

Impact of Load Modelling Parameters on Motor Start simulation in The Alberta Electric System

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SUMMARY

Motor start simulation is a dynamic study which simulates power system response as a large motor is connected to the power system. Motor start simulations are done in several system planning and interconnection studies. However, to perform these simulations, load models are required. Load models are mathematical equations used to represent physical loads in power system simulations. One of the dynamic load models used by the industry is the default composite load model called the Complex Load Model (CLOD) model from the Power System Simulator for Engineering (PSS[®]E) software. This model was approved by the Western Electrical Coordinating Council (WECC) to deal with the California-Oregon operational issues after the July 2 and August 10, 1996 outages. CLOD is a model that works by having the user define the distribution of load components at a certain bus. In many typical industry simulations, two sets of generic parameters are used for this model. The first is a 70% motor load (40% large motor and 30% small motor) and 30% static load. This second, which was developed by WECC, is 20% motor load and 80% static load. However, with the integration of new technology, and economic growth, load compositions are changing. Thus, in this paper, the impact of changing the CLOD model parameters on motor start simulation outcomes are investigated.

We approach the investigation in three stages. The first stage will be to identify the test buses, the second stage will be to identify the motor load sizes in which can be added to the test buses, and the third stage is to perform the motor start simulations. In the first stage, voltage stability studies are used to identify a small set of buses of various voltages and power transfer sizes are selected. Once the test buses are selected, the second stage will size the motor loads for the test bus, using the motor start simulations, but with static load models. Afterwards, for the third stage, the motor start simulations with the different percentage parameter CLOD models applied are performed. The simulations performed are divided into two scenarios; the first scenario shows how changing the overall percentage of the CLOD model affects the outcome of the motor start simulations. The second scenario shows how changing the large and small motor parameters affects the motor start outcome. The complete planning model of Alberta's electrical grid is used for the studies.

From the motor start simulations, it is observed that by applying the CLOD models, and using different percentages to the motor start simulation affects the simulations results, as expected. However, the amount that the results change by varies depending on the voltage level and power transfer size of the bus. From the results, it is recommended that close attention be paid to the accuracy of the CLOD model parameters when the bus voltage is 4.16 kV or less, when the bus power transfer size is 15 MW or smaller, or if the lowest voltage values of the results fall very close to the motor start limits.

KEYWORDS

Load models, CLOD model, PV analysis, Motor start simulation, Power System Simulator for Engineering (PSS[®]E).

1 INTRODUCTION

With the economic growth and integration of new technology being implemented into power grids, system simulations are important in understanding the response of power related events. One of which is the motor start simulation, which is a simulation that evaluates how a power system responds when an electric motor is connected. This simulation is important, especially when many of the loads attached to the electrical grid are industrial in nature and have many induction motor loads (e.g., in Alberta).

To perform these simulations, dynamic load models are required. This is because studies have shown that using static load models in dynamic simulations are unable to accurately represent certain loads, such as motors [1, 2]. One such paper is [3], as it is demonstrated that static load flow calculations are unable to predict voltage instability outcomes. In this paper, a simple dynamic load model for the capture of nonlinear steady-state behaviors in voltage stability studies is proposed. Another paper, written by I. A. Hiskens, explores the importance of accurate load modelling and when it is required through the use of trajectory sensitivity concepts [4].

However, creating these dynamic load models is very challenging, as indicated by the IEEE Task Force [5] that reviews the ZIP and induction motor loads and their performances. Furthermore, Grande-Moran et al [6] discuss the difficulties and challenges of load model development, their different load modeling approaches, and their impacts in power system studies [6]. Masato Yamamoto [7] introduces a dynamic load model for voltage stability analysis. This model, which is a combination of a “first-order delay differential equation dynamic model and the response of load admittance” [7], is verified through multiple study cases. Liang et al [8] developed and proposes a new modeling technique for solving the facility modeling problem. This technique, which is a bottom-up machine load aggregation scheme for radial networks. Through testing, it is identified that this method is capable of capturing major dynamic characteristics of an existing refinery facilities large industrial facilities [8].

