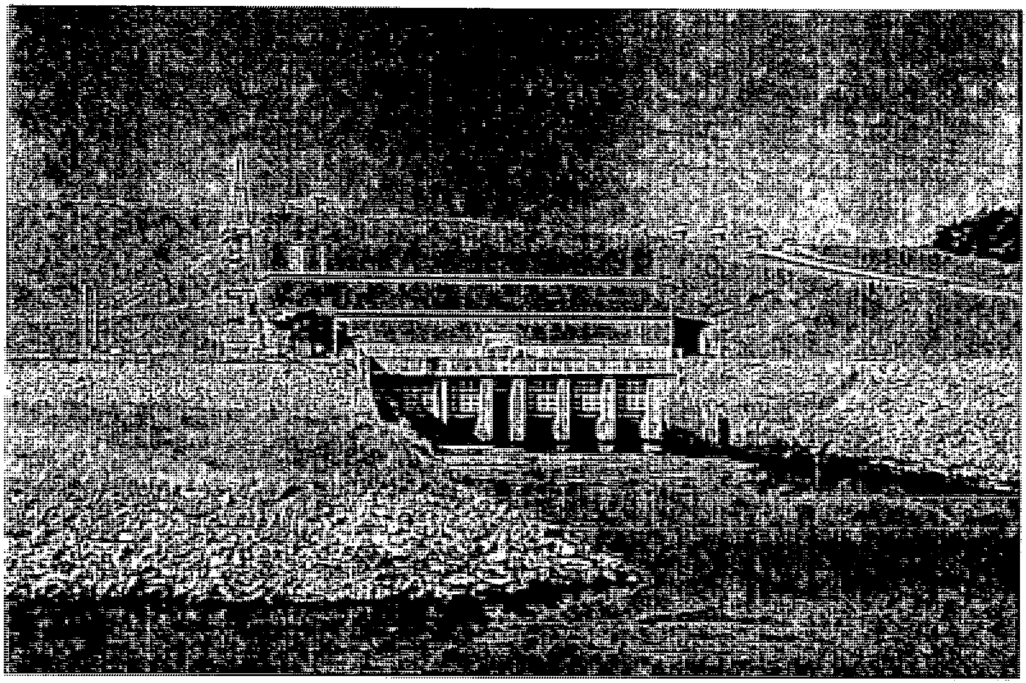
DUKE POWER COMPANY

Oconee Nuclear Station



CYME Modeling of Emergency Power and Engineered Safeguards Functional Tests 2, 5 and 6

DUKE POWER COMPANY

OCONEE NUCLEAR STATION

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Executive Summary

Purpose

The purpose of this report is to show the degree of correlation between data measured during the Oconee Emergency Power and Engineered Safeguards Functional Test on January 2-5, 1997 versus data predicted by the CYME analytical model. CYME results are compared to data collected during Tests 2, 5, and 6 to further demonstrate that the CYME program adequately predicts the Oconee Emergency Power Distribution system responses for each of the three emergency power paths. This report supplements the Oconee Emergency Power and Engineered Safeguards Functional Test Report forwarded to the NRC by a Duke Power letter dated April 30, 1997.

Scope

This report provides sufficient information to demonstrate that the CYME software is an acceptable tool for predicting the Oconee Emergency Power System operational characteristics and responses to various electrical power distribution system perturbations. The CYME model output data simulating three of the actual Oconee Emergency Power and Engineered Safeguards Functional Test Scenarios are presented and compared to show the adequacy of the CYME models for predicting the electrical power distribution system response(s). Tests 2, 5, and 6 were chosen for CYME model simulation because they sufficiently test the CYME analytical model for the three distinct emergency power paths (Keowee overhead, Keowee underground, and Lee CT) for Oconee Nuclear Station.

The data presented in this report is in graphical form. Reviews and discussions are provided for each plot with additional information for those areas where there may appear to be a significant discrepancy or anomaly between measured data and CYME model output data.

Background

On January 2-5, 1997, a comprehensive, integrated test was performed on the Oconee Emergency Power and Engineered Safeguards Systems. Because of the Oconee emergency power system design, "integrated testing" of one Oconee unit cannot be performed without some impact on the reliability of emergency power to the other two operating Oconee units during the time these tests would be performed. However, in late 1996, a rare opportunity for testing occurred when all three of the Oconee nuclear reactors were shut down for non-test reasons. Duke Power, in consultation with the NRC, decided to perform a one-time integrated test of the three Oconee Nuclear units.

The scenarios selected for this test were worst case or bounding loading scenarios. The scenarios included both three Unit Loss of Offsite Power (LOOP) and Loss of Coolant Accident (LOCA) /LOOP scenarios. Both of the Keowee emergency power paths (overhead and underground), from the Keowee unit through the respective path to the main feeder buses of each Oconee unit, were included in the test scope. Likewise, both modes of Keowee operation (standby and grid generation), were included. Similarly, a worst case loading scenario for the Lee CT was included in the test scope.

A significant effort was made during the tests to obtain all of the information necessary to allow a post-test comparison between actual test and analytical model results. The response from the power source (Keowee Hydro Generator or Lee Combustion Turbine (CT) Generator) through the auxiliary power system down to the safety related 208V buses was monitored during the tests. Various pieces of selected equipment including 4000V and 575V motors, a battery charger, and selected motor operated valves (MOVs) were monitored.

Due to the unlikely occurrence of a similar opportunity for testing with all three Oconee units out of service in the future, the impact of load changes on the Oconee Emergency Power and Engineered Safeguards System will need to be justified by analysis. In order to provide a basis for justifying future changes by analysis, Duke has proceeded to analytically model test case scenarios for each of the three emergency power paths with a CYME dynamic analysis software system. The test data was previously provided to the NRC by a Duke Power letter dated April 30, 1997. A commitment to provide this report to the NRC is documented in Duke Power letters to the NRC dated January 30, 1997 and April 30, 1997.

Results and Conclusions

Overall, the results of the CYME models developed to simulate the Oconee Emergency Power and Engineered Safeguards Functional Tests 2, 5, and 6 are satisfactory. Good correlation was seen between the test data and the CYME model predictions except for the RBCF B motor. Although Test 3 (reduced voltage and frequency starting scenario) is not included in this report, a comparison of the test data and the CYME model predictions show the model to predict conservative results (i.e. motors take a slightly longer time to accelerate in the model versus the test) also except for the RBCF B motor. In all cases, the RBCF B motor is an exception in that the CYME model predicts that this motor accelerates faster than the test data proves to be true. This difference in start time of the RBCF B motor is apparently due to the reverse rotation of this fan before it starts as a result of back-leakage due to air dampers not sealing completely. A modification (NSM ON-3014) has been planned to replace these dampers and should resolve this reverse rotation problem. Until this modification is implemented, additional time will be added to the RBCF B motor starting time predicted by CYME to compensate for this RBCF reverse rotation problem.

Based on the above, the CYME model was verified to be an adequate analytical tool for predicting the operational characteristics and responses for the Oconee Emergency Power System.

Some enhancements have been made to the CYME model based on information gathered during the Oconee Emergency Power and Engineered Safeguards Functional Test on January 2-5, 1997, as described in Section 4. The changes made in the CYME model are not significant enough to affect the conclusions of evaluations performed in the past.

1. CYME ANALYTICAL MODEL SIMULATION(S)

The CYME model dynamic analyses have been used in the past to simulate and support the Oconee Emergency Power and Engineered Safeguards System design.

Employing analytical models as a tool for evaluating and assessing the adequacy of, and the need for changes to, electrical power distribution systems is a widespread, standard practice in the industry for all types of electrical distribution and transmission systems. Based on the need for an accurate model, a significant effort was made during the performance of the Oconee Emergency Power System Tests on January 2-5, 1997 to obtain information required to allow a comprehensive post-test comparison between actual test data and analytical model results. The response from the power source (Keowee Hydro Generator or Lee Combustion Turbine Generator (CT)) through the auxiliary power system down to the safety related 208V buses was monitored during the test. Various pieces of selected equipment including 4000V and 575V motors, a battery charger, and several motor operated valves (MOVs) were monitored.

As committed in a Duke Power letter to the NRC dated January 30, 1997, a CYME analytical model has been developed for Test Scenarios 2, 5, and 6. This report:

1) Compare the CYME output for generator, motor, and bus voltage and current waveforms to actual test data. The comparison is shown graphically by overlaying the CYME results on the same plots that show the recorded test data.
2) Identify any changes made to the CYME model based on new data gathered from additional motor signature testing, new Lee CT generator benchmark data reflecting recent modifications in the generator voltage regulator droop setting, and based on 'lessons learned' from the data collected during the tests.

2. CYME MODEL / TEST DESCRIPTIONS

2.1 Model 1 / Test 2 - Oconee Three Unit LOOP with Keowee Initially Generating to the Grid

This test case represented the single largest block load applied to the Keowee overhead path. All three Oconee Units were aligned to their respective startup transformer, and hot shutdown loads were started on each Oconee Unit. The Keowee overhead unit was generating to the Grid at 60MW. This case included the entire overhead circuit from Keowee through the isolated 230 KV switchyard yellow bus to each Oconee unit and its applicable Loss of Offsite Power (LOOP) loads. In this scenario, three Oconee units were loaded onto a Keowee unit at 1.0 per unit (PU) voltage and 1.1 PU frequency decreasing following load rejection of that Keowee unit. A Switchyard Isolation was initiated which resulted in 1) a loss of power to each Oconee Unit, 2) emergency start of both Keowee Units, and 3) a load rejection of the Keowee Overhead Unit. All three Oconee Units received power from the Keowee Overhead unit through their respective startup transformer in approximately 20 seconds as expected.

To simplify the creation of the CYME model for this test scenario, the Oconee auxiliary buses are modeled connected to Keowee with no load on the buses. This modeling technique has no impact on the results once loading occurs. This resulted in voltage appearing in the model plots of the Oconee auxiliary system buses during the period when the system is actually de-energized. Loads were then connected and transformer inrush current is applied at the appropriate time based on test results. In creating the CYME model for this test, motors are modeled at the load condition actually applied to the motors during the test. For the non-safety, non-loadshed loadcenters, loading was approximated based on the test results. For 600V and 208V MCCs, worst case calculated loading was used in the model to demonstrate the conservatism that will be used in modeling the 600 and 208 Volt systems in the future.

2.2 Model 2 / Test 5 - Oconee LOCA/LOOP with a Failure of the Overhead Path and Keowee Initially Generating to the Grid

This test case represented the largest cumulative load automatically applied to the Keowee underground path. All three Oconee Units were aligned to their respective startup transformers. The Keowee underground unit was generating to the Grid at 60MW. All three startup transformers were de-energized simultaneously, and a Loss of Coolant Accident (LOCA) signal was initiated on Oconee Unit 3, while all three Oconee units sustained a LOOP.

During this scenario the load that was applied to the Keowee unit was sequenced on in two blocks. First, the LOCA/LOOP unit was loaded (including Motor Driven Emergency

Feedwater (MDEFW) pumps) onto a Keowee unit at 1.0 PU voltage and 1.1 PU frequency decreasing following a load rejection of the Keowee unit. The second transient was block loading the other two LOOP only Oconee units(including one Low Pressure Injection (LPI) pump per unit).

This case demonstrated the ability of Keowee to start and accelerate the Oconee LOCA loads, as well as continue to carry the LOCA loads during and following the second loading transient which was encountered when the other two Oconee LOOP units started. The second loading transient occurred with Keowee near 1.0 PU voltage and 1.0 PU frequency.

To simplify the creation of the CYME model for this test scenario, the Oconee auxiliary buses are modeled connected to Keowee with no load on the buses. This modeling technique has no impact on the results once loading occurs. This resulted in voltage appearing in the model plots of the Oconee auxiliary system buses during the period when the system is actually de-energized. Loads were then connected and transformer inrush current was applied at the appropriate time based on test results. In creating the CYME model for this test, motors are modeled at the load condition actually applied to the motors during the test. For the non-safety, non-loadshed loadcenters, loading was approximated based on the test results. For 600V and 208V MCCs, worst case calculated loading was used in the model to demonstrate the conservatism that will be used in modeling the 600 and 208 Volt systems in the future.

2.3 Model 3 / Test 6 - Oconee LOCA/LOOP with Lee CT Supplying Emergency Power

A Lee CT Generator serves as the emergency onsite power source when the Keowee unit(s) are not available. This test case represented the largest cumulative load applied to a Lee CT. The LOCA/LOOP (including MDEFW) loads applied to the Lee CT was sequenced on in three blocks. First the LOCA/LOOP Oconee unit was loaded with Lee at steady state voltage and frequency. A second block load of the other two LOOP only Oconee units occurred approximately 20 seconds later. Finally, a third transient of block loading the non-safety, non-loadshed loadcenters of the LOOP only unit occurred approximately 10 seconds after the second load transient.

To simplify the creation of the CYME model for this test scenario, the Oconee auxiliary buses are modeled connected to Lee with no load on the buses. This modeling technique has no impact on the results once loading occurs. This resulted in voltage appearing in the model plots of the Oconee auxiliary system buses during the period when the system is actually de-energized. Loads are then connected and transformer inrush current is applied at the appropriate time based on test results. In creating the CYME model for this test, motors are modeled at the load condition actually applied to the motors during the test. For the non-safety loadcenters, loading is approximated based on the test results. For 600V and 208V MCCs, worst case calculated loading is used in the model to demonstrate the conservatism that will be used in modeling the 600 and 208 Volt systems in the future.

