

Uncertainties of TBLM and Information Needed to Assess it.

White paper

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1. Introduction

The Transmission Bus Load Model (TBLM) [1-5] is predominantly to be used in the short-term look-ahead EMS and DMS applications. Therefore it is based on the forecasts of some basic input components of TBLM and on “what-if” reactions of other components to these inputs and to the actions of the EMS and DMS applications.

Components of TBLM uncertainty:

- **Uncertainty of load models**
 - **Uncertainty of base nodal loads in distribution**
 - **Uncertainty of forecast of external factors (weather, price, etc.)**
 - **Uncertainty of load dependencies on external factors (weather, price, etc.)**
 - **Uncertainty of load-to-voltage dependencies**
 - **Uncertainty of load-to-frequency dependencies**
 - **Uncertainty of overlapping load components**
- **Uncertainty of DER models**
 - **Not monitored DER**
 - **Participation**
 - **Mode of operations and settings**
 - **Monitored DER**
 - **Uncertainty of effective capability curves**
 - **Assessment of look-ahead performance based on expected external input and power flow model**
 - **Intermittent operations**
- **Uncertainty of secondary equivalent models**
- **Uncertainty of DR models and behavior**
- **Uncertainty of execution of commands and requests**
 - **Uncertainties of control actions (e.g., the bandwidth of voltage controllers)**
 - **Uncertainties of utilization of dispatchable load**
- **Errors of measurements (e.g., the measurements of reference voltage and other used for state estimation)**
- **Errors of modeling (e.g., power flow models)**
- **Other**

The uncertainties of the components of the TBLM to be taken into account are different for a particular instance of the model utilization and for a series of utilizations. The uncertainty of the average impact of the series of TBLM utilization

is typically smaller than the uncertainty of an individual instance due to the random components of the errors (see an example in Figure 1).

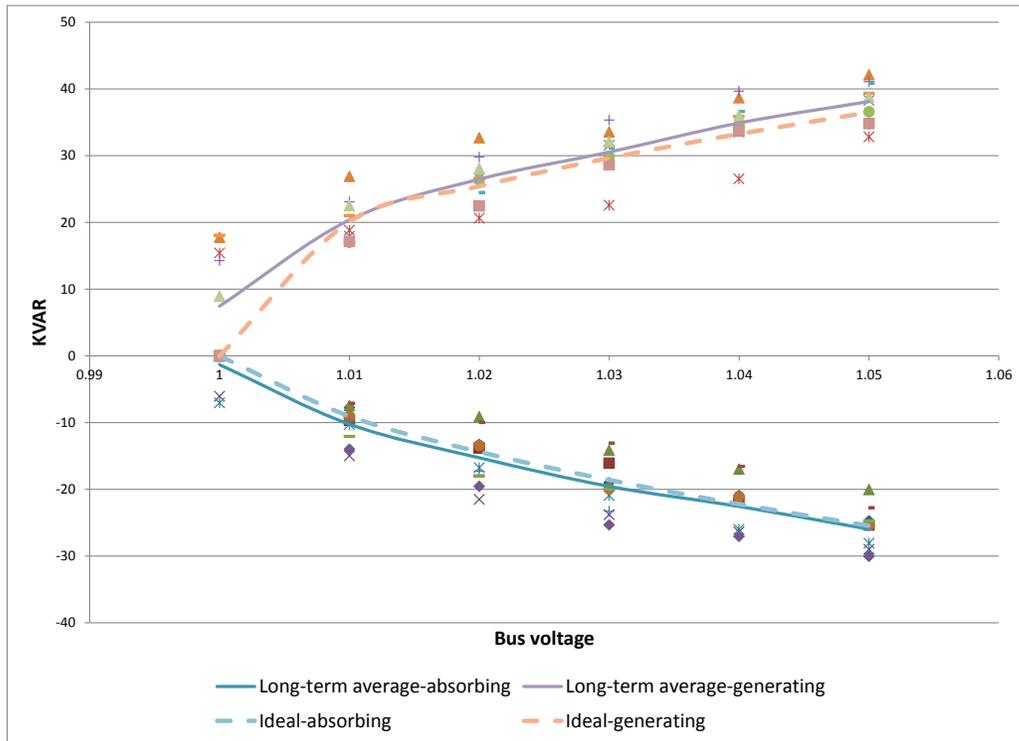


Figure 1. Example of a DER capability curve vs bus voltage

Some components of uncertainty can be assessed analytically. The analytical assessment can be used for the analysis of the uncertainty and for ways of its mitigation, if needed. For instance, the uncertainty in the voltage models is partially caused by the voltage controller bandwidths. If the value of the bandwidth and the distribution of the controlled voltage within the bandwidth are known, one can define the probabilities of this component of the voltage model uncertainty.

In other cases, the uncertainties of the model components cannot be assessed analytically with a sufficient confidence. In these cases, the uncertainties can be derived statistically based on samples of comparison between the models and the measurements. These statistics can be clustered differently for different conditions. For instance, the statistics of DER model uncertainties during clear sky days would be different from the ones for the cloudy days.

Hence, collections of measurements from representative primary sources will be needed for the validation of the models, including the assessment of the model errors. The validation based on the comparison of the models with the measurements should take into account the accuracies of the measurements, which should be an attribute of the corresponding object model.

2. Uncertainty of load models

2.1 Uncertainty of short-term forecast of aggregated load

The real-time values of the bus load are measured (typically by SCADA), and the uncertainty of these values are defined by the accuracy of the measurements and are used by the EMS state estimation application. The short-term forecasted load values are used by EMS decision-making applications as initial load before the effects of the to-be-implemented solutions take place in the short-term look-ahead time intervals. The changes of the loads during and after the solutions are implemented are also subjects of the TBLM and have a degree of uncertainty.

The uncertainties of the forecasted initial load models are caused by a number of factors. The load aggregated at the T/D bus is a combination of the following components:

- **Customers' natural (nominal) load**
- **DER generation/absorption**
- **Implemented DR**
- **Other reactive power sources generation/absorption**
- **Power losses**
- **Load changes due to voltage deviations**
- **Load changes due to weather and other external conditions**

Figure 2 illustrates the short-term forecast of the load aggregated at a transmission bus. In these examples, the assumed penetration of DER is about 20%. As seen in the figure, the load forecast is significantly different depending on the participation of DER and DR. If the participation of these components is unknown, the area of the TBLM uncertainty ranges within about $\pm 20\%$.

