RELIABILITY EVALUATION OF DISTRIBUTION SYSTEM IN THE PRESENCE OF UPS USING TIME SEQUENTIAL MONTE CARLO SIMULATION

Dr. C. BHARGAVA
Associate professor
SNIST, HYD
bhargav_3417@gmail.com

R. SOUPRIKA
Student
SNIST, HYD
souprika240@gmail.com

ABSTRACT

*Smart Grid initiative requires improvements to distribution system operation. If Distribution system is not reliable, the utility unable to get continuous power supply. In this paper the main concept is to improve the reliability of distribution system. One of the improvements is to use battery storage to support the distribution system. These batteries have the ability to improve the system reliability. The best method is used to improve the reliability of distribution system is Time Sequential Monte Carlo Simulation (TSMC). This algorithm is applied to Roy Billinton Test system (RBTS). The first part of the work is to evaluate reliability indices using TSMC and results are compared with analytical. The second part of the work evaluates the reliability indices of the system with battery storage and results are compared with the reliability indices of system without battery. This operation is performed in the MATLAB/SIMULINK platform***.**

Keywords— *Reliability, Roy Billinton Test System, reliability indices, Battery model, Time Sequential Monte Carlo Simulation.*

I. INTRODUCTION

Reliability is the main important factor in designing and planning of distribution systems that should operate in an economic manner with less interruption of customer loads. Over the past decades distribution systems have less concentration on reliability than generating systems. The main reasons are that the generating systems are very capital investment and generation inadequacy will have greater impact on both the transmission and distribution systems. A distribution system is relatively cheap and outages have a much localized effect compared to generating system.

The main purpose of a power distribution system is to supply electricity to its customers in an economical and reliable manner. It is important to maintain reliable power supply to utilities, because of cost of interruptions and power outages .In the distribution systems, most of the outages or failures would result in direct impact on the customers. If the distribution is not reliable even though the generation and transmission systems are reliable, the utility unable to get continuous power supply. This problem clearly explains the importance of reliability of distribution systems. In this paper the reliability of distribution system is improved by using battery storage system [1]. For decreasing the complexity in the calculation, the fallowing assumptions are considering. Namely (i) infinite battery capacity based [5](ii) the life of the battery is assumed to be infinite .

Reliability of distribution system is calculated by using primary indices these are failure rate, repair rate, unavailability which is random in nature. These indices are, given by mean values of probability distributions. The mean values of the probability distributions are useful to calculate the reliability indices in the conventional and simulation method. The basic distributed system reliability indices at a load point are average failure rate (λ), average repair rate (r), and annual outage duration (U)[2]. With these three basic load point indices, the following system reliability indices can be calculated. To model the effects accurately heavy tailed distributions such as chi-squared, log normal or Weibull distribution could be used [9]. These require simulation based analysis as analytical modeling will be complex.

In this paper for improving reliability of distribution system Time Sequential Monte Carlo simulation is used. This method is executed in MATLAB/SIMULINK platform. This algorithm is implemented to RBTS distribution system without and with battery storage and obtain results are compared. Monte-Carlo simulation have been used to model the battery as storage element in distribution system to decrease the outage duration of customers. Time Sequential Monte Carlo Simulation (TSMC) [6] is one such technique that simulates the operating life of each component in a system over a long period of time and provides useful information about the failure duration of each element and number of failures of each element over a simulation period. This paper focuses on improving reliability of distribution system with battery storage. This battery storage system reduces the outage time of customers. The battery storage system has repair rate and failure rate, state of charge, battery age and battery capacity. The TSMC is applied to RBTS system without and with battery storage. This algorithm gives the reliability indices of system without and with battery and these results are compared.

II. DISTRIBUTION SYSTEM RELIABILITY

Distribution system consists of several components are arranged in different manner. Distribution system consisting of circuit breakers, transmission lines/cables, disconnects etc. A number of customers connected to a particular node will create a load point. Proper functioning of all the components up to the load point is important. Failure to do so results in interruption downstream. The basic reliability parameters such as average failure rate (λ), average outage time (r) and annual outage time (u); equations (1), (2) and (3) are calculated based on principle of series system [2].

$$\lambda_s=\sum_i \lambda_i \quad (1)$$

$$U_s=\sum_i \lambda_i r_i \quad (2)$$

$$r_s=\frac{U_s}{\lambda_s}=\frac{\sum_i \lambda_i r_i}{\sum_i \lambda_i} \quad (3)$$

Where $\lambda_i$the failure rate of component is, $r_i$is the repair rate of the component, and U_s is the unavailability of the component.