3. CYME MODEL / Test Results

This section documents both the test and the CYME dynamic analysis model results for tests 2, 5, and 6. Recorded data for each test from the source down to the 208V MCCs is included in the applicable sections. Various parameters for each test are plotted in the figures as referenced in the sections below. The figures for Tests 2, 5, and 6 are documented in this report in Appendices 1, 2, and 3 respectively. The time scale used in the figures for all data is cycles. The major scale is 300 cycles (5 seconds). The minor scale is 60 cycles (1 second). In all cases, the CYME model analyzes the system until an essentially steady state condition is reached.

3.1 Model 1 / Test 2, Oconee Three Unit LOOP With Keowee Initially Generating To The Grid

This test case simulated a three unit LOOP with the load applied to the overhead circuit. Keowee Unit 2 was initially loaded to approximately 60 MW to the grid. The Keowee unit load rejected and the three Oconee units LOOP loads were supplied by the overhead path. The scenario for this case is as follows:

- A three unit Oconee LOOP occurs and Keowee Unit 2 load rejects at t=0
- The overhead path is energized when the Keowee generator frequency decreases to 66 Hz following load rejection.
- Oconee Units 1, 2 and 3 Main Feeder Buses (MFBs) are energized including Unit 1 Loadcenter X7 and Units 2 and 3 Loadcenter X4 at t ≈ 20 seconds.

3.1.1 Model 1 / Test 2, Keowee Profile (V, I, KVA, KW, f)

Figures 1-1 through 1-5 plot the Keowee response to this case. In these plots, t = 0 is assigned to the point in time when the Keowee unit load rejected on Emergency Start actuation.

Figure 1-1 is a plot of the Keowee voltage and current response.

TEST DATA:

Maximum current inrush is slightly below 3300 amperes rms. There are two distinct high inrush currents. The first inrush occurred approximately 884 cycles (14.7 seconds) and has a maximum current of 3293 amperes. This inrush was when the Keowee Main Step-Up (MSU) and Startup Transformers (SU) CT1, CT2 and CT3 were energized. The second inrush occurred approximately 1058 cycles (approximately 17.6 seconds) and had a maximum current of approximately 2570 amperes when all three unit MFBs were energized. Connection to the three LOOP units appeared to have occurred essentially simultaneously. At approximately 1974 cycles (32.9 seconds) and again at approximately 2723 cycles (45.4

seconds) additional inrush currents occurred as the Reactor Building Cooling Fans (RBCFs) transferred to high speed.

MODEL DATA:

The model data tracks the test data with the primary differences being magnitudes. The first inrush period current has a magnitude of approximately 1900 amperes (model) as compared to 3293 amperes (test). This difference is attributed primarily to the fact that the test data includes dc offset current and harmonic currents, whereas the model data includes only 60 Hz currents. This is not a problem since the protective relaying for the transformers (Keowee MSU, CT1, CT2, CT3) is designed to account for the DC offset and harmonic currents. The second inrush current has a magnitude of approximately 3130 amperes (model) as compared to 2570 amperes (test). This difference is attributed to the fact that 1) during the test all loads would not have been expected to be energized at precisely the same instant in time as is true in the model, and 2) the loadcenter transformer inrush current is modeled as an exponentially decaying current based on signature test results with the loadcenter transformer inrush current modeled to occur at exactly the same time. In addition, transformer inrush magnitudes are highly dependent on transformer residual flux and voltage phase angle during energization, so the inrush during the test may have been less than that modeled. During the test, the current rises between 1980 and 3120 cycles was a result of the RBCF motors switching from low speed to high speed. This is not simulated in the model since the model would assume the motor was starting in high speed from a zero speed condition and not from the low speed running condition as was true during the test. To compensate, the safety system battery chargers are modeled as running continuously at their current limit value of 110 percent of rated value instead of with an exponentially decaying current as observed during the test. This safety system battery charger modeling approach adds a steady state load equivalent to the RBCFs transferring to high speed.

Figure 1-2 is a plot of the Keowee voltage response for both the test and the model.

TEST DATA:

The voltage dip during the first inrush to 12.512KV at 885 cycles (14.8 seconds) was not as great as the voltage dip during the second inrush to 11.757KV at 1066 cycles (17.8 seconds) (or 85.2 percent of rated value) even though the current was higher for the first inrush. The first inrush was due to charging the large transformers, which contains a large DC offset component. This DC current will not significantly impact the flux in the generator air gap, and thus the voltage dip was smaller for this inrush even though the magnitude of the current was larger. Recovery to near rated voltage occurred in approximately 2.5 seconds.

MODEL DATA:

The Keowee load rejection voltage response of the model and the test are very similar. The first voltage dip occurs when the Keowee MSU and Transformers CT1, CT2 and CT3 are energized and is approximately 3 percent greater for the model than for the test even though the model inrush current is less than the test inrush. The test inrush includes dc offset and harmonics which do not contribute directly to the 60 Hz voltage dip. The 60 Hz component

of the test inrush current could not be determined from the test data, so a conservative estimate was made of the 60 HZ component for input to CYME. The estimate is confirmed to be conservative by the fact that the voltage dip during the inrush transient in the model is greater than the voltage dip measured during the test, which infers that the 60 Hz inrush component input to CYME is larger than the inrush that actually occurred during the test. The second inrush which occurs when the Oconee MFBs are loaded onto Keowee also results in an approximately 3 percent greater voltage dip due to the higher model inrush currents. This difference is attributed to 1) the fact that during the test all loads would not have been expected to be energized at precisely the same instant in time as is true in the model, and 2) loadcenter transformer inrush is modeled as an exponentially decaying current based on signature test results with the loadcenter transformer inrush current modeled to occur at exactly the same time. In addition, transformer inrush magnitudes are highly dependent on transformer residual flux and voltage phase angle during energization, so the inrush during the test could be expected to be less than that modeled. The model steady state Keowee voltage is essentially the same as the test steady state voltage.

Figure 1-3 is a plot of the KVA output from Keowee.

TEST DATA:

During the first inrush, the maximum load was approximately 69,000 KVA. During the second inrush, the maximum load was approximately 54,600 KVA. Steady state KVA loading was 12,647 KVA.

MODEL DATA:

The first model inrush is 40,300 KVA and is less than the test inrush due to the test including dc offset and harmonics. The second model inrush of 61,400 KVA is higher than the test inrush value. This difference is attributed to 1) the fact that during the test all loads would not have been expected to be energized at precisely the same instant in time as is true in the model, and 2) loadcenter transformer inrush is modeled as an exponentially decaying current based on signature test results with the loadcenter transformer inrush currents modeled to occur at exactly the same time. In addition, transformer inrush magnitudes are highly dependent on transformer residual flux and voltage phase angle during energization, so the inrush during the test may have been less than that modeled. Final steady state load is 14,280 KVA which is conservative compared to test results.

Figure 1-4 is a plot of the KW output from Keowee.

TEST DATA:

The first KW inrush occurred during transformer energization. The maximum inrush occurred when the MFBs were energized and was approximately 16,200 KW. The steady state load was 8,918 KW.

MODEL DATA:

The model inrush KW when the Oconee auxiliary system loaded onto Keowee is essentially the same as the Test 2 inrush. The final steady state load is 9,350 KW which is slightly higher than the test load due to conservative load estimates.

Figure 1-5 is a plot of the frequency response for Keowee.

TEST DATA:

Frequency was approximately 65.4 Hz when the Keowee Main Step-up (MSU) and Start-up Transformers CT1, CT2, and CT3 were energized. Distortion caused by the transformer inrush currents resulted in an inaccurate measurement of frequency as can be seen by the discontinuities in the frequency plot. When the MFBs were energized the Keowee frequency was approximately 59.6 Hz. Minimum frequency after loading was approximately 57.56 Hz. Frequency recovered to 60.92 Hz due to the governor speed droop characteristic.

MODEL DATA:

The model overspeed is not quite as great as the test overspeed. The Oconee loads are placed onto the model at the time the loading actually occurred during the test. Frequency at MFB loading is approximately 60.9 Hz versus 59.6 Hz in the test. Minimum frequency is approximately 59.3 Hz versus 57.76 Hz in the test. The model simulation steady state frequency value is the same as in the test. The frequency in the model at loading is slightly higher resulting in a slightly lower V/Hz ratio than in the test which yields conservative model results.

3.1.2 Model 1 / Test 2, MFB Profiles (V, I, KVA, KW)

Time t=0 starts with the loss of voltage on Unit 1 for all of the plots. A close examination of the test data shows the units loaded almost simultaneously with Unit 2 loading first, then Unit 1, followed by Unit 3.

Figures 1-6 and 1-7 are the plots of the Unit 1 MFB profiles.

TEST VERSUS MODEL DATA:

Voltage Data:

The model is created such that the Unit 1 MFB remains connected (with all unit loads off) to the CT1 transformer, which is simulated to remain connected to Keowee prior to the time the Oconee unit loads onto Keowee. Thus the Unit 1 MFB CYME model indicates that voltage is available on the main feeder bus during the time prior to the Unit loading onto the main feeder bus. Once the Unit 1 load start is initiated, the CYME MFB voltage correlates well with the test data.

Current Data:

The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The inrush currents during the first second on the Unit 1 MFB in the CYME model are approximately 10 percent greater than the test data. The difference in inrush currents is attributed to the loadcenter transformers. Loadcenter transformer inrush current magnitudes are highly dependent upon transformer residual flux and voltage phase angle when energized, so the transformer inrush current during the test was apparently less than the value assumed in the model. After the first second, the current profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 1980 and 3120 cycles. To compensate, the safety system battery chargers are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The steady state current and voltages from CYME matches the test data.

KVA Data:

The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The inrush KVA during the first second on the Unit 1 MFB in the CYME model is approximately 13 percent greater than the test data attributed to the inrush current variance as discussed above. After the first second of inrush, the KVA profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 1980 and 3120 cycles. To compensate, the safety system battery chargers are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The steady state KVA from the CYME model matches the test data.

KW Data:

The time for LOOP unit loading and the inrush time duration correlate well with the test data. The KW profiles during load start periods and steady state KW correlate well with the test.

Figures 1-8 and 1-9 are plots of the Unit 2 MFB profiles.

TEST VERSUS MODEL DATA:

Voltage Data:

The model is created such that the Unit 2 MFB remains connected (with all unit loads off) to the CT2 transformer, which is simulated to remain connected to Keowee prior to the time Oconee Unit 2 loads onto Keowee. Thus the Unit 2 MFB CYME model indicates that voltage is available on the main feeder bus during the time prior to the Unit loading onto the main feeder bus. Once the Unit 2 load start is initiated, the CYME MFB voltage correlates well with the test data.

Current Data:

The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The inrush currents during the first second on the Unit 2 MFB in the CYME model are approximately 7 percent greater than the test data. The difference in inrush currents is attributed to the loadcenter transformers. Loadcenter transformer inrush current magnitudes are highly dependent upon transformer residual flux and voltage phase angle when energized, so the transformer inrush current during the test was apparently less than the value assumed in the model. After the first second, the current profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 1980 and 2400 cycles. To compensate, the safety system battery chargers are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The steady state current and voltages from CYME matches the test data.

KVA Data:

The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The inrush KVA during the first second on the Unit 2 MFB in the CYME model is approximately 13 percent greater than the test data attributed primarily to the current variance discussed above. After the first second of inrush, the KVA profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 1980 and 2400 cycles. To compensate, the safety system battery chargers are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The steady state KVA from CYME is slightly more than the test data, which is conservative.

KW Data:

The time for LOOP unit loading and the inrush time duration correlate well with the test data. The KW profiles during load start periods and steady state KW correlate well with the test. The steady state KW is slightly more than the test data, which is conservative.

Figures 1-10 and 1-11 are plots of the Unit 3 MFB profiles.

TEST VERSUS MODEL DATA:

Voltage Data:

The model is created such that the Unit MFBs remains connected (with all unit loads off) to the CT3 transformer, which is simulated to remain connected to Keowee prior to the time the Oconee unit loads onto Keowee. Thus the Unit 3 MFB CYME model indicates that voltage is available on the main feeder bus during the time prior to the Unit loading onto the main feeder bus. Once the Unit 1 load start is initiated, the CYME MFB voltage correlates well with the test data.

Current Data:

The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The inrush currents during the first second on the Unit 3 MFB in the CYME model are approximately 13 percent greater than the test data. The difference in inrush currents is attributed to the loadcenter transformers. Loadcenter transformer inrush current magnitudes are highly dependent upon transformer residual flux and voltage phase angle when energized, so the transformer inrush current during the test was apparently less than the value assumed in the model, which is conservative. After the first second, the current profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 2100 and 3300 cycles. To compensate, the safety system battery chargers are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The steady state current and voltages from CYME matches the test data.

KVA Data:

The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The inrush KVA during the first second on the Unit 3 MFB in the CYME model is approximately 14 percent greater than the test data attributed primarily to the current variance discussed above. After the first second of inrush, the KVA profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 2100 and 3300 cycles. To compensate, the safety system battery chargers are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The steady state KVA from CYME is slightly more than the test data, which is conservative.

KW Data:

The time for LOOP unit loading and the inrush time duration correlate well with the test data. The KW profiles during load start periods and steady state KW correlate well with the test. The steady state KW is slightly more than the test data, which is conservative.

3.1.3 Model 1 / Test 2, 4KV Motor Profiles (V, I, KVA, KW)

During the test, voltages were monitored at the 4.16KV switchgear level. Points from the motor feeder overcurrent relay settings are also plotted for each motor on Figures 1-12, 14, 16, and 18. The test data and the model data indicates a significant margin between motor starting and overcurrent relay tripping for each motor. The voltage plotted is the voltage at the switchgear supplying the motor. A comparative discussion of the test versus model data is included below.

Figures 1-12 and 1-13 are the plots of the MDEFW 3B profile.