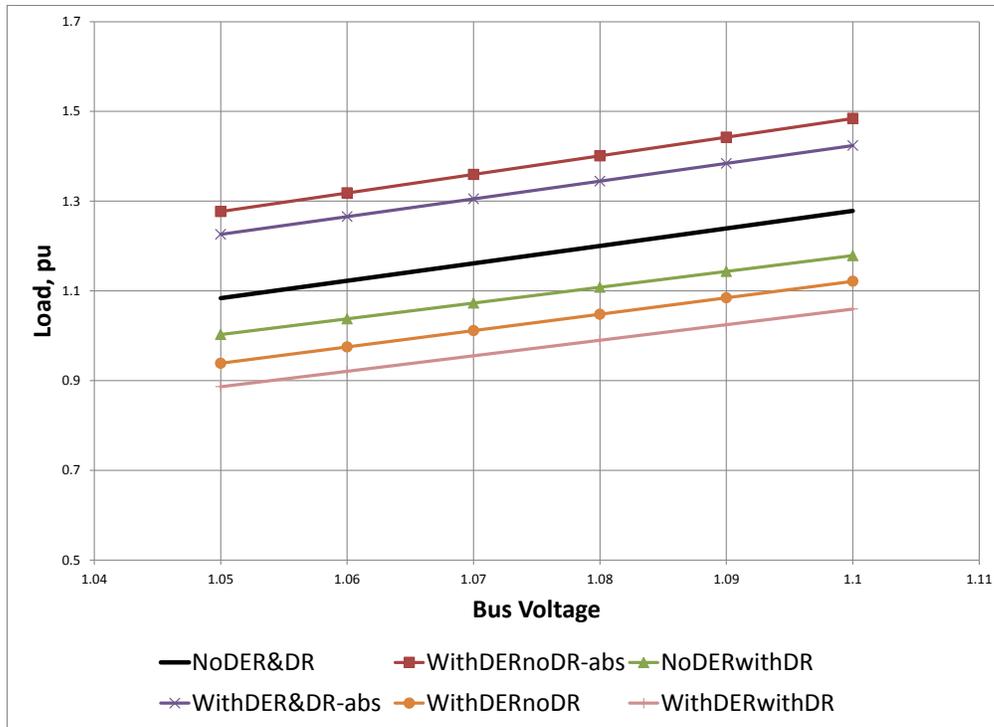


Figure 2. Illustration of aggregated at the transmission bus reactive load (unknown states of DER and DR introduce uncertainty)

Error! Reference source not found. illustrates the forecasted aggregated dispatchable load by applying IVVO and DR under different conditions of DER operations. In these examples, in the worst-case scenario the uncertainty of the forecasted dispatchable load is about 10% of the actual dispatchable load. If the actual state of the demand respond execution is unknown, the uncertainty is greater.

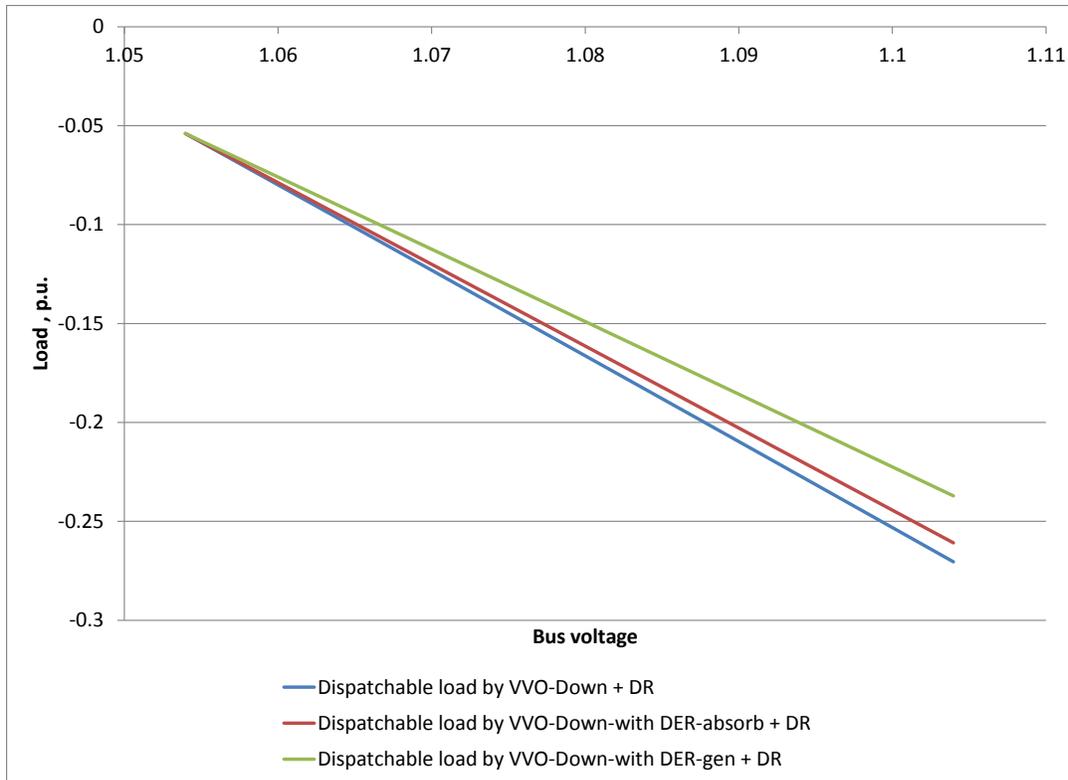


Figure 3. Dispatchable reactive load via VVO and DR (5%) with and w/o DER (unknown states of DER and DR introduce uncertainty)

The illustrations emphasize the importance of the knowledge of the expected operations of DER and DR under the expected ambient and utility operating conditions.

This information can be made available by utilization of IEC 61850 for collecting primary information and IEC 61968 for exchanges between the various Data Management and Modeling Systems and TBLM-related set of applications.

The basic (nominal) primary information about DER should include the following:

- **The DER capability curves (tables)**
- **The modes of operations and the settings of the DER under steady-state, intermittent, and abnormal operating conditions**
- **The rules of changing the modes of operations and settings**
- **The near real-time measurements from large DER systems**
- **Other**

The nominal information about the DR should include the contractual conditions for individual or clustered DR systems.

Analyses of historic data on the responsiveness of the DER and DR systems to different kind of triggers should be performed and used for the verification of the DER performance under different modes of operations and external operating conditions.

Lack of the nominal information about the DER and DR may lead to significant systemic errors in the forecasts of the aggregated load model attributes.

Note 1: The impacts of different factors on the end results may significantly differ - some of them may be insignificant and would not justify the information support efforts.

Note 2: **The degree of uncertainty caused by the same factor can be different under different conditions and times (sunny/cloudy, peak / off-peak...)**

The uncertainties of the load models affected by the execution of the application are defined by additional factors, such as

- **Load models associated with enabled load management means**
- **Models of overlapping loads between enabled load management means**
- **Load dependencies on voltages and frequency in the ranges pertinent to the performance of the subject applications.**
- **Behavior of DMS applications in reaction to the conditions caused by the execution of the EMS application.**

Note 3: What is insignificant under initial conditions may become significant under contingencies.

a. Impact of random errors

The nominal information about the loads, DER, DR, and other components of the Active Distribution Network, even if generally known, still has errors. If the reference nominal information is selected based on the average performance for given conditions, then the errors in the models of these components are mostly of a random nature. For instance, if the nominal generations of real power by non-monitored DER are assumed to be the maximum generation, then the errors will be on the negative side. If the nominal generation of these DERs is set to average values, based on historic data analyses, then the errors will be random.

Figure 4 and Figure 5 illustrate the spread of uncertainty of the aggregated bus load and dispatchable load due to random errors of voltage control, measurements, models of nodal loads, DER and DR, and CVR factors. As seen in the figures, the uncertainties of individual instances of the aggregated loads are somewhere within $\pm 5\%$. The average deviation of the aggregated load over ten consecutive instances, practically, coincides with the ideal model. This is the effect of the large number of random individual errors and low correlation between them.

