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Reliability Analyses of Electrical Distribution System: A Case Study

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Abstract:- In electrical power system, the reliability is defined as the ability to provide uninterrupted electricity to customer, and the reliability of any system is usually evaluated on the average customer interruption indices. These indices provide customer risk dimension. Accordingly, this paper presents the result of reliability indices obtained by analytically for the Nigde Region's electricity systems. An approach based on the Monte Carlo (MC) simulation method is also utilized to estimate the performance indices for the systems. The system reliability is evaluated for system's feeders and their load points. Firstly, reliability indices such as the SAIFI and SAIDI are determined, analytically, by using one year of outage information gathered from the distribution Company, and the MC simulation based approach is then applied. Results obtained by two approaches are presented and the reliability of system' feeders are discussed.

Keywords:- Electrical distribution system, Monte Carlo simulation method, Reliability analysis, Reliability indices.

I. INTRODUCTION

Any of the components, devices or systems, which are intended to perform specific functions, and which exist today, have reliability as an inherent property. Reliability in power systems is associated with the ability to provide customers with electric power in static-dynamic situations; and this providence must be performed in a continuous and qualified manner for both parties, i.e. the provider and the customer. When we consider the concept of "System reliability", it is possible to separate it into two main sub-concepts as "system adequacy" and "system security". In "system adequacy", adequate facilities are kept at hand in the system to cover the demands of the customers or to meet the system requirements. Under this sub-title, there are the facilities that are needed to produce adequate energy, and the facilities that are needed to transfer and distribute the electric power to the end-users. In this context, the term "adequacy" is related to static conditions, and there are no system disturbances in this system. "System security" refers to the ability in responding to possible disturbances that may occur within the system. For this reason, security is related to the system response in any disturbances. Under this umbrella term, there are the situations that are related to local disturbances or general disturbances, and even to loss of profound amounts of power-generation and distribution facilities [1].

Analytical methods used to calculate reliability in distribution systems are useful in assessing system security or adequacy and usually based on average customer interruption indices called reliability indices. The parameters of system components and load characteristics are used in computing the abovementioned indices. The load properties depend on statistical values, and these values are obtained from the experiences in the past in normal conditions. The remaining components of the system parameters come from the data on historical failures and repairs [2]. Reliability indices are categorized as the load point indices of the mean value of the failure rates (l), the mean value of the outage time (r), the mean value of the annual unavailability (U). The system reliability indices are categorized as;

- System Average Interruption Frequency Index (SAIFI)
- System Average Interruption Duration Index (SAIDI)
- Customer Average Interruption Duration Index (CAIDI)
- Average Service Availability Index (ASAI)
- Average Service Unavailability Index (ASUI)
- Energy Not Supplied (ENS)
- Average Energy Not Supplied (AENS)

There are a variety of reliability studies, in the literature, in which Basic Failure Models and the analytical approach are used to measure the reliability of the systems [3-8]. Additionally, the reliability indices in question have been utilized by some commissions for the purpose of determining the service quality and sometimes to influence the rate-making decisions [9-12].

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The Monte Carlo (MC) methods give us approximate solutions of mathematical problems and do this through statistical sampling experiments. These methods may be defined in general terms as the statistical simulation methods. In this definition, the statistical simulation is assumed to be any method which uses the sequences of random numbers in order to obtain the simulation [13]. Using the MC method in system reliability analyses provides us with some valuable properties. One of the most important properties of it is the ability of checking the failure criterion without being dependent on the complexity of the system. There are several studies conducted on system reliability based on the MC simulation method in the literature [14]-[16]. In the Roy Billinton Test System (RBTS) [14], the reliability analyses are made for different buses by defining the reliability indices for load points and performance indices for the system utilizing the MC simulation method. In [15], the reliability analyses for distribution system with distributed generation is carried out; and as a result, two new indices which are; the Distributed Generation Average Interruption Frequency Index (DGIFI); and the Distributed Generation Average Interruption Duration Index (DGIDI) are suggested. In [16], a MC simulation based method was developed to predict the reliability of the structural system; and the system reliability is expressed with the failure probability.

