Short-Circuit Updates in Con Edison's Power System: Methodology, Challenges, and Lessons Learned

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***Abstract*— Accurate short-circuit models are fundamental for power system planning, design, operation, and protection. The short-circuit model can be divided into two main components: the internal network and the external network. The internal network is the portion of the system modeled and maintained by each utility containing utility-owned or third-party assets that the utility operates. The external network represents all equipment beyond the internal network not owned by a given utility and is usually not maintained by a given utility. Updating internal networks to capture short-circuit contributions from external networks properly is a task that every utility regularly undertakes to ensure accurate short-circuit studies, but such updates can be overwhelming if not performed methodologically. This paper presents a practical approach to performing network model updates and tackling typical challenges associated with this task, especially when the external and internal networks reside in different short-circuit programs. A practical application of this approach applied to Con Edison's power system illustrates its effectiveness.**

Keywords—Short-circuit model, network equivalent, power system topology, model verification

I. INTRODUCTION

The accuracy of a short-circuit model is critical in calculating a power system's relay settings, evaluating a system's protection coordination, performing planning studies, assessing breaker duties, and calculating equipment operating limits in general. The model used in the aforementioned activities must capture the quantity of electrical components that form today's changing, dynamic, and interconnected grid. Therefore, while performing short-circuit model updates periodically to account for the growing grid is desirable, it remains challenging. In particular, utilities are often challenged when departments use different software to model the system based on their needs. Maintaining multiple models could be extremely labor-consuming and introduce errors, as system topology, generation schedule, and equipment service status are all subject to manual data manipulation. This paper identifies a practical approach that utilities can adopt in order to align system models used for different purposes that describe the same system. The alignment between models is defined in terms of short-circuit variances, and a target of less than 5% short-circuit variances between models was adopted when applying this approach to Con Edison's power system.

Establishing a methodology to conduct these short-circuit updates allows utilities to expedite this task and ensure the accuracy of results. It also provides a starting point to develop automation tools to streamline and integrate the process into other network model management (NMM) initiatives.

II. METHODOLOGY FOR NETWORK MODEL UPDATES

This section discusses a methodological way to perform updates in short-circuit models, especially when internal and external networks are maintained in different short-circuit software. This methodology assumes that regardless of the software hosting different short-circuit models, converting the database from one software to another is possible, such that the model can be read from either software. For each step of this methodology, advantages and disadvantages are discussed to illustrate different options for implementing this approach or defining a new one.

A. Selecting the Network Model Software

Since most short-circuit programs available today offer the option to convert the models so that they can be read from other software, the first step in this approach is to select the desired software to host the updated short-circuit model. In most cases, the software selected is the one that contains the network model for relay protection studies. Another consideration when making this selection is to ensure the software can perform network model reductions if such a capability is needed during the short-circuit update process. Network model reduction considerations are discussed in Section C of this chapter.

B. Converting All Available Short-Circuit Models to a Common Format

After selecting the network model's format for manipulating the short-circuit updates as needed, the next step is to convert all available short-circuit models into the selected format. The conversion procedure is straightforward since most short-circuit programs offer this feature via built-in software tools. Nevertheless, the user must carefully set some parameters when performing the network model conversion, especially those indicating impedance thresholds for modeling infinite or negligible impedances in different network elements.

After performing the network model conversion, a validation step is recommended to ensure result consistency. This validation can be performed by comparing short-circuit results in the converted model against the original model. Typical issues found by the authors at this step include the following:

- Impedances not specified in the source model (blank fields) are interpreted as infinite impedances in the converted model. This causes large differences when comparing the single-line ground fault current between models.
- Three-winding transformers with one winding out-of-service converted to all the three windings in service.
- Zero-sequence impedance for three-winding transformers in Y-Y-D connections is improperly converted since transformer modeling differs between models.

C. Performing System Model Reductions if Needed

In general, when utilities receive a network model from their reliability council or regional ISO, they need to update their network model to include the updated contributions from the external network. So, they perform the system reduction of the external network and join it with their existing internal detailed bus model.

Since the details of the whole external network are not of interest to the utility, a system model reduction can be made to create an equivalent circuit that can replace the extensive neighboring network with fewer elements: equivalent generators and transferred impedances. The created equivalent circuits should yield to the same or client-defined close enough voltage-current relationship at the internal buses as the original neighboring network. System verification can be done by applying the same type of fault at the same location before and after the system reduction, which the next chapter will address in detail.

