WECC Air Conditioner Motor Model Test Report

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1.0. EXECUTIVE SUMMARY

Many utilities continue to experience slow voltage recoveries after system faults; these slow voltage recoveries have been attributed to stalling air conditioners (A/C). In 2006 and 2007 Bonneville Power Administration (BPA), Electric Power Research Institute (EPRI), and Southern California Edison (SCE) tested more than 25 residential air conditioners (RAC) to assess their response during under-voltage transients and sags. EPRI conducted the testing for Arizona Power Services (APS). Every RAC tested stalled and a majority remained stalled until their internal overload protection tripped them off from the system. These RAC tests validate the hypothesis that stalling air conditioners result in slow voltage recoveries after system faults. After analysis of the RAC tests, the WECC developed an air conditioner motor model in EPCL language. General Electric incorporated its performance features into its new *PSLF* A/C motor model (*ldlpac*).

The WECC tested the *ld1pac* to assess its response during under-voltage transients, voltage oscillations, and frequency oscillations. This report contains a detailed account of these tests, which determined that the *ld1pac* model has the capacity to:

A). Stall the A/C load within 1 cycle of a predetermined under-voltage transient – its stall time can be adjusted
B). Model the A/C's I, P, and Q stall and non-stall parameters
C). Operate power contactor model within 2 cycles of certain under-voltage transients
D). Model the restart of A/C load – load restarting time can be adjusted
E). Model the aggregated behavior of the A/C thermal protection switch
F). Model under-voltage protection relay with a response time of 2 cycles

The *ld1pac* model test results indicate that this model's performance is very close to the actual A/C test data and the aggregated A/C behavior under-voltage transients, voltage oscillations, and frequency oscillations. Various extreme tests including prolonged faults and high concentration of A/C load do not show numerical instability. This model is currently being incorporated in the new GE composite load model (cmpld) and will be tested in the near future.

2.0. WECC AIR CONDITIONER MOTOR MODEL

Figure 1 is the PSLF case diagram used to test the *ld1pac* model. Its Generator (1) generates 200 MW and 54 MVAR at steady-state for the Bus 22 branch circuit; Bus 22 serves the "AC" load which is modeled with the *ld1pac* model. The purpose of this test was to assess the response of the *ld1pac* during various under-voltage transients and sags and then adjust its parameters so it behaves like an aggregated A/C load in a particular area. The aggregated A/C load consists of a great number of A/C that stall during undervoltage transients and sags. A typical residential split A/C system consumes between 4 kW and 6 kW at a power factor between 0.90 p.u. and 0.97 p.u. This aggregated *ld1pac* model represents approximately 40,000 A/C assuming that A/C consume an average of 5 kW.

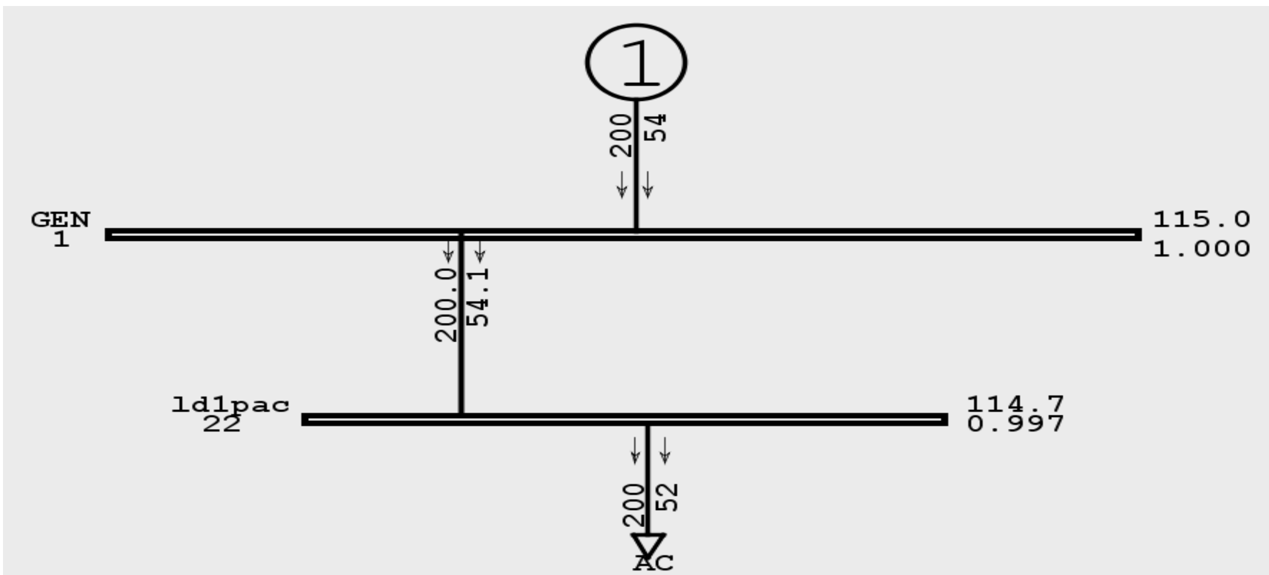

Figure 1. Air Conditioner Model Test Diagram

Figure 2 shows the dynamics case models and its parameters used to perform the test. The models used in this case are the generator model "gencels" and the load model "ld1pac". The other models are monitoring meters.

```
models
monit        1 "GEN     "   115.0  "1 " : #9  9999.00
vmeta        1 "GEN     "   115.0  "1 " : #9  0.0 0.0
fmeta        1 "GEN     "   115.0  "1 " : #9  0.0 0.0 0.050000
#Generator Model
gencls     1 "GEN      " 115.00  "1 " : #9  mva=1000000. 5.5 0.0 0.0 0.18 0.0 0.0 1.0 vsag60.csv 0 0 0 0 0
#
ld1pac     22  "ld1pac  "  115.00 "AC"   : #99 mva=-1.0  "pul" 1.0 "tv" 0.016 "tf" 0.1  /
 "CompPF" 0.97   "Vstall" 0.70  "Rstall" 0.124  "Xstall" 0.114  "Tstall" 0.033 "LFadj" 0.3  /
 "Kp1" 0.0 "Np1" 1.0 "Kq1" 6.0 "Nq1" 2.0 "Kp2" 12.0 "Np2" 3.2 "Kq2" 11.0 "Nq2" 2.5 /
 "Vbrk" 0.86 "Frst" 0.50 "Vrst" 0.70 "Trst" 0.80 "CmpKpf" 1.0 "CmpKqf" -3.3 /
 "Vc1off" 0.45 "Vc2off" 0.35 "Vc1on" 0.50 "Vc2on" 0.40 /
 "Tth" 20  "Th1t" 0.3 "Th2t" 1.30 /
 "fuvr" 0.00  "uvtr1" 0.50  "ttr1" 0.05 "uvtr2" 0.9 "ttr2" 5.0
```

Figure 2. PSLF Case Models Parameters

3.0. THERMAL OVERLOAD PROTECTION MODEL TEST

Air conditioner compressor motors have internal *thermal overload protection switches* (*TOL*) to protect them from high currents that can compromise or damage their windings especially when they last for as long as 25 seconds, this number is much larger when aggregates it. These high currents are normally part of the compressor's startup process, but only last for up to 30 cycles. The A/C testing verified that when air conditioners experience low voltages they stall, withdrawing these dangerously high currents for a few to several seconds. Most *TOL* are located within the compressor motor windings and are electrically connected to the start winding (S), running winding (R), and common wire (C). Because *TOL* directly influence the slow voltage recovery experienced by utilities it is extremely important that they are modeled. Figure 3 shows a *TOL* typically imbedded within the motor windings.

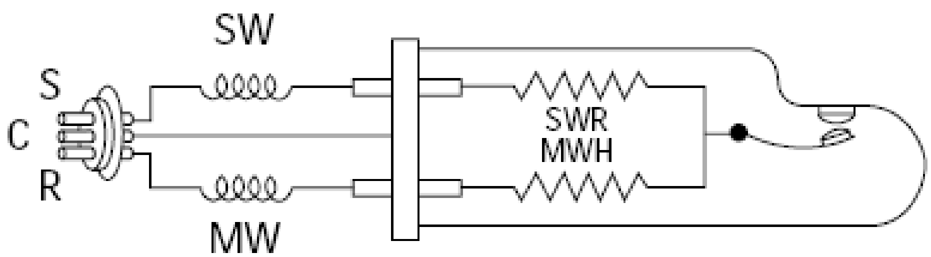

Figure 3. Thermal Overload Protection Switch

The air conditioner test data was analyzed to evaluate *TOL* performance for each air conditioner unit tested. Figure 4 shows BPA, EPRI, and SCE analyzed test data when the *TOL* operates. This figure's horizontal axis represents the time it takes the *TOL* to operate under the stall currents of the vertical axis. This graph clearly shows that the stall current is inversely proportional to the time it takes for the *TOL* to operate – the higher the stall current the shorter the activation time – the lower the stall current the longer the activation time.

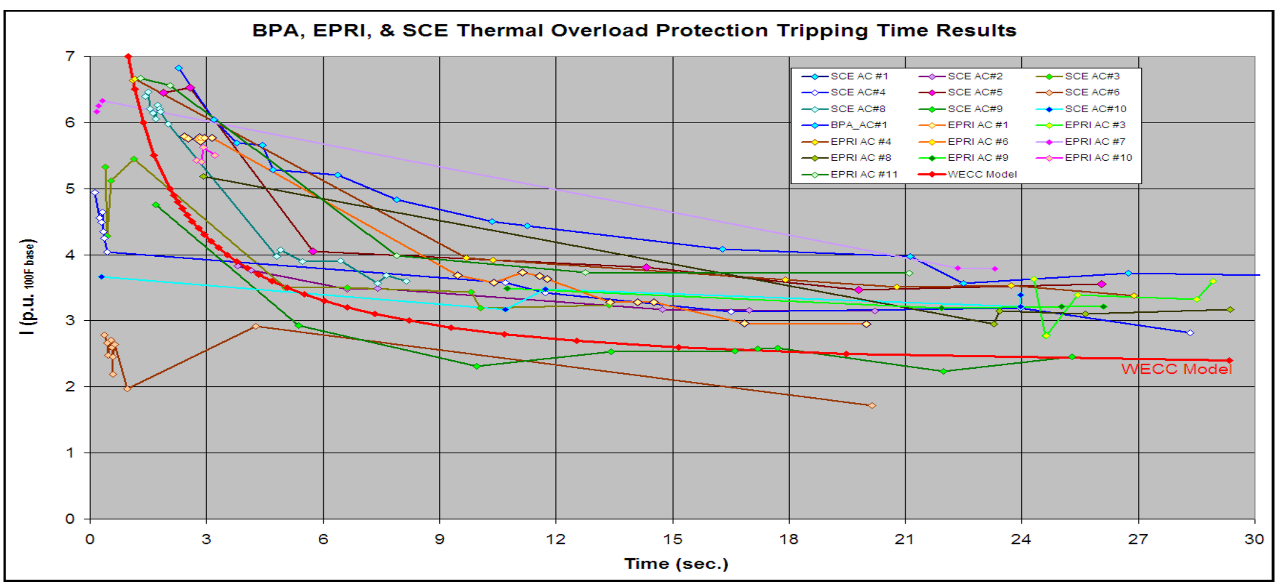

Figure 4. BPA, EPRI, and SCE *TOL* Operation Analysis

For the *ld1pac's Thermal Protection* model test, the A/C load was maintained at 200 MW and 30 MVAR. The *restarting load fraction* ("frst") and *under-voltage relay fraction* ("fuvr") were set to zero so no other parameters could alter the test results. It is important to mention that the *compressor breakdown voltage ("Vbrk")* has a default setting of 0.86 p.u. Table 1 shows the *ld1pac'sThermal Protection* model parameters.

Parameter	Description	Typical Settings
Tth	Compressor Heating Time Constant	10
Th1t	Compressor Motors Begin Tripping	0.5
Th2	Compressor Motors Finished Tripping	2.5

Table 1 - Thermal Protection Model Parameters

The *ld1pac's Thermal Protection* model simulates the aggregated behavior of A/C thermal protection switches. The next three sections discuss the testing and analysis for each of the *ld1pac's Thermal Protection* model parameters. Figure 5 shows the parameters used for this portion of tests with the exceptions being *Tth, Th1t,* and *Th2t* which are adjusted according to each test's requirements.

```
models
monit        1 "GEN     "    115.0   "1 " : #9   9999.00
vmeta        1 "GEN     "    115.0   "1 " : #9   0.0 0.0
fmeta        1 "GEN     "    115.0   "1 " : #9   0.0 0.0 0.050000
#Generator Model
gencls      1 "GEN      " 115.00   "1 " : #9   mva=1000000. 5.5 0.0 0.0 0.18 0.0 0.0 1.0 vsag60.csv 0 0 0 0 0
#
ld1pac      22  "ld1pac   "   115.00 "AC"   : #9 mva=-1.0  "pul" 1.0 "tv" 0.02 "tf" 0.05  /
 "CompPF" 0.97   "Vstall" 0.70  "Rstall" 0.090  "Xstall" 0.095  "Tstall" 0.033 "LFadj" 0.3  /
 "Kp1" 0.0 "Np1" 1.0 "Kq1" 6.0 "Nq1" 2.0 "Kp2" 12.0 "Np2" 3.2 "Kq2" 11.0 "Nq2" 2.5 /
 "Vbrk" 0.86 "Frst" 0.00 "Vrst" 0.70 "Trst" 0.40 "CmpKpf" 1.0 "CmpKqf" -3.3 /
 "Vc1off" 0.45 "Vc2off" 0.35 "Vc1on" 0.50 "Vc2on" 0.40 /
 "Tth" 10  "Th1t" 0.40 "Th2t" 1.30 /
 "fuvr" 0.00  "uvtr1" 0.50  "ttr1" 0.05 "uvtr2" 0.9 "ttr2" 5.0
```

Figure 5. PSLF Case Models Parameters

NOTE: When the *ld1pac* load is allowed to stall, it remains stalled until either the thermal overload protection trips it off or it is allowed to restart. No load tripped by thermal protection is allowed to restart. A/C test results indicate that thermal overload protection may take several minutes to re-close after being tripped.

3.1. Compressor Heating Time Constant (*Tth*) Test

A 6-cycle 60 percent under-voltage transient was used to perform the *ld1pac's Compressor Heating Time Constant (Tth)* test. In these tests the *Tth* parameter was adjusted to assess the behavior of this model during these changes. The other two thermal overload protection parameters were kept constant at *"Th1t"* 0.10 and *"Th2t"* 2.3.

Table 2 shows the *Tth* test results for Figures 6 through 11. The *Tth* parameter was found to be directly proportional to the time the model took to gradually disconnect the A/C load. The higher the *Tth* number the longer it took to disconnect gradually the A/C load.

Figure	*Tth*	Slow Voltage Recovery Time (sec.)
6	1	1.08
7	10	11.0
8	20	15.0
9	30	33.0
10	40	44.0
11	50	55.0

Table 2 - *Tth* Test Results

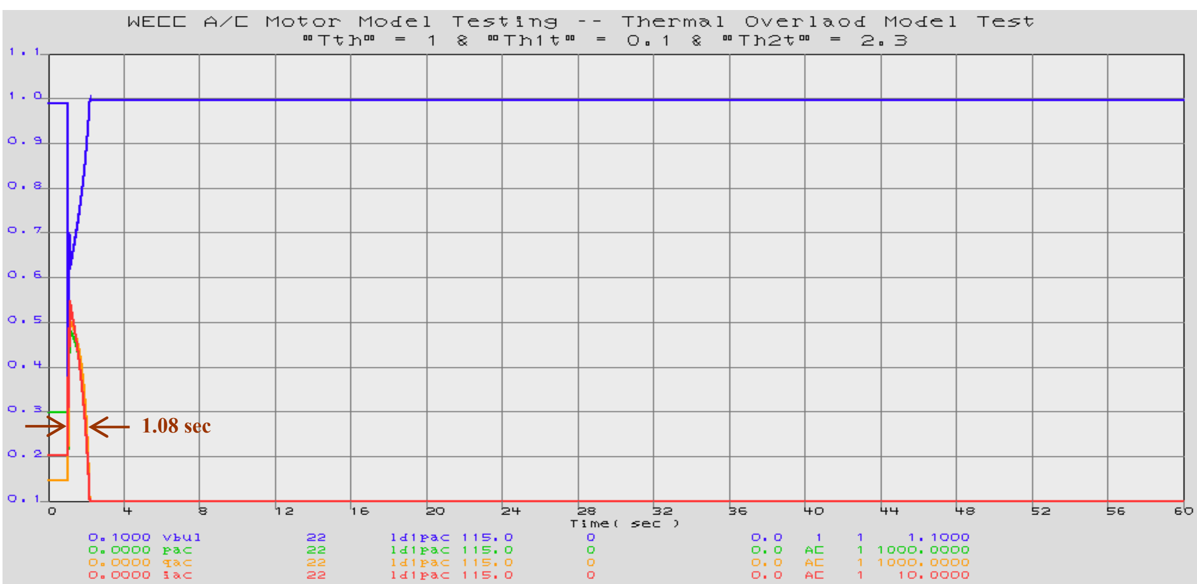

Figure 6. *Tth* Test (Tth = 1)

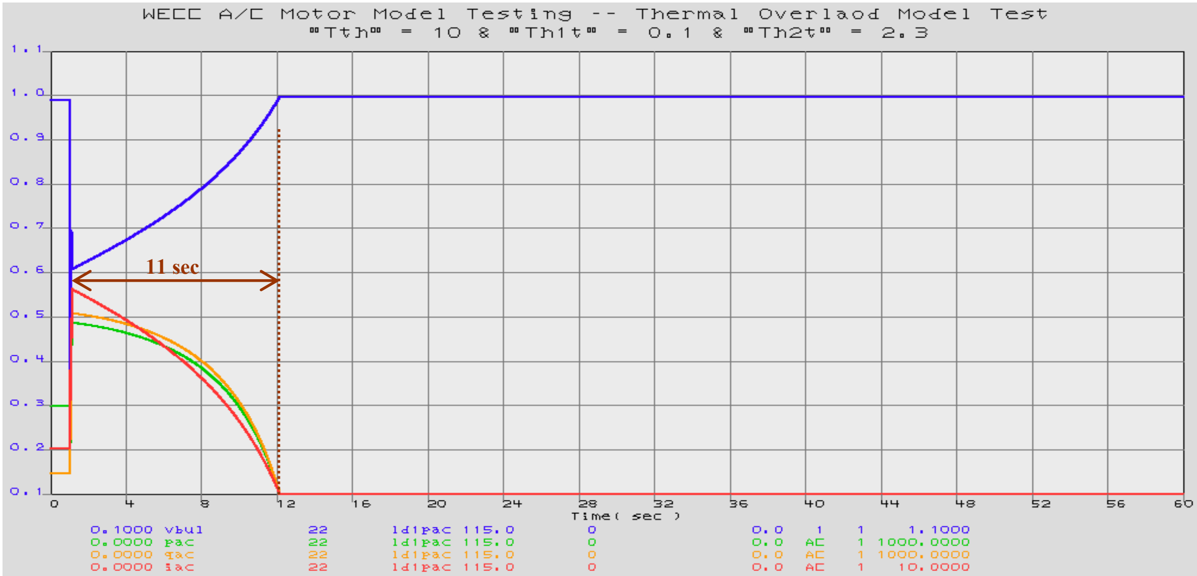

Figure 7. *Tth* Test (Tth = 10)

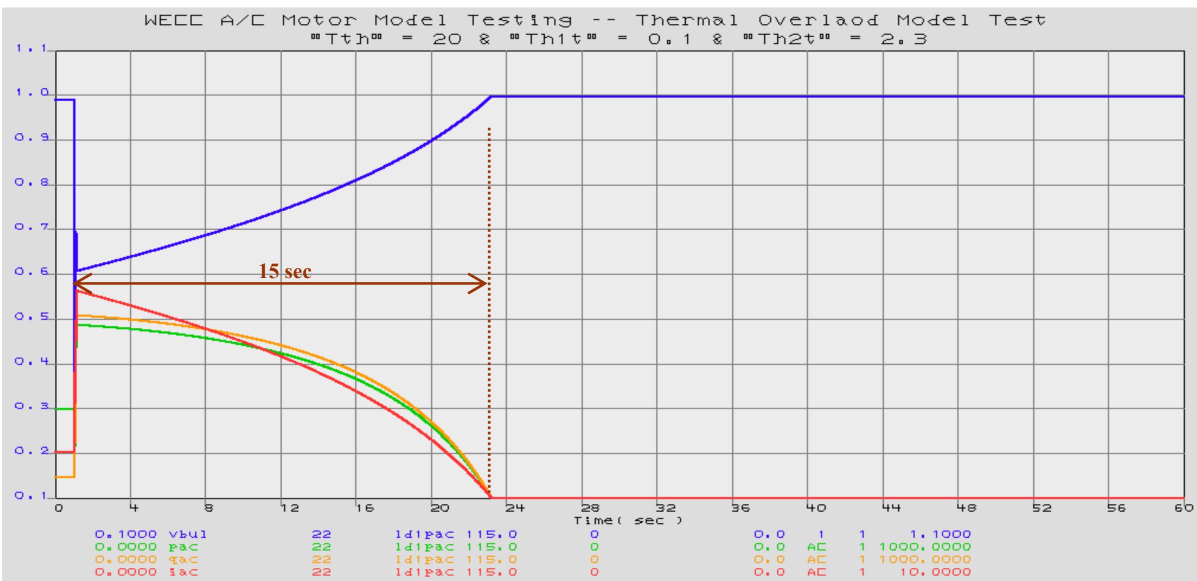

Figure 8. *Tth* Test (Tth = 20)

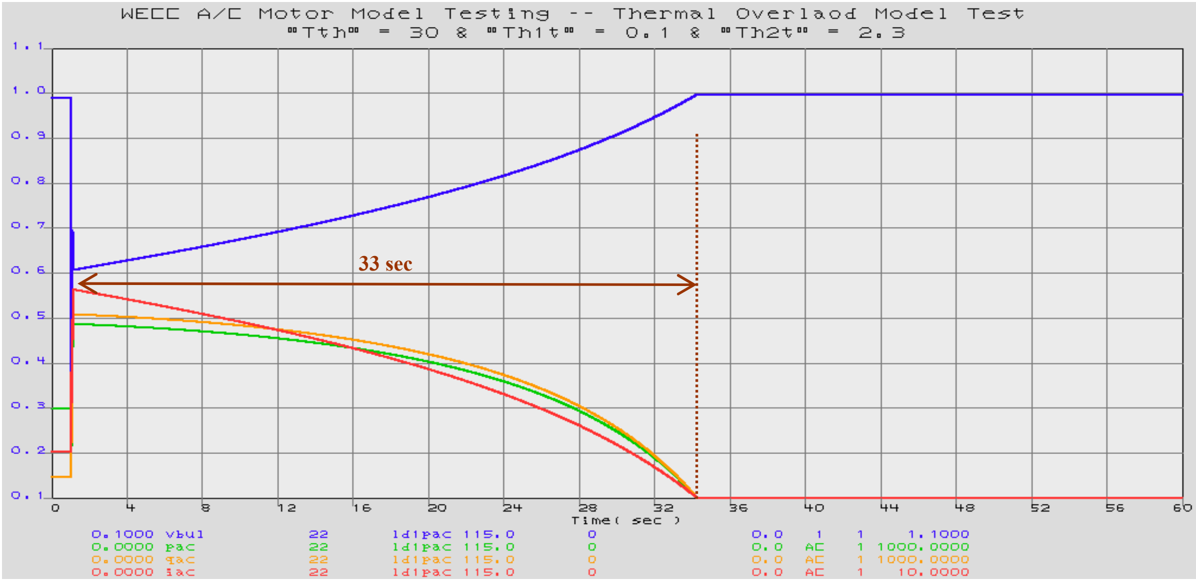

Figure 9. *Tth* Test (Tth = 30)

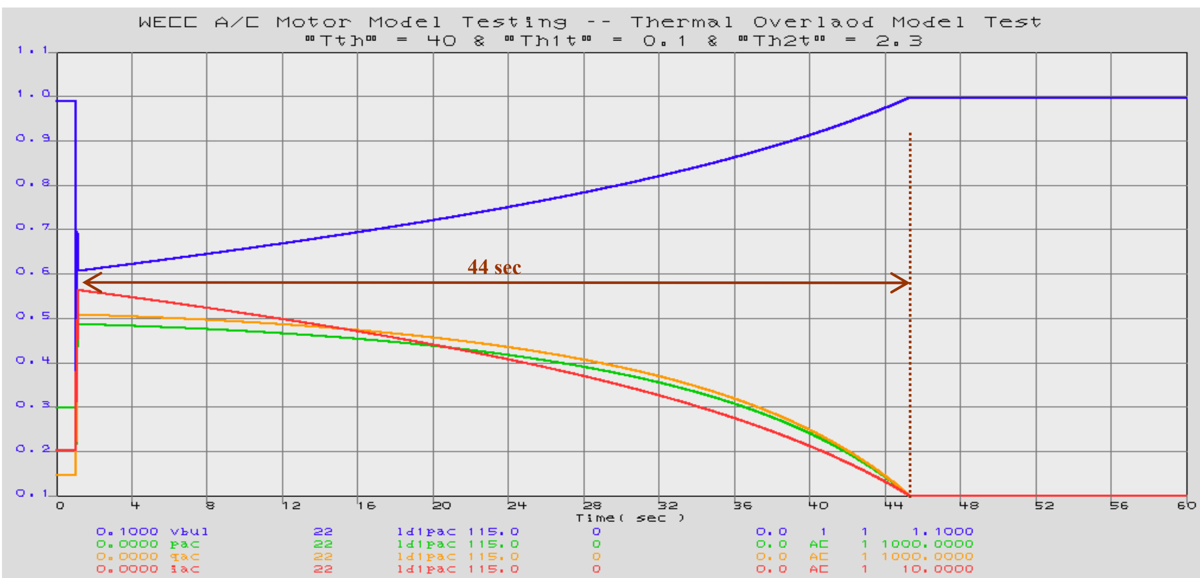

Figure 10. *Tth* Test (Tth = 40)

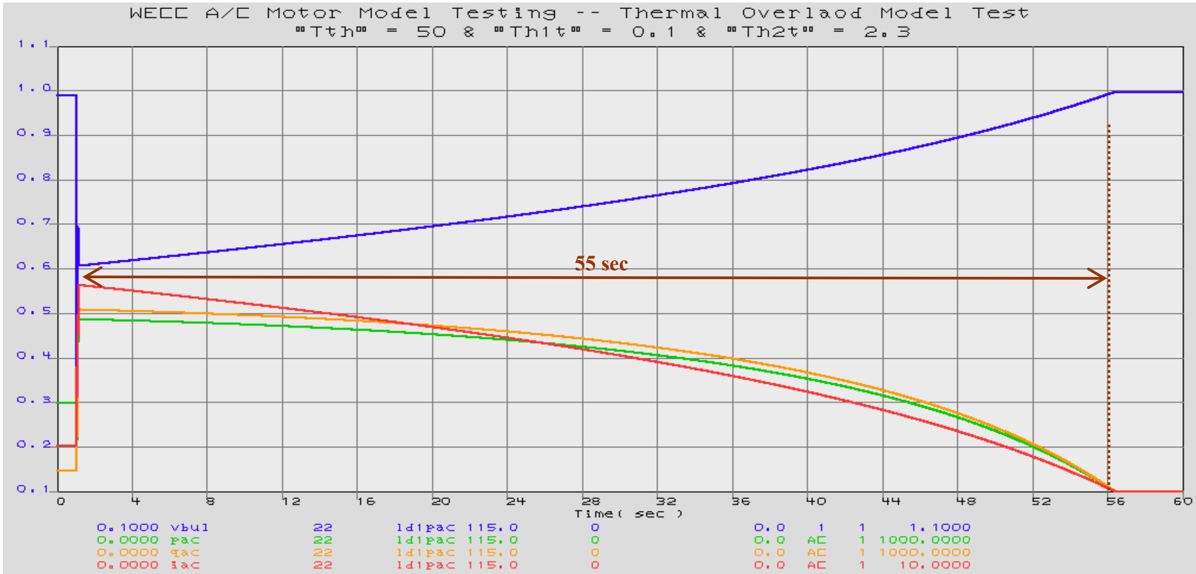

Figure 11. *Tth* Test (Tth = 50)

3.2. Temperature at Which Compressor Motors Begin Tripping (*Th1t*) Test

A 6-cycle 60 percent under-voltage transient was used to perform the *ld1pac's Temperature at Which Compressor Motors Begin Tripping ("Th1t")* test. In these tests the *Th1t* parameter was adjusted to assess the behavior of this model during these changes. The other two parameters of the thermal overload protection characteristic were kept constant at "*Tth*" 10 and "*Th2t*" 2.3.

Table 3 shows the *Th1t* test results for figures 12 through 15. These results reveal that the *Th1t* is proportional to the time that the thermal protection model starts tripping the A/C load. The higher the *Th1t* number the longer the model waits to start tripping the A/C load.

Figure	Th1t	Time before Thermal Protection Switch Begin Tripping (sec.)
12	0.20	0.70
13	0.40	2.00
14	0.80	5.00
15	1.60	17.00

Table 3 - *Th1t* Test Results

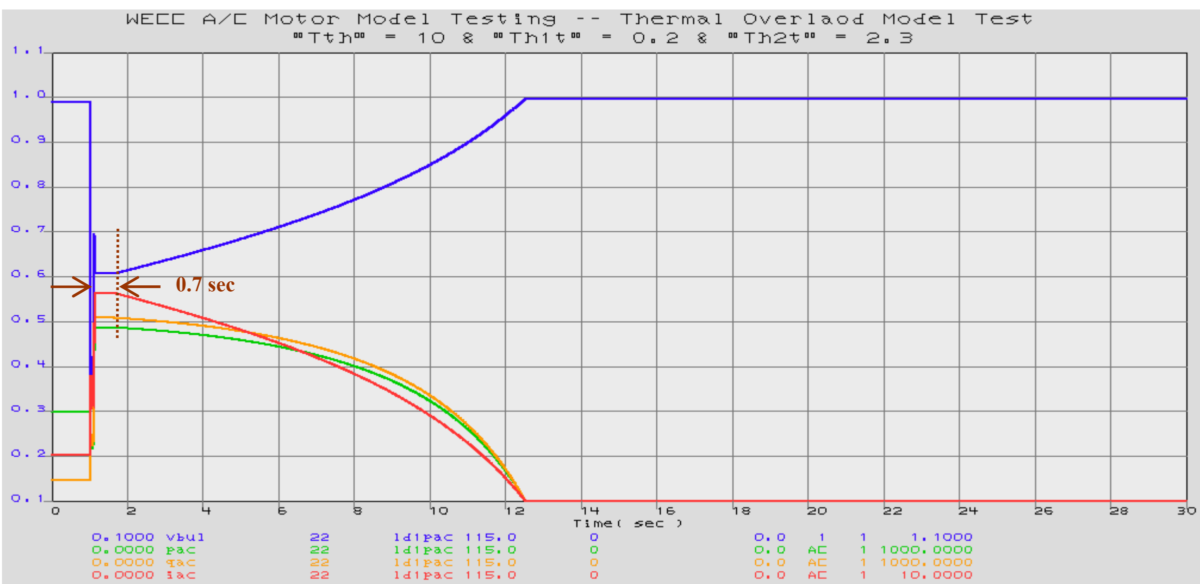

Figure 12. *Th1t* Test (Th1t = 0.20)

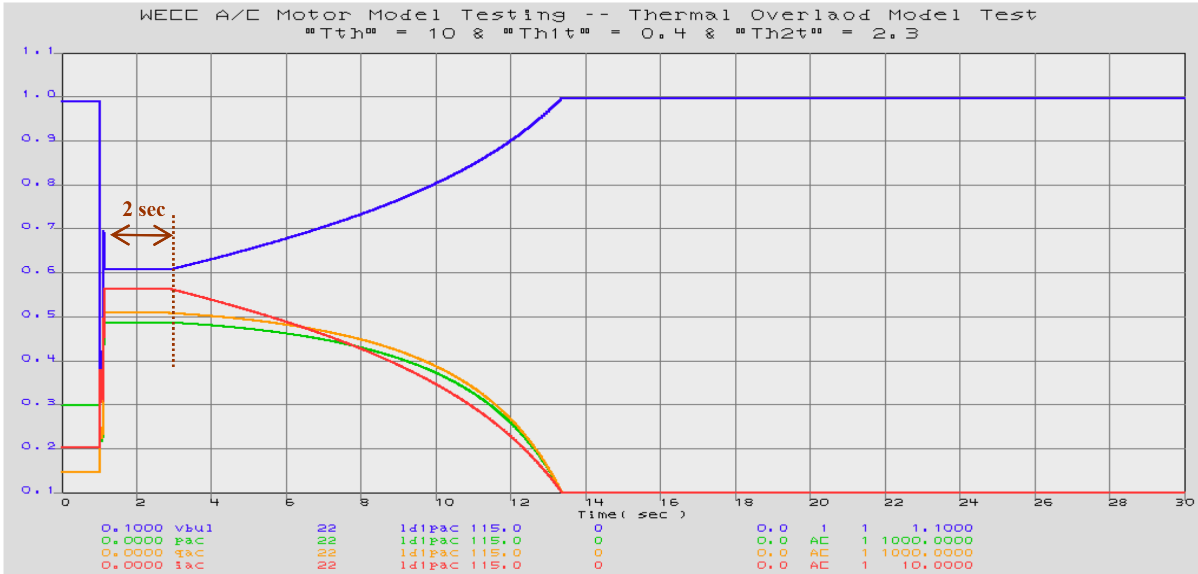

Figure 13. *Th1t* Test (Th1t = 0.40)

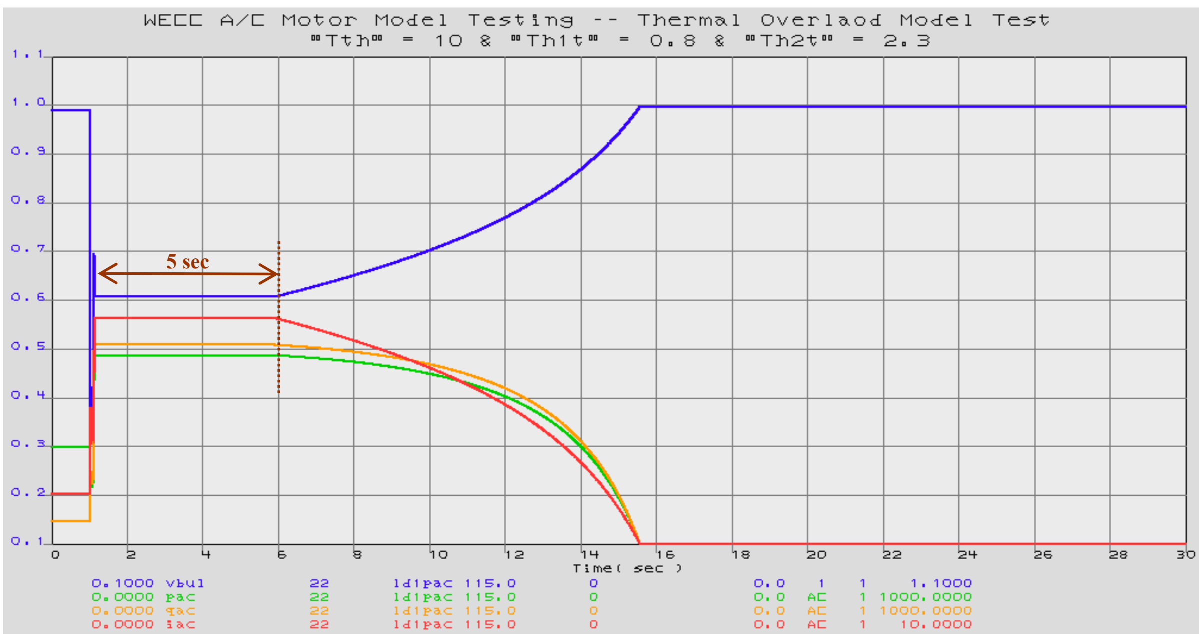

Figure 14. *Th1t* Test (Th1t = 0.80)

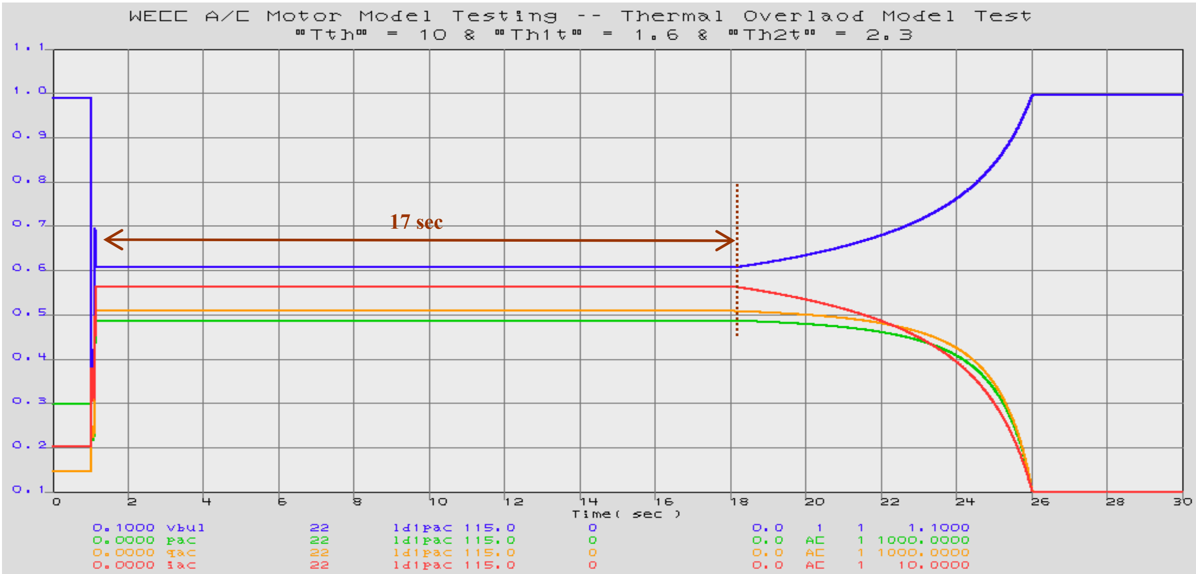

Figure 15. *Th1t* Test (Th1t = 1.60)

3.3. Temperature at Which All Motors are Tripped (*Th2t*) Test

A 6-cycle 60 percent under-voltage transient was used to perform the *ld1pac's Temperature at Which All Motors are Tripped ("Th2t")* test. In these tests the *Th2t* parameter was adjusted to assess the behavior of this model during these changes. The other two parameters of the thermal overload protection characteristic were kept constant, *"Tth"* 10 and *"Th1t"* at 0.80.