In this study, the reliability analysis of electrical distribution system in Nigde Region is carried out. The system reliability is evaluated for system's feeders determining their performance indices. The performance indices, namely SAIFI and SAIDI, are computed by analytically. A MC simulation based approach is also utilized. Results obtained by two methods are presented and discussed.

II. SYSTEM RELIABILITY ANALYSES

The Electric Utility Industry (EUI) is in a world in where there is a deregulated and competitive environment in which the utilities provided to the customers must give true information on the performance of the system in order to show that the money paid to the institutions in this industry is spent in a wise manner, and to cover the expectations of the customers. There are some reliability performance measures developed in the Electric Utility Industry (EUI) in order to measure the performance of the system. In these Reliability Performance Measures (RPM), the outage duration, frequency of outages, system availability, and response time are measured. System reliability is different from the concept of power quality. It is about sustained interruptions and momentary interruptions. Power quality, on the other hand, is related to the voltage fluctuations and harmonic distortions. An interruption, which is greater than 5 min is considered as being a reliability issue in general terms; and an interruption, which lasts for less than 5 min is considered within the power quality concept.

The reliability analyses approach for power systems are divided into two sub-groups: Analytical Evaluation Techniques (AET) and Simulation Evaluation Techniques (SET). AET consists of analytical methods, and they evaluate the reliability indices by analytically [6-8]. The MC simulation method, on the other hand, predicts the reliability indices by simulating the real process and the random behavior of the system [14, 16]. For this reason, this method requires a series of experiments.

Reliability Indices:

The main problem for the reliability assessment in electrical distribution networks is the measuring of the effectiveness of the services provided in the past. In a common solution, there is the condensing of the effects of the service interruptions into the indices of the system performance. Some institution, namely Institute of Electrical and Electronics Engineers (IEEE) have proposed several performance indices [15]. These indices generally consist of yearly mean values of the interruption frequency or the duration. They try to find the severity of the disturbances by load-lost in each interruption. They consist of the weighted indices obtained for load points. The following are among the most common system performance indices:

- The system average interruption frequency index (SAIFI) shows how often an average customer faces a sustained interruption over a predefined time period and defined as;

$$\mathrm{SAIFI} = \frac{\sum \text{Total Number of Customers Interrupted}}{\text{Total Number of Customers Served}} \tag{1-a}$$

$$\mathrm{SAIFI} = \frac{\sum \lambda_i N_i}{N_T} \tag{1-b}$$

- System average interruption duration index (SAIDI) shows the total duration of any interruption for an average customer during a predefined time period, and is generally measured in customer minutes or customer hours of interruption and defined as;

$$\text{SAIDI} = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Served}} \quad (2\text{-a})$$

$$\text{SAIDI} = \frac{\sum R_i N_i}{N_T} \quad (2\text{-b})$$

- Customer average interruption duration index (CAIDI) shows the mean values of the time that is necessary to restore the service provided and defined as follows;

$$\text{CAIDI} = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Interrupted}} \quad (3\text{-a})$$

$$\text{CAIDI} = \frac{\sum R_i N_i}{\sum N_i} = \frac{\text{SAIDI}}{\text{SAIFI}} \quad (3\text{-b})$$

- Customer average interruption frequency index (CAIFI) shows the average frequency of the sustained interruptions for customers who are experiencing sustained interruptions, and the customer is counted once without considering the number of times in this calculation. It is computed as follows;

$$\text{CAIFI} = \frac{\sum \text{Total Number of Interruptions}}{\text{Total Number of Customers Interrupted}} \quad (4\text{-a})$$

$$\text{CAIFI} = \frac{\sum \lambda_i}{C_N} \quad (4\text{-b})$$

- Average service availability index (ASAI) shows the Fraction of Time (usually in percentage) in which a customer receives power during the defined reporting period and defined as follows;

$$\text{ASAI} = \frac{\text{Customer Hours Service Availability}}{\text{Customer Hours Service Demands}} \quad (5\text{-a})$$

$$\text{ASAI} = \frac{N_T(\text{Number of hours/year}) - \sum R_i N_i}{N_T(\text{Number of hours/year})} \quad (5\text{-b})$$

where, C_N denotes the number of the total customers who experience a sustained interruption during the reporting period, λ_i is the number of the interruption, R_i is the repair time for each interruption event, N_T is the total number of the customers, and N_i is the number of the interrupted customers for each sustained interruption during the related time (period).