After defining the need for a network reduction, a set of boundary buses between the external and internal networks should be created. In most short-circuit programs, two strategies are used for network reduction: reducing a set of buses or retaining a set of buses. Reducing a set will create equivalent generators and transfer impedances out of the buses in the set. Buses that are not in the set are retained. Retaining a set works the other way around. The buses in the set are retained, and buses outside the set are converted or reduced to equivalent generators and transfer impedances.

For the case presented in this paper on Con Edison's power system, the team identified the need to perform a network reduction of the model received from the ISO. The criteria used to determine the external network to retain was keeping the boundary buses plus two to three more buses away into the external network. The result of this system reduction was, at the boundary buses of the created bus set, the equivalent generators and shunts are created to replace and represent the external network. As well as the transfer impedances are created between internal buses and boundary buses to represent the electrical relationship between them. Through these steps, the network model was updated from one consisting of every utility's information in the area to one consisting of detailed network information of one utility plus an equivalent circuit representing the rest of the system.

D. Defining External Network

When defining the external and internal networks, the whole procedure's goal is to update the short-circuit model to represent a portion of the non-utility-owned network properly. This portion of the network is called external. It contains not only equivalent generators and transfer impedances to represent the short-circuit power available from the non-utility network, but also a portion of this network which often called tie lines and tie transformers that the utility might need to conduct other studies on, such as relay coordination. Having a portion of the external network that includes two or three buses beyond the utility's boundary buses is a reasonable practice. In the previous section, we discussed the method of performing system reduction on the external network to obtain a simpler circuit. The next step involves carving the network's external portion from the system.

In real-world practice, partitioning the reduced external network into a new model or database is unnecessary. Instead, one only needs to clearly define or identify the boundary buses and their connected power equipment. In doing so, what should be kept and removed in each database during the merge process becomes clear. For the case of an external network, we would like to keep the portion where we now have the equivalent generators and transfer impedances, as those represent the neighboring system more simply and clearly. This step's main goal is to make clear that part of the data is to be kept in the reduced network.

E. Defining Internal Network

Like the previous section, the main goal of defining the internal network is to know from whence the data should come. The internal network refers to the database the utility uses to store the system configuration, network data (which alters the short-circuit current level), and, in most cases, relay protection information. Often the database consists not only of assets that belong to the owning utility but also some boundary buses and beyond which belong to neighboring utilities. Each utility keeps this kind of database and maintains it reasonably often to reflect changes and updates to their assets that happen in the real world. Therefore, the internal part of this database is considered up to date and should be kept. This section highlights the importance of knowing the fine line where one can separate the up-to-date internal network from the rest of the system.

F. *Perform Model Merges of Internal and External Networks*

Performing an internal and external network merge is the process of putting two puzzles that have been previously polished into one map. In the previous two sections, the aurthors discussed identifying good internal and external network data. This section introduces the common method used in the short-circuit platform to merge the two networks' data.

Before the merge process starts, we identify the source and target databases. The source database is the one that holds the reduced external network, and the target database is the one that the utility used for maintaining the internal network. The first step of the merge is to create a bus map. A bus map is a cross-reference table that correlates buses in the source database with buses in the target database. In other words, if one bus exists in both databases, it shall appear in the bus map so that the program understands how to translate one bus from database A to database B. This association can be done by bus number, name and voltage level, or name and area code. Usually, associating buses with their number is the easiest way. But what buses should be included in this bus map to correlate two databases? Thinking about the goal of updating the external network for a utility short-circuit network. One should merge the external network—which should have been reduced to a simplified circuit in the previous step—into the target database. Therefore, the bus map should include all buses with equivalent generators or shunts created on them.

Then the next step is to specify what data should be included in the merge process. Some short-circuit programs divided power system data into several categories, like protection, line constant, and primary system data. Additional steps can control what data is considered during the database merge process and make a specific selection to keep or drop certain pieces of information. The other program compared all data differences and displayed them in a comparison table format, then let the user make the select/unselect choice to the data for which they want to keep/drop during the merge. Both methods are popular in practice and can be easily adopted based on the short-circuit platform. Once the data selection is made and confirmed, the update will be made to the target database. The new target database becomes the new short-circuit network containing the updated external network. The complete process of system reduction and internal and external network extraction is shown in Figure II-1.

III. SHORT-CIRCUIT MODEL VALIDATION

In most of this methodology's steps, validations based on short-circuit comparisons are recommended to ensure the whole process converges. This section discusses the approach followed to investigate short circuits after comparing network models. This approach is important because it prevents short-circuit discrepancies from worsening in a given bus's neighboring buses after correcting short-circuit discrepancies at that bus.

