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An Optimization Method on System Model Verification

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SUMMARY

Line and load models are essential on system capability studies for operating reliability. This paper presents a unique way to derive the system model parameters in PSCAD based on the real time data collections. The system capability study was performed with the derived model in VSAT and confirmed with the real time outage event.

This paper investigates the determinations of transmission line models using historical voltage and power flow measurements. The analysis is based on the data obtained from one 230kV line planned outage in August 2020. The station 66 kV line model parameters were verified to study the area 66 kV system radial supply capability. The derived line model will be applied to the EMS system to support real time operations.

The goal of the study is to take real time measured date from the system and automatically produce a system model for online operations and future analysis. Manually tuning model parameters is time consuming and less efficient therefore the proposed method includes the automatic tuning functions in the process. The starting point is the theoretical model calculated from expected line parameters such as line length, resistance per unit length, line geometry, and ground impedance. From this starting point the process will accept the data and produce the model.

Measurement data was obtained from the Manitoba Hydro transmission system and categorized into different operating scenarios such as high /low loading conditions. These scenarios were fed into a model in PSCAD and the model outputs across the scenarios were coupled by the transmission line model. The line model utilizes PI section models for each segment of the line. Data were collected from a variety of sources: line sensors, historical data, on site field measurements, and so on.

The R, L, and C parameters for the model were determined using an iterative optimization process. The transmission line parameters were optimized across operating scenarios using a simplex optimizer with the goal of producing a model to best fit the data across scenarios. The outputs of the model were compared against their associated historical data counterparts and the differences were aggregated by weighted sum into an error signal. This error signal was used as the input to the optimizer. The signal weights were chosen based on the relative expected measurement error and importance. The more accurate (or important) data points were given a heavier weighting to ensure that the process fits the model closer to those relevant data points.

This method produced a model for the transmission line of interest which accurately reproduced the historical data. One 230kV line planned outage event will be used as a case study in this paper to verify the produced transmission line models matching the measured data from the real system.

We conclude that the vast amounts of data available to electric utilities represents a significant opportunity to produce accurate transmission line models. Although the modelling optimization process works well in PSCAD, other modelling tools which are able to perform optimization should work for this process as well. The accurate model will be applied to real time to provide better system operations. Potential future work should include investigation of other optimization methods, the applicability to other types of models, and the use of other modelling tools.

KEYWORDS

system model parameters ; system capability studies ; operating reliability ; PSCAD ; VSAT

INTRODUCTION

This paper investigates the determination of transmission line models using historical voltage and power flow measurements. The analysis is based on the data obtained from one 230kV line planned outage in August 2020. The station 66 kV line model parameters were verified to study the area 66 kV system radial supply capability. The derived line model will be applied to the EMS system to support real time operations.

The goal of the study is to take real time measured date from the system and automatically produce a model which fits the data. Manually tuning model parameters is undesirable therefore the process must do the tuning. The starting point is the theoretical model calculated from expected line parameters such as line length, resistance per unit length, line geometry, and ground impedance. From this starting point the process should accept the data and produce the model.

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We conclude that the vast amounts of data available to electric utilities represents a significant opportunity to produce accurate transmission line models. Although the modeling optimization process works well in PSCAD, other modeling tools which can also perform optimization should work as well. The accurate model will be applied to real time to provide better system operations. Potential future work should include investigation of other optimization methods, the applicability to other types of models, and the use of other modeling tools.

METHODOLOGY

Modelling Tools

PSCAD is the primary modeling tool used to perform the analysis. This tool is selected because of the ease of building a model graphically and the presence of a pre-built optimization algorithm [1]. Any tool which can perform steady state load flow analysis and has an optimization algorithm could have been used instead.

DSA tools is used in addition to PSCAD. PSCAD will produce the model parameters. DSA tools will use the model parameters to validate them against real time data and to confirm modeling assumptions such as the choice of and scaling method for loads. It also provides graphic results such as PV curves [2].

Model

The line model utilizes PI section models for each segment of the line. This setup is consistent with how the lines are modelled in the current EMS model. The line segments all have similar tower geometry, and therefore, the modelling process determines per-unit-length parameters which are distributed based on line-length across all the segments.

Three line segments use a narrower conductor than the other segments. An additional multiplier will be added to the resistive component for these segments which is based on the existing line model. The length multiplier is obtained by normalizing the R' values so that the lowest value is set to 1. It is assumed that the reactive and line charging components are not significantly impacted by the size of the conductor and therefore no multiplier is added for these parameters.