Table 4 shows the *Th2t* test results for figures 16 through 19. These results reveal that *Th2t* is proportional to the time that the thermal protection model trips the entire A/C load. The higher the *Th2t* the longer it took to trip the entire A/C load.

Figure	Th2t	Time At Which All Motors Are Tripped (sec.)
16	1.30	4.2
17	2.30	10.3
18	3.30	21.0
19	4.30	47.0

Table 4 - *Th2t* Test Results

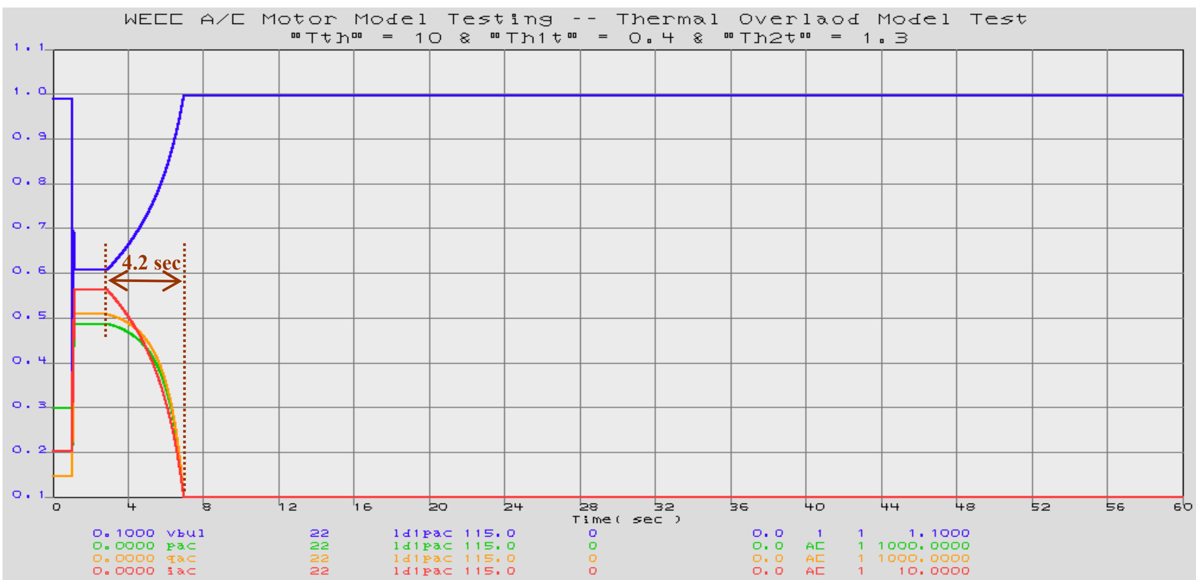

Figure 16. *Th1t* Test (Th2t = 1.30)

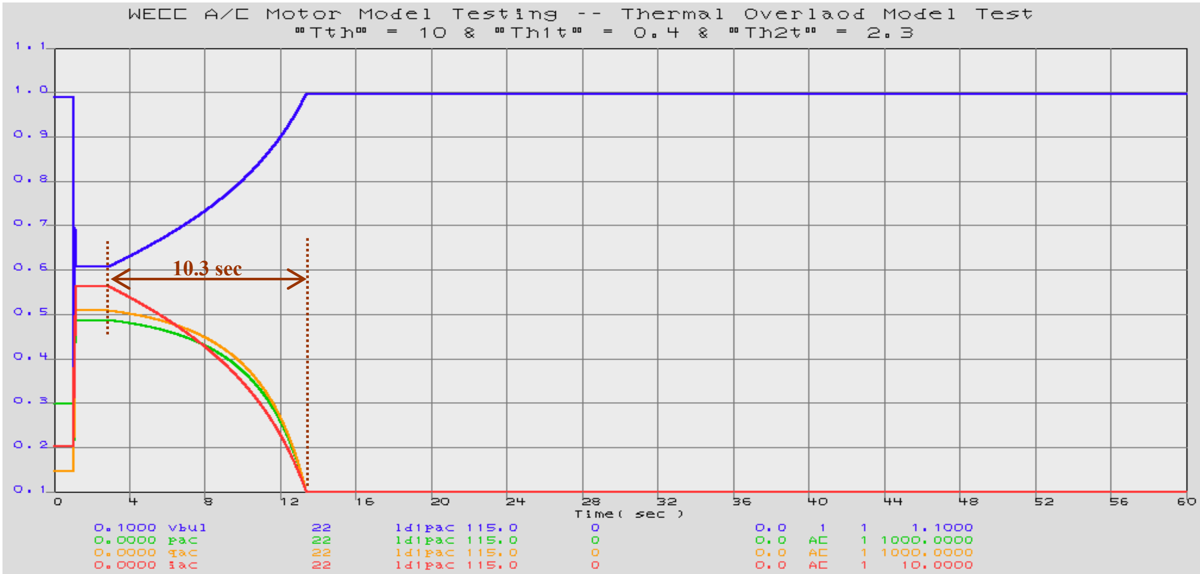

Figure 17. *Th1t* Test (Th2t = 2.30)

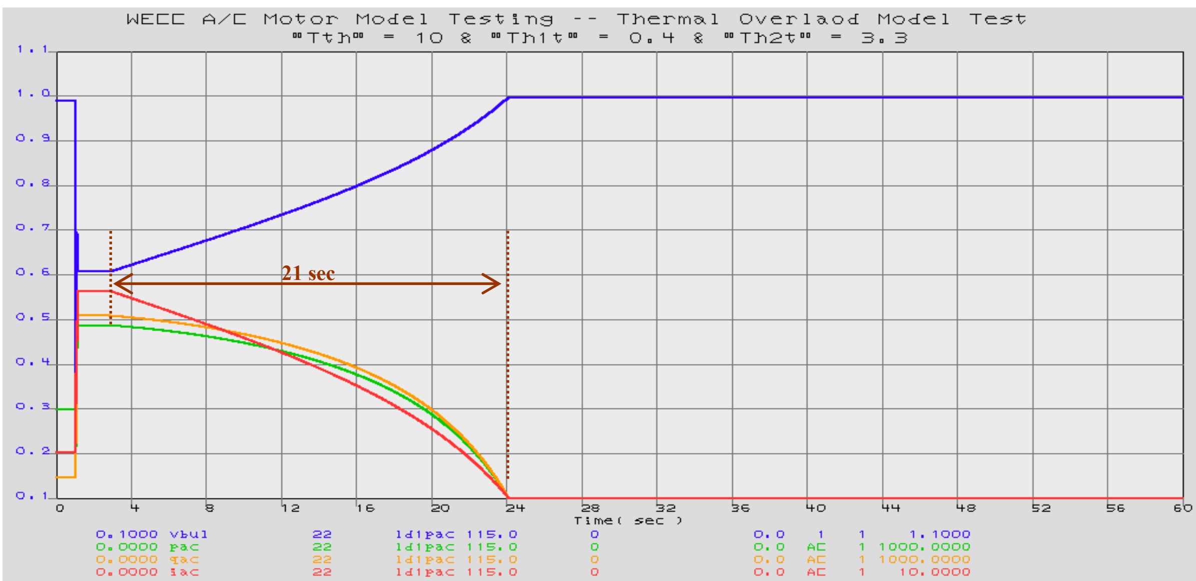

Figure 18. *Th1t* Test (Th2t = 3.30)

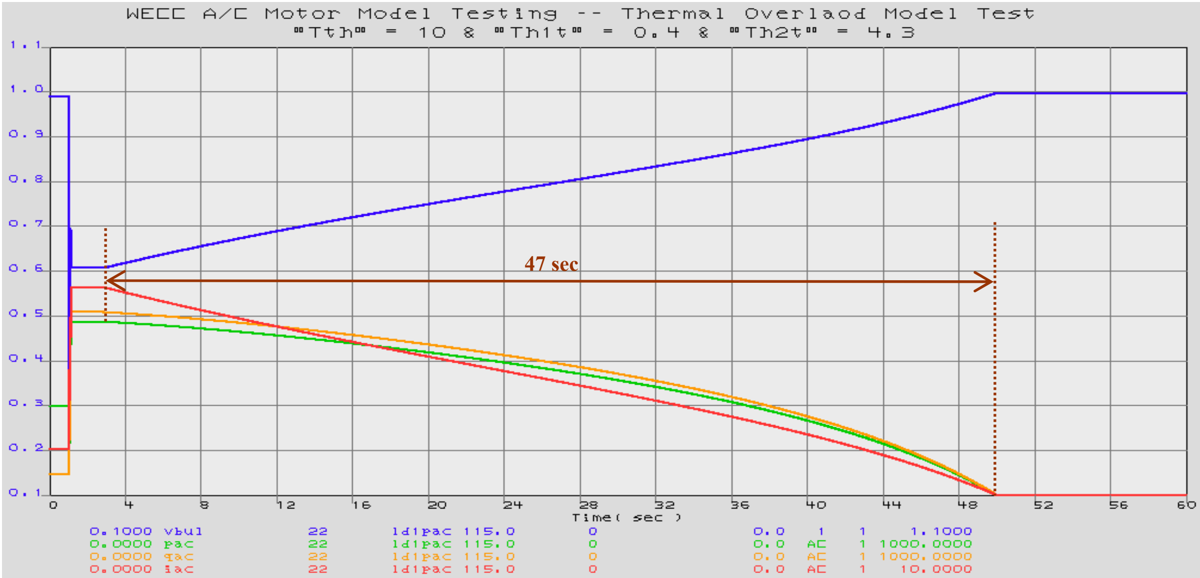

Figure 19. *Th1t* Test (Th2t = 4.30)

4.0. STALLING TEST

Air conditioner test results reveal that the A/C stalling threshold voltage rises with temperature as indicated by the red plot lines in figures 20 and 21. The stalling threshold at high temperatures was found to be in the low seventies percentile range of the normal operating voltage of 240 VAC; therefore, any time voltage falls below 70 percent of the nominal voltage at the service point of connection (end user), the A/C will potentially stall, especially in Southern California inland areas where summer peak inland temperatures often exceed 100 degrees Fahrenheit.

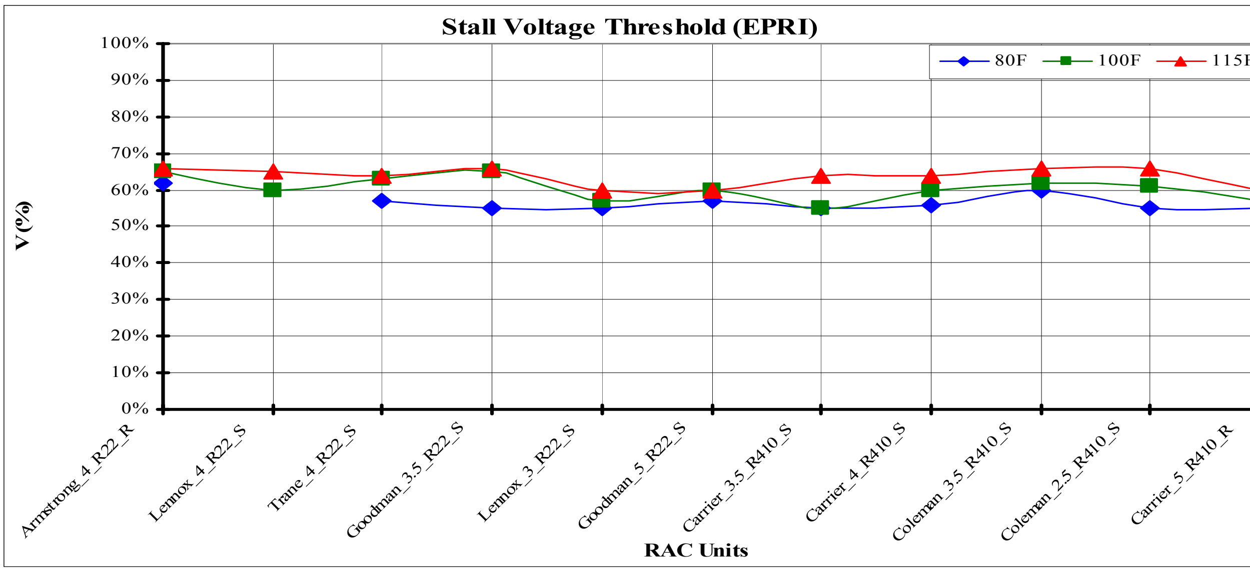

Figure 20. EPRI (APS) A/C Stalling Thresholds

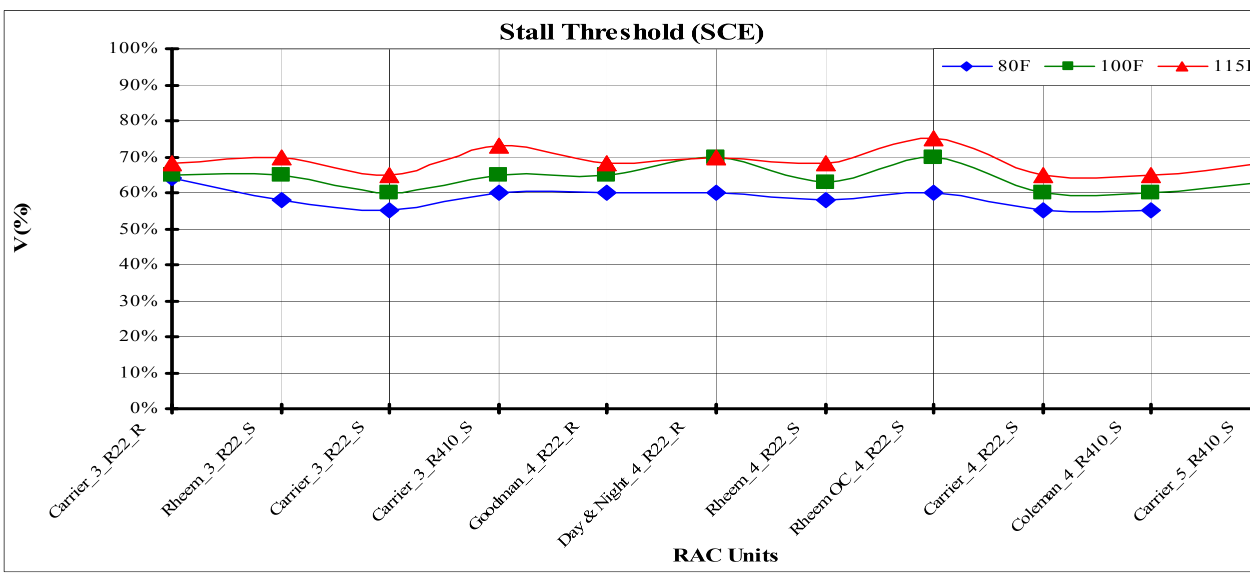

Figure 21. SCE Air Conditioner Testing

NOTE: The stalling threshold voltage at the subtransmission and transmission level is much higher than the distribution-level voltage; therefore, whenever the model is placed in either of these two levels the stalling thresholds must be adjusted to a higher value (0.80~0.90 p.u.).

For the *ld1pac's stalling threshold* test, the A/C load was maintained at 200 MW and 30 MVAR. The restarting load fraction ("frst") and under-voltage relay fraction ("fuvr") were set to zero so no other parameters could alter the test results. It is important to mention that the *compressor breakdown voltage ("Vbrk")* has a default setting of 0.86 p.u. Table 5 shows the *ld1pac's stalling threshold* and *stalling delay time* model parameters. The *ld1pac's stalling threshold ("Vstall")* model parameter is where the model starts stalling the A/C load when the bus voltage goes below the *Vstall.* The stall time ("*Tstall*") parameter determines how fast the transients need to be in order to stall. If the undervoltage transient is faster than the *Tstall,* then the *ld1pac* model does not stall.

Parameter	**Description**	**Typical Settings**
Vstall	Stalling threshold voltage, p.u.	0.60
Tstall	Stall Delay Time, sec.	0.033

Table 5 - Stall Parameter

4.1. Stalling Threshold (*Vstall*) Test

In the *Stalling Threshold ("Vstall")* tests the under-voltage transient was adjusted to find out where the model starts stalling at various "*Vstall*" parameters. Table 6 provides the stalling threshold test results for different *Vstall* parameters at a 3-cycle under-voltage transient. Additional tests were conducted under the same *Vstall* parameters with the UV transient times of 1, 2, 6, 9, 12, 15, and 30 cycles, and 1, 2, and 3 seconds. The test results were consistent with those shown in Table 6 and indicate that the *ld1pac* model stalls for any voltage below the *Vstall* parameter. In the table the stalling thresholds are highlighted in yellow for the different *Vstall* parameters. In order for the model to stall at the stalling threshold the *Tstall* parameter must be set to 0.001 seconds or higher.

V_{STALL} Parameter (p.u.)	UV Transient (p.u.)	Stalled
0.55	0.56	No
0.55	0.55	Yes
0.60	0.61	No
0.60	0.60	Yes
0.65	0.66	No
0.65	0.65	Yes
0.70	0.71	No
0.70	0.70	Yes

Table 6 - Stalling Threshold Test Results

Figures 22 and 23 provide examples of stalling and non-stalling conditions when the model's *Vstall* and *Tstall* parameters are set to 0.60 and 0.001 respectively. In figure 22 the model stalls when the voltage goes down to 0.60 p.u. Figure 23 illustrates that the model does not stall when voltage decreases to 0.61 p.u. and the *Vstall* is set to 0.60 p.u.

NOTE: The model must have its *Tstall* set to a minimum of 0.001 second in order for the model to stall at the stalling threshold.

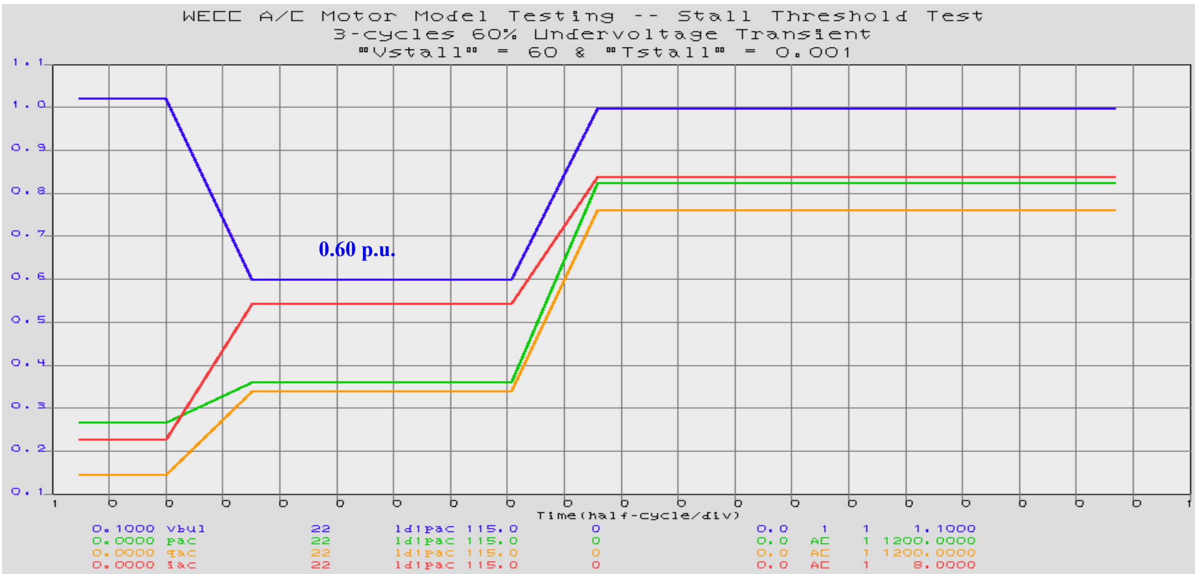

Figure 22. *Vstall* Test (Vstall=60% & UVsag = 59 %)

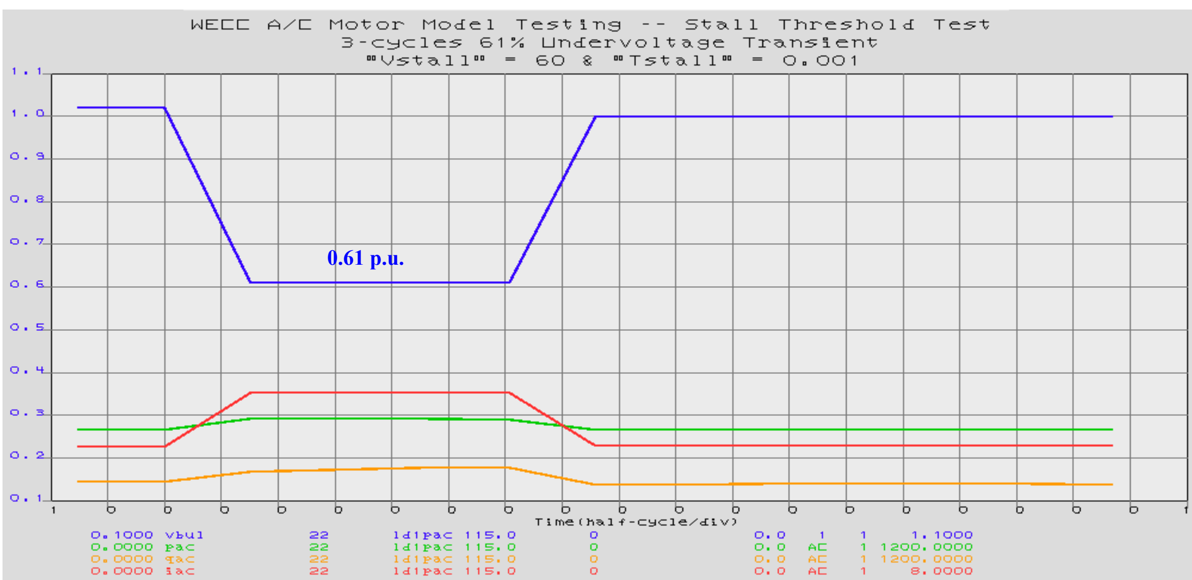

Figure 23. *Vstall* Test (Vstall=60% & UVsag = 61 %)

4.2. Stalling Response Time Test

The stall response time of the model is the time that the model takes to stall during undervoltage transients. In order to determine the stalling response time the under-voltage transient duration was adjusted. Figure 24 show that the *ld1pac* model did not stall for 4 milliseconds of undervoltage transients. Figure 25 shows that the model stalls for transients 8 milliseconds. This verifies that the *ld1pac* model stalls within one cycle after the voltage goes below the stalling threshold ("*Vstall*"). Figure 25 also reveals that the model takes about 4 milliseconds to go into stall condition.

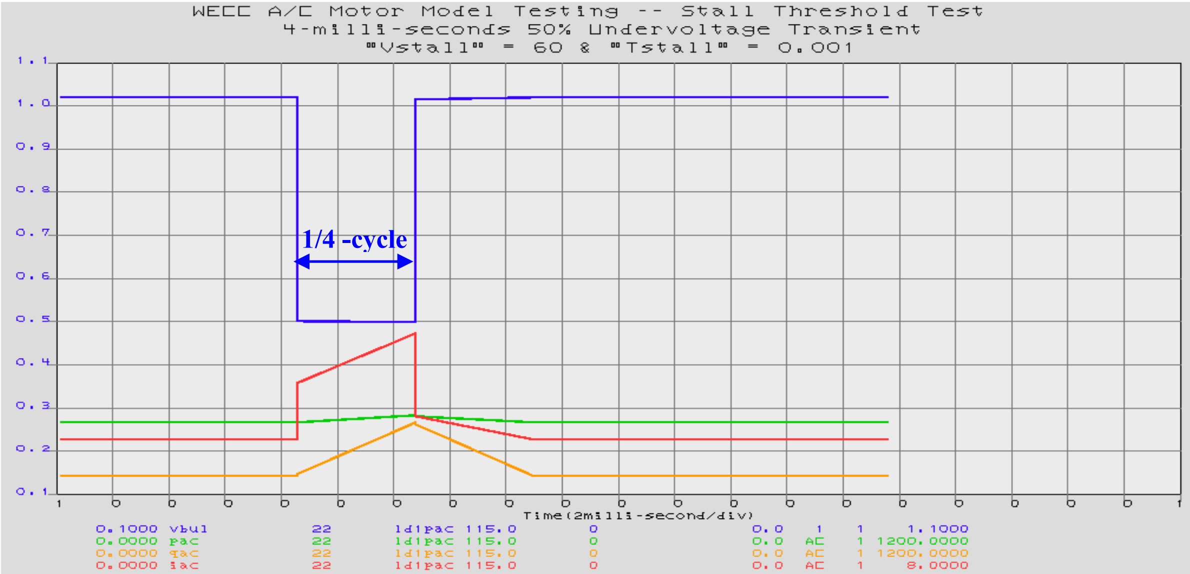

Figure 24. *Stalling Response Time* Test (Vstall=60% - UVsag = 50 % & 4-ms)

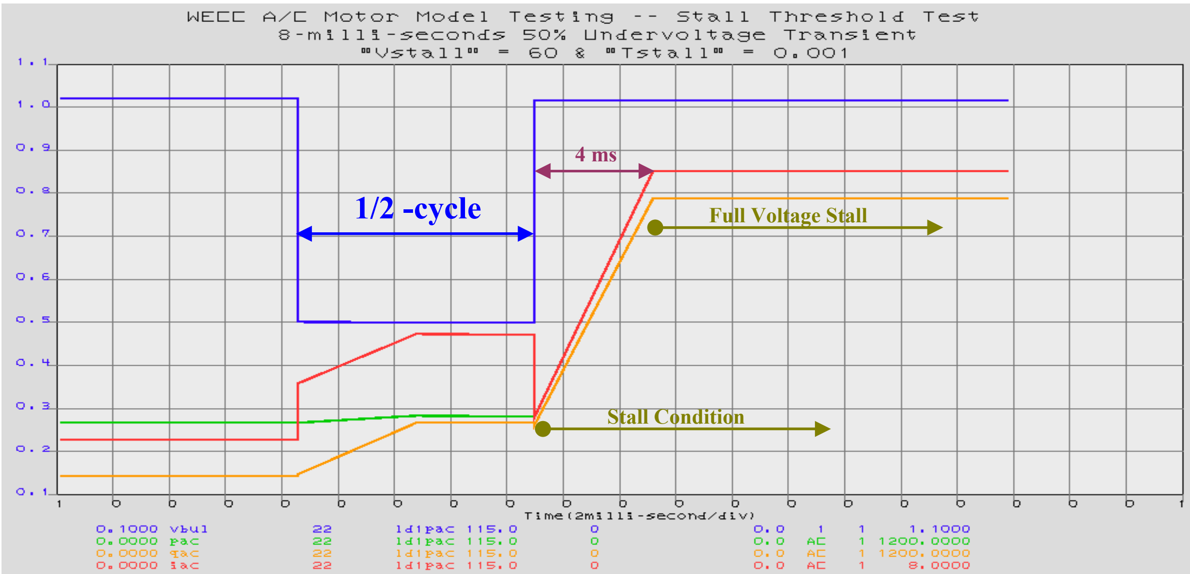

Figure 25. *Stalling Response Time* Test (Vstall=60% - UVsag = 50 % & 8-ms)

4.3. Stall Time (*Tstall*) Test

The stall time ("*Tstall*") is the time an A/C takes to stall during an undervoltage transient. The A/C test results indicated that air conditioners can stall within a few cycles; therefore, it is recommended that the *Tstall* setting not exceed 4 cycles. Table 7 shows the test results for *Tstall* set to 1, 2, and 3 cycles (Figures 26 through 31). These results indicate that the model does not stall for transients shorter than the *Tstall* parameter plus a couple of milliseconds.