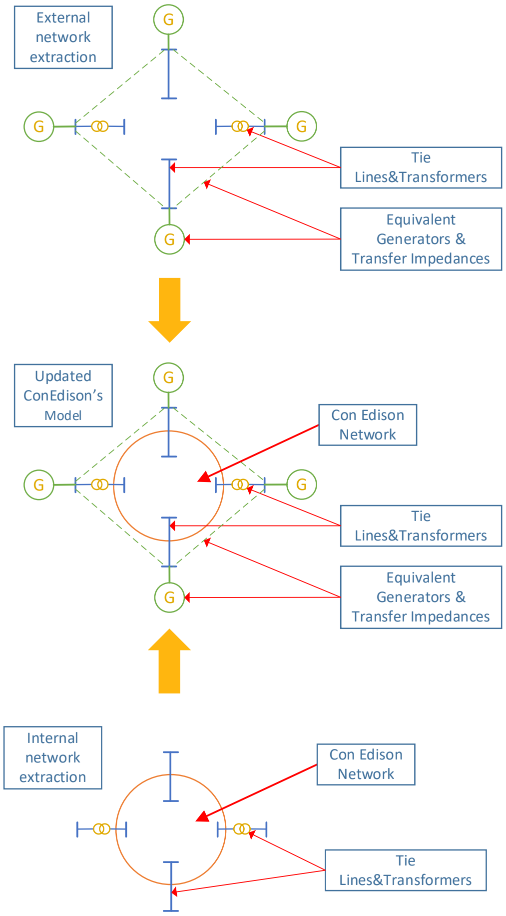

Figure II-1 Merging process to update network model.

A. *General Approach*

This approach is illustrated in Figure III-1 and starts with comparing short-circuit discrepancies for three-phase (TPH) faults. Discrepancies in TPH faults usually unveil impedance discrepancies or short-circuit source discrepancies. Therefore, the short-circuit comparison is started at boundary substations so that short-circuit contributions from external and internal networks can be easily identified. Variations in short-circuit currents due to external network contributions lead to the investigation of network equivalents (equivalent generators, shunts, and transfer impedances) and other impedances in the external network.

When the short-circuit variations are due the internal network's contributions, a topological comparison must be done. This comparison ensures that all compared models have the same elements connected to the faulted bus. Once the topology is compared, the next comparison is between the impedances of all the elements connected to the bus. When comparing impedances, starting with elements that have the

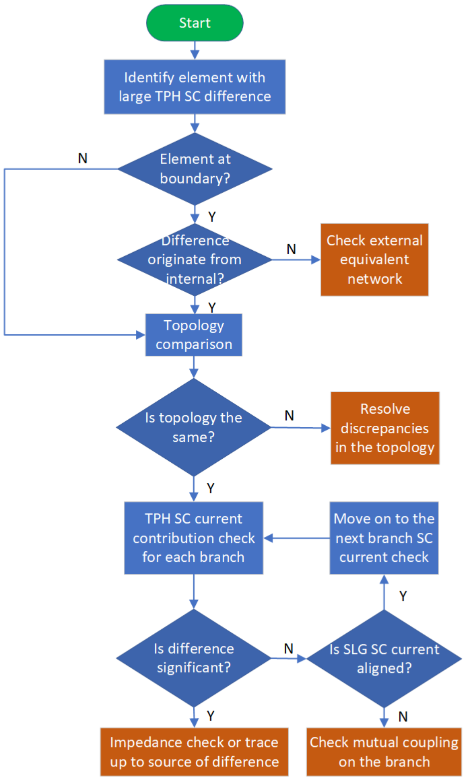

Figure III-1 General approach for short-circuit discrepancies investigation.

most significant short-circuit variances usually leads to a quicker convergence of the results.

B. Typical Short-Circuit Model Discrepancies

Line and transformer impedance discrepancy is one major contributor to short-circuit current discrepancies, especially the significant discrepancy found in zero-sequence impedances which caused obvious fault current differences between models for single line-to-ground (SLG) fault. Topology difference is another contributor. For example, in one model, the transformer is connected to a short line, whereas in the other model, the same transformer is connected to a station bus without the line. Therefore, the line impedance adds discrepancy to the total branch impedance.

