ELECTRIC POWER RESEARCH INSTITUTE

Memorandum

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TO: NERC LMTF

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SUBJECT: **DRAFT MODEL SPECIFICATIONS FOR VARIABLE FREQUENCY DRIVE (VFD) INTERFACED MOTOR LOADS**

This document presents a specification for a proposed model to represent the aggregate dynamic behavior of VFDs in positive sequence time domain simulations. The model has been constructed based on lab test measurements of VFDs of various sizes from different manufacturers.

The block diagram of the proposed model, list of parameters and sample results are shown in this model specification document.

<u>Presently used model</u>

The present model in positive sequence software is represented as shown in *Figure 1*. The values of V_1 and V_0 are 0.7pu and 0.5pu respectively, as per the latest NERC recommended values.

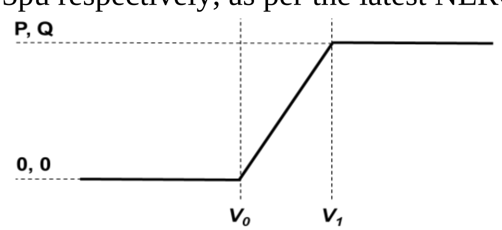


Figure 1: Present power electronic model P and Q variation with terminal voltage

<u>Proposed model</u>

The block diagram for this proposed model is shown in *Figure 2*. The model utilizes 2 states associated with 2 washout blocks to capture the response of VFDs as observed from the laboratory test measurements. The washout blocks, with the limiters, are used to accurately capture the effect of:

1. reverse biasing of drive diodes during a terminal voltage sag, and

2. the inrush drawn by the VFD during the terminal voltage recovery/increase.

During a voltage sag, the diodes at the front end of the drive get reverse biased causing the current drawn by the drive to drop until the internal capacitor discharges into the end load and the diode becomes forward biased again (if it does). This results in the active and reactive power to drop first and then slowly rise back (like a washout action). When the voltage recovers after the sag the partially discharged capacitor now draws an inrush causing the active and reactive power to rise first and then slowly go down to the steady state value (again like a washout action). Upon voltage recovery, the magnitude of inrush current drawn by the model is limited by the limiters.

The parameter/variable list for this modeling approach is tabulated in *Table 1*. Internal to the model, the actual values of active and reactive power limits are calculated as

$$P_{\max\_internal} = P_{max} * P_0 * Mul$$
$$Q_{\max\_internal} = Q_{max} * Q_0 * Mul$$

Table 1 Parameter/variable list for modeling approach 1

Name	**Description**	**Sample Value**
V_t	Terminal voltage (pu)	Input
K_1	Washout gains for active power	0.8
τ_1	Time constants for active power (s)	0.2
K_2	Washout gains for reactive power	0.03
τ_2	Time constant for reactive power (s)	0.05
Mul	Multiplier value from partial trip characteristic	Obtained from partial trip block
P_{max}	Maximum value of active power (pu)	1.1
Q_{max}	Maximum value of reactive power (pu)	1.1
P_0	Steady state load active power (pu)	Evaluated during initialization
Q_0	Steady state load reactive power (pu)	Evaluated during initialization