Currently one of the load models that is widely used to represent loads is the CLOD model. However, current research of this model has tended to be focused more on representation of specific industrial loads [9] rather than the impact it has on dynamic simulations. Thus, this paper studies the impact of changing the CLOD model parameters has on the outcome of the motor start simulations. For this paper, simulations are performed on the complete model of Alberta’s power grid, and the test buses are selected based on their voltage, and their power transfer size.

The remaining parts of this paper are organized as follows. In Section 2, we provide some details of the CLOD model. Section 3 provide a summary of the research methodology. In section 4, the results are discussed, followed by the concluding remarks in Section 5.

2 COMPLEX LOAD MODEL (CLOD)

Load models are mathematical equations that display the relationship between the magnitude and frequency of the bus voltage and the active and reactive power or current flowing into the bus load [5, 10]. Classified into either static or dynamic models [11], these models are important, as they are used in the operation and planning of large power systems, to accurately represent each component. Furthermore, load models are important, as they have a considerable role on the behavior of the power system when there is a change in the voltage and frequency [12, 2, 5, 11].

Static load models are models that expresses the active and reactive powers of the load as algebraic functions of the bus voltage magnitude and frequency at any instant of time [5, 10, 13], and are also used in short duration steady-state analysis, such as power flow studies [14]. While dynamic load models, which are models that express the active and reactive power equations as a function of voltage and time [12], are used for simulations where the system state varies over a period time, such as motor start simulations. Mainly used in representing the dynamic components such as motor and generators, these models are expressed as voltage and/or frequency dependent transfer functions [10]. As stated, load models have usually fallen into either a static or a dynamic category [11].

The CLOD model is a composite load model, which contains both the static and dynamic components [12, 15]. This model, which is used by the power system operators, is provided by the Power System Simulator for Engineering (PSS®E) program is used in dynamic simulations to model loads that do not have enough available dynamics data [16]. Consisting of many types of equipment that could be connected to any typical substations, the model works by allowing the users to specify the general characteristic of the composite load [16] in percentages. After the parameters have been determined, the PSS®E program applies the composite model outline to the designated loads in the system, and uses the resultant dynamic details tailored for each load to replace all the constant MVA, current and admittance loads [16]. Figure 1 is a schematic that displays all the components of a CLOD model.

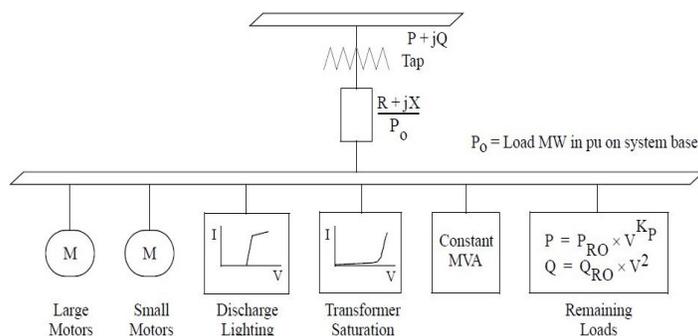


Figure 1: CLOD model schematic [17]

3 METHODOLOGY

In this section, the methodology and the procedures used to perform this research are described. Noticing Figure 2, the methodology of the motor start study is divided into three stages, each with their own objective:

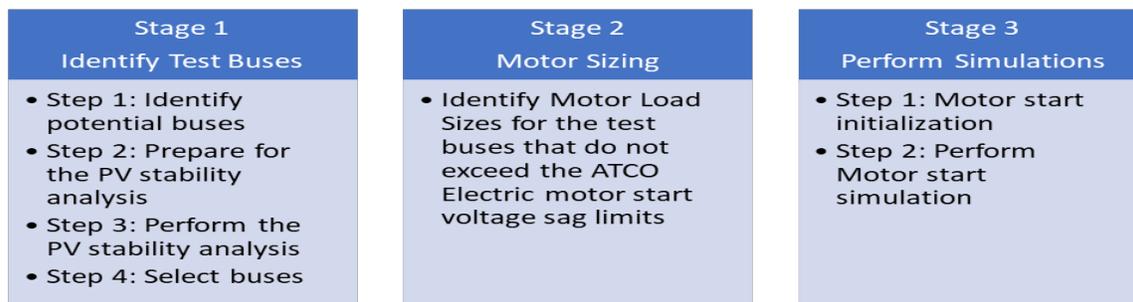


Figure 2: Steps performed in each stage of the methodology

3.1 Stage 1: Identify Test Buses

In this first stage, the objective is to identify test buses of various voltage strengths for the direct on-line induction motor start simulation. For the first step, data about Alberta's electrical power system and the loads currently attached are obtained. Once completed the data is then organized into an easy to read database format which allows the user to easily filter buses that do not meet the selection criteria. For this paper, the North West region of Alberta was selected for the studies because there are many industrial load buses in this region. As one of the criteria is the size of the power transfer for the bus, the next step is to perform the voltage stability analysis on each bus to identify the power transfer size. Based on the stability results, the buses are sorted into three groups based on their power transfer strength. Using the information from both the system database, and the stability analysis, 6 buses are selected based on their power system voltage and their power transfer sizes.

3.2 Stage 2: Identify Motor Load Sizes

The purpose of this stage is to identify the motor sizes for the selected buses. This is accomplished by performing the motor start simulation for each test bus to identify the largest motor load size in which

can be added to the bus before violating voltage sag limits. The limits are based on the ones defined in the *System Standard for the Installation of New Loads* [18]. However, any other voltage limit could be used. In these simulations, the voltage sag limits used are the ATCO voltage sag limits for motor start simulations, as they are the main power distribution company in Northern Alberta. In addition, for these simulations performed, no CLOD models are used, as these results are to set the baseline for the comparison. As the CLOD model will not be used for the simulation, the static loads in the simulation will then be represented, as dynamic loads using the PSS®E load static to dynamic load conversion

3.3 Stage 3: Motor Start Simulation with the CLOD models

In this stage, we will perform multiple motor start simulations on each test bus with the CLOD model using different motor load percentages to see how it impacts the torque, current and voltage results of the motor start simulation. The simulations are divided into two scenarios;

- Scenario #1: The total CLOD percentage used for the model shall be placed all on the large motors and will be adjusted between 50% and 90% in increments of 10%.
- Scenario #2: The total CLOD percentage is kept constant, while percentages of the large and small motor parameter are adjusted in increments of 10%.

4 SIMULATION RESULTS

While there were many results, for this paper, the buses selected, and their properties are listed on the table below:

Table 1: Selected Buses for Paper

Bus #	Power System Voltage	Power Transfer Size	Group Strength
Bus #1	13.8 kV	25.7 MW	Strong
Bus #2	13.8 kV	11.1 MW	Weak
Bus #3	4.16 kV	8 MW	Weak
Bus #4	4.16 kV	18 MW	Strong

Analyzing the results, it is seen that adding the CLOD model to the dynamic motor start simulations does have an impact on the results. Observing the outcomes of applying different CLOD model percentages compared to the static simulation in Scenario #1, as presented in Figure 3, Figure 4, and Figure 5, it is noticed that this impact varies based on several variables.

Through Figure 3, which is a motor start simulation on Bus #1, which is strong bus, the effects of applying a 50% Large motor (LM) and 90% LM CLOD model percentages are displayed. Examination of this figure notices that applying the CLOD models to the simulation causes the voltage to sag more than the static simulations, as well as increase the duration of the motor start simulation. However, the magnitude of this change is minor.

As for both Figure 4 and Figure 5, which are both weak buses though for different voltages, it is observed that adding the 50% LM and 90% LM CLOD models causes the voltage to sag further and for longer in comparison to Figure 3. Especially for Figure 5, which sags past the ATCO voltage sag limit. This indicated that buses with either a weaker power transfer size or a weaker power system voltage is more notably impacted by the application of the CLOD model.

Note that from Figure 3 and Figure 4 that for all models, the voltage outcomes are nevertheless above the limit. Though, for Bus #2 in Figure 4, the voltages with a 90% CLOD model becomes very close to the limit. However, in the case of Figure 5, while using a static load model leads to the voltages being above the limit and thus, the motor start would be allowed. But with the 90% CLOD model added, the limit is violated, and the motor start is considered failed. As for the 50% CLOD, the voltages are right at the limit and this could be a marginal pass or fail. From a wide range of simulations results, we concluded that for the cases where the buses have a high-power system voltage and a high-power transfer size, there is more flexibility on the choice of load model parameters. However, for the cases where the buses have a low power system voltage or a low power transfer size, much more care needs to be put in selecting a more accurate load model.