T_{STALL} Parameter (sec)	UV Transient (p.u.)	UV Transient Time (sec)	Stalled
0.017	0.50	0.022	No
0.017	0.50	0.023	Yes
0.033	0.50	0.035	No
0.033	0.50	0.036	Yes
0.050	0.50	0.052	No
0.050	0.50	0.053	Yes

Table 7 - Stalling Threshold Test Results

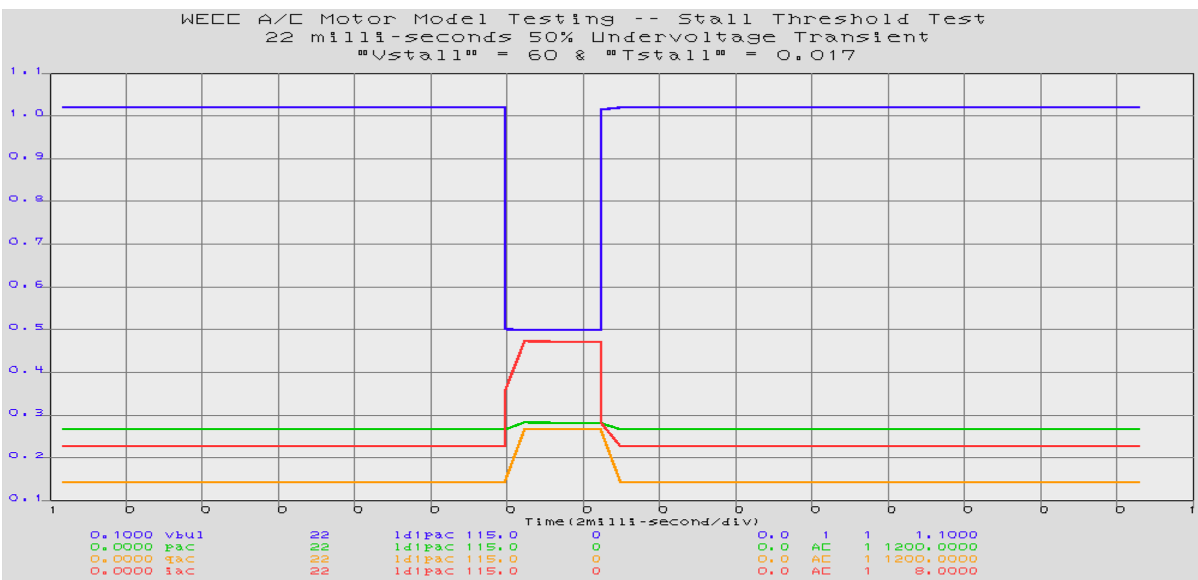

Figure 26. *Stall Delay Time* Test (22-ms 50 % UVsag)

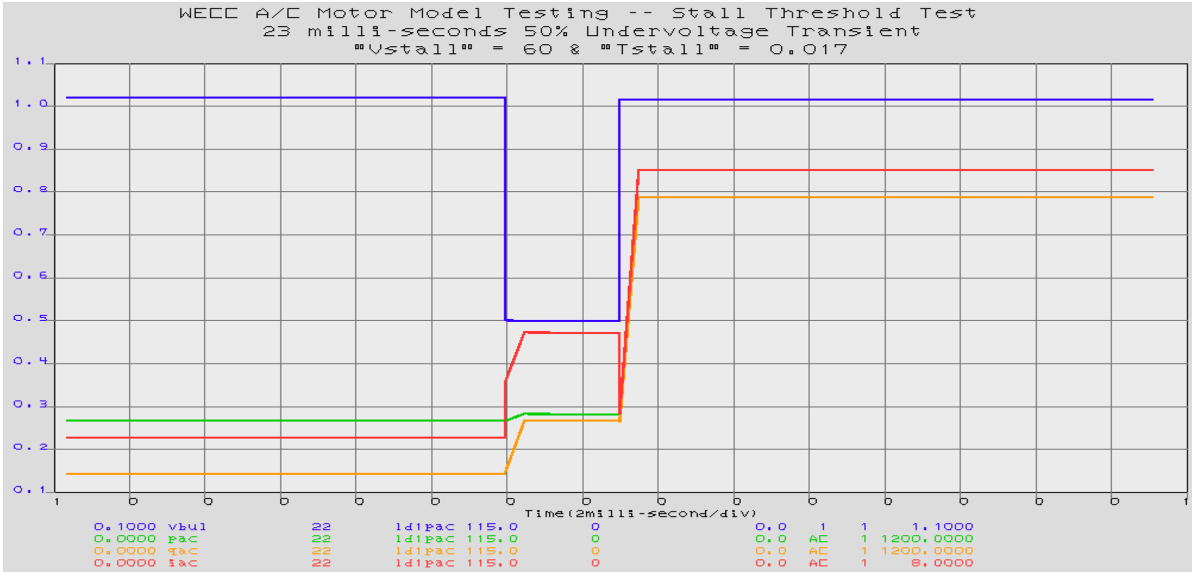

Figure 27. *Stall Delay Time* Test (23-ms 50 % UVsag)

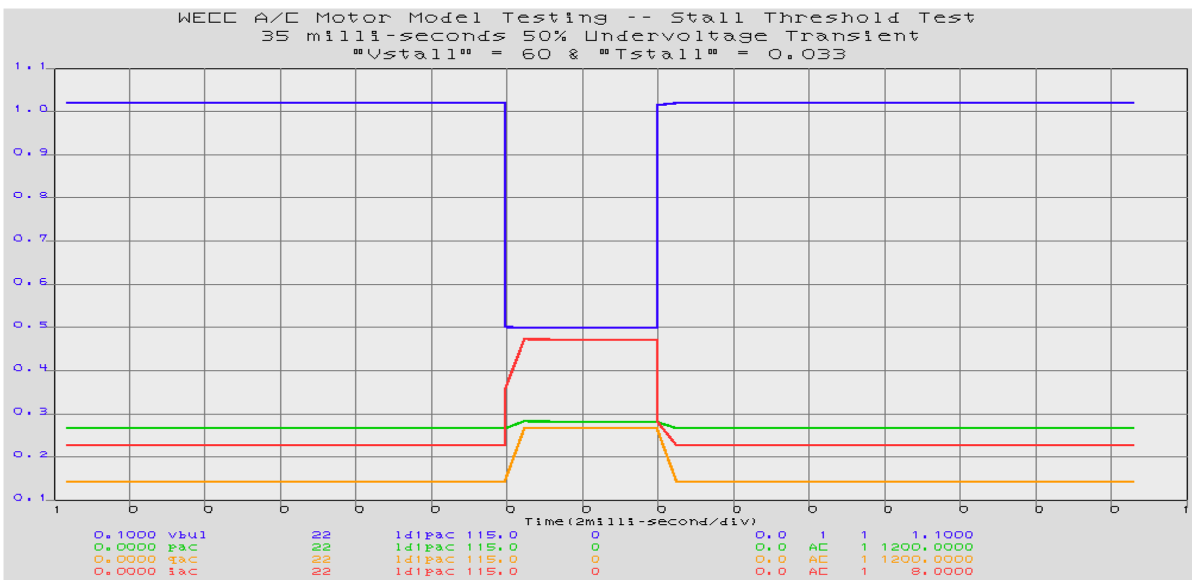

Figure 28. *Stall Delay Time* Test (35-ms 50 % UVsag)

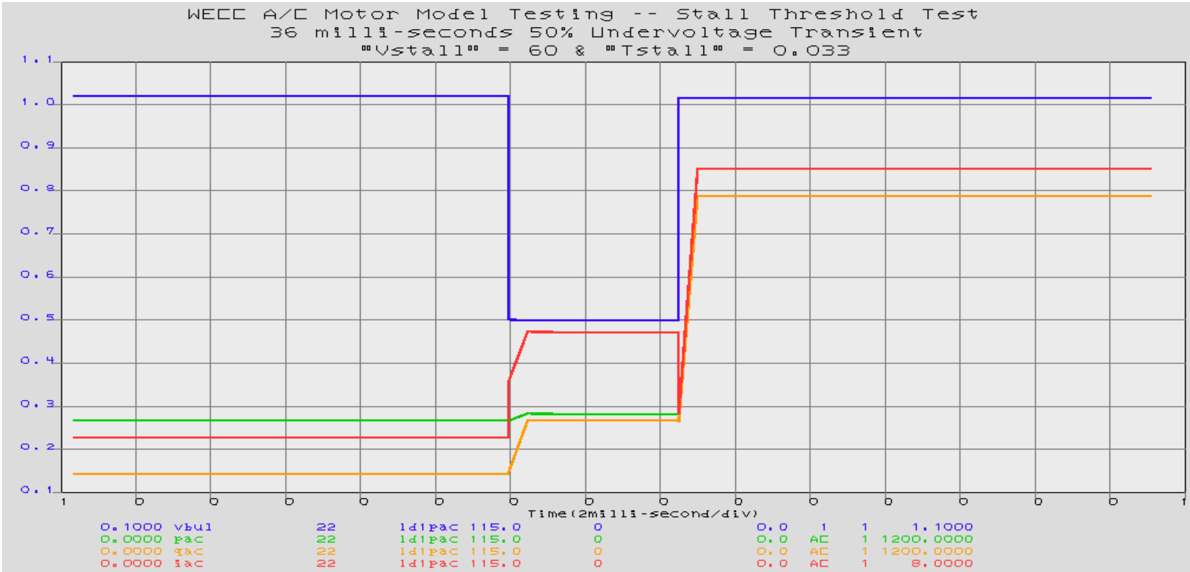

Figure 29. *Stall Delay Time* Test (36-ms 50 % UVsag)

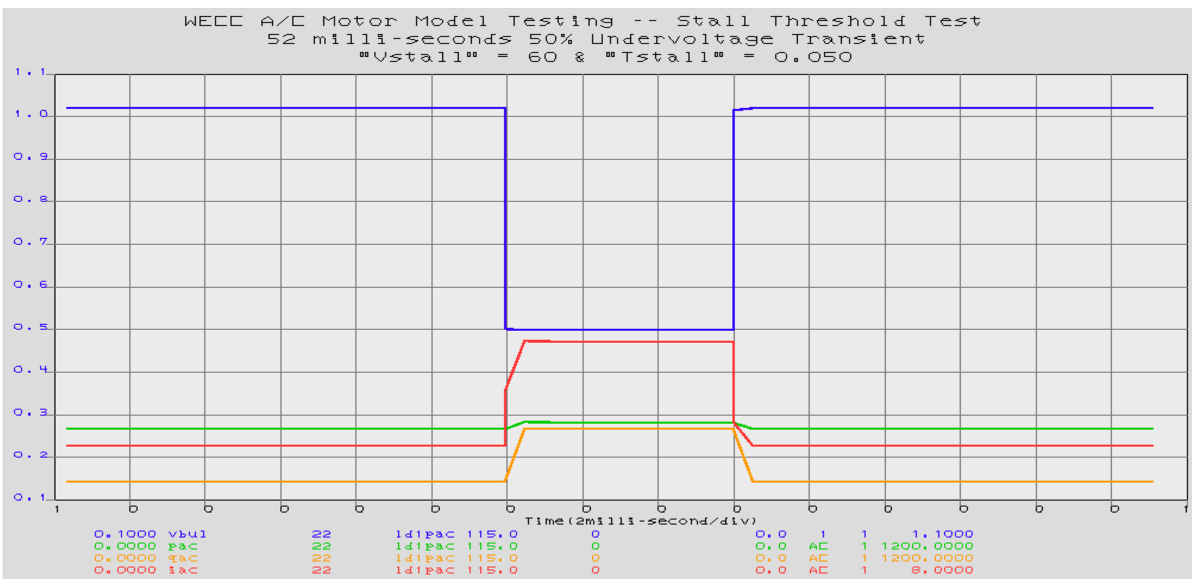

Figure 30. *Stall Delay Time* Test (52-ms 50 % UVsag)

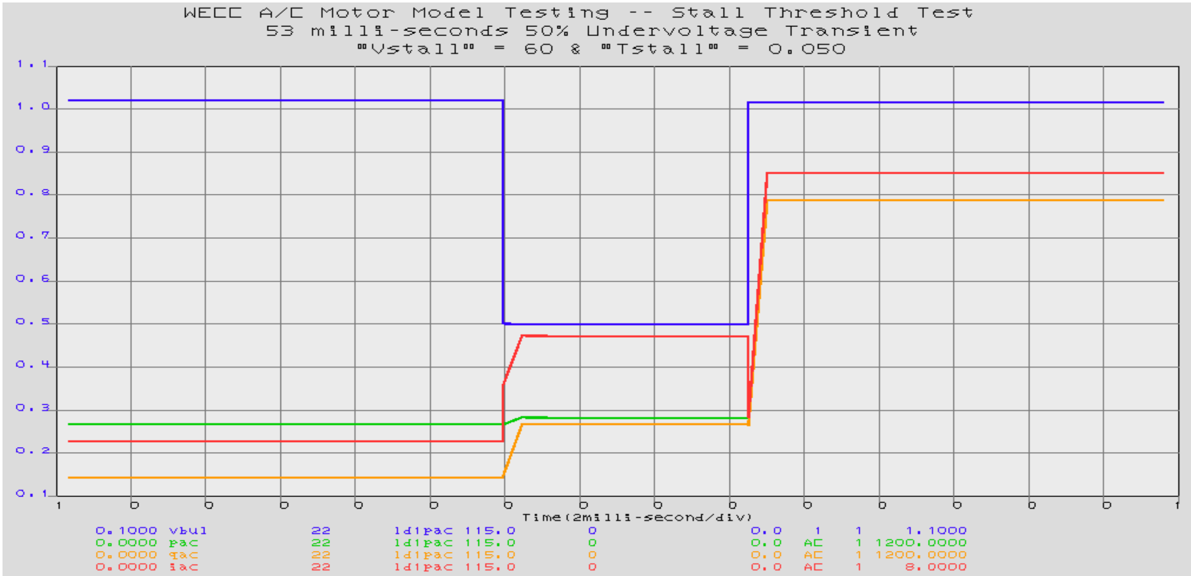

Figure 31. *Stall Delay Time* Test (53-ms 50 % UVsag)

5.0. POWER CONTACTOR MODEL TEST

RAC systems typically use an electromechanical power contactor to connect the source voltage to the A/C compressor using low voltage controls rated 24 VAC. The tested RAC systems had power contactors with 24 VAC coils. Figure 24 shows a typical electromechanical contactor used in RAC systems.

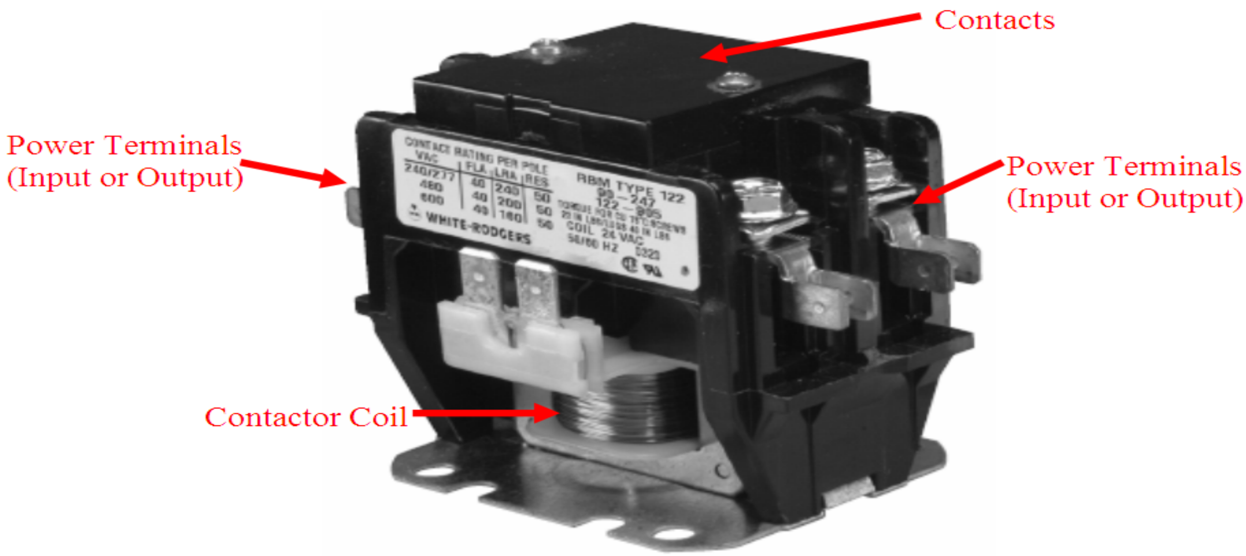

Figure 32. Typical Electromechanical Power Contactor in RAC Systems

EPRI and SCE A/C testing revealed that most of these power contactors drop out (disconnect) the compressor when their coil voltage goes below about 53 percent. Figure 33 shows the power contactor dropout thresholds for various air conditioner units.

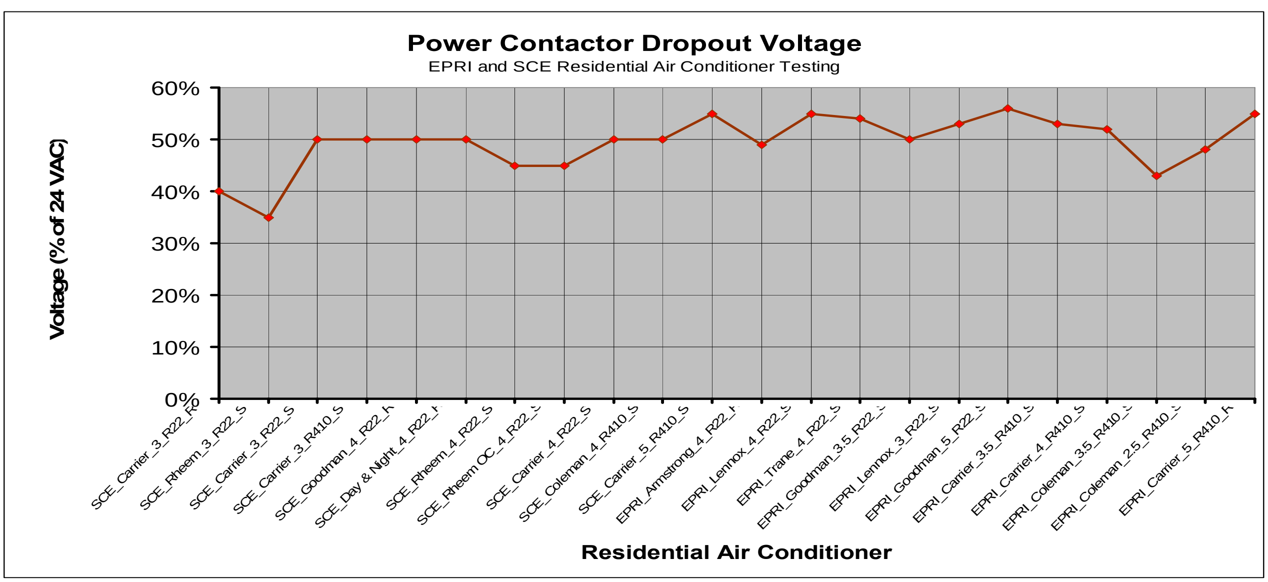

Figure 33. Power Contactor Dropout Voltages

For the *ld1pac's power contactor* model test, the air conditioner load was maintained at 200 MW and 30 MVAR. The *restarting load fraction* ("frst") and *under-voltage relay fraction* ("fuvr") were set to zero so no other parameters could alter the test results. It is important to mention that the *compressor breakdown voltage ("Vbrk")* has a default setting of 0.86 p.u. Table 8 shows the *ld1pac's power contactor* model parameters. The model's test results are shown in figures 34, 35 and 36 with the contactor drop load percentage *fcon* in Fuchsia.

Parameter	Description	Typical Settings
Vc1off	Voltage 1 at which contactors disconnect (open) the load gradually, p.u.	0.45
Vc2off	Voltage 2 at which contactors disconnect (open) all the remaining load, p.u.	0.35
Vc1on	Voltage 1 at which contactors re-connect (close) the load gradually, p.u.	0.50
Vc2on	Voltage 2 at which contactors re-connect (close) all the remaining load, p.u.	0.40

Table 8 - Power Contactor Parameters

5.1. Power Contactor First Set of Parameters (*Vc1off & Vc1on*) Test

Figure 34 represents the test results for the *power contactor's first set of parameters (Vc1off & Vc1on)*. In this test the voltage profile is taken from full-rated voltage, dropped to 0.47 p.u. and then gradually decreased in steps of 0.01 p.u. down to 0.39 p.u. The voltage is then increased in the same incremental values up to 0.52 p.u. and returned to a full-rated voltage of 1.00 p.u. (240 VAC). With the *Vc1off* set to 0.45 p.u. and the voltage at 0.45 p.u. the model starts disconnecting the A/C load gradually until it reaches 0.39 p.u. Once voltage begins to increase, the load does not reconnect immediately. When voltage reaches 0.45 p.u. the load begins to reconnect gradually until it reaches 0.50 p.u. The entire remaining load reconnects at 0.50 p.u., an action taken by the *Vc1on* setting.

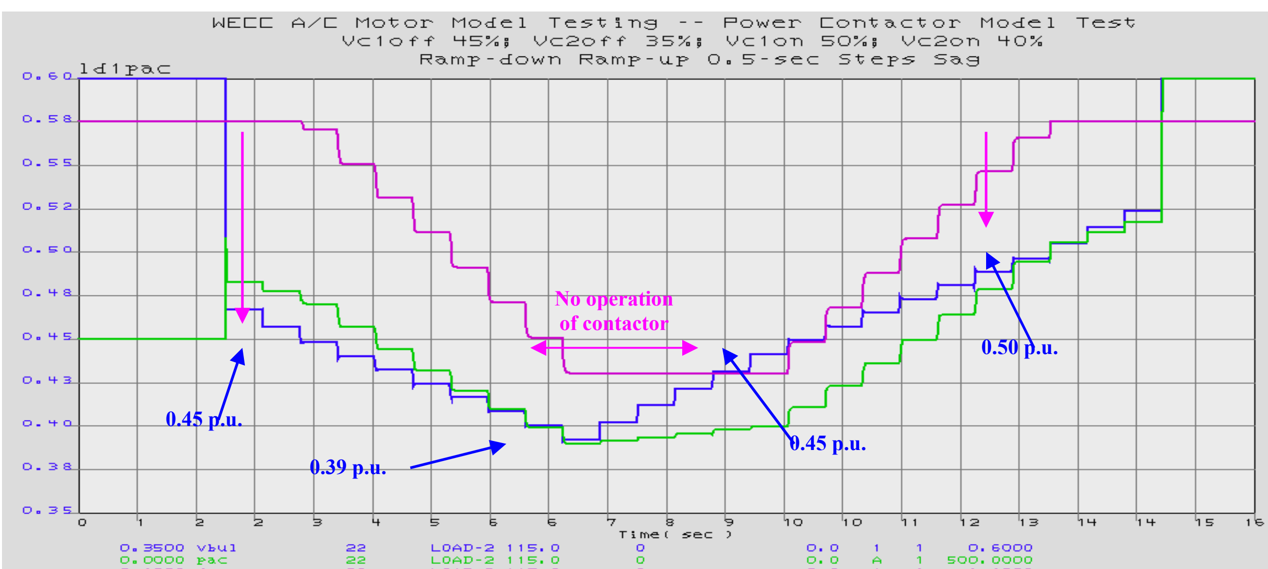

Figure 34. Contactor First Set of Parameters (*Vc1off and Vc1on*) Test

5.2. Power Contactor Second Set of Parameters (*Vc2off* & *Vc2on*)Test

Figure 35 shows the *power contactor's* second set of parameters *(Vc2off & Vc2on)* test results. Here the voltage is taken to 0.31 p.u. for 0.5 seconds and then increased to 0.36 p.u. again for 0.5 seconds where it again increases to 0.43 p.u. for 0.5 seconds; all of this was repeated one mode at a time. Notice that when the voltage was dropped to 0.31 p.u. the entire load was dropped and maintained even when the voltage increased to 0.36 p.u. This action was taken by the *Vc2off* setting at 0.35 p.u. The entire load was reconnected once voltage increased to 0.43 p.u. This action was taken with the *Vc2on* set to 0.40 p.u.

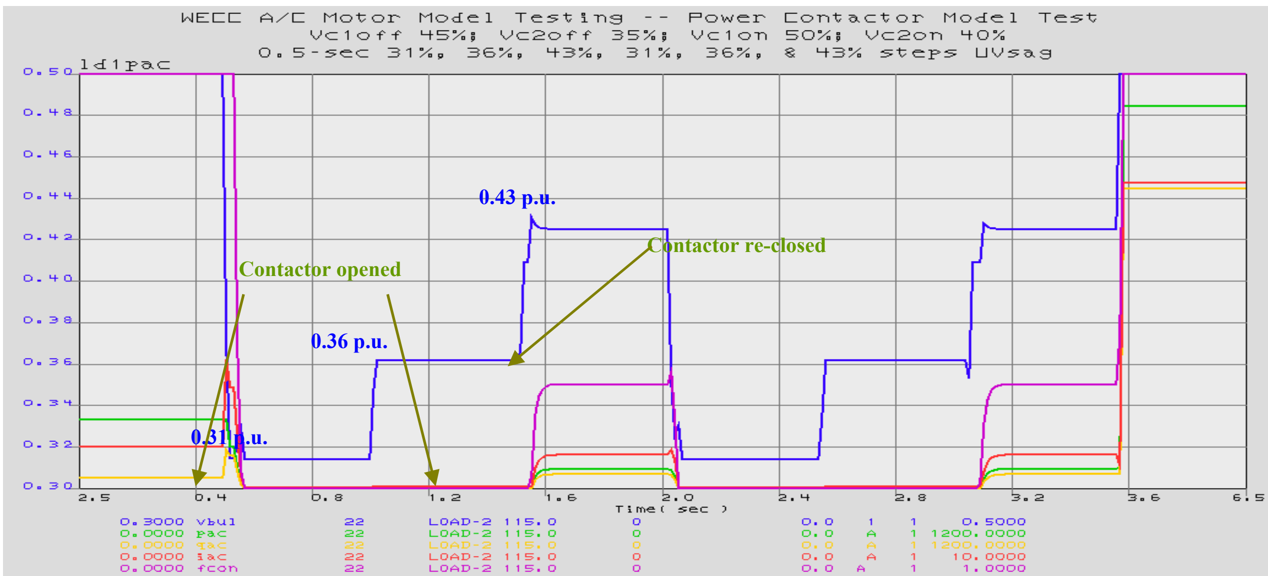

Figure 35. Contactor Second Set of Parameters (*Vc2off and Vc2on*) Test

Figure 36 illustrates that if the voltage goes below 45 percent the contactor begins a gradual disconnection of the load in 1.5 cycles; therefore, we can say the contactor operation time is approximately 1.5 cycles. The disconnect lag time of 1.5 cycles was consistent throughout this testing sequence. A/C tests performed by BPA, EPRI, and SCE found that the contactor dropout time was approximately 1~2 cycles.

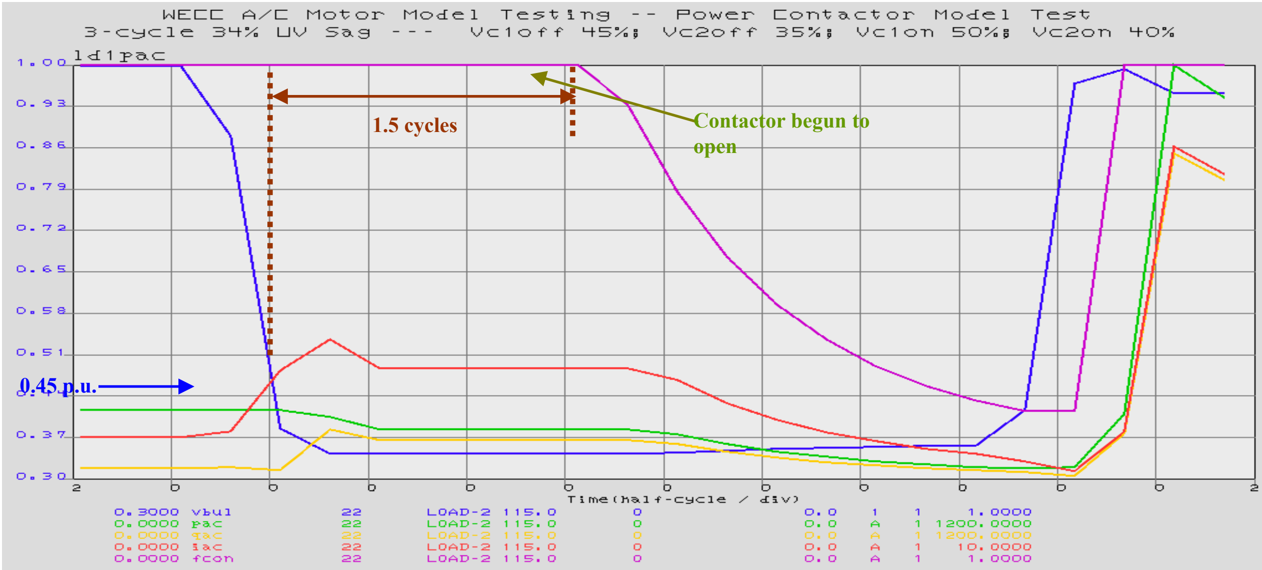

Figure 36. 3-cycles 34 UV Transient Contactor Model Test

6.0. RESTARTING A/C LOAD MODEL TEST

BPA, EPRI, and SCE A/C testing indicates that a small fraction of A/Cs are capable of restarting at certain voltages after stalling for some time. The new *ld1pac* model has been programmed to allow restarting of A/C load. The *ld1pac* model has two parameters for adjusting the restarting A/C load, *fraction of motors capable to restart ("Frst")* and *voltage where motors restart ("Vrst").*

The *fraction of motors capable to restart ("Frst")* and *voltage where motors restart ("Vrst")* parameters were adjusted to determine how these parameters behave at different set points. Table 9 shows the A/C restarting model parameters.

Parameter	Description	Typical Settings
Frst	Fraction of motors that are capable of restarting	0.10
Vrst	Voltage at which motors can restart, p.u.	0.60
Trst	Restarting Time Delay, sec.	0.40

Table 9 - Air Conditioner Restarting Parameters

For the *ld1pac's restarting load* model test, the A/C load was maintained at 200 MW and 30 MVAR. The under-voltage relay fraction ("fuvr") was set to zero so no other parameters could alter the test results. It is important to mention that the *compressor breakdown voltage ("Vbrk")* has a default setting of 0.86 p.u.

6.1. Fraction of Motors Capable of Restarting Test (*Frst*) Test

For the following tests, the *Vrst* and the *Trst* parameters were kept constant, 0.60 and 0.40 respectively. Additionally the source voltage was depressed to 0.6 p.u. in order to stall the *ld1pac* model. Table 10 provides the *Frst* test results for the different *Frst* parameters shown in Figures 37 through 40. The results indicate that the *Frst* parameter is relatively close to the actual restarting P and I.

Figure	Set Frst (%)	Actual Restarting P (MW)	Actual Restarting P (%)	Actual Restarting I (%)
37	0	0	0	0
38	25	50	25	25.7
39	50	100	50	51.0
40	75	150	75	77.4

Table 10 - *A/C Restarting Fraction* Test Results

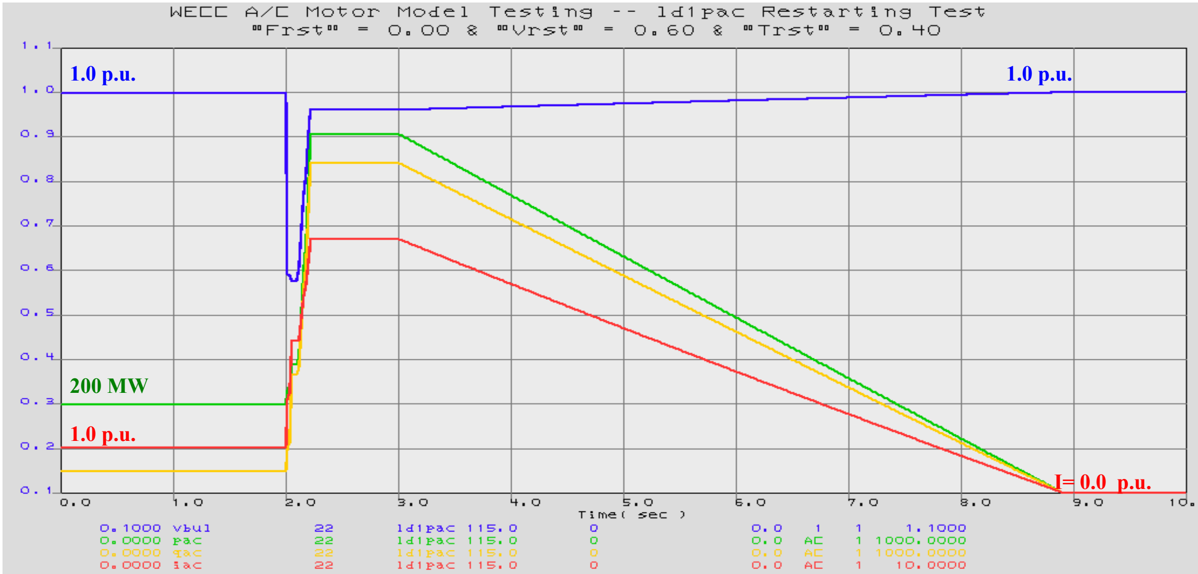

Figure 37. Restarting Fraction Test (*Frst* = 0%)

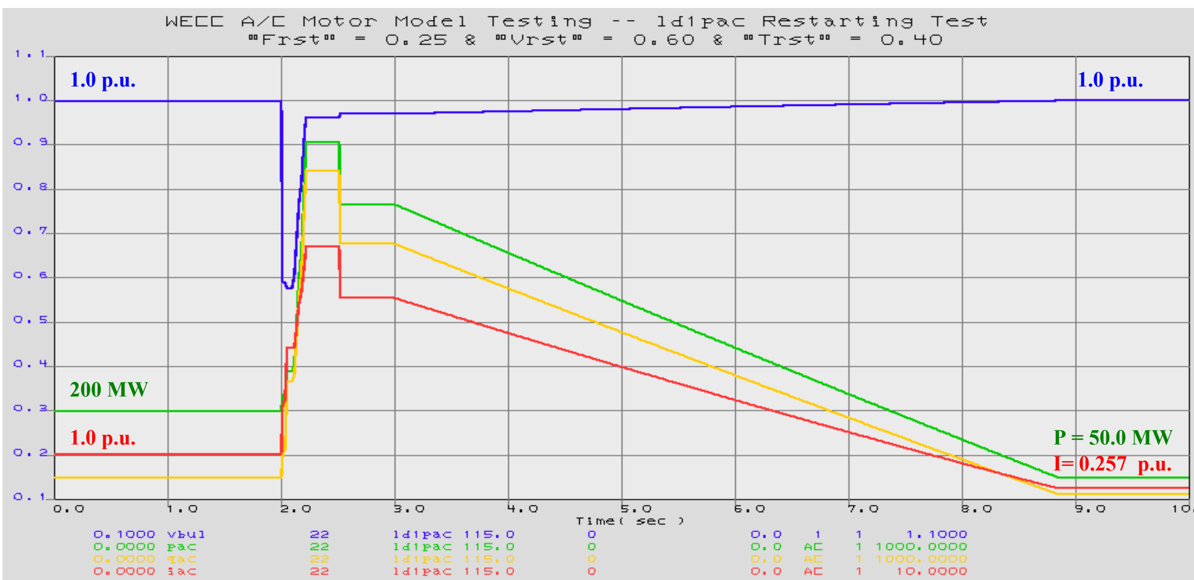

Figure 38. Restarting Fraction Test (*Frst* = 25%)

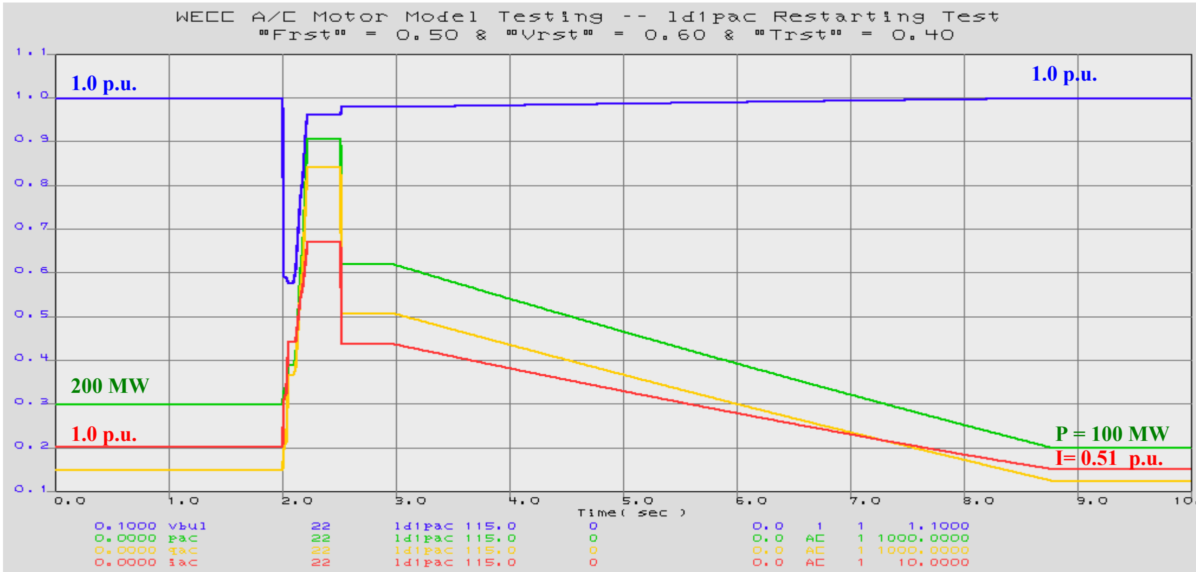

Figure 39. Restarting Fraction Test (*Frst* = 50%)

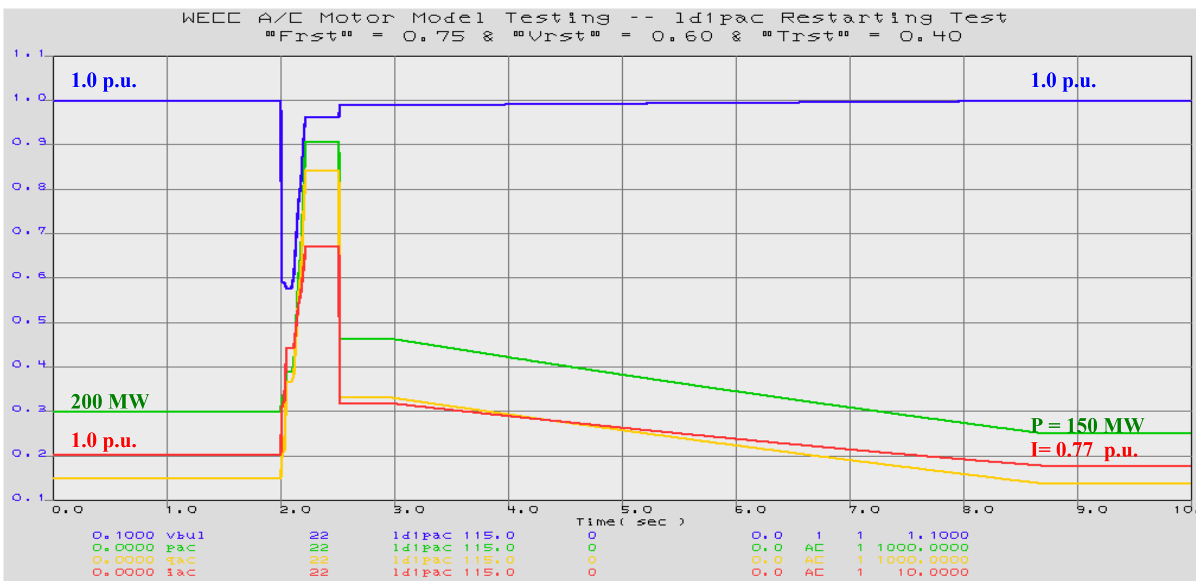

Figure 40. Restarting Fraction Test (*Frst* = 75%)

6.2. Voltage at Which Motors Can Restart (*Vrst*) Test

For the following tests, the *Frst* and the *Trst* parameters were kept constant, 0.50 and 0.00 respectively. Additionally the source voltage was depressed to 0.6 p.u. and gradually increased to full-rated voltage in 4.0 seconds. Table 11 provides the *Vrst* test results for the different *Vrst* parameters shown in Figures 41 through 44. The results indicate that actual restarting voltage is the same as the *Vrst* set point parameter. The first test was performed with a high *Vrst* set point parameter to verify that the model does not restart any load during these high set conditions and indeed the model did not restart any load.