Transformer winding and grounding configuration is another top contributor. In some cases, we have seen the transformer connection discrepancy that caused fault current deviation. For example, at a 138 kV bus, the transformer is connected in a Wye pattern in one model, whereas it is configured as Delta in the other model. This altered the 3I0 zero-sequence current distribution, creating a short-circuit discrepancy between the two models at this branch. In some other places, the discrepancy appeared at the transformer grounding. For example, in one model, the transformer is Yn-Yn connected, whereas, in the other model, the grounding is missing.

The generator's unit rating MVA and impedance parameters are also found to be one major type of discrepancy that contributed to short-circuit current deviation.

IV. EQUIPMENT OPERATION STATUS DISCREPANCY IS WITNESSED DURING SHORT-CIRCUIT COMPARISON AND HAS BEEN A VALID CAUSE OF SHORT-CIRCUIT CURRENT DEVIATION. USUALLY, THE SHORT-CIRCUIT PLATFORM USES "ONLINE" AND "OFFLINE" OR SIMILAR TERMS TO CATEGORIZE THE POWER SYSTEM EQUIPMENT BY ITS CURRENT OPERATION STATUS. THE OPERATION STATUS, WHICH SHALL ACCURATELY REFLECT IF A CERTAIN PIECE OF EQUIPMENT IS ACTIVELY IN SERVICE IN THE SYSTEM, IS NOT ALWAYS IN SYNC BETWEEN MODELS. FROM THE EXERCISE OF COMPARING TWO MODELS, WE FOUND SEVERAL MISMATCHED CASES. ONE EXPLANATION IS THAT DIFFERENT PEOPLE MANAGE THE TWO MODELS IN THE SAME OR DIFFERENT ORGANIZATIONS. AS SUCH, UPDATING INFORMATION IS NOT ALWAYS GUARANTEED.EXAMPLE OF SHORT-CIRCUIT MODEL UPDATES IN CON EDISON'S POWER SYSTEM

This section will illustrate the application of the methodology described in Section II via Con Edison's power system. The proven effectiveness of the methodology will be illustrated with short-circuit current difference comparison of the original system and the system after applying the short-circuit updates using the prescribed methodology. At each step of the methodology, a brief description of actions taken to update the model and to mitigate differences found between source and target models will be provided.

In the application of Con Edison's network model update, Con Edison's transmission planning team maintains the network model in one platform while the protection team runs their network model in the other. We converted the planning model into the protection model's format. Hence, these two objects are being compared.

Figure IV-1 and Figure IV-2 illustrate the short-circuit current difference in percentage for TPH and SLG fault types at different stages for each monitored bus. In the original system with no update performed, more than two-thirds of the stations had TPH current difference greater than 10%. And half of the stations had SLG current difference greater than 10%. Following the methodology discussed in this paper, we performed system reduction to obtain updated external equivalent generators and transfer impedance circuits and then merged them with the protection model to form a new network model. The result of this update was shown in Stage 1, which was the initial assessment of short-circuit profile of the system after the update. As seen from the Stage 1 graph, the short-circuit current difference dropped significantly, with all monitored buses' current variance below 10%. While this great improvement was expected based on the methodology described, we were still a little above the 5% target that we would have liked to achieve. Then further work investigating the internal network was performed using the approach in section III. The final result after fine-tuning the internal network was shown in Stage 2 graph. With the combination of both internal and external networks being updated, the short-circuit current variations of all monitored buses were now well below 5%. This proves the effectiveness of this paper's practical methodology.

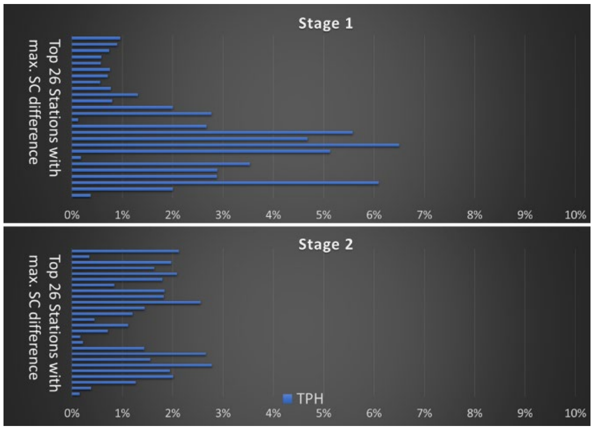

Figure IV-1 Short-circuit current difference in percentage between two models for TPH fault.