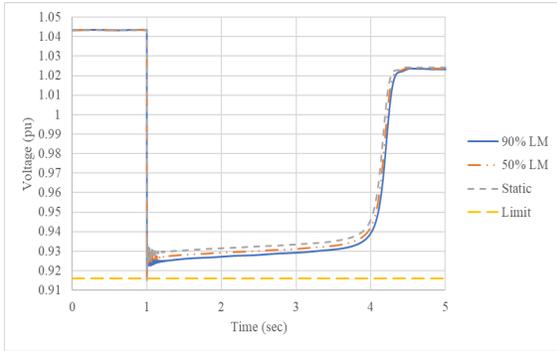


Figure 3: Motor Start Simulation Voltage Results on Bus #1

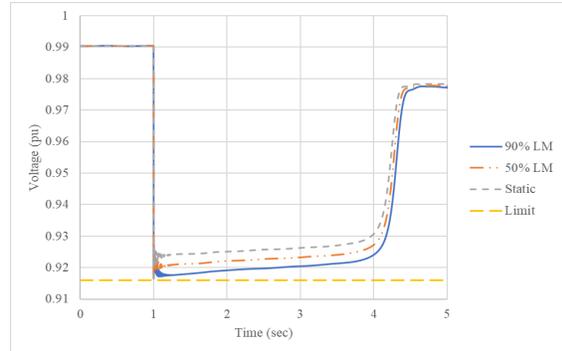


Figure 4: Motor Start Simulation Voltage Results on Bus #2

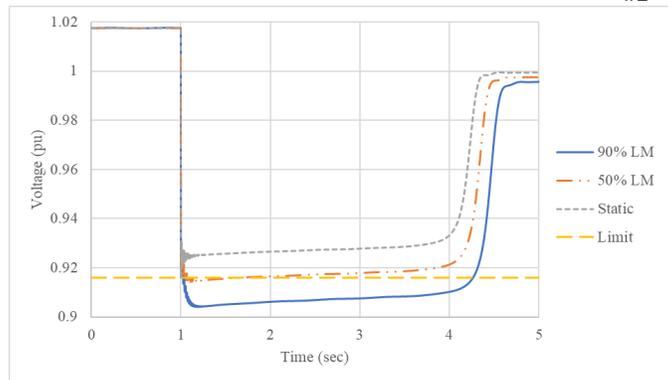


Figure 5: Motor Start Simulation Voltage Results on Bus #3

From Scenario #2, where the total CLOD percentage is held constant and the small and large motor percentages are adjusted, it is observed that this change in the motor percentages has very little effect in comparison to the results of Scenario #1, which is shown in Figure 6, Figure 7, and **Error! Reference source not found.**Figure 8.

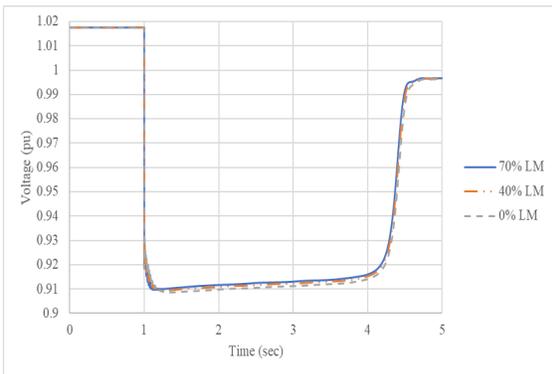


Figure 6: Comparing different motor percentages voltage response of Bus #3

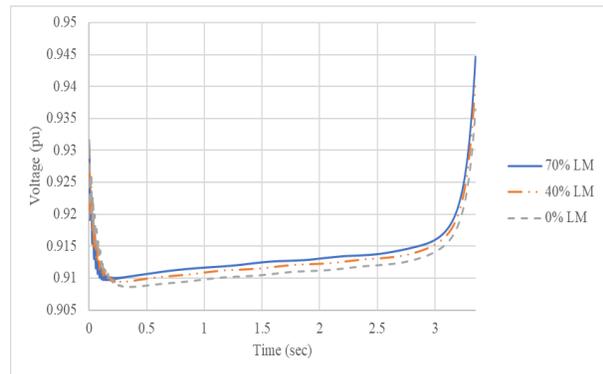


Figure 7: Zoomed in comparison of different motor percentages voltage response of Bus #3