Figure	Set Vrst (%)	Actual Restarting Voltage (%)
41	100	Did not restarted because restarting voltage set Vrst point was too high
42	70	70
43	80	80
44	90	90

Table 11 - *A/C Restarting Voltage* Test Results

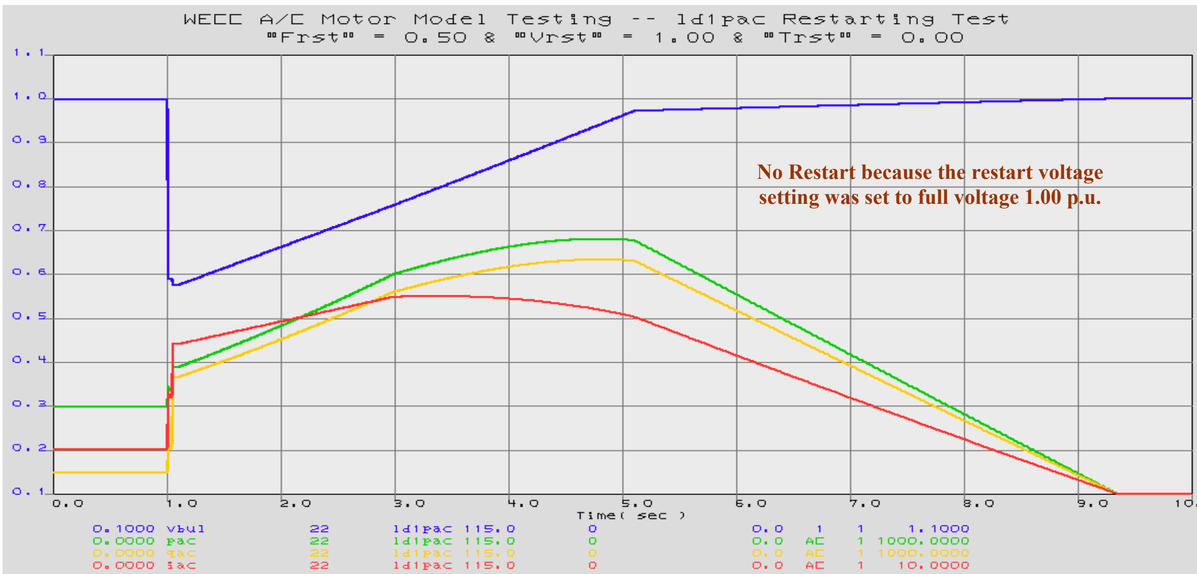

Figure 41. Restarting Voltage Test (Vrst = 100%)

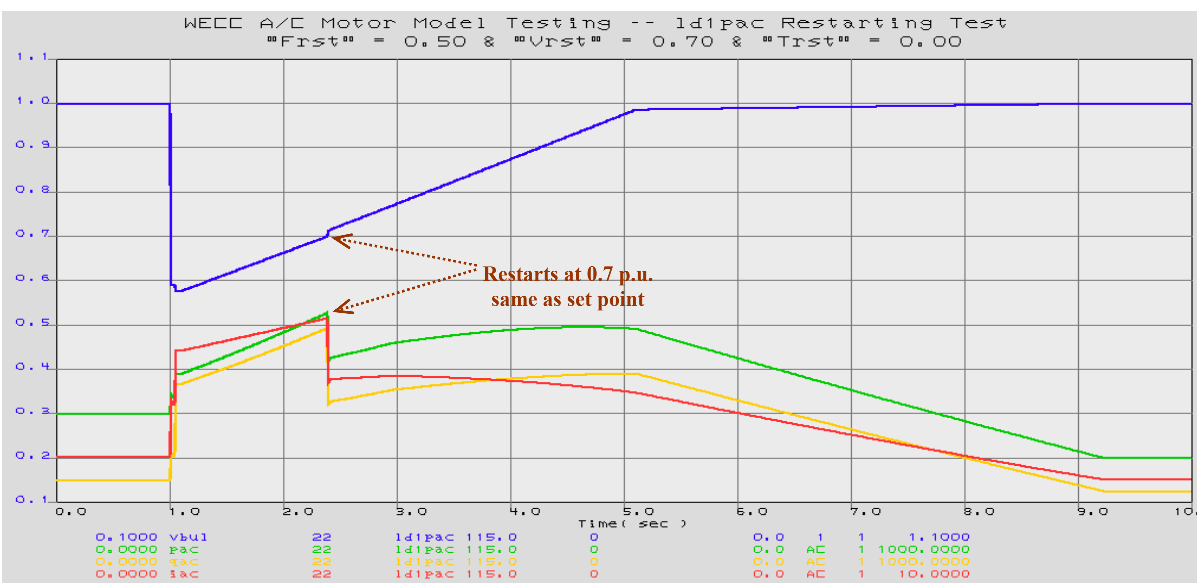

Figure 42. Restarting Voltage Test (Vrst = 70%)

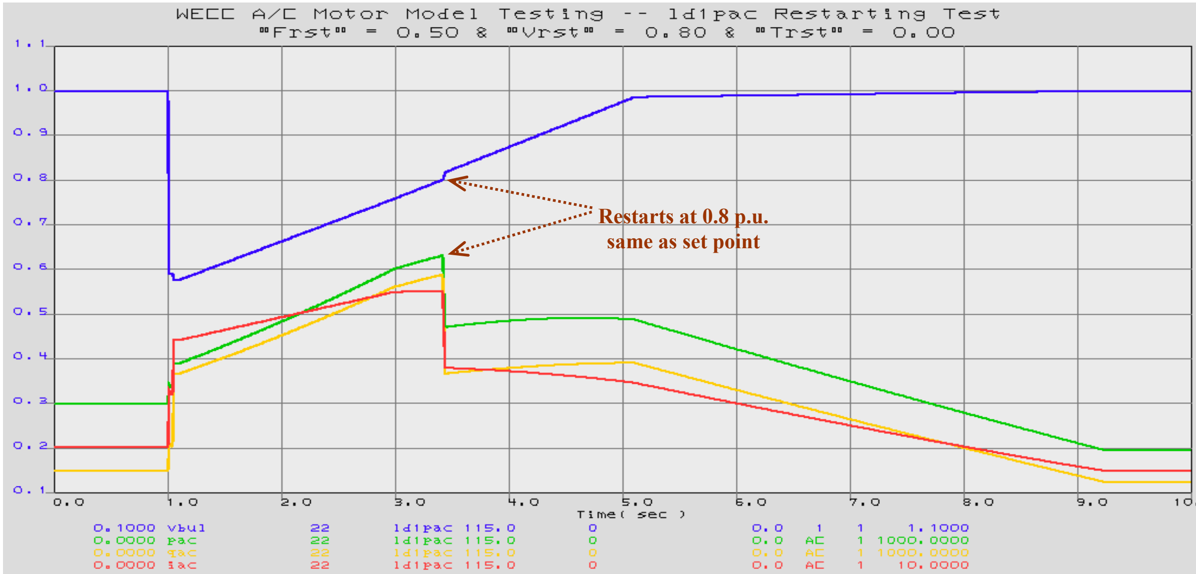

Figure 43. Restarting Voltage Test (Vrst = 80%)

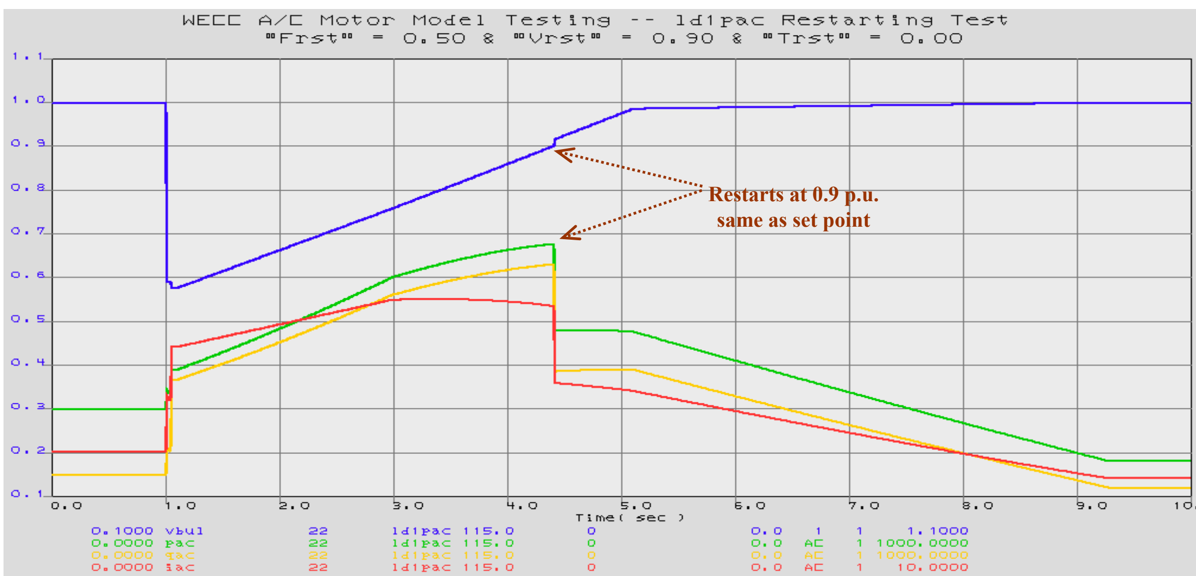

Figure 44. Restarting Voltage Test (Vrst = 90%)

6.3. Restart Delay (*Trst*) Test

For the following tests, the *Frst* and the *Vrst* parameters were kept constant, 0.50 and 0.80 respectively. Additionally, the source voltage was depressed to 0.6 p.u. and gradually increased to full-rated voltage in 4 seconds. Table 12 provides the *Trst* test results for the different *Trst* parameters shown in Figures 45 through 48. The results indicate that actual restarting delay is the same as the *Trst* set point parameter.

Figure	Set Trst (sec)	Actual Restarting Delay (sec)
45	0.20	0.20
46	0.40	0.40
47	0.60	0.60
48	0.80	0.80

Table 12 - *A/C Restarting Delay* Test Results

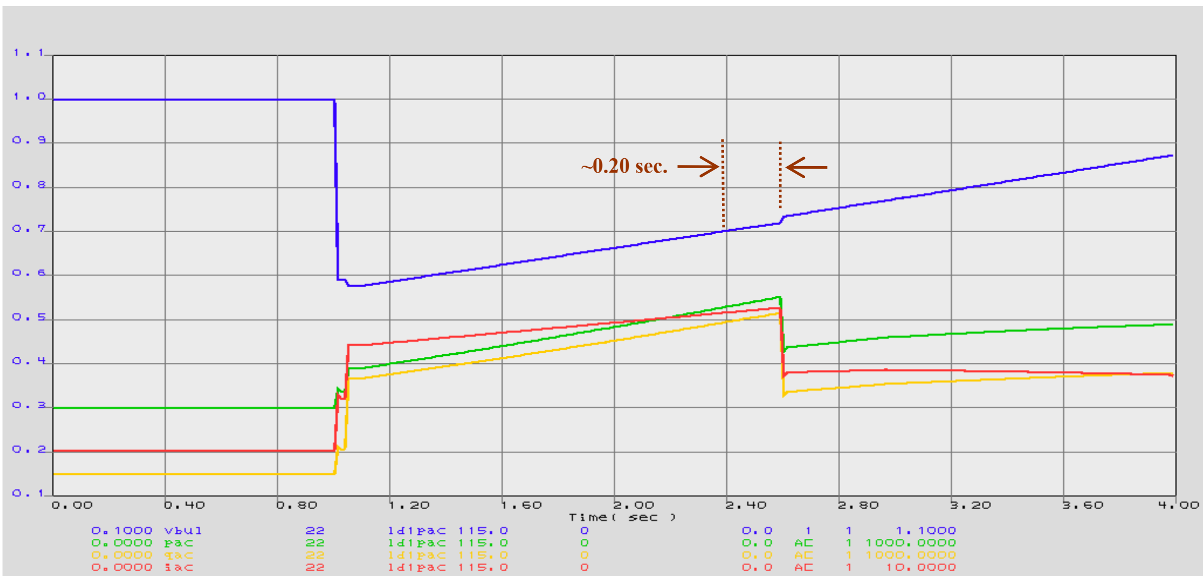

Figure 45. Restarting Delay Test (*Trst* = 0.20)

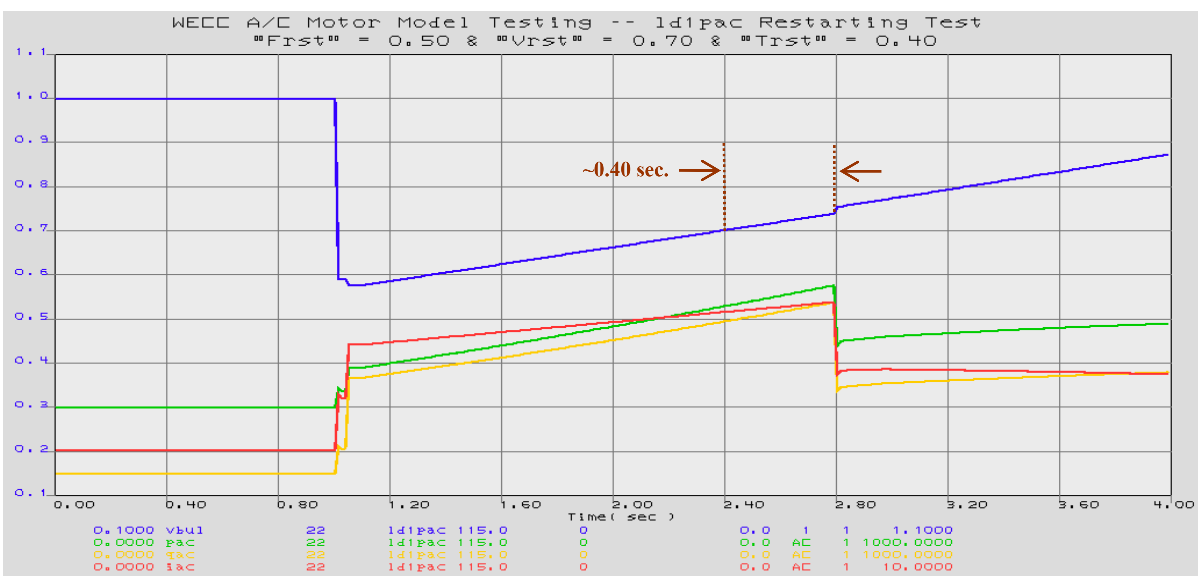

Figure 46. Restarting Delay Test (*Trst* = 0.40)

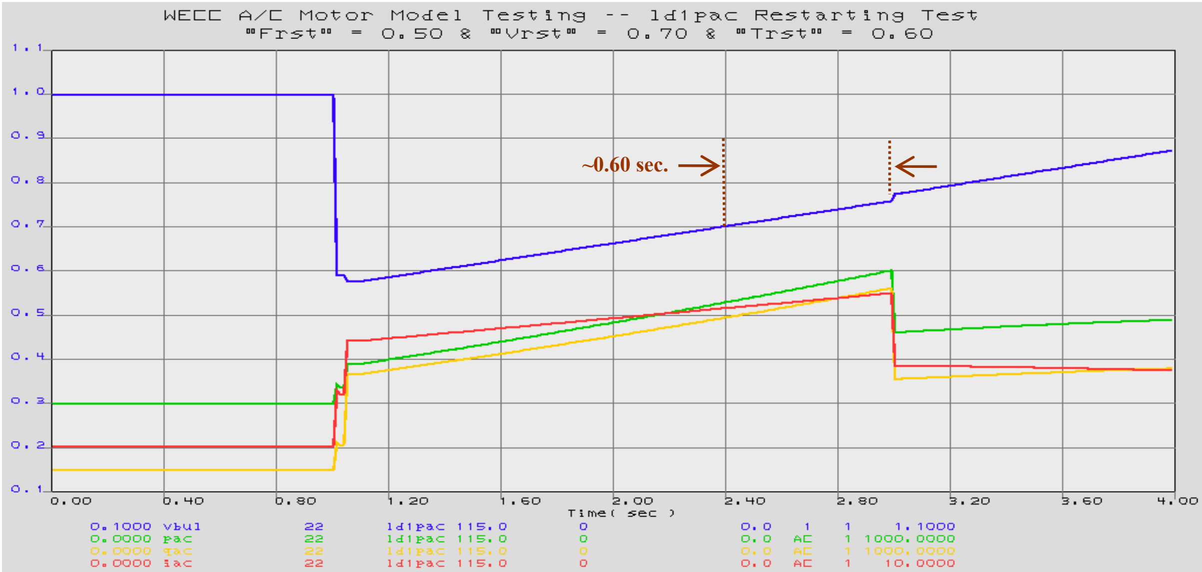

Figure 47. Restarting Delay Test (*Trst* = 0.60)

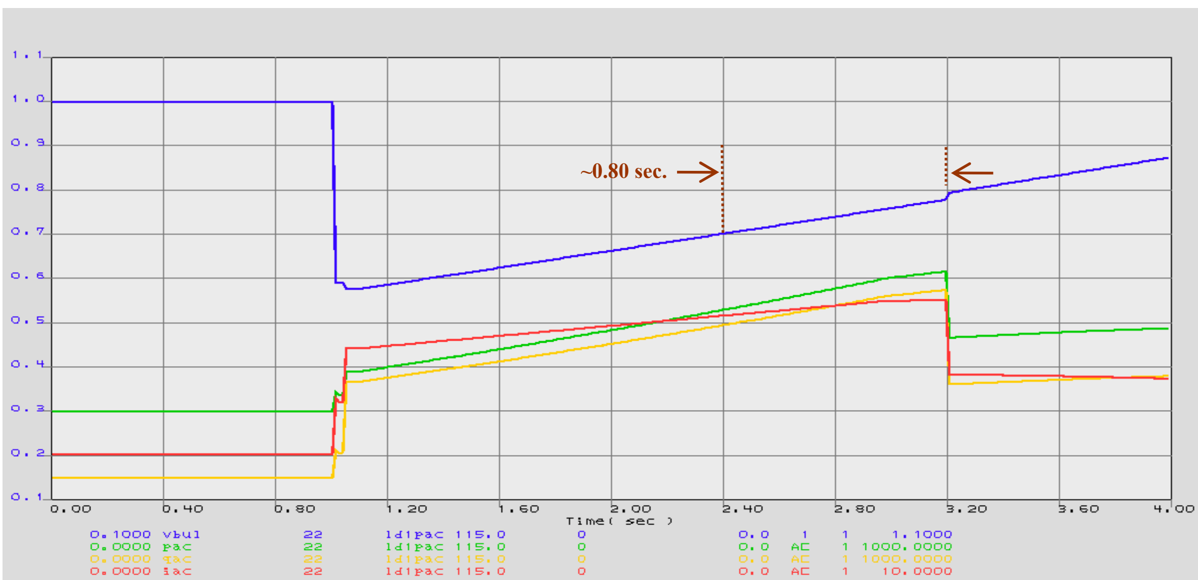

Figure 48. Restarting Delay Test (*Trst* = 0.80)

7.0. UNDER-VOLTAGE RELAY (UVR) TEST

It is now well documented that air conditioners stall during under-voltage transients making it necessary to have a device that takes the units out of their stalls in order to protect the system. One such device is a simple under-voltage protection relay that disconnects an air conditioner whenever voltage dips below an under-voltage protection threshold (*UVtr1 and UVtr2*) and remains there for an under-voltage protection response time (*Ttr1 and Ttr2*). The *Fuvr* represents the penetration of these under-voltage relays in the air conditioners. Table 13 provides all the typical settings and definitions for these parameters.

Parameter	Typical Settings	Description
Fuvr	0.0 p.u.	Fraction of compressor motors with undervoltage relays
UVtr1	0.75 p.u.	First undervoltage pickup level
Ttr1	0.2 sec.	First definite time for U/V trip
Uvtr2	0.9 p.u.	Second undervoltage pickup level
Ttr2	5.0 sec.	Second definite time for U/V trip

Table 13 - *Ld1pac Under-Voltage Relay* Model Parameters

For the *ld1pac's under-voltage protection relay* model test, the air conditioner load was maintained at 200 MW and 30 MVAR. The *restarting load fraction ("frst")* and *under-voltage relay fraction ("fuvr")* were set to zero so no other parameters could alter the test results. It is important to mention that the *compressor breakdown voltage ("Vbrk")* default setting is 0.86 p.u.

7.1. Fraction of Under-Voltage Relays (*Fuvr*) Test

Table 14 provides the *fraction of under-voltage relay ("Fuvr")* test results for the *Fuvr* parameters shown in Figures 49 through 51. The results indicate that the *Fuvr* setting is relatively close to the actual values in the simulation, *Fuvr Output*.

Figure	*Fuvr Setting (p.u.)*	*Fuvr Output (p.u.)*
49	0.25	0.25
50	0.50	0.50
51	0.75	0.75

Table 14 - Fuvr Test Results

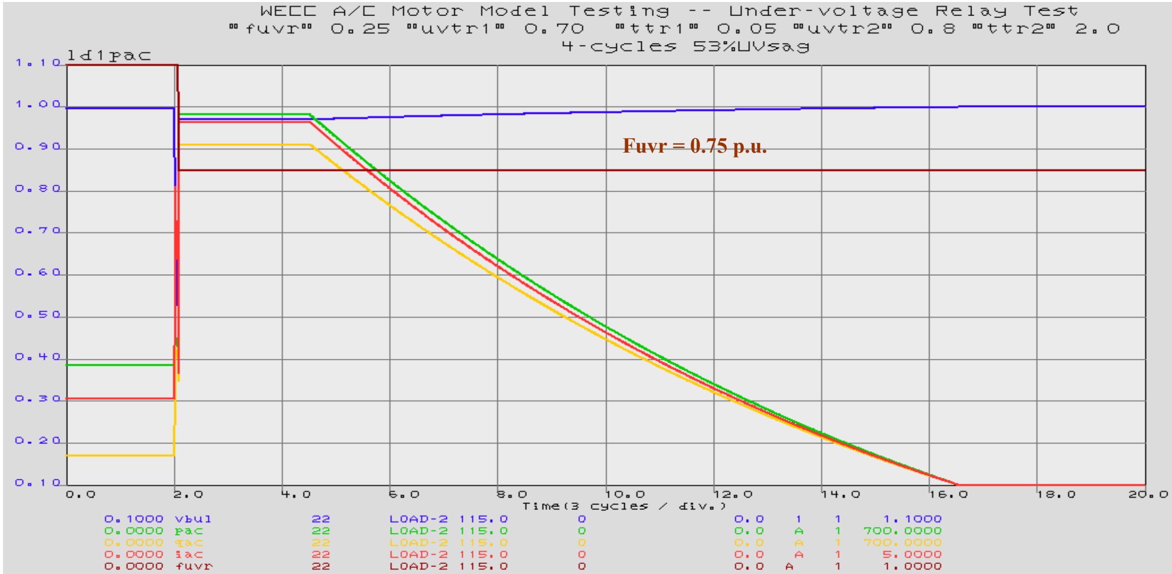

Figure 49. Fraction of UV Relay Penetration (Fuvr = 25%)

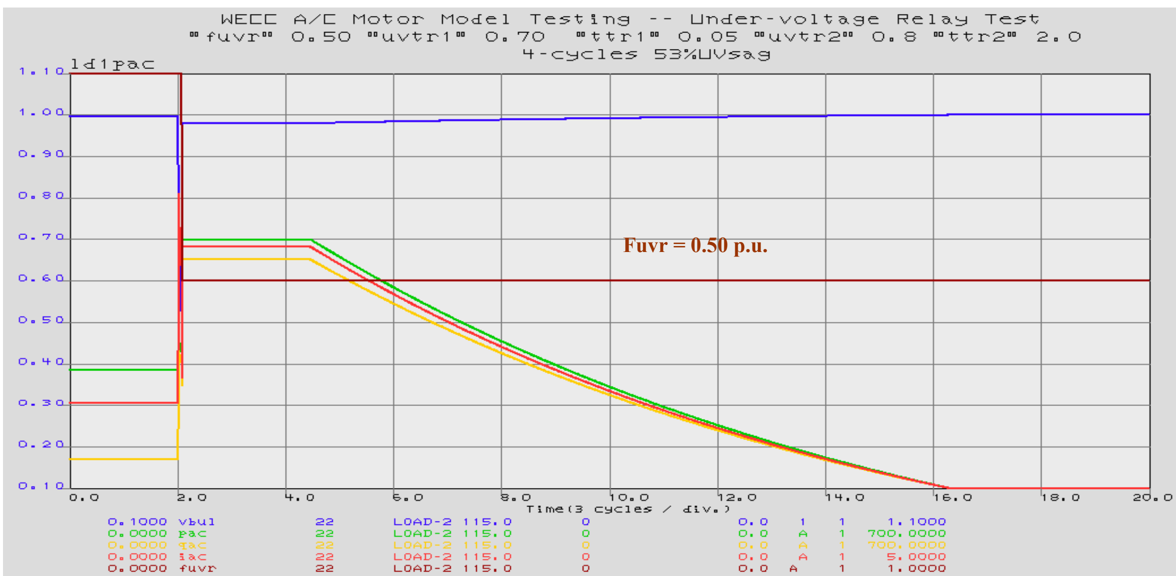

Figure 50. Fraction of UV Relay Penetration (Fuvr = 50%)

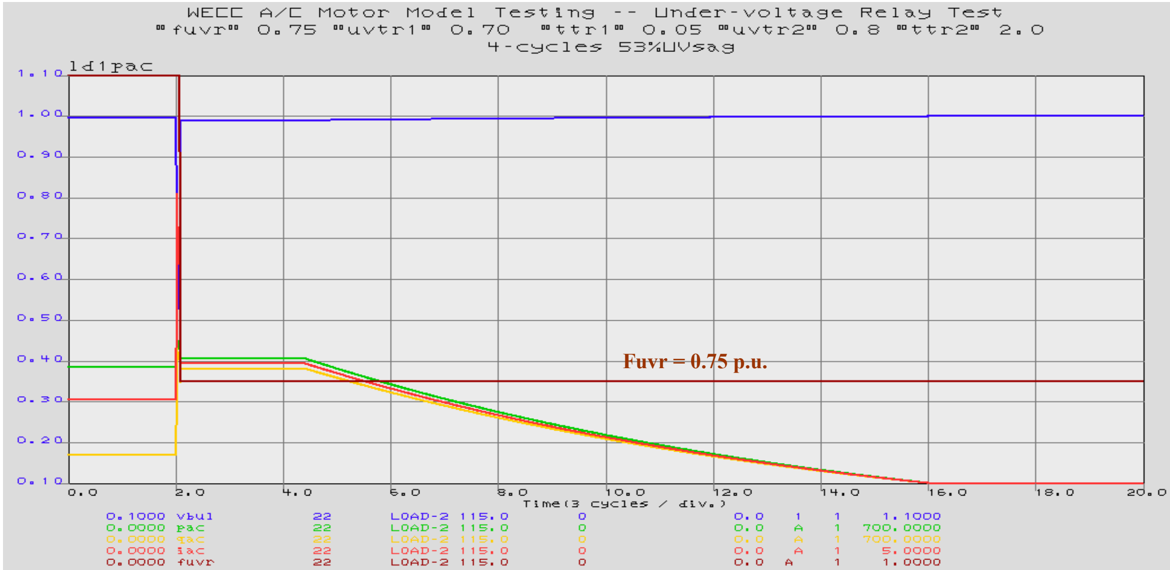

Figure 51. Fraction of UV Relay Penetration (*Fuvr* = 75%)

7.2. First UV Pickup Level (*UVtr1*) and First Definite Time For U/V Trip (*Ttr1*) Test

Table 15 provides the *ld1pac's first UV pickup level ("UVtr1")* and *first definite time for U/V trip ("Ttr1)* test results for the *Ttr1* parameters shown in Figures 52 thru 55. The results indicate that the set *UVtr1* load drop parameter is close to the actual load drop values for the first three cases. These test results also indicate that the *Ttr1* response time is 2 cycles for all the cases where the undervoltage sag is below the *UVtr1* set point. The fourth case, the undervoltage relay did not trip because the undervoltage sag was above the set *UVtr1* set point.

Figure	*Set UVtr1 (p.u.)*	*Actual UV Sag (p.u.)*	Set *Ttr1* (cycles)	Actual Trip Time (cycles)	*Ttr1* Response Time (cycles)
52	0.70	0.686	0	2	2
53	0.70	0.686	3	5	2
54	0.70	0.686	6	8	2
55	0.70	0.706	6	No response	N/A

Table 15 - UVtr1 and Ttr1 Test Results

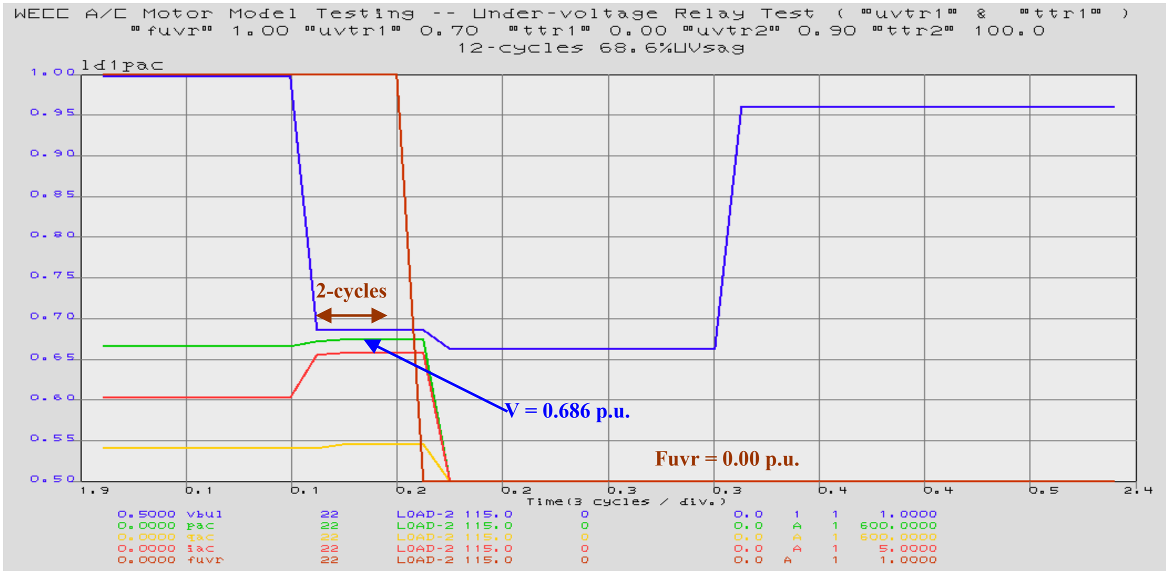

Figure 52. First UV Relay Tripping Parameters Test (uvtr1=0.70 & ttr1=0.00)

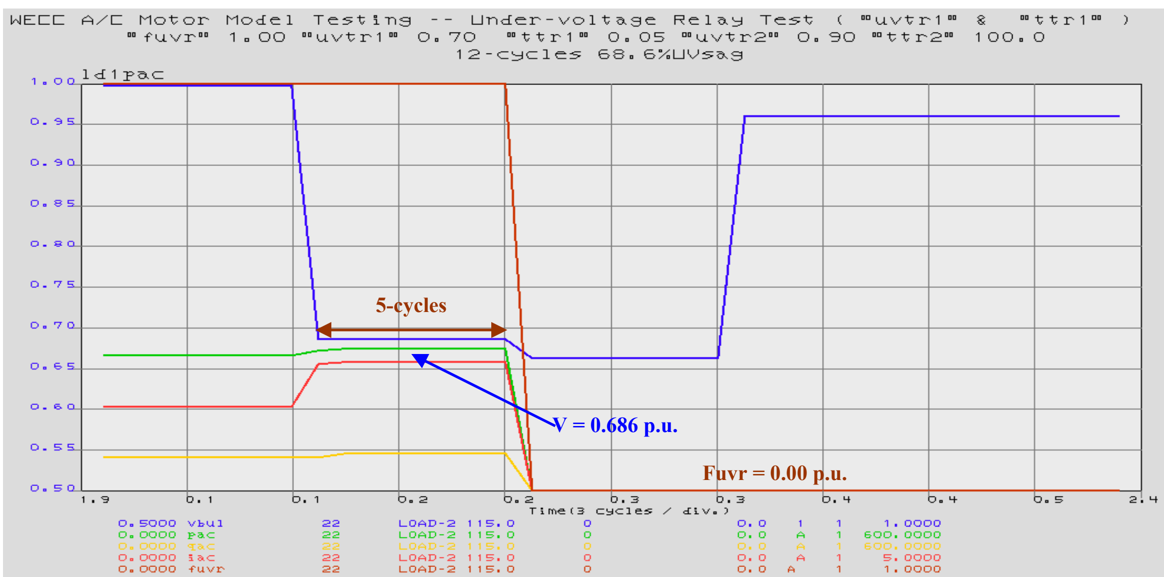

Figure 53. First UV Relay Tripping Parameters Test (*uvtr1*=0.70 & *ttr1*=0.050)

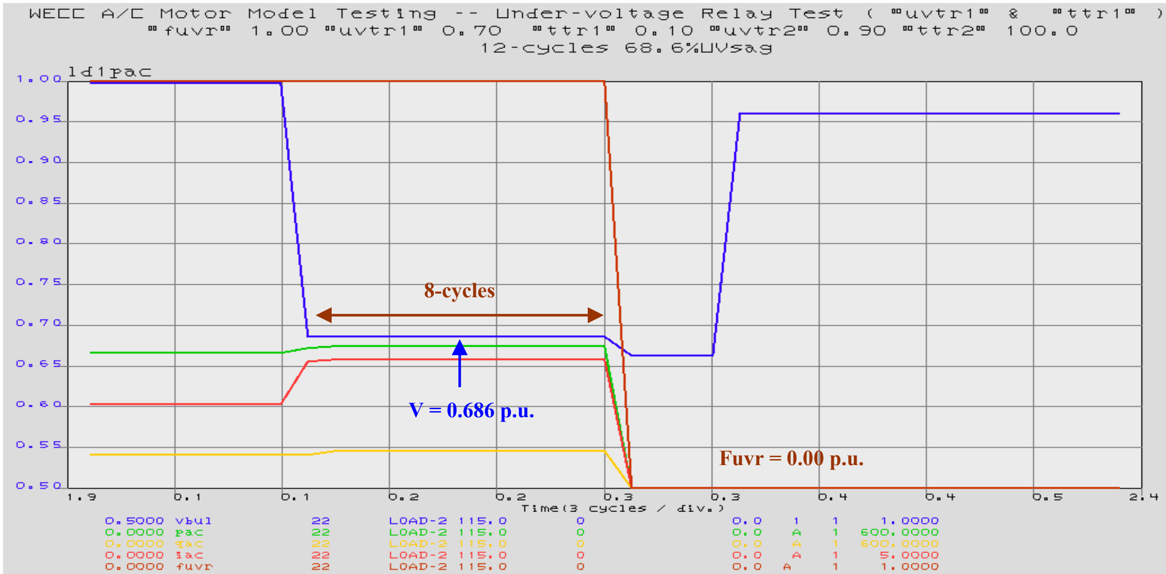

Figure 54. First UV Relay Tripping Parameters Test (*uvtr1*=0.70 & *ttr1*=0.100)

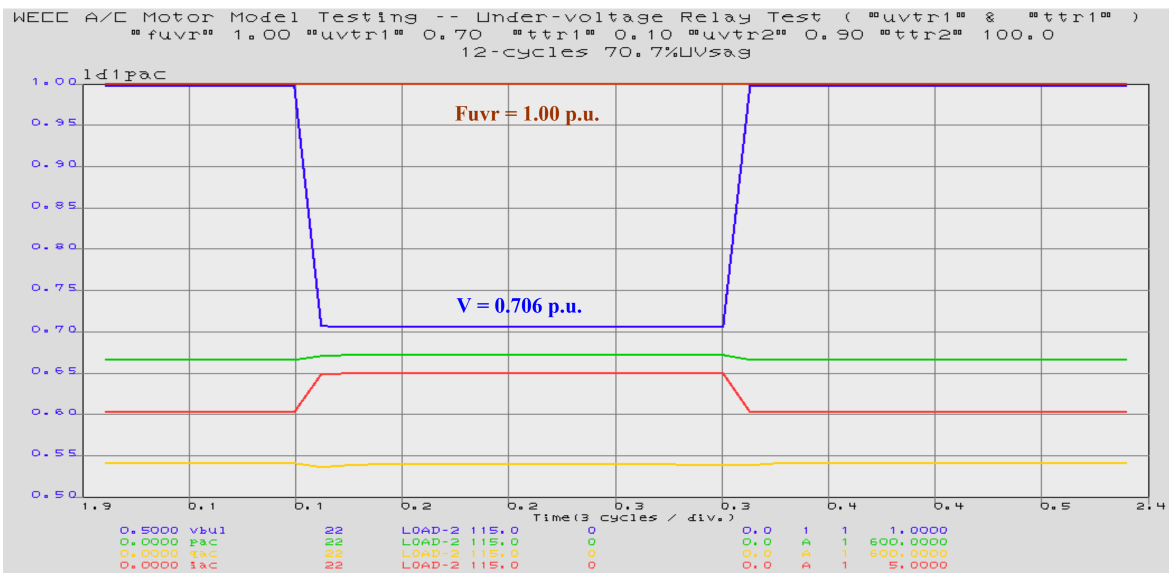

Figure 55. First UV Relay Tripping Parameters Test (*uvtr1*=70% & *ttr1*=0.100)

NOTE: The *UVtr1* and *Ttr1* parameters were set at 70 percent and 6 cycles respectively for a total load shed "*Fuvr*". The relay did not actuate because the voltage only decreased to 70.6 percent above the under-voltage setting.

