Definition of Maintenance Policies in Power Systems Using a Sequential Monte Carlo

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Abstract — This paper reports an application of a simulation method to power systems reliability. The Monte Carlo methods are nowadays, the most widely used method for the estimation of reliability indices. The work reported in this paper shows that most of reliability studies that use Monte Carlo simulations are based on hypothetical situations: the use of a constant failure rate \( \lambda \). This paper demonstrates a new application that is able to include the typical variation of the failure rate \( \lambda \) of electrical components and, moreover, is able to introduce different maintenance policies. The results obtained with the Monte Carlo applications are compared with each other and with a typical Monte Carlo process.

Index Terms — Failure rate, maintenance, Monte Carlo, reliability.

I. INTRODUCTION

Monte Carlo simulations remain the standard method to compute estimates of reliability indices in Power Systems. These simulations are divided in two approaches: the chronological and the non chronological.

One of the goals of this paper is the inclusion of different types of maintenance policies in the life cycle of a Power System. Sometimes, maintenances are based on the elapse of time and, for this reason, this paper presents a chronological simulation.

However, most of reliability studies that present a chronological approach use an exponential distribution to generate the life cycle of the components of a Power System. The use of this approach simplifies a lot the generation of the life cycles. The problem of this approach lies on the consequence of the use of an exponential distribution. To use such distribution, the failure rate \( \lambda \) of the components needs to be constant. In Power Systems, this assumption isn’t true. The failure rate \( \lambda \) of electrical components suffers an evolution during their lives. The well-known bathtub curve illustrates this evolution. Therefore, this paper presents a new approach that allows to include the bathtub curve in order to achieve a realistic situation in the Power Systems reliability evaluations.

This paper also includes the analysis of the introduction of three different maintenance policies: reactive maintenance, preventive maintenance and predictive maintenance. The goal of these approaches is to delay the natural process of degradation of the electrical components. In other words, the introduction of the maintenance policies helps to delay the entrance on the wear-out period.

II. STATE OF THE ART

Several techniques were developed in order to evaluate the power systems reliability. The two main approaches that are described in the literature are: the deterministic approach [1] and the probabilistic approach [2]. It is now known that the systems behavior is stochastic and, for that reason, the evaluation of such systems should be made by probabilistic techniques. Analytical [2] and simulation [1][3] are the two different methods that compose the probabilistic approach. The simulation methods are based on Monte Carlo simulations. The Monte Carlo simulations can take basically two major types: chronological/sequential simulations and non chronological simulations.

Through the Monte Carlo simulations is possible to generate the life cycle of a power system. Therefore, these simulations allow to generate the times of operation and the times of repair of each component of a power system. In the literature of the reliability field, the generation of these times follows an exponential distribution. This fact means that, in the literature, is common to consider that the failure rate of the electrical components is constant. As it was said before, this paper will present a new approach that will add some news to the actual state of the art.

III. THE DEVELOPED METHODOLOGY

Most reliability studies consider that the components of a power system have a constant failure rate. In this new approach, a non constant failure rate will be used. Therefore, all the simplifications that are introduced by the exponential distribution will no longer take place.

In [4], an approach to implement a non constant failure rate is presented. This approach is based on the construction of the cumulative failure distribution, \( Q(t) \). After the construction of \( Q(t) \), through the use of a non constant failure rate, it is possible to generate the time of operation, of each unit. In this

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new approach, this procedure, when compared to a typical Monte Carlo simulation, is totally different. So, in order to generate the life cycle of each generating unit, the following steps are crucial:

1. Use a pseudo-random number generator to provide an uniformly distributed number in a [0,1] range.
2. The uniformly distributed number is used to intersect the constructed Q(t) curve. So, Q(t) = uniformly distributed number.
3. The time interval (t) that will result from this intersection will be the new time to failure of a specific component.
4. Repeat the process until all the generating units have their own time to failure.

Concluding, this is an approach that allows the introduction of a variable failure rate. This means that the infant mortality and the wear-out regions are included in this method.

IV. THE RESULTS OF THE DEVELOPED METHODOLOGY

As it was said before, all the approaches that were developed during the last four months were based on the construction of the cumulative distribution function Q(t). The analysis of this curve is very interesting, since it allows to understand the differences between the developed approaches and the typical method. The following figure shows this aspects:

![Figure 1](image.jpg)

Fig. 1 - Comparison between the developed approaches and the typical Monte Carlo method

Through the analysis of this figure, the following conclusions can be withdrawn. The green curve represents the widely used approach: the use of constant failure rate λ. Therefore, this curve can be compared to an ideal maintenance case, in which the components don’t get older. The red curve represents the followed methodology, in which the bathtub curve is applied. It is possible to observe that these two curves diverge in a certain moment. This moment represents the beginning of the wear-out period. The other two curves are related with two different types of maintenance actions. By observing this figure, is clear that the inclusion of the maintenance actions actions delay the entrance on the wear-out period. This figure also shows that predictive maintenance leads to a bigger extension of the useful life period of the generating units. This was already expected, since the predictive maintenance is based on the actual state of the components. Therefore, the predictive maintenance isn’t affected by the existence of unnecessary maintenances.

Table I – The impact of the developed approaches in LOLE

<table>
<thead>
<tr>
<th></th>
<th>LOLE (hour/year)</th>
<th>Reliability Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant λ</td>
<td>9.3755</td>
<td></td>
</tr>
<tr>
<td>Variable λ</td>
<td>11.196</td>
<td></td>
</tr>
<tr>
<td>Preventive Maintenance</td>
<td>10.882</td>
<td></td>
</tr>
<tr>
<td>Predictive Maintenance</td>
<td>10.486</td>
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</tbody>
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V. CONCLUSIONS

Through the presented results, we can withdraw several important conclusions. First, it was proved that the inclusion of the real variation of the failure rate has a significant impact upon the reliability indices. Although this new approach is more complex, it allows to include the impact of the natural process of degradation of electrical components. Therefore, with this new approach, it’s possible to understand the moments when maintenance actions should occur. Furthermore, it was possible to figure out that the inclusion of the maintenance policies allowed to extend the useful life period of the generating units.

Another very important conclusion needs to be taken: the improvements on the development of innovative methodologies like the one presented in this paper must be accompanied by improvements on the data storage. Therefore, manufacturers and companies have to start the process of collecting data on the actual variation of the failure rate of the components.

REFERENCES