21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2018 Grid of the Future Symposium

Automated Enhancement of Transmission Planning Bus-Branch Model with EMS Node-Breaker Substation Models

M. H. ATHARI [a,b], K. D. HANNAH [a], Z. WANG [b]
[a] Dominion Energy
[b] Virginia Commonwealth University
USA

SUMMARY

Currently, most of the off-line planning studies are utilizing bus-branch models to represent power system networks, making it impossible to recognize the substation breaker configuration and determine the operations during contingencies. The North American Electric Reliability Corporation (NERC) System Analysis and Modeling Subcommittee (SAMS) has identified the utilization of node-breaker representation in planning studies as a long-term goal with strategic milestones towards achieving widespread adoption of these practices. This paper presents an approach to automatically enhance existing bus-branch planning models by adding node-breaker substation models using Energy Management System (EMS) database. An automated conversion tool is developed that maps node-breaker substation models exported in Common Information Model (CIM) format from EMS database to the Multiregional Modeling Working Group (MMWG) planning summer base case. The multi-stage process includes: importing CIM-exported EMS case to Siemens PTI PSS/E, building substation models, and assigning facility ratings from Line Optimization and Analysis Database (LOAD). The developed tool takes advantage of PSS/E's Application Program Interface (API) Python functions and the CIM importer module. The effectiveness of the proposed approach has been verified on the Dominion Energy's (DE) 500 kV network. We successfully built substation node-breaker model for every 500 kV substation in DE's transmission network using the developed tool.

KEYWORDS

Node-breaker Substation Models, Transmission Planning, Automated Mapping, Energy Management System Database.

atharih@vcu.edu

I. INTRODUCTION

The majority of off-line planning studies currently adopt bus-branch models for power system networks. These models typically represent each substation with a single bus at its nominal voltage level. Without external knowledge obtained outside the bus-branch model, it is not possible to determine the substation breaker configuration therefore optimize its contingency operations. The lack of breaker information requires that a large number of contingency manually created to replicate bus contingencies and breaker failure contingencies. For instance, in a breaker-and-a-half substation layout if one of the two breakers of the branch is out of service that could potentially impact the line total loading limit in contingency analysis. However, without proper knowledge of breaker layout and individual ratings, multiple scenarios have to be manually simulated to cover every possible contingency. These manual efforts are usually very time consuming and often increase the probability of human errors.

A solution to this challenge is to enhance the original bus-branch system model with node-breaker substation configuration, which means to remodel substations into node-breaker topology from the normal power flow bus-branch configuration. Bus-branch model to node-breaker conversions require creation and maintenance of a mapping of each station into its constituent elements. However, the converse mapping is merely a reduction of zero-impedance elements into the resultant buses to consolidate node-breaker topology to simplified bus-branch topology. Therefore, use of a node-breaker model is more advantageous to maintain and keep linked to the system topology used in the Energy Management System (EMS). These models can provide a fully built out substation representation (e.g., elements such as breakers, switches, branches, or shunts are modeled individually and connected via nodes).

During recent years, there have been a number of industry efforts to implement the node-breaker models in the transmission and operation planning studies. Authors in [1] present an implementation of node-breaker full topology in Bonneville Power Administration (BPA) for system operation planning studies. The implementation helped save customer's cost by reducing curtailments and more effective using of transmission capacity. It is also found that full topology models provide better reliability and improve System Operating Limits (SOLs). In [2] the authors summarize a new framework developed by Western Electricity Coordinating Council (WECC), Peak Reliability, and General Electric (GE) to facilitate the use of node-breaker operations model for validation of planning dynamic models used in the western interconnection using GE PSLF. Another example of bridging the gap between operation and planning models is presented in [3] with program features that enable traditional software to read a node-breaker power flow snapshot and perform different types of system studies and then link the model to planning database. Authors in [4] propose a Common Information Model (CIM) based bus-branch model that can be easily incorporated into CIM-based node-breaker models to facilitate the coordination between operation and planning. The issues of using bus-branch model for operation and transmission planning studies have been identified in [5] and the need for the node-breaker model for contingency studies is also discussed. However, to the best of our knowledge there is no automated approach in the industry to build substation node-breaker models for transmission planning long-term studies based on EMS information.

The manual modeling of substation node-breaker topology from engineering drawings is a tedious and error-prone procedure and potentially increases the number of discrepancies between the planning model and the real-time operations model. On the other hand, an automated process to build substation models using direct information from EMS can result 1) the maximum consistency between the two models, 2) an efficient and on-demand tool to regularly build and update planning cases, and 3) the foundation of a unified EMS and planning model. In this paper we will present an approach adopted in the Dominion Energy (DE) which automatically implements node-breaker representation of network substations using the EMS data in CIM format. The proposed approach will build full node-breaker topology of substations within four stages including exporting EMS network data to CIM format, importing EMS-CIM export case into Siemens PTI PSS/E using the CIM Importer Module, building the substation correct topology in transmission planning case based on the imported data, and finally assigning breaker ratings for different substation layouts. The Multiregional Modeling Working Group

(MMWG) 2018 summer base case is used to implement the node-breaker models and the whole process is fully automated to avoid tedious and error-prone manual procedures. The enhanced MMWG case will retain original bus-branch model while encapsulating the node-breaker model of substation as an additional layer of network data, thus making all the previous power flow studies still valid. The developed automated conversion tool can also be used for regular model update and management and may also constitute the foundation of the ultimate goal which is unifying the operations and planning cases to have fully coordinated network model management and facility rating process.