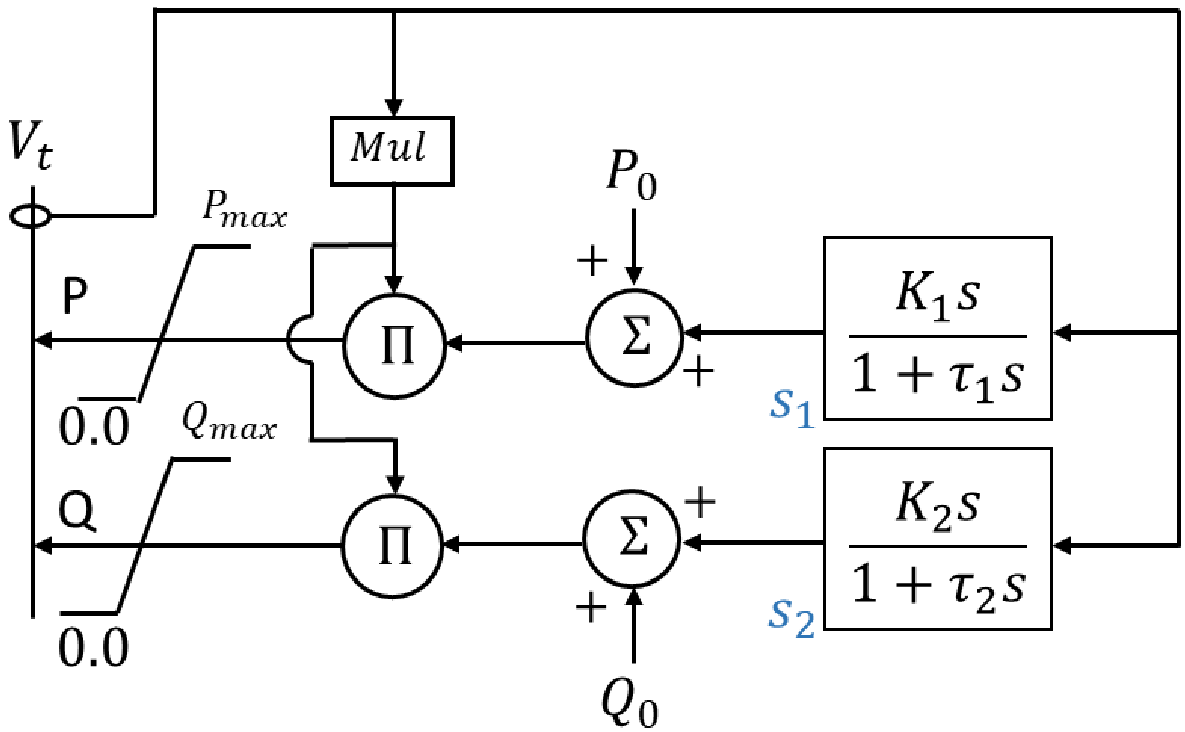


Figure 2 Block diagram of modeling approach

Representative results

Lab tests were performed on drives from two manufacturers with the ratings of:

1. Manufacturer 1: 30 HP – 480V line – line.
2. Manufacturer 2: 30 HP – 480V line – line.
3. Manufacturer 2: 30 HP – 240V line – line.
4. Manufacturer 2: 60 HP – 480V line – line.
5. Manufacturer 2: 125 HP – 480V line – line.
6. Manufacturer 2: 100 HP – 480V line – line.

The tests performed on these drives are defined as per
Table 2.

Table 2: Lab tests run on the drives

Depth	**Duration**
0.95pu	120 cycles
0.9pu	120 cycles
0.85pu	120 cycles
0.8pu	120 cycles
0.75pu	120 cycles
0.7pu	8 cycles

⋮	⋮
0.5pu	8 cycles
0.5pu	120 cycles or until trip
⋮	⋮
0.2pu	8 cycles
0.2pu	120 cycles or until trip

From the tests conducted, a profile of the trip characteristic was constructed as shown in *Figure 3*.

