Simulation designed specifically for the investigated cases of low and high penetration of DGs are proposed in detail.

In [4] the reliability enhancement of a distribution system with implemented distributed generation is presented. The paper reviews five different cases, by adding different components in the systems, with and without distributed generation. Also, customers are taken into account. The analysis is done by using analytical methods and the results show reliability enhancement in systems with distributed generation.

In [5] by using the MCMC method the reliability of complex power networks is calculated. The method is based on the random number generator, which generates $n$ numbers from [0, 1] and calculation of the number of variables that satisfies the certain requirement. The requirement is the variables to be smaller or equal to the value of the total unavailability rate of the connected components. By generating a sufficient number of variables, the estimated value i.e. the portability of failure is calculated.

## 3. Markov Chain Monte Carlo Method

Markov Chain method describes a probability of event occurrence in a stochastic system with a random sequence. It states that

the probability of one event occurrence depends only on the previous events. These probabilities are represented in a matrix, known as transition matrix. The main disadvantage of the Markov Chain model is that the transition matrix significantly enlarges if the number of states increases. This disadvantage can be overcome by dividing the states into smaller independent matrices with smaller dimensions [6].

Monte Carlo simulation is used for different outcomes probability modelling in a process that cannot be easily forecasted due to the random values of the variables. This method is used for better understanding of the influence of risk and uncertainty in the forecast models and it is applicable in the fields of economy, engineering and science [7]. When facing uncertainty in the forecast process or estimation, instead of listing the independent variables' average values, Monte Carlo Simulations offer a better solution.

This method turned out to be inefficient in case of rare events, i.e. events that have probability smaller or equal to $10^{-5}$. Therefore, a high number of variables are needed so that the system can be analysed. Monte Carlo method is designed for solving problems with random number generation, but simultaneously for solving deterministic problems tracking the behaviour of random variables an insufficient number of samples [8].

The expected value of the random variable is estimated through a certain number of samples, instead of calculating it mathematically. The determined number of samples is the key factor in Monte Carlo Simulation since it determines precision in the estimation process. The precision can be measured through the coefficient of variation, also known as relative standard deviation. The coefficient of variation is related to the reliability indexes since it represents the degree of accuracy of the indexes estimation.

## 4. The Proposed Approach

In [4] a method based on the MCMC method for reliability evaluation of complex systems consisting of serial and parallel-connected components is presented. The method proposed in this paper is based on that method. Calculation of equivalent reliability in a system is based on the theory of series and parallel connected components.

Assuming that the unavailability rates of all components in the system are given, the first step is to calculate the equivalent unavailability of the system. That indicates the probability of system failure.

The analysed system is a complex system which consists of two parallel-connected transformers, two power lines and a distributed generator with storage system, connected to a distribution power network.

Despite the many states of the system, generally they can be divided into three main states, regarding the installed equipment in the substation and the operation state of the distributed generator:

- o State 0: The system is in an outage, there is no power supply;
- o State 1: The system runs partially, i.e. only half of the required power is supplied;
- o State 2: The system is in a normal operational state.

The application of Markov Chain model on this problem results with a complex solution. However, the solution to the problem can be simplified by performing a Monte Carlo Simulation on the analysed substations. The MCMC method is easily applicable to complex systems, since it allows simulation of contingencies that might happen in the installed equipment. For that purpose, random number generators are used, which are defined functions as part of some software. In this paper, random number generator in MATLAB is used, applying rand(n) function (rand $\in$ (0,1)).