TEST VERSUS MODEL DATA:

The model voltage is very close to the test value through out the motor start. The initial motor starting current is approximately the same as the test value but during the start, the model starting current drops below the test value. The model steady state value for the current is essentially the same as the test current. Thus, the starting time for the model at loading is slightly longer than for the test, which is conservative. Model KVA and KW draw during the motor starting period is slightly less than the test values. Model steady state voltage, current, KVA and KW are close to the test values.

Figures 1-14 and 1-15 are the plots of the HPI 3B profile.

TEST VERSUS MODEL DATA:

The model voltage is close to the test voltage. Model motor starting current is essentially the same as the test value except the model takes slightly longer to start which is conservative. Model inrush KVA and KW are very near the test values except that the model takes slightly longer to start. Model steady state voltage, current, KVA and KW are very close to the test values.

Figures 1-16 and 1-17 are the plots of the MDEFW 1A profile.

TEST VERSUS MODEL DATA:

The model voltage is very close to the test value through out the motor start. The initial motor starting current is approximately the same as the test value but during the start, the model starting current drops slightly below the test value. Model steady state value for the current is essentially the same as the test current. Thus, the starting time for the model is slightly longer than for the test, which is conservative. Model KVA and KW draw during the motor starting are slightly less than the test values. While the present degree of motor parameter correlation is acceptable, it is anticipated that motor signature tests will allow an even closer correlation for starting motor current, KW, and KVA in the future. Model steady state voltage, current, KVA and KW are close to the test values.

Figures 1-18 and 1-19 are the plots of the LPSW 3B profile.

TEST VERSUS MODEL DATA:

Model starting voltage for the LPSW motor is slightly less than the test value. Starting current, KVA and KW are less than the test values. Model motor start time is longer than the test time which is conservative. While the present degree of motor parameter correlation is acceptable, it is anticipated that motor signature tests will allow an even closer correlation for starting motor current, KW, and KVA in the future. Steady state voltage, current, KVA and KW are very close to the test values.

3.1.4 Model 1 / Test 2, 600V RBCF 3B

The RBCF 3B was not started during Test 2.

3.1.5 Model 1 / Test 2, 600V Loadcenter Profiles (V, I, KVA, KW)

Figures 1-20 and 1-21 are the profiles for 1X5. After approximately a 0.5 second delay there is a significant increase in load, which is consistent with motors starting after the voltage reaches the contactor pickup voltage.

Figures 1-22 and 1-23 are the profiles for 1X6. There is a significant increase in load after approximately 0.5 seconds, which is consistent with motors starting when the voltage reaches contactor pickup voltage. Approximately 6 seconds after energization, a battery charger is loaded.

Figures 1-24 and 1-25 are the profiles for 3X5. There is a significant increase in load after approximately 1.5 seconds, which is consistent with motors starting when the voltage reaches contactor pickup voltage. Approximately 9 seconds after energization, a battery charger is loaded.

Figures 1-26 and 1-27 are the profiles for 3X6. The characteristics for 3X6 are very similar to the profiles for 3X5.

TEST DATA VERSUS MODEL DATA:

The loads fed from 1X5, 1X6, 2X5, 2X6, 3X5 and 3X6 are non-safety-related loads. The loads are not individually modeled in CYME. To ensure that the model reflected the impact of these loads on safety system voltages, the 1X5, 1X6, 3X5 and 3X6 test data was used to determine an equivalent KVA and KW, broken down into 4 time intervals, and block loaded on the appropriate bus. Since data was not measured on 2X5 and 2X6, the 1X5 and 1X6 data is used for the Unit 2 buses. A review of the Unit 1 and 3 KW and KVA plots indicate that the simulated loads adequately represent the actual loads seen during test 2.

Figures 1-28 and 1-29 are the profiles for 3X8. The loading right after energization includes a RBCF starting on low speed. At approximately 3 seconds after energization, the battery charger is loaded. At approximately 31 seconds the RBCF transfers to high speed.

Figures 1-30 and 1-31 are the profiles for 3X9. There is an immediate increase in loading when the loadcenter is energized as a RBCF starts on low speed. Approximately 5 seconds after energization, a battery charger is loaded. The RBCF transfers to high speed approximately 17 seconds after energization.

TEST VERSUS MODEL DATA

The Units 1, 2, and 3 loadcenter X8 and X9 loads are modeled individually where possible. CYME does not provide a specific model for a battery charger, and thus the load due to the charger is simulated, using a 1 step block loading approach.

The modeling for 3X8 includes a RBCF starting on low speed as well as a battery charger restarting. The model starts the RBCF from zero speed whereas in the test, the RBCF was initially running on high speed and would still be rotating near the low speed value when re-energized on low speed. Thus, there is a difference between the test and CYME model data for the time this motor is starting. In the model, the fan continuously runs on low speed whereas in the test the fan later transfers to high speed. To compensate, the safety system battery chargers are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The net effect on steady state loading is that the model will have a slightly greater running load. The figures indicate that the voltage profiles for the model and test correlate very closely. Model starting time for the RBCF (the first inrush value) is longer than for the test because the RBCFs were still rotating when started during the test. Model steady state loading is slightly higher as expected.

The modeling for 3X9 includes a RBCF starting on low speed as well as a battery charger restarting. The model starts the RBCF from zero speed whereas in the actual test, the RBCF was initially running on high speed and would still be rotating near the low speed value when re-energized. In the model, the fan continues to run on low speed whereas in the test the fan later transfers to high speed. In the model, the battery charger is modeled running at 110 percent load when re-energized whereas in the actual test, the load decreased exponentially to a much lower value. The net effect on steady state loading is that the model will have a slightly greater running load. The figures indicate that the voltage profiles for the model and test correlate very closely. Model starting time for the RBCF (the first inrush value) is longer than for the test because the RBCFs were still rotating when restarted in the test. Model steady state loading is slightly higher as expected.

3.1.6 Model 1 / Test 2, 600V Safety MCC Profiles (V, I, KVA, KW)

Figures 1-32 thru 1-37 chart the voltage, current, KVA and KW profiles for 600V Safety Motor Control Centers (MCCs) 3XS1, 3XS2, and 3XS3 that were monitored during the test. The load increase at energization is small. A significant increase in loading occurs on 3XS1 and 3XS2 when the battery chargers load. Note that the charger loading has negligible impact on MCC voltage. Minimum voltage after MCC energization is 439.3V (73.2 percent of rated value) and occurs on 600V MCC 3XS2. The minimum MCC steady state voltage is 627V (104.5 percent of rated value) on 3XS1. Voltage recovers to near the steady state value in approximately 2 seconds for 3XS1 and 3XS2, and 3 seconds for 3XS3.

TEST VERSUS MODEL DATA:

The largest load on the motor control center 3XS1 is the battery charger. CYME does not provide a specific model for a battery charger. Thus, the charger is modeled as an one step block load. Therefore, the battery charger is modeled running at 110 percent load when re-energized whereas in the actual test, the load decreased exponentially to a much lower value. The net effect on steady state loading is that the model will have greater running load at the motor control center level. From the figures, we see that the voltage profiles for the model and test correlate very closely during the inrush or large motor starting period. During steady state conditions, the model voltage is slightly higher than the test voltage. This difference is attributed to recording tolerance since the model voltage at loadcenter 3X8 which directly feeds this motor control center correlates well with the test results.

The largest load on the motor control center 3XS2 is the battery charger. CYME does not provide a specific model for a battery charger. Thus, the charger is modeled as an one step block load. Therefore, the battery charger is modeled running at 110 percent load when re-energized whereas in the actual test, the load decreased exponentially to a much lower value. The net effect on steady state loading is that the model will have greater running load at the motor control center level. The figures indicate that the voltage profiles for the model and test correlate very closely during the inrush or larger motor starting period and the steady state period.

The model load on MCC 3XS3 is the calculated loading and as can be seen in the figures conservatively exceeds the measured loading. The model voltage profile correlates well with the measured results.

3.1.7 Model 1 / Test 2, 208V Safety MCC Profiles (V, I, KVA, KW)

Figures 1-38 thru 1-43 chart the voltage, current, KVA and KW profiles for 208V Safety MCCs 3XS1, 3XS2, and 3XS3 monitored during the test. The load increase at energization is small. The 208V MCCs primarily serve MOVs which do not operate during a LOOP. Minimum voltage after MCC energization is 149.8V (72 percent of rated value) and occurs on 208V MCC 3XS2. The minimum steady state voltage occurs on 3XS2 and is 219.9V. Figure 1-42 indicates a constant load on 208V MCC 3XS3 of approximately one ampere, even during the loss-of-voltage. The expected load on this MCC is near zero (motor controller power), and the lack of current change during the loss and restoration of power confirms this is correct.

TEST VERSUS MODEL DATA:

The model loading on the 208V MCCs is all worst case calculated loading. In each case, the model loading is conservatively greater than the test loading. For example in the actual test, the load on 3XS3 was 0 KW, but the calculated worst case loading is 2 KW. In all cases, the model voltage profiles correlate well with the measured profiles.

3.1.8 Model 1/ Test 2, Battery Charger 3CA (V, I)

The battery charger was monitored to provide an indication of the peak and steady state charger load that can be expected after an event. CYME does not provide a specific model for a battery charger, and thus the load due to the charger is simulated, using a block loading approach. Since CYME did not directly create the battery charger operation, the charger plot was not recreated for this report. The 600V MCC plots (Figures 1-32, 33, 34, and 35) may be reviewed if desired to compare charger simulated data versus test data.

3.2 Model 2 / Test 5, Oconee LOCA/LOOP With Failure Of The Overhead Path And Keowee Initially Generating To The Grid

This test simulated a LOCA/LOOP on Oconee Unit 3 and a LOOP on Units 1 and 2. The LOCA unit loads first followed later by the two LOOP units. This test represents the largest cumulative load automatically applied to the Keowee Underground Circuit. In this test, Keowee Unit 2 was initially loaded to approximately 60 MW. The load applied to Keowee is sequenced in two blocks. The LOCA unit will be loaded following load rejection at rated voltage and 110 percent frequency decreasing. The two LOOP units load later. The expected scenario for this test is as follows:

- Oconee Unit 3 LOCA/LOOP, Unit 1 and 2 LOOP at t=0 seconds
- CT4 energized from Keowee Unit 2
- Oconee 3 MFB loads onto the Underground Circuit at $t \approx 20$ seconds
- Units 1 and 2 load onto the underground at $t \approx 31$ seconds
- Unit 3 loadcenter 3X4 loads at $t \approx 61$ seconds
- Unit 1 Loadcenter X7 and Unit 4 Loadcenter X4 load at $t \approx 81$seconds

3.2.1 Model 2 / Test 5, Keowee Profile (V, I, KVA, KW, f)

Figures 2-1 through 2-5 plot the Keowee response to this case. In these plots, t = 0 is assigned to the time when Keowee Unit 2 load rejects on Emergency Start actuation.

Figure 2-1 is a plot of the Keowee voltage and current response.

TEST DATA:

Transformer CT4 is energized approximately 879 cycles (14.7 seconds). Maximum CT4 inrush current is 513 amperes. The MFB bus on Unit 3 loads at approximately 892 cycles (14.9 seconds). Maximum current inrush is 1303 amperes rms, and lasts approximately 3 seconds. At approximately 1919 cycles (32 seconds) the first LOOP unit loads and the second LOOP unit loads at approximately 1963 cycles (32.7 seconds). Maximum inrush current due to the LOOP units loading was 1583 amperes. Between 2340 and 3800 cycles, additional inrush currents occur as the Reactor Building Cooling Fans on the LOOP units transfer to high speed. At approximately 3868 cycles (64.5 seconds) an additional small inrush occurs as Loadcenter 3X4 loads on Unit 3. Loadcenters 1X7 and 2X4 load simultaneously at 4990 cycles (83.4) seconds. Final steady state current is approximately 500 amps.

MODEL DATA:

The CYME data time is adjusted to align with the timing of the initiating event (the Keowee load rejection). The time for LOCA and LOOP unit loading and the inrush time duration correlate well with the test data.

LOCA Unit Load Transient at approximately 900 Cycles: The transformer inrush current when the LOCA Unit loads has a magnitude of approximately 480 amperes (model) as compared to 520 amperes (test). This difference is attributed primarily to the fact that the test data includes dc offset current and harmonic currents, whereas the model data includes only 60 Hz currents. The relaying protecting the CT4 transformer is designed to account for the DC offset and harmonic currents. The inrush current during LOCA unit load start has a magnitude of approximately 1620 amperes (model) as compared to 1300 amperes (test). This difference is attributed to 1) the fact that during the test all loads would not have been expected to be energized at precisely the same instant in time as is true in the model, and 2) loadcenter transformer inrush is modeled as an exponentially decaying current based on signature test results with the loadcenter transformer inrush current modeled to occur at exactly the same time. In addition, transformer inrush magnitudes are highly dependent on transformer residual flux and voltage phase angle during energization, so the lower inrush during the test as compared to the model could be expected.

LOOP Unit Load Transient at approximately 1920 Cycles: The 0.7 second difference between the LOOP Unit load time is modeled. The inrush current during the first LOOP unit load start has a magnitude of approximately 1200 amperes (model) as compared to 1140 amperes (test). The inrush current during the second LOOP unit load start has a magnitude of approximately 1850 amperes (model) as compared to 1590 amperes (test). This difference in the inrush currents is attributed to 1) the fact that during the test all loads would not have been expected to be energized at precisely the same instant in time as is true in the model, and 2) loadcenter transformer inrush is modeled as an exponentially decaying current based on signature test results with the loadcenter transformer inrush current modeled to occur at exactly the same time. In addition, transformer inrush magnitudes are highly dependent on transformer residual flux and voltage phase angle during energization, so the lower inrush during the test as compared to the model could be expected.