The rest of the paper is organized as follows. Section II gives an overview of the employed approach. Section III discusses the development and implementation of the multi-stage automated conversion tools, and section IV presents an example node-breaker substation model automatically built using the developed tool for a select substation in DE's 500 kV network and demonstrates the effectiveness of the proposed approach. Finally, section V will present the concluding remarks and the road map for full implementation of the node-breaker model in DE's entire transmission network for long and short-term transmission planning studies.

II. PROPOSED APPROACH OVERVIEW

Currently, most of the utility companies including DE use the traditional facility rating process that involves separate investigation and interpretation for model development and maintenance in transmission operations and planning. The existing facility rating process in DE is shown in Fig. 1. In this diagram LOAD stands for the Line Optimization and Analysis Database. The facility rating information in EMS and transmission operations is supplied by transmission planning; however, the EMS incorporates these data differently as they use more detailed node-breaker model while the simplified bus-branch model is being used in transmission planning for long-term reliability and contingency studies. Although the foundation of the two models is the same substation and transmission one-line drawings, there are considerable differences between the two causing duplicative maintenance of equipment data in real-time models and operational planning (offline) models. Also, potential inconsistencies in operational planning and real-time modeling data, difficulty in benchmarking operational planning (off-line) models with real-time data, and overlooking some topology dependent contingencies in transmission planning are among the drawbacks of the existing process.

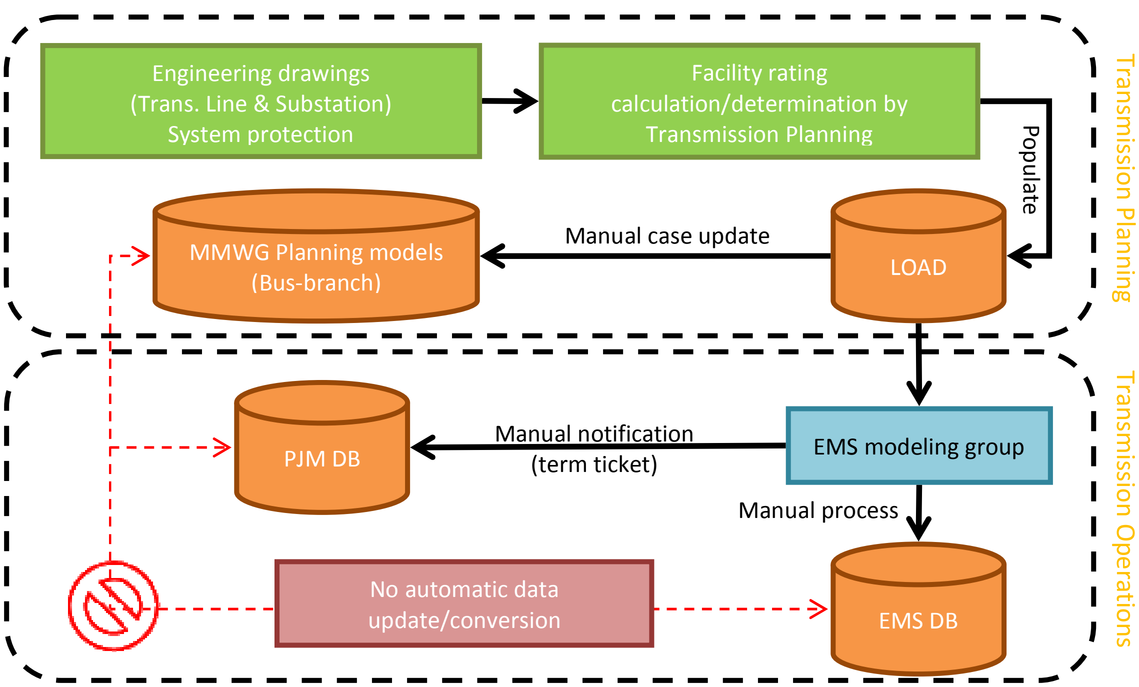


Figure 1. Existing facility rating process in Dominion Energy

NERC support of the industry in the advancement and utilization of node-breaker representation in planning studies motivated pilot projects to implement node-breaker full topology of substations within each transmission owner's (TO) territory. The benefits of using node-breaker topology representation for off-line and real-time study models as NERC outlines in its proposal [6] include:

- Maintenance of one system data set for real-time and operational planning (off-line) analysis, with the ability to extract data relevant to a particular application
- Facilitation of model benchmarking to real-time conditions
- More accurate representation of the transmission system
- Automatic recognition of split buses/stations and multi-terminal lines
- Reduction of errors in defining and processing contingencies
- Allowing analysis of individual busses and equipment nominal capacity
- Easier simulation of the Requirements of TPL-001-latest
- Enhanced Capability to transfer real-time data into off-line study environment by having common element identification

NERC SAMS has identified this activity as a long-term goal with strategic milestones towards achieving widespread adoption of these practices. These activities include manual modeling of substation node-breaker topologies in transmission planning MMWG cases that might impose extra efforts for comparison and validation of the developed model with real-time models. Whereas we believe that by making use of readily available node-breaker models in EMS DB, one can automate this process and avoid the labor intensive and error-prone manual modeling. This is also part of a long-term goal to have a unified planning and operation model for a coordinated facility rating and short and long-term contingency analysis.

Fig. 2 shows the flowchart of our proposed automation tool to map substation node-breaker model from EMS DB to transmission planning MMWG case.

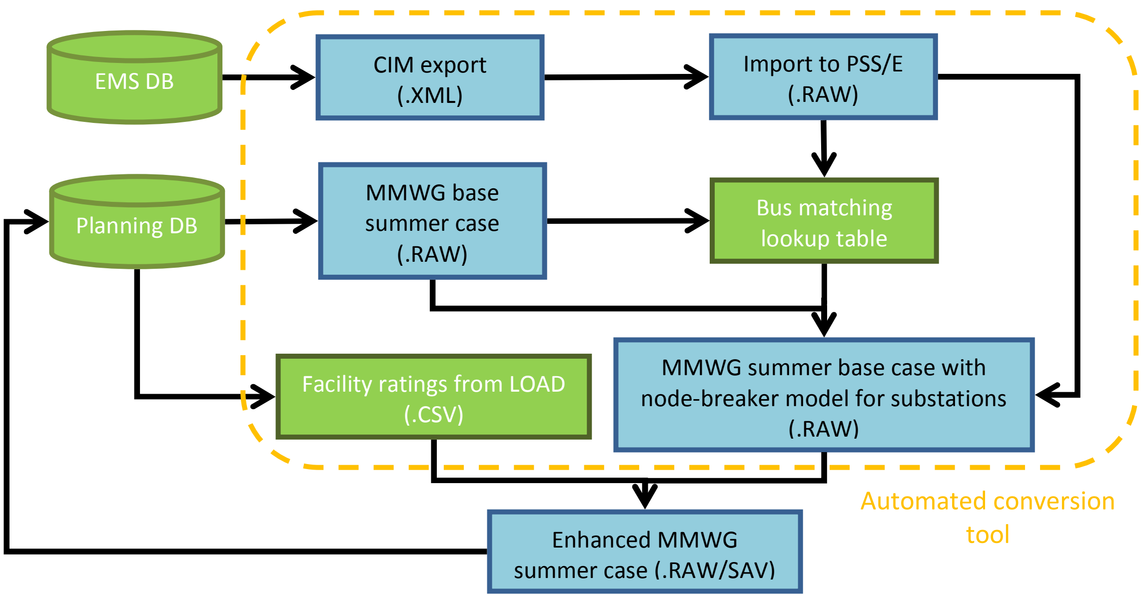


Figure 2. Flowchart of the developed automated conversion tool

The proposed automated mapping process consists of four stages to implement node-breaker substation models in MMWG summer base case. These stages are as follow:

1. Exporting TO's network from EMS database to CIM format.
2. Importing the CIM case to PSS/E using the CIM importer module.
3. Building substation node-breaker topology for MMWG case.
4. Assigning the facility ratings for substation breakers using Line Optimization and Analysis Database (LOAD).

Note that for the diagram shown in Fig. 2, a green box is used to represent either database or reference table that serves as an information reference for the conversion process which does not get updated regularly. The resulted enhanced planning case will have substation detailed node-breaker model with all facility ratings embedded. It is also worth noting that the node-breaker model of substation is attached to the base case as an extra layer of the case data and has no impact on power flow calculation, thus making all previous solutions still valid. This allows users to interact with the network through the traditional bus-branch view, while also having the ability to drill down into the details of breakers and switches as required. The details of each step of the developed tool will be discussed in the next section.

III. AUTOMATED CONVERSION TOOL

Today, the utilities in Eastern Interconnection (EI) are predominantly using Siemens PTI PSS/E in their transmission planning and operation studies. Prior to PSS/E version 34, the only way to model node-breaker in PSS/E was to model each node as a bus and each switching device as a regular AC branch or zero impedance line. With this method, the simulated node-breaker model is no different than the bus-branch model. However, using this direct method to model the node-breaker topology has some adverse impacts on planning studies, such as [7]:

- Requiring huge numbers of connection nodes (buses) and breakers (lines and zero impedance lines).
- The components are always connected to buses and difficult to identify.
- Transitioning from the bus-branch model to the node-breaker model is not automatic, and is time consuming and difficult.