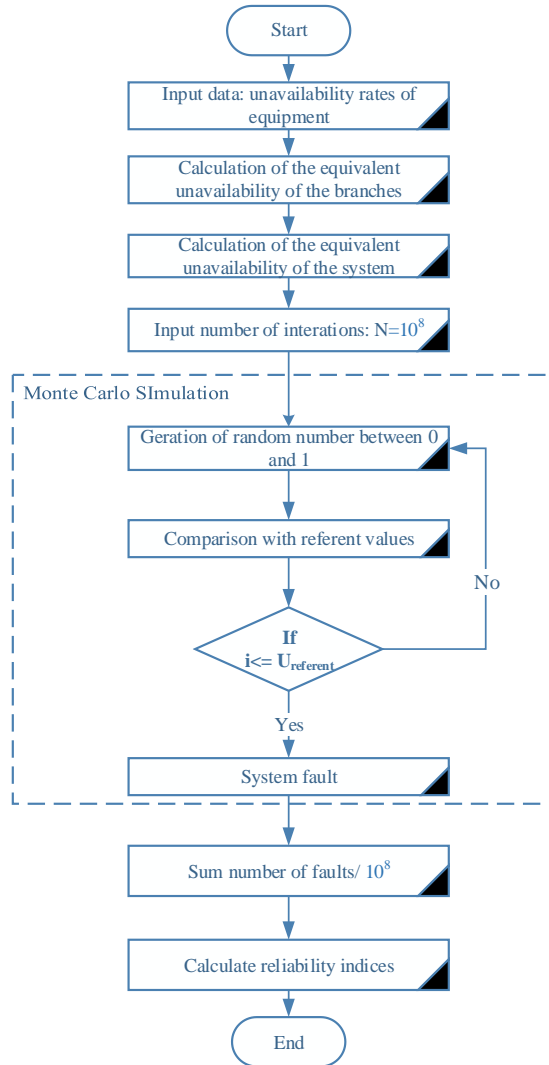The algorithm of performing the MCMC method is presented in Fig. 1.

**Fig. 1** *Simple MATLAB MCMC method algorithm for reliability estimation*

The MATLAB code consists of three parts:

- Monte Carlo Simulation part: the random number generator,
- Markov Chain part: calculation of partial and total system outage, determining the fixed values that the random numbers are compared to, and,
- Comparison part: determining whether the random number can be analysed as a fault or not.

Firstly, through the input dialogue, the unavailability rates of the components are entered. Then, the equivalent unavailability rates of the power lines and transformer branches are calculated. Finally, using a *for cycle*, the randomly generated numbers are compared with the determined values for faults. This way, the number of partial and total outages is calculated. In the end, the values for the partial and the total number of outages are divided with the total number of randomly generated numbers, which represents the probability of one event occurrence.

## 5. Case study

The case analysis reviewes two different substation configurations with connected distributed generation.

The first substation configurations reviewed consists of distributed generator connected on the high voltage bus bar. In case of supply interruption due to an outage in the power lines or in one of the transformer branches, part of the load can be supplied by the distributed generator. The single line diagram of the described power system is shown in **Fig. 2**.
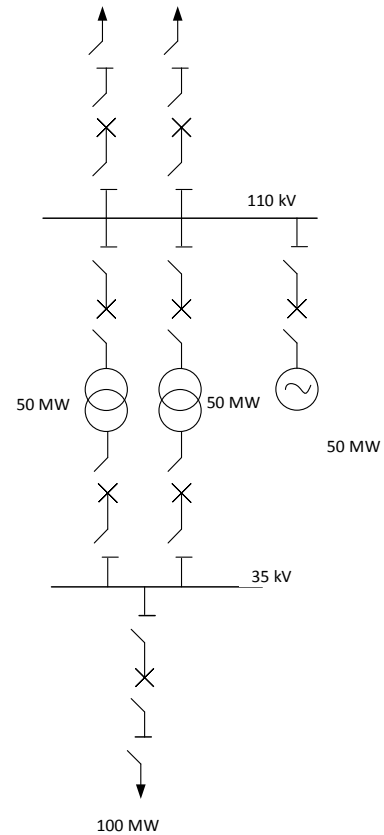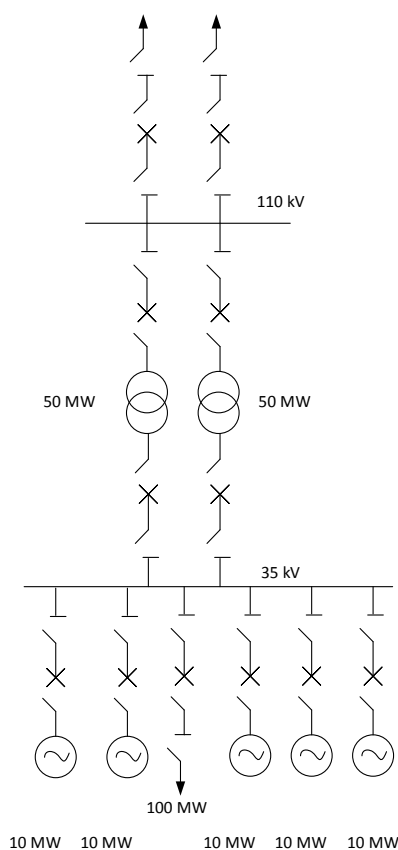


**Fig. 2** *DG connected on the 110 kV bus*

Distributed generator represents a large renewable energy source power plant (wind farm, solar power plant, biogass power plant or hydro power plant).