7.3. Second UV Pickup Level (*UVtr2*) and Second Definite Time For U/V Trip (*Ttr2*) Test

Table 16 provides the ld1pac's *second UV pickup level ("UVtr2")* and *second definite time for U/V trip ("Ttr2)* test results for the *Ttr2* parameters shown in Figures 56 thru 59. The results indicate that the set *UVtr2* load drop parameter is close to the actual load drop values for the first three cases. These test results also indicate that the *Ttr2* response time is 2 cycles for all the cases where the undervoltage sag is below the *UVtr2* set point. The fourth case, the undervoltage relay did not trip because the undervoltage sag was above the set *UVtr2* set point.

Figure	*Set UVtr2 (p.u.)*	*Actual UV Sag (p.u.)*	Set *Ttr2* (cycles)	Actual Trip Time (cycles)	*Ttr2* Response Time (cycles)
56	0.70	0.686	0	2	2
57	0.70	0.686	3	5	2
58	0.70	0.686	6	8	2
59	0.70	0.706	6	No response	N/A

Table 16 - *UVtr2* and *Ttr2* Test Results

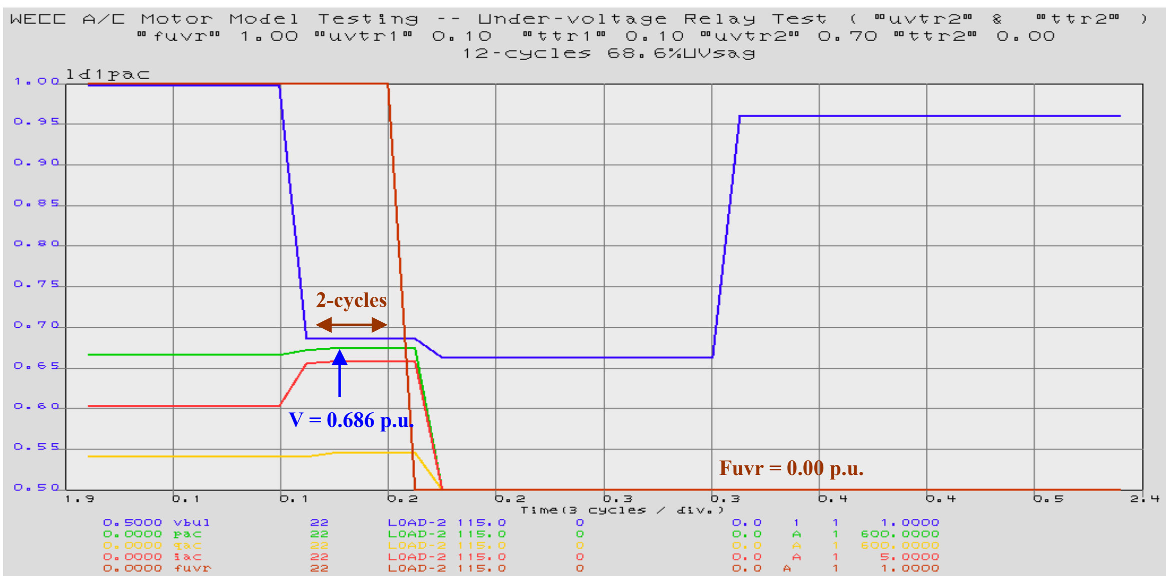

Figure 56. Second UV Relay Tripping Parameters Test (*uvtr2*=70% & *ttr2*=0.00)

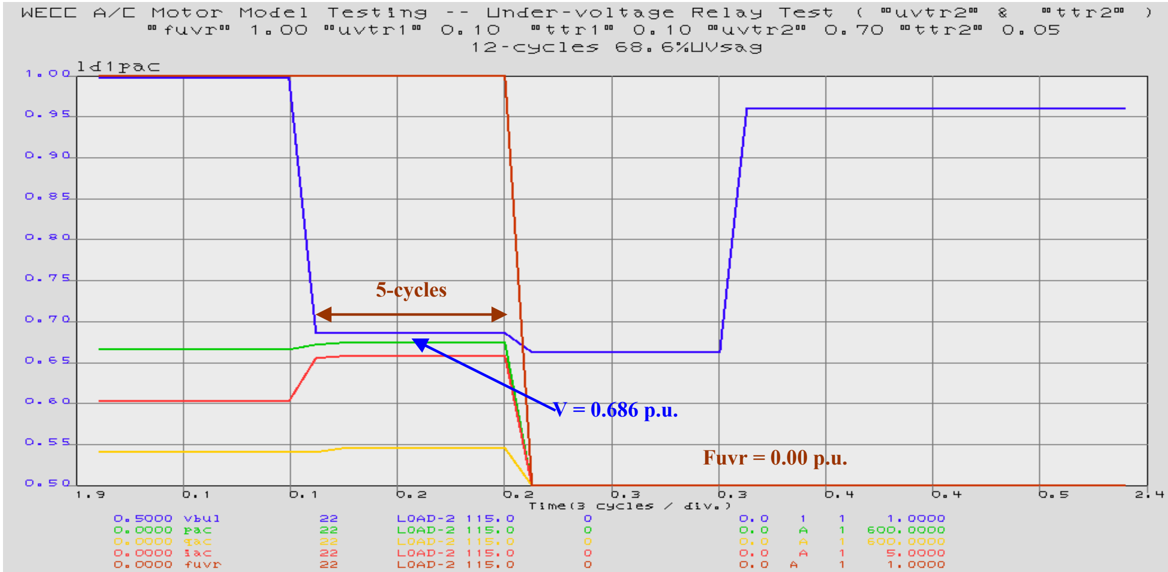

Figure 57. Second UV Relay Tripping Parameters Test (*uvtr2*=0.70% & *ttr2*=0.05)

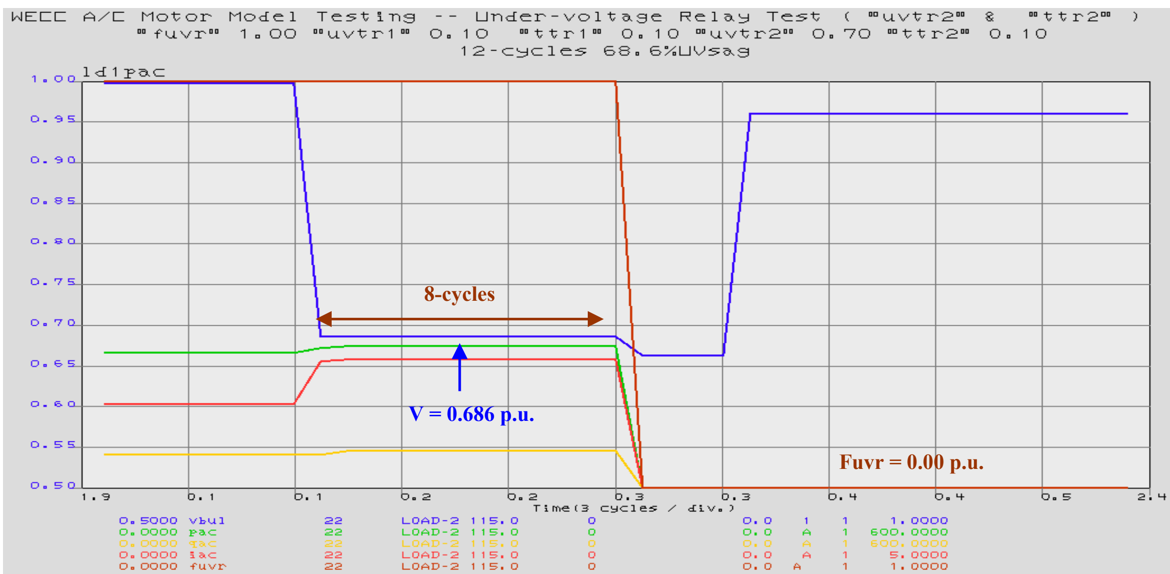

Figure 58. Second UV Relay Tripping Parameters Test (*uvtr2*=0.70 & *ttr2*=0.01)

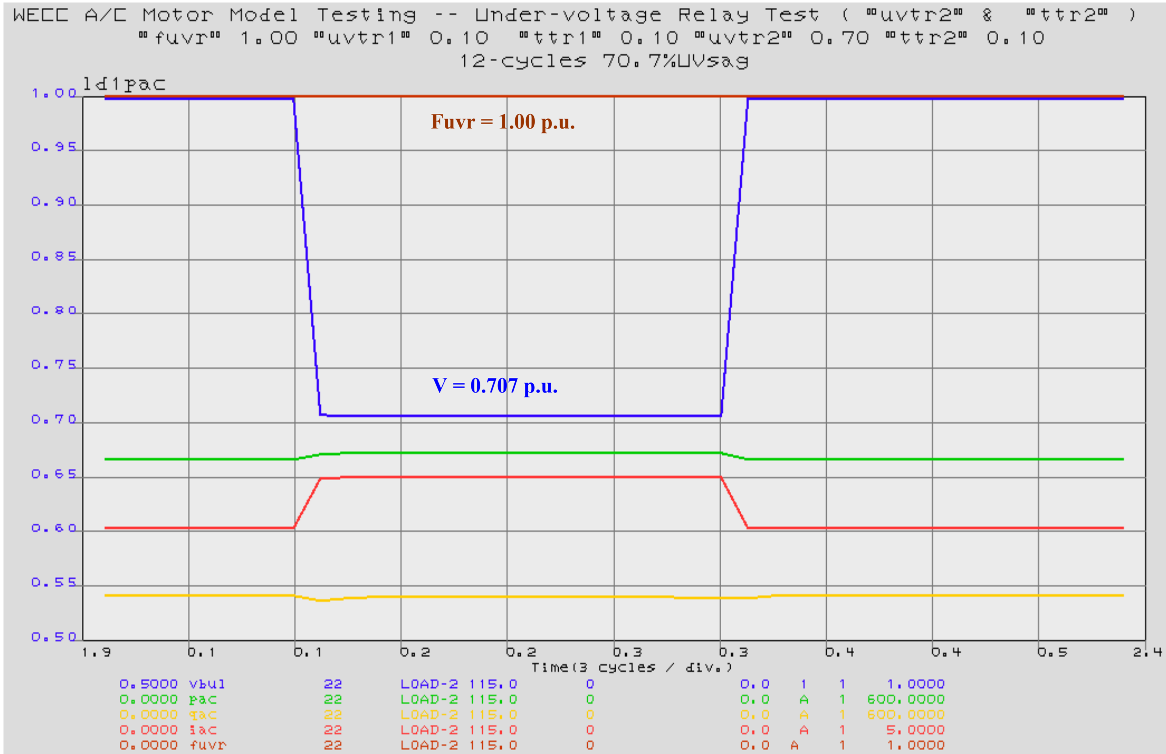

Figure 59. Second UV Relay Tripping Parameters Test (*uvtr*2=0.70 & *ttr2*=0.10)

<u>NOTE</u>: The *UVtr2* and *Ttr2* parameters were set at 70 percent and 6 cycles respectively for a total load shed *"Fuvr"*. The relay did not actuate because the voltage only decreased to 70.6 percent, above *UVtr2* the under-voltage setting.

8.0. LD1PAC MODEL AND A/C TEST RESULTS COMPARISON

The following section is a comparison between the actual A/C tests and the *ld1pac* model test results.

8.1. Ramp Down and Ramp Up Test

BPA and SCE tested A/Cs during ramp-down ramp-up voltage sags. The test consisted of taking the voltage from the full-rated voltage of 240 VAC, ramping it down to 0.10 p.u. (24 VAC) in 15 seconds, and then ramping it back up to full-rated voltage (240 VAC) in 15 seconds. This test was performed to determine how the A/C behaves at various voltages, especially I, P, and Q. The *ld1pac's power contactor* model settings (*Vc1off, Vc2off, Vc1on, and Vc2on*) were set to zero in order to bypass the power contactor's logic. Additionally, the *ld1pac's thermal protection* settings (*Tth, Th1t, and Th2t*) were set extremely high in order to bypass its logic. In the actual A/C test the contactor was bypassed and the thermal protection switch did not operate.

In order to compare the performance of the *ld1pac* model with the actual test, test data from one of the tested units was taken. Figures 60 and 61 show the actual A/C test data and the *ld1pac* simulated data, respectively. It is important to mention that the *ld1pac* model parameters such as rstall, xstall, and PF (r_{STALL} r=0.1235, X_{STALL} =0.114 and pf=0.97) were calculated from the actual A/C test data. The *ld1pac* simulation results are very close to the actual A/C test data as shown in Figures 60 and 61. Notice that the steady state and stalling plots are very close in both figures.

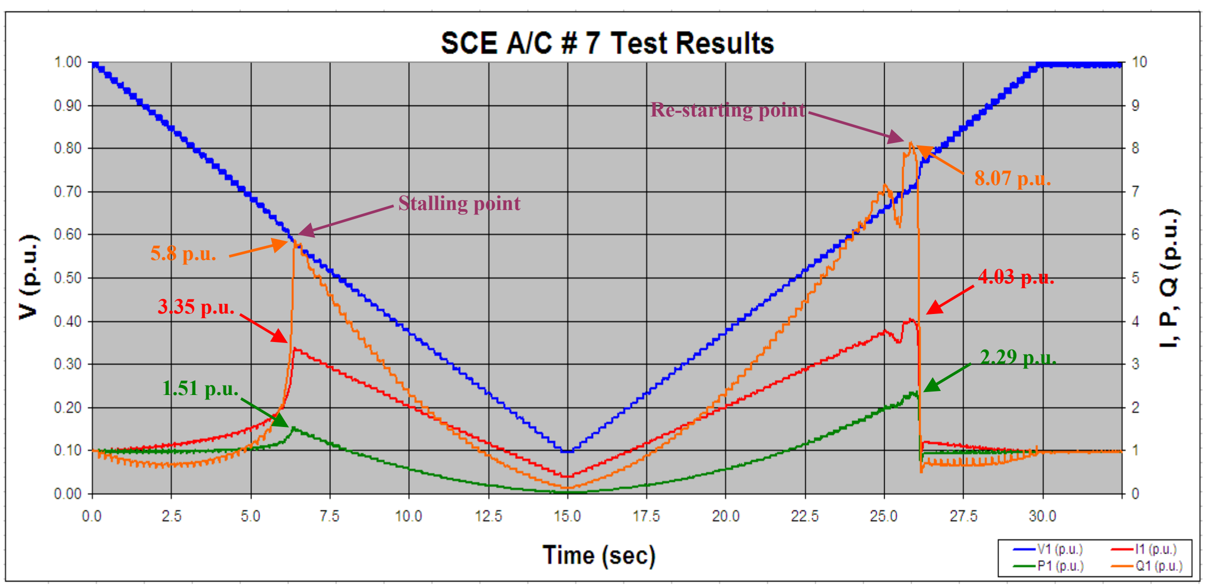

Figure 60. SCE A/C #7 Ramp-Down Ramp-Up Test Results

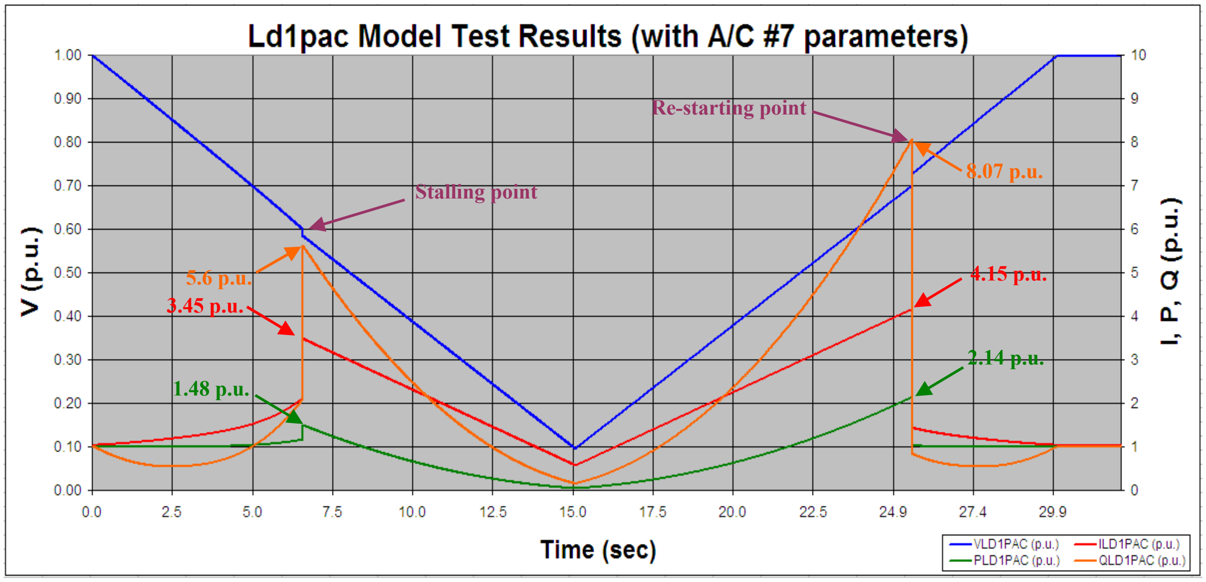

Figure 61. *Ld1pac Ramp-Down Ramp-Up* Test Results (w/ A/C #7 Parameters)

The following simulations were performed to compare with the test results of a 3.5 ton A/C unit tested by BPA at an outdoor temperature of 100 F. Figure 62 shows the parameters used for the following simulations in this section in which the *ld1pac* power contactors were bypassed as in the actual A/C test. Supply voltage is specified in the sag tests, actual motor voltage is lower due to feeder impedance. Actual motor voltage is played back in the simulations.

```
ld1pac    3 "LOAD    "  12.5 "AC" : #9  mva=3.7  "pul" 1.0  "tv" 0.02  "tf" 0.1  /
 "CompPF" 0.95 "Vstall" 0.6  "Rstall" 0.1   "Xstall" 0.1 "Tstall" 0.03  "LFadj" 0.3 /
 "Kp1" 0.0 "Np1" 1.0 "Kq1" 6.0 "Nq1" 2.0 "Kp2" 12.0 "Np2" 3.2 "Kq2" 11.0 "Nq2" 2.5 /
 "Vbrk" 0.86 "Frst" 0.0 "Vrst" 0.9 "Trst" 0.40 "CmpKpf" 1.0 "CmpKqf" -3.3 /
 "Vc1off" 0.01 "Vc2off" 0.01 "Vc1on" 0.01 "Vc2on" 0.01 /
 "Tth" 20 "Th1t" 0.95 "Th2t" 0.95 /
 "fuvr" 0 "uvtr1" 0.7 "ttr1" 0.25 "uvtr2" 0.8 "ttr2" 5
```

Figure 62. *Ld1pac* Parameters

Recorded test voltage and frequency were played back in the dynamic simulations. Then the actual A/C response was compared with the one simulated using the *ld1pac* model. Table 17 provides the standard plot names and colors used in both the simulated and play back plots.

Plot Name	*A/C Test (measured)*	Color		Plot Name	*Ld1pac(simulation)*	Color
a2	kW	*Blue*		pac	kW	Light green
a3	kVAR	*Red*		qac	kVAR	Purple
a4	A	*Dark green*		iac	A	Pink

Table 17 - Plot Tags and Colors

Figure 63 compares the actual test with the simulated results during a ramp-down and ramp-up voltage sag. The comparison between the actual and the simulations test results are very close.

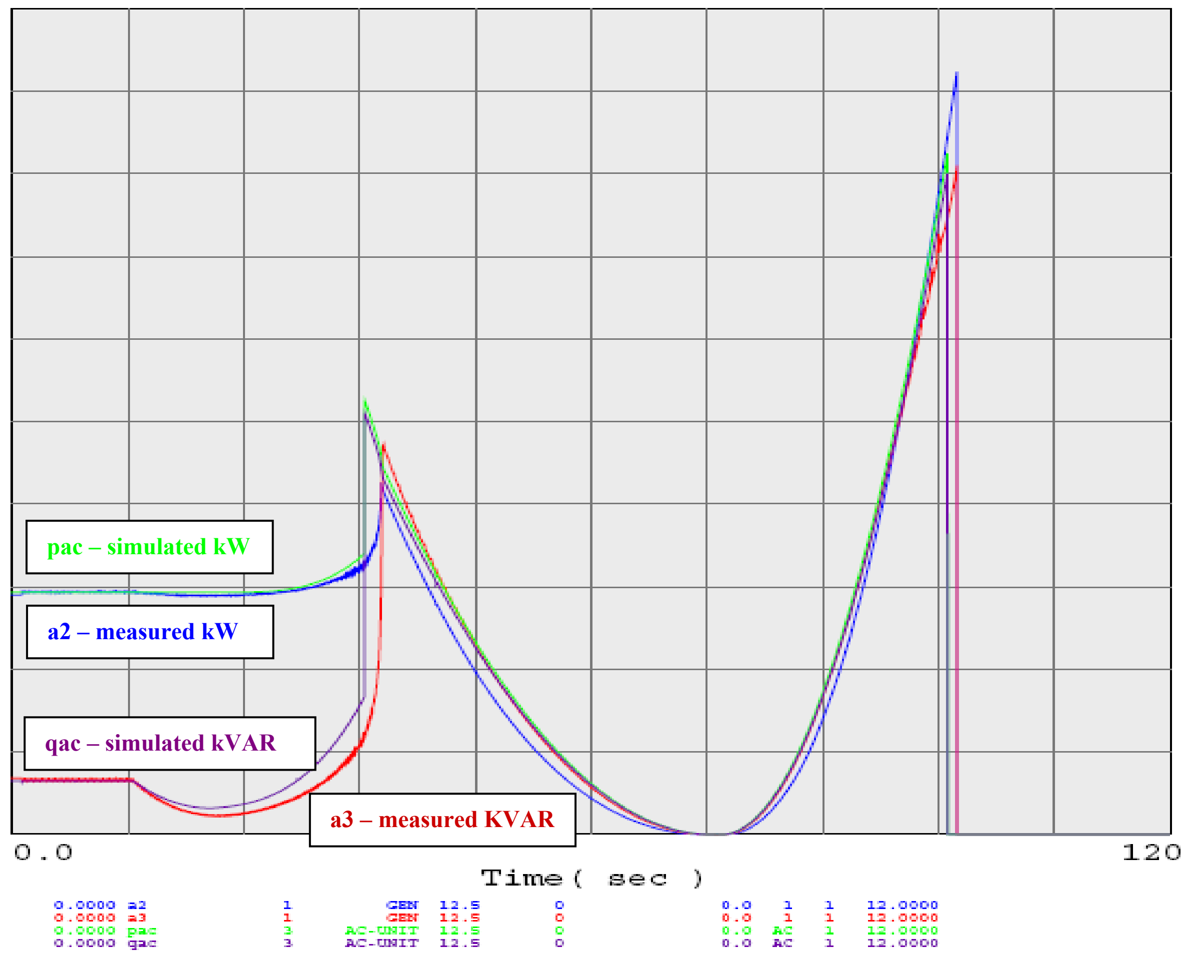

Figure 63. Ramp-Down and Ramp-Up Comparison

8.2. Voltage Oscillations Test

Voltage oscillations are a typical phenomenon when there is either a fast increase/decrease of load or a fast increase/decrease of generation. The *ld1pac* was tested during voltage oscillations where the voltage is oscillates between 1.00 p.u. and 0.95 p.u. at a given frequency. It is imperative to know that the *ld1pac* has no numerical or stability problems under these conditons.

Figure 64 compares the actual (measured) A/C test results with the *ld1pac* simulations at 0.1 Hz voltage oscillation. The measured and simulations results were very similar at 0.25 Hz voltage oscillation. This simulation does not show any stability or numerical problems with the *ld1pac* model.

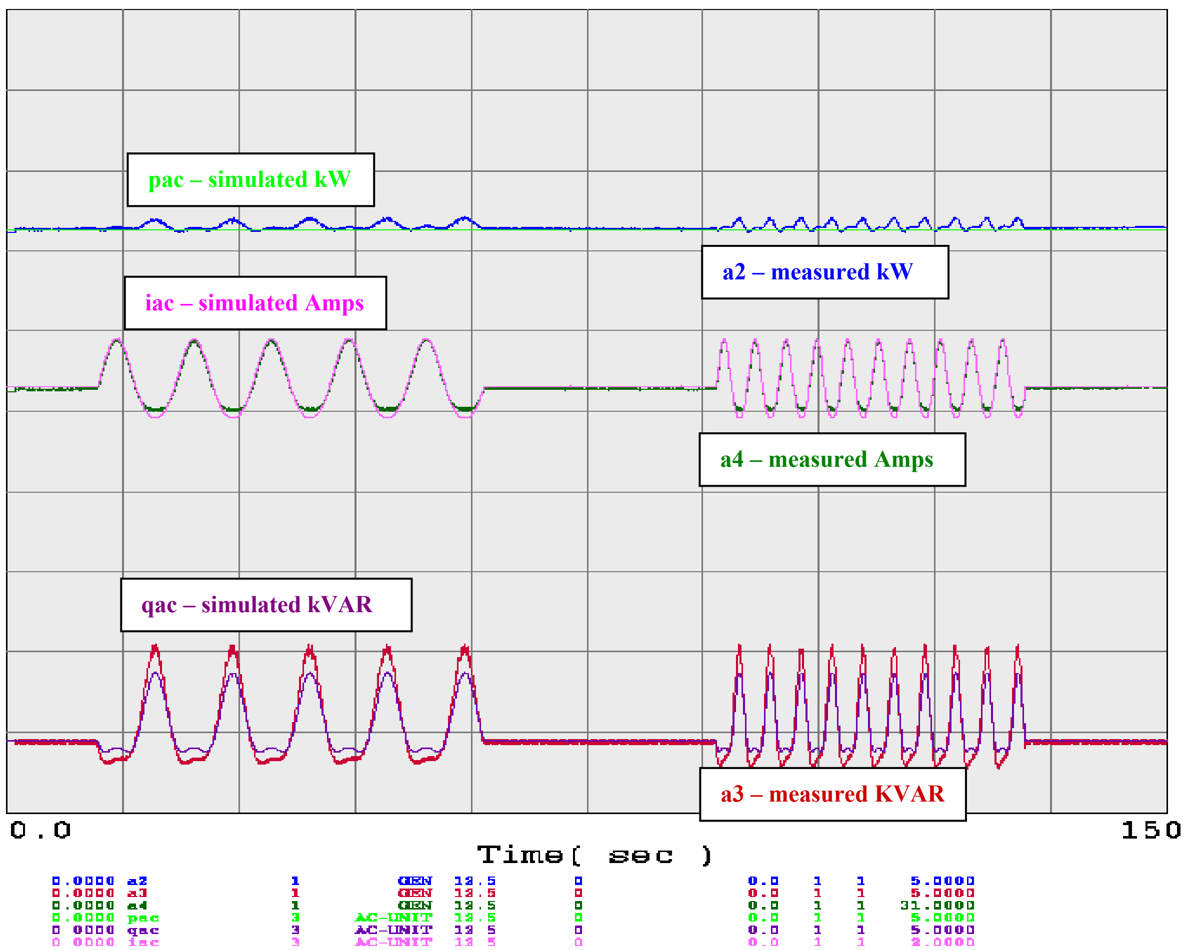

Figure 64. Voltage Oscillation at 0.1 Hz

Figure 65 compares the actual A/C test results with the *ld1pac* simulations at 0.7 Hz. Likewise, at this frequency, the test results are very close to each other and the simulation does not show any stability or numerical problems with the *ld1pac* model.

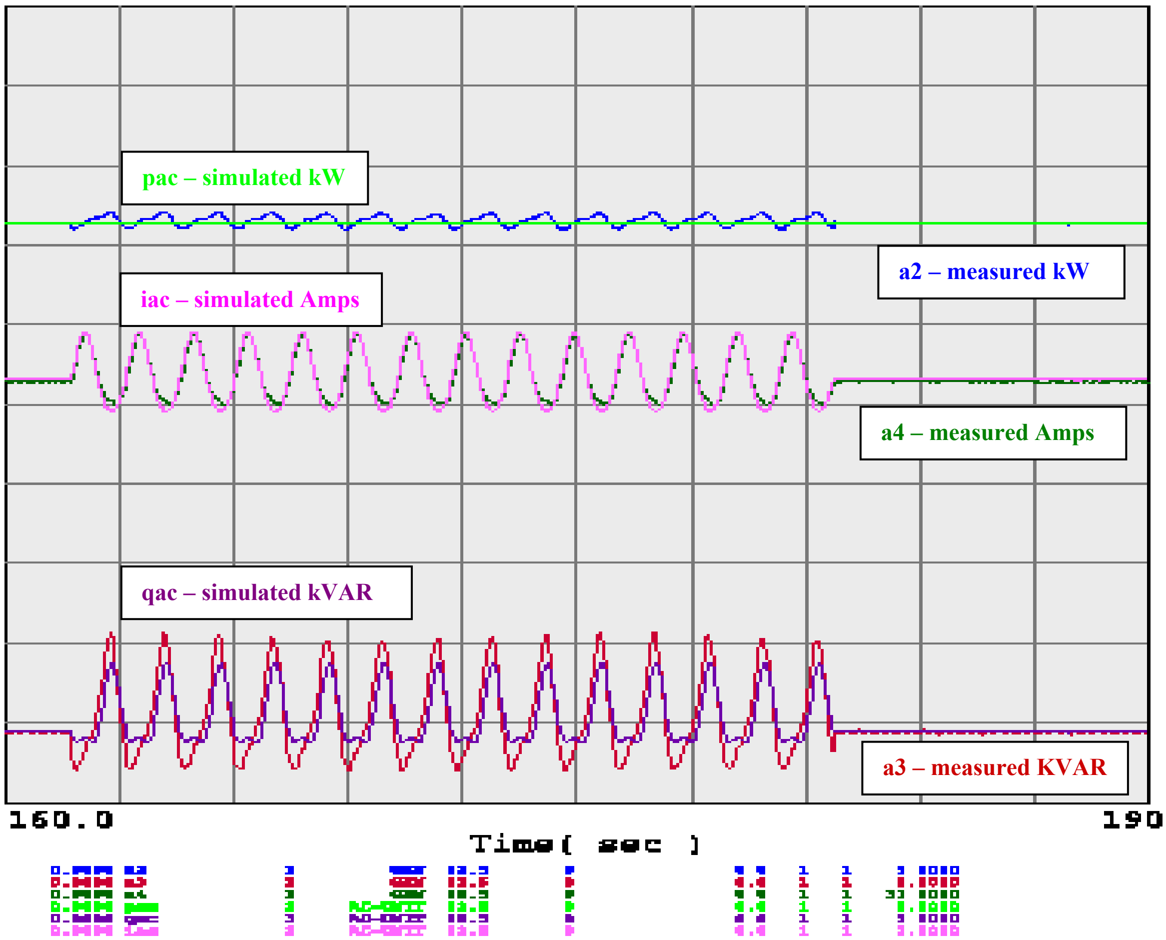

Figure 65. Voltage Oscillation at 0.7 Hz

Figure 66 compares the actual A/C test results with the *ld1pac* simulations at 1.0 Hz. Again, the results are very similar to those at 1.5 Hz and the simulation does not show any stability or numerical problems in the *ld1pac* model.