Monte Carlo (MC) Simulation Method:

The Monte Carlo (MC) methods are based on using random numbers and probability statistics in order to examine problems, and are stochastic techniques [17]. It is also possible to define it as statistical simulation methods. In order to perform the simulation, they use the sequences of random numbers. In this way, the MC methods may be claimed to be a collection of various methods, which perform the same process. In this process, many simulations are made by utilizing random numbers and probability for the purpose of having an approximation of the answer to the problem. The usage of the MC method has some charming properties. One of the most important properties is the failure criterion being relatively easy to check without depending on the structural features of the system [18]. To measure the reliability of the electrical distribution network in Nigde Region, an algorithm based on MC simulation method is developed. The algorithm is constituted to find the number of interrupted customers from generating random numbers. The implemented algorithm to estimate performance indices for any region of the system is summarized as follows. Its flow chart is given in Figure 1.

Step 1: Input the system data about the number and time of interruptions, and customers (N_T, N_i, R_i and λ_i).

Step 2: Define a vector F_{1xNT} with the size of N_T and set its elements by generating different random numbers whose values are ranging from 0 to N_T.

Step 3: Define counters as u=0, d=0.

Step 4: Compare each elements of F_{1xNT} with N_i. If $F(j)>N_i$, set u=u+1 else d=d+1.

Step 5: Compute performance indices as follows;

$$SAIFI = \frac{\sum d_i * N_i}{N_T} \quad (6\text{-a})$$

$$SAIDI = \frac{\sum d_i * R_i}{N_T} \quad (6\text{-b})$$

$$CAIDI = \frac{SAIDI}{SAIFI} \quad (6\text{-c})$$

$$CAIFI = \frac{\sum d_i * N_i}{C_N} \quad (6\text{-d})$$

$$ASAI = \frac{N_T 8760 - \sum d_i R_i}{N_T 8760} \quad (6\text{-e})$$

Step 6: Stop.

III. RELIABILITY ANAYSES OF DISTRIBUTION NETWORK

The structure of electrical distribution system in Nigde Region is given in Figure 2-4. It comprises three radial feeders, which have 3x1/0 swallow conductor with 31.5 kV voltage level, called ULUKISLA (Feeder-I), ALTUNHISAR (Feeder-II) and CAMARDI (Feeder-III). Each feeder has different number of load points and their data required for the calculations of reliability indices are taken from [19]. In the analyses, one year of outage information is used, and peak load demand of the each load point is considered. The component data of each feeder determined their load points are given as follows:

Feeder-I: 5 load points, 19039 number of customers, 13.065 MW load demands, 408 failures/year with 0.79 hours average repair time.

Feeder-II: 5 load points, 5395 number of customers, 7.39 MW load demands, 154 failures/year with 0.65 hours average repair time.

Feeder-III: 7 load points, 9660 number of customers, 8.139 MW load demands, 228 failures/year with 0.43 hours average repair time.

