Evaluation of System Reliability Using Seasonal and Random Operation Techniques

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Abstract— The target of any power system is to deliver stable, clean and cheap electrical power to the customer. This paper offers two independent approaches to simulate the operation of the generating units in a power network. The first methodology depends on the load variation in each season while the other one is random through a certain sequence. Using the proposed approaches a comparison between the different suggested PDF that describes the failure and repair for any component is made. The simulation is done based on Monte Carlo method through a small radial system and the IEEE 13 node test system.

Index Terms— Seasonal operation, Random operation, reliability indices, Monte Carlo Simulation.

I. NOMENCLATURE

List of Abbreviations:

DG         Distributed Generated
T          Sampling Period (hours)
WTm        Monthly Working Time for a generator
WTw        Weekly Working Time for a generator
PDF        Probability Distribution Function
MTTF       Mean Time To Fail, hours
MTTR       Mean Time To Repair, hours
SAIFI      System average interruption frequency index
SAIDI      System average interruption duration index
CAIFI      Customer average interruption frequency index
CAIDI      Customer average interruption duration index
MCS        Monte Carlo Simulation
RTS        Reliability Test System

II. INTRODUCTION

Reliability or how well does the system perform was and still the main concern of all the power engineers. High quality and less cost is the hard aim that all the designers tend to achieve. The reliability studies were done in most of literatures focusing on this point have presented the system component either by a two state model [1-3] or a three state model which takes the maintenance phase into consideration [4]. On the other hand the load sometimes considered to be constant at each load point [5] or time variant [6]. Most of these studies do not put any restrictions on the operation of the generating stations present in the system. Many reliability indices could evaluate to judge the system performance. SAIDI, SAIFI, CAIDI and CAIFI are the most dominant indices, all the comparisons created in this paper count on the values of CAIDI at a certain load point for the different cases of study suggested.

Electrical consumption in many countries is strongly dependent on the weather case and the climate nature in these countries. In hot countries the power loads are almost doubled due to using the air conditioning units, more power is needed to operate the refrigerators and other cooling devices. While during winter the load is much decreased. On the contrary to the cold countries the load is increased due to the rising use of heating devices for water beside the air conditioners which are used to overcome the cold weather. As a conclusion the operating hours of DGs are not realistic to be fixed through out the whole year. In other words; these operating hours should be proportional to the load demands within the different seasons of the year. This concept may be called seasonal operation. Each approach has advantages and disadvantages. Considering the advantages; the continued operation durations of the DGs will be reduced so that the probability of failures and malfunctioning is reduced, their will be wide time gaps so that proper and scheduled maintenance procedures could be performed. More number of DGs are available in case of failures leading to extended flexibility of operation to overcome the fault minimizing the number of load points that are interrupted, Which means that the system security will be increased.

The main disadvantage is the planning for the operation of these DGs, many parameters should be determined; how many hours per season which depend on the nature of load, should these hours be distributed on a daily, weekly or monthly basis, Also the sequence of operation of the connected DGs during emergency cases. As a conclusion great efforts to achieve a wise analysis for the previous points are done by the responsible engineers.

This paper discusses two proposed approaches for the generating units operation. The first approach depends on the seasonal operation of the DG which is connected to the radial test presented before. The second approach deals with a concept that is based on using a random sequence with some constrains on the operation of the generators connected to the system. Finally, a clear comparison is held between the results of these two approaches.
III. TEST SYSTEMS

A small radial system is used to execute the steps of the first case of study on it. System reliability givens and the single line diagram are presented in Table (1) and Figure (1) respectively.

![Small test radial system diagram](image1)

**TABLE 1 RADIAL SYSTEM RELIABILITY DATA**

<table>
<thead>
<tr>
<th>Section name</th>
<th>length</th>
<th>MTTF</th>
<th>MTTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>2 miles</td>
<td>43800</td>
<td>3</td>
</tr>
<tr>
<td>Y</td>
<td>3 miles</td>
<td>29200</td>
<td>3</td>
</tr>
<tr>
<td>Z</td>
<td>1 mile</td>
<td>87600</td>
<td>3</td>
</tr>
<tr>
<td>W</td>
<td>Valid for all</td>
<td>17520</td>
<td>1</td>
</tr>
</tbody>
</table>

This research work furnishes a comparison between the two suggested methods by applying them on the IEEE 13-bus system, this system components reliability data [7] is stated in table (2).

