Development of an Improved Monte Carlo Simulation Algorithm for Reliability Assessment of Large Distribution Systems

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Abstract

Reliability of power system refers to the ability of the system to supply electrical energy to its customers as at when due. Failure of power system to do this makes the system to be unreliable. The parametric indices employed in assessing the level of performance of the power system are termed "reliability indices". Assessment of distribution system reliability can be done with two notable reliability indices- System Average Interruption Duration Index SAIDI and System Average Interruption Frequency Duration Index SAIFI. Previous studies have focused attentions on reliability assessment of large distribution systems using Monte-Carlo simulation method. This Method suffered some draw-backs such as computational efficiency and convergence problems. This research paper then developed an improved Monte-Carlo simulation algorithm for reliability assessment of large distribution systems. In the improved Monte Carlo Simulation algorithm, all the feeders were simulated separately for a period of 100 years. At the end of each iteration, the contribution of outages on various feeders was cumulated to compute the annual system indices and the confidence level of the output data was then computed to determine if the simulation had attained convergence at a specified precision level.

The time of failure and repair duration of all the segments of the feeders were generated and the faults were processed in a sequential order to evaluate the contributions of each outage to the annual system indices-SAIDI and SAIFI. The faults and repair times of the segments were saved after loading the next feeder once the time has reached the iteration period of 100years. Confidence test was performed on the annual system reliability indices-SAIDI and SAIFI after all the feeders have been simulated. Subsystems of different sizes but similar reliability characteristics i.e average SAIDI and SAIFI values were created from the 100 feeder system.

The results of the research paper showed that the computational times increased as the number of feeders increased, thus obeying a linear relationship because the state-duration employed in the algorithm generated a list of failure times for individual feeder segments so that the time of all outages in a given year were known. The same number of faults were generated for obtaining a specified accuracy level for systems of different sizes which indicated that the number of faults that must be simulated for a given accuracy level was independent of the system size.

The mean SAIDI for 100, 90, 80, 70, 60 and 50 feeders were 3.39, 3.36, 3.34, 347, 3.53 and 3.55 respectively while feeders of system sizes 40, 30, 20 and 10 gave mean SAID of 3.68, 3.92, 3.26 and 3.77 respectively because the concept of relative standard deviation can be used to compare the deviation of the reliability indices of different systems.. There was an inverse relationship between the system sizes and the standard deviation. Thus, for system sizes 100, 90, 80, 70, 60, 50, 40, 30, 20 and 10, the standard deviations were 1.287, 1.312, 1.426, 1.510, 1.687, 1.818, 2.113, 2.415, 2.437 and 3.553 respectively. The mean SAIFI did not obey any definite pattern as they fluctuated as the system sizes changed. Thus, for system sizes 100, 80, 60, 40 and 20, the mean SAIFI were recorded as 0.947, 0.912, 0.902, 0.894 and 0.921 respectively due to the configuration of the system feeders. As the system sizes decreased, the SAIFI standard deviation increased proportionately due to the number of customers experiencing prolonged interruptions during the time. The spread of the annual system indices depends on the size of the system, thus the smaller the system size, the greater is the deviation in annual reliability indices. In this case, smaller systems had greater variations in the annual indices as compared to larger systems, even though, the average reliability level was the same in both cases.If the same reliability standard was used for different *systems, smaller systems were likely to experience more interruptions more frequently as compared to larger ones. The reliability standards must ensure that smaller systems were not affected inadvertently.*

The results of the research paper indicated that the performance improvement of the improved Monte Carlo simulations was due to the state-duration method used in the algorithm which generated a list of failure times for individual feeder segment. In addition, as the system size increased, the number of years for which the simulation must be performed to obtain the indices with 85% confidence level decreased and the number of faults analyzed for attainment of convergence which must be simulated for a given accuracy level was independent of the system size

Keywords — *Improved Monte Carlo Simulation, Algorithm, Reliability Indices, SAIDI, SAIFI, Confidence test, Feeders.*

I. INTRODUCTION

Power system reliability is the ability of the power system to provide continuous power to the user. Any interruption of power system will not only result in a large economic loss, but also affect the lives of the citizenry as well as their social lives. A large power system reliability is not only what power consumers demand, but also what power supply organizations pursue in self-development [1],[2],[3],[4].

Reliability assessment methods include: analytical and simulation methods. Analytical method has to do with building a corresponding model according to original reliability data of the components, and the obtaining power grid reliability indicators through mathematical analysis. Analytical method deals with physical concept, high model accuracy and clear logical concept. Complexity in computation increase when the number of components involved increases and direct use of analytical method becomes more difficult when the power grid attains a certain level. Commonly used analytical methods include Failure mode and effects analysis (FMEA). FMEA classifies component failures and determines the impact of the failure in combination with pre order first traversal methods. The algorithm computation increases as the power distribution network increases [5],[6],[7].Simulation method which samples according to probability distribution of components was recently introduced in the field of reliability analysis. It judges the state of components, and then obtains reliability –oriented indicators with the aid of statistical knowledge. Monte Carlo simulation method with intuitive and adequate configurations can handle dynamic load variations. Its accuracy varies linearly as the consumed time.

Monte Carlo Simulation (MCS) Method are free from interference by other components.. For accuracy, MC method involves a lot of simulations which will sacrifice the operation time [8],[9],[10].In MCS, the network is first divided into components and the failure probability of the grid is divided into components, and the failure probability of the grid is simulated according to the failure probability of each component. Such a simulation is an assessment of of the grid to be simulated. After collecting enough data, analysis can be made to obtain relevant and necessary indicators. MC supports evaluation of complex systems irrespective of the structure of the power system network [11],[12], [13].