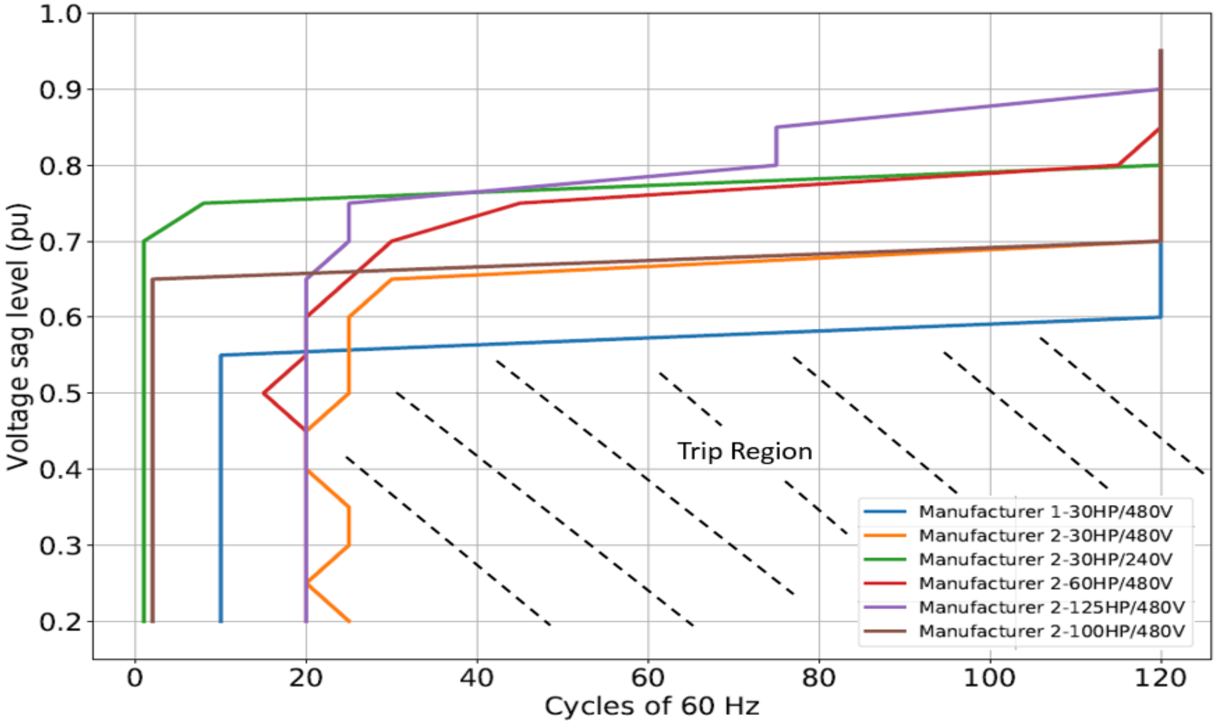


Figure 3: Profile of trip characteristic

The characteristics can also be constructed as shown in *Figure 4* for specific sag durations. The values on y axis of this figure are calculated as the ratio of sum of the ratings of the drives that were able to ride through the sag to the sum of ratings of all drives used in the tests.

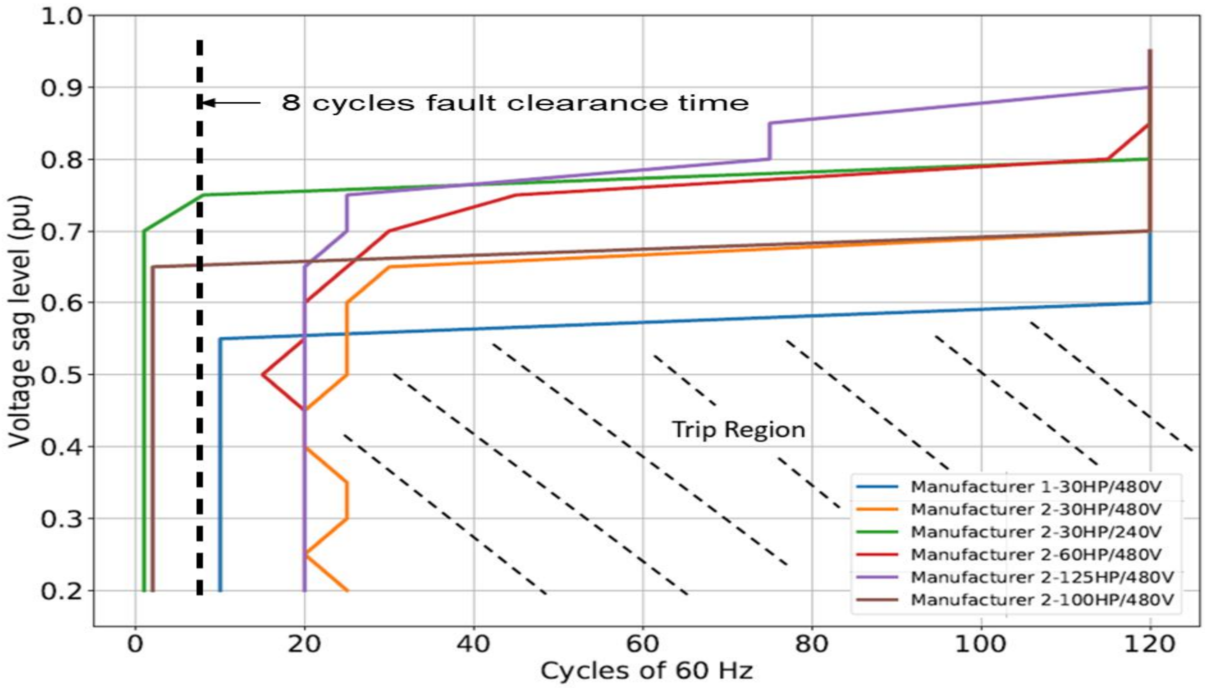


Figure 4: Trip characteristics for specific sag durations

The total horsepower rating of all drives tested is 375 HP ((30*3) + 60 + 125 + 100). Assuming a generic 8 cycle fault clearing time, *Table 3* can be constructed

Table 3 Derivation of per unit ride through parameter values

Sag level (pu)	**Drive tripped (HP)**	**Per unit of ride through**
$V_{sag} > 0.75$pu	0	375/375 = 1.00pu
$0.65 < V_{sag} < 0.75$	30	340/375 = 0.91pu
$V_{sag} < 0.65$	30 + 100 = 130	245/375 = 0.65pu

Based on these observed trip characteristics, the partial trip characteristic was setup as shown in *Figure 5* with parameter values as tabulated in
Table 4. The structure of this partial trip characteristic is the same as the one included in the recently approved aggregated distributed energy resource *der_a* model.