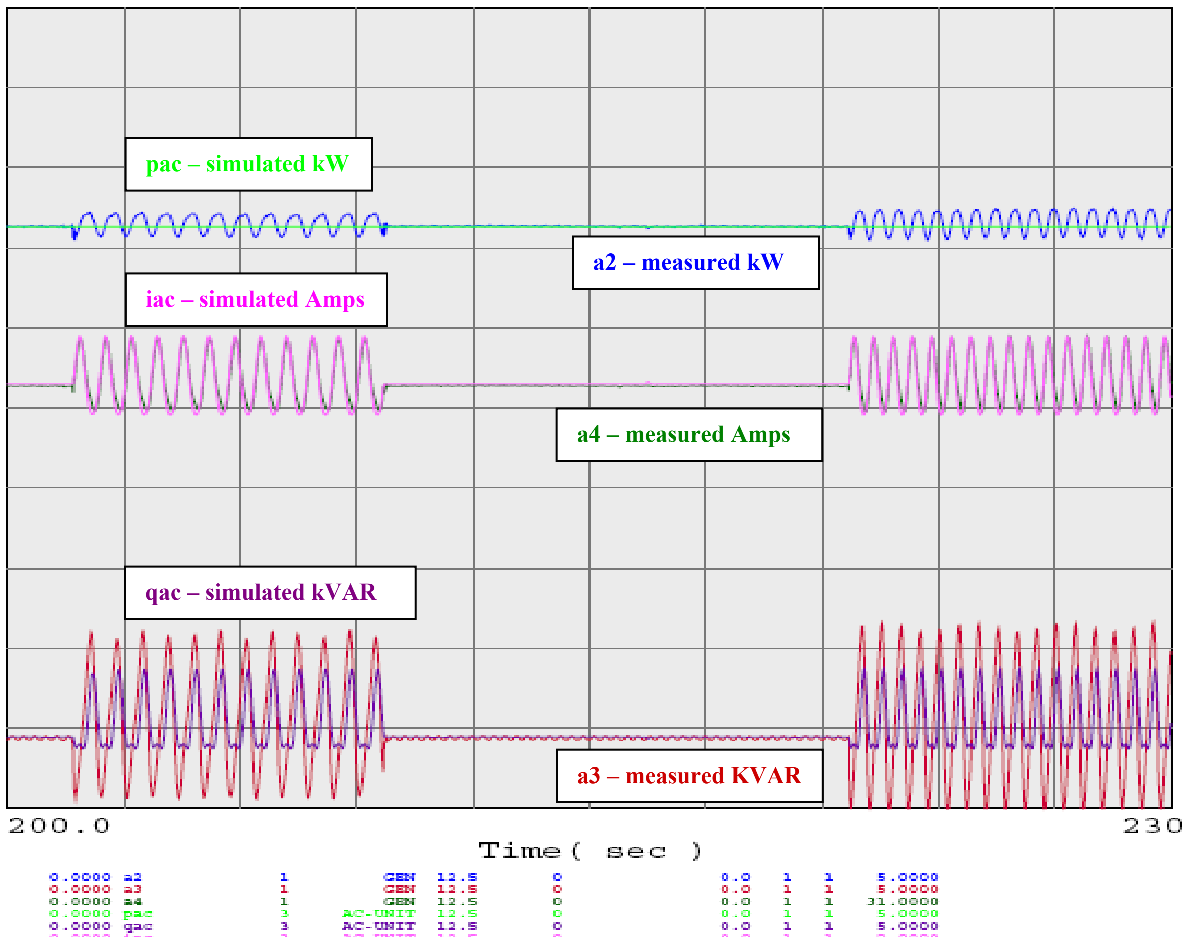

Figure 66. Voltage Oscillation at 1.0 Hz

8.3. Frequency Oscillations Test

Frequency oscillations are also a typical phenomenon when there is either a rapid increase/decrease of load or a rapid increase/decrease of generation, or a disturbance in the sytem. For the next tests, the voltage is kept constant while the frequency is changed to assess the behavior of the model. BPA, EPRI, and SCE tested the A/Cs during frequency oscillations and the *ld1pac* was tested under these same conditions to verify that this model works properly.

Figure 67 shows the test results for a *frequency ramp* test. Both the simulated and the A/C test results are very close and no signs of numerical or stability problems were observed during the simulation.

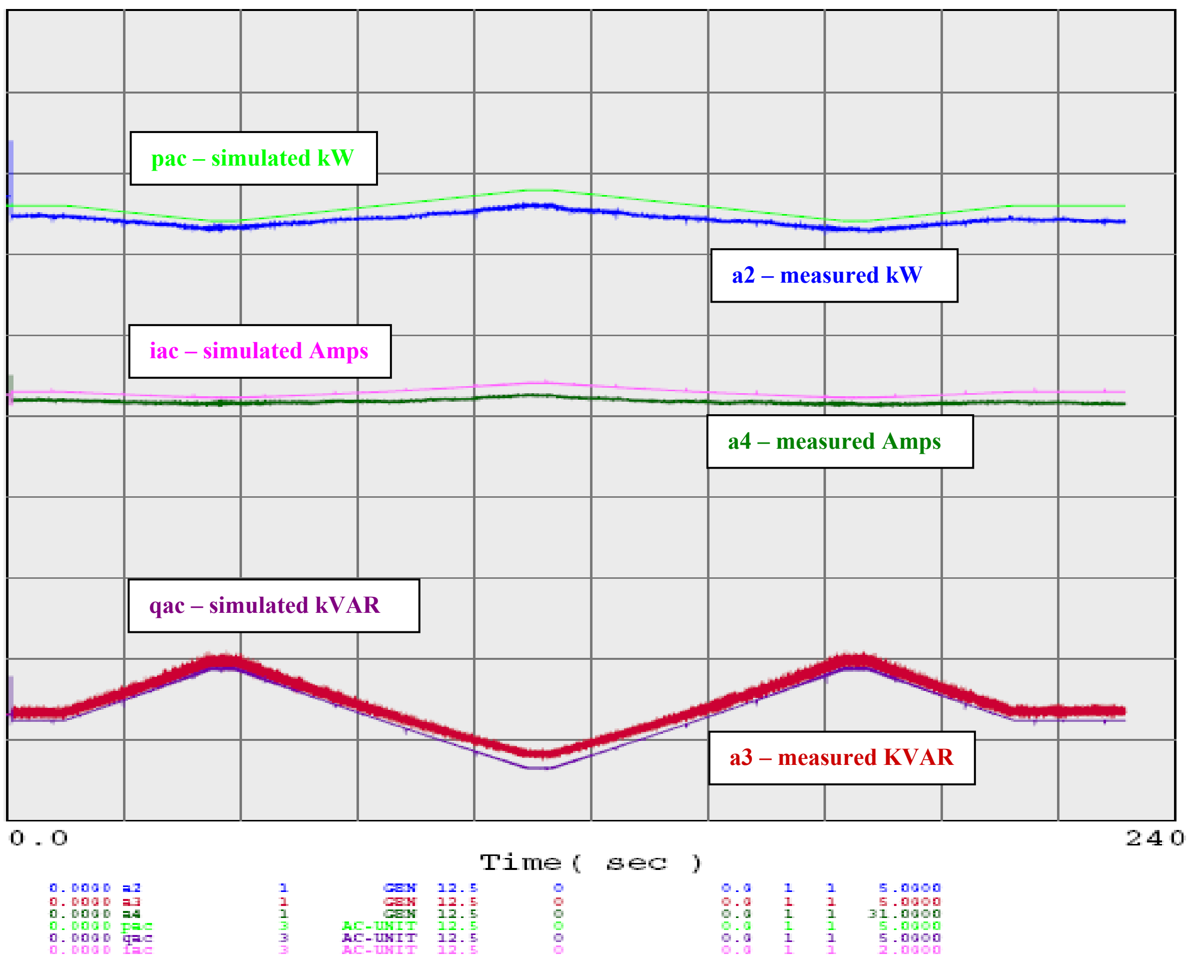

Figure 67. Frequency Ramp Test

Figure 68 shows the test results for a 0.1 Hz frequency oscillation test. The simulated *ld1pac* and the measured A/C test results are very close and no signs of numerical or stability problems were observed during the simulation. Testing for a 0.25 Hz frequency oscillation had similar results.

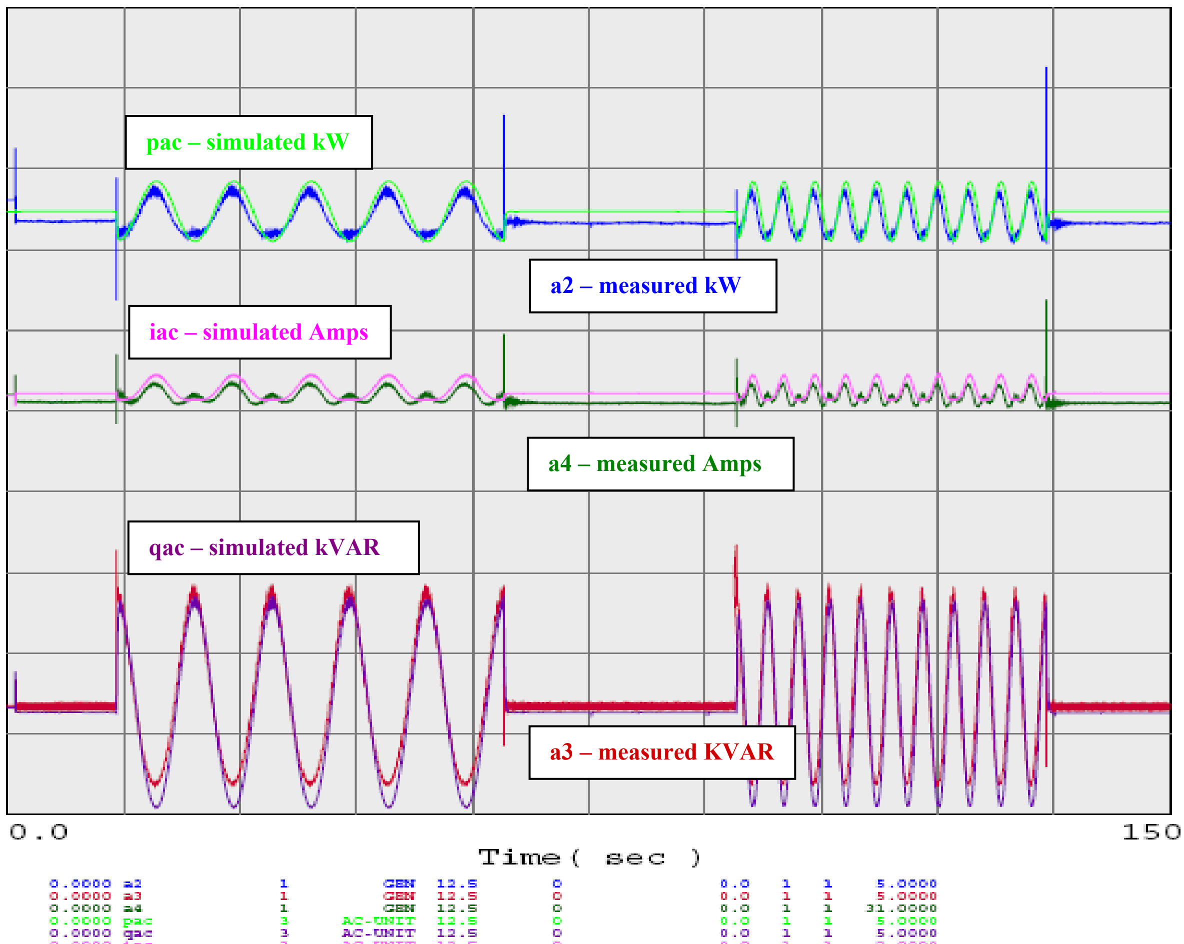

Figure 68. Frequency Oscillation at 0.1 Hz

Figure 69 shows the test results for a 0.7 Hz frequency oscillation. Again, the *ld1pac* and A/C test results are very close and no signs of numerical or stability problems were observed during the simulation.

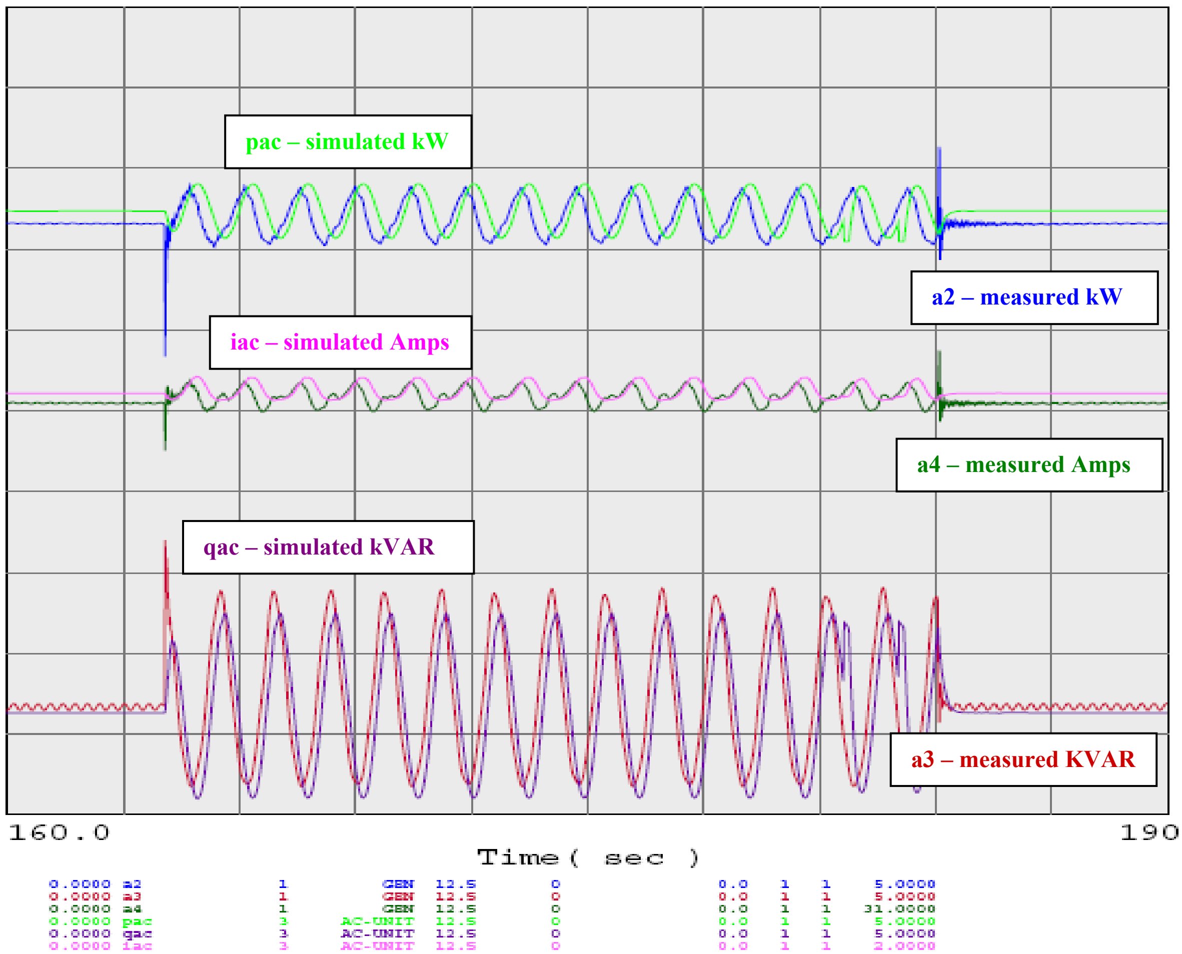

Figure 69. Frequency Oscillation at 0.7 Hz

Figure 70 shows the test results for a 1.0 Hz frequency oscillation. The *ld1pac* and A/C tests again reveal results that are very similar and no signs of numerical or stability problems were observed during the simulation. Testing for a 1.5 Hz frequency oscillation had similar results.

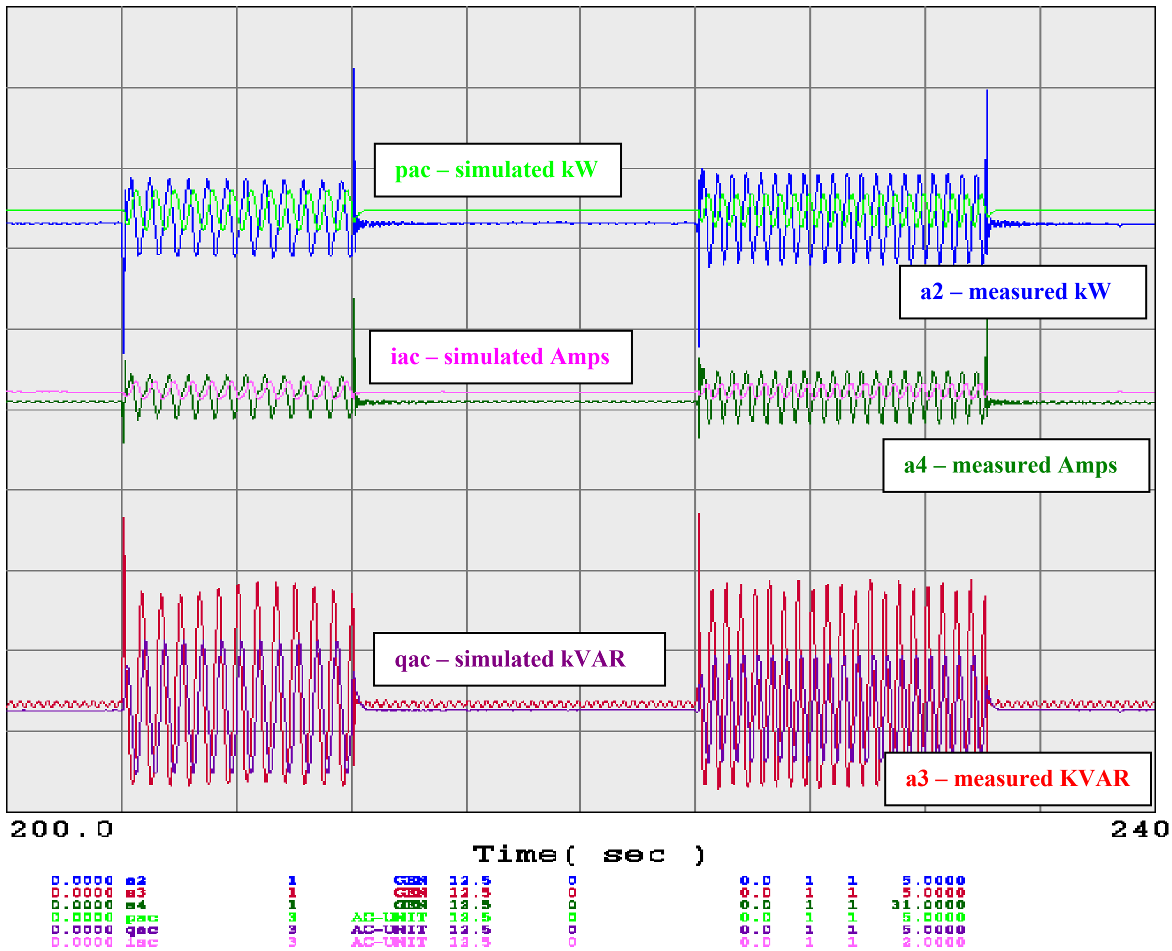

Figure 70. Frequency Oscillation at 1.0 Hz

8.4. Voltage Sag Test

A/C stalling occurs whenever there is a interruption of nominal voltage for as short as three cycles. A/C test results indicate that the majority of A/C units remain stalled until their internal thermal overload protection trips them off and only a small fraction of the A/C units were capable of restarting. BPA, EPRI, and SCE tested the A/Cs during undervoltage transients and sags, as was the *ld1pac* model to make sure that under these conditions, the model works properly.

Figure 71 shows the test results for a 6-cycle fault with a recovery voltage of 70 percent following the fault. The actual A/C test and the *ld1pac* simulation results show that both stall for about 11 seconds when the thermal overload trips off. No signs of numerical or stability problems were observed during the simulation.

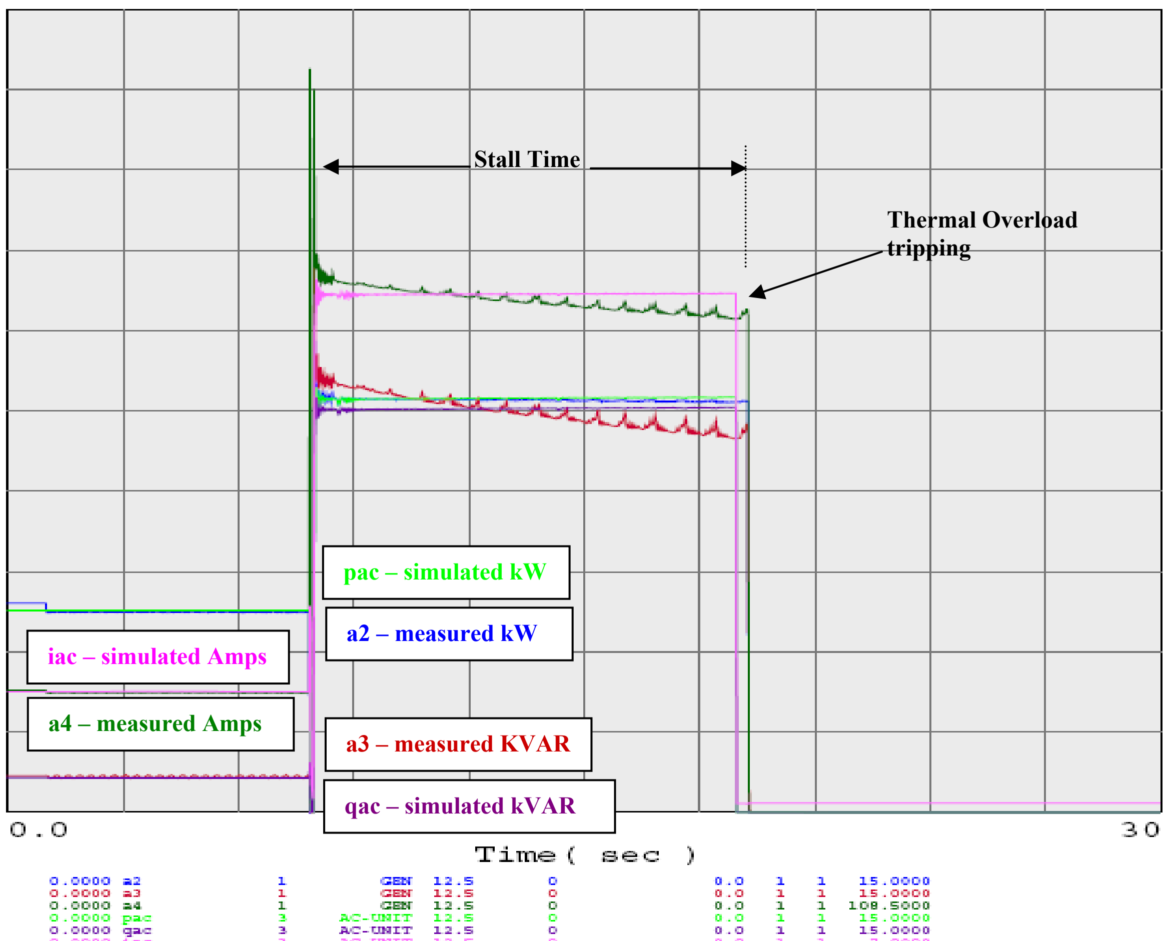

Figure 71. Voltage Sag: from 100% to 0 for 6 cycles with recovery to 70%

Figure 72 shows the test results for a 12-cycle, 62 percent undervoltage transient with a recovery voltage of 80 percent. The actual A/C test and the *ld1pac* simulation results show that both stall and remain stalled after testing is complete. No signs of numerical or stability problems were observed during the simulation.

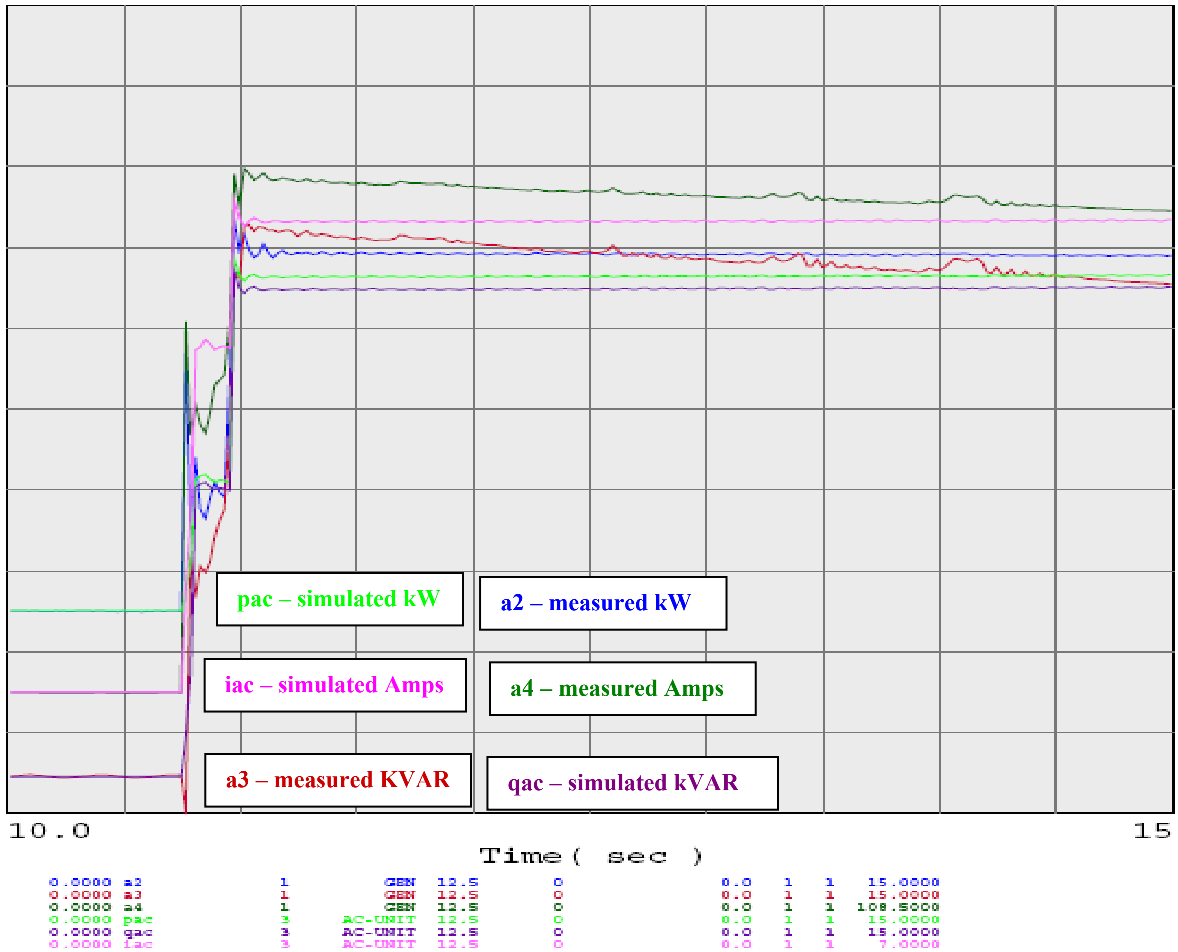

Figure 72. Voltage Sag: from 100% to 62% for 12 cycles with recovery to 80%

Figure 73 shows the test results for a 6-cycle, 60 percent undervoltage transient with a recovery voltage of 80 percent. The actual A/C test and the *ld1pac* simulation results show that both units stall and remain stalled after the testing is complete. No signs of numerical or stability problems were observed during the simulation.

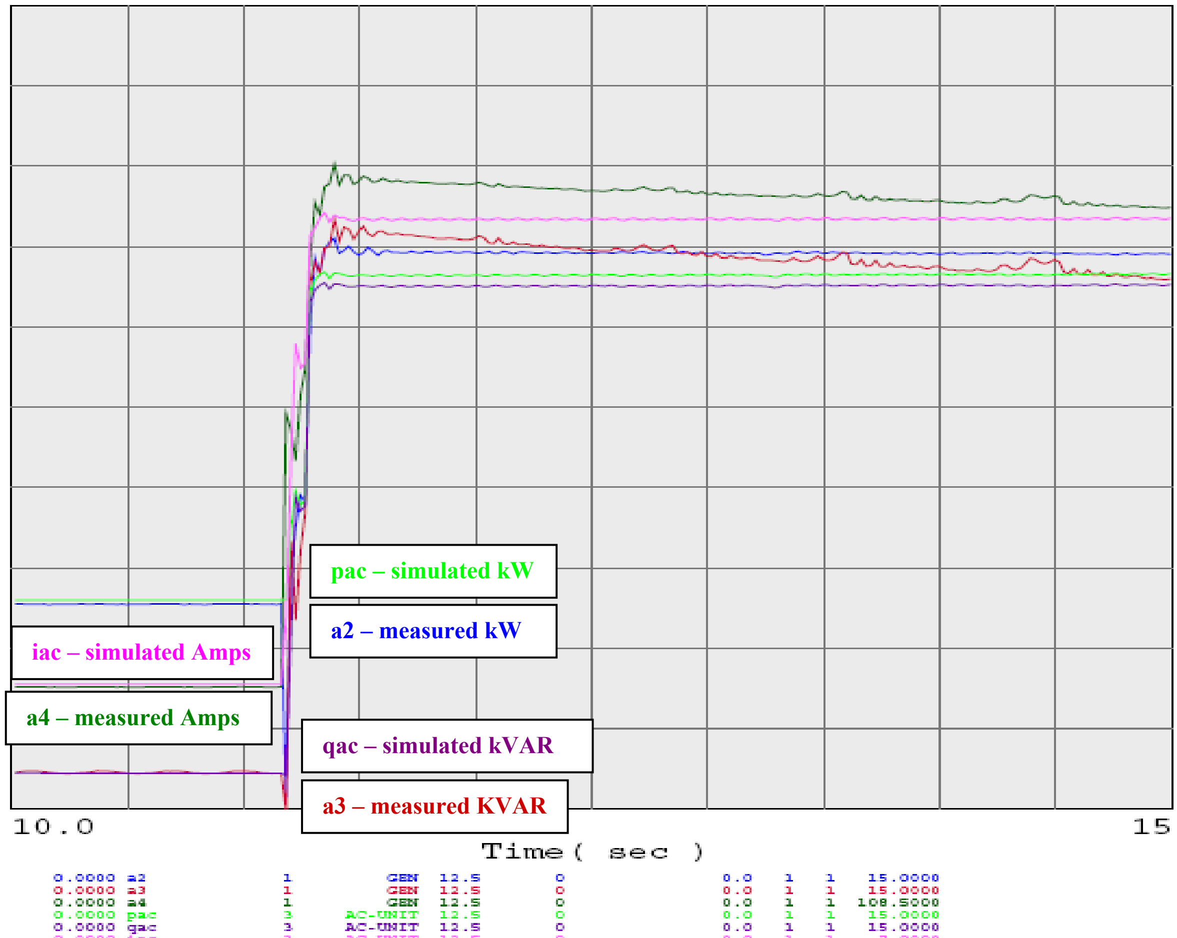

Figure 73. Voltage Sag: from 100% to 60% for 6 cycles with recovery to 80%

Figure 74 shows the test results for a 6-cycle, 60 percent undervoltage transient with a recovery voltage of 90 percent. The *ld1pac* simulation results show that the model stalls and remains stalled. During the measured A/C test the unit restarted. This difference is because for the *ld1pac* model the restart setting was 0 percent; therefore, the load cannot restart. No signs of numerical or stability problems were observed during the simulation.

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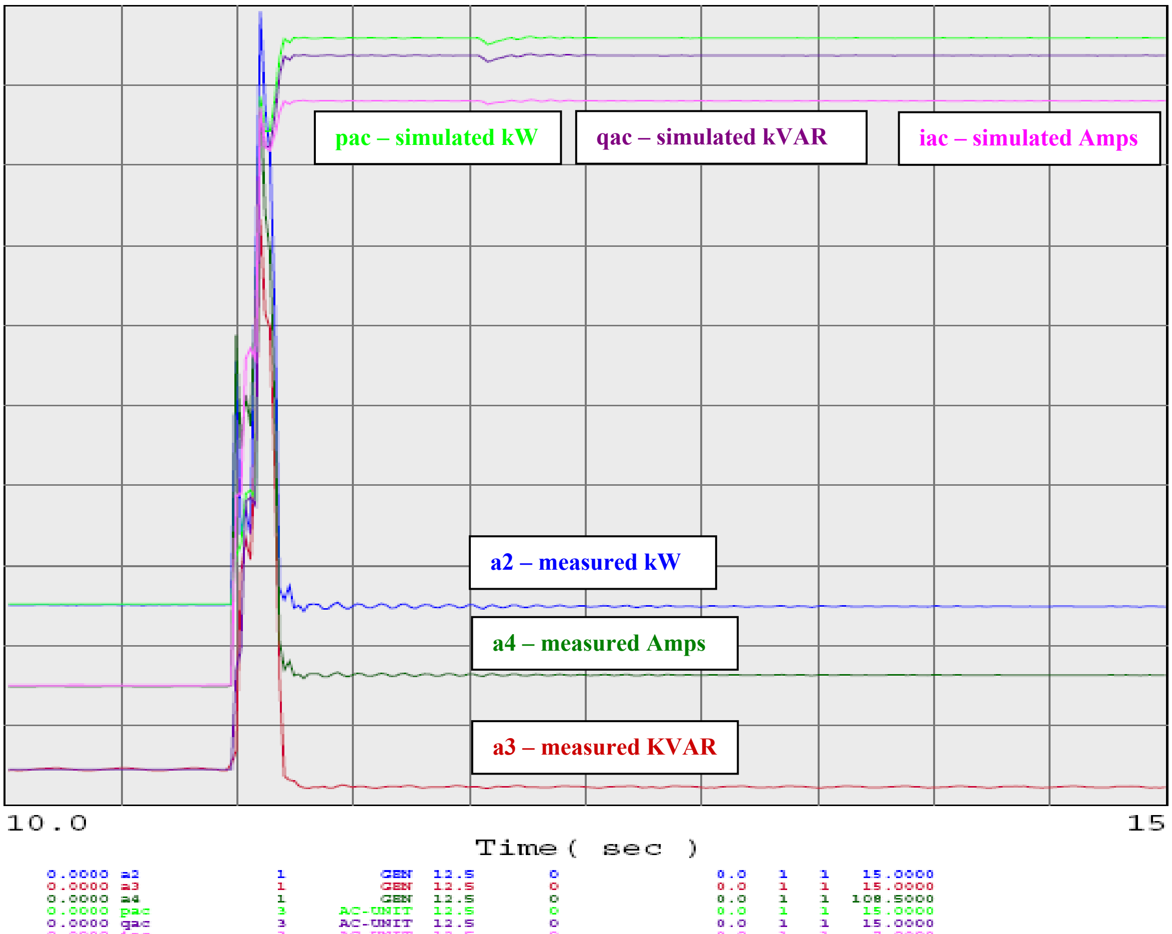


Figure 74. Voltage Sag: from 100% to 60% for 6 cycles with recovery to 90%

9.0. LD1PAC STALLING PARAMETERS

The *ld1pac* model was installed in a small system to assess its response to under-voltage transients during a stall. Six cases were modeled using the *ld1pac* model: 100 MW, 200 MW, 300 MW, 400 MW, 500 MW, and 600 MW, all with a power factor of 0.95. The reactive power for the six cases is calculated using the following formula: $Q = P * \tan(\cos^{-1}(PF))$ resulting in approximately 33, 66, 99, 131, 164, and 197 MVARs. The *ld1pac* model r_{STALL} and x_{STALL} parameters are 0.114 and 0.124 respectively. These two parameters are average values calculated using the SCE A/C test data.