In the conventional MC method, each component is divided into two states independent from each other. The computational efficiency of Monte Carlo simulation technique can be improved by considering the characteristics of the problem to be solved. Such characteristics include: low component failure rates, outage times and the faults on the feeders. If the time between component outages is assumed to obey the exponential distribution, then the artificial fault history can be developed [14],[15],[26].

A. *Convergence Criteria:*

The number of years to be simulated to obtain satisfactory results of system reliability requires that the distribution system simulation incorporates two stoppage criteria. The simulation process will continue until at least one of the conditions below is satisfied [17],[18],[19].:

(i) The average system indices are computed to be within a specified confidence level.

(ii) The specified maximum number of years to be simulated has been reached.

B. *Simulation Algorithm:*

The outage history of the Monte Carlo simulation represents an imaginary log- book of system outages. The operators log book contains all outages of the system posted in a sequential array. Faults on each feeder are independent. In this way, the MC simulation is carried out for one feeder at a time so that the amount of topological and outage data handled at any time is reduced appreciably. In each iteration of the MC simulation, all the feeders are simulated separately for a period of 100 years. At the end of each iteration, the contribution of outages on various feeders is cumulated to compute the annual system indices and the confidence level of the output data is then computed to determine if the simulation has attained convergence at a specified precision level [20].

C. *Factors affecting Reliability*

The following factors affect reliability of power system [15],[16], [18], [20].:

i. Equipment factors meaning that the power supply of the power grid is affected for the reason of the equipment itself.

ii. Network structures like line segmentation and connection may affect line maintenance which will eventually affect the control of the outage range.
iii. Power outage events which means that the power company needs to cut off a part of the load when there is the need to operate the relevant equipment according to the actual operation of the power grid.
iv. External factors which can be divided into climatic and human factors.
v. Reliability Improvement.

The following measures can be taken to improve the power distribution reliability based on specific grid conditions [1], [11], [13], [16], [17]:

i. Improve equipment reliability.
ii. Change or strengthen the structure of the grid: A strong grid structure can reduce the average time of scheduled and fault outage, which serves as the basis for improving the reliability of the power supply.
iii. Change the equipment mode of maintenance.
iv. Investment in distribution automation equipment.

II. MATERIALS AND METHOD

The following steps are involved in MC simulation:

Step 1: Generate the time of failure and repair duration of all segments of a feeder.

Step 2: Process the faults in a sequential order and evaluate the contributions of each outage to the annual system indices.

Step 3: If the time has reached the iteration period of 100 years, then, load the next feeder. Before loading the new feeder, save the fault and repair times of all the segments so that the next iteration of the simulation can continue from where it was left off.

Step 4: After all the feeders have been simulated, perform confidence test on the annual reliability indices-SAIDI and SAIFI.

Step 5: If stoppage criteria are not satisfied, generate the output history for another 100 years by going back to step 2.

The flowchart of the simulation algorithm is shown in Figure 1.The simulation was performed on a large practical distribution system.