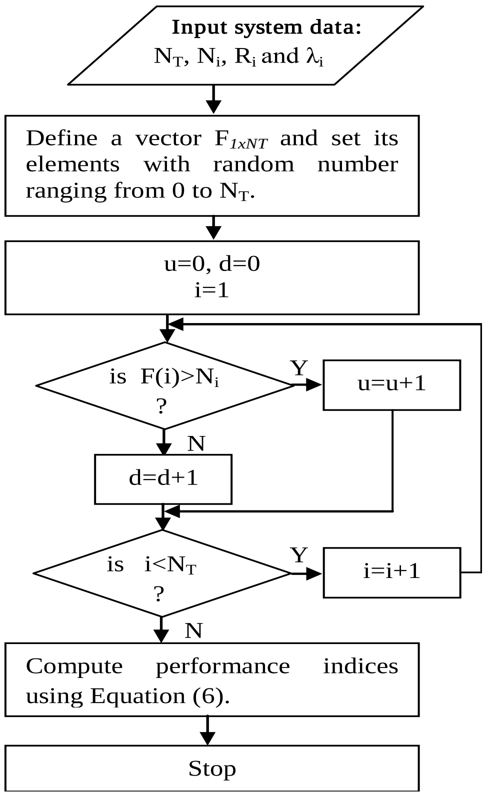

Figure 1. Flow chart of MC simulation method

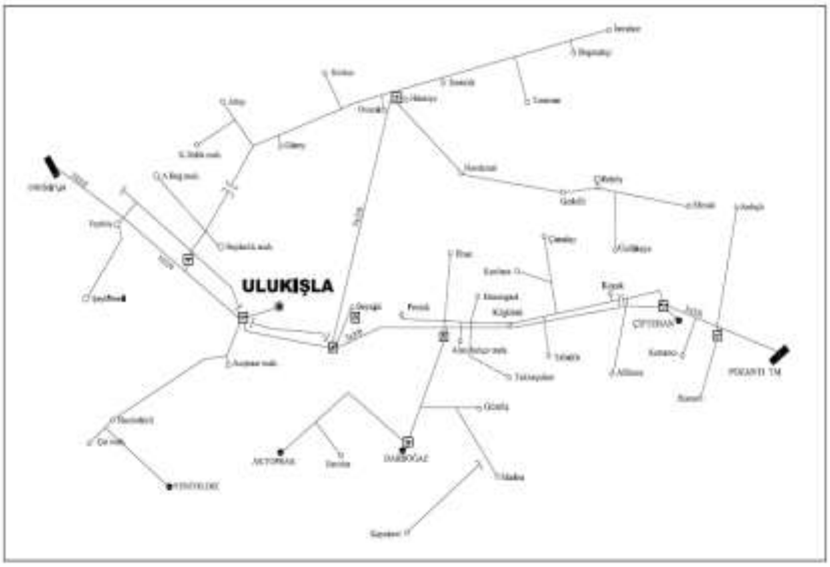

Figure 2. Single phase circuit of ULUKISLA feeder in Nigde Region

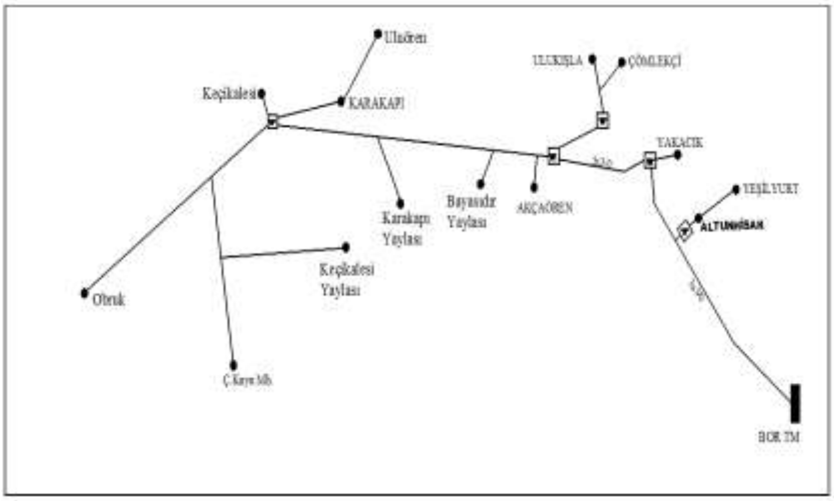

Figure 3. Single phase circuit of ALTUNHISAR feeder in Nigde Region

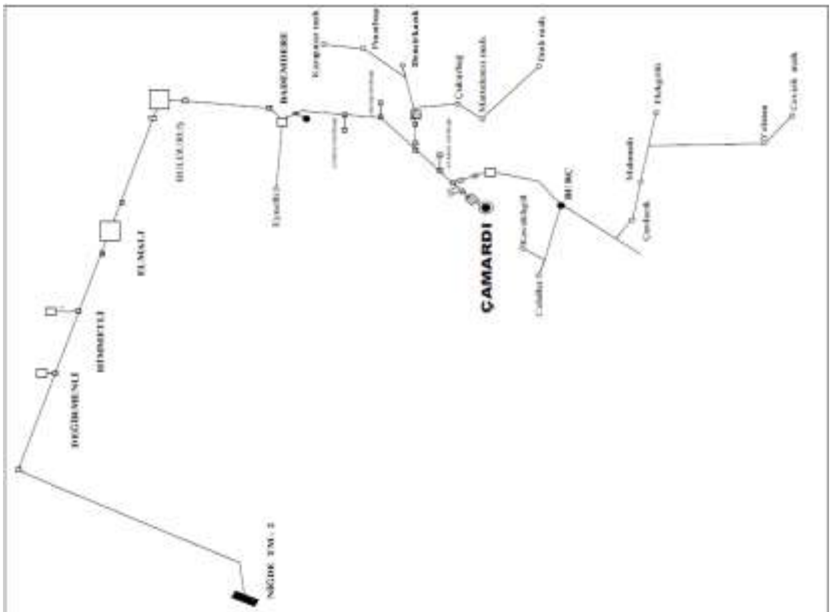

Figure 4. Single phase circuit of CAMARDI feeder in Nigde Region

The size of the customers does not make any difference in the 4 popular indices in reliability analysis; in other words, the peak demand, energy sales, or class do not matter. SAIFI; CAIFI (which measures only frequency); SAIDI (which measures only duration); and CAIDI are the most four popular indices, and generally used in combination with each other, and provide a rough estimation about what is going on in the system's reliability. In this study, firstly, these performance indices of each feeder and their load points are computed by using Equations (1)-(4), respectively. Table 1 shows system performance indices of the distribution systems. It is obvious from the table that the BEYAĞIL load point has the maximum values of SAIFI and SAIDI, 18.22 and 13.77, respectively. This means that the customers at this load point had an 18.22 probability of experiencing a power outage and the average customer was out for 13.77 minutes in the last year. In addition, the CAIDI index is the maximum for the load point CIFTEHAN with the value of 1.34 which means that on average, any customer of this load point who experienced an outage in the last year was out of service for 1.34 minutes.

The Average Service Availability Index (ASAI) shows the rate of the total number of the customer hours in which the service was provided within a certain time period to the total customer hours demanded; and is also called as the Service Reliability Index (SRI) [20]. Accordingly, it is also determined by using Equation (5) and