In both Figure 6 and Figure 7 it is observed that alternating the motor load percentages does produce different outcomes for the motor start simulation. However, these differences in the results are very minor, with the largest change being a magnitude of 1×10^{-4} per unit, which, makes it negligible for consideration. Yet, depending on the proximity of the results to voltage sag limit, analysts may need to observe them closely as they may change the marginal outcome of the motor start from a pass to a fail, as shown in Figure 8.

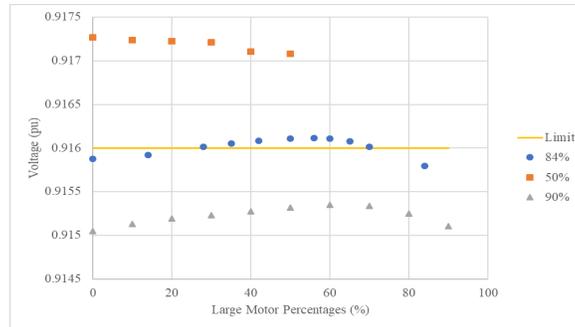


Figure 8: Comparison of Lowest Voltage between Simulations with different CLOD percentages and parameters for Bus #4

Figure 8 shows the recorded lowest voltage values on Bus #4 from the motor start simulation using different CLOD models. In this diagram, observations made from Figure 6 and Figure 7 about changing the motor load percentages does not affect the overall motor start results are supported by the orange squares and the grey triangles. However, analyzing the round blue dots, it is observed that adjusting the motor parameter percentages of the CLOD models when the voltage levels fall very close to the voltage sag limitations, can change the outcome of the motor start simulations. Thus, as stated above, this implies that analysts need to pay close attention to the motor load parameter composition if the results fall very close to the voltage sag limits.

5 CONCLUSION

In this paper, the impact of applying the CLOD model with different percentage motor load parameters on the motor start simulations, was investigated. Divided into two scenarios, observations were made about how this model adjusted both the magnitude of the outcomes and the duration of the motor start.

In Scenario #1, it was observed that adding the CLOD model to the motor start simulation impacts the outcome by increasing both the magnitude of the decrease in the voltages, as well as the duration of the motor starts. This increase varied depending on the percentage used for the motor parameters, the bigger the percentage, the bigger the impact. In addition, this voltage sag magnitude, and increase in the duration of the motor start had a much bigger reaction when the motor start simulation was performed on test buses that had a smaller power system voltage or a low power transfer size.

From Scenario #2, it was observed that adjusting the motor parameter percentages of the CLOD model altered the outcome of the motor start. However, the size of change in the outcome did not vary as much as the change in the overall total percentage. Yet, these results can still play a role in changing the outcome of the motor start simulation, though this depends on the lowest voltage's proximity to the voltage sag limit. From what was observed, if the results fell very close to the limit, changing the motor parameter percentages, could change a motor start failure into a success.

Reviewing these results and observations, it is best summarized that CLOD model parameters doesn't affect the motor start simulation outcome for buses where both the power transfer size and the power system voltage are strong. However, analysts should pay close attention to the CLOD motor load parameters when the buses have a power system voltage of 4.16 kV or less, a power transfer size approximately 15 MW or less, or if the lowest voltage of the simulation falls very close to the voltage sag limit, as applying the CLOD model can change a successful motor start and fail it.