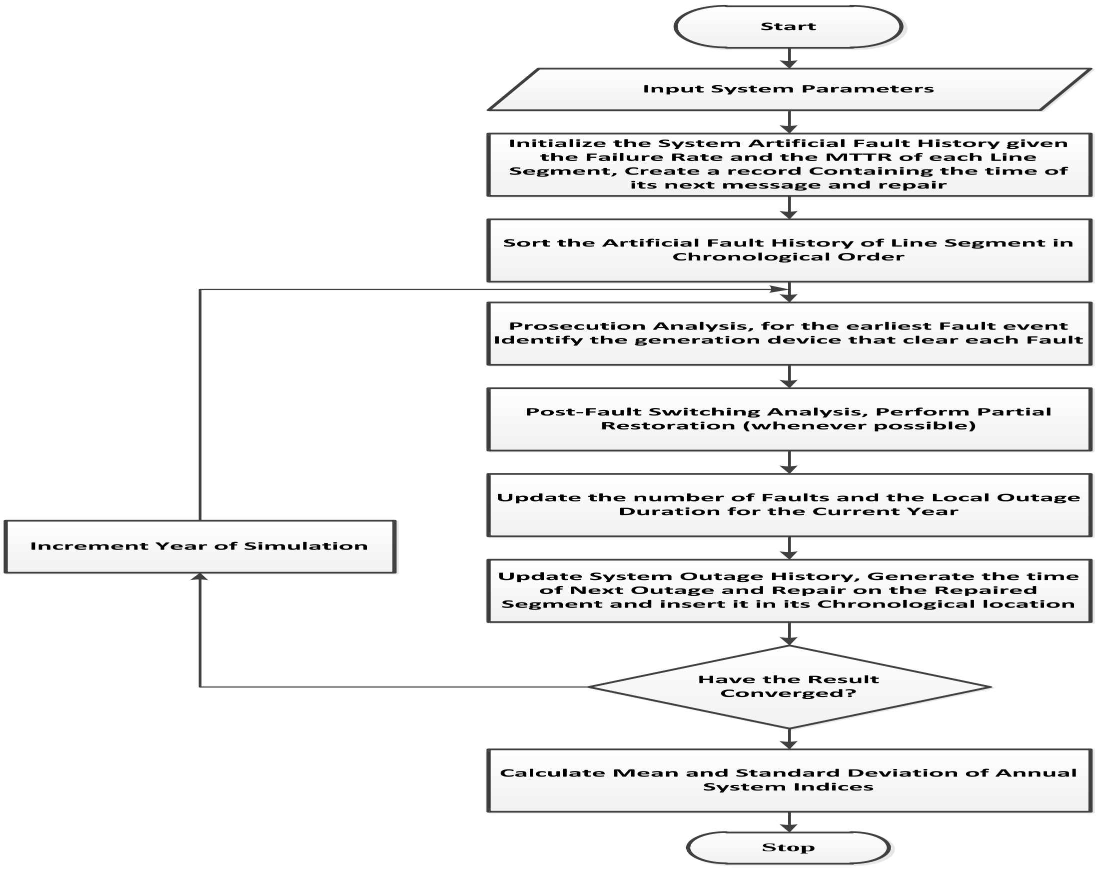

Figure 1: Improved Monte Carlo Simulation for Reliability Assessment

The computational times of the MC simulation for the practical distribution system consisting of 100 feeders is recorded as shown in Table 1.Systems of different sizes but rather similar reliability characteristics were created by randomly selecting subsets of feeders from the 100 feeder system. The simulation is performed until the SAIDI is obtained within 5% error with 95% confidence on a PC with a 300 MHZ Pentium II processor

III. DISCUSSION OF RESULTS

The computational performance of the feeders is illustrated in Figure 1.The computational times increase as the number of feeders increase. The computational times were 7 seconds, 11 seconds and 11 seconds with 10, 20 and 30 feeders respectively. When the number of feeders increased to 100, 120 and 140 feeders, the computational times increased correspondingly to 21 seconds, 23 seconds and 27 seconds respectively because the state-duration employed in the algorithm generates a list of failure times for individual feeder segments so that the time of all outages in a given year are known. The segments are then ordered according to the chronological order of their failure times thus making processing of faults based on such chronologically ordering results in fast computationally efficient calculation of annual feeder indices. Thus, the least computational time of 7 seconds was recorded with 10 feeders while with 200 feeders, the highest computational times of 38 seconds were recorded.

Figure 2 shows the convergence characteristics of the simulation. The simulation converged after 220 years for 10 feeders. For 20, 30, 40 and 50 feeders, the simulation converged after 335 seconds, 250 seconds. 230 seconds and 220 seconds respectively. As the number of feeders increased to 100, 120, 140, 160, 180 and 200, the simulation duration appreciably decreased to 110 years, 95 years, 70 years, 55 years and 35 years respectively. Observation from the Figure revealed that the fewer the number of feeders, the higher the simulation duration hence the higher the convergence rate and vice-versa. This is because individual feeders can be simulated independently since failures on one feeder are independent of other feeders. Thus, as the system size increases, the number of years for which the simulations were performed to obtain the indices with about 98% confidence decreased. As a result of this, at any given time, only the segments of one feeder were processed instead of all the line segments of the system, thereby reducing the memory requirements to enhance the computational performance.

Figure 3 illustrates the number of faults analyzed to obtain convergence which is was plotted as a function of the system size .For 10feedres, 20feeders and 30feeders, 46650, 49750 and 50350faults were simulated. When the number of feeders increased to 50, 100, 150 and 200, the number of faults simulated became 53250, 49850, 50100 and 52340 respectively. However, the same number of faults were generated for obtaining a specified accuracy level for systems of different sizes which indicated that the number of faults that must be simulated for a given accuracy level was independent of the system size.

Subsystems of different sizes but similar reliability characteristics i.e average SAIDI and SAIFI values were created from the 100 feeder system. The average SAIDI and SAIFI for the subsystems are shown in Figures 4 to 9. The mean SAIDI for the distribution system is illustrated in Figure 4.The mean SAIDI for 100, 90, 80, 70, 60 and 50 feeders were 3.39, 3.36, 3.34, 347, 3.53 and 3.55 respectively while feeders of system sizes 40, 30, 20 and 10 gave mean SAID of 3.68, 3.92, 3.26 and 3.77 respectively because the concept of relative standard deviation can be used to compare the deviation of the reliability indices of different systems.. The relative standard deviation is is the ratio of the standard deviation of a random variable to its mean value. Figure 5 shows the SAIDI standard deviation for the distribution system feeders.

Observation from the Figure reveals that there is an inverse relationship between the system sizes and the standard deviation. Thus, for system sizes 100, 90, 80, 70, 60, 50, 40, 30, 20 and 10, the standard deviations were 1.287, 1.312, 1.426, 1.510, 1.687, 1.818, 2.113, 2.415, 2.437 and 3.553 respectively. The mean SAIFI for the distribution system feeders were displayed in Figure 6. The mean SAIFI did not obey any definite pattern as they fluctuated as the system sizes changed. Thus, for system sizes 100, 80, 60, 40 and 20, the mean SAIFI were recorded as 0.947, 0.912, 0.902, 0.894 and 0.921 respectively due to the configuration of the system feeders. Figure 7 showed the SAIFI standard deviation for the distribution system feeders. As the system sizes decreased, the SAIFI standard deviation increased proportionately due to the number of customers experiencing prolonged interruptions during the time. Figure 8 shows the SAIDI mean and standard deviation of the distribution feeders. The spread of the annual system indices depends on the size of the system, thus the smaller the system size, the greater is the deviation in annual reliability indices. In this case, smaller systems have greater variations in the annual indices as compared to larger systems, even though, the average reliability level is the same in both cases.

Figure 9 illustrates the SAIFI mean and standard deviation for the distribution system feeders. If the same reliability standard is used for different systems, smaller systems are likely to experience more interruptions more frequently as compared to larger ones. The reliability standards must ensure that smaller systems are not affected inadvertently. The comparative analysis of SAIDI mean and standard deviation as well as the SAIFI mean and standard deviation are illustrated in Figure 10. Variations of the mean and standard deviations of the system reliability indices-SAIDI and SAIFI with respect to the system sizes were clearly revealed at a glance. Thus, the SAIDI mean and standard deviation with system size 100 were 3.39 and 1.287 respectively while the SAIFI mean and standard deviation for the same system size of 100 were 0.947 and 0.2995 respectively.

