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Probabilistic Reliability Modeling to Support System Planning

R. HASAN[1], M. VIELE[1], W. WINTERS[1], J. HAUFLER[1],
D.J. ALLEN[2]
[1]Con Edison, [2]The Risk Research Group
USA

SUMMARY

This paper describes a practical exercise in probabilistic reliability modeling to support system expansion and infrastructure planning, specifically, a need for a new transmission substation close to an existing transmission substation as well as a new distribution substation to handle local load growth. Detailed reliability models of alternative designs for transmission and distribution substations were prepared and exercised. These alternatives include the installation of additional transformers to distribution substations and transfers of load between substations. It is demonstrated that some alternatives are more cost-effective than others in maintaining system reliability in a, thereby illustrating how detailed transmission system reliability models can be used to help optimize system design and expenditures.

KEYWORDS

Transmission, reliability, probabilistic modeling, Monte Carlo, simulation, system planning.

razibnj@gmail.com

INTRODUCTION

The building of a new transmission substation will allow for load relief at an existing transmission substation and at several nearby distribution substations that supply adjoining distribution networks where major load growth is predicted. Of particular concern at present is the question as to how best to mitigate this load growth by reassigning feeders from the existing transmission substation to the new transmission substation and the transfer of load to a new distribution substation. This question is addressed here making use of a detailed and complete reliability model of the transmission system; the advantage of such models is being recognized increasingly (e.g., [1]).

MODELS AND DATA

Reliability predictions were made using a detailed reliability model of Con Edison's entire transmission system. This employs a sequential Monte-Carlo simulation using historical 10-year hourly load data. This model has been described elsewhere [2, 3]; as the simulation progresses and equipment is removed from, and restored to, service, contingencies developed from load flow calculations are checked to see if they prevail. If so, and if they cannot be mitigated, load drop is assumed. The measures of system reliability predicted are the counts of instances in which distribution networks and non-network circuits are dropped over the simulated course of 10,000 summers as a result of the isolation of distribution substations or the need to resolve the overloading of equipment in the transmission system. Particular attention is paid in this model to cascading, common-mode and dependent outages [4]; issues of increasing concern [5].

The present and proposed configuration scenarios are depicted in Figure 1. The cases run included a base case and several sensitivity cases. The base case represents the system as expected in the year modeled. In this case, the loads supplied from distribution substations E1 and E2 are markedly higher than at present. Substations E1 and E2 are fed from the same set of transformers in an existing transmission substation. This load growth translates into the possibility of new or more severe contingencies involving overloaded transformers in distribution substations and the existing transmission substation. In addition, the transfer of load to the new distribution substation from an existing distribution substation, E3, is examined as one way to relieve transformer loads in E3.

The sensitivity analyses address the transmission system as it might be restructured in future:

- A first set of sensitivity cases in which the new transmission substation and a 3-transformer distribution substation, N, are commissioned, network load being transferred from the existing distribution substation E2 to the new distribution substation N resulting in lower loads both on the transformers in substation E2 and in the transformers in the existing transmission substation that supply distribution substations E1 and E2. The sensitivity cases are:

    - Case 1.1. The installation of three transformers in the new distribution substation, N, and the transfer of 120 MW of load to this substation from the existing substation E2. This design is quite adequate, this load being such that a single transformer in the new distribution substation suffices to carry the load without exceeding its emergency ratings (i.e., the substation meets an N-2 design criterion).
    - Case 1.2. As Case 1.1 but with a 4th transformer added to the new distribution substation N.

- A second set of sensitivity cases in which a distribution substation, E3, unrelated to the existing transmission substation is reinforced. The sensitivity cases are:
  - Case 2.1. As Case 1.1 but with a 5th transformer installed in the distribution substation E3.
  - Case 2.2. As Case 1.1 but with and the transfer of a 60 MW of load from substation E3 to the new substation, N, which, in this case, has three transformers.
  - Case 2.3. As Case 2.2 but with a 4th transformer installed in the new substation N.

