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ADVANCED COMPUTATION METHOD FOR VALUE-BASED DISTRIBUTION SYSTEMS RELIABILITY EVALUATION

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Motivation

It has been reported that approximately 80 % of all customer interruptions occur due to failures in the distribution systems [1]. A prominent problem in distribution systems planning studies is the accurate and fast assessment of the value-based reliability index termed expected interruption cost (ECOST). Estimation of only average interruption cost based on sector customer damage function (SCDF) can provide results with large errors. ECOST vary unevenly with the random nature of the failures and associated time-varying load and cost models. Knowledge of the probability distributions associated with the index can be used to more accurately estimate the ECOST rather than using only average value. Conventionally used Monte Carlo simulation (MCS) can estimate ECOST by taking account of its random nature. However, the limitation in MCS is that large computational burden arises for a high accuracy level.

Contribution

The objective of this research is to speed up the computation of ECOST estimation considering time-varying load and cost models. A novel Multilevel Monte Carlo (MLMC) method [2] has been applied for this purpose. We verify the performance of the proposed method by comparing to MCS in terms of computational efficiency and accuracy. Using the proposed method, the following studies are carried out and presented in the paper.

- Developing a general simulation framework based on MLMC method for customer interruption costs evaluation.
- Analysing the effects of network reinforcement, size, and complexity and load types on the estimation process.
- Calculating the impacts of time-varying load and cost models on the estimation.

Method

In methodology presented, there are two phases. In the 1st phase, the stochastic model of ECOST is established. A time sequential MLMC simulation is considered for this estimation. Distribution system components are represented by the two-state model. Two basic random variables, i.e., component time-to-failure and time-to-repair are modelled stochastically based on the Brownian motion. The Milstein discretisation scheme is used for the approximate numerical solution of the stochastic models. The operating and restoration histories of each component are generated using random number generators and exponential probability distribution. The impact of each component failure on the load points is determined using two primary load point reliability indices; average failure rate and annual unavailability. Time-varying load model of each load during failure period is established based on peak load, hourly, daily and weekly load diversity factors. Similarly, time-varying cost models are established based on SCDF and cost weight factors. In the 2nd phase, MLMC based estimator is developed to accelerate the estimation. The MLMC method uses a geometric sequence of coarse grids and hence computations are done on multiple discretisation timesteps (levels). By simulating on multiple levels, the MLMC needs fewer samples on the finest level than MCS to achieve the same accuracy. In MCS, all the samples are only simulated on the finest level. The MLMC conducts the simulations on an order of coarse grids so that the less accurate estimate on the preceding coarser grid can be sequentially corrected by estimating on the following finer grids. The computational cost of a fine grid is higher than a coarse grid. Thus, the MLMC reduces the computational cost by performing most of the simulations on the coarse grids with low accuracy at a correspondingly low cost and relatively few simulations being performed on the computationally expensive fine grids at high accuracy and cost.

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Results

The following Figures and Tables present the results for a number of scenarios and related sensitivity analysis. Six different case studies are carried out, where availability of protective devices and switches are considered in different ways. The variation of ECOST values and their estimation time prove the effect of network reinforcement on cost value and estimation time, as shown in Figure 1 and Table 1, respectively. Figure 2 shows the effect of time-varying load and cost models in ECOST estimation while considering the starting of failure at different times. Figure 3 presents the effects of network size and load types in ECOST variation. The benchmark six-bus Roy Billinton test system connected to five load buses (Bus2 to Bus6) is considered for this purpose [3]. The computation time differences are displayed in Tables 2 and 3 for these studies. The output results show that the MLMC method can estimate the ECOST with an acceptable accuracy and less computation time when compared to the results based on MCS method.

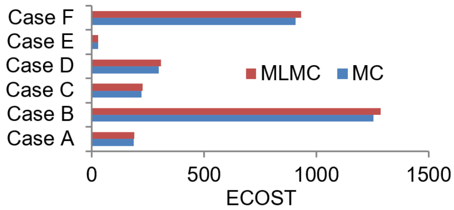

Figure 1: ECOST (1000$/yr) variation due to network reinforcement

Method	MC (s)	MLMC (s)
Case A	35.23	1.14
Case B	1110.13	48.19
Case C	49.67	1.71
Case D	80.19	2.76
Case E	0.9151	0.03228
Case F	317.25	25.15

Table 1: Effect of network reinforcement on cost estimation time

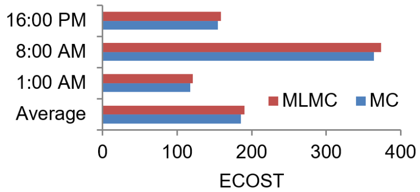

Figure 2: ECOST (1000$/yr) variation due to time-varying load and cost models

Failure starting time	MC (s)	MLMC (s)
Average	35.23	1.14
1:00 AM	15.87	0.51
8:00 AM	134.37	5.04
16:00 PM	25.43	0.87

Table 2: Effect of time-varying load and cost models on computation time

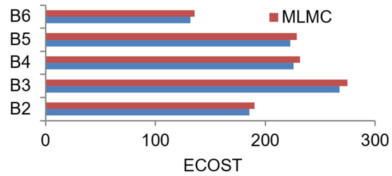

Figure 3: ECOST (1000$/yr) variation due to network size and load types

System	MC (s)	MLMC (s)
B2	35.23	1.14
B3	69.27	3.65
B4	49.33	1.85
B5	47.40	1.58
B6	27.06	0.9

Table 3: Effect of network size and load types on computation time

Discussion

Accurate and fast evaluation of reliability worth value of the distribution system is very important for its cost-effective planning, design, operation and power market structure. The paper has presented a new method for customer interruption costs estimation based on the Multilevel Monte Carlo method. The method can accelerate the estimation process by providing all benefits of traditionally used Monte Carlo method. The effects of different aspects are taken into consideration for accurate estimation e.g. network reinforcement, time-varying cost and load models rather than considering only average load models and customer damage function-based cost models. The proposed method can be easily modified for cost estimation by considering the momentary interruption and the effects of time-varying weather dependent failure rates.

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