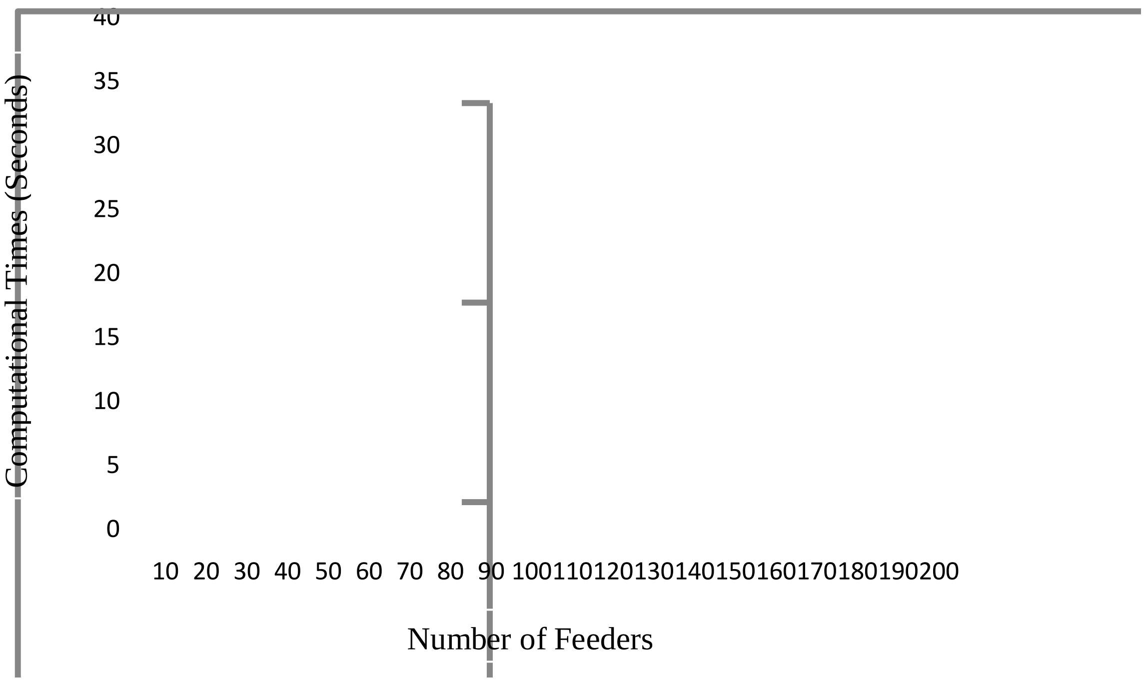

Figure 1: Computational Performance of Monte Carlo Simulation

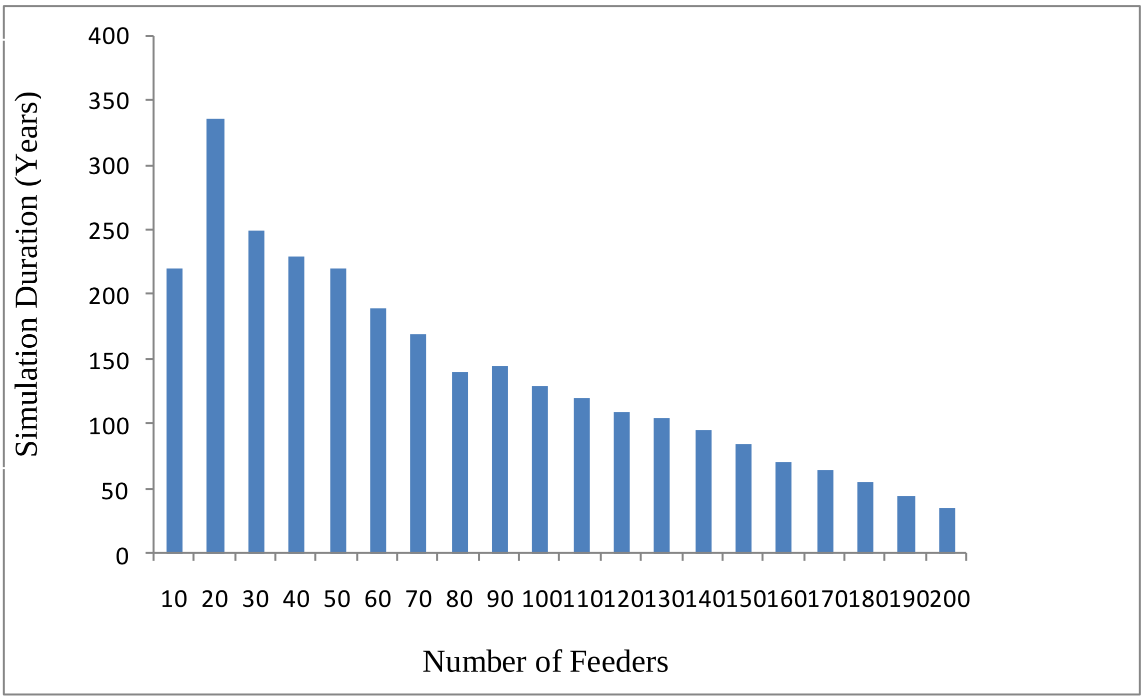

Figure 2: Convergence Characteristic of the Simulation

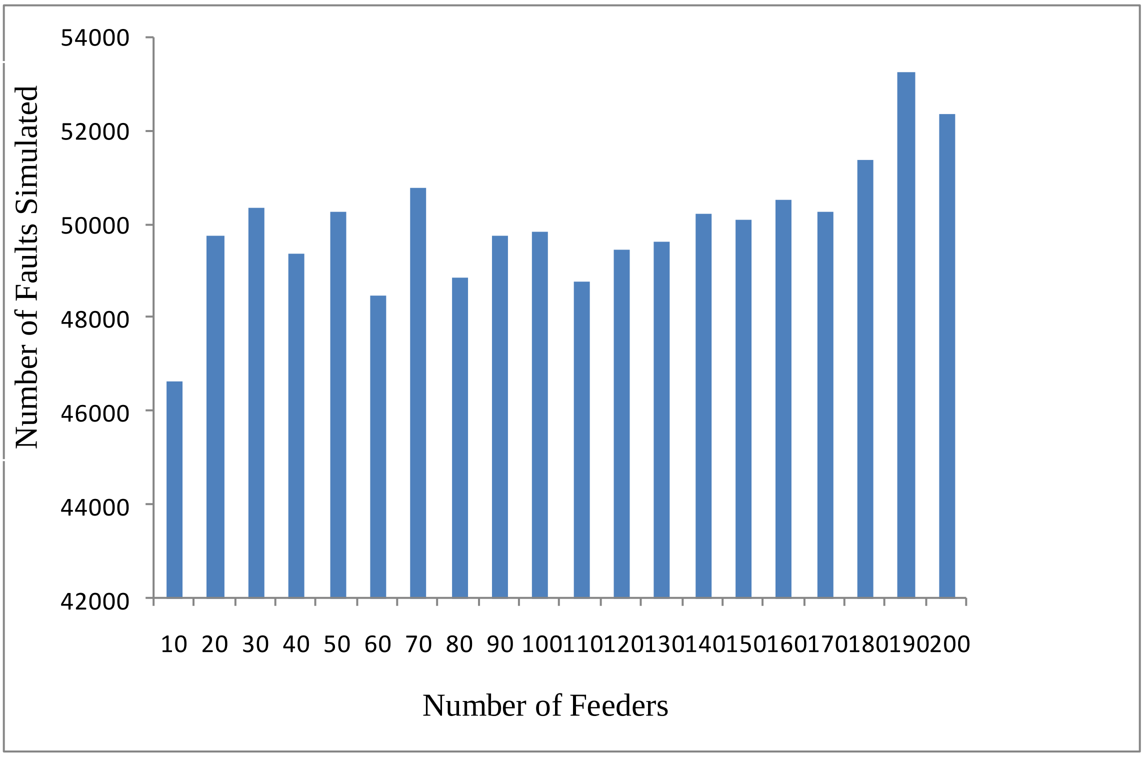

Figure 3: Fault Simulated

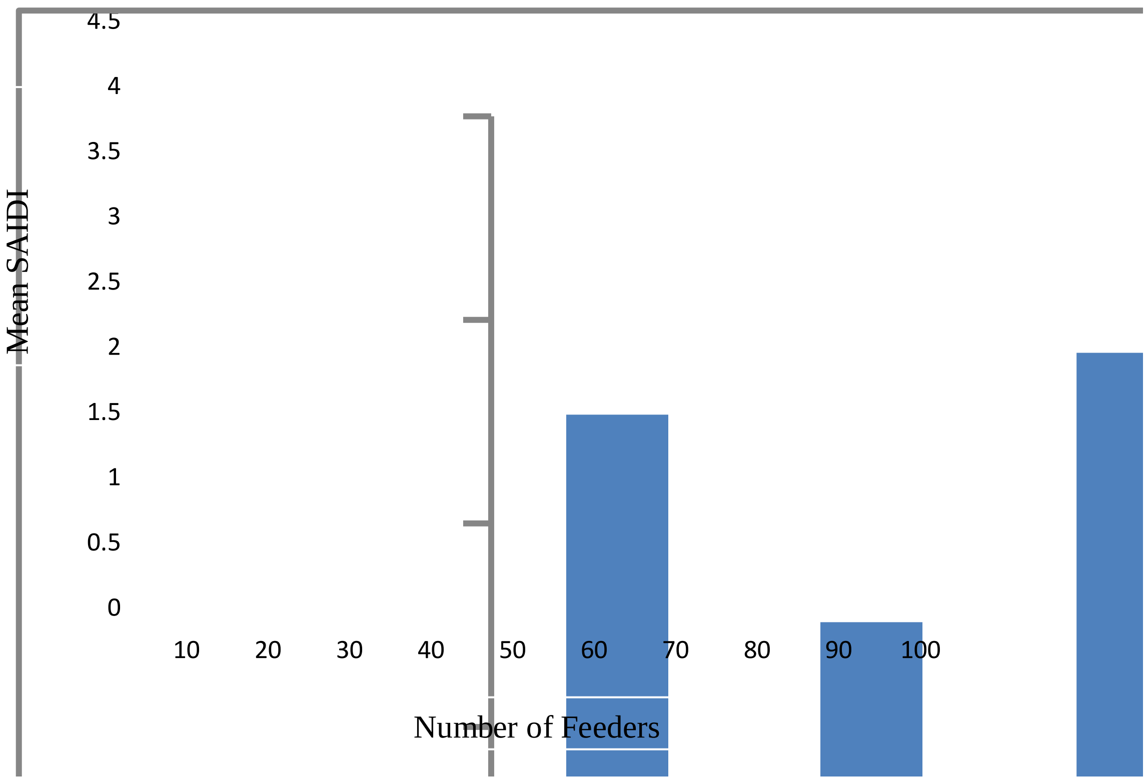

Figure 4: Mean SAIDI for Distribution Feeders