Figure 75, 76, 77, and 78 show the V, I, P, and Q stall parameters. Each figure represents the six different cases (100 MW through 600 MW) listed from top to bottom in the figure's corresponding table and legend.

Table 18 provides the *ld1pac* test results for the six different A/C loads cases in Figure 75. The model test results indicate that I, P, and Q are within the A/C stalling test results. The stalling parameters are calculated using actual A/C data gathered by SCE. Details on the calculation of stall parameters at different stall voltages can be found in Appendix 2.

Case	V_{stall} (p.u.)	Simulation I_{stall} (p.u.)	A/C Test I_{stall} (p.u.)	Simulation P_{stall} (p.u.)	A/C Test P_{stall} (p.u)	Simulation Q_{stall} (p.u.)	A/C Test Q_{stall} (p.u.)
100	1.0	5.8	5.3 ~ 6.3	4.4	4.2 ~ 5.5	12.1	10 ~ 14
200	1.0	5.8	5.3 ~ 6.3	4.3	4.2 ~ 5.5	12.1	10 ~ 14
300	1.0	5.8	5.3 ~ 6.3	4.3	4.2 ~ 5.5	12.0	10 ~ 14
400	1.0	5.8	5.3 ~ 6.3	4.3	4.2 ~ 5.5	12.1	10 ~ 14
500	1.0	5.8	5.3 ~ 6.3	4.3	4.2 ~ 5.5	12.0	10 ~ 14
600	1.0	5.8	5.3 ~ 6.3	4.3	4.2 ~ 5.5	11.9	10 ~ 14

Table 18 - *Ld1pac* Model Test Results

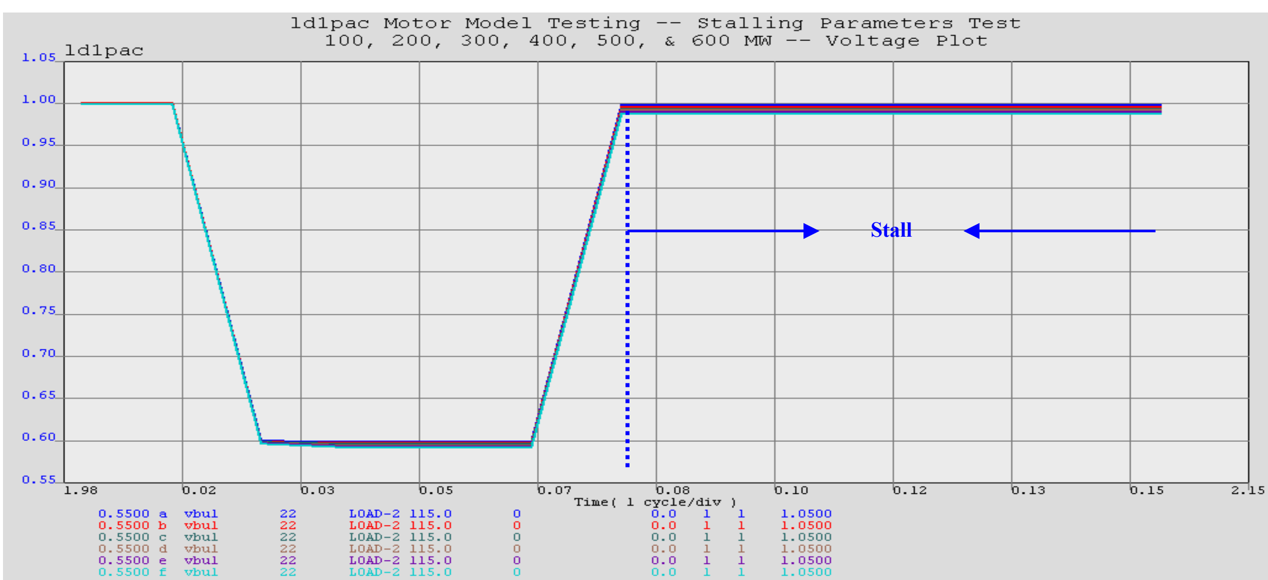


Figure 75. Ld1pac Model Parameters Test (Voltage Plot)

Table 19 provides the *ld1pac* summarized test results for Figure 76.

Case	V_{stall} (p.u.)	*Simulation* I_{stall} (p.u.)	*A/C Test* I_{stall} (p.u.)
100	1.0	5.8	5.3 ~ 6.3
200	1.0	5.8	5.3 ~ 6.3
300	1.0	5.8	5.3 ~ 6.3
400	1.0	5.8	5.3 ~ 6.3
500	1.0	5.8	5.3 ~ 6.3
600	1.0	5.8	5.3 ~ 6.3

Table 19 - *Ld1pac* Stall (I) Test Results

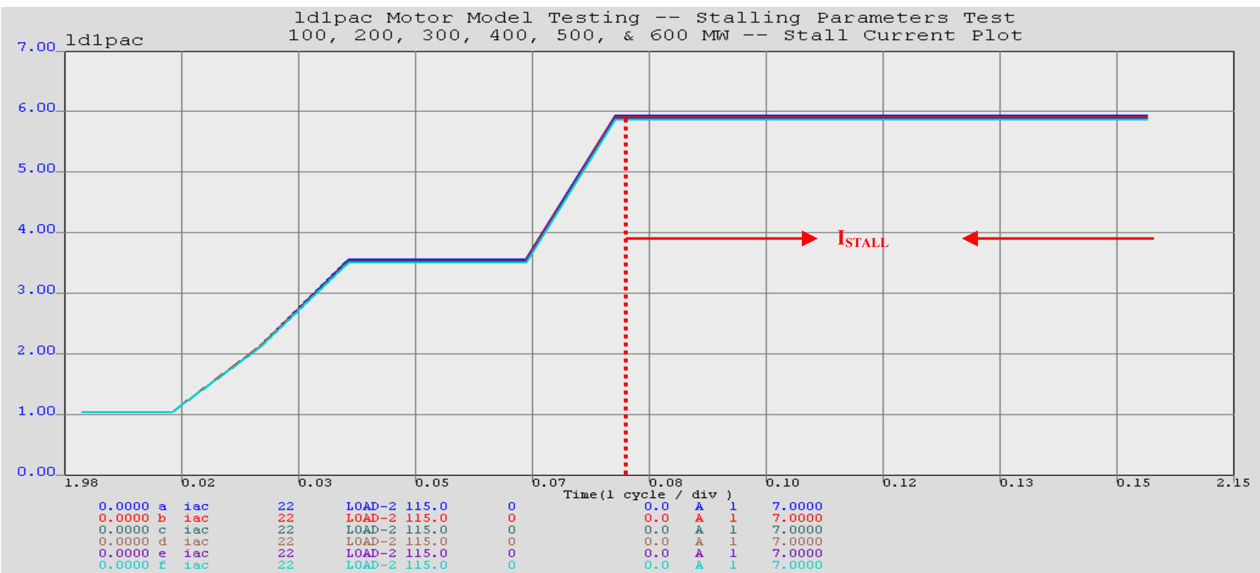


Figure 76. *Ld1pac* Model Parameters Test (Stall Current Plot)

Table 20 provides the *ld1pac* summarized test results for Figure 77.

Case	*Simulation* $P_{steady-state}$ (MW)	*Simulation* P_{stall} (MW)	*Simulation* P_{stall} (p.u.)	*A/C Test* P_{stall} (p.u.)
100	100	435	4.4	4.2 ~ 5.5
200	200	866	4.3	4.2 ~ 5.5
300	300	1294	4.3	4.2 ~ 5.5
400	400	1718	4.3	4.2 ~ 5.5
500	500	2139	4.3	4.2 ~ 5.5
600	600	2556	4.3	4.2 ~ 5.5

Table 20 - *Ld1pac* Stall (P) Test Results

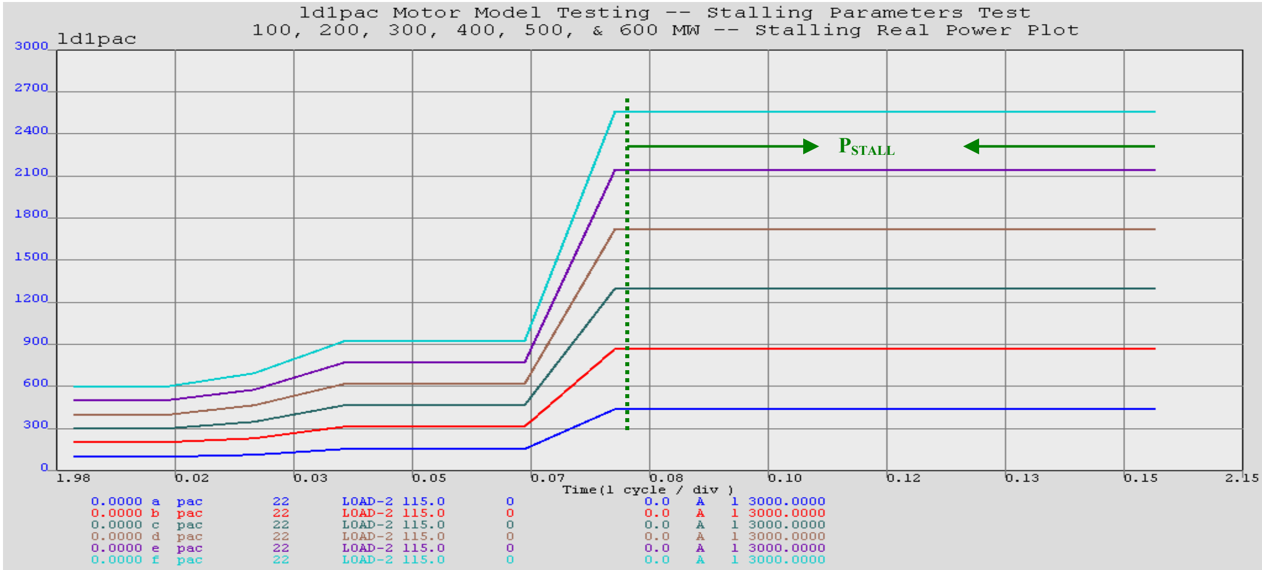


Figure 77. *Ld1pac* Model Parameters Test (Stall Real Power Plot)

Table 21 provides the *ld1pac* summarized test results for Figure 78.

Case	*Simulation* $Q_{steady\text{-}state}$ (MW)	*Simulation* Q_{stall} (MW)	*Simulation* Q_{stall} (p.u.)	*A/C Test* Q_{stall} (p.u.)
100	33	400	12.1	10 ~ 14
200	66	796	12.1	10 ~ 14
300	99	1190	12.0	10 ~ 14
400	131	1580	12.1	10 ~ 14
500	164	1966	12.0	10 ~ 14
600	197	2350	11.9	10 ~ 14

Table 21 - *Ld1pac* Stall (Q) Test Results

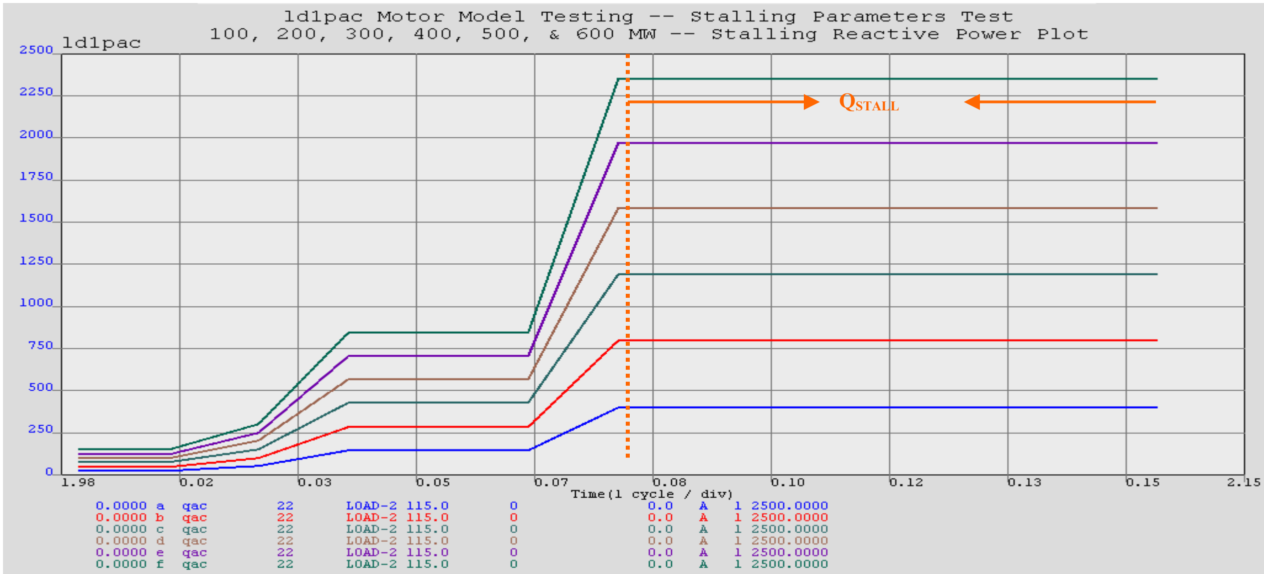


Figure 78. *Ld1pac* Model Parameters Test (Stall Reactive Power Plot)

10.0. LD1PAC MODEL STABILITY

It is important to test the stability of the *ld1pac* model, especially when there is a high penetration of A/C load. For this test, a new system case was created and is shown in Figure 79. This system case has its load in a 12 kV bus, approximating the place of the load for a typical 240 VAC residential voltage. This system has four loads that are 10 percent motor-w (M1 and M2) of which half are tripped off after three cycles of fault initialization. Additionally it has 10 percent ZIP (ZP) load and 80 percent A/C load (AC). The high A/C load penetration provides the opportunity to test this model under these extreme high A/C load composition conditions.

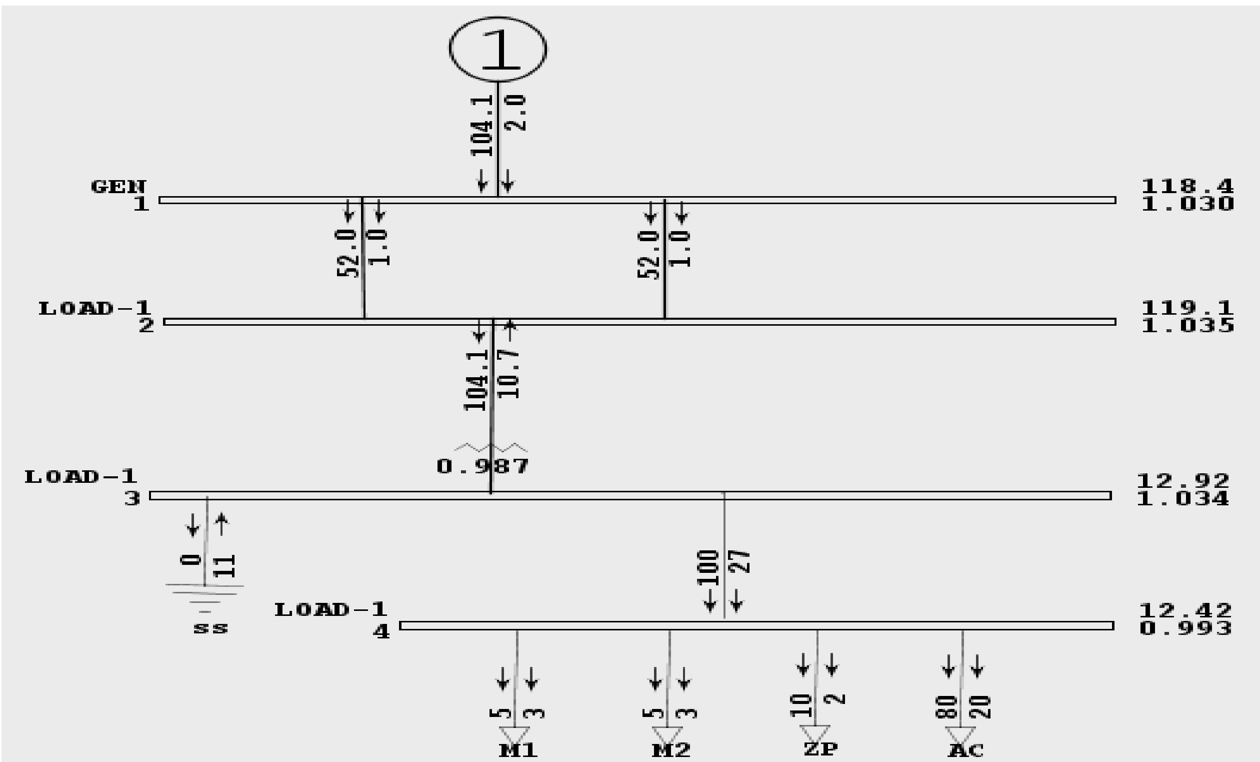


Figure 79. System Case Diagram

Figure 80 shows the test results when a 6-cycle fault is applied to the load bus (4). This simulation shows no signs of numerical instability or oscillations. The model goes into stall condition after the fault is applied; then the thermal protection switch starts disconnecting the load gradually.

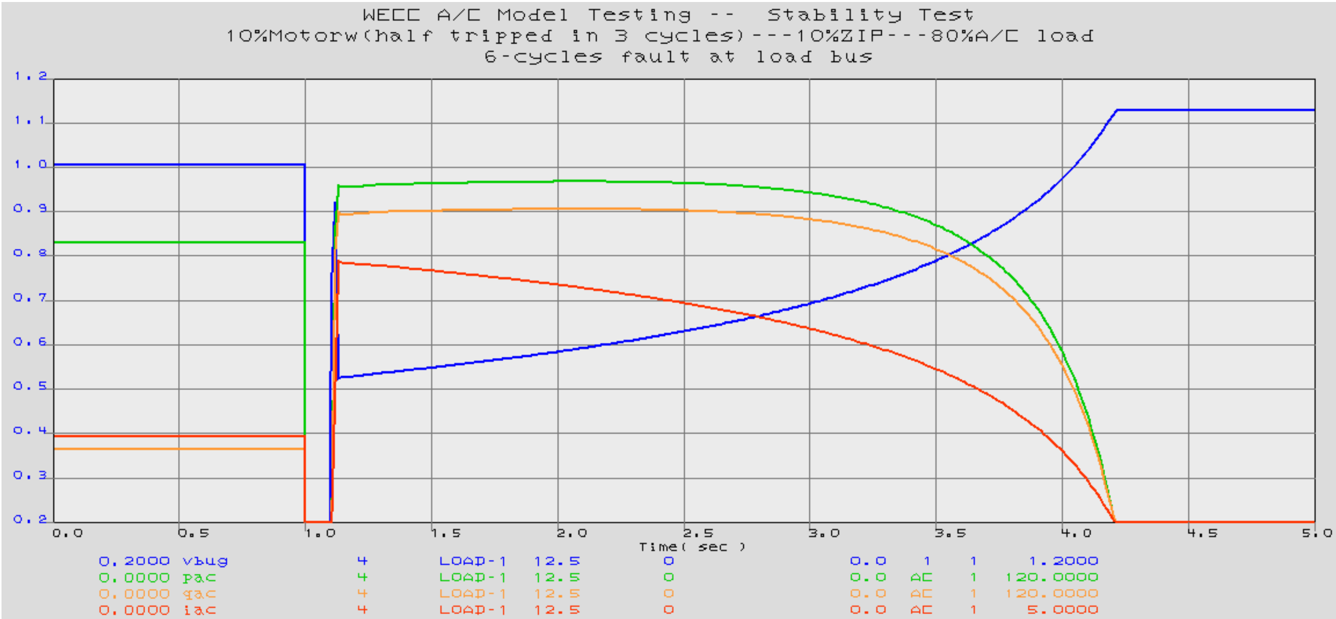


Figure 80. 6-Cycles Fault in the Load Bus

Figure 81 shows the test results when a 30-cycle fault is applied to the load bus (4). This simulation shows no signs of numerical instability or oscillations except for a minor slip in voltage immediately following the fault. Once the fault is applied the model goes into a stall condition and the thermal protection switch starts disconnecting the load gradually.

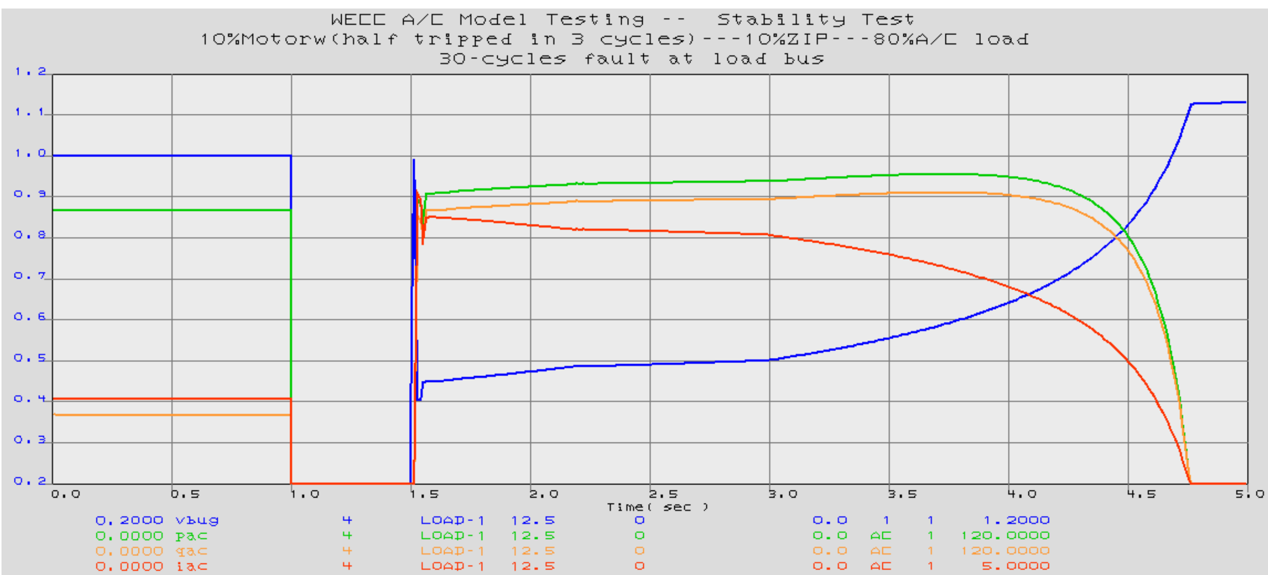


Figure 81. 30-Cycles Fault in the Load Bus

Figure 82 shows the test results when a 6-cycle fault is applied to one of the 115 kV lines located between Busses 1 and 2 and then the line is turned off. This simulation shows no signs of numerical instability or oscillations. The model goes into a stall condition after the fault is applied; then thermal protection switch starts disconnecting the load gradually. The load bus voltage is lower in this case because of the removal of the line. This low voltage prolongs the thermal protection switch action removing the A/C load from the system. The overvoltage is due to the removal of 85 percent of the load and the shunt capacitors still in the circuit.

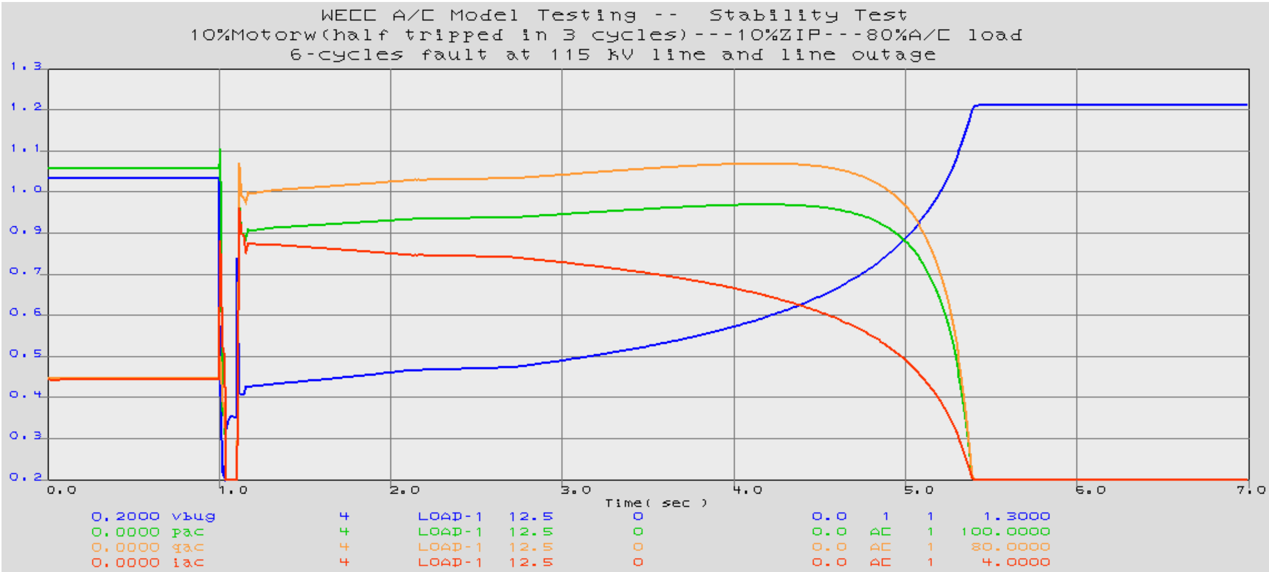


Figure 82. 6-Cycles Fault at Line and Line Clearance

11.0. LD1PAC MODEL VALIDATION

Sensitivity studies were performed using General Electric's Positive Sequence Load Flow (**PSLF**) software to validate the *ld1pac* model during an actual slow voltage recovery (SVR) event recorded by a phasor measurement unit (PMU). It concluded that the following load composition at the 115 kV level provides the best match to the actual SVR event:

a) Single-phase A/C load at the transmission level $P_{ac}\% = 25\%$

b) Three-phase induction motor (tripping load) $P_{motorw}\% = 20\%$

c) Static load $P_{ZIP}\% = 55\%$

Among the static load, P load is composed of only constant impedance load Z_P, and Q load is composed of only constant power load P_Q.

The A/C percentage at 12 kV equivalent case is higher than that at 115 kV equivalent case This is because the A/C terminal voltage in the 12 kV equivalent case is lower than the 115 kV equivalent case due to the voltage drop on the equivalent distribution transformer bank and feeder requiring a higher A/C percentage in the 12 kV equivalent case to achieve the same power effect as in the 115 kV equivalent case. Figure 83 compares the PSLF simulation to the PMU at 500 kV.

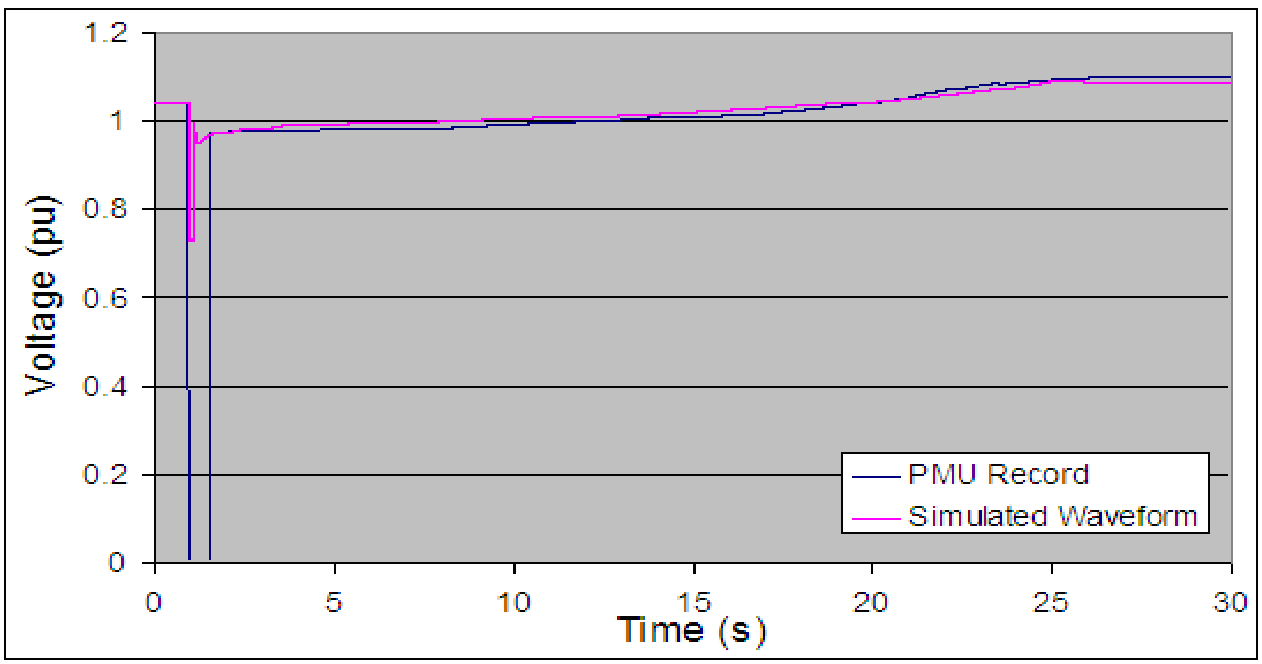


Figure 83. PSLF Simulation and PMU Comparison at 500 kV

APPENDIX 1. ld1pac Model Description

Model Name:	**ld1pac**
Description	Performance-based model of single-phase air conditioner load
Prerequisites:	Load present in load flow working case as an ordinary load with non-zero constant-P component
Inputs:	
Invocation:	ld1pac [<n>] {<name> <kv>} <id> : [n] [mva=<value>]
Parameters:	

	EPCL Variable	*Default Data*	*Description*
	Pul	1.0	Fraction of constant-power load to be represented by this model (between 1.0 and 0.0)
	Tv	0.02	Voltage input time constant, sec.
	Tf	0.05	Frequency input time constant, sec.
	CompPF	0.97	Compressor power factor
	Vstall	0.70	Compressor stall threshold voltage p.u.
	Rstall	0.124	Compressor stall resistance, p.u.
	Xstall	0.114	Compressor stall reactance, p.u.
	Tstall	0.033	Stall time, sec.
	LFadj	0.30	Vstall adjustment proportional to loading factor
	Kp1	0.0	Real power coefficient for running state 1, p.u.P/p.u.V
	Np1	1.00	Real power exponent for running state 1
	Kq1	6.00	Reactive power coefficient for running state 1, p.u.Q/p.u.V
	Nq1	2.00	Reactive power exponent for running state 1
	Kp2	12.0	Real power coefficient for running state 2, p.u.P/p.u.V
	Np2	3.20	Real power exponent for running state 2
	Kq2	11.0	Reactive power coefficient for running state 2, p.u.Q/p.u.V
	Nq2	2.50	Reactive power exponent for running state 2
	Vbrk	0.86	Compressor motor breakdown voltage, p.u.
	Frst	0.0	Fraction of motors capable of restarting
	Vrst	0.90	Voltage at which motors can restart, p.u.
	Trst	0.40	Restarting time delay, sec.
	CmpKpf	1.0	Real power frequency sensitivity, p.u.P/p.u.f
	CmpKqf	-3.3	Reactive power frequency sensitivity, p.u.Q/p.u.f
	Vc1off	0.45	Voltage 1 at which contactors disconnect (open) the load gradually, p.u.
	Vc2off	0.35	Voltage 2 at which contactors disconnect (open) all the remaining load, p.u.
	Vc1on	0.50	Voltage 1 at which contactors re-connect (close) the load gradually, p.u.
	Vc2on	0.40	Voltage 2 at which contactors re-connect (close) all the remaining load, p.u.
	Tth	10.0	Compressor motor heating time constant, sec.
	Th1t	1.3	Temperature at which compressor motors begin tripping, p.u.
	Th12	4.3	Temperature at which all motors are tripped, p.u.
	Fuvr	0.0	Fraction of compressor motors with undervoltage relays
	UVtr1	0.80	First undervoltage pickup level, p.u.
	Ttr1	0.20	First definite time for U/V trip, sec.
	Uvtr2	0.90	Second undervoltage pickup level, p.u.
	Ttr2	5.0	Second definite time for U/V trip, sec.

Notes:

a) This model is used to represent a fraction of an ordinary load or a *single-phase air conditioner* load. It allows load treated as an ordinary constant power in load flow work to be represented by an A/C model in a dynamic simulation. The intent of this model is to represent the aggregations of many air conditioners dispersed throughout a load on a high-voltage bus.

b) **Ld1pac** treats a fraction of the constant power part of a load as an equivalent air conditioner load. When the INIT command is executed, **ld1pac**, moves a fraction (**Pul)** of the load from **load.p** to **load.pm** where:

load.pm = ld1pac.pul * load.p
load.p = load.p - load.pm

The reactive power demand for the air conditioner compressor motor is calculated as a function of voltage at the load bus and is stored in **load.qm**. This reactive power demand can be less than or greater than the constant Q component of the load. If the motor's reactive demand is greater than the constant Q component of the load, **ld1pac** places a capacitor at the terminals of the motor so the total Q equals the constant Q reactive load and **load.q** is set to zero. If the compressor motor's Q demand is less than the constant Q load, the motor's Q is subtracted from **load.q**. The remaining **load.q** is modeled by whatever other load model (**alwscc)** applies to that bus.

c) **Ld1pac** can be used with static load models such as **alwscc;** however, the order in which the models are called will affect the amount of load represented as an air conditioner. **Ld1pac** treats a fraction of the constant power load as motor. If a static load model is called before **ld1pac**, **ld1pac** will work with only that part of the load still at constant power. If **ld1pac** is called before the static load model, the static load model will work with that portion of load not represented as a motor.

d) Tripping the load by setting **load.st** to zero removes the entire load from the system including the **ld1pac** component and the capacitor. A load that includes an **ld1pac** component may not be reconnected to the system once it has been tripped.

e) Per unit parameters are on the load's MVA base specified in the .dyd file. This value is specified using **"mva=<value>"** following the colon and reporting level. If this is not specified, the MVA base is set to **load.mbase** from the load flow data. If **load.mbase** is zero, the motor MVA base and **load.mbase** are set to **load.pm.**

f) If the **"mva=<value>"** is a **negative** value, its absolute value is interpreted as a **loading factor**. The MVA base is calculated as the initial electrical power consumption of the motor divided by the absolute value of this loading factor. This value should typically be less than or equal to 1. If **mva=0** is entered, the loading factor defaults to 1.0.

g) Note: the output channels for power and reactive power variables use **load conventions**.

h) The "fix bad data" option does the following:
1). If not zero, set **Tv, Tf**, and **Tth** to a minimum of 4*delt
2). Set **Frst** to a minimum of 0

3). Set CompPF to a minimum of 0.01

i) Once the load stalls, it will remain stalled until the thermal protection trips it or it will restart if a restarting portion is allowed.

j) The load tripped by thermal protection means will not reconnect.

k) Load tripped by the contactor will reconnect and then go into stall condition.

l) The model has three running states:

1). **Running State 1** is when the model is running above the compressor motor's breakdown voltage V_{brk}.