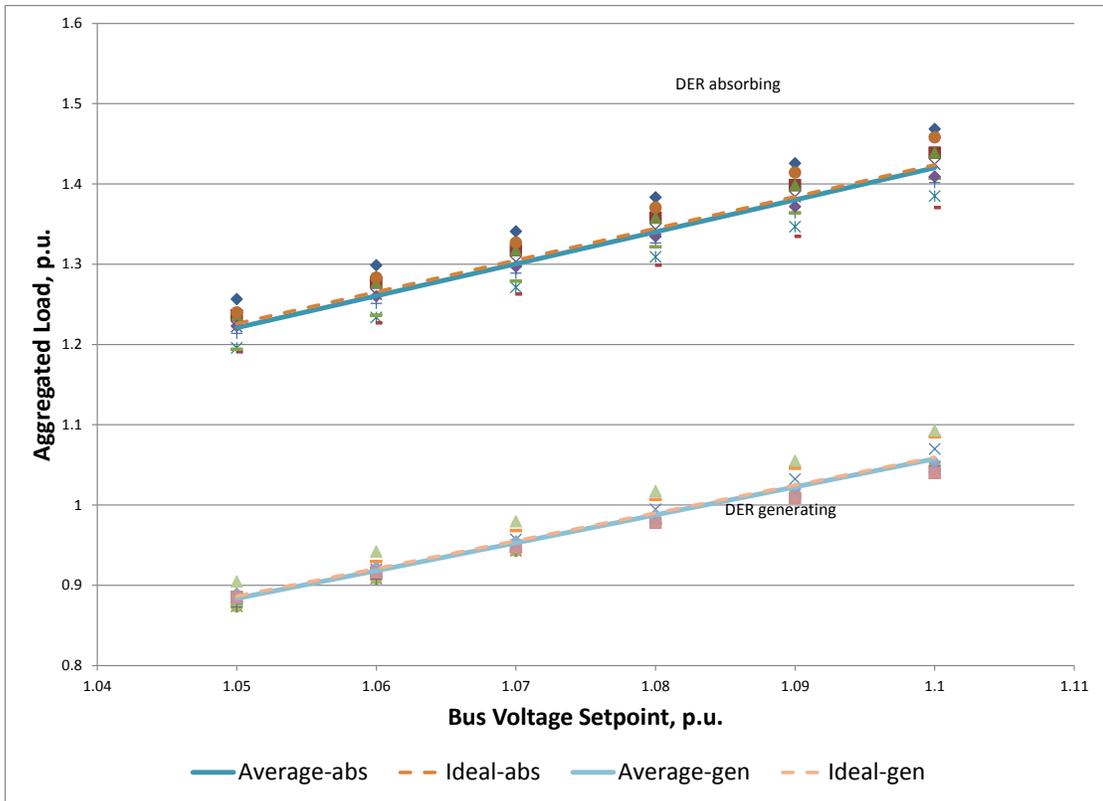


Figure 4. Impact of random errors in control, measurements, and models on the uncertainty of the aggregated load model at the transmission bus.

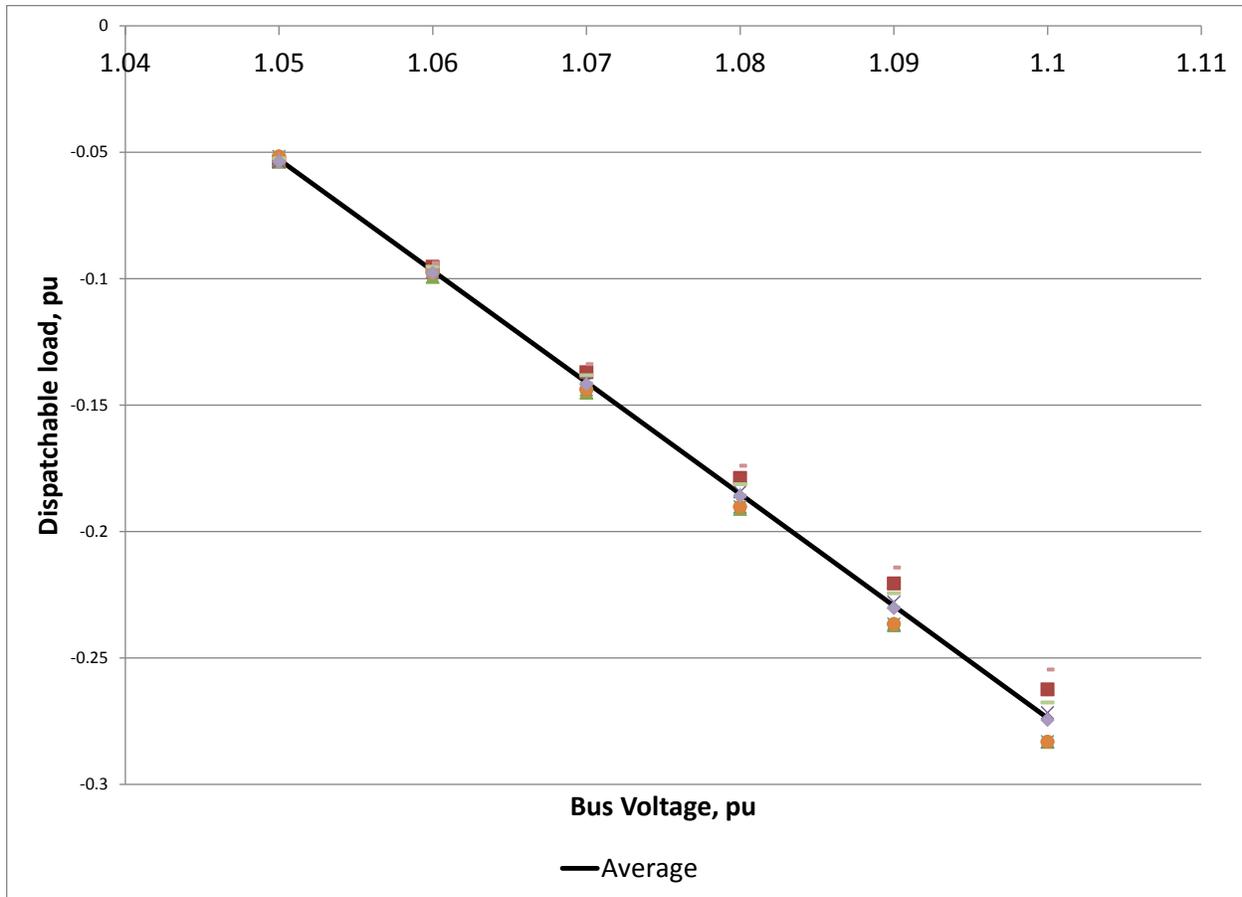


Figure 5. Impact of random errors in control, measurements, and models on the uncertainty of the dispatchable load

b. Impact of systemic errors.

Errors of some component models under some conditions cannot be considered random errors. In these cases, information about the probable systemic error should be available to take these errors into account by relevant DMS and EMS applications.

Consider as an example the errors of voltage control by a step-wise LTC with a bandwidth of different sizes.

Figure 6 illustrates a case where the uncontrolled voltage changes from higher than the desired voltage to lower than the desired voltage and the bandwidth of the controller is two times the step of control.

As seen in the figure, the controlled voltage deviates from the band-center setting by up to one step, when the uncontrolled voltage is on the higher level, and by down to one step, when it is on the lower level. Most of the time, the controlled voltage is close to the target voltage (see the histogram in Figure 7).