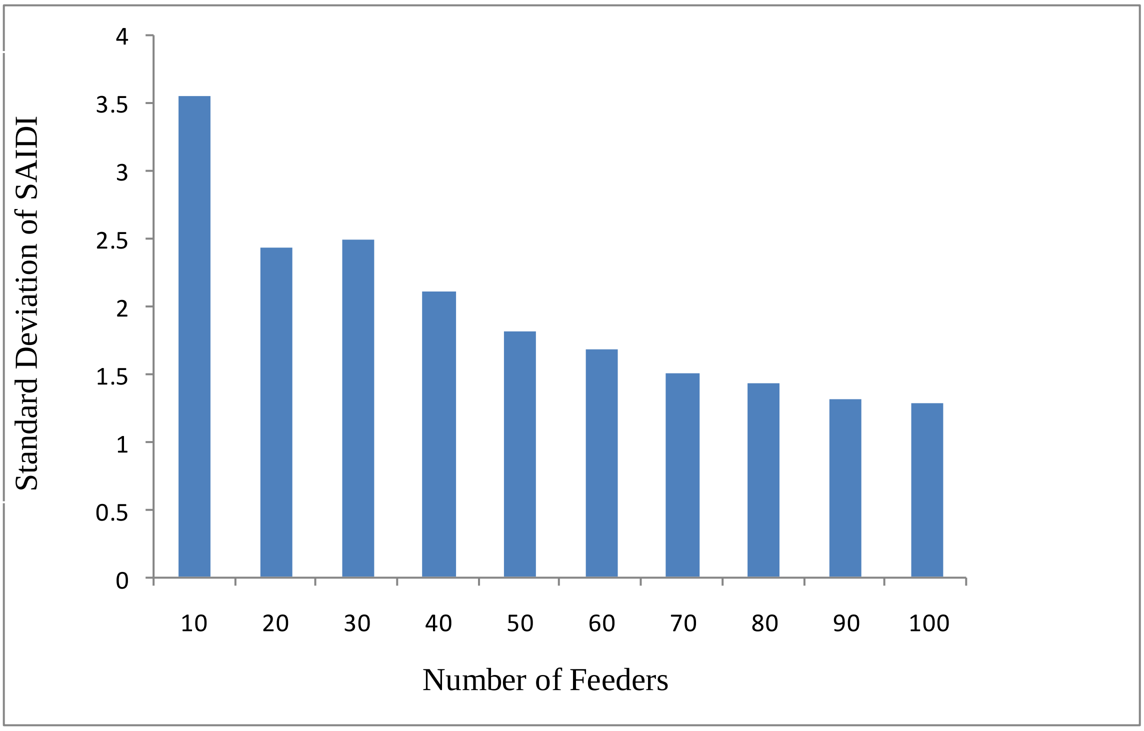

Figure 5: Standard Deviation of SAIDI for Distribution Feeders

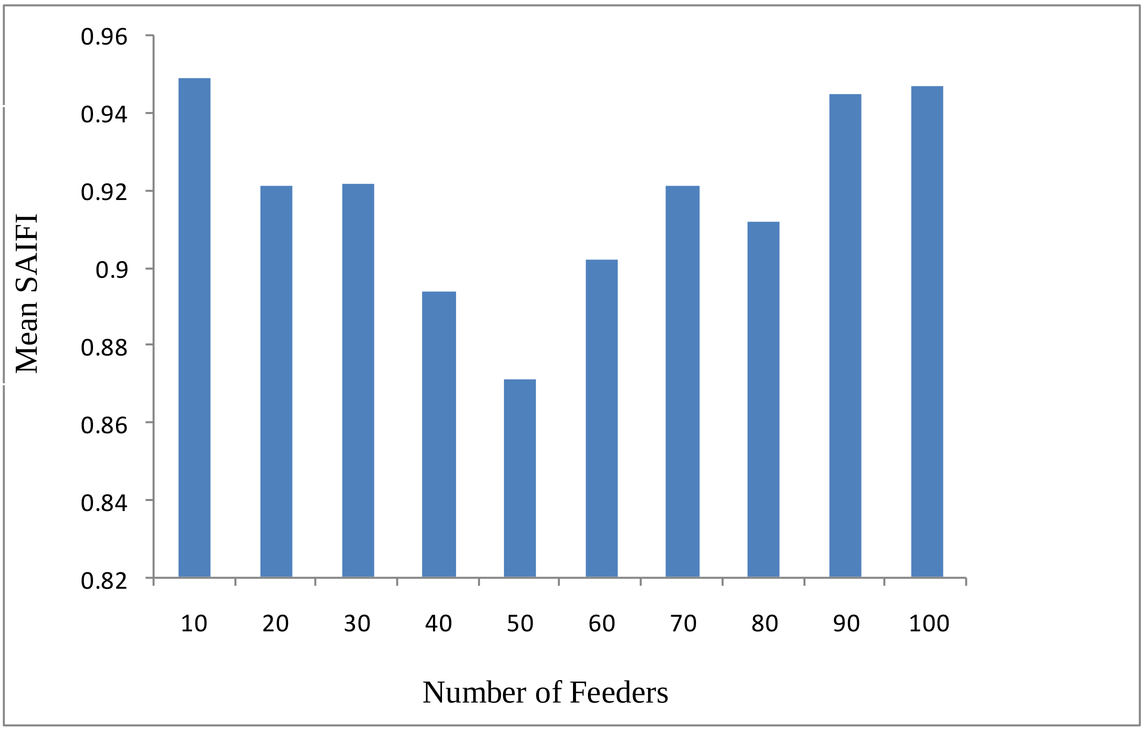

Figure 6: Mean SAIFI for Distribution Feeders

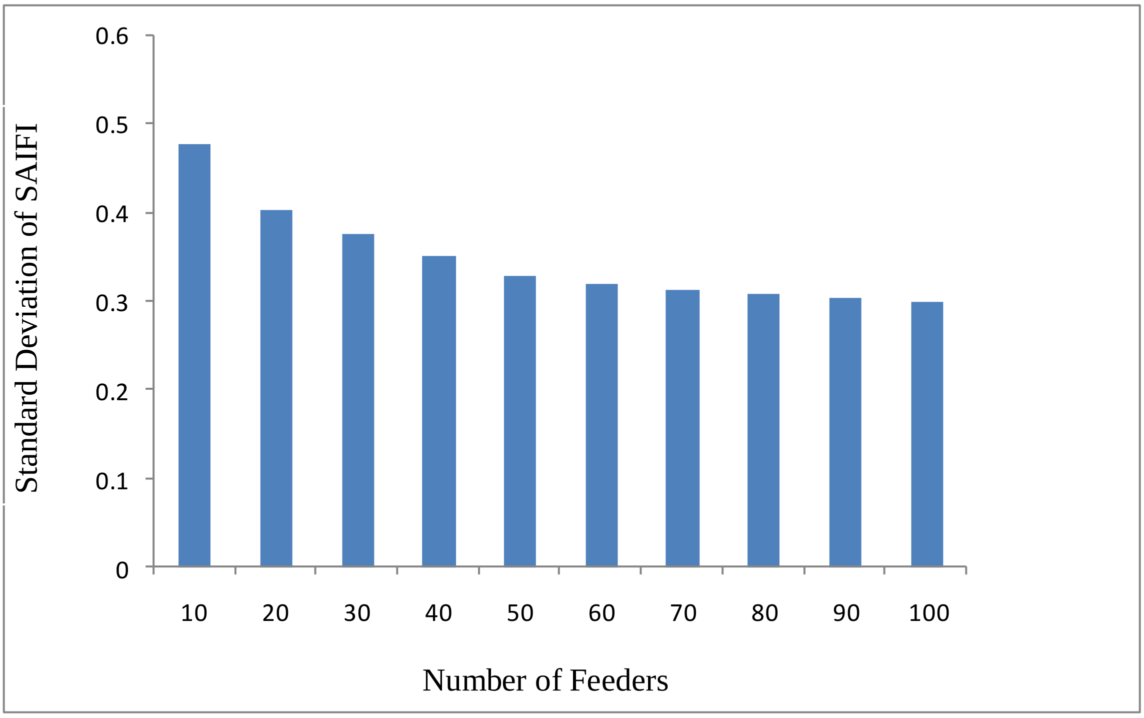

Figure 7: Standard Deviation of SAIFI for Distribution Feeders

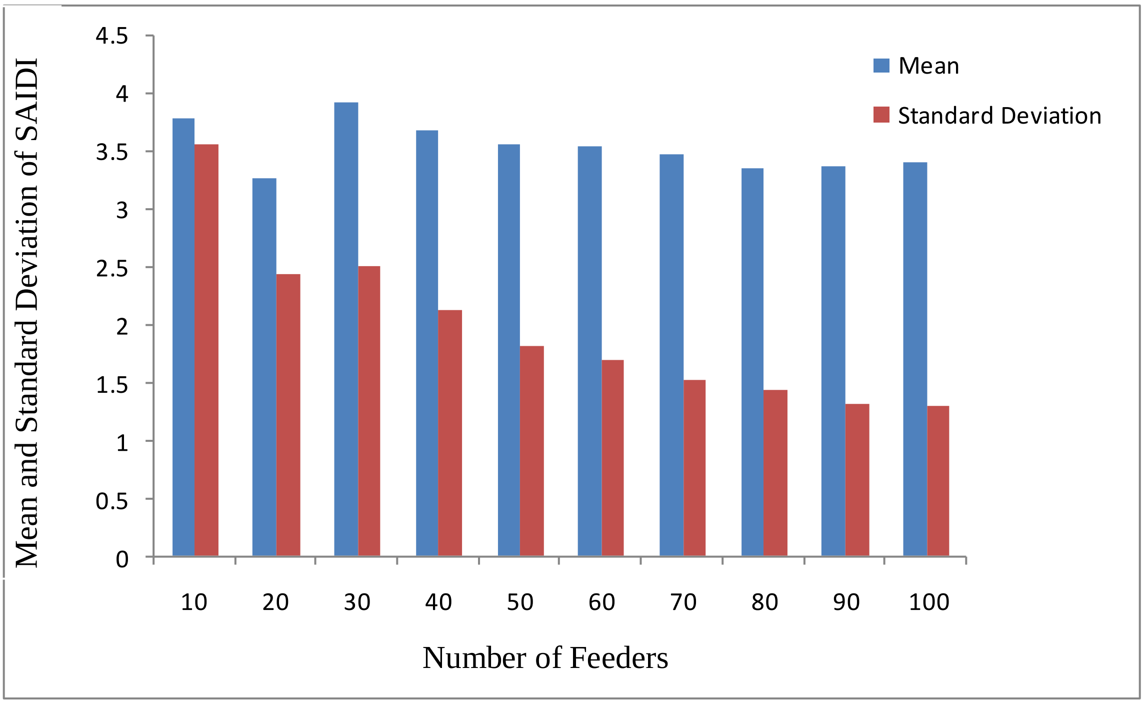