After the LOOP unit start transient, a current rise at approximately 3600 cycles was a result of the RBCF motors switching from low speed to high speed. This is not simulated in the model since the model would assume the motor is starting in high speed from a zero speed condition and not from the low speed running condition as was true during the test. Hence, no benefit is seen in modeling the motor, and thus there is some loss of correlation between approximately 2800 and 4200 cycles. To compensate, the safety system battery chargers (for the LOOP units only) are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The delayed energization of loadcenters 3X4, 1X7, and 2X4 are modeled and correlate well with the test results. The steady state current and voltages from the CYME model matches the test data.

Figure 2-2 is a plot of the Keowee voltage during the main inrush periods.

TEST DATA:

The generator voltage dips to a minimum of 12.990 KV (94.1 percent of rated value) during the Unit 3 load inrush at 892 cycles (14.9 seconds). The voltage recovers to near steady state value in slightly over 2 seconds. The voltage sags slightly (to approximately 13.95KV) at approximately 1200 cycles when the Keowee frequency undershoots due to action of the V/Hz limiter. The voltage dips to 13.004KV (94.2 percent of rated value) at 1920 cycles (32.8 seconds) when the two LOOP Units load. Voltage recovery to near steady state value occurs in less than 3 seconds. The small 0.73 second time difference in the loading of the LOOP units can be seen reflected in the voltage dips.

MODEL DATA:

The Keowee load rejection voltage response of the model and the test are very similar.

LOCA Unit Start Transient: The first voltage dip occurs when the CT4 transformer is energized and the dip is approximately 1.5 percent greater for the model than for the test even though the model inrush current is less than the test value. The test inrush includes dc offset and harmonics which do not contribute directly to the 60 Hz voltage dip. The 60 Hz component of the test inrush current could not be determined from the test data, so a conservative estimate was made of the 60 HZ component for input to CYME. The estimate is confirmed to be conservative by the fact that the voltage dip during the inrush transient in the model is greater than the voltage dip measured during the test, which implies that the 60 Hz inrush component input to CYME is larger than the inrush that actually occurred during the test. A second inrush occurs immediately after the transformer inrush due to the LOCA Unit loading onto Keowee, resulting in an approximately 3 percent greater voltage dip for the model compared to the test due to the higher model inrush currents. This difference is attributed to 1) the fact that during the test all loads would not have been expected to be energized at precisely the same instant in time as is true in the model, and 2) loadcenter transformer inrush is modeled as an exponentially decaying current based on signature test results with the loadcenter transformer inrush current modeled to occur at exactly the same time. In addition, transformer inrush magnitudes are highly dependent on transformer residual flux and voltage phase angle during energization, so the inrush during the test may have been less than that modeled. The time required for the model voltage to recover to nominal, and the model voltage profile during the transient correlates well with the test voltage.

Steady State period from approximately 1050 to 1900 cycles: The model steady state Keowee voltage is essentially the same as the test steady state voltage, although some cycling of the test voltage is not reflected in the model. The test voltage cycling is attributed to action of the V/Hz limiter module in the voltage regulator. The model voltage does not cycle since the model frequency does not dip appreciably below 60 Hz.

LOOP Unit Start Transients: The first voltage dip occurs when the first LOCA Unit loads onto Keowee, resulting in an approximately 2 percent greater voltage dip for the model compared to the test due to the higher model inrush currents. This difference is attributed to 1) the fact that during the test all loads would not have been expected to be energized at

precisely the same instant in time as is true in the model, and 2) loadcenter transformer inrush is modeled as an exponentially decaying current based on signature test results with the loadcenter transformer inrush current modeled to occur at exactly the same time. In addition, transformer inrush magnitudes are highly dependent on transformer residual flux and voltage phase angle during energization, so the inrush during the test may have been less than that modeled. The time required for the model voltage to recover to nominal correlates well with the test voltage, and correlation of the voltage profiles during the transient is good (approximately 1.5 percent difference).

The second voltage dip occurs when the other LOOP Unit loads onto Keowee. The magnitude of this decrease in the model voltage is approximately the same as the test, however when the second unit is applied, the model voltage had recovered more than the test voltage from the first Unit load transient, and thus the test voltage dipped to a value 2 percent less than the model. After the second dip, the initial rate of increase of the model voltage is again faster than the test voltage, but the maximum difference in the model and test voltages during the transient is less than 2.5 percent, which is considered good. After the LOOP loading transient, the steady state voltages correlate well.

Figure 2-3 is a plot of the KVA output from Keowee.

TEST DATA:

Just before load rejection, the load was 58,800 KVA. During the Unit 3 LOCA loading, the maximum load is approximately 30,600 KVA. During LOOP unit loading, the maximum load was 36,000 KVA. The steady state load is approximately 12,000 KVA.

MODEL DATA:

The time for LOCA and LOOP unit loading and the inrush time duration correlate well with the test data. The model transformer KVA inrush matches the test KVA. The inrush model LOCA Unit start inrush of 35000 KVA is conservatively greater than the test inrush of 31,000 KVA. The model steady state KVA between the LOCA and LOOP Unit load transients is the same as the test value. The model first LOOP Unit start inrush of 28,000 KVA is conservatively greater than the test inrush of 26000 KVA, and the model second LOCA Unit start inrush of 43000 KVA is conservatively greater than the test inrush of 36,000 KVA. Final model steady state load of 12000 KVA matches the test results. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 2800 and 4200 cycles. To compensate, the safety system battery chargers (for the LOOP units only) are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The net effect on steady state loading is that the model will have a slightly greater running load. The delayed energization of loadcenters 3X4, 1X7, and 2X4 at approximately 4980 cycles is modeled, and correlates well with the test results.

Figure 2-4 is a plot of the KW output from Keowee.

TEST DATA:

Just before load rejection, the load was 58,200 KW. The maximum inrush when the Unit 3 LOCA loads is connected is 8,400 KW with a steady state LOCA load of 4,200 KW. The maximum inrush KW occurs after the Unit 1 and Unit 2 LOOP units load and is 13,200 KW. Once all loads is operating, steady state load is 9,637 KW.

MODEL DATA:

The time for LOCA and LOOP unit loading and the inrush time duration of the model correlate well with the test data. The model LOCA Unit start inrush of 9000 KW matches the test inrush. The model steady state KW between the LOCA and LOOP Unit load transients is approximately the same as the test value, with the difference attributed to the difference between model and test frequency during this time. The model LOOP Unit start inrush KW for both Units correlates well with the test inrush KW. The model steady state load of approximately 9800 KW matches the test results. The delayed energization of loadcenters 3X4, 1X7, and 2X4 is modeled, and correlates well with the test results.

Figure 2-5 is a plot of the frequency response.

TEST DATA:

Frequency is approximately 65 Hz when CT4 is energized and 64.7 Hz when Unit 3 loads. Minimum frequency after loading was approximately 57.6 Hz at 1169 cycles. Frequency recovers to above 60 Hz (60.9 Hz) due to the governor speed droop characteristic.

MODEL DATA:

The model overspeed is less than the test overspeed. The Oconee loads are placed onto the model at the time the loading actually occurred during the test. Model peak frequency is approximately 74.7 Hz versus approximately 77.5 Hz. Model Frequency at LOCA Unit loading is approximately 62 Hz versus 64.7 Hz in the test. Model minimum frequency is approximately 60 Hz versus approximately 57 Hz in the test. The model steady state frequency value is the same as in the test.

3.2.2 Model 2 / Test 5, MFB Profiles (V, I, KVA, KW)

Time t=0 is defined as the loss of voltage on Unit 1 for all of these plots. An examination of the plots show that Unit 3 (LOCA unit) loaded first, Unit 2 loaded second and Unit 1 loaded approximately 0.8 seconds after Unit 2.

Figures 2-6 and 2-7 are the plots of the Unit 1 MFB profiles.

TEST VERSUS MODEL DATA:

Voltage Data:

The model is created such that the Unit MFBs remains connected (with all unit loads off) to the CT4 transformer, which is simulated to remain connected to Keowee prior to time the unit loads onto Keowee. Thus the Unit 1 MFB CYME voltage indicates that voltage is available on the standby bus during the time prior to the Unit loading onto the standby bus. Once the Unit 1 load start is initiated, the CYME MFB voltage correlates well with the test data.

Current Data:

The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The initial inrush currents on the Unit 1 MFB in the CYME model peak approximately 20 percent greater than the test data. The difference in inrush currents is attributed to the loadcenter transformers. Loadcenter transformer inrush current magnitudes are highly dependent upon transformer residual flux and voltage phase angle when energized, so the transformer inrush current during the test was apparently less than the value assumed in the model. After the initial inrush, the current profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 2800 and 4200 cycles. To compensate, the safety system battery chargers are modeled on the LOOP units as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The delayed energization of loadcenter 1X7 is modeled, and correlates well with the test results. The steady state current and voltages from CYME matches the test data.

KVA Data:

The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The initial inrush KVA on the Unit 1 MFB in the CYME model is approximately 14 percent greater than the test data attributed primarily to the current variance discussed above. After the initial inrush, the KVA profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 2800 and 4200 cycles. To compensate, the safety system battery chargers are modeled on the LOOP units as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The delayed energization of loadcenter 1X7 is modeled, and correlates well with the test results. The steady state KVA from CYME matches the test data.

KW Data:

The time for LOOP unit loading and the inrush time duration correlate well with the test data. The KW profiles during load start periods and steady state KW correlate well with the test.

Figures 2-8 and 2-9 are the plots of the Unit 2 MFB profiles.

TEST VERSUS MODEL DATA:

Voltage Data:

The model is created such that the Unit MFBs remains connected (with all unit loads off) to the CT4 transformer, which is simulated to remain connected to Keowee prior to time the unit loads onto Keowee. Thus the Unit 2 MFB CYME model indicates that voltage is available on the standby bus during the time prior to the Unit loading onto the standby bus. Once the Unit 2 load start is initiated, the CYME MFB voltage correlates well with the test data.

Current Data:

The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The initial inrush currents on the Unit 2 MFB in the CYME model are approximately 3 percent greater than the test data. The difference in inrush currents is attributed to the loadcenter transformers. Loadcenter transformer inrush current magnitudes are highly dependent upon transformer residual flux and voltage phase angle when energized, so the transformer inrush current during the test was apparently less than the value assumed in the model. After the initial inrush the current profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 3700 and 4300 cycles. To compensate, the safety system battery chargers are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The delayed energization of loadcenter 2X4 is modeled, and correlates well with the test results. The steady state current and voltages from CYME matches the test data.

KVA Data:

The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The initial inrush KVA on the Unit 2 MFB in the CYME model is approximately 5 percent greater than the test data attributed primarily to the current variance discussed above. After the initial inrush, the KVA profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 3700 and 4300 cycles. To compensate, the safety system battery chargers are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The delayed energization of loadcenter 2X4 is modeled, and correlates well with the test results. The steady state KVA from CYME match the test data.

KW Data:

The time for LOOP unit loading and the inrush time duration correlate well with the test data. The KW profiles during load start periods and steady state KW correlate well with the test.

Figure 2-10 is a plot of the standby bus voltage and Unit 3 MFB current. Since the standby bus voltage was monitored for Unit 3, the test data in Figure 2-10 shows the standby bus being energized from Keowee prior to the MFBs being energized on any of the units.

Figure 2-11 is a plot of the Unit 3 loading.

TEST VERSUS MODEL DATA:

Voltage Data:

The model is created such that the Unit MFBs remains connected (with all unit loads off) to the CT4 transformer, which is simulated to remain connected to Keowee prior to time the unit loads onto Keowee. Thus the CYME model reflects the voltage on the standby bus during the time prior to the Unit loading onto the standby bus. Once the Unit 3 loads start, the CYME standby bus voltage correlates well with the test data.

Current Data:

The time for the LOCA unit loading and the inrush time duration correlate well with the test data. The initial inrush currents on the Unit 3 MFB in the CYME model are approximately 15 percent greater than the test data. The difference in inrush currents is attributed to the loadcenter transformers. Loadcenter transformer inrush current magnitudes are highly dependent upon transformer residual flux and voltage phase angle when energized, so the transformer inrush current during the test was apparently less than the value assumed in the model. After the initial inrush, the current profiles during load start periods correlate well with the test data. The delayed energization of loadcenter 3X4 is modeled, and correlates well with the test results. The steady state current and voltages from CYME matches the test data.

KVA Data:

The time for the LOCA unit loading and the inrush time duration correlate well with the test data. While the initial inrush KVA on the Unit 3 MFB in the CYME model is approximately 11 percent greater than the test data attributed primarily to the current difference discussed above. After the initial inrush, the KVA profiles during load start periods correlate well with the test data. The delayed energization of loadcenter 3X4 is modeled, and correlates well with the test results. The steady state KVA from CYME matches the test data.

KW Data:

The time for LOCA unit loading and the inrush time duration correlate well with the test data. The KW profiles during load start periods and steady state KW correlate well with the test data.

3.2.3 Model 2 / Test 5, 4KV Motor Profiles (V, I, KVA, KW)

During the test, voltages were monitored at the 4.16KV switchgear level. Points from the motor feeder overcurrent relay settings are also plotted for each motor on Figures 2-12, 14, 16, and 18. The test data and the model data indicates a significant margin between motor starting and overcurrent relay tripping for each motor. A comparative discussion of the test versus model data is included below.

Figures 2-12 and 2-13 are the plots of the MDEFW 3B profiles.

TEST VERSUS MODEL DATA:

The model voltage during motor starting is very close to the test value. Model starting current is also close to the test value. Model motor start time is approximately the same as the test start time. Model starting KVA and KW magnitudes are close to the test values. Model running voltage, current, KVA and KW are very close to the test values.