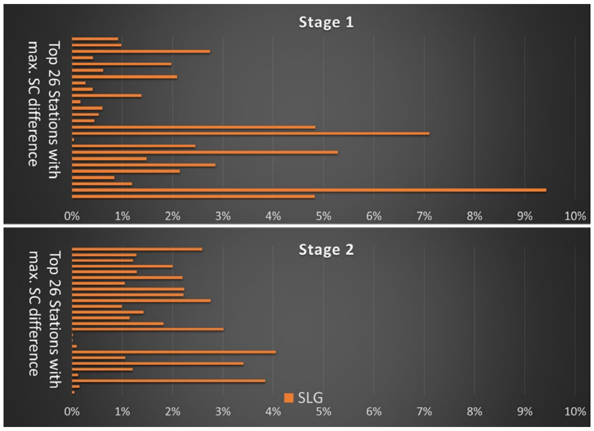

Figure IV-2 Short-circuit current difference in percentage between two models for SLD fault.

V. CONCLUSIONS

Updating power system models for accurate short-circuit representation is a task that must be frequently performed, especially under the significant changes that power systems are experiencing due to the increasing availability of distributed energy resources (DERs). These changes directly impact the short-circuit current magnitudes and distribution in the system, so capturing those changes in the utility's network model is a pressing need.

Having a proper representation of the short-circuit contributions from the external network can be a demanding task, especially if the network's source data resides in software different than the software used by a given utility to maintain their own model. Therefore, establishing a methodology to conduct network model updates allows utilities to streamline this task, ensuring the accuracy of results. It also provides a starting point to develop automation tools to expedite portions of the process and to integrate it into potential NMM initiatives.

Short-circuit comparisons along every step of the network model update process are fundamental to ensure consistency between models and, consequently, the accuracy of results.

This paper's methodology proves efficacious when applied to complex power systems. When different models are maintained, differences can occur over time. Internal models should be validated against Independent System Operator's model. In the case of this study, fault differences were able to be reduced to less than 5% between the models with consolidation of topologies and impedances update.

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VII. BIOGRAPHIES

Hibourahima Camara received his B.S. degree in electrical engineering from the City College of New York in 2001 and an M.S. in electrical engineering from the State University of New York (SUNY) at New Paltz in 2008. In December 2012, he received his professional engineer (PE) certification in New York. He joined IBM, Microelectronics Division, in Fishkill, New York in 2001. In his 10-year tenure with the company, he worked as a High-Speed Analog/Mixed-Signal Designer, designing serial-deserializer (SERDES) chips operating at data rates up to 40 Gbps. He joined the Con Edison Transmission Planning Department in January 2011 and has transferred to Control Systems Engineering where he has been working as a relay protection engineer since June 2013. He holds four U.S. patents in high-speed analog/mixed-signal design.

George Goddard received his B.S. degree in electrical engineering from the University of Michigan. He join Con Edison's Control Systems Engineering team in 2019, working in the relay protection analysis and system support section. His previous experience is with relay protection and design in the Michigan transmission and distribution system.

Majida Malki a Senior Director of Protection, Control & Automation at Quanta Technology, LLC. She is a professional engineer and certified project manager with over 20 years of utility and consulting experience working directly with power utilities and consulting companies. She has extensive experience in designing protection and control schemes in digital and electromechanical technologies for transmission and distribution systems, developing relay settings and coordination studies using software tools like ASPEN and CAPE, and performing power quality engineering analysis and distributed generation impact studies. Majida has knowledge of IEC 61850 and experience in performing T&D loss assessment studies and improvements.

Jinrong Li is a Principal Engineer at Quanta Technology. Her areas of expertise resides in power system primary and protection modeling, short-circuit analysis, protection coordination studies. She has worked on multiple transmission line protective relay setting design projects. She is proficient in using CAPE and ASPEN to manage short-circuit model updates for utility client.

Jorge Velez is a Principal Advisor at Quanta Technology, where he has worked since 2015. He received his Master of Science in Electrical Engineering from Iowa State University and his Bachelor of Science in Electrical Engineering from the Universidad Nacional de Colombia. He has over 18 years of experience in power system protection, control, and automation. He has worked in the design, settings, maintenance, testing, and commissioning of protective relays for transmission and distribution systems. He has also worked on planning studies, remedial action schemes (RAS) design, fault investigations, protection system modeling, protection database management, short-circuit and breaker duty analysis, impact studies of renewable energy penetration in utility grids, and automated protection coordination studies using CAPE and ASPEN.