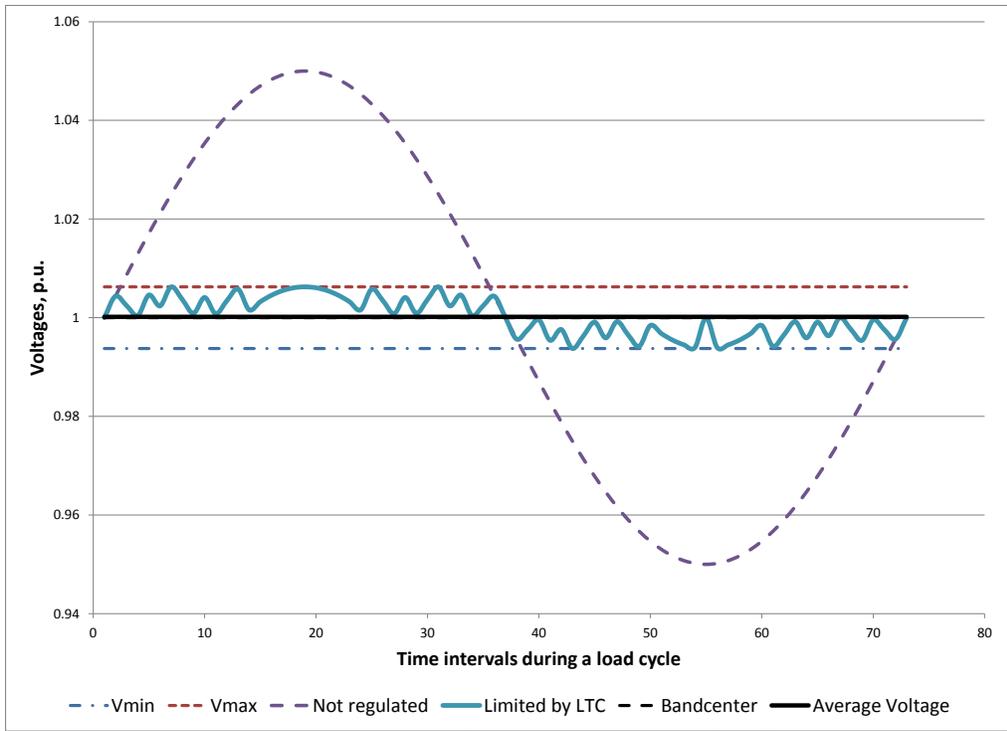


Figure 6. Symmetrical unregulated voltage deviations. Bandwidth = 2*LTC step (0.625%)

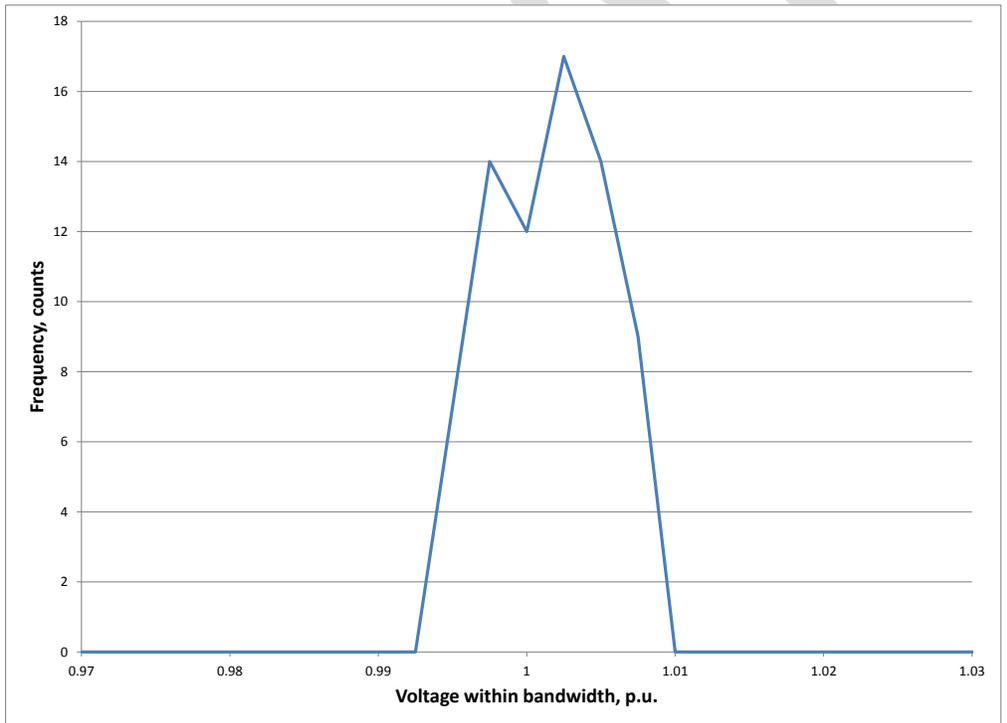


Figure 7. Histogram of voltages within the bandwidth for the case in Figure 6.

Figure 8 illustrates a case where the bandwidth is four times the step of control. In this case, the systemic bias is much more noticeable, and the probability of the controlled voltage to be close to the target is low (see the histogram in Figure 9).

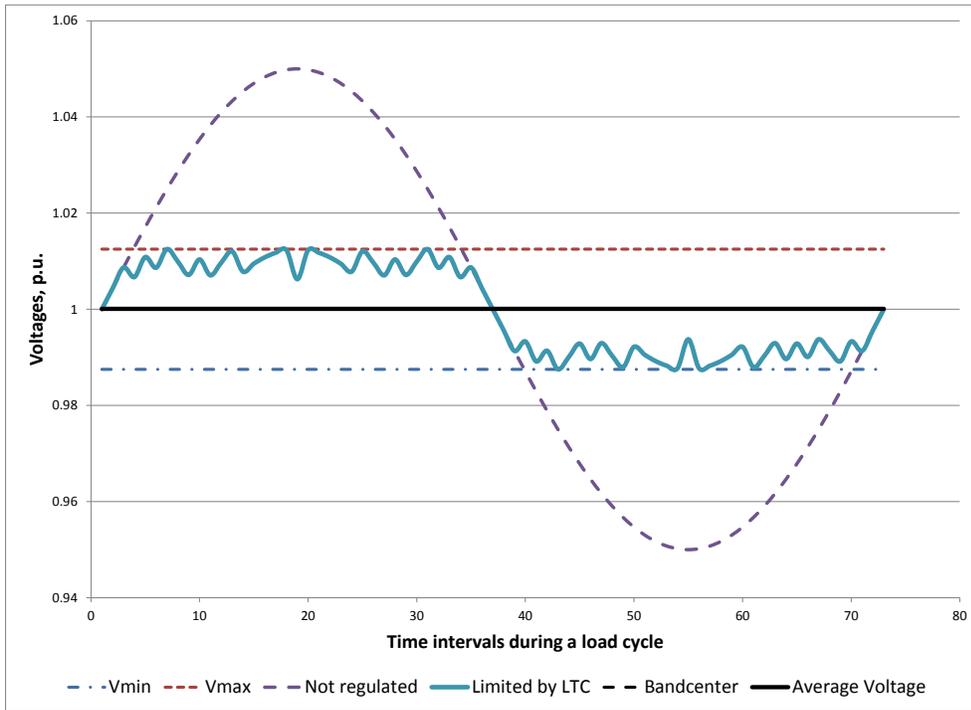


Figure 8. Symmetrical unregulated voltage deviations. Bandwidth = 4*LTC step (0.625%)