Figures 2-14 and 2-15 are the plots of the HPI 3B profiles.

TEST VERSUS MODEL DATA:

The model voltage is very near the test voltage. Model motor starting current is essentially the same as the test value. Model inrush KVA and KW are very near the test values. Model steady state voltage, current, KVA and KW are very close to the test values.

Figures 2-16 and 2-17 are the plots of the MDEFW 1A profiles.

TEST VERSUS MODEL DATA:

The model voltage is very close to the test value through out the motor start. The model motor starting current is initially greater than the test value, and then drops slightly below the test value during the start. Thus the starting time for the model is slightly longer than for the test, which is conservative. While the present degree of motor parameter correlation is acceptable, it is anticipated that motor signature tests will allow an even closer correlation for starting motor current, KW, and KVA in the future. Model steady state value for the current is slightly higher than the test current. Model KVA and KW draw during the motor starting are slightly less than the test values. Model steady state KVA and KW are close to the test values.

Figures 2-18 and 2-19 are the plots of the LPSW 3B profiles.

TEST VERSUS MODEL DATA:

Model starting voltage for the LPSW motor is slightly less than the test value. Starting current, KVA and KW are slightly less than the test values. Model motor start time is essentially the same as the test time. While the present degree of motor parameter correlation is acceptable, it is anticipated that motor signature tests will allow an even closer correlation for starting motor current, KW, and KVA in the future. Steady state voltage, current, KVA and KW are very close to the test values.

Figures 2-20 and 2-21 are the plots of the LPI 3B profiles.

TEST VERSUS MODEL DATA:

Model starting voltage for the LPI motor is slightly less than the test value. Starting current, KVA and KW are less than the test values. Model motor start time is longer than the test time which is conservative. While the present degree of motor parameter correlation is acceptable, it is anticipated that motor signature tests will allow an even closer correlation for starting motor current, KW, and KVA in the future. Steady state Current, KVA, and KW are very close to the test values, although the test steady state values are initially lower than the model. The steady state test values increased after the start due to throttling of the LPI system, while CYME modeled the motor starting to the post-throttling load , which would explain the longer start time.

Figures 2-22 and 2-23 are the plots of the RBS 3B profiles.

TEST VERSUS MODEL DATA:

Model starting voltage for the RBS motor is slightly less than the test value. Starting current, KVA and KW are less than the test values, due to the model frequency being closer to 60 Hz. Model motor start time is slightly shorter than the test time, but the difference is insignificant considering the large margin between the motor start curve and the overcurrent trip curve. While the present degree of motor parameter correlation is acceptable, it is anticipated that motor signature tests will allow an even closer correlation for starting motor current, KW, and KVA in the future. All model steady state values are close to the test values.

3.2.4 Model 2 / Test 5, 600V RBCF 3B Motor Starting Profiles (V, I, KVA, KW)

Figures 2-24 and 2-25 plot the response of RBCF 3B starting on the LOCA unit. During a LOCA, the RBCFs should start and run on low speed, and RBCF 3B functioned as expected.

TEST DATA VERSUS MODEL DATA:

Immediately prior to the test, the RBCFs 3A and 3C were running in high speed, and RBCF 3B was shutdown. It is postulated that RBCF 3B was rotating backwards due to damper back-leakage. Thus, starting this fan required energy for a longer time during the test than a start from 0 RPM. The model RBCF start assumes a start from 0 RPM, and thus there is a 1.5 second difference in the start time, and higher current and KVA during the start. The CYME model for the RBCF was previously compared to a motor signature where the motor was known to have started from 0 RPM, and the CYME model correlated well with the signature test. Model steady state values correlate well with the test. NSM-3041 will replace the RBCF dampers, and is expected to fix the back-leakage problem causing the reverse rotation.

3.2.5 Model 2 / Test 5, 600V Loadcenter Profiles (V, I, KVA, KW)

Figures 2-26 and 2-27 are the profiles for 1X5. Since voltage was approximately 75 percent of rated value when the loadcenter was energized, loads started simultaneously with loadcenter energization.

Figures 2-28 and 2-29 are the profiles for 1X6. After less than a 1 second delay there is a significant increase in load, which is consistent with motor starting after the voltage reaches the contactor pickup voltage. Approximately 6 seconds after energization, a battery charger is loaded.

Figures 2-30 and 2-31 are the profiles for 3X5. After approximately a 1 second delay there is a significant increase in load, which is consistent with motor starting after the voltage reaches the contactor pickup voltage. Approximately 9 seconds after energization, a battery charger is loaded. Loading of the LOOP units result in a voltage dip, during which the loadcenter current decreased momentarily.

Figures 2-32 and 2-33 are the profiles for 3X6. The characteristics for 3X6 are very similar to profiles for 3X5.

TEST DATA VERSUS MODEL DATA:

The loads fed from 1X5, 1X6, 2X5, 2X6, 3X5 and 3X6 are non-safety-related loads, and their operation during an emergency event is not safety significant. These loads are not individually modeled in CYME. To ensure the model reflected the impact of these loads on safety system voltages, the 1X5 and 1X6 Test 5 data was used to determine an equivalent KVA and KW, broken down into 4 time intervals, to be block loaded on the appropriate bus for all three units. A review of the Unit 1 and 3 KW and KVA plots indicate that the simulated loads adequately represent the actual loads seen during Test 5.

Figures 2-34 and 2-35 are the profiles for 3X8. There is less than a 1 second delay after energization before a significant load increase occurs. The loading at approximately 1 second after energization is a RBCF starting on low speed and other motor loads starting. Approximately 3 seconds after energization, the battery charger is loaded. Loading of the LOOP units causes a short dip in the loadcenter amperes. The current on 3X8 (which is the source for the 3CA battery charger) during this transient correlates well with the 3CA battery charger current for the same time period.

Figures 2-36 and 2-37 are the profiles for 3X9. There is an increase in load approximately 1.5 seconds after the loadcenter is energized as a RBCF starts on low speed and other motors start. Approximately 5 seconds after energization, a battery charger is loaded. Loading of the LOOP units causes a momentary dip in the loadcenter ampere load.

The time delay in load increases on some buses due to the power battery charger restarting is expected. The chargers are designed with an automatic time delay in the startup of the charger. No loading anomalies were evident.

TEST DATA VERSUS MODEL DATA:

The Units 1, 2, and 3 loadcenter X8 and X9 loads are modeled individually where possible. There is some mismatch in the initial inrush seen on 3X8 and 3X9 due to the RBCF start.

These motors were running in high speed prior to the test, and drift down slowly on a loss of power. According to RBCF test information, these fans could be expected to reach approximately 400 RPM 15 seconds after the power is removed from the high speed, and would only be required to accelerate 200 RPM to the slow speed running RPM. The CYME model assumes these motors are starting from 0 RPM, and thus calculated a higher start current, KVA, and KW, and a longer start time. CYME does not provide a specific model for a battery charger, and thus the load due to the charger is simulated, using a 1 step block load for LOOP units and 2 step block loading approach for the LOCA unit. A review of loadcenters 3X8 and 3X9 current, KVA and KW plots indicate that the model loads adequately envelope the test loads, and the correlation between the test and model voltages is very good.

3.2.6 Model 2 / Test 5, 600V Safety MCC Profiles (V, I, KVA, KW)

Figures 2-38 through 2-43 chart the voltage, current, KVA and KW profiles for 600V Safety MCCs 3XS1, 3XS2, and 3XS3 that were monitored during the test. The load increases immediately at energization. A significant increase in loading occurs after approximately 5 seconds on 3XS1 and 3XS2 when the battery chargers load. The charger loading has negligible impact on MCC voltage. Starting of RBCF 3B on low speed can be clearly seen in the figures for 3XS3. Loading of the LOOP units causes a short decrease in MCC load amperes. Minimum voltage after MCC energization is 431V (71.8 percent of rated value) and occurs on 600V MCC 3XS3. The minimum steady state voltage MCC voltage is 592V (98.7 percent of rated value) and occurs on 3XS1. Voltage recovers to near the steady state value in 2.5 seconds on 3XS1 and 3XS2. Voltage recovery on 3XS3 takes 6 seconds since the RBCF is starting.

TEST DATA versus MODEL DATA:

The large inrush current on the 3XS3 MCC is due to the RBCF start. Immediately prior to the test, the RBCF 3B was shutdown. It is postulated that RBCF 3B was rotating backwards due to damper back-leakage. Thus, starting this fan required energy for a longer time during the test than a start from 0 RPM. The model RBCF start assumes a start from 0 RPM, and thus there is a 1.5 second difference in the start time, and higher inrush current and KVA during the start. CYME does not provide a specific model for a battery charger, and thus the load due to the charger is simulated, using a 2 step block loading approach. A review of MCCs 3SX1 and 3XS2 current, KVA and KW plots indicate that the model loads adequately envelope the test loads. The correlation between the test and model voltages on 3XS1 is good, and on 3XS2 and 3 is very good.

3.2.7 Model 2 / Test 5, 208V Safety MCC Profiles (V, I, KVA, KW)

Figures 2-44 through 2-49 chart the voltage, current, KVA and KW profiles for 208V Safety MCCs 3XS1, 3XS2, and 3XS3 that were monitored during the test. The load increase

at energization due to MOVs starting is immediate and of short duration. The LOOP units loading causes a momentary dip in the MCC amperes. Minimum voltage after MCC energization is 146V (70.2 percent of rated value) and occurs on 208V MCC 3XS2. The minimum steady state voltage occurs on 3XS1 and 3XS2 and is 208V. The momentary current spike seen on 208V MCCs 3XS1 and 3XS2 at loss of voltage is due to the ES channels 1 and 2 (HPI) MOVs receiving a start signal prior to the actual loss of power to the MCCs.

TEST DATA versus MODEL DATA:

The MOVs powered from these MCCs are modeled to start concurrently, with the starting current required for 15 cycles, and the valves running for 15 seconds (900 cycles). In actuality, the starting times of the MOVs vary, and some of the MOVs take longer than 15 seconds, thus for a period of time on MCC 3XS2, the model KVA and current drops slightly below the actual, but this difference is so small it is not considered significant. For all other intervals on 3XS2, and all intervals on the other MCCs, the model loading is conservatively greater than the test loading as expected, since other model loads on the 208V MCCs are worst case calculated loading. In all cases, the model voltage profiles correlate well with the measured profiles.

3.2.8 Model 2/ Test 5, Battery Charger 3CA (V, I)

The battery charger was monitored to provide an indication of the peak and steady state charger load that can be expected after an event. CYME does not provide a specific model for battery charger, and thus the load due to the charger is simulated, using a 2 step block loading approach. Since CYME does not provide a specific model for battery charger operation, the charger plot was not recreated for this report. The 600V MCC plots (Figures 2-38, 39, 40, and 41) may be reviewed if desired to compare charger simulated versus test data.

3.3 Model 3 / Test 6, Oconee LOCA/LOOP with Lee CT Generator Supplying Emergency Power

This test represented the largest cumulative load automatically applied to the Lee Combustion Turbine (CT) Generator. The LOCA (Unit 3) unit was loaded at rated voltage and frequency. The two LOOP units (Units 1 and 2) loaded approximately 20 seconds later. Finally the non-safety, non-loadshed loadcenters on the LOOP only units load approximately 30 seconds after the second load transient. The expected scenario for this test is listed below:

- Oconee Unit 3 LOCA and Unit 1 and 2 LOOP at t=0 seconds
- Oconee 3 MFB loads onto Lee at t ≈ 11 seconds
- Units 1 and 2 load onto Lee at t ≈ 31 seconds
- Units 1, 2 and 3 loadcenters 1X5, 1X6, 2X5, 2X6, and 3X4 load at t ≈ 61 seconds
- Unit 1 Loadcenter 1X7 and Unit 2 Loadcenter 2X4 load at t ≈ 81seconds

In all plots for this test, Time t = 0, is assigned to 6 cycles after the power source was lost from the Unit 3 MFB on LOOP and ES actuation.

3.3.1 Model 3 / Test 6, Lee Profile (V, I, KVA, KW, f)

Figures 3-1 thru 3-5 are plots of the Lee response for this case

Figure 3-1 is a plot of the Lee voltage and current response.

TEST DATA:

Unit 3 LOCA loads connect to Lee at approximately 757 cycles (12.6 seconds). Maximum inrush current was 1243 amperes. The first LOOP loads at approximately 1889 cycles (31.5 seconds) followed by the other LOOP unit at 1952 cycles (32.5 seconds) Maximum current inrush is 1244 amperes rms. At approximately 2400 cycles (49.7 seconds) a RBCF transfers to high speed. Between approximately 2600 cycles and 4200 cycles additional loads are connected which includes RBCF transfers to high speed and loading loadcenters X5 and X6 on Units 1 and 2. Loadcenters 1X7 and 2X4 load approximately 1 second apart starting at 4950 cycles. Steady state current is approximately 552 amperes.

MODEL DATA:

The CYME data time is adjusted to align with the timing of the event which is the first Lee load increase. The time for LOCA and LOOP unit loading and the duration of the inrush period correlate well with the test data.

LOCA Unit Load Transient at approximately 750 Cycles: The load inrush current during LOCA unit load start has a magnitude of approximately 1,310 amperes (model) as compared to 1,250 amperes (test). The differences in magnitudes for the load inrush current is attributed to 1) the fact that during the test all loads would not have been expected to be energized at

precisely the same instant in time as is true in the model, and 2) loadcenter transformer inrush current is modeled as an exponentially decaying current based on signature test results with the loadcenter transformer inrush current modeled to occur at exactly the same time. In addition, transformer inrush magnitudes are highly dependent on transformer residual flux and voltage phase angle during energization, so the inrush during the test may have been less than that modeled.