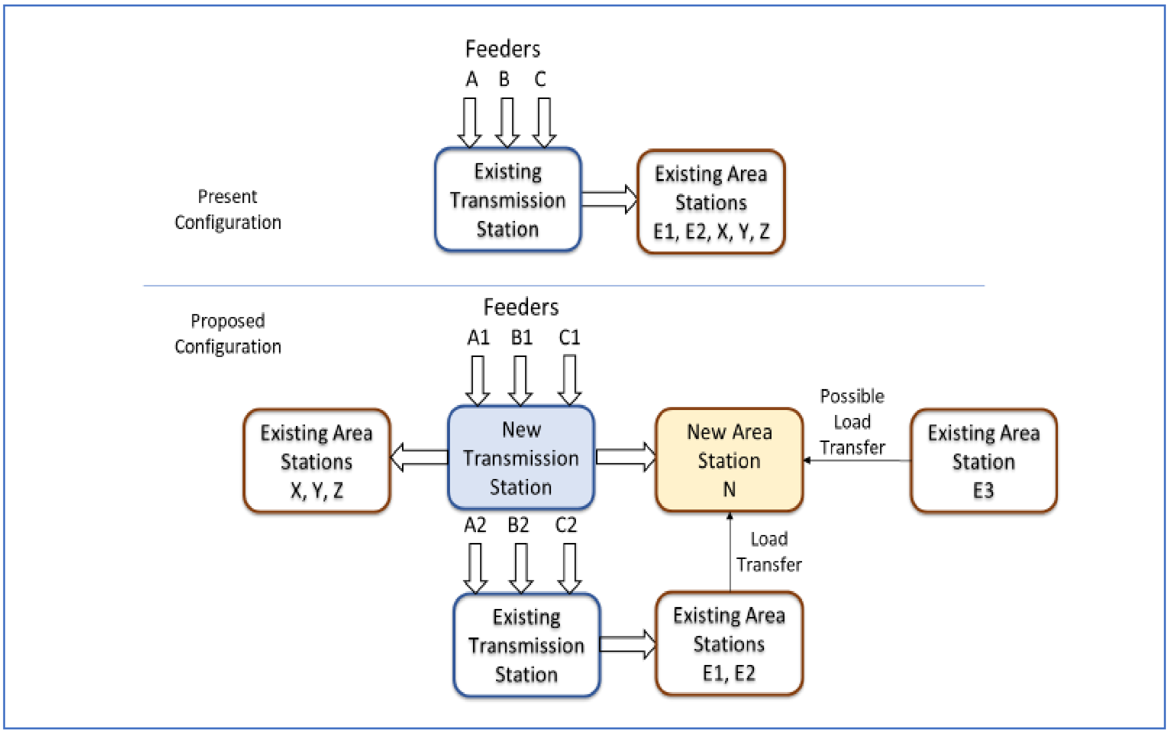

Figure 1: Present and proposed configuration scenarios considered for simulation

In all the sensitivity cases, feeders supplying other existing area substations are reassigned to the new transmission substation, but this has no effect on the sensitivity analyses described here.

PREDICTIONS

The predictions made for the cases are summarized in Table 1. These present the counts of load-drop events predicted in 10,000 summers. The counter-intuitive prediction that the transfer of load from distribution substation E2 results in a reduction in the frequency of load drop from distribution substation E1 arises because, prior to load transfer from E2, load drop occurs mostly because of the overloading of the transformers in the exiting transmission substation that serves both distribution substations E1 and E2 and, for various reasons, this overloading is best dealt with by dropping load from E1.