DATA COLLECTION

Data were collected from a variety of sources: line sensors, historical data, on site field measurements, and so on. The data was collected during a seven period and all data were of 15-minute granularity. MW, MVAr, and voltage were measured at the line head and at a bus "Bus 1" near the end of the line.

Data was aggregated to produce two scenarios: high load (usually during the day) and low load (usually in the night time). The MW data from the line head was used to index the data into the top 5% and the bottom 5%. The middle 90% of the data was discarded. The average of the top and bottom data produced the following final outage scenario parameters:

The rationale behind producing these two extreme scenarios is that the model produced from the process should match both extremes. This should lead to more accuracy for the more voltage sensitive parameters such as line susceptance.

LINE MODEL

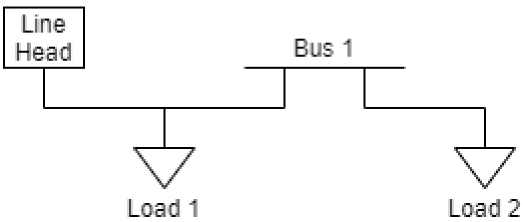

Figure 1: Line SLD

Figure 1 shows a single line diagram of the line model. The head end of the line is modeled as a 3-phase balanced constant voltage 230 kV source feeding the 66 kV network through a transformer. The two loads along the line "Load 1" and "Load 2" are modeled as constant power loads. The source values were fixed from the data and not part of the optimization process. Measurements taken from the model are:

- MW at line head (used as constraint)
- MVAr at line head (used as constraint)

- MW at Load 1
- MVAr at Load 1
- kV at Bus 1 (used as constraint)
- MW at Load 2
- MQ at Load 2

Note that load MW and MVAr were measured but not constrained. This is due to the low data quality associated with the measurements of those values. These values were used for sanity checking at the completion of the optimization process and were then fed into the final PSAT model.

MODEL OPTIMIZATION PROCESS

The R, L, and C parameters for the model were determined using an iterative optimization process. Line models which share the R, L, and C are set up in PSCAD. In addition to the line model, the load model must also be determined because the data only gives load MVA. The load will be modelled as constant power loads and its parameters will be determined as part of the optimization process. One model uses the "Low" measurements and the other uses the "High" measurements. Any changes to a parameter will impact all PI sections. Only a single set of R, L, and C are required since the line segments are assumed to be very similar. The model using a single constant P-Q ratio scaling factor for both loads between the "high" and "low" scenarios. This decision was made to be consistent with how DSA and the Manitoba Hydro EMS do load scaling. The following flow chart shows a simplified process.

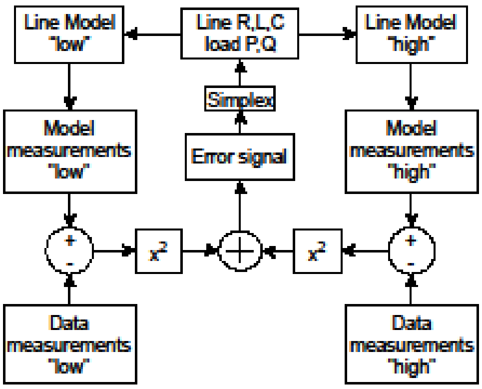

Figure 2: Study process flow chart

The simplex module accepts an error signal and outputs Line R,L,C and load P,Q. The simplex outputs are shared by both the "high" and "low" models and therefore changes impact the measured values on both sides. The simplex attempts to adjust its output in each iteration until the error signal finds a minimum within a specified tolerance.

Weighting Error Signals

Not all measurements were considered to be equal in quality. For example, the load MVA data required many assumptions beyond the measurent and therefore is likely not as accurate. For this reason, the error signals from the measurements were individually weighted to bias the result towards more accurate/important signals. A higher weight means that signal will be prioritized proportionally more. Note that a different selection of weighting factors is possible and would result in different final parameters. Many combinations of constraints and weighting factors were evaluated.

The line head measurements are the most important indicators of model accuracy since every piece of the model impacts those measurements. In addition, the voltage measurement at Bus 1 is the primary measurable constraint in real time and therefore it is given equal weight to the line head measurements. Although Bus 1 measurements are taken from permanent measurement devices and are considered to be of high quality, a lower weight is placed on the MW and MVAr constraints. The impact of error on those measurements is small since they determine mostly just Load 2 and have a relatively low impact on line parameters. Constraining the optimization equally on the basis of those measurements tended to produce low accuracy for the measurements at the line head. No weight is given to the load MVA even though data exists because that data is of low quality due to assumptions. This gives the model some additional freedom and will provide better accuracy for line parameters at the expense of matching load data. Instead the MVA data is used as a sanity check to ensure that no unrealistic loads are used.