LOOP Unit Load Transient at approximately 1850 Cycles: The 1 second difference between the LOOP Unit load time is modeled. The current during the first LOOP unit load start has a magnitude of approximately 970 amperes (model) as compared to 940 amperes (test). The peak current during the second LOOP unit load start has a magnitude of approximately 1320 amperes (model) as compared to 1250 amperes (test). This difference in the current magnitudes is attributed to 1) the fact that during the test all loads would not have been expected to be energized at precisely the same instant in time as is true in the model, and 2) loadcenter transformer inrush is modeled as an exponentially decaying current based on signature test results with the loadcenter transformer inrush current modeled to occur at exactly the same time. In addition, transformer inrush magnitudes are highly dependent on transformer residual flux and voltage phase angle during energization, so the inrush during the test may have been less than that modeled. After the LOOP unit start transient, a current rise at approximately 2800 and 3600 cycles was a result of the RBCF motors switching from low speed to high speed. This is not simulated in the model since the model would assume the motor is starting in high speed from a zero speed condition and not from the low speed running condition as was true during the test. Hence, no benefit was seen in modeling the motor on high speed. To compensate, the safety system battery chargers on the LOOP units are modeled as running continuously at their current limit value of 110 percent rated instead of an exponentially decaying current as observed during the test. This safety system battery charger modeling approach adds a steady state load equivalent to the RBCFs transferring to high speed. The delayed energization of loadcenters 3X4, 1X7, and 2X4 is modeled, and correlate well with the test results. The steady state current and voltages from CYME matches the test data.

Figure 3-2 is a plot of the Lee voltage during the main inrush periods.

TEST DATA:

Generator voltage dips to 12.474KV (90.4 percent of rated value) during the Unit 3 load inrush at 766 cycles (12.8 seconds), and recovers back to nominal in less than 1 second. When Units 1 and 2 load, the voltage dips to 13.278KV (96.2 percent of rated value) at 1899 cycles (31.65 seconds). Generator voltage overshoots during recovery, and stabilizes near the initial steady state value.

MODEL DATA:

LOCA Unit Start Transient: The first voltage dip due to the LOCA Unit loading onto Lee results in an approximately 2 percent greater model voltage dip as compared to the test because of the higher model inrush currents. The difference in inrush currents is attributed to 1) the fact that during the test all loads would not have been expected to be energized at

precisely the same instant in time as is true in the model, and 2) loadcenter transformer inrush is modeled as an exponentially decaying current based on signature test results with the loadcenter transformer inrush current modeled to occur at exactly the same time. In addition, transformer inrush magnitudes are highly dependent on transformer residual flux and voltage phase angle during energization, so the inrush during the test may have been less than that modeled. The time required for the model voltage to recover to nominal, and the model voltage profile during the transient correlates well with the test voltage. The steady state voltages after the first transient correlate almost exactly.

LOOP Unit Start Transients: The first voltage dip when the first Oconee LOOP Unit loads onto Lee results in an approximately 1 percent greater model voltage dip due to the higher inrush currents. This difference is attributed to 1) the fact that during the test all loads would not have been expected to be energized at precisely the same instant in time as is true in the model, and 2) loadcenter transformer inrush is modeled as an exponentially decaying current based on signature test results with the loadcenter transformer inrush current modeled to occur at exactly the same time. In addition, transformer inrush magnitudes are highly dependent on transformer residual flux and voltage phase angle during energization, so the inrush during the test may have been less than that modeled. The time required for the model voltage to recover to nominal correlates well with the test voltage, and correlation of the voltage profiles during the transient is adequate. Another voltage dip occurs when the other LOOP Unit loads onto Lee, and the model voltage profile correlates well. After the LOOP loading transients, the steady state voltages are essentially the same.

Overall, the model voltage profile correlates extremely well with the test results.

Figure 3-3 is a plot of the KVA output from Lee.

TEST DATA:

Just before Oconee Unit 3 loads, the Lee CT was supplying its own auxiliary loads equal to approximately 3,120 KVA. During Unit 3 LOCA loading, the maximum load is approximately 30,713 KVA. Steady state LOCA loading was approximately 8,000 KVA. During LOOP unit loading, the maximum load was 30,720 KVA. The total steady state load is approximately 13,000 KVA.

MODEL DATA:

The time for LOCA and LOOP unit loading and the inrush time duration correlate well with the test data. The LOCA Unit model start inrush of 33000 KVA is conservatively greater than the test inrush peak of 30,500 KVA. The model steady state KVA between the LOCA and LOOP Unit load transients are essentially the same as the test values. The first LOOP Unit model start inrush of 23,000 KVA is conservatively greater than the test inrush of 22,500 KVA, and the second LOOP Unit model start inrush of 32,000 KVA is conservatively greater than the test inrush peak of 31,000 KVA. Final model steady state load of 14,000 KVA matches the test results. The delayed energization of loadcenters 3X4, 1X5, 1X6, 1X7, 2X4, 2X5, and 2X6 is modeled, and correlates well with the test results.

Figure 3-4 is a plot of the KW output from Lee.

TEST DATA:

Just before Oconee Unit 3 loads , the Lee CT auxiliary load was approximately 3120 KW. The maximum inrush when the Unit 3 LOCA loads are connected is 11,040 KW with a steady state LOCA load of approximately 7,200 KW. The maximum inrush of 14,400 KW occurs after the Unit 1 and Unit 2 LOOP loads are applied. Once all loads are operating, steady state load is approximately 11,400 KW.

MODEL DATA:

The time for LOCA and LOOP unit loading and the inrush time duration correlate well with the test data. The LOCA Unit model start inrush of 12,000 KW is conservatively greater than the 11,000 KW test inrush. The model steady state KW loading in the time between the LOCA and LOOP Unit load transients is approximately the same as the test value. The LOOP Unit model start inrush KW for both Units correlate well with the test inrush KW. The delayed energization of loadcenters 3X4, 1X5, 1X6, 1X7, 2X4, 2X5, and 2X6 is modeled, and correlate well with the test results. The final model steady state load of approximately 12,200 KW is conservatively greater than the test result of 12,000 KW.

Figure 3-5 is a plot of the frequency response of the Lee unit.

TEST DATA:

The initial Lee speed before loading was 60.4 Hz. Minimum frequency during loading was approximately 59.3 Hz at 4147 cycles (69.1 seconds). Due to governor speed droop, frequency recovers to approximately 59.4 Hz. Since the CYME program cannot begin its analysis at a frequency different from 60 Hz, the test data was normalized to 60 Hz for comparison with the model.

MODEL DATA:

The steady state frequency decreases with increased load due to governor speed droop. The model steady state values correlate well with the test. During the load application transients, the model frequency dips and then recovers to steady state with no signs of instability, while the test data appears to transition without overshoot. The difference between the model response and the test response is insignificant.

3.3.2 Model 3 / Test 6, MFB Profiles (V, I, KVA, KW)

Figures 3-6 and 3-7 are the plots of the Unit 1 MFB profiles.

TEST VERSUS MODEL DATA:

Voltage Data: The model is created such that the Unit MFBs remains connected (with all unit loads off) to the CT5 transformer, which is simulated to remain connected to Lee prior to the time the unit loads onto Lee. Thus the Unit 1 MFB CYME model indicates that voltage

is available on the standby bus during the time prior to the Unit loading onto the standby bus. Once the Unit 1 load start is initiated, the CYME MFB voltage correlates well with the test data.

Current Data: The time for the LOOP unit loading and the inrush time duration correlates well with the test data. The initial inrush current on the Unit 1 MFB in the CYME model is essentially the same as the test data, and after the initial inrush the current profiles during load start periods also correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 2800 and 4200 cycles. To compensate, the safety system battery chargers on the LOOP units are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The delayed energization of loadcenters are modeled, and correlates well with the test results. The steady state current and voltages from CYME matches the test data.

KVA Data: The time for the LOOP unit loading and the inrush time duration correlates well with the test data. While the initial inrush KVA on the Unit 1 MFB in the CYME model is slightly greater than the test data, after the initial inrush, the KVA profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 2800 and 4200 cycles. To compensate, the safety system battery chargers on the LOOP units are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The delayed energization of loadcenters 1X5, 1X6, and 1X7 are modeled, and correlates well with the test results. The steady state KVA from CYME matches the test data.
KW Data: The time for LOOP unit loading and the inrush time duration correlate well with the test data. The KW profiles during load start periods and steady state KW correlate well with the test.

Figures 3-8 and 3-9 are the plots of the Unit 2 MFB profiles.

TEST VERSUS MODEL DATA:

Voltage Data: The model is created such that the Unit MFBs remains connected (with all unit loads off) to the CT5 transformer, which is simulated to remain connected to Lee prior to the time the unit loads onto Lee. Thus the Unit 2 MFB CYME model indicates that voltage is available on the standby bus during the time prior to the Unit loading onto the standby bus. Once the Unit 2 load start is initiated, the CYME MFB voltage correlates well with the test data.

Current Data: The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The initial inrush current on the Unit 2 MFB in the CYME model is essentially the same as the test data, and after the initial inrush, the current profiles during load start periods also correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 3600 and

4200 cycles. To compensate, the safety system battery chargers on the LOOP units are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The delayed energization of the non-safety loadcenter is modeled, and correlates well with the test results. The steady state current and voltages from CYME matches the test data.

KVA Data: The time for the LOOP unit loading and the inrush time duration correlates well with the test data. The initial inrush KVA on the Unit 2 MFB in the CYME model is greater than the test data, which is conservative. After the initial inrush the KVA profiles during load start periods correlate well with the test data. The RBCF transfer to high speed is not modeled, and thus there is some loss of correlation between approximately 2800 and 4200 cycles. To compensate, the safety system battery chargers on the LOOP units are modeled as running continuously at their current limit value of 110 percent of rated value instead of as an exponentially decaying current as observed during the test in order to add a steady state load equivalent to the RBCFs transferring to high speed. The delayed energization loadcenters 2X4, 2X5, and 2X6 are modeled, and correlates well with the test results. The steady state KVA from CYME matches the test data.

KW Data: The time for LOOP unit loading and the inrush time duration correlates well with the test data. The KW profiles during load start periods and steady state KW correlate well with the test.

Figure 3-10 is a plot of the Standby Bus voltage and Unit 3 MFB current. Since the standby bus voltage was monitored for Unit 3, the test data in Figure 3-10 shows the standby bus being energized from Lee prior to the MFBs being energized on any of the units.

Figure 3-11 is a plot of the Unit 3 loading.

TEST VERSUS MODEL DATA:

Voltage Data: The model is created such that the Unit MFBs remains connected (with all unit loads off) to the CT5 transformer, which is simulated to remain connected to Lee prior to the time a unit loads onto Lee. Thus the Unit 3 MFB CYME voltage indicates that voltage is available on the standby bus during the time prior to the unit loading onto the standby bus. Once the Unit 3 loads start, the CYME MFB voltage correlates well with the test data.

Current Data: The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The initial inrush currents on the Unit 3 MFB in the CYME model are approximately 6 percent greater than the test data. The difference in inrush currents is attributed to the loadcenter transformers. Loadcenter transformer inrush current magnitudes are highly dependent upon transformer residual flux and voltage phase angle when energized, so the transformer inrush current during the test was apparently less than the value assumed in the model. After the initial inrush the current profiles during load start periods correlate well with the test data. The delayed energization of loadcenter 3X4 is modeled, and correlates well with the test results. The steady state current and voltages from CYME matches the test data.

KVA Data: The time for the LOOP unit loading and the inrush time duration correlate well with the test data. The initial inrush KVA on the Unit 3 MFB in the CYME model are approximately 8 percent greater than the test data attributed to the current variance discussed above. After the initial inrush, the KVA profiles during load start periods correlate well with the test data. The delayed energization of loadcenter 3X4 is modeled, and correlates well with the test results. The steady state KVA from CYME matches the test data.

KW Data: The time for LOOP unit loading and the inrush time duration correlates well with the test data. The KW profiles during load start periods and steady state KW loading correlate well with the test.

3.3.3 Model 3 / Test 6, 4KV Motor Profiles (V, I, KVA, KW)

Points from the motor feeder overcurrent relays for each motor are plotted on figures showing current and voltage and indicate a significant margin between motor starting and overcurrent relay tripping for both the model and the test cases.

Figures 3-12 and 3-13 are the plots of the MDEFW 3B profile.

TEST VERSUS MODEL DATA:

The model voltage is very near the test voltage. Model motor starting current is essentially the same as the test current except the model takes slightly longer to start which is conservative. Model inrush KVA and KW are very near the test values. Model steady state voltage, current, KVA and KW are very close to the test values.

Figures 3-14 and 3-15 are the plots of the HPI 3B profile.

TEST VERSUS MODEL DATA:

The model voltage is very near the test voltage. Model motor starting current is essentially the same as the test current, and the model takes slightly longer to start which is conservative. Model inrush KVA and KW are very near the test values. Model steady state voltage, current, KVA and KW are very close to the test values.

Figures 3-16 and 3-17 are the plots of the MDEFW 1A profile.

TEST VERSUS MODEL DATA:

The model voltage during motor starting is very close to the test value. Model starting current is slightly less than the test value. Model motor start time is approximately the same as the test time. Model starting KVA and KW magnitudes are close to the test values. While the present degree of motor parameter correlation is acceptable, it is anticipated that motor signature tests will allow an even closer correlation for starting motor current, KW, and KVA in the future. Model running voltage, current, KVA and KW are very close to the test values.

Figures 3-18 and 3-19 are the plots of the LPSW 3B profile.