System average interruption frequency index (SAIFI) is the measure of number of interruptions seen by an average customer and is defined as:

$$\text{SAIFI}=\frac{\text{total number of customers interruption}}{\text{total number of customers served}}=\frac{\sum_i \lambda_i N_i}{N_i}$$

System average interruption duration index (SAIDI) is the measure of the duration of outage seen by an average customer and is defined as:

$$\text{SAIDI}=\frac{\text{sumofcustom erinterruptionduration}}{\text{totalnumberofcustomersserved}}=\frac{\sum U_i N_i}{N_i}$$

Customer average interruption duration index(CAIDI) is defined as:

$$\text{CAIDI}=\frac{\text{total customer imterruption duration}}{\text{total number of customers interruption}}=\frac{\sum U_i N_i}{\sum \lambda_i N_i}$$

III LOAD POINT FAILURE CALCULATION

The calculation of load point failure with battery storage is difficult in a distribution network [10]. These calculations are given in the form of matrices. This matrix gives the information about how the failure elements affect the other elements or load points in the system. This matrix reduces the computational time other than using a search algorithm. This matrix is applied to feeder 1 of RBTS system is shown in fig4. The following matrices are given below

Element Switching Matrix (ESM)

The matrix gives the information about the position of the circuit breaker and isolation switch. For each protection device in the system is given by a unique number. If any element in the system fails first circuit breaker is open then the adjacent switches are open after that the circuit breaker is closed. IF 'A' section is failed, the position of the switches of each section and load point protection devices is indicated in the matrix ESM . The below matrix is for feeder1 in the fig4 showing that the circuit breaker and isolator are indicated by 1 and 2 respectively.

$$ESM = \begin{array}{c} \begin{matrix} A & B & C & D & E & F & G & H & I & J & K \end{matrix} \\ \begin{bmatrix} 1 & 1 & 1 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 \end{bmatrix} \end{array}$$

B. Element Load Matrix (ELM)

This matrix is used to identify the load points which are undergoes repair and which load points are supplied by the alternative source, if any section or element fails. The rows and columns represent the sections and load points respectively in the matrix. The repair time and restoration by battery storage is represented by 1 and 2 in the below matrix. The below matrix is for feeder1in fig4,

$$ELM = \begin{array}{c} \begin{matrix} L_1 & L_2 & L_3 & L_4 & L_5 & L_6 & L_7 \end{matrix} \\ \begin{bmatrix} 1 & 1 & 2 & 2 & 2 & 2 & 2 \\ 1 & 1 & 2 & 2 & 2 & 2 & 2 \\ 1 & 1 & 2 & 2 & 2 & 2 & 2 \\ 2 & 2 & 1 & 1 & 2 & 2 & 2 \\ 2 & 2 & 1 & 1 & 2 & 2 & 2 \\ 2 & 2 & 1 & 1 & 2 & 2 & 2 \\ 2 & 2 & 2 & 2 & 1 & 1 & 2 \\ 2 & 2 & 2 & 2 & 1 & 1 & 2 \\ 2 & 2 & 2 & 2 & 1 & 1 & 2 \\ 2 & 2 & 2 & 2 & 2 & 2 & 1 \\ 2 & 2 & 2 & 2 & 2 & 2 & 1 \end{bmatrix} \end{array}$$

IV BATTERY MODEL

Batteries are made of stacked cells wherein chemical energy is converted into electrical energy. The desired battery voltage as well as current levels is obtained by electrically connecting the cells series or parallel.

In this work valve regulated lead acid (VRLA) batteries are used, as VRLA batteries are widely used in telecommunication industry due to their low maintenance and long life [12].