In contrast, the ideal benefits of an integrated node-breaker modeling system for planning studies are:

- Node-breaker contingency events can be properly simulated and validated.
- Breaker failure events can be simulated.
- The node-breaker model is represented on a substation by substation basis.
- The ability to display both a bus-branch view and the substation view.
- Power flow results can be reported on bus-branch and node-breaker models.
- The addition of node-breaker representations will not affect computational speed or solution stability.
- Hybrid node-breaker and bus-branch modeling is allowed in the same power flow case.

The support of PSS/E 34 for hybrid bus-branch and node-breaker modeling, good automation capabilities in PSS/E using Python language, and introduction of add-on CIM importer module pave the way for developing an automated process for mapping substations node-breaker topology from EMS to transmission planning cases. Note that although in PSS/E 34 the automatic substation build functionality has been introduced, still there is a need to modify the topology of the built substation to match the actual topology from real-time operation. Whereas making use of readily available node-breaker models from EMS and pinning them to existing bus-branch planning cases eliminates the need for manual modification/validation of substation models.

A. Exporting EMS data to CIM

As shown in Fig. 2, the starting point of the developed conversion tool is the EMS DB. Most EMS vendors incorporate the ability of exporting the network in CIM format which is becoming the standard for data sharing among different entities and departments in the industry. To begin with, we obtained a snapshot of the network with CIM version 12 format due to CIM importer module compatibility.

B. Importing CIM to PSS/E

Fig. 3 shows the interface of the CIM Importer Add-On Module in PSS/E. After loading the XML file with compatible CIM version, the module allows the user to specify importing option to build the RAW case. The options include the Network Hierarchy, Bus Identification, and Case Initialization. We used “SubGeographicalRegion” for area mapping, the “TopologicalNode ‘Bus Number’” for bus number mapping and “TopologicalNode ‘Description’” for bus name mapping, and State Variable (SV) profile for initial operational state and “SvStatus ‘In Service’” for switch status mapping.
Next, the module allows the user to specify the limit mapping options; however we were not able to import the facility limit data via the importer module.