TEST VERSUS MODEL DATA:

The model voltage is very near the test voltage. Model motor starting current is somewhat less than the test current, but the model takes slightly longer to start which is conservative. Model inrush KVA and KW are slightly less than the test values. While the present degree of motor parameter correlation is acceptable, it is anticipated that motor signature tests will allow an even closer correlation for starting motor current, KW, and KVA in the future. Model steady state voltage, current, KVA and KW are very close to the test values.

Figures 3-20 and 3-21 are the plots of the LPI 3B profile.

TEST VERSUS MODEL DATA:

Model starting voltage for the LPI motor is very close to the test value. Starting current, KVA and KW are slightly less than the test values. Model motor start time is longer than the test time which is conservative. While the present degree of motor parameter correlation is acceptable, it is anticipated that motor signature tests will allow an even closer correlation for starting motor current, KW, and KVA in the future. Steady state current, KVA, and KW are very close to the test values, although the test steady state values were initially lower than the model. The steady state test values increased after the start due to throttling of the LPI system, while CYME modeled the motor starting to the post-throttling load, which would explain the longer start time. The model steady state voltage, current, KVA, and KW values are very close to the test values.

Figures 3-22 and 3-23 are the plots of the RBS 3B profile.

TEST VERSUS MODEL DATA:

Model starting voltage for the RBS motor is slightly less than the test value. Starting current, KVA and KW are slightly less than the test values. Model motor start time is the same as the test time. The model steady state voltage, current, KVA, and KW values are close to the test values.

3.3.4 Model 3 / Test 6, 600V RBCF 3B Motor Starting Profiles (V, I, KVA, KW)

Figures 3-24 and 3-25 plot the response of RBCF 3B starting on the LOCA unit. During a LOCA, the RBCFs should start and run on low speed, and the RBCF 3B functioned as expected.

TEST VERSUS MODEL DATA:

Immediately prior to the test, the RBCFs 3A and 3C were running at high speed, and the RBCF 3B was shutdown. It is postulated that RBCF 3B was rotating backwards due to damper back-leakage. Thus, starting this fan required energy for a longer time during the test than a start from 0 RPM. The RBCF 3B model start assumes a start from 0 RPM, and thus it starts 1.5 seconds faster than it started during the test. This postulation is based on the fact that immediately prior to the test, RBCFs 3A and 3C were running on high speed, and RBCF 3B was not running. A modification (NSM 3041) is planned which should resolve the damper back-leakage problem and hence the start time difference. Model steady state values correlate well with the test values.

3.3.5 Model 3 / Test 6, 600V Loadcenter Profiles (V, I, KVA, KW)

Figures 3-26 and 3-27 are the profiles for 1X5. Loads started simultaneously with loadcenter energization.

Figures 3-28 and 3-29 are the profiles for 1X6. Load pickup was almost simultaneous with loadcenter energization. Approximately 6 seconds after energization, a battery charger was loaded.

Data was not collected for 3X5 in Test 6 due to a recorder programming error. The unavailability of this data would not have adversely impacted any test acceptance criteria, and thus this problem is not significant.

Figures 3-30 and 3-31 are the profiles for 3X6. After approximately a 1 second delay, there is a significant increase in load, which is consistent with motors starting after the voltage reaches contactor pickup voltage. A battery charger is loaded after approximately a 9 second delay.

TEST DATA VERSUS MODEL DATA:

The loads fed from 1X5, 1X6, 2X5, 2X6, 3X5 and 3X6 are non-safety-related loads. These loads are not individually modeled in CYME. To ensure the model reflected the impact of these loads on safety system voltages, the 1X5 and 1X6 Test 5 data was used to determine an equivalent KVA and KW, broken down into 4 time intervals, to be block loaded on the appropriate bus for all three units. A review of the Unit 1 and 3 KW and KVA plots indicates that the simulated loads adequately represent the actual loads seen during Test 6.

Figures 3-32 and 3-33 are the profiles for 3X8. The loading at approximately 1 second after energization is a RBCF starting on low speed and other motor loads starting. Approximately 4 seconds after energization, the battery charger is loaded. Loading of the LOOP units causes a short dip in the loadcenter amperes. A similar dip in load amperes was seen in the battery charger profile.

Figures 3-34 and 3-35 are the profiles for 3X9. There is an increase in loading approximately 1 second after the loadcenter is energized as a RBCF starts on low speed and

other motors start. Approximately 6 seconds after energization, a battery charger is loaded. Loading of the LOOP units causes a momentary dip in the loadcenter ampere load.

TEST DATA VERSUS MODEL DATA:

The Units 1, 2, and 3 loadcenters X8 and X9 loads are modeled individually where possible. There is some mismatch in the initial inrush seen on 3X8 and 3X9 due to the RBCF start. These motors were running in high speed prior to the test, and drift down slowly on a loss of power. According to RBCF test information, these fans could be expected to reach approximately 400 RPM 15 seconds after the power is removed from the high speed, and would only be required to accelerate 200 RPM to the slow speed running RPM. The CYME model assumes these motors are starting from 0 RPM, and thus calculated a higher start current, KVA, and KW, and a longer start time. CYME does not provide a specific model for battery charger, and thus the load due to the charger is simulated, using a 2 step block loading approach. A review of loadcenters 3X8 and 3X9 voltage, current, KVA and KW plots indicate that the model loads adequately envelope the test loads, and the correlation between the test and model voltages is very good.

3.3.6 Model 3 / Test 6, 600V Safety MCC Profiles (V, I, KVA, KW)

Figures 3-36 thru 3-41 chart the voltage, current, KVA and KW profiles for 600V Safety MCCs 3XS1, 3XS2, and 3XS3 monitored during the test. The load increases immediately upon energization on 3XS1 and 3XS2. The load on 3XS3 increases approximately 9 seconds after energization as RBCF 3B starts. A significant increase in loading occurs after approximately 4 to 6 seconds on 3XS1 and 3XS2 when the battery chargers are connected. Note that the charger loading has negligible impact on MCC voltage. Loading of the LOOP units causes a sharp decrease in MCC load amperes. Minimum voltage after MCC energization is 396V (66.0 percent of rated value) and occurs on 600V MCC 3XS1. The minimum steady state MCC voltage is 590V (98.3 percent of rated value) and occurs on 3XS1. Voltage recovers to near the steady state value in 2.5 seconds on 3XS1 and 3XS2. Voltage recovery on 3XS3 takes 6 seconds since the RBCF is starting.

TEST DATA versus MODEL DATA:

The large inrush current on MCC 3XS3 is due to the RBCF start. Immediately prior to the test, the RBCF 3B was shutdown. It is postulated that RBCF 3B was rotating backwards due to damper back-leakage. Thus, starting this fan required energy for a longer time during the test than is required for a start from 0 RPM. The model RBCF start assumes a start from 0 RPM, and thus there is a 1.5 second shorter start time when compared to test data. This postulation is based on the fact that immediately prior to the test RBCFs 3A and 3C were running on high speed, and RBCF 3B was not running. A modification (NSM 3041) is planned which should resolve the damper back-leakage problem and hence the start time difference. CYME does not provide a specific model for battery charger, and thus the load due to the charger is simulated, using a 2 step block loading approach. A review of MCCs 3SX1 and 3XS2 current, KVA and KW plots indicate that the model loads adequately

envelope the test loads. The correlation between the test and model voltages on 3XS2 and 3XS3 is excellent. The voltage measured on 3XS1 is lower than the model voltage and the difference is attributed to recorder tolerance since the correlation is good on loadcenter 3X8 which feeds MCC 3XS1.

3.3.7 Model 3 / Test 6, 208V Safety MCC Profiles (V, I, KVA, KW)

Figures 3-42 thru 3-47 chart the voltage, current, KVA and KW profiles for 208V Safety MCCs 3XS1, 3XS2, and 3XS3 monitored during the test. The load increase at energization due to MOVs starting is almost immediate and of short duration. The LOOP units loading causes a momentary dip in the MCC load. Minimum voltage after MCC energization is 133V (63.9 percent of rated value) and occurs on 208V MCCs 3XS2. The minimum steady state voltage occurs on 3XS2 and is 207V (99.5 percent of rated value). The momentary current spike seen on 208V MCCs 3XS1 and 3XS2 at loss of voltage is due to the channel 1 and 2 (HPI) MOVs receiving a start signal prior to the actual loss of power to the MCCs.

TEST DATA versus MODEL DATA:

The MOVs powered from these MCCs are modeled to start concurrently with the starting current required for 15 cycles and the valves running for 15 seconds (900 cycles). In actuality, the starting times of the MOVs vary, and some of the MOVs take longer than 15 seconds, thus for a period of time on MCC 3XS2, the model KVA and current drops slightly below the actual, but this difference is so small it is not considered significant. For all other intervals on 3XS2, and all intervals on the other MCCs, the model loading is conservatively greater than the test loading as expected since other modeled loads on the 208V MCCs are worst case calculated loading. In all cases, the model voltage profiles correlate well with the measured profiles.

4. CYME Model Refinements

Some enhancements were made to the CYME model based on information gathered during the test, as described herein. The changes to the CYME model are not significant enough to affect the conclusions of evaluations performed in the past.

4.1 Keowee Model

The following adjustments were made in the Keowee model:

1) Voltage droop was added to the Keowee voltage regulator model consistent with the voltage regulator design,
2) The voltage regulator model was adjusted to take the damping feedback signal from the field current instead of the field voltage, consistent with the voltage regulator design, and
3) Generator and voltage regulator parameters were adjusted to improve the model response.

4.2 Lee Model

The following adjustments were made to the Lee model:

1) Voltage droop was removed from the Lee voltage regulator model consistent with the voltage regulator design, and
2) Governor gain and damping adjustments were made to improve the speed response.

4.3 Oconee Model

The following adjustments were made in Oconee modeling:

1) 4KV motors and RBCF loading was adjusted to values existing during the test,
2) HPI and the Unit 3 MDEFW motor starting power factors were adjusted to agree with signature test results,
3) RBCF inertia was increased in order to match signature test response,
4) RBCF transfer to high speed was not modeled, but instead safety system battery chargers were run at their current limit value (when re-energized) on the LOOP units which places a load on the auxiliary system equivalent to the difference in RBCF high speed and low speed steady state load,
5) Loading on loadcenters X4, X5, X6 and X7 was applied based on the test measured load, and
6) Transformer inrush was modeled as an exponentially decaying current based on test results and a loadcenter transformer signature test instead of modeling it as a fixed inrush for a fixed time duration.

5. Conclusions

Overall, the results of the CYME models developed to simulate the Oconee Emergency Power and Engineered Safeguards Functional Tests 2, 5, and 6 are satisfactory. Good correlation was seen between the test data and the CYME model predictions except for the RBCF B motor. Although Test 3 (reduced voltage and frequency starting scenario) is not included in this report, a comparison of the test data and the CYME model predictions show the model to predict conservative results (i.e. motors take a slightly longer time to accelerate in the model versus the test) also except for the RBCF B motor. In all cases, the RBCF B motor is an exception in that the CYME model predicts that this motor accelerates faster than the test data proves to be true. This difference in start time of the RBCF B motor is concluded to be due to the reverse rotation of this fan before it starts as a result of back-leakage due to air dampers not sealing completely. A modification (NSM ON-3014) has been planned to replace these dampers and should resolve this reverse rotation problem. Until this modification is implemented, additional time will be added to the RBCF B motor starting time predicted by CYME to compensate for this RBCF reverse rotation problem.

Based on the above, the CYME model was verified to be an adequate analytical tool for predicting the operational characteristics and responses for the Oconee Emergency Power System.

Some enhancements have been made to the CYME model based on information gathered during the Oconee Emergency Power and Engineered Safeguards Functional Test on January 2-5, 1997, as described in Section 4. The changes made in the CYME model are not significant enough to affect the conclusions of evaluations performed in the past.

5.1 Model 1 / Test 2 Conclusions

The CYME model voltage results correlate well with the results for Test 2. Motor start times also correlate well, and in many cases are conservative in that the model shows the motors taking longer to start than was the case during the test. In this report, signature test data was available and was used to adjust motor information for the High Pressure Injection Pump Motor, the 600 HP Emergency Feedwater Pump Motor, and the Reactor Building Cooling Fan Motor. Signature tests are being performed on other motors and will be used to adjust the motor starting current and PF for each other large motor design in future CYME analyses. While the present degree of motor parameter correlation is acceptable, it is anticipated that the signature test data will allow an even closer correlation for the other motors.

The Keowee generator model adequately predicts generator speed transient behavior during load rejection scenarios.

In summary, the existing CYME model is considered to be an acceptable tool for predicting the operational characteristics and responses of the Oconee Emergency Power System due to similar postulated source/load scenarios when supplied from the Keowee Hydro Station.

5.2 Model 2 / Test 5 Conclusions

The CYME model voltage results correlate very well with the results for Test 5. Motor start times also correlate well, and in many cases are conservative in that the model shows the motors taking longer to start than was the case during the test, with the exception of the RCBF 3B motor. The RBCF 3B motor starts approximately 1.5 seconds faster in the model than during the test, which is well within the motor starting capability. This difference in starting time is postulated to be due to reverse rotation of the motor before starting because of damper back-leakage. Immediately prior to the test, RBCFs 3A and 3C were running on high speed and RBCF 3B was not running. A modification (NSM 3041) is planned which should resolve the damper back-leakage and hence the start time difference. Until NSM 3041 is implemented, 1.5 seconds will be added to any CYME model analyses to adjust motor information for any RBCF motor that is started with the other RBCF motors on the same unit running. In this report, signature test data was available and used to adjust motor information for the High Pressure Injection Pump Motor, the 600 HP Emergency Feedwater Pump Motor, and the Reactor Building Cooling Fan Motor. Signature tests are being performed on other motors and will be used to adjust the motor starting current and PF for each other large motor design in future CYME analyses. While the present degree of motor parameter correlation is acceptable, it is anticipated that the signature test data will allow an even closer correlation for the other motors.