During charge and discharging the battery capacity deceases with age. The battery capacity is calculated by the following equation,

$$C(t) = (\beta t^5 - \theta t^4 + \vartheta t^3 - \varepsilon t^2 + \rho t + \sigma)$$

Where,
t= battery age, C= design capacity and constant parameters are $\beta = 1.72\times 10^{-4}, \theta = 0.0107, \vartheta = 0.24, \varepsilon = 2.47, \rho = 11.43, \sigma = 86.4$

The battery capacity is expected to be 100% but the charging and discharging of the battery capacity is reduces with age. State of charge is defined as how much time the battery has to perform before it takes recharging. Due to the age the battery capacity is less than 100%. In practical the SoC is calculated by using Weilbull distribution. This distribution consists two parameters that is sacle parameter and shape parameter,this values are given below

soc=wei(1,1.1)

The UPS considered for the paper is a non redundant uninterruptible power supply type shown in Fig.2 , [8]without static transfer switch (STS) as the load is not switched between two sources.

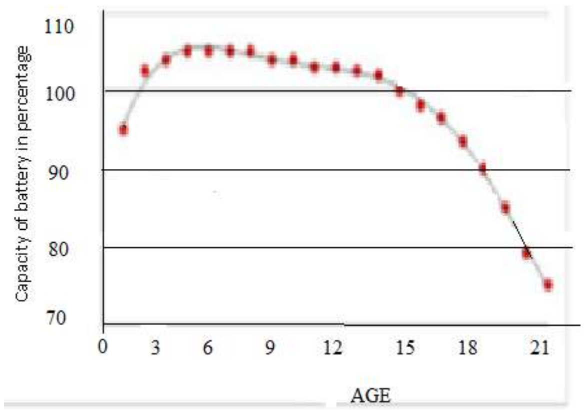


Fig1. Age versus battery capacity

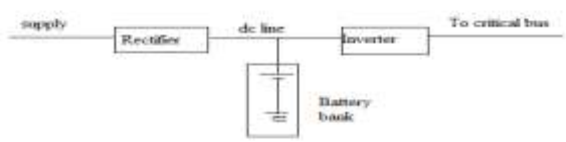


Fig2: uninterruptible power supply

Table1: Uninterruptible power supply data

Compnent	Failure Rate (f/hr)	Repair time (hr)
Supply	$6.1259X10^{-5}$	5.66
Inverter	$1.4305x10^{-4}$	107
Rectifier	$4.3349x10^{-5}$	39
Battery	$3.5706x10^{-5}$	24

Since the battery has repair rate failure rate, and battery capacity in terms of time and SoC, algorithm is developed to compute the outage time of the component which is connected to the battery. TSMC algorithm is used to calculate the unavailability of load points with battery storage.

V MONTECARLO SIMULATION

Monte Carlo simulation performs risk analysis by building models of possible results by substituting a range of values. It gives reliability indices and probability distribution graphs. Simulation period is given in the algorithm so the calculations are repeat up to the simulation time. For each time the random number of elements are changed. This algorithm performs thousands time before it completes.

Time to fail from the present time of any component cannot be represented by a deterministic value. Due to the randomness in the operating conditions and operational behavior the failure time of any component needs to be represented by a probabilistic distribution. Similarly time to repair a component is also random due to the availability of the components, human behavior etc. In most cases the time to fail (up time) and time to repair (down time) of the elements follow a distribution. In most of the engineering analysis exponential distribution is used to simplify the computation. However different probability distributions such as lognormal, gamma, Poisson and normal distributions can be used to simulate these times [3].

The time to fail, TTF, is determined for probability distribution by,

$$TTF=1/\lambda(t)$$

Where $\lambda(t)$ is the failure rate for the given distribution. The time to repair is determined by,

$$TTR=1/\mu(t)$$

Where, $\mu(t)$ is the repair rate as probability distribution function. The time to switch is determined by,

$$TTS=1/\delta(t)$$

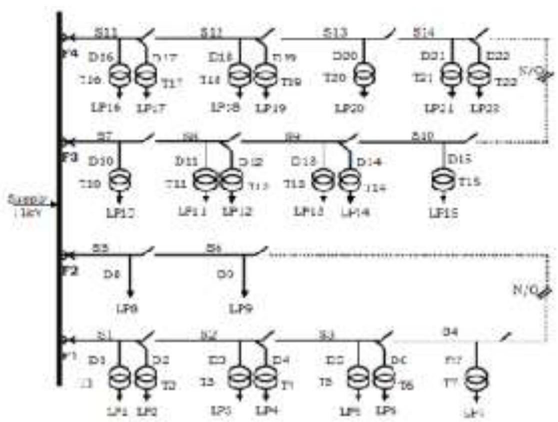


Fig 3: RBTS system

Table2: Feeder section and lateral distributor lengths

Length	Feeder sections	Lateral distributors
0.60 km	S4, S6, S9, S14	D1, D4, D10, D15, D17, D18
0.75 km	S1, S2, S3, S5,S7,S10, S12, S13	D6, D11, D13, D16, D21
0.80 km	S8, S11	D2, D3, D5, D7, D8, D9,D12, D14, D19, D20, D22

The length of feeder section and lateral distributors is given in the table 2. The RBTS system date is given in [1].