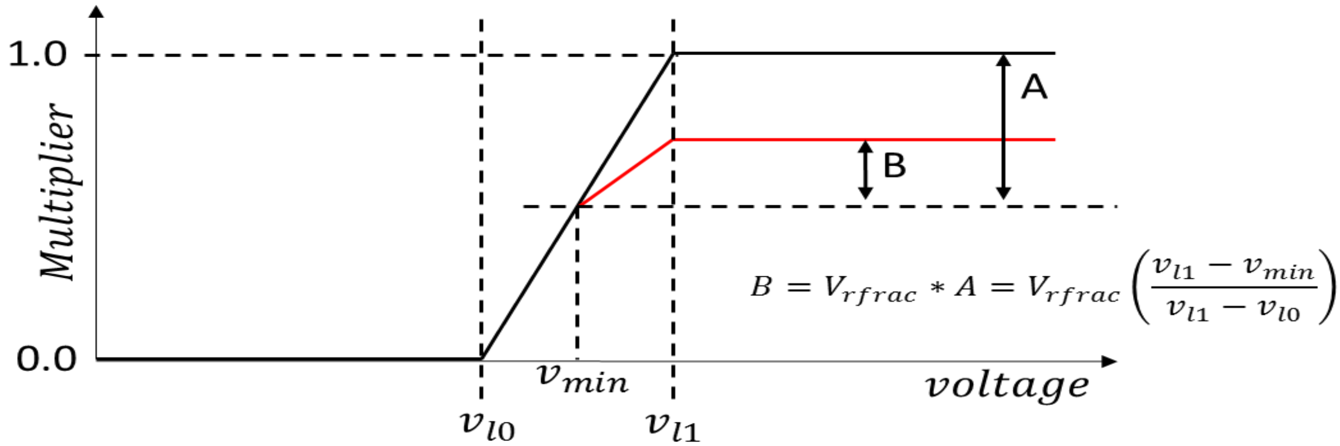


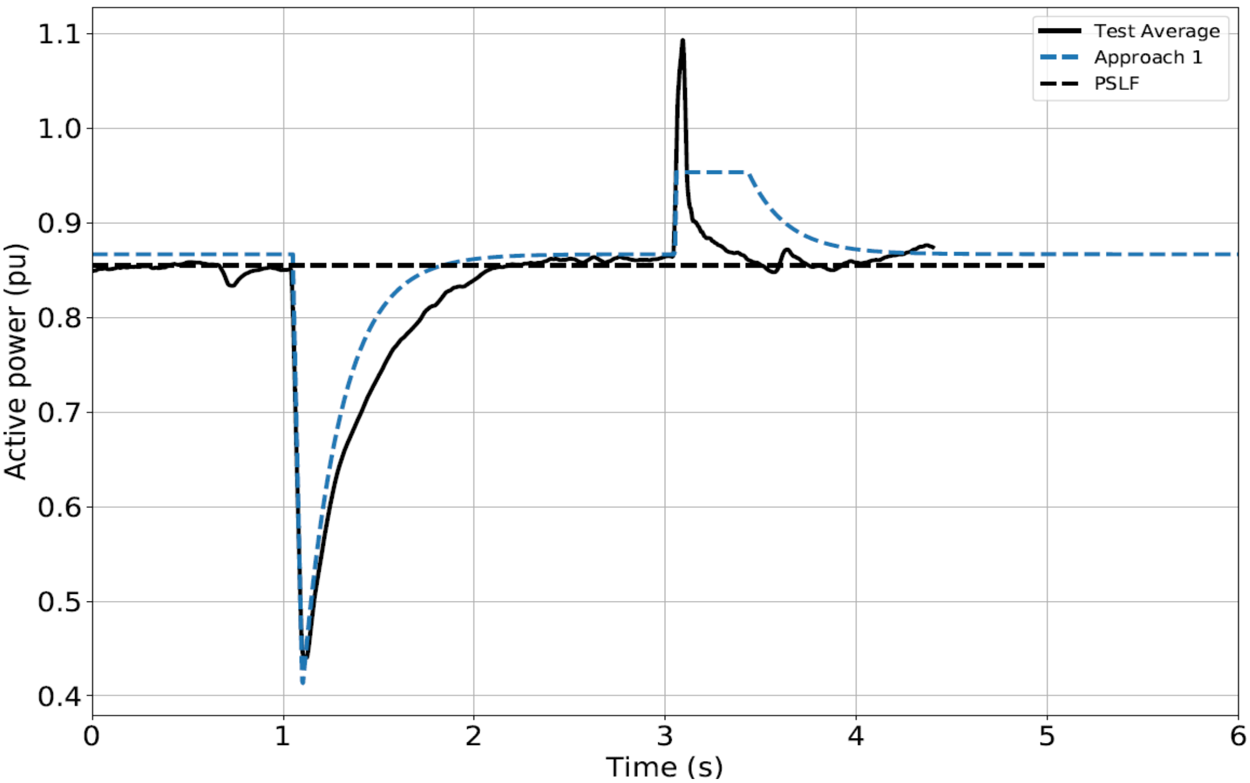
Figure 5: Partial trip characteristic

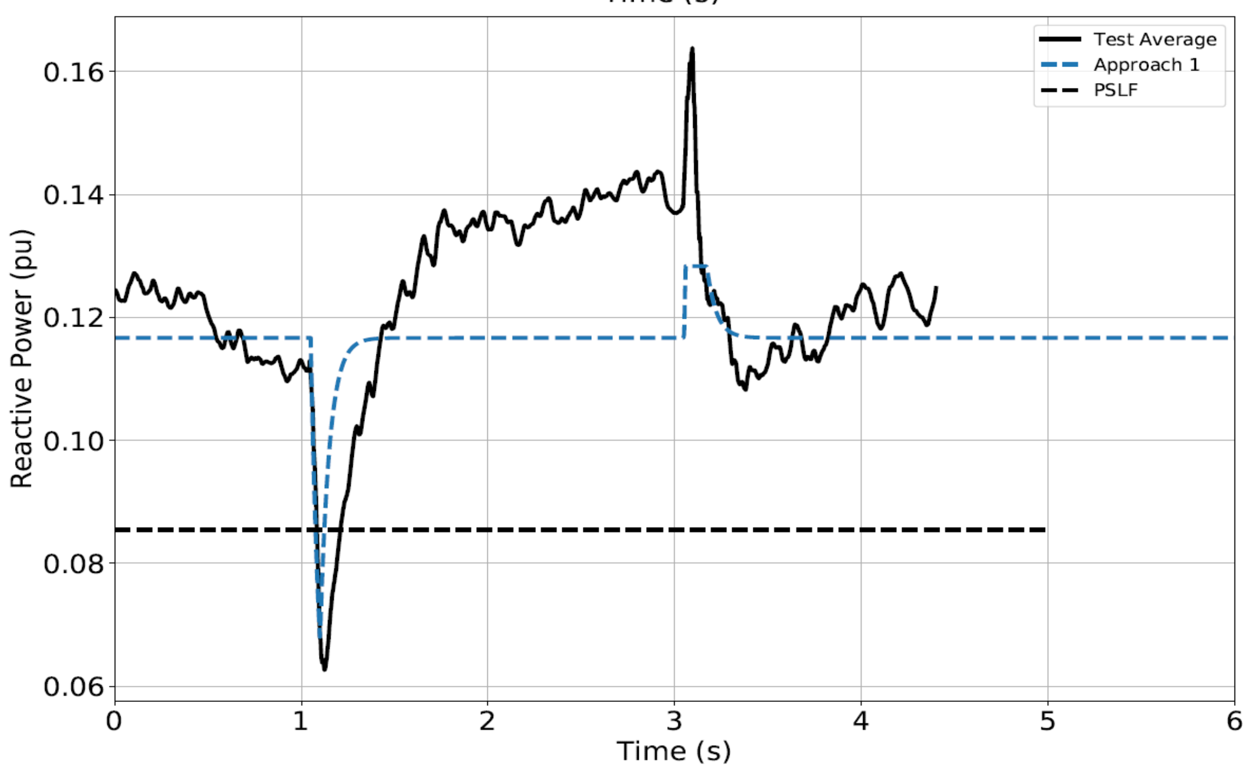
Table 4: Parameter description for partial trip characteristic

Name	Description	Sample Value
v_{l0}	Low voltage threshold 0 (pu)	0.55
tv_{l0}	Timer associated with v_{l0} (s)	1.05
v_{l1}	Low voltage threshold 1 (pu)	0.75
tv_{l1}	Timer associated with v_{l1} (s)	0.13
V_{rfrac}	Fraction of drives remaining online	0.65

To compare the performance of the model with the test results, the model was constructed as standalone equations in Python. Below, few comparative results of the models and the test data are shown. The legend entry PSLF refers to the performance of the state of the art model used to represent power electronic load, i.e. *Figure 1*.

Voltage sag to 0.9pu for a period of 120 cycles





Voltage sag to 0.4pu for a period of 8 cycles