given in the table. It is seen from result that the BEYAGIL load point has the minimum index value when compared with the values other load points. It has an average availability of 99.84% for one year period. From these results, it can be concluded that the reliability of Feeder-I which feeds these load points is poor when compared with the other feeders of the electrical system. It is also be seen from the Table 1 when comparing with the value of performance indices of each feeder. It has minimum average availability (ASAI=99.89%), maximum average number of interruptions for a customer (CAIFI=0.1937) and its customers has maximum probability of experiencing a power outage (SAIFI=10.86).

Secondly, system reliability is evaluated using MC method. The performance indices are computed by using MC simulation based algorithm whose flow chart is given in Figure 1. All load points of feeders and feeders' performance indices are computed using the proposed simulation algorithm, which is coded in MATLAB program [21], and results are given in Table 1 with the analytical results. It is obvious in the table that the MC simulation results are in closely agreement with the analytical results. The maximum difference between simulation and analytical results is comparatively small, and therefore, can be neglected. Figure 5 shows how the SAIFI and SAIDI indices of each feeder vary with different number of MC simulations. Different number of MC simulations was carried out applying different number of multiple simulations and the mean value of the results obtained by each simulation are used for the value of these indices. When the figures are examined it becomes obvious that the MC simulation results and analytical values of SAIFI and SAIDI indices are in accordance with each other. Additionally, the difference between the results obtained by two approaches closes to zero as the number of the MC simulation increases.