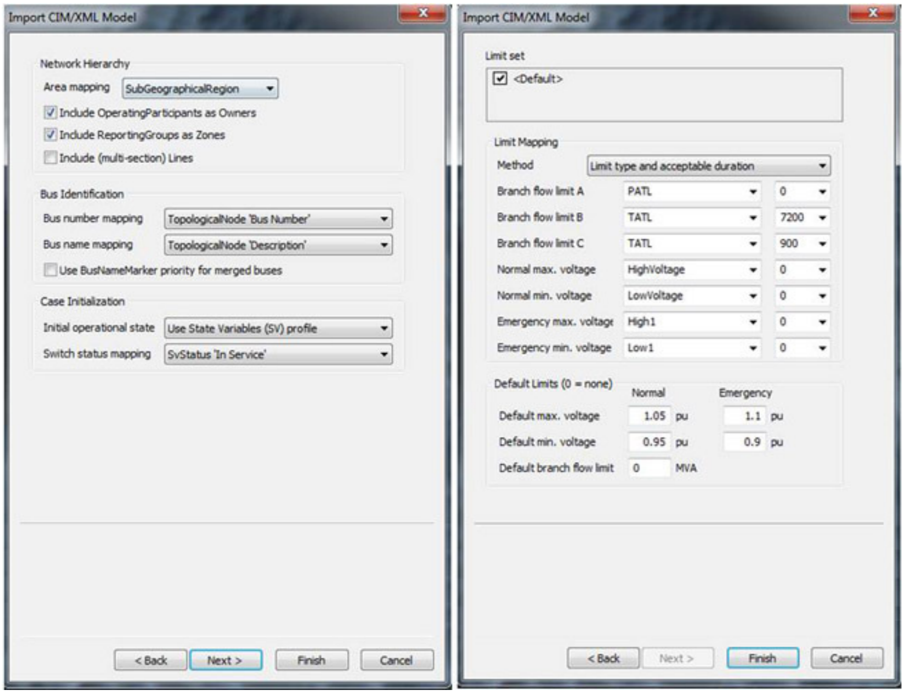


Figure 3. CIM importer add-on module in PSS/E

Fig. 4 shows the substation data block in the imported RAW file for a select substation. These data now can be retrieved with PSS/E Application Program Interface (API) through Python for automated substation node-breaker modeling for MMWG base case. It is also possible to directly read from RAW file, manipulate, and then write to the target file.

```
@! BEGIN SUBSTATION DATA BLOCK
@!  IS,              'N A M E'                 ,   LATITUDE,   LONGITUDE,     SGR
[redacted]'    [redacted]                      ',  0.0000000,   0.0000000,  0.0000
@! BEGIN SUBSTATION NODE DATA
@!  NI,              'N A M E'                 ,     I,STATUS,   VM  ,    VA
     1,'          D_49441                      ', [redacted]        1
     2,'          B_50173                      ', [redacted]        1
     3,'          A_50329                      ', [redacted]        1
     4,'          3_51446                      ', [redacted]        1
     5,'          H_52765                      ', [redacted]        1
     6,'          2_56369                      ', [redacted]        1
     7,'          E_60791                      ', [redacted]        1
     0 / END OF SUBSTATION NODE DATA, BEGIN SUBSTATION SWITCHING DEVICE DATA
@!  NI, NJ,CKTID,              'N A M E'                  , TYPE,STATUS, NSTAT,     X  ,    RATE1,    RATE2,    RATE3
     1,  2, '1 ','     [redacted]                       ',     3,      1,      1, 0.00010,     0.0,      0.0,      0.0
     1,  7, '1 ','     [redacted]                       ',     3,      1,      1, 0.00010,     0.0,      0.0,      0.0
     2,  3, '1 ','     [redacted]                       ',     3,      1,      1, 0.00010,     0.0,      0.0,      0.0
     2,  4, '1 ','     [redacted]                       ',     3,      1,      1, 0.00010,     0.0,      0.0,      0.0
     2,  6, '1 ','     [redacted]                       ',     3,      1,      1, 0.00010,     0.0,      0.0,      0.0
     0 / END OF SUBSTATION SWITCHING DEVICE DATA, BEGIN SUBSTATION TERMINAL DATA
@!   I, NI, TYP,      J,      K, ID
 [redacted]   6, 'B', [redacted]      '1 '
 [redacted]   3, 'B', [redacted]      '1 '
 [redacted]   7, '2', [redacted]      '1 '
 [redacted]   5, 'L',                 '1 '
 [redacted]   5, '2', [redacted]      '1 '
     0 / END OF SUBSTATION TERMINAL DATA
0 / END OF SUBSTATION DATA
```

Figure 4. Example substation data block in the imported case

C. Building substation node-breaker model

Due to different modeling assumptions in EMS and planning cases, the imported case is significantly different than the MMWG base case. The first step in building the node-breaker substation models from the imported case is to match the buses in planning case with their corresponding bus from the imported case. For this, the bus name attribute in both cases can be used to match the pair of the buses. Therefore, a string matching algorithm is needed to find the find the corresponding matching bus for each bus in MMWG case. We used Fuzzy string matching which is the process of finding strings that match a given pattern approximately rather than exactly. In this algorithm, the degree of closeness between two strings is measured using Levenshtein Distance, also known as edit distance which is based on counting number of primitive operations required to convert one string to the exact match of the other string [8].

The process of matching buses has been performed for each nominal voltage level starting from the highest voltage level in DE's network being 500 kV. The reason for choosing the 500 kV network to start with is that it is the backbone of the entire Dominion transmission network and the mapping process for the lower nominal voltage levels is similar. The output of this step is a lookup table storing the bus name and number of the corresponding bus from the imported case for each bus in MMWG case. Note that it is usually impractical to find exact one-to-one match for every bus in the network. Several exceptions were found where there exist multiple buses matching a particular bus in either case that needs manual decision by a modeling expert in both planning and operation and involve bus merging/splitting actions. Note that the development of the matching lookup table is only required during the first case mapping and it can be supplied to the tool for the future mappings. We have completed the matching lookup table for all 500 kV buses in DE's network and the matching of lower voltage level network buses is in progress.

Next, the bus matching lookup table is served as the reference to build substation node-breaker models based on the substation data block from the imported case (Fig. 4). To perform this, one has two options; using PSS/E node-breaker modeling APIs or directly writing data to MMWG case RAW file. In our developed tool, the PSS/E APIs are used to build node-breaker models for substations and then assign ratings based on LOAD data which will be discussed next.

D. Facility ratings assignment

Due to either CIM exporter from EMS or PSS/E CIM importer module, the facility ratings data were missing from the imported case. Furthermore, in DE and many other utilities, the facility ratings are reported to operations and EMS after careful investigation and approval from transmission planning groups. Therefore, it is required in our case and is recommended for other companies to assign/reassign facility ratings in the node-breaker substation models.

The facility ratings in the LOAD are grouped within multiple categories including:

- Transmission line terminal breaker ratings: this includes equipment at a terminal but not on the line itself. The equipment include breaker, breaker switch, breaker lead, CT, relay trip, and secondary CT.
- Transmission line device ratings: this includes equipment on the line localized at a given substation terminal or line tap terminal which include line lead, line switch, and wavetrap.
- Transmission line loading limits: this is the ratings assigned to a line considering the most limiting of transmission line terminal breaker rating, transmission line device rating, and conductor of the line.