MODEL VERIFICATION

One goal of this study is to produce a transmission line model (and load models) that matches the measured data from the real system. The model parameters were fed into PSAT and a PV curve was produced which is shown in Figure 3. The plot shows the model data as a line and the real time data as points. Two "V" locations were compared: the line head 66 kV bus, and Bus 1. The "P" is power flowing from the line head transformer. The figure shows that the model produced from this study is in good agreement with the data. The produced model is sufficiently accurate to analyze real time system events in the future.

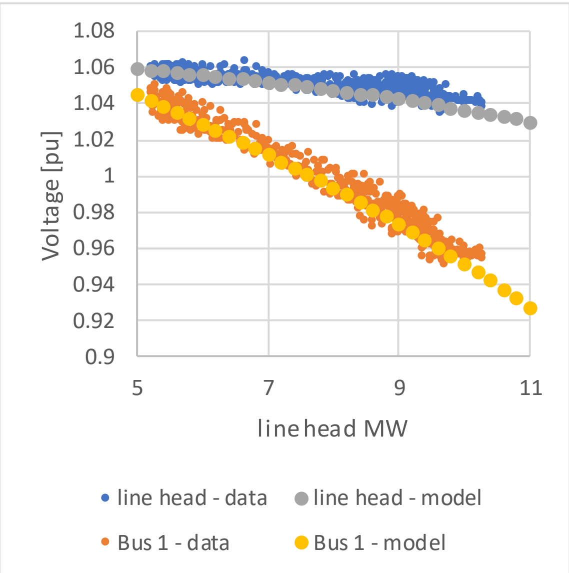

Figure 3: Model vs data PV curve

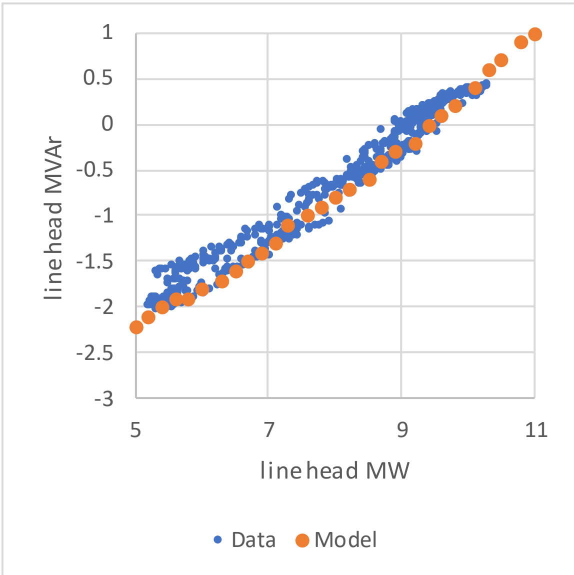

Figure 4:Model vs data PQ curve

Similarly, a PQ curve was produced and is shown in Figure 4. In this case both "P" and "Q" are measured flowing through the line head 230 kV – 66 kV transformer. The plot shows the model data as a line and the real time data as points. The model is again in good agreement with the data. Note that the "lumpiness" of the model line is due to rounding in the output from DSA. This figure also supports the accuracy of the proposed model for use in real time system analysis.

CONCLUSION

We conclude that the vast amounts of data available to electric utilities represents a significant opportunity to produce accurate transmission line models. Although the modeling optimization process works well in PSCAD, other modeling tools which can also perform optimization should work as well. The accurate model will be applied to real time to provide better system operations. Potential future work should include investigation of other optimization methods, the applicability to other types of models, and the use of other modeling tools.

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[2] Voltage Security Assessment Tool User Manual, Powertech Labs Inc, Sept 22, 2020

BIOGRAPHY

Chris Beaudoin is currently working as a Professional Engineer at Manitoba Hydro where he is responsible for performing system operations studies. His professional interests include process optimization and automation. Chris is also working as a part time student to complete his master's degree in electrical engineering at the University of Manitoba. Chris is a registered Professional Engineer in the Province of Manitoba, Canada.

Lana Zhu currently works as the Principal Network Studies Engineer at Manitoba Hydro. Her job duties include leading day ahead study group to perform daily studies to Manitoba Hydro Control Centre and provide technical support to real time operations. She has worked with Manitoba Hydro for more than 15 years. Before joining Manitoba Hydro, she was a Design Engineer in the electrical utility industry. Lana received the MSc degree from Lakehead University, Canada in 2005 and the BSEE degree from Southeast University in China in 1998. She is a registered Professional Engineer in the Province of Manitoba, Canada.