- $V_t > V_{brk}$
- $p_{run} = K_{p1} \left|(V_t - V_{brk})^{Np1}\right| + [1] - K_{p1} \left|(1 - V_{brk})^{Np1}\right|$
- $q_{run} = K_{q1} \left|(V_t - V_{brk})^{Nq1}\right| + [\sqrt{(1-pf^2)} \div pf] - K_{q1} \left|(1 - V_{brk})^{Nq1}\right|$

2). **Running State 2** is when the model is running at a lower voltage than the breakdown voltage V_{brk} but above the stalling voltage V_{stall}

- $V_{brk} > V_t > V_{stall}$
- $p_{run} = K_{p2} \left|(V_t - V_{brk})^{Np2}\right| + [1] - K_{p2} \left|(1 - V_{brk})^{Np2}\right|$
- $q_{run} = K_{q2} \left|(V_t - V_{brk})^{Nq2}\right| + [\sqrt{(1-pf^2)} \div pf] - K_{q2} \left|(1 - V_{brk})^{Nq2}\right|$

3). **Stalling State** is when the model is running at a lower voltage than the stalling voltage and above the contactor dropout voltage:

- $V_{stall} > V_t$
- $p_{run} = R_{stall} * (I_{stall})^2$
  $= (R_{stall}) * [(V_t)^2 \div (Z_{stall})^2]$
  $= (R_{stall}) * [(V_t)^2 \div (R_{stall})^2 + (X_{stall})^2]$
- $q_{run} = X_{stall} * (I_{stall})^2$
  $= (X_{stall}) * [(V_t)^2 \div (Z_{stall})^2]$

$$= (X_{stall})^* \left[(V_t)^2 \div (R_{stall})^2 + (X_{stall})^2 \right]$$

The **ld1pac** model is represented as an exponential function of voltage in the running state and as a constant impedance in the stalling state.

m) The model has the capability to restart. The restarting load will not be able to stall.

n) The model has the ability to model under-voltage protection on a fraction of the load.

o) The model will not stall for transients shorter than the stall time **(Tstall)**.

Output Channels:

	Record Level	Name	Description
	1	vt	Terminal voltage, p.u.
	1	freq	Frequency, p.u.
	1	pac	A/C real power, MW
	1	qac	A/C reactive power, MVAR (includes capacitor, if any)
	1	iac	A/C current, p.u. (does not include capacitor, if any)
	2	fuvr	Fraction of motors tripped by undervoltage relay p.u.
	2	fcon	Fraction of motors tripped by contactor p.u.
	2	icom	Motor electrical torque, p.u.
	99	tmpA	Temperature of motor A, p.u. of rated
	99	fthA	Fraction of A motor tripped by termal protection
	99	tmpB	Temperature of motor B, p.u. of rated
	99	fthA	Fraction of B motor tripped by termal protection
	99	uvrA	First U/V relay time after pick-up, sec.
	99	uvrB	Second U/V relay time after pick-up, sec.

Block Diagram/Equations:

APPENDIX 2. Calculated A/C Stall Characteristics

Appendix 2 – Table 1 shows the steady-state (ss) and stall-state air conditioner test data for 9 of the 10 A/C units tested by SCE. The power consumed by the air conditioners is a function of temperature at steady state. At stall condition, the power wasted by the air conditioners is a function of voltage.

SCE AC #	Steady State @ 100F					Stall @ 100F				
	V_{ss}	I_{ss}	P_{ss}	S_{ss}	Q_{ss}	V_{stall}	I_{stall}	P_{stall}	S_{stall}	Q_{stall}
AC #1	240	16	3550	3768	1264	154	59	6402	9130	6510
AC #2	237	14	3283	3393	854	137	51	5066	6933	4733
AC #3	240	17	3953	4153	1275	145	60	6318	8721	6013
AC #4	238	15	3495	3562	687	229	82	14063	18801	12479
AC #5	237	22	5109	5262	1260	221	142	21925	31528	22656
AC #6	235	26	5509	6098	2614	157	80	9482	12449	8067
AC #7	236	22	5045	5175	1152	145	78	8440	11394	7653
AC #8	237	19	4208	4537	1696	225	109	18838	24544	15734
AC #10	235	26	5837	6086	1720	132	88	8302	11525	7994

Appendix 2 -- Table 1 - Steady State and Stall State A/C Test Data

Appendix 2.1. PSLF r_{stall} and x_{stall} Calculations

In PSLF simulation, p_{gen} is the default MVA base in the *ld1pac* model. In order to apply the calculated parameters to the model (r_{stall} and x_{stall}), these two parameters need to be changed into P_{ss} based ($r_{stall\text{-}p.u.\text{-}new}$ and $x_{stall\text{-}p.u.\text{-}new}$). Appendix 2 – Table 2 shows the steady state A/C test data and the calculated parameters at steady state.

Assume:

$$S_{base} = S_{ss} \qquad V_{base} = V_{ss} \qquad I_{base} = I_{ss}$$

Steady State Calculation formulas:

$$pf_{ss} = P_{ss} \div S_{ss} \qquad Z_{base} = V_{ss} \div I_{ss}$$

$$r_{ss\text{-}p.u.} = [P_{ss} \div I_{ss}^2] \div Z_{base} \qquad x_{ss\text{-}p.u.} = [Q_{ss} \div I_{ss}^2] \div Z_{base}$$

SCE AC #	Steady State @ 100F								
	V_{ss}	I_{ss}	P_{ss}	S_{ss}	Q_{ss}	pf_{ss}	Z_{base}	$r_{ss\text{-}p.u}$	$x_{ss\text{-}p.u.}$
AC #1	240	16	3550	3768	1264	0.94	15	0.94	0.34
AC #2	237	14	3283	3393	854	0.97	17	0.97	0.25
AC #3	240	17	3953	4153	1275	0.95	14	0.95	0.31
AC #4	238	15	3495	3562	687	0.98	16	0.98	0.19
AC #5	237	22	5109	5262	1260	0.97	11	0.97	0.24
AC #6	235	26	5509	6098	2614	0.90	9	0.90	0.43
AC #7	236	22	5045	5175	1152	0.97	11	0.97	0.22
AC #8	237	19	4208	4537	1696	0.93	12	0.93	0.37
AC #10	235	26	5837	6086	1720	0.96	9	0.96	0.28
Average	237	20	4443	4670	1391	0.95	13	0.95	0.29

Appendix 2 -- Table 2 - Steady State A/C Test Data and Calculations

Stall State Calculation formulas:

$pf_{stall} = P_{stall} \div S_{stall}$

$r_{stall\text{-}p.u.} = [P_{stall} \div I_{stall}^2] \div Z_{base}$

$Z_{base} = V_{ss} \div I_{ss}$ *(same as steady state)*

$x_{stall\text{-}p.u.} = [Q_{stall} \div I_{stall}^2] \div Z_{base}$

$$r_{stall\text{-}p.u.\text{-}new} = r_{stall\text{-}p.u.} * [Z_{base} \div Z_{base\text{-}new}]$$
$$= r_{stall\text{-}p.u.} * [(V_{base}^2 \div S_{base}) \div (V_{base\text{-}new}^2 \div S_{base\text{-}new})]$$
$$= r_{stall\text{-}p.u.} * [(V_{base}^2 * S_{base\text{-}new}) \div (V_{base\text{-}new}^2 * S_{base})]$$

since: $V_{base} = V_{ss}$; $P_{ss} = S_{base\text{-}new}$; $S_{base} = S_{ss}$

$$= r_{stall\text{-}p.u.} * [(V_{ss}^2 * P_{ss}) \div (V_{ss}^2 * S_{ss})]$$
$$= r_{stall\text{-}p.u.} * [P_{ss} \div S_{ss}]$$

since: $pf_{ss} = P_{ss} \div S_{ss}$

$$= r_{stall\text{-}p.u.} * pf$$

similarly

$$x_{stall\text{-}p.u.\text{-}new} = x_{stall\text{-}p.u.} * pf_{ss}$$

Appendix 2 – Table 3 shows the stall A/C test data and the calculated stall parameters with the new base.

SCE	Stall @ 100F										
AC #	V_{stall}	I_{stall}	P_{stall}	S_{stall}	Q_{stall}	pf_{stall}	Z_{base}	$r_{stall\text{-}p.u}$	$x_{stall\text{-}p.u.}$	$r_{stall\text{-}p.u - new}$	$x_{stall\text{-}p.u. - new}$
AC #1	154	59	6402	9130	6510	0.70	15	0.12	0.12	0.113	0.115
AC #2	137	51	5066	6933	4733	0.73	17	0.12	0.11	0.115	0.107
AC #3	145	60	6318	8721	6013	0.72	14	0.13	0.12	0.119	0.114
AC #4	229	82	14063	18801	12479	0.75	16	0.13	0.12	0.129	0.114
AC #5	221	142	21925	31528	22656	0.70	11	0.10	0.10	0.098	0.102
AC #6	157	80	9482	12449	8067	0.76	9	0.17	0.14	0.149	0.127
AC #7	145	78	8440	11394	7653	0.74	11	0.13	0.12	0.124	0.112
AC #8	225	109	18838	24544	15734	0.77	12	0.13	0.11	0.119	0.099
AC #10	132	88	8302	11525	7994	0.72	9	0.12	0.11	0.114	0.110
Average	172	83	10982	15003	10204	0.73	13	0.13	0.12	**0.120**	**0.111**

Appendix 2 -- Table 3 - Steady State A/C Test Data and Calculations

Appendix 2.1. Current, Real Power, and Reactive Power Calculated Stall Parameters

In order to back check the **ld1pac** model stall performance, calculating stall parameters such as I, P, and Q at a given stall voltage proves indispensable. These parameters are normalized (calculated in a per unit basis) in order to be used with any amount of load. Appendix 2 – Figures 1, 2, and 3 show the stall currents, real power, and reactive power versus any stall voltage from 0.0 p.u. to a full-rated voltage of 1.00 p.u. When the **ld1pac** model goes into stall mode, it should follow the parameters found in the following three Appendix2-Figures (1, 2, and 3) seen below.

	Steady State (Pre-stalling)										Stall									
AC Unit #	V_1	I_1 100F	I_1(p.u.) 100F	W	VA	VAR	Z_{SS}	Z_{SS} (Φ)	r_{SS}	X_{SS}	V_1	I_1 100F	I_1(p.u.) 100F	W	VA	VAR	Z_{STALL}	Z_{STALL} (Φ)	r_{STALL}	X_{STALL}
AC #1	240	16	1.0	3549.9	3768	1264	15	20	14	5.12	154	59.3	3.8	6402	9130	6510	3	45	1.82	1.85
AC #2	237	14	1.0	3283.3	3393	854	17	15	16	4.17	137	50.7	3.5	5066	6933	4733	3	43	1.97	1.84
AC #3	240	17	1.0	3952.9	4153	1275	14	18	13	4.25	145	60.3	3.5	6318	8721	6013	2	44	1.74	1.65
AC #4	238	15	1.0	3494.7	3562	687	16	11	16	3.07	229	82.1	5.5	14063	18801	12479	3	42	2.09	1.85
AC #5	237	22	1.0	5108.7	5262	1260	11	14	10	2.56	221	142.4	6.4	21925	31528	22656	2	46	1.08	1.12
AC #6	235	26	1.0	5509.4	6098	2614	9	25	8	3.90	157	79.5	3.1	9482	12449	8067	2	40	1.50	1.28
AC #7	236	22	1.0	5045.4	5175	1152	11	13	11	2.40	145	78.5	3.6	8440	11394	7653	2	42	1.37	1.24
AC #8	237	19	1.0	4207.9	4537	1696	12	22	12	4.64	225	108.9	5.7	18838	24544	15734	2	40	1.59	1.33
AC #10	235	26	1.0	5837.4	6086	1720	9	16	9	2.57	132	87.6	3.4	8302	11525	7994	2	44	1.08	1.04

Black Font is the actual test data
Brown Font is the calculated data based on the test data

Appendix 2 -- Table 4 - Steady State and Stall State A/C Test Data and Calculations

The impedance (Z), resistance (r), and reactance (x) for both steady-state and stall conditions appear in brown in the following calculation procedures:

A). The impedance (**Z**) is calculated by squaring the voltage (V) and dividing it by the apparent power S (VA).

$$Z = V^2 \div S$$

B). The angle (**Θ**) of the impedance is calculated as the arccosine of the real power (P) divided by the apparent power S (VA).

$$\Theta = \cos^{-1}(P \div S)$$

C). The resistance (r) or real part of the impedance is calculated by multiplying the cosine of the angle by the impedance.

$$r = \cos(\Theta) * Z$$

D). The reactance (x) or imaginary part of the impedance is calculated by multiplying the sine of the angle by the impedance.

$$x = \sin(\Theta) * Z$$

Based on the stalled calculated impedance (Z_{STALL}), resistance (I_{STALL}), and reactance (x_{STALL}), the real power (P_{STALL}), reactive power (Q_{STALL}), and current (I_{STALL}) at stall condition are calculated for all the voltage ranges from 0 percent to 100 percent of the nominal rated voltage in one percent steps as shown in the Appendix2-Figures (1, 2, and 3).

E). The stall current (I_{STALL}) is calculated by taking the voltage (V_{STALL}) at stall condition and dividing it by the stall impedance (Z_{STALL}).

$$I_{STALL} = V_{STALL} \div Z_{STALL}$$

F). The stall apparent power (S_{STALL}) is calculated by taking the voltage (V_{STALL}) at stall condition and multiplying it by the stall current (I_{STALL}).

$$S_{STALL} = V_{STALL} \times I_{STALL}$$

G). The stall real power (P_{STALL}) is calculated by taking the cosine of the angle ($\cos \Theta$) and multiplying it by the stall apparent power (S_{STALL}).

$$P_{STALL} = \cos \Theta \times S_{STALL}$$

H). The stall reactive power (Q_{STALL}) is calculated by taking the sine of the angle ($\sin \Theta$) and multiplying it by the stall apparent power (S_{STALL}).

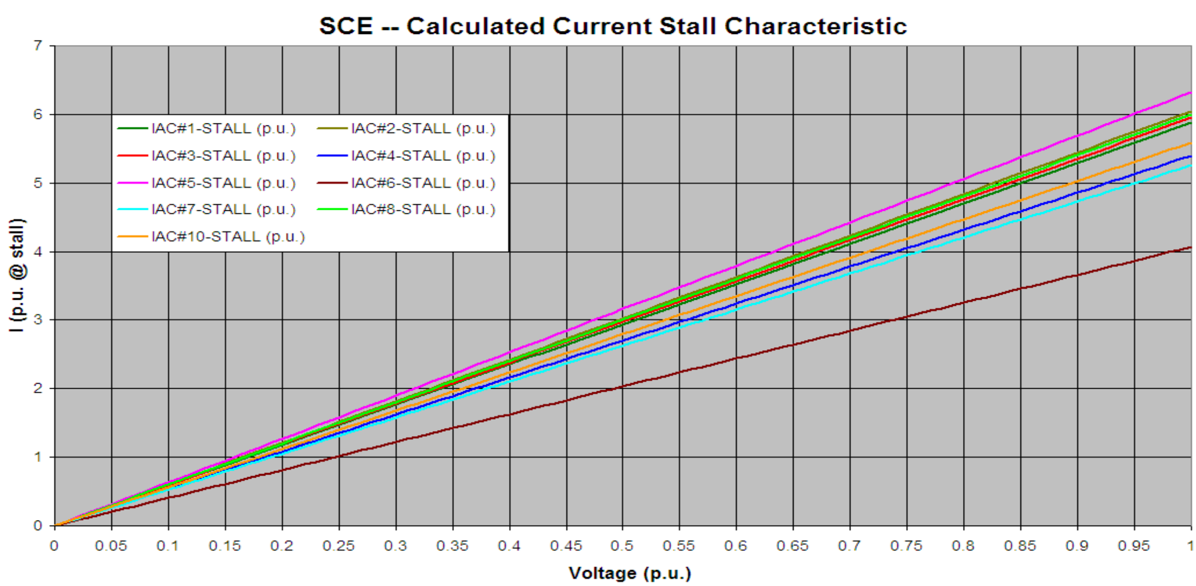
$$Q_{STALL} = \sin \Theta \times S_{STALL}$$

The next three graphs reflect the calculated stall current, stall real power, and stall reactive power versus stall voltage for nine out of the ten A/C units tested by SCE. For example: if the unit goes into stall mode and the voltage at stall mode is 75 percent then:

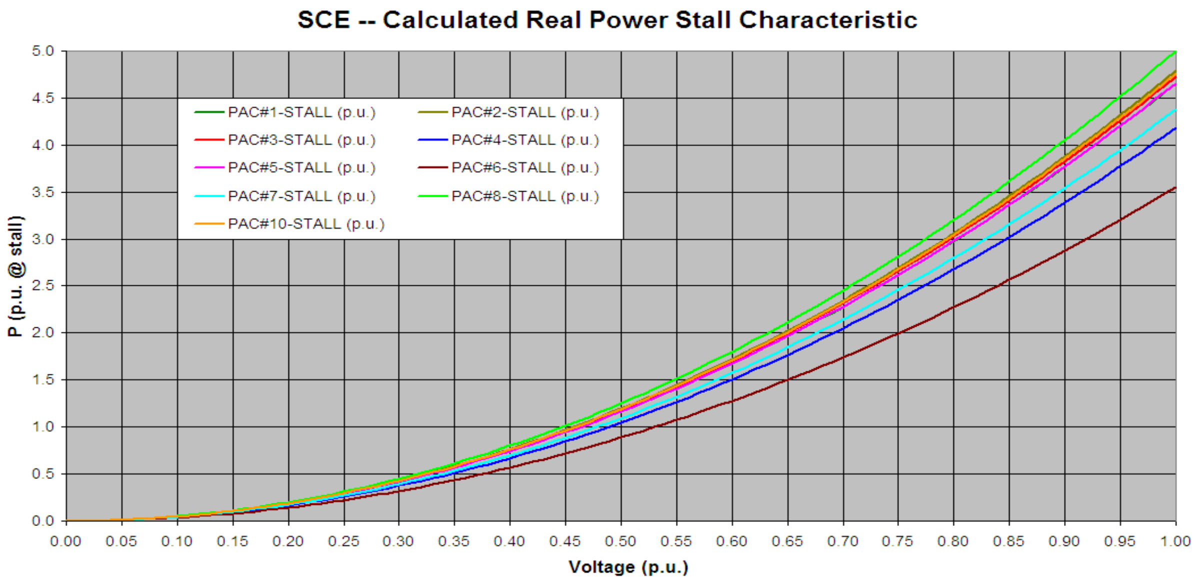
A). The stall current I_{STALL} should be between approximately 4.0 and 4.6 p.u.

B). The stall real power P_{STALL} should be between approximately 2.4 and 2.8 p.u.

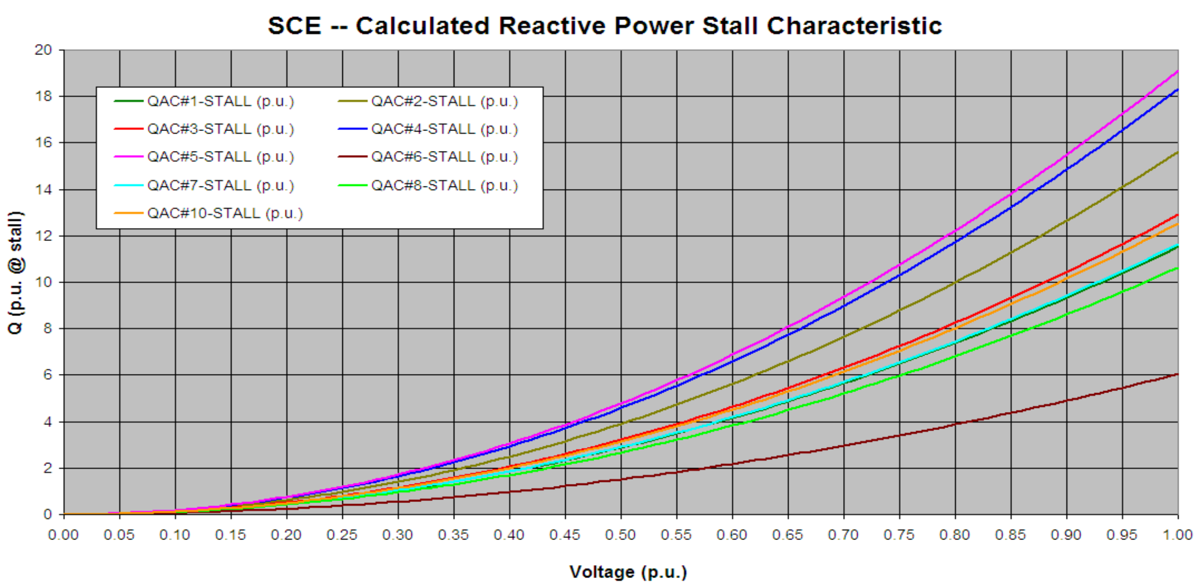
C). The stall reactive power Q_{STALL} should be between approximately 6.5 and 10.0 p.u.



Appendix 2 -- Figure 1. Stall Current vs. Stall Voltage



Appendix 2 -- Figure 2. Stall Real Power vs. Stall Voltage



Appendix 2 -- Figure 3. Stall Reactive Power vs. Stall Voltage

APPENDIX 3. Ld1pac Model Settings for the Composite Load Model

The table below contains the settings that need to be available, not hardwired into the model, but in the composite load model.

Model Name:			ld1pac
Description			Performance-based model of single-phase air conditioner load
Ld1pac settings that need to be available for changes in the composite load model. Other parameters not mentioned here need to be hardwired into the program.			
	EPCL Variable	***Default Data***	***Description***
	Pul	-1.00	Fraction of constant-power load to be represented by this model (between 1.0 and 0.0)
	CompPF	0.97	Compressor power factor
	Vstall	0.70	Compressor stall threshold voltage p.u.
	Rstall	0.124	Compressor stall resistance, p.u.
	Xstall	0.114	Compressor stall reactance, p.u.
	Vstall	0.70	Compressor stall threshold voltage p.u.
	LFadj	0.30	Vstall adjustment proportional to loading factor
	Frst	0.20	Fraction of motors capable of restarting
	Vrst	0.90	Voltage at which motors can restart, p.u.
	Vc1off	0.45	Voltage 1 at which contactors disconnect (open) the load gradually, p.u.
	Vc2off	0.35	Voltage 2 at which contactors disconnect (open) all the remaining load, p.u.
	Vc1on	0.50	Voltage 1 at which contactors re-connect (close) the load gradually, p.u.
	Vc2on	0.40	Voltage 2 at which contactors re-connect (close) all the remaining load, p.u.
	Tth	10.0	Compressor motor heating time constant, sec.
	Th1t	1.30	Temperature at which compressor motors begin tripping, p.u.
	Th12	4.30	Temperature at which all motors are tripped, p.u.
	Fuvr	0.00	Fraction of compressor motors with undervoltage relays
	UVtr1	0.80	First undervoltage pickup level, p.u.
	Ttr1	0.20	First definite time for U/V trip, sec.
	Uvtr2	0.90	Second undervoltage pickup level, p.u.
	Ttr2	5.00	Second definite time for U/V trip, sec.
	Tstall	0.033	Stall time, sec.
	Trst	0.400	Restart delay time, sec.

OUTDOOR UNIT					80F											
AC Unit	Ton	Comp.	Refrig.	SEER	$V_{STEADY-STATE}$ (V)	$I_{STEADY-STATE}$ (A)	$P_{STEADY-STATE}$ (kW)	$Q_{STEADY-STATE}$ (kVAR)	V_{INRUSH} (V)	I_{INRUSH} (A)	P_{INRUSH} (kW)	Q_{INRUSH} (kVAR)	V_{STALL} (V)	I_{STALL} (A)	P_{STALL} (kW)	Q_{STALL} (kVAR)
BPA_AC#1	3	R	R22	10	238	12	2.69	0.64	N/A	N/A	N/A	N/A	185	70	7.8	10.1
BPA_AC#2	3	S	R22	12	238	10	2.28	0.29	238	79	13.7	10.8	174	58	7.4	6.9
BPA_AC#3	3	R	R22	10	238	12	2.82	0.6	237	92	15.3	15.4	N/A	N/A	N/A	N/A
BPA_AC#4	3	S	R22	12	237	11	2.64	0.28	N/A	N/A	N/A	N/A	158	63	9.2	5
BPA_AC#5	3	R	R22	10	N/A	N/A	N/A	N/A	237	89	14.4	13.3	N/A	N/A	N/A	N/A
BPA_AC#6	3.5	R	R22	10	237	15	3.1	1.7	237	120	18.8	20	225	118	17.5	20
BPA_AC#7	4	S	R22	10	238	16	3.8	1.4	238	139	20.8	23.3	170	100	10.3	13
EPRI_AC#1	4	R	R22	10	237	18	4.2	0.6	233	121	19.51	20.5	144	63	5.5	7.3
EPRI_AC#2	4	S	R22	13	237	12	2.9	0.3	233	111	19.17	17.8	161	72	8.0	8.4
EPRI_AC#3	4	S	R22	13	237	13	2.9	0.5	234	92	16.66	14.1	169	58	7.7	6.0
EPRI_AC#4	3.5	S	R22	13	237	14	2.9	1.3	233	109	17.95	17.5	144	60	6.0	6.1
EPRI_AC#6	3	S	R22	13	237	10	2.2	0.8	234	91	15.81	14.6	144	49	4.9	5.0
EPRI_AC#7	5	S	R22	13	237	16	3.6	1.2	233	139	24.42	21.2	144	73	7.9	7.0
EPRI_AC#8	3.5	S	R410	14	236	17	3.7	1.6	233	110	19.09	17.6	144	63	6.7	6.2
EPRI_AC#9	4	S	R410	13	237	19	4.1	2.1	234	124	22.35	18.6	144	72	7.8	6.9
EPRI_AC#10	3.5	S	R410	13	237	18	3.9	1.8	233	118	18.53	19.7	144	68	6.5	7.2
EPRI_AC#11	2.5	S	R410	13	237	9	1.8	0.7	235	77	13.75	11.7	144	43	4.5	4.2
EPRI_AC#12	5‡	R	R410	13	237	19	4.5	0.8	233	118	23.05	15.3	163	78	10.5	7.2
SCE_AC #1	3	R	R22	10	240	14	3.1	1.3	233	99	17.5	15.1	129	47	4.4	4.2
SCE_AC #2	3	S	R22	12	241	12	2.7	0.8	227	99	16.0	15.8	127	46	4.4	3.9
SCE_AC #3	3	S	R22	10	238	14	3.1	1.2	225	107	17.1	16.9	227	101	17.2	15.3
SCE_AC #4	3	S	R410	13	241	12	2.8	0.6	229	84	14.1	13.0	232	61	11.7	8.1
SCE_AC #5	4	S	R410	13	237	18	4.0	1.1	220	149	21.8	24.4	150	90	9.1	9.9
SCE_AC #6	4	S	R22	10	239	22	4.5	2.5	222	138	21.3	22.0	136	70	7.1	6.3
SCE_AC #6_Overcharged	4	S	R22	10	236	22	4.4	2.6	223	128	21.2	19.3	145	40	5.3	2.4
SCE_AC #7	4	S	R22	12.5	237	15	3.5	1.0	222	133	22.0	19.8	139	35	4.5	1.9
SCE_AC #8	4	R	R22	10	238	17	3.8	1.6	223	119	19.0	18.5	225	113	19.1	16.7
SCE_AC #9	4	R	R22	10	236	20	4.3	2.2	225	111	21.6	12.7	146	69	8.6	5.2
SCE_AC #10	5	S	R410	13	236	20	4.5	1.6	217	163	25.5	24.5	131	63	7.4	3.9

OUTDOOR UNIT					100F							
AC Unit	Ton	Comp.	Refrig.	SEER	$V_{STEADY-STATE}$ (V)	$I_{STEADY-STATE}$ (A)	$P_{STEADY-STATE}$ (kW)	$Q_{STEADY-STATE}$ (kVAR)	V_{STALL} (V)	I_{STALL} (A)	P_{STALL} (kW)	Q_{STALL} (kVAR)
BPA_AC#1	3	R	R22	10	238	14	3.18	0.73	184	68	7.9	9.6
BPA_AC#2	3	S	R22	12	238	12	2.76	0.34	214	76	12.2	11
BPA_AC#3	3	R	R22	10	238	14	3.16	0.66	160	59	5.85	7.4
BPA_AC#4	3	S	R22	12	237	12	2.87	0.32	157	57	7.6	4.55
BPA_AC#5	3	R	R22	10	237	11	2.46	0.91	132	45	4.3	4
BPA_AC#6	3.5	R	R22	10	237	16	3.46	1.75	181	90	10.5	12.5
BPA_AC#7	4	S	R22	10	238	18	4.09	1.42	135	75	6.1	8.2
EPRI_AC#1	4	R	R22	10	237	19	4.4	0.6	144	61	5.7	6.8
EPRI_AC#2	4	S	R22	13	237	16	3.6	0.4	156	63	7.2	6.7
EPRI_AC#3	4	S	R22	13	237	15	3.6	0.7	144	49	5.2	4.7
EPRI_AC#4	3.5	S	R22	13	237	16	3.5	1.4	144	60	6.0	6.2
EPRI_AC#6	3	S	R22	13	237	12	2.6	0.8	144	49	5.0	5.0
EPRI_AC#7	5	S	R22	13	237	20	4.6	1.3	144	74	7.9	7.1
EPRI_AC#8	3.5	S	R410	14	236	20	4.4	1.7	144	63	6.7	6.2
EPRI_AC#9	4	S	R410	13	237	21	4.6	2.1	144	72	7.8	6.8
EPRI_AC#10	3.5	S	R410	13	237	20	4.4	1.8	144	68	6.5	7.3
EPRI_AC#11	2.5	S	R410	13	237	11	2.5	0.7	144	42	4.5	4.0
EPRI_AC#12	5‡	R	R410	13	237	21	5.0	0.9	150	74	9.6	5.5
SCE_AC #1	3	R	R22	10	238	16	3.6	1.3	153	58	6.3	6.3
SCE_AC #2	3	S	R22	12	237	14	3.3	0.9	138	51	5.2	4.8
SCE_AC #3	3	S	R22	10	237	17	3.9	1.2	145	60	6.3	5.9
SCE_AC #4	3	S	R410	13	238	15	3.5	0.7	231	63	11.9	8.4
SCE_AC #5	4	S	R410	13	236	23	5.2	1.3	230	100	11.1	20.1
SCE_AC #6	4	S	R22	10	236	26	5.5	2.6	159	81	9.8	8.1
SCE_AC #6_Overcharged	4	S	R22	10	236	26	5.5	2.6	171	40	6.4	2.5
SCE_AC #7	4	S	R22	12.5	240	19	4.4	1.1	140	73	7.7	6.7
SCE_AC #8	4	R	R22	10	237	19	4.2	1.7	225	111	19.0	16.4
SCE_AC #9	4	R	R22	10	237	22	4.8	2.1	225	113	22.1	12.5
SCE_AC #10	5	S	R410	13	239	26	6.0	1.8	133	88	8.5	8.1

OUTDOOR UNIT					115F							
AC Unit	**Ton**	**Comp.**	**Refrig.**	**SEER**	$V_{STEADY-STATE}$ (V)	$I_{STEADY-STATE}$ (A)	$P_{STEADY-STATE}$ (kW)	$Q_{STEADY-STATE}$ (kVAR)	V_{STALL} (V)	I_{STALL} (A)	P_{STALL} (kW)	Q_{STALL} (kVAR)
BPA_AC#1	3	R	R22	10	238	15	3.46	0.795	N/A	N/A	N/A	N/A
BPA_AC#2	3	S	R22	12	238	16	3.48	0.44	195	66	9.4	8.6
BPA_AC#3	3	R	R22	10	238	15	3.4	0.74	149	53	4.88	6.5
BPA_AC#4	3	S	R22	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BPA_AC#5	3	R	R22	10	237	14	3.2	0.95	146	50	5.5	5
BPA_AC#6	3.5	R	R22	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BPA_AC#7	4	S	R22	10	238	23	5.2	1.6	213	61	8.7	9.2
EPRI_AC#1	4	R	R22	10	237	19	4.5	0.7	144	61	5.6	6.8
EPRI_AC#2	4	S	R22	13	237	18	4.2	0.5	156	61	7.2	6.4
EPRI_AC#3	4	S	R22	13	237	17	3.7	0.8	144	49	5.3	4.6
EPRI_AC#4	3.5	S	R22	13	237	19	4.2	1.4	144	60	6.0	6.2
EPRI_AC#6	3	S	R22	13	237	13	2.9	0.8	144	49	4.9	5.0
EPRI_AC#7	5	S	R22	13	237	25	5.6	1.4	144	73	7.9	6.9
EPRI_AC#8	3.5	S	R410	14	236	21	4.7	1.7	144	61	6.6	5.8
EPRI_AC#9	4	S	R410	13	237	24	5.1	2.1	144	71	7.8	6.7
EPRI_AC#10	3.5	S	R410	13	237	23	5.1	1.9	144	67	6.5	7.1
EPRI_AC#11	2.5	S	R410	13	237	13	2.9	0.7	144	41	4.4	3.9
EPRI_AC#12	5‡	R	R410	13	237	23	5.5	1.1	164	81	11.5	6.5
SCE_AC #1	3	R	R22	10	240	17	3.8	1.4	157	60	6.7	6.6
SCE_AC #2	3	S	R22	12	237	18	4.1	1.0	156	58	6.9	6.0
SCE_AC #3	3	S	R22	10	239	20	4.6	1.3	160	67	8.0	7.1
SCE_AC #4	3	S	R410	13	237	18	4.2	0.8	174	56	7.4	6.4
SCE_AC #5	4	S	R410	13	236	27	6.3	1.5	157	91	10.1	10.2
SCE_AC #6	4	S	R22	10	235	31	6.7	2.8	158	82	9.7	8.6
SCE_AC #6_Overcharged	4	S	R22	10	238	31	6.9	2.7	168	7	1.1	0.6
SCE_AC #7	4	S	R22	12.5	239	22	5.1	1.2	147	79	8.7	7.6
SCE_AC #8	4	R	R22	10	237	21	4.6	1.7	225	109	18.8	15.9
SCE_AC #9	4	R	R22	10	239	25	5.4	2.3	160	72	10.5	4.4
SCE_AC #10	5	S	R410	13	238	31	7.1	1.9	149	99	10.8	10.1