As we need to assign the ratings of breakers in node-breaker models of the substations, the transmission line terminal breaker ratings can be used for our purpose. However, the breaker layout must be taken into consideration when assigning the ratings. The most common breaker layouts in transmission substations are breaker-and-a- half and ring bus configuration. Fig. 5 shows a typical breaker-and-a-half configuration. When determining the terminal breaker rating for LINE 1, the ratings of all equipment on both side of the line terminal node (node 4) are calculated and then the minimum of the two has been recorded as the terminal breaker rating of LINE 1. Now, we want to assign the ratings of the individual breakers using the available terminal breaker ratings. Obviously we need to follow the reverse path; assigning the terminal rating of LINE 1 to Br 1, assigning the terminal rating of LINE 2 to Br 3, and then assigning the minimum of the two to Br 2. While this approach might be conservative, it assures that the ratings of the terminals are either equal or less than the ratings of the most limiting element which is a key consideration in the simulation of breaker level contingencies. Also, this is the only way of effective use of readily available ratings data without overestimating the facility ratings. In the long run, calculation and assignment of accurate facility ratings from substation one-line diagrams is recommended.

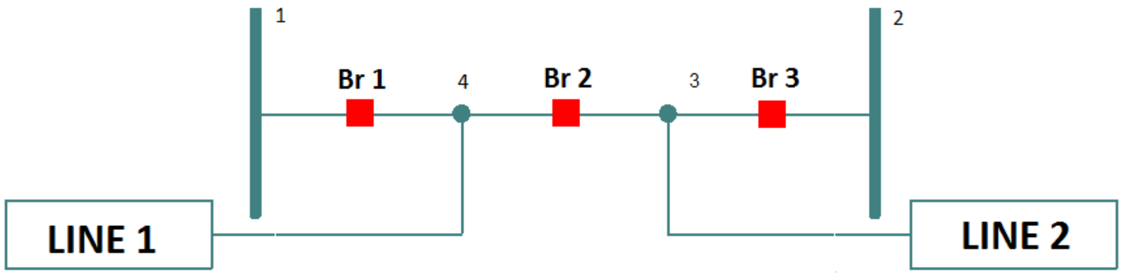


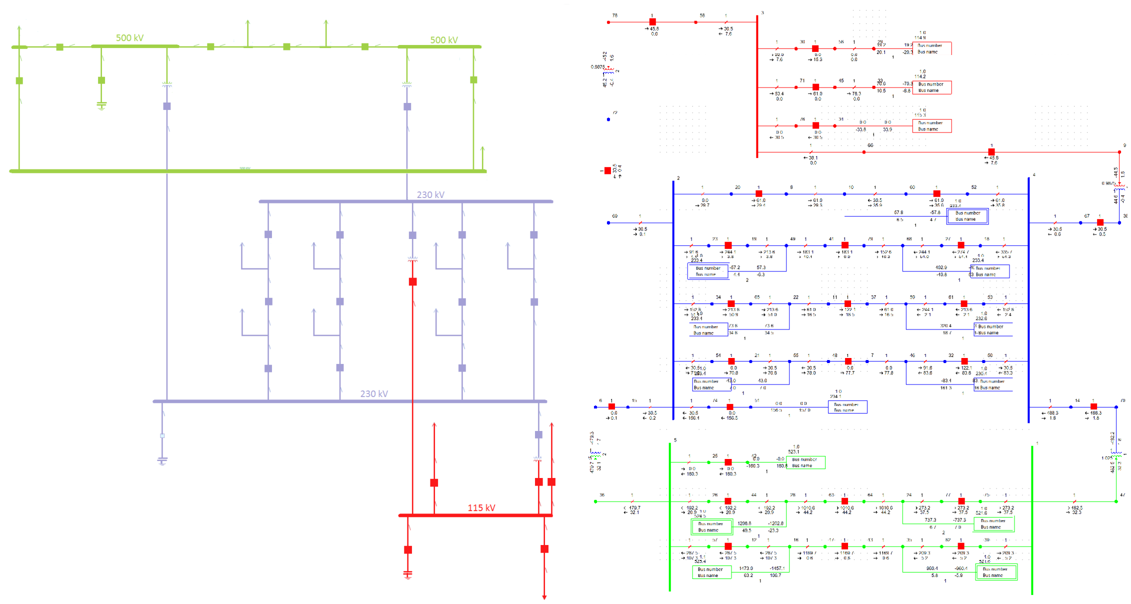
Figure 5. Breaker-and-a-half layout

IV. RESULTS

In this section, an example of the substation node-breaker model automatically built by the developed tool with ratings assigned to corresponding breakers will be presented. Fig. 6 shows the node-breaker display of a select substation with three voltage levels including 500, 230, and 115 kV. Fig. 6 (a) shows the node-breaker diagram of the substation in EMS that is displayed with CIMSpy, a standard-based model and engineering tool designed to address the open model exchange and information integration requirements in the power industry for CIM-based power system models. Fig. 6 (b) shows the substation display in PSS/E 34 for the converted substation.

The imported EMS case contains all switching devices including breakers and disconnects switches and accurately models the topology of the actual substation. However, during the importing process the type information of the switching devices are lost and they all appear as disconnect switches in the substation data block. Hence, an algorithm is developed to locate the breakers starting from the terminal node which is the connection point between terminal device and the substation bus (node 3 and 4 in Fig. 5).