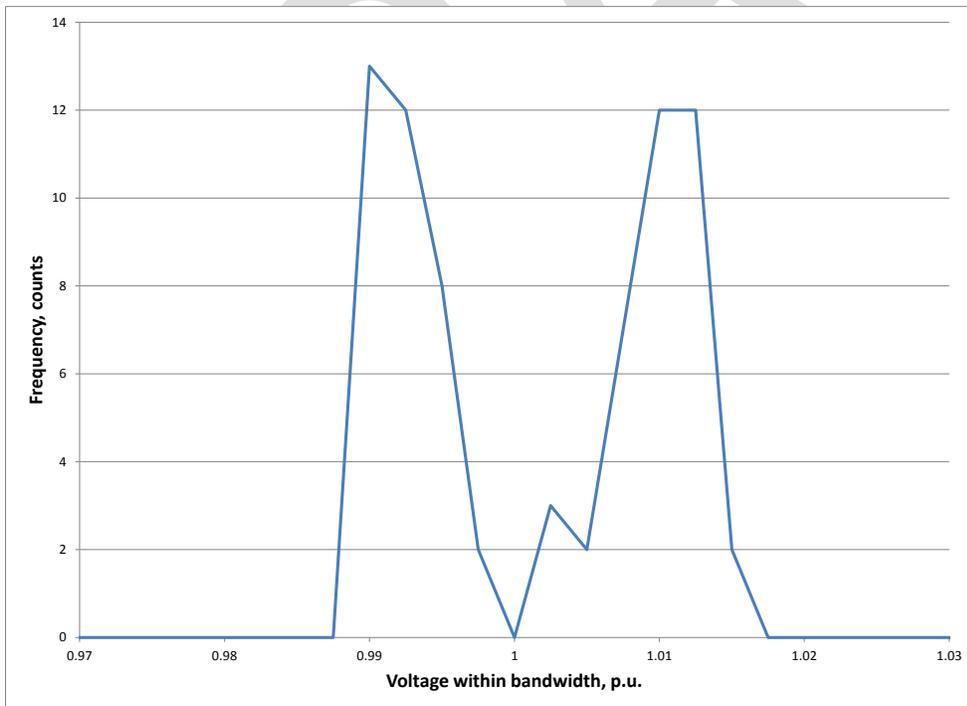


Figure 9. Histogram of voltages within the bandwidth for the case in Figure 8.

Figure 10 through Figure 13 illustrate cases, where the unregulated voltage does not deviate from the bandwidth for a part of the day time. Figure 14 illustrates a case, where there are two voltage control settings during the day, and Figure 15 illustrates a case, where the range of the LTC control is insufficient for keeping the voltage within the bandwidth.

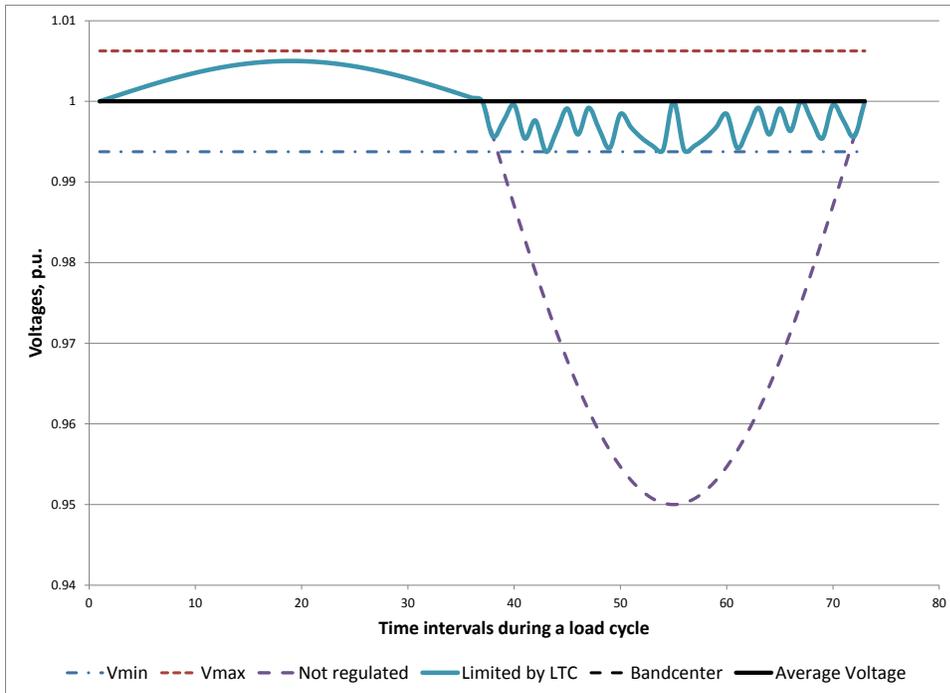


Figure 10. Asymmetrical unregulated voltage deviations. Bandwidth = 2*LTC step (0.625%)

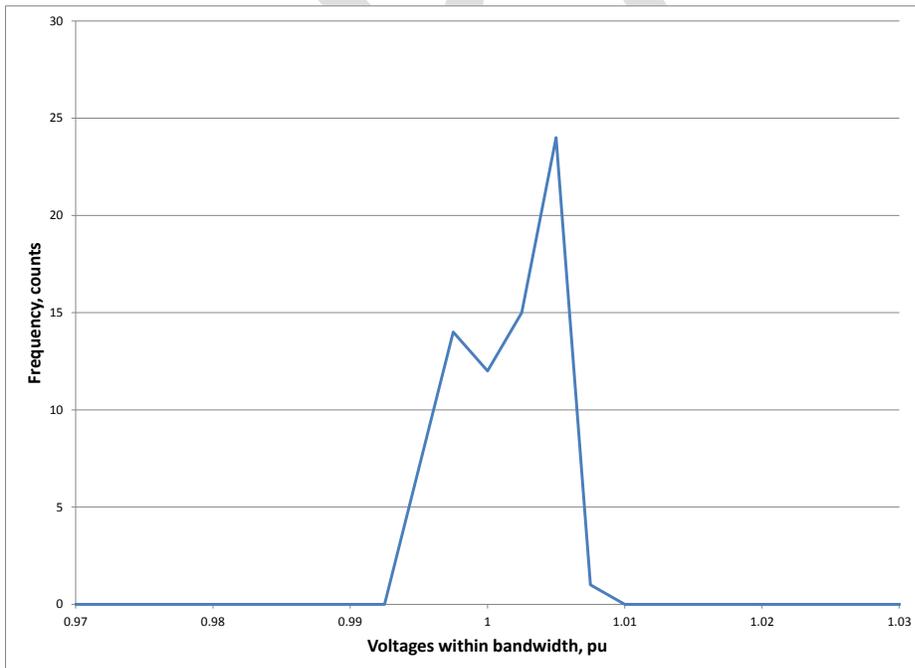


Figure 11. Histogram of voltages within the bandwidth for the case in Figure 10.

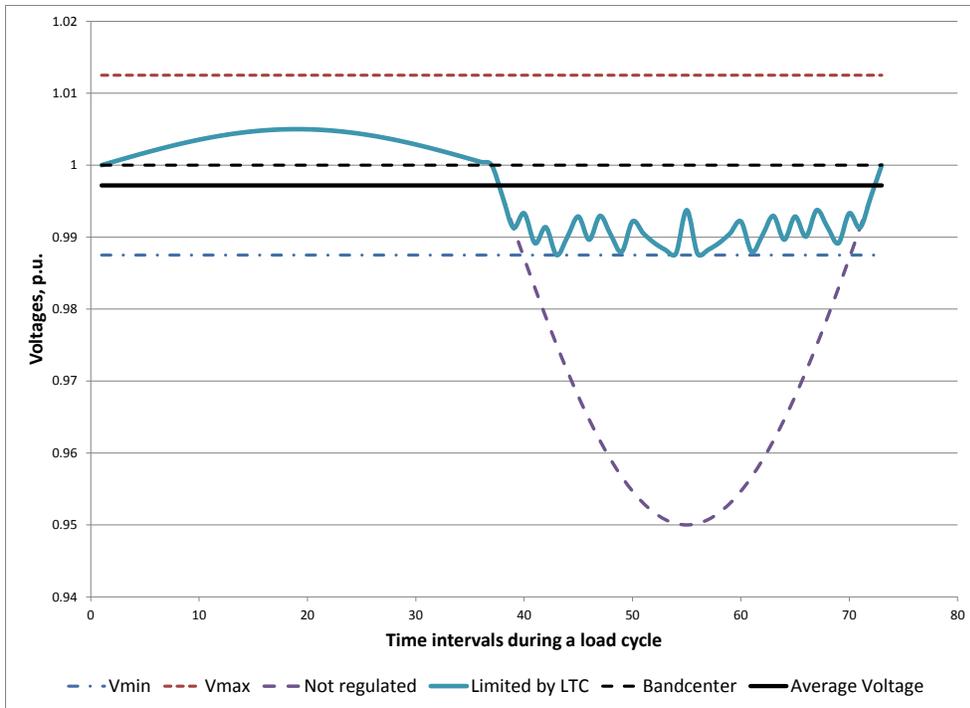


Figure 12. Asymmetrical unregulated voltage deviations. Bandwidth = 4*LTC step (0.625%)