![IEEE 13 bus system single line diagram](image2)

**TABLE 2 MODIFIED IEEE 13 BUS SYSTEM COMPONENTS RELIABILITY DATA**

<table>
<thead>
<tr>
<th>Section</th>
<th>length (ft)</th>
<th>Feeder Type</th>
<th>MTTF</th>
<th>MTTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>X, M and N</td>
<td>300</td>
<td>Lateral</td>
<td>1536842</td>
<td>3</td>
</tr>
<tr>
<td>Y and z</td>
<td>500</td>
<td>Lateral</td>
<td>922105</td>
<td>3</td>
</tr>
<tr>
<td>W and V</td>
<td>2000</td>
<td>Main</td>
<td>230526</td>
<td>3</td>
</tr>
</tbody>
</table>

IV. METHODOLOGIES APPLIED

A. Seasonal Operation

DGs can be operated for a pre defined number of hours per each month or week or even on a daily bases. The number of hours of operation hours depends on the load demand at the different seasons of the year. The load demand variation mainly occurs between summer and winter, the load may increase or decrease according to the climate of the country where the system is studied. It is assumed that we are dealing with a hot country where the summer load is greater than the winter load. Each DG operates for 25% of the year (about 2180 hour) this duration will not be executed totally random. Two ways of distributing the operation hours overall the year will be implemented:

1) Weekly Limited Operation

The target operation duration will be divided on the 48 weeks of the year. Note that the operation hours are not divided equally; the following assumption is made 60% of the operation hours are directed during the summer months while the rest will be during the winter period. For simplicity one year can be divided into 6 months of summer (starting from April to September) and 6 months of winter (the rest months of the year). So each DG has the permission to work for 54.75 hours within one week during the summer and 36.5 hours weekly working time (WTw) during the rest of year.

2) Monthly Limited Operation

The target operation duration will be divided on the 12 months of the year. Similarly to the previous section the same percentages in summer and winter are applied for this approach. A new parameter can be defined which is the monthly working time (WTm); it should be 219 and 146 hours during summer and winter respectively.

Both approaches are applied through the following steps which are used to evaluate the reliability index (CAIDI); the only difference will be the WT and the period of each sample for the chronological curves of each DG:

1- Generate the chronological curves [6] of the main supply and the other system components (main and lateral feeders), using the sampling period (8760 hours).

2- Generate the chronological curves of the DGs connected to the system, taking into consideration the limitation of the working time of the DG which differs according to the duration of limitation operation as it was explained previously. Also the sampling time is 730 hours in case of monthly limitation and about 182.5 if weekly basis is selected. The MTTF and the MTTR average weekly or monthly values are obtained by dividing their given values by 48 (no. of weeks/year) or 12(no. of months/year) respectively. For example if hydro DG is connected the given value of MTTF for this type is 1980 hours, if monthly sampling is applied its value should be 165 hours. Figure (3) shows the chronological curve of a DG within the first 5000 hours of a year. All the data of MTTF and MTTR are taken from the data of the IEEE RTS [1].
3- Add all the chronological curves that the load point depends on to obtain a chronological curve for the point itself. Note that any failure for one component or more will cause the interruption of power transmitted to the load point under investigation (the curve should be at the down state).

4- The periods at which curve of the load point is in the down state will refer to the interruption of the load feeding. As a conclusion the duration of each interruption could be easily determined and also the number of interruptions per the time span of simulation.

5- Finally, generate a Monte Carlo prediction curve for the CAIDI based on the equation (1).

Note that this procedure uses several probability distributions in case of generation of the chronological curves of the DG; these distributions are:

- Exponential (the default distribution used throughout this research work), Box and Muller (a method to get Normal distribution), Log Normal, Weibull (different values for freedom factor (β) are tested), Gamma (different values for freedom factor (β) are tested).