Table 1. System performance indices obtained by analytically and MC method for electrical distribution System of Nigde Region

No	Load Point	SAIFI		SAIDI		CAIDI		CAIFI		ASAI	
		Analytic	MC Sim.	Analytic	MC Sim.	Analytic	MC Sim.	Analytic	MC Sim.	Analytic	MC Sim.
Feeder-I	Bajdarlik	7.500	7.573	5.940	6.006	0.793	0.793	0.1387	0.1374	0.9993	0.9993
	Ulukisla	5.540	5.886	2.610	2.778	0.447	0.471	0.3161	0.2979	0.9997	0.9997
	Beyağil	18.22	19.41	13.77	13.42	0.756	0.755	0.1859	0.1745	0.9984	0.9985
	Ilhan	12.42	12.65	11.18	11.39	0.900	0.900	0.1734	0.1702	0.9987	0.9987
	Ciftehan	6.790	6.820	9.160	9.199	1.340	1.348	0.1666	0.1660	0.9989	0.9989
	Feeder-I	**10.86**	**10.92**	**8.816**	**8.832**	**0.811**	**0.808**	**0.1937**	**0.1871**	**0.9989**	**0.9990**
Feeder-II	Kecikalesi	7.09	7.244	6.27	6.404	0.88	0.884	0.2157	0.2113	0.9992	0.9993
	Akcaören	3.98	3.762	2.07	1.960	0.52	0.521	0.0740	0.0784	0.9997	0.9998
	Comlekci	5.11	5.119	3.75	3.750	0.732	0.732	0.1387	0.1387	0.9995	0.9996
	Yakacik	3.83	3.752	1.37	1.346	0.358	0.358	0.1619	0.1655	0.9998	0.9998
	Altunhisar	5.38	5.359	3.30	3.291	0.614	0.614	0.2523	0.2535	0.9996	0.9996
	Feeder-Ii	**5.32**	**5.276**	**3.56**	**3.583**	**0.669**	**0.671**	**0.1748**	**0.1795**	**0.9995**	**0.9996**
Feeder-III	Değirmenli	8.54	8.277	4.38	4.318	0.52	0.521	0.0716	0.0728	0.9994	0.9995
	Himmetli	10.98	10.50	9.74	9.318	0.88	0.887	0.0800	0.0837	0.9988	0.9989
	Elmali	6.52	6.520	4.98	4.986	0.76	0.764	0.0607	0.0608	0.9994	0.9994
	Bademdere	6.26	5.970	4.69	4.476	0.75	0.750	0.0701	0.0736	0.9994	0.9995
	Demirkazik	13.16	12.48	3.18	3.019	0.24	0.241	0.2227	0.2350	0.9996	0.9997
	Camardi	6.20	6.187	3.59	3.588	0.58	0.580	0.0635	0.0637	0.9995	0.9996
	Burc	8.77	9.282	1.22	1.299	0.14	0.140	0.1496	0.1517	0.9998	0.9998
	Feeder-Iii	**8.23**	**8.217**	**3.45**	**3.474**	**0.419**	**0.423**	**0.0977**	**0.0994**	**0.9996**	**0.9996**

The reliability analysis of the power points like the center, county and district/village group, which are fed by Feeder-I and which constitute the majority of the established power of Nigde region in low voltage has been made in the study as the last part. The residential areas that are fed by these load points have been evaluated according to the population density, and 10 load points have been formed. It has been assumed that one single transformer made the distribution in low voltage in these load points. In addition, the branch lines in each load point have been assessed as one single load. The reliability analysis has been performed by finding the number of the customer, the subscribers receiving energy from the transformer in that load point, low voltage breakdowns, and the number of the customers influenced by these interruptions have been found in each load point. The data have been formed by evaluating the values received from Nigde MEDAS records [19]. The reliability index values obtained for the load points with low voltage (380 V line to line) are given in Figure 6. As it may be observed in the figure, Aktoprak region has the highest reliability value among the other regions. The region with the lowest reliability level is the Beyagıl Region, which was also determined as the region with the lowest reliability in the analysis that was made for high voltage. For this reason, it is necessary that the necessary maintenance is performed in the region in order to increase the reliability. In addition to this, it is also necessary that the transformer power of the regions is increased or additional transformers are built for the regions where there are too many customers and/or where it is possible to increase.