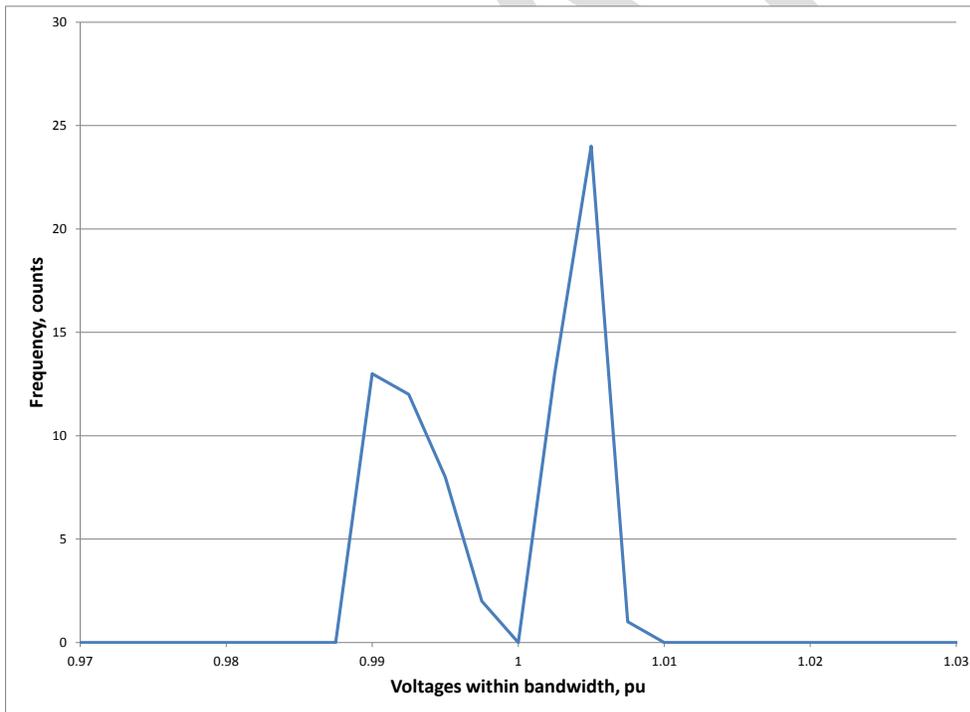


Figure 13. Histogram of voltages within the bandwidth for the case in Figure 12.

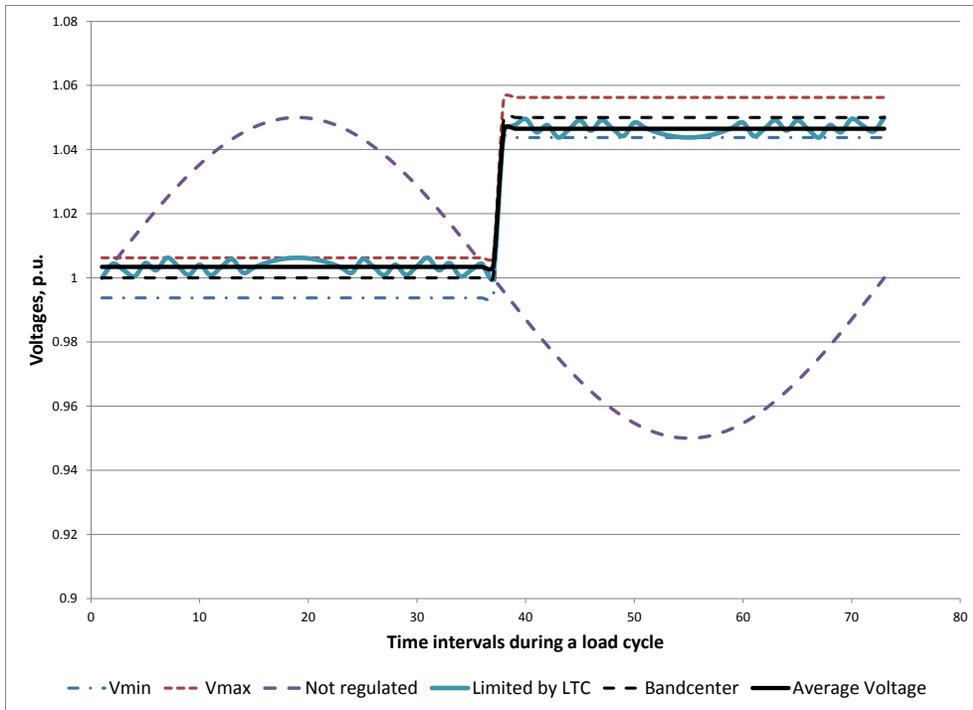


Figure 14. Symmetrical unregulated voltage deviations. Bandwidth = $2 * \text{LTC step}$ (0.625%). Two bandcenters.

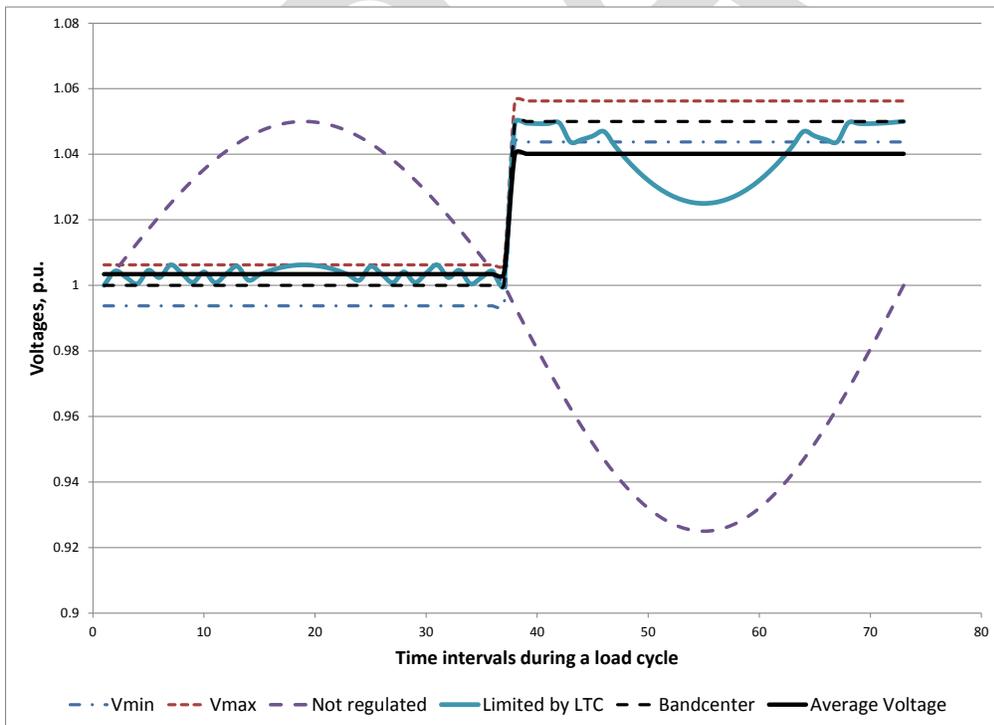


Figure 15. Asymmetrical unregulated voltage deviations. Bandwidth = $2 * \text{LTC step}$ (0.625%). Two bandcenters. Insufficient regulation range of LTC.