The second substation configuration reviewed consists of multiple smaller distributed generators connected on the low voltage bus. The installed power capacity of each of the generators equals to the installed power capacity of the single distributed generator in the first test example.

In this case, distributed generators provide backup power in case of outage of the both, power lines and transformer branches, at the same time, providing island work and power supply of the consumers. The single line diagram of the described system is shown in Fig. *3*.



***Fig. 3** DGs connected on the 35 kV bus*

It is assumed that the rating power of each of the transformers in the test examples in both

of the substation configurations, is 50 MW, and the power of the distributed generator is also 50 MW. The unavailability rates of the components are given in Table 1. The generator's unavailability rate includes the unavailability of the generators as units and it also takes into account the dependency of the weather conditions.

***Table 1.** Unavailability rates of the equipment*

| Components | Voltage rate | Symbol | Unavailability rates |
|---|---|---|---|
| Earth Switch | 110 kV | $u_{ES}$ | 0.00004 |
| Disconnector | 110 kV | $u_{D,110}$ | 0.00025 |
| Circuit breaker | 110 kV | $u_{CB,110}$ | 0.00038 |
| Bus 110 kV | 110 kV | $u_{bus,110}$ | 0.00007 |
| Power transformer | 110/35 kV/kV | $u_{TR}$ | 0.0006 |
| Circuit breaker | 35 kV | $u_{CB,35}$ | 0.00024 |
| Disconnector | 35 kV | $u_{D,35}$ | 0.0004 |
| Bus | 35 kV | $u_{bus,35}$ | 0.00001 |
| Generator | 35 kV | $u_{gen}$ | 0.03 |

The probabilities of each situation, for different substation configurations, are given in Table 2.

The calculated probabilities of system's different states' occurrence are used to compute the Energy Not Supplied (ENS), which is a power network reliability parameter. The ENS in the analysed substation configurations is given in Table 3.

***Table 2.** Probabilities of normal operation state and outage for different DG configurations*

| System | | Operation state | Partial operation state | Total outage |
|---|---|---|---|---|
| **DG on 110 kV** | *p* | 0.99743 | 0.00175 | 0.00082 |
| | $\frac{h}{year}$ | 8737.40 | 15.35 | 7.17 |
| **DG on 35 kV** | *p* | 0.99911 | 0.00015 | 0.00074 |
| | $\frac{h}{year}$ | 8752.16 | 1.35 | 6.48 |
| **No DG** | *p* | 0.99654 | 0.00264 | 0.00082 |

| | | | |
|---|---|---|---|
| $\dfrac{h}{year}$ | 8729.69 | 23.14 | 7.18 |

*Table 3. Energy Not Supplied for different DG configurations*

| System | ENS (MWh/year) |
|---|---|
| **No DG** | 3030.96 |
| **DG on 110 kV bus** | 2251.32 |
| **DG on 35 kV bus** | 779.64 |

## 6. Conclusion

In this paper, the Markov Chain Monte Carlo method was used for reliability evaluation of distribution 110/35 kV/kV substation with distributed generation. The method is based on the MCMC method, and a simulation of fault occurrence in the presented system was made in MATLAB.

The analysis reviewed two cases of implemented distributed energy generators. The results show that the implementation of distributed generation enhances the reliability in the power networks, especially in the distributive systems with local consumers.

However, there is a slight difference in the calculated reliability of such system. Results show that DG implemented on the low voltage bus provides higher reliability, meaning more operational hours. Besides that, the improvement of power network reliability decreases the penalty costs for ENS.

The MCMC method is applicable for power systems reliability estimation and it provides fast computation and more accurate results compared to the analytical methods. This enables easy calculation of reliability indices, including ENS, and evaluation of integration of such systems.

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