VI OPERATION AND SIMULATION

The following algorithm is used to calculate the reliability indices of distribution system with battery storage.

A. Algorithm

Step 1: Generate TTF for all the components

Step 2: Compare the TTF's of each element, determine the element with minimum TTF.

Step 3: Generate the TTR and TTS for the element with minimum TTF.

Step 4: Determine the load points that are affected by the failed element, load points that can be restored by the main supply and the ones that can be restored by battery; using the element switching matrix (ESM) and the element load point matrix (ELM).

Step5: give the battery data

Step6: check the condition BAT>TTR+SW, it satisfies go to next step14,otherwise go to step 13.

Step7: check the condition TTR+SW>TTFB, it satisfies go to next step, otherwise go to step 13

Step8: count=o, UP=0

Step9: determine TTRB

Step10: UP=UP+TTFB, Count = Count=TTFB+TTRB

Step11: check the condition TTR<COUNT, it satisfy go to step21 ,otherwise go to next step 23

Step12: compute new TTFB and go back to step9.

Step13: UA=SW

Step14: check BAT>TTFB, it satisfies go to next step, otherwise go to step 20

Step15: COUNT=0, UP=0.

Step16: determine TTRB

Step17: UP=UP+TTFB,COUNT=COUNT+TTFB+ TTRB.

Step18: check BAT<COUNT, it satisfies go to step 21 ,otherwise go to next step.

Step19: compute new TTFB and go to step 16

Step20: UA = TTR+SWTBAT

Stpe21: check TTR>COUNT-TTRB, it satisfies go to next step, otherwise go to step

Step22: UA = TTR –Up+ SW

Step23: UA = Count –Up –TTR B+SW

Step24: Generate a new TTF for the failed element; update the TTF of every element incorporating the outage time using the following relationship.

$$TTF_{i(new)} = TTF_{i(new)} + \beta(t)\ (TTR_k - \text{TTRB})$$

Where, subscript i denotes every element that saw the outage due of failure of element k. β(t) is a probability distribution function associated with the prolonged life of component i. and TTRB is the time to repair of battery.

Step25: Calculate the number and duration of failures for each load point for each year.

Step26: Calculate the average value of the load point failure rate and failure duration for the sample years.

Step27: Calculate the system indices of SAIFI, SAIDI, CAIDI, ECOST, ENS and IEAR and record these indices for each year.

Step28: Calculate the average values of these system indices.

Step29: Return to **Step 3** if the simulation time is less than the specified total simulation years, otherwise output the results.

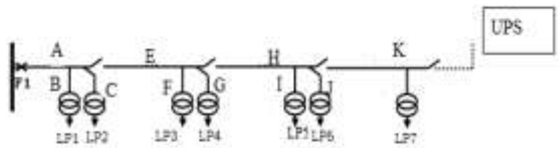


Fig4: feeder1 of RBTS system

VII RESULTS AND ANALYSIS

The results consists two steps. First the results are obtained by analytical method and TSMC method. These results are compared. The second step is done by performing TSMC method on RBTS system in the presence battery. These results are compared with the results which are obtained for the RBTS system without adding battery. The result of TSMC is computed by averaging of 100 runs for 1yr.

SAIFI is approximately equal in both the cases and SAIDI is reduced. The higher the battery capacity lower is the SAIDI. However, the failure rate of UPS has negligible effect on SAIDI. The cost worth indices i.e ENS, ECOST AND IEAR also reduced and it is shown in the fig.

The results of below **Table** gives the Information about system/secondary indices for each feeder without battery and with battery using Monte Carlo simulation and percentage deviation. The system indices are calculated by average of all feeder values. The system SAIFI is improved to 18% and SAIDI is improved to 4% and CAIDI is improved to 8%. It is clear that the system indices are improved using battery storage in the system compared to system without battery.