Table 1

Predicted Counts of Network Load Drop Events in 10,000 Summers

Distribution Substation from which networks are dropped	**Cases**					
	Base Case	**Cases 1.1 and 1.2: Future, 120 MW transfer from substation E2 to the new distribution substation N**		**Cases 2.1, 2.2 and 2.3: Future, 120 MW Transfer from substation E2 to the new distribution substation N**		
		Case 1.1: N has 3 transformers	**Case 1.2: N has 4 transformers**	**Cases 2.1: 5^{th} transformer added at existing distribution substation, E3**	**Case 2.2: 60 MW transfer from E3 to the new distribution substation N, N has 3 transformers**	**Case 2.3: 60 MW transfer from E3 to the new distribution substation N, N has 4 transformers**
E1: Existing, fed from existing transmission substation	49	6	4	6	2	2
E2: Existing, fed from existing transmission substation	6	0	0	0	1	0
N: New	NA	0	0	0	16	0
E3: Existing, fed from another transmission substation	14	16	19	1	0	1
Other	0	0	1	0	0	1
Total count	69	22	24	7	19	4

The predictions observed from the simulation are presented in Figures 2 (Base Case, Sensitivity Cases 1.1 and 1.2):

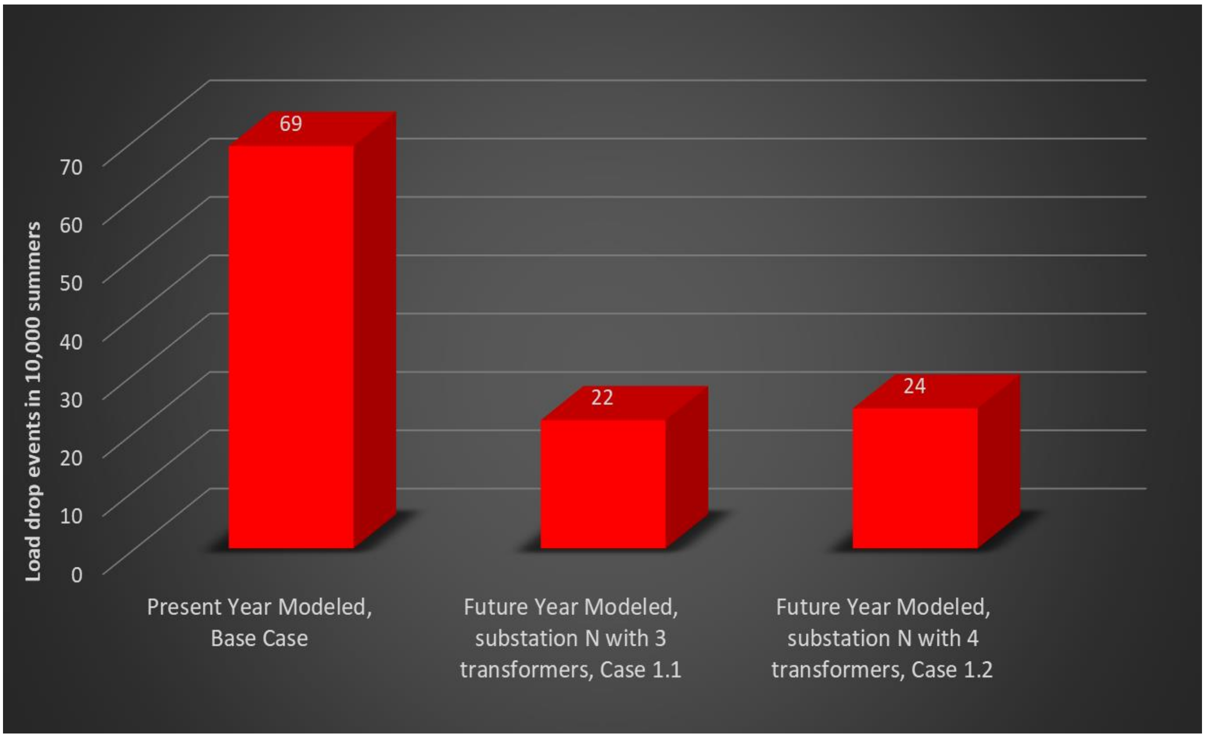

Figure 2: Total Count of Load Drop for Base Case, Sensitivity Cases 1.1 and 1.2

The predictions observed from the simulation are presented in Figures 3 (Sensitivity Cases 2.1, 2.2 and 2.3):