Fig. 7 shows the 500 kV bus of the selected substation shown in Fig. 6. Fig. 7 (a) shows the original bus-branch model in MMWG base case and Fig. 7 (b) shows the automatically built node-breaker model in the enhanced case. The bus has the breaker-and-a-half layout with every two line sharing a tie-breaker. As explained before, to locate the breakers for every terminal, our algorithm starts from terminal node (e.g. node 28) ignores two adjacent switches and marks the next two switches as breakers and then assigns the breaker ratings.



(a) (b)

Figure 6. The node-breaker model of a selected substation: a) EMS display, b) PSS/E substation display

The node-breaker model for the substation now enables us to study contingency cases such as stuck breaker or one breaker out for maintenance which was not possible with the simplified bus-branch model before. For example, Fig. 8 shows the scenario where Br 1 is out for maintenance and all the line flow passes through Br 2 for LINE 2. This can potentially impact the overall line loading limits and will result in different contingency analysis. In addition, it is now possible to determine the accurate flow passing through each breaker for breaker-and-a-half and ring bus whereas traditionally it is assumed that the flow is split equally between the two breakers therefore the overall terminal ratings is calculated as the minimum rating of two sides multiplied by two. This example shows that this assumption does not always hold true and may lead to misleading results in contingency analysis. Furthermore, the PSS/E 34 now supports new node-breaker contingency definitions that make it possible for the user to analyse additional scenarios. These new definitions by PSS/E include:

- Isolate a single end of an in-service branch, system switching device or two-winding/three-winding transformer by breaker operations.
- Place a closed breaker in the status of “stuck”. It will fail to open in subsequent isolation operations in that contingency.
- Create contingencies for every in-service substation switching device (which can be limited to switches or breakers) in a subsystem.
- Create stuck breaker contingencies for a subsystem. For each substation in the subsystem, for each node in that substation, all combinations of in-service branches or transformers and closed breakers connected to that node will be found. Each combination will generate a contingency consisting of a stuck breaker record for that breaker and an isolate record for that branch or transformer.

(a)

(b)

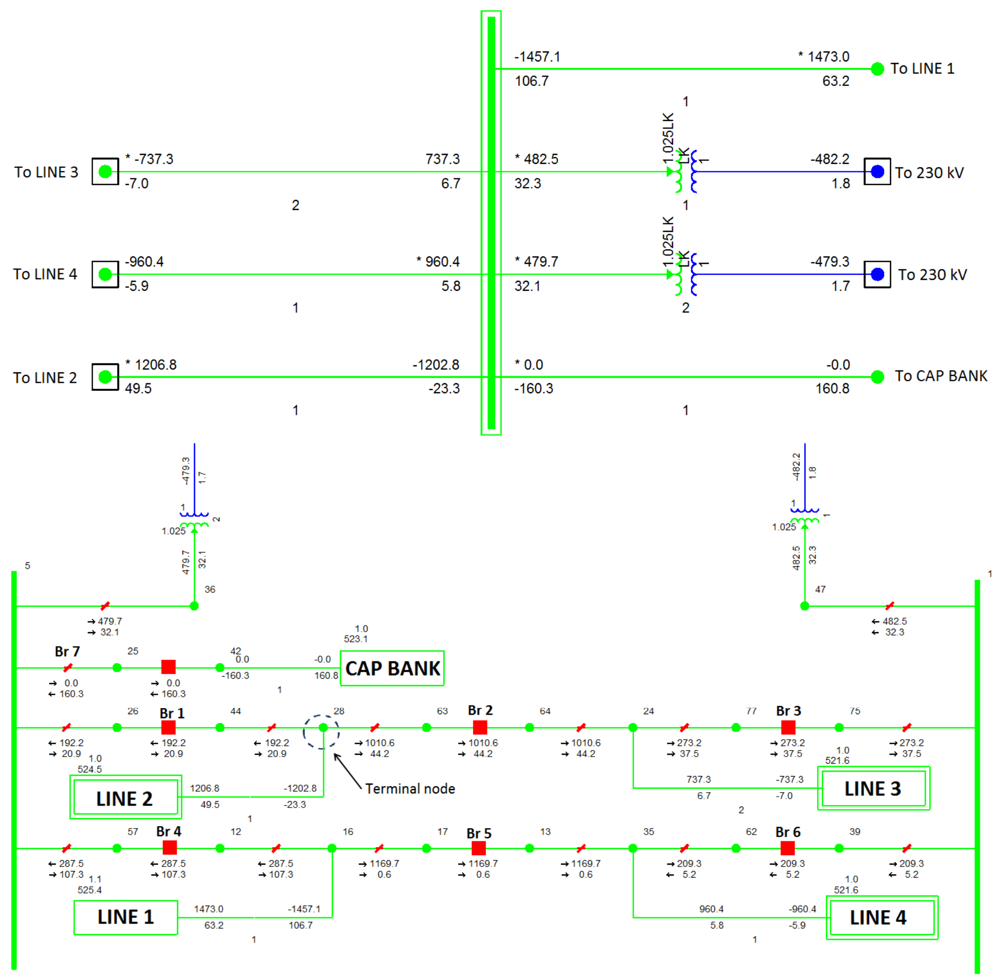


Figure 7. 500 kV bus for the selected substation: a) bus-branch model b) automatically built node-breaker model