Table3: comparison of system indices

Feeder	SAIFI(inte/cust)			SAIDI(hr/cust)			CAIDI(hr/cust.inte)		
	with out UPS	with UPS	percentage difference	with out UPS	with UPS	percentage difference	with out UPS	with UPS	percentage diffrence
F1	0.213	0.2	6%	0.714	0.612	14%	3.343	3.053	9%
F2	0.313	0.119	62%	0.463	0.501	-8%	3.864	3.698	4%
F3	0.175	0.153	62%	0.727	0.730	0%	4.138	3.724	10%
F4	0.215	0.223	-40%	0.763	0.716	6%	3.541	3.208	20%
System	0.229	0.117	18%	0.666	0.639	4%	3.721	3.420	8%

The below Table shows the comparison of percentage difference in cost/worth indices. From the table, the indices are improved by using battery than without battery. The ECOST of system is improved to 6%. The IENS of system is improved to 13%. The IEAR of system is improved to 1%. It is clear that the cost/worth indices are improved using battery storage in the system compared to system without battery.

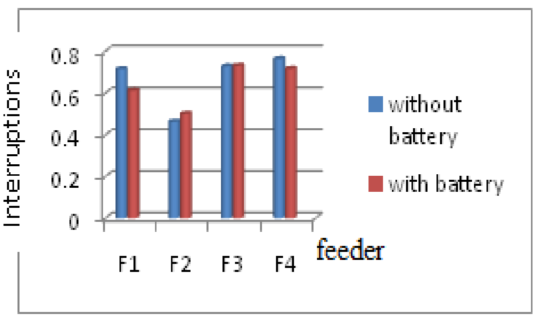
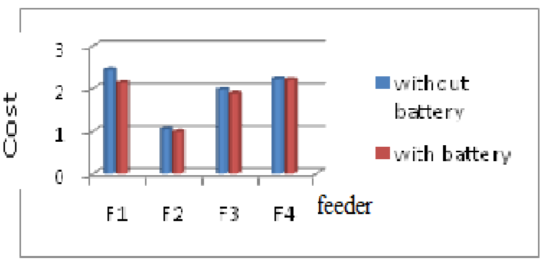


Fig5: comparison of SAIDI for each feeder

The above fig shows the comparison of SAIDI of each feeder. The comparison between the system with and without battery was shown in the above Fig. From the graph it is clear the SAIDI of each feeder is reduced with system having battery than system without battery. It means SAIDI is improved.

Table 4: comparison of cost/worth indices

Feeder	ECOST(kRs/hr)			EENS(MWh/yr)			IEAR(Rs/kwh)		
	with out UPS	with UPS	percentage difference	with out UPS	with UPS	percentage difference	with out UPS	with UPS	percentage diffrence
F1	6.612	5.797	12%	2.437	2.134	12%	2.712	2.815	-4%
F2	17.859	16.988	5%	1.040	0.981	6%	17.167	17.050	1%
F3	4.894	4.65	5%	1.967	1.879	4%	2.448	2.509	-2%
F4	7.286	6.854	6%	2.216	2.194	1%	3.287	3.123	5%
System	9.162	8.572	6%	1.915	1.797	13%	6.403	6.374	1%



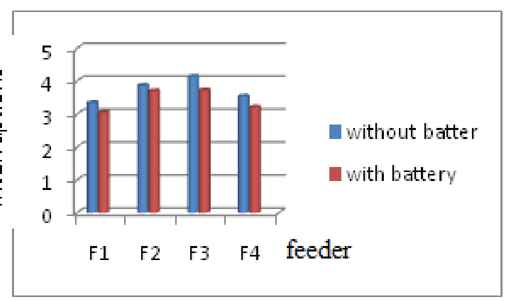


Fig6: comparison of CAIDI for each feeder

The above fig shows the comparison of CAIDI of each feeder. The comparison between the system with and without UPS was shown in the above Fig. From the graph it is clear the CAIDI of each feeder is reduced with system having UPS than system without UPS. It means CAIDI is improved.

Fig7: comparison of ECOST for each feeder

The above fig shows the comparison of ECOST of each feeder. The comparison between the system with and without UPS was shown in the above Fig. From the graph it is clear the ECOST of each feeder is reduced with system having UPS than system without UPS. It means ECOST is improved.