As it follows from the above examples, to assess the systemic error in voltage control, the sizes of the steps of control and of the bandwidth, the current or prospective band-center settings, the position of the uncontrolled voltage relative to the control settings, and the current availability of range of the controlling devices must be known.

The unknown uncertainty of the TBLM may be a cause of non-optimal and even harmful decisions made by the DMS and EMS applications.

The greater is the uncertainty of the TBLM, the smaller are the achievable benefits of the dynamic optimization of the power system operations.

Sometimes, the reduction of the control errors, which is a partial cause of the TBLM uncertainty, may have conflicting outcomes. The choice of the voltage control bandwidth is such an example. The errors of control, which depend on the size of the bandwidth, should be taken into account, when defining the voltage control tolerances. The greater the errors, the narrower the tolerance and smaller the voltage control benefits. On the other hand, the greater the bandwidth, the smaller the number of LTC operations, which may impact the cost of LTC maintenance.

Figure 16 through Figure 19 illustrate the relationships between the size of the bandwidth, loss of benefits, and the number of operations for the cases considered above. As seen in the figures, the dependence of the benefits on the size of the bandwidth is, practically, the same under all conditions considered, while the number of LTC operations is different.

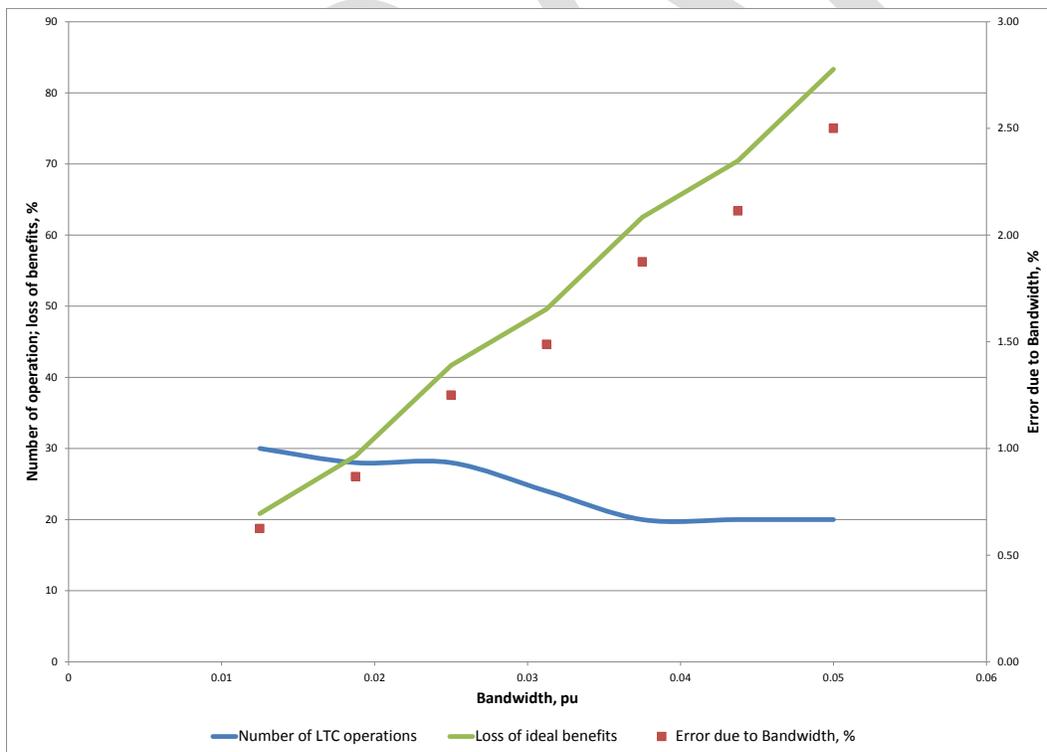


Figure 16. Number of LTC operations; errors of voltage control; and loss of benefits vs size of bandwidth. Symmetrical unregulated voltage deviations.

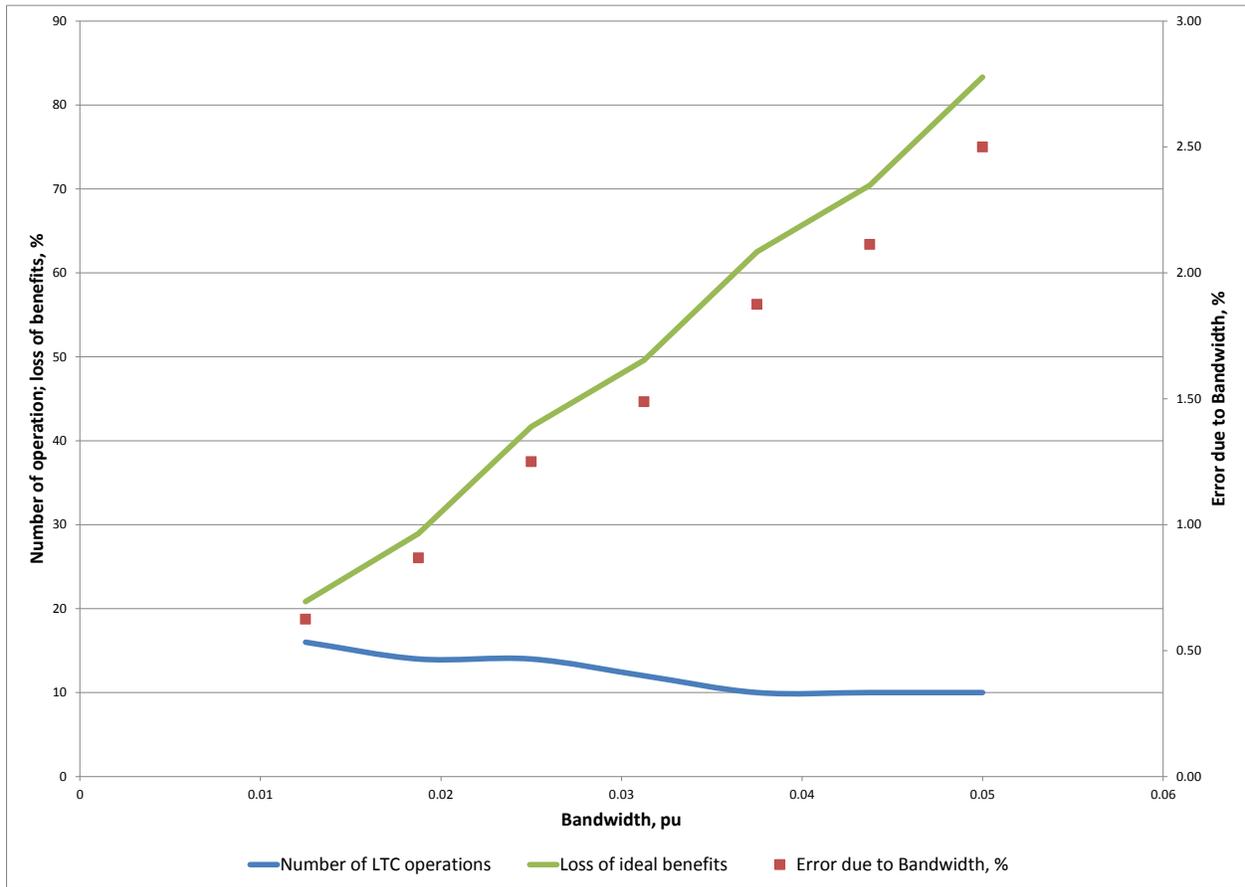


Figure 17. Number of LTC operations; errors of voltage control; and loss of benefits vs size of bandwidth. Asymmetrical unregulated voltage deviations.