BIBLIOGRAPHY

- [1] J. Jatskevich and T. Aboul-Seoud, "Dynamic modeling of induction motor loads for transient voltage stability studies," 6 10 2008. [Online]. Available: <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4763318>. [Accessed 9 2 2019].
- [2] Y. Li, H. d. Chiang, B. k. Choi, Y. t. Chen, D. h. Huang and M. g. Lauby, "Representative static load models for transient stability analysis: development and examination," 21 05 2007. [Online]. Available: <https://ieeexplore-ieee-org.ezproxy.lib.ualgary.ca/stamp/stamp.jsp?tp=&arnumber=4202022>. [Accessed 15 02 2019].
- [3] D. J. Hill, "NONLINEAR DYNAMIC LOAD MODELS WITH RECOVERY FOR VOLTAGE STABILITY STUDIES," 1 2 1993. [Online]. Available: <https://ieeexplore-ieee-org.ezproxy.lib.ualgary.ca/stamp/stamp.jsp?tp=&arnumber=221270>. [Accessed 4 4 2019].
- [4] I. Hiskens, "SIGNIFICANCE OF LOAD MODELLING IN POWER SYSTEM DYNAMICS," 25 5 2006. [Online]. Available: <https://web.eecs.umich.edu/~hiskens/publications/IP-027.pdf>. [Accessed 25 10 2018].
- [5] IEEE Task Force, "Load Representation for Dynamic Performance Analysis," 01 05 1993. [Online]. Available: <http://home.engineering.iastate.edu/~jdm/ee554/TaskForcePaper1993.pdf>. [Accessed 18 01 2019].
- [6] C. Grande-Moran, B. Fernandes, D. Feltes, J. Feltes, M. Wu and R. Wells, "Case Studies on Dynamic Load Modeling," 4 9 2018. [Online]. Available: <https://ieeexplore-ieee-org.ezproxy.lib.ualgary.ca/stamp/stamp.jsp?tp=&arnumber=8664069>. [Accessed 4 4 2019].
- [7] Y. Masato, "A Dynamic Load Model for Analysis of Power System Voltage," 12 12 1994. [Online]. Available: <https://onlinelibrary.wiley.com/doi/pdf/10.1002/ej.4391150609>. [Accessed 25 10 2018].
- [8] X. Liang, W. Xu, C. Y. Chung, W. Freitas and K. Xiong, "Dynamic Load Models for Industrial Facilities," 8 8 2011. [Online]. Available: <https://ieeexplore-ieee-org.ezproxy.lib.ualgary.ca/stamp/stamp.jsp?tp=&arnumber=5978809>. [Accessed 8 4 2019].
- [9] W. Xu, X. Liang and S. Li, "Dynamic load modeling for industrial facilities using template and PSS/E composite load model structure CLOD," 11 5 2017. [Online]. Available: <https://ieeexplore-ieee-org.ezproxy.lib.ualgary.ca/stamp/stamp.jsp?tp=&arnumber=7945123>. [Accessed 25 10 2018].
- [10] X. Liang, "Dynamic Load Models for Industrial Facilities," University of Alberta, Edmonton, 2013.
- [11] A. P. Tellez, "Modelling aggregate loads in power systems," 2017. [Online]. Available: <https://www.diva-portal.org/smash/get/diva2:1085518/FULLTEXT01.pdf>. [Accessed 19 3 2019].
- [12] A. Arif, Z. Wang, J. Wang, B. Mather, H. Bashualdo and D. Zhao, "Load Modeling – A Review," 2 5 2017. [Online]. Available: <https://www.osti.gov/servlets/purl/1435710>. [Accessed 11 3 2019].
- [13] P. Kundur, Power System Stability and Control, Toronto: McGraw-Hill, 1993.
- [14] M. Michael, A. Petoussis, S. Stavrinou and A. Polycarpou, "The Impact of Load Modeling on Power Flow Studies for the Cyprus Power System," 2 09 2014. [Online]. Available: <https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6934744>. [Accessed 09 02 2019].
- [15] EPRI, "Measurement-Based Load Modeling," 26 9 2006. [Online]. Available: <https://www.epri.com/#/pages/product/1014402/?lang=en-US>. [Accessed 21 3 2019].
- [16] Siemens Power Technologies International, PSS®E 33.4, PROGRAM APPLICATION GUIDE, VOLUME 2, New York, 2013.
- [17] SIEMENS, "PSS®E 33.4 MODEL LIBRARY," Siemens Industry, Inc., Schenectady, NY, 2013.
- [18] ATCO Electric, "System Standard For the Installation of New Loads," 3 08 2011. [Online]. Available: http://www.atcoelectric.com/Services/Industrial-Customers/Documents/dload_std2011.pdf. [Accessed 8 12 2018].