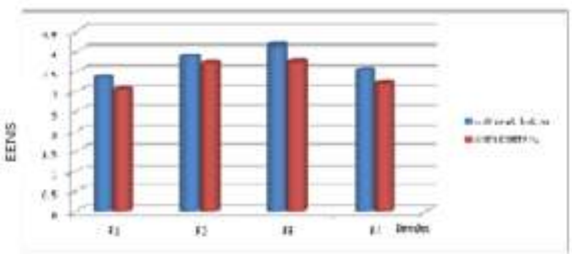


Fig8: comparison of EENS for each feeder.

The above fig shows the comparison of EENS of each feeder. The comparison between the system with and without UPS was shown in the above Fig. From the graph it is clear the EENS of each feeder is reduced with system having UPS than system without UPS. It means EENS is improved

VIII CONCLUSION

In this paper, Time sequential Monte-Carlo simulation method for calculation of distribution system including UPS has been presented. The sequential Monte-Carlo simulation without UPS is used to compare with the proposed method with UPS. The difference of reliability indices appears differently, according as battery storage is a standby power unit and techniques to evaluate reliability are simulation methods with or without UPS. A distribution system reliability evaluation method using UPS as an alternative supply to minimise the outage duration is evaluated in this paper. In this paper an algorithm to include the capacity degradation with age, state of charge of the battery and finite failure rate is also developed. The proposed method is flexible and easy to implement, although there are difference between results of two techniques.

REFERENCES

[1] Radial Feeder Reliability Evaluation in the Presence of Battery Storage using Modified Sequential Monte Carlo Simulation

[2] R. Billinton and R. Goel," An Analytical Approach to Evaluate Probability Distribution Associated with the Reliability indices of Electrical Distribution System",IEEE Trans. on Power Delivery,PWRD1 No .3 pp.245-251 1986.

[3] R.Billinton and R.N. Allan "Reliability evaluation of power system", 2nd edition, Plenum Press, New York, 1996

[4] Generation Journal, Vol. 4, Issue. 3, pp 211 -220, 2010 [6] C. Singh & N. Gubbala, N. Gubbala, "Reliability Analysis of Electric Supply Including Standby Generators and an Unintemptible Power Supply System", IEEE Trans. on Industry Application, v.30, n.5, pp.1298-1302, September-October 1994.

[5] H.Qian, J.Zhang, J.S. Lai, and W. Yu, " high-efficiency grid-tie batteryenergy storage system," IEEE Trans. Power Electronics, vol. 26, no. 3,pp. 886–896, Mar. 2011

[6] R. Billinton and P. Wang,"Teaching distribution system reliability evaluation using Monte Carlo Simulation", IEEE Trans.on power Systems, vol.14(2), pp.397-403, May 1999

[7] M.K. Rahmat, S. Jovanovic, K. Lo, " Reliability Modelling of the DC Uninterruptible Power Supply", The 3rd IET International Conference on Power Electronics, Machines and Drives, pp 368-372, April 2006.

[8] M.K. Rahmat and S. Jovanovic, " Reliability and Availability Modelling of Uninterruptible Power Supply (UPS) Systems using Monte Carlo Simulation", Telecommunication Energy Conference 'Smart Power and Efficiency' (INTELEC), 35th International, Oct 2013.

[9] C. Singh and R. Billinton, "System Reliability Modelling and Evaluation," Hutchinson Educational Publishers, 1977, London, UK

[10] M.Sepehry, M.Kapourchali, A.Banajiger and V.Aravinthan,"A New Algorithm for Reliability Evaluation of Radial Distribution Networks", in North American Power Symposium (NAPS), 2014, pp. 1 –6

[11] IEEE Std 1366-2012 "IEEE Guide for Electric Power Distribution Reliability Indices

[12] "Battery Life and Death" online: http://www.mpoweruk.com/life.htm

[13] X.Liu and W.Wang, "VRLA battery system reliability and proactive maintenance", in Proc. 32nd Int. Telecommunication Energy Conference (INEC), , 2010, pp. 1-7

[14] M.Sepehry, M.Kapourchali, A.Banajiger and V.Aravinthan,"A New Algorithm for Reliability Evaluation of Radial Distribution Networks", in North American Power Symposium (NAPS), 2014, pp. 1 –6