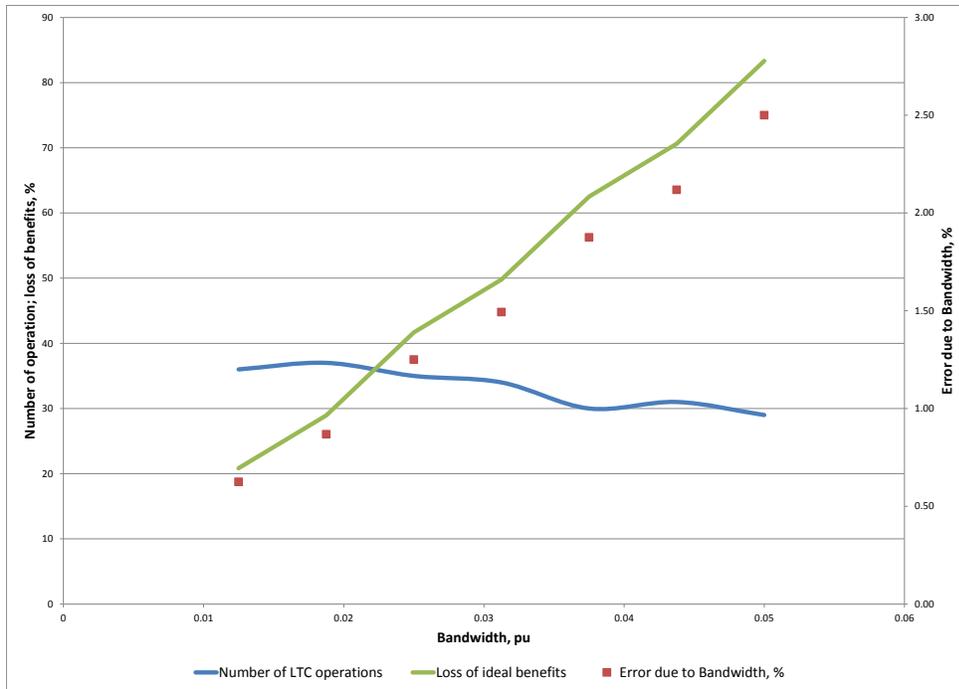


Figure 18. Number of LTC operations; errors of voltage control; and loss of benefits vs size of bandwidth. Symmetrical unregulated voltage deviations. Two bandcenters.

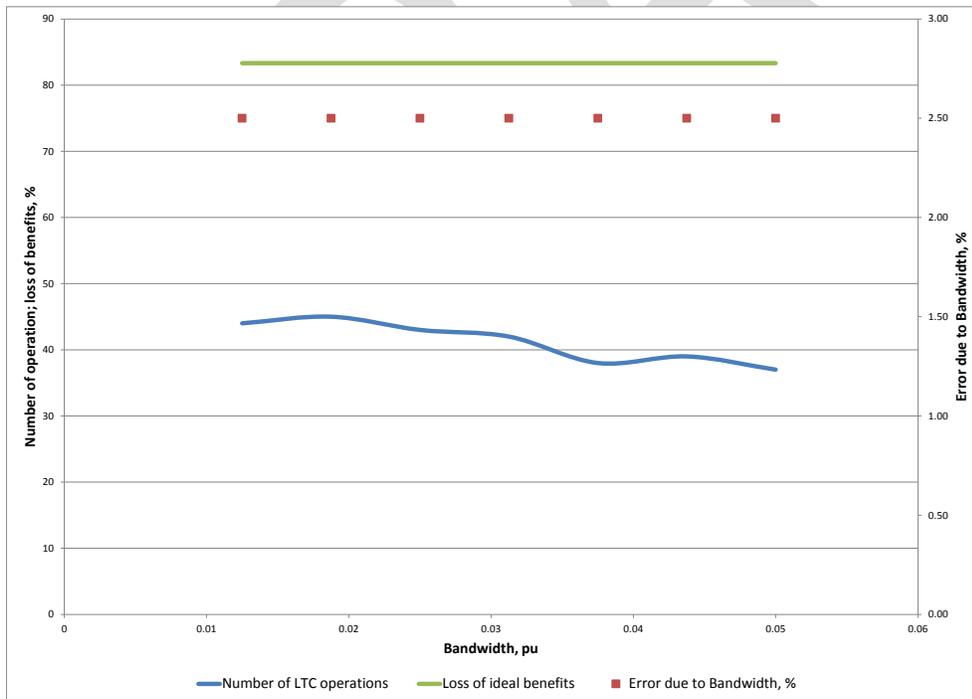


Figure 19. Number of LTC operations; errors of voltage control; and loss of benefits vs size of bandwidth. Asymmetrical unregulated voltage deviations. Two bandcenters. Insufficient regulation range of LTC.

3. Uncertainty of Secondary Equivalent

The voltage drop in the secondaries may be comparable with the voltage drops the primary distribution and in the distribution transformers. Currently, there is not much information in the corporate utility databases about the secondaries to support detailed power flow models down to the customer terminals. Also, most of the power flow models are not designed for such detailed modeling. Therefore, secondary equivalents focused mostly on the voltage drop are used in modern DMS applications [6-7]. The voltage drops in the secondaries may vary in a wide range (e.g., from 0% through 5%). This component of the power flow model impacts the assessment of the benefits of all DMS applications and subsequently the TBLM. Therefore, the knowledge of these equivalents is critical for the validity of the TBLM. With the advances of AMI and DMS, the secondary equivalents can be determined by corresponding processing of historic data [8-13].

4. Conclusions.

1. The ranges of uncertainties of TBLM components must be known to the DMS and EMS applications to avoid harmful decisions and to realistically assess the expected benefits.
2. The uncertainty of the average impact of the series of TBLM utilization is typically smaller than the uncertainty of an individual instance due to the random components of the errors.
3. The lack of the knowledge of the expected reference (nominal) state of large individual and clusters of localized DER and DR under the expected ambient and utility operating conditions and of the secondary equivalent contributes to the most of the TBLM uncertainty.
4. The information about the reference states of the DER and DR can be made available by using SCADA, AMI, and other data acquisition means, utilizing corresponding interoperability standards, like IEC 61850 (for collecting primary information) and IEC 61968 for exchanges between the various Data Management and Modeling Systems and TBLM-related set of applications.
5. The information about the reference nodal loads and secondary equivalents can be made available via AMI, communication with customer EMS, and micro-grid controllers and by processing historic data in load and secondary equivalent processors.
6. The actual states of the component models used for developing the TBLM may differ from the reference states by random and systemic errors.
7. It can be expected that the composite TBLM errors due to the random errors of the multiple components are not critical because of the mutual compensation of the random and weakly correlated individual errors.
8. The systemic errors of components may be critical, especially if they are errors of dominant components. Therefore, collecting information from such components to determine the systemic errors is critically important. Obtaining such information may require the use of communication means with the field equipment and between the EMS and DMS databases and applications. Additional Object Models may need to be developed [14].

5. References.

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