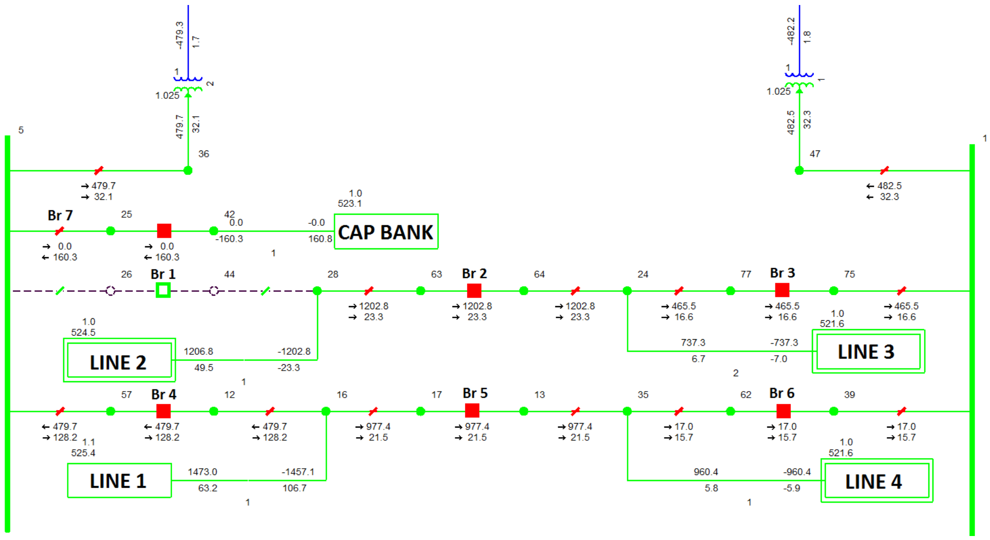


Figure 8. 500 kV bus with Br 1 opened for maintenance

V. CONCLUSION

In this paper, we presented an automatic mapping tool to enhance transmission planning bus-branch models by adding node-breaker substation models from Energy Management System (EMS) database. The developed tool creates node-breaker models on top of existing bus-branch model within four steps: 1) exporting EMS case in CIM format, 2) importing CIM case to Siemens PTI PSS/E using CIM importer module, 3) building substation node-breaker topology based on imported data, and 4) assigning the facility ratings using Line Optimization and Analysis Database (LOAD) in Dominion Energy's (DE) transmission planning group. The tool is developed using PSS/E's Python Application Program Interface (API) functions and uses a bus matching lookup table as a reference when mapping the EMS case to the planning case. The effectiveness of the approach has been verified in DE's 500 kV transmission network. The enhanced planning case enables the planners to study multiple contingency scenarios which was not possible previously with the simplified bus-branch model.

The work for full implementation of the approach for other nominal voltage levels is under progress and once finished, the advanced contingency analysis will follow for the enhanced planning case.

BIBLIOGRAPHY

[1] R. Ramanathan and B. Tuck. "BPA's experience of implementing node breaker model for power system operations studies," (48th International Universities' Power Engineering Conference (UPEC), September 2013, pages 1–6).

[2] B. Thomas, S. Kincic, D. Davies, Hongming Zhang, and J. Sanchez-Gasca. "A new framework to facilitate the use of node-breaker operations model for validation of planning dynamic models in WECC," (IEEE Power and Energy Society General Meeting, July 2016, pages 1–5).

[3] S. Kincic *et al.*. "Bridging the gap between operation and planning models in WECC," (IEEE Power and Energy Society General Meeting, July 2016, pages 1–5).

[4] Y. Pradeep, P. Seshuraju, S. A. Khaparde, and R. K. Joshi. "CIM-Based Connectivity Model for Bus-Branch Topology Extraction and Exchange," (IEEE Trans. Smart Grid, June 2011,vol. 2, no. 2, pages 244–253).

[5] R. Ramanathan and B. Tuck. "Contingency analysis using node/breaker model for operation studies," (2015 IEEE Power & Energy Society General Meeting, July 2015, pages 1–5).

[6] North American Electric Reliability Corporation. "Proposal for Development and Use of Node-Breaker Topology Representations for Off-line and Real-time Study Models," (Node Breaker Modeling Group, November 2013, pages 1–6) [https://www.nerc.com/comm/PC/Node%20Breaker%20Modeling%20Group%20NBMG/3g_-_Node_Breaker_Proposal_12-10-13.pdf][accessed: 7.24.2018].

[7] Siemens Power Technologies International. “Program Operation Manual,” (PSS/E 34.3 Documentation, April 2017, pages 1–1464).
[8] N. Singla and D. Garg. “String Matching Algorithms and their Applicability in various Applications,” (Int. J. Soft Comput. Eng., January 2012, no. 6, pages 2231–2307).