Figure 8: Mean and Standard Deviation of SAIDI

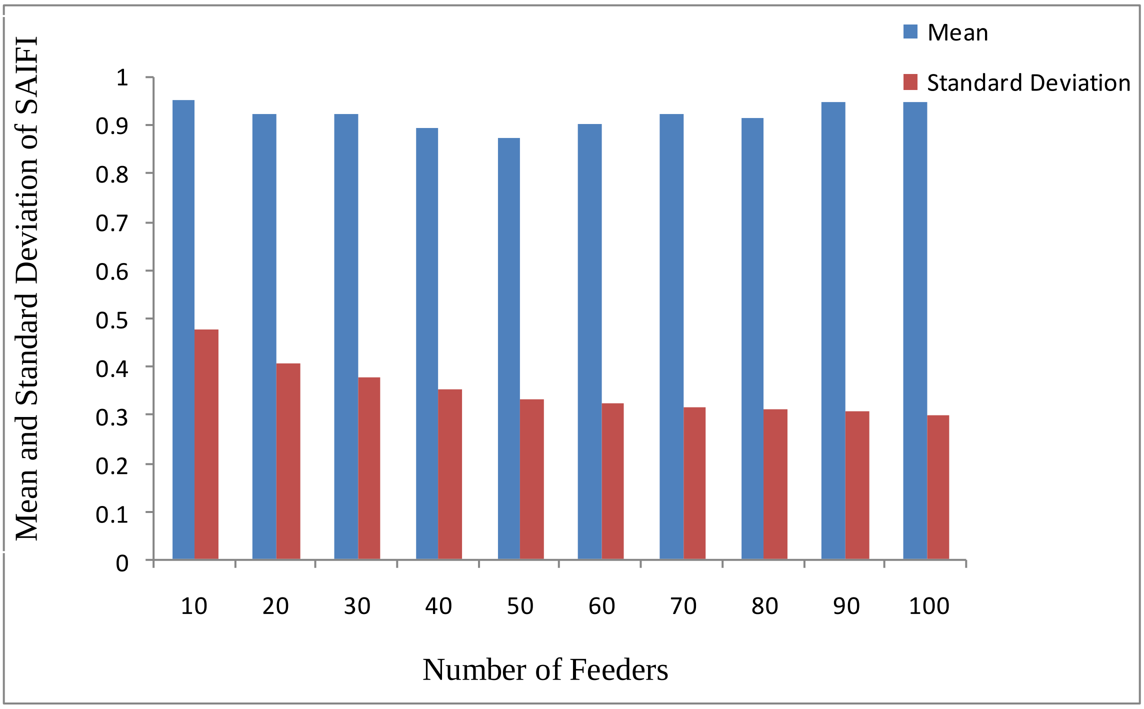

Figure 9: Mean and Standard Deviation of SAIFI

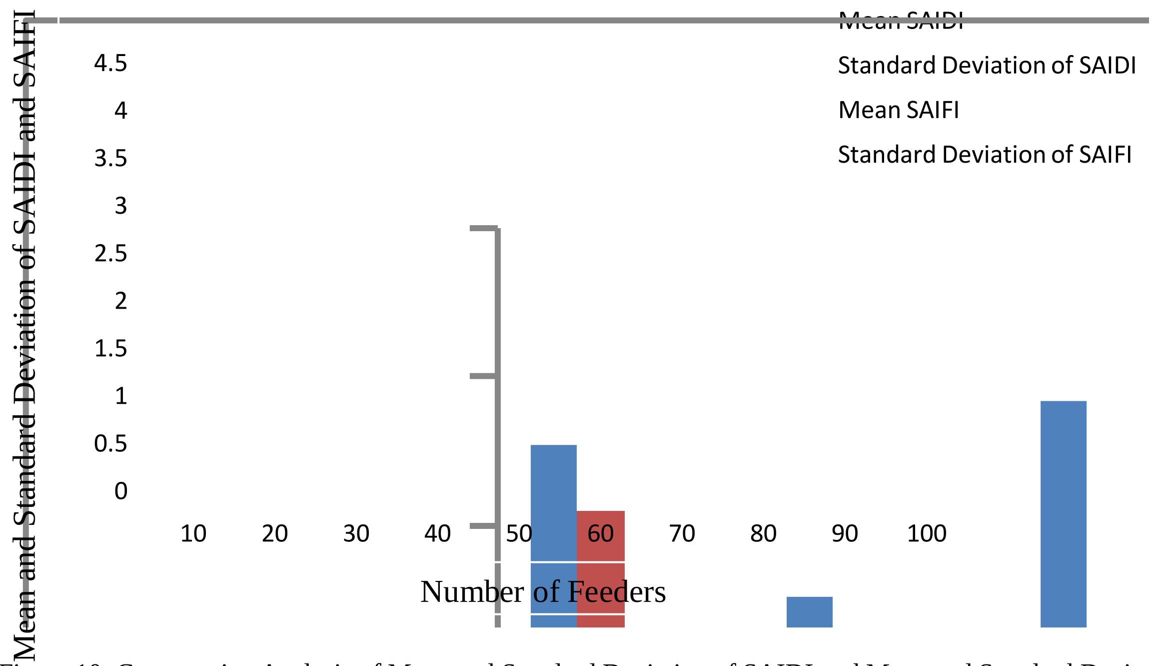

Figure 10: Comparative Analysis of Mean and Standard Deviation of SAIDI and Mean and Standard Deviation of SAIFI

IV. CONCLUSIONS

An improved Monte Carlo simulation algorithm for reliability assessment of large distribution system has been developed. The results of the research paper indicated that the performance improvement of the improved Monte Carlo simulations was due to the state-duration method used in the algorithm which generated a list of failure times for individual feeder segments. In addition, as the system size increased, the number of years for which the simulation must be performed to obtain the indices with 85% confidence level decreased. and the number of faults analyzed for attainment of convergence which must be simulated for a given accuracy level was independent of the system size

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