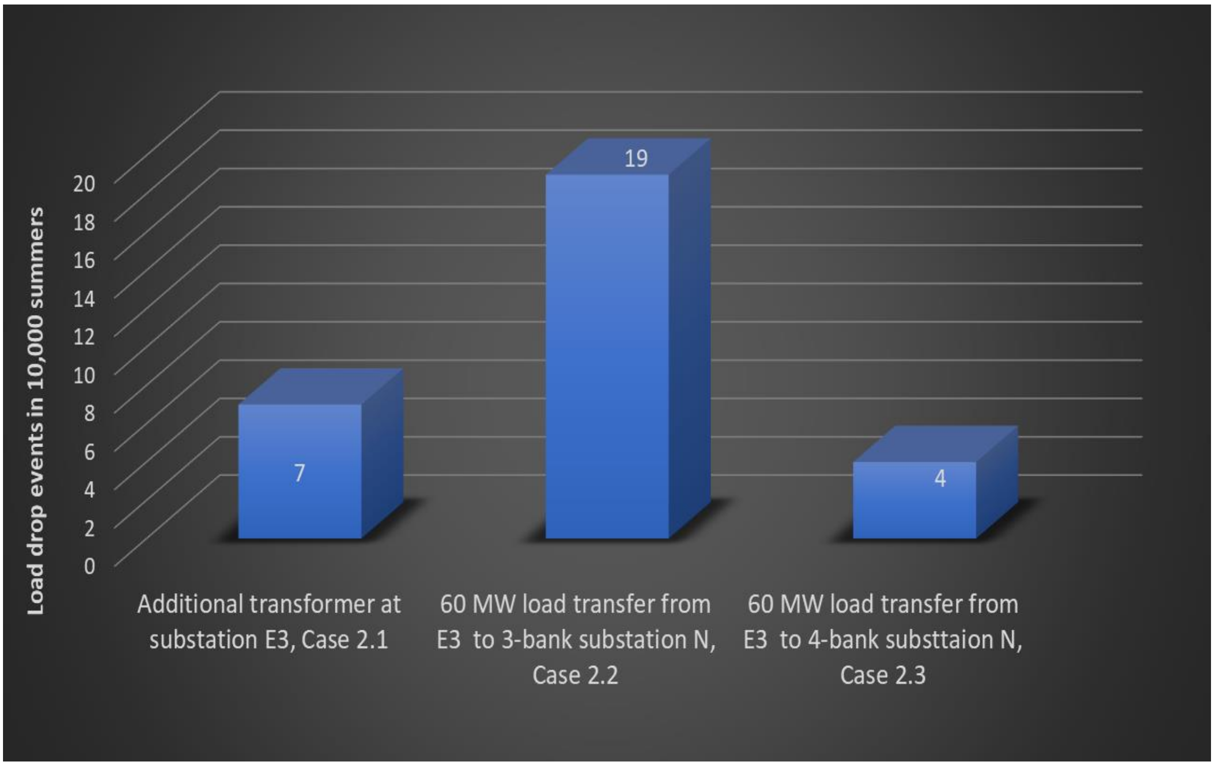

Figure 3: Total Count of Load Drop for Sensitivity Cases 2.1, 2.2 and 2.3

CONCLUSIONS

This work illustrates how a detailed and complete reliability model of the transmission system can be used effectively in routine assessments made to help ensure the best choices are made in system reinforcement. Reviewing the predictions presented in Table 1, we conclude that:

- The transfer of load from an existing distribution substation, E2, will result in a marked reduction in the predicted count of load drop events from this and an adjoining distribution substation, E1. This is primarily because of lower predicted frequency of overloaded transformers in the existing transmission substation.
- Little is gained by adding a 4th, transformer at the new distribution substation, N, if the load transfer to this distribution substation is 120 MW, a load that can be carried by a single transformer in N. Installing a 4th transformer reduces the number of load-drop events only with larger load transfers.
- The addition of a 5th, transformer at the existing distribution substation, E3, and the transfer of 60 MW from this substation to the existing distribution substation N are equally effective in reducing the predicted count of load drop events from E3. This transfer will, however, result in a higher predicted frequency of load drops from N unless a 4th transformer is installed in N.

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