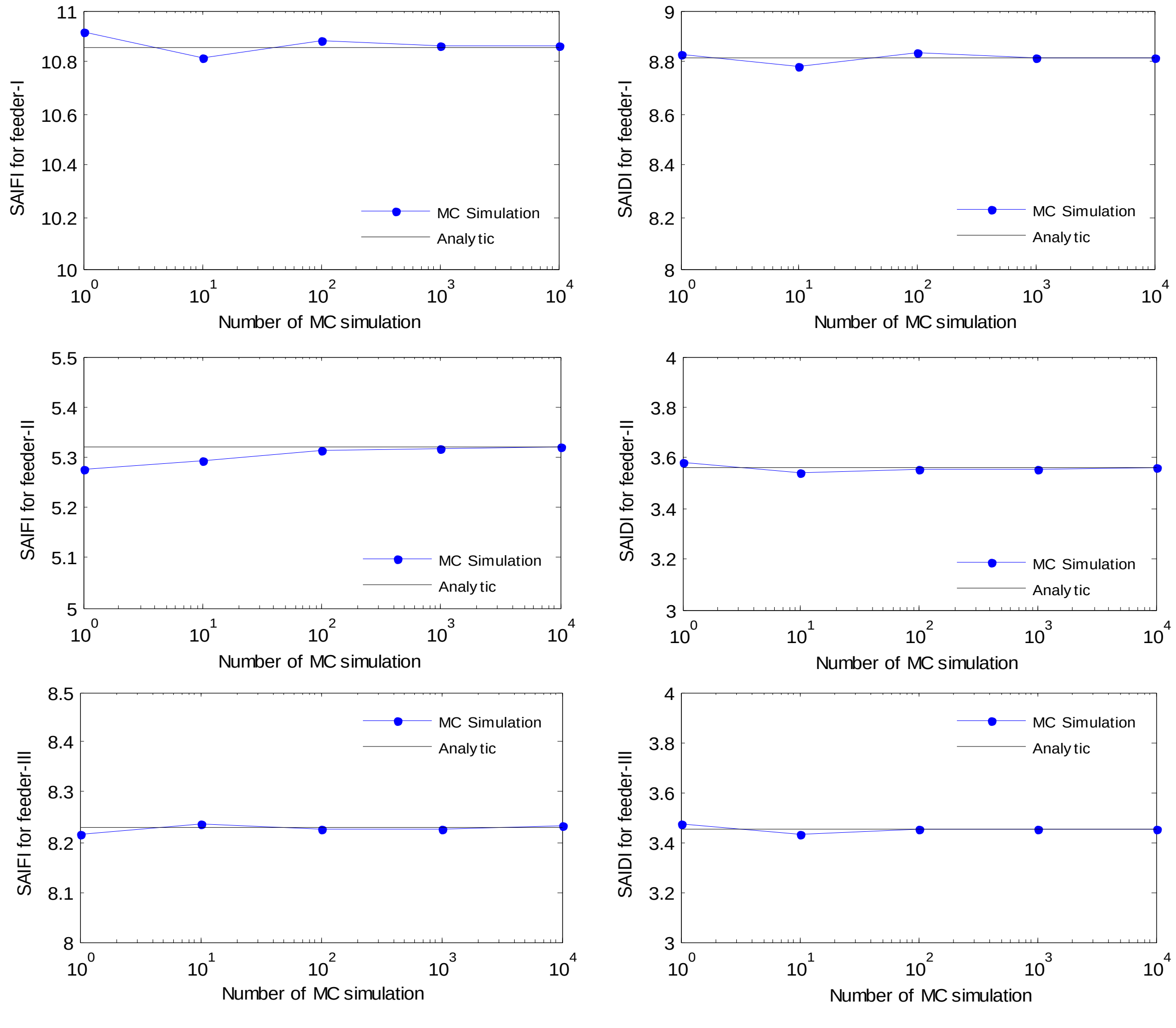

Figure 5. Variation of feeders' performance indices (SAIFI and SAIDI) with different number of MC simulation