**B. Random Operation**

This section presents a totally different approach to obtain the reliability indices taking into account that the DGs are not available 24/7 all over the year. This time their operation is not scheduled on a seasonal basis but a certain random sequence is applied which will be explained in the next few lines:

1. Generate a random number (m) between 0 and (n), where n is the number of available DGs found in the studied power network. This random number is the number of the DGs that are turned on during a certain sampling period.
2. Randomly select the DGs that are on. For example concerning the small radial system; if the number of turned on DGs is 1, so it may be alternative supply 1 or 2. This choice is random.
3. Note that the expression (turned on) does not mean by necessity that the DG is in up state during the whole sampling period but it means that its chronological curve will be involved when the chronological state curve of the required load point is evaluated during period within which the DG curve.

4. A matrix whose dimensions are (m+1)*(T) is formed, this matrix is called generators/load point (G/Lpt.) matrix, as it is clear in equation (1). Each row represents the chronological curve of the path between the load point under study and one DG from the group which is turned on. Note that (T) is the sampling period of each simulation shot of the DG. (T) May be 168 and 730 hours in case of weekly and monthly simulation respectively.

5. The summing of the matrix rows yields a vector which is the chronological curve of the target load point.

6. After that the load point indices can be normally evaluated as stated in [7]. Focus is directed on CAIDI in this paper.

Some important points and assumptions should be highlighted in this sequence, which are as follows:

- The main supply yearly chronological curve is generated on a single shot with a sampling period of 1 year (8760 hours), assuming that the main supply is turned during the whole year.
- The components yearly chronological curves are also generated on a single shot with a sampling period of 1 year (8760 hours).
- The DGs yearly chronological curves are generated on a certain number of shots, this number depends on the sampling period. If we are talking about weekly sampling period (168 hours) we need to perform 48 weekly chronological curves to get the yearly chronological curve of each DG. A question is asked at this point; why we need to get the chronological curve on many shots, because it is not realistic that the DG is scheduled to be turned off for 1 year, as sampling period is reduced it turns to be more logic. In this research work weekly sampling was selected.
- The required indices are calculated at the end of each year, then using Monte Carlo simulation and after a certain number of experiments the predicted values of these indices are obtained.

\[
G / Lpt. = \begin{pmatrix}
\text{Main supply} & \rightarrow \text{path to} & \rightarrow \text{Load point A} \\
DG1 & \rightarrow \text{path to} & \rightarrow \text{Load point A} \\
DG2 & \rightarrow \text{path to} & \rightarrow \text{Load point A} \\
\downarrow & & \\
DGn & \rightarrow \text{path to} & \rightarrow \text{Load point A}
\end{pmatrix}
(1)
\]

V. CASE STUDIES

This paper deals with two completely independent cases of study; the first one applies the seasonal and random operation approaches on the small radial system shown latter, it also compares between the different probabilities distribution function that were suggested to estimate the TTF and TTR in [1]. The second one drives a comparison between the two suggested approaches to prove the validity of random approach, the impact of both approaches was studied on the modified IEEE 13 node test system shown in section (III).

A. Case Study 1

CAIDI was the only index to be evaluated for this work. Brief description for the two cases is shown in tables (5-1 and 5-3).
Table 3 Seasonal operation first case of study description

<table>
<thead>
<tr>
<th>Generator</th>
<th>Type</th>
<th>Sampling time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main supply</td>
<td>Hydro</td>
<td>8760 hr</td>
</tr>
<tr>
<td>DG I</td>
<td>Comb. turbine</td>
<td>730hr</td>
</tr>
<tr>
<td>DG II</td>
<td>Comb. turbine</td>
<td>730hr</td>
</tr>
</tbody>
</table>

Table 4 Random operation first case of study description

<table>
<thead>
<tr>
<th>Generator</th>
<th>Type</th>
<th>Sampling time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main supply</td>
<td>Hydro</td>
<td>8760 hr</td>
</tr>
<tr>
<td>DG I</td>
<td>Comb. turbine</td>
<td>168hr</td>
</tr>
<tr>
<td>DG II</td>
<td>Comb. turbine</td>
<td>168hr</td>
</tr>
</tbody>
</table>

B. Case Study 2

Random operation of each DG leads to a certain WT for this DG; this WT can be determined by predicting all number of hours that the DG is turned on through the whole year. This process is done using Monte Carlo simulation method. After obtaining this yearly WT, the daily or monthly WT for this DG is obtained, this would be the key used to compare between the two approaches. This WT is used in seasonal approach so that it is distributed in the same percentages described previously.

Table 5 Seasonal operation second case of study description

<table>
<thead>
<tr>
<th>Generator</th>
<th>Type</th>
<th>Sampling time</th>
<th>PDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main supply</td>
<td>Hydro</td>
<td>8760 hr</td>
<td>Exp.</td>
</tr>
<tr>
<td>DG I</td>
<td>Comb. turbine</td>
<td>730hr</td>
<td>Wie-Bull</td>
</tr>
<tr>
<td>DG II</td>
<td>Comb. turbine</td>
<td>730hr</td>
<td>Exp.</td>
</tr>
<tr>
<td>DG III</td>
<td>Comb. turbine</td>
<td>730hr</td>
<td>Exp.</td>
</tr>
</tbody>
</table>

Table 6 Random operation first case of study description

<table>
<thead>
<tr>
<th>Generator</th>
<th>Type</th>
<th>Sampling time</th>
<th>PDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main supply</td>
<td>Hydro</td>
<td>8760 hr</td>
<td>Exp.</td>
</tr>
<tr>
<td>DG I</td>
<td>Comb. turbine</td>
<td>168hr</td>
<td>Wie-Bull</td>
</tr>
<tr>
<td>DG II</td>
<td>Comb. turbine</td>
<td>168hr</td>
<td>Exp.</td>
</tr>
<tr>
<td>DG III</td>
<td>Comb. turbine</td>
<td>168hr</td>
<td>Exp.</td>
</tr>
</tbody>
</table>

VI. RESULTS

A. Case of Study (1)

Tables (7) and (8) show all the results obtained for every probability distribution, case of study the output values yielded from using two DGs, each one has its own probability distribution function in case of seasonal and random operation. Note that the equations used to evaluate the TTF and the TTR of each unit based on different probability distribution functions are equations () found at Appendix (). Figure (5-3) summarizes the results of seasonal operation first case of study.

<table>
<thead>
<tr>
<th>PDF</th>
<th>CAIDI (Hours/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG I</td>
<td>DG II</td>
</tr>
<tr>
<td>Wiebull (β=5)</td>
<td>Gamma (β=5)</td>
</tr>
<tr>
<td>Wiebull (β=5)</td>
<td>Wiebull (β=5)</td>
</tr>
<tr>
<td>Wiebull (β=5)</td>
<td>Box and Muller</td>
</tr>
<tr>
<td>Wiebull (β=5)</td>
<td>Exponential</td>
</tr>
</tbody>
</table>

B. Case of Study (2)

A MATLAB code was created to determine the value of the weekly working time for a DG; it was assumed that this DG chronological curve generation depends on an exponential probability distribution function. 47 hours was the predicted weekly WT, as shown in figure (5-5) with approximately 52 weeks per year this DG should operate for 2444 hours per year. This duration is divided into two sections; summer operation and winter operation which are 1467 hours (60%) and 977 hours (40%) respectively. This data was taken as an input for the seasonal approach to evaluate the outcome...
CAIDI under these conditions. Figure (5) show the MCS curve of the WTw for a DG in case of random operation. While figure (6) compares between the MCS curves of CAIDI at point (A) in IEEE 13 node test system for modes of operation.

VII. CONCLUSION

Results have proved that as the number of experiments increase all these methods will converge to the same values. It was found that the difference in the result of the two approaches investigation is about 0.02 hours (10%), figure (5.6) shows this slight difference which can be considered as a slight and acceptable to prove the validity of both approaches. These two methods of operation could be more reasonable than the classical methods that are used nowadays. Future work will focus on the enhancement of the random operation constrains so that the generation unit reliability would be reflected on its operation.

VIII. APPENDIX

Exponential PDF:

\[
TTF = MTTF \times \ln(X_1)
\]

\[
TTR = MTTR \times \ln(X_2)
\]

Where \( X_1 \) and \( X_2 \) are random numbers between 0 and 1.

Weibull PDF:

\[
TTF = ((MTTF) \times \ln(u_a))^{1/\beta}
\]

\[
TTR = ((MTTR) \times \ln(u_b))^{1/\beta}
\]

Where \( u_a \) and \( u_b \) are random numbers between 0 and 1.