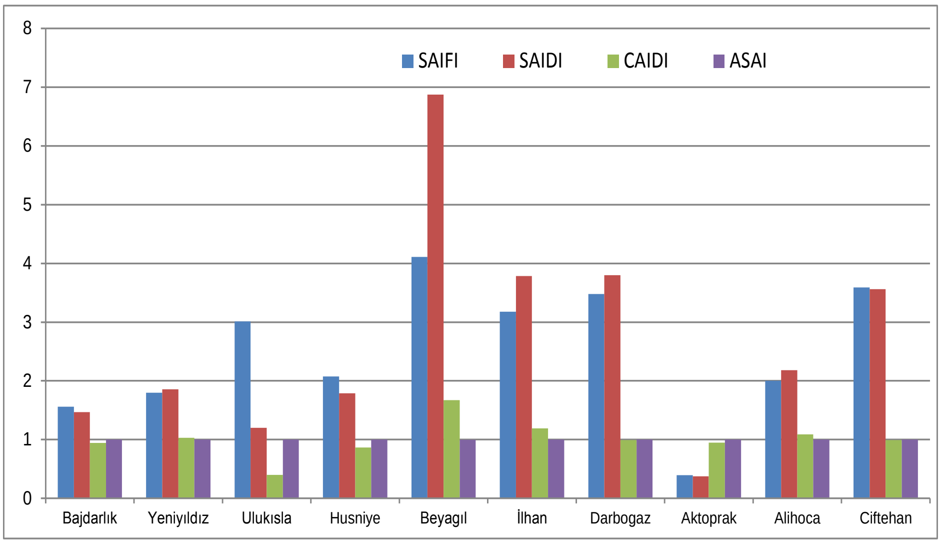

Figure 6. The value of reliability indices for load points with low-voltage level in Feeder-I

IV. CONCLUSIONS

The operation and planning of the distribution system consists of the assessment of the Customer Power Supply Reliability, which is an important characteristic of the system. Power System Reliability Evaluation Techniques (PSRET) has two basic classes; which are Analytical Techniques and Simulation Techniques. Analytical Techniques refers to the system by analytical models. It evaluates the reliability indices from these models by utilizing mathematical solutions. The MC simulation method predicts the reliability indices by simulating the real process and the random behavior of the system.

In this study, reliability analysis of Nigde Region's electricity system was carried out. The system reliability was evaluated for system's main feeders and their load points determining their performance indices. Firstly, performance indices were computed by analytically. Then, the MC simulation approach was applied, and reliability indices obtained by two methods were presented. For the MC simulation method, an algorithm constituted to find the number of interrupted customers from generating random numbers is proposed and applied to the system. From results, it was observed that simulation results are in close agreement with the analytical results. Maximum difference between methods are comparatively small, and these absolute error decreases with the number of MC simulations. Moreover, from the both analytical and MC simulation analyses, the reliability of Feeder-I (ULUKISLA) which has minimum average availability and maximum average number of interruptions for a customer was found poor when compared with the other feeder of the system.

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Nomenclature

AET	Analytical Evaluation Technique
ASAI	Average service availability index
CAIDI	Customer average interruption duration index
CAIFI	Customer average interruption frequency index
CEA	Canadian Electric Association
DGIF	Distributed generation average interruption frequency index
EUI	Electric utility industry
IEEE	Institute of Electrical and Electronics Engineers
MC	Monte-Carlo
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
SET	Simulation Evaluation Technique
SPI	System performance indices
C_N	Total number of customers experienced a sustained interruption
l	Average failure rate
N_i	Number of the interrupted customers
N_T	Total number of customers served for the areas
r	Average outage time
R_i	Repair (restoration) time
U	Average annual unavailability
λ_i	Interruption time