The Keowee generator model adequately predicts generator speed transient behavior during load rejection scenarios.

In summary, the existing CYME model is considered to be an acceptable tool for predicting the operational characteristics and responses of the Oconee Emergency Power System due to similar postulated source/load scenarios when supplied from the Keowee Hydro Station.

5.3 Model 3 / Test 6 Conclusions

The CYME model voltage results correlate very well with the results for Test 6. Motor start times also correlate well, and in many cases are conservative in that the model shows the motors taking longer to start than was the case during the test, with the exception of the RBCF 3B motor. The RBCF 3B motor starts approximately 1.5 seconds faster in the model than during the test, which is well within the motor starting capability. This difference in starting time is postulated to be due to reverse rotation of the motor before starting because of damper back-leakage. Immediately prior to the test RBCFs 3A and 3C were running on high speed and RBCF 3B not running. A modification (NSM 3041) is planned which should

resolve the damper back-leakage and hence the start time difference. Until NSM 3041 is implemented, 1.5 seconds will be added to any CYME model analyses to adjust motor information for any RBCF motor that is started with the other RBCF motors on the same unit running. In this report, signature test data was available and used to adjust motor information for the High Pressure Injection Pump Motor, the 600 HP Emergency Feedwater Pump Motor, and the Reactor Building Cooling Fan Motor. Signature tests are being performed on other motors and will be used to adjust the motor starting current and PF for each other large motor design in future CYME analyses. While the present degree of motor parameter correlation is acceptable, it is anticipated that the signature test data will allow an even closer correlation for the other motors.

The existing Lee generator model adequately predicts generator behavior during block load scenarios.

In summary, the existing CYME model is considered to be an acceptable tool for predicting the operational characteristics and responses of the Oconee Emergency Power System due to similar postulated source/load scenarios when supplied from the Lee Combustion Turbine Generators.

Appendix 1 - Test 2, Figures of Results

APPENDIX 1: Figures for Test 2

Figure 1-1: Test2, Keowee Voltage and Current

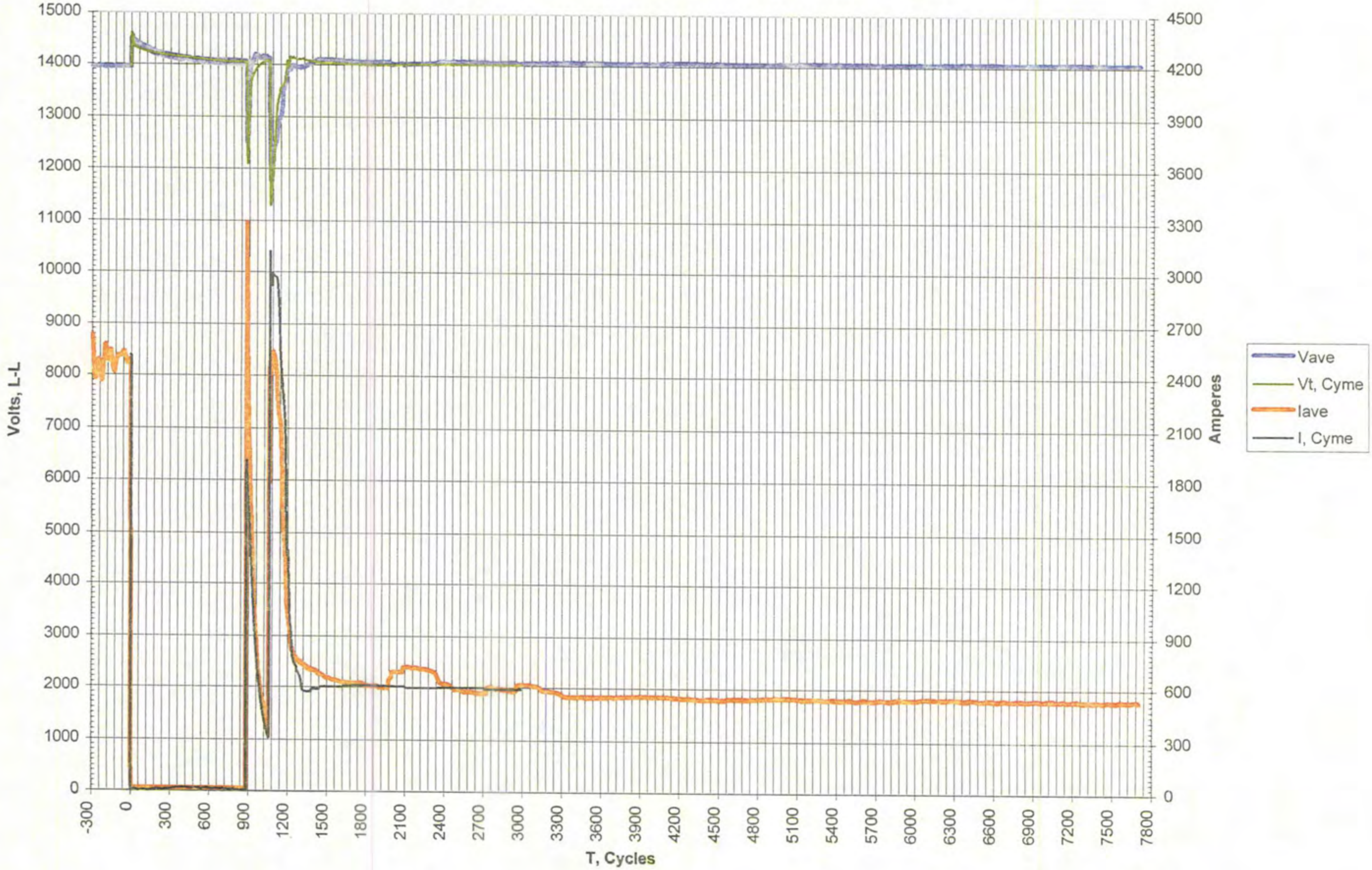


Figure 1-2: Test2, Keowee Voltage

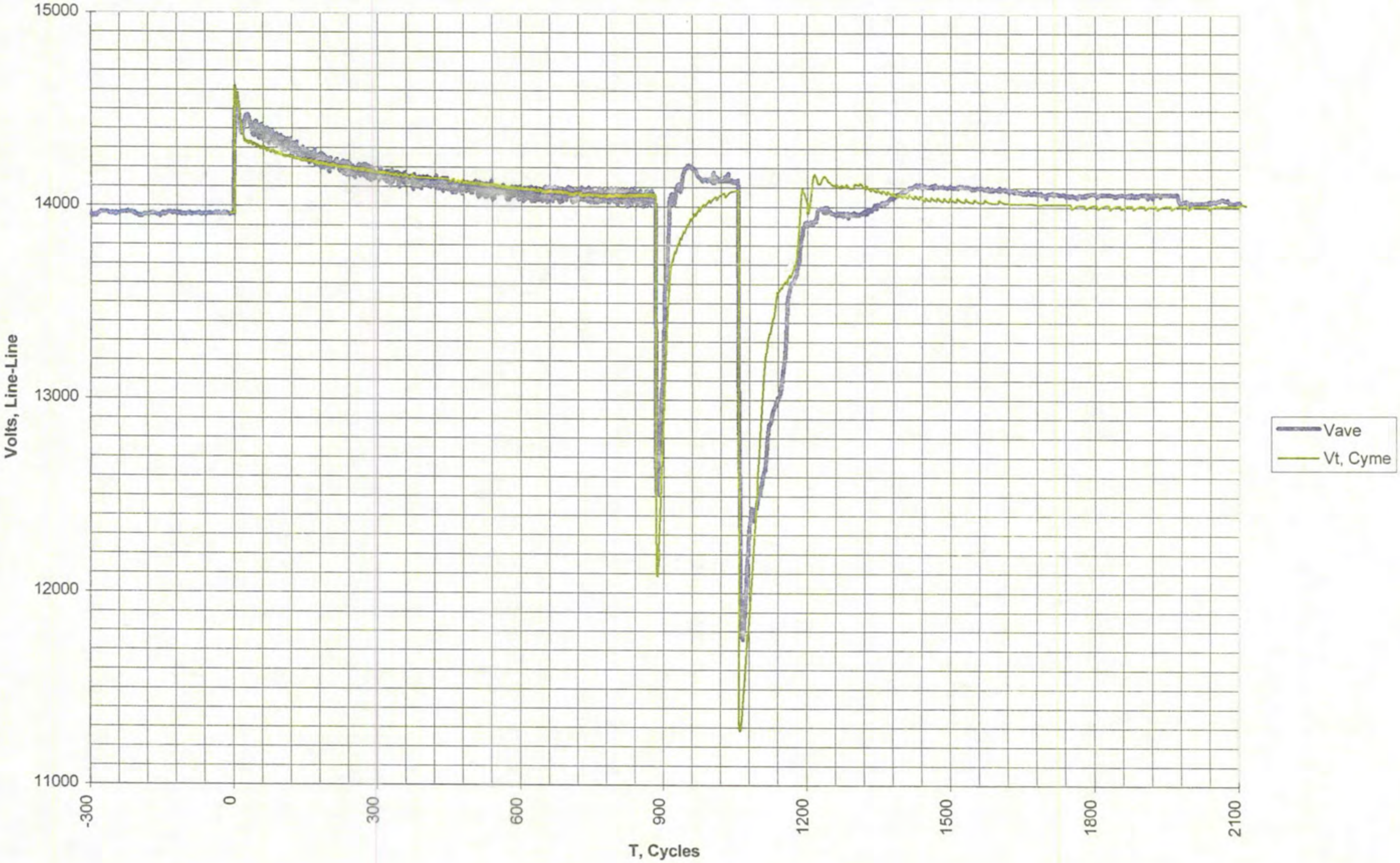


Figure 1-3: Test2, Keowee KVA

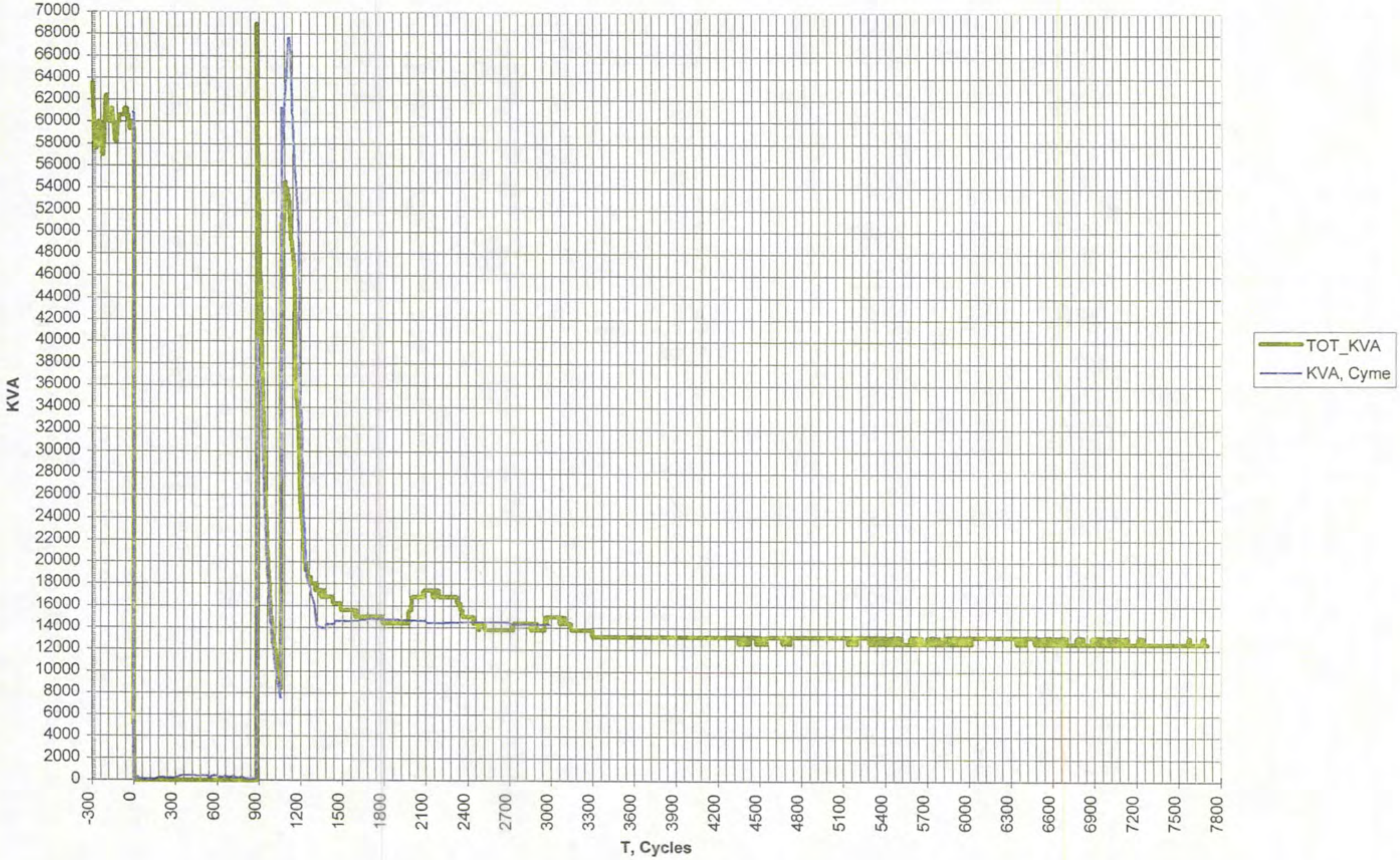


Figure 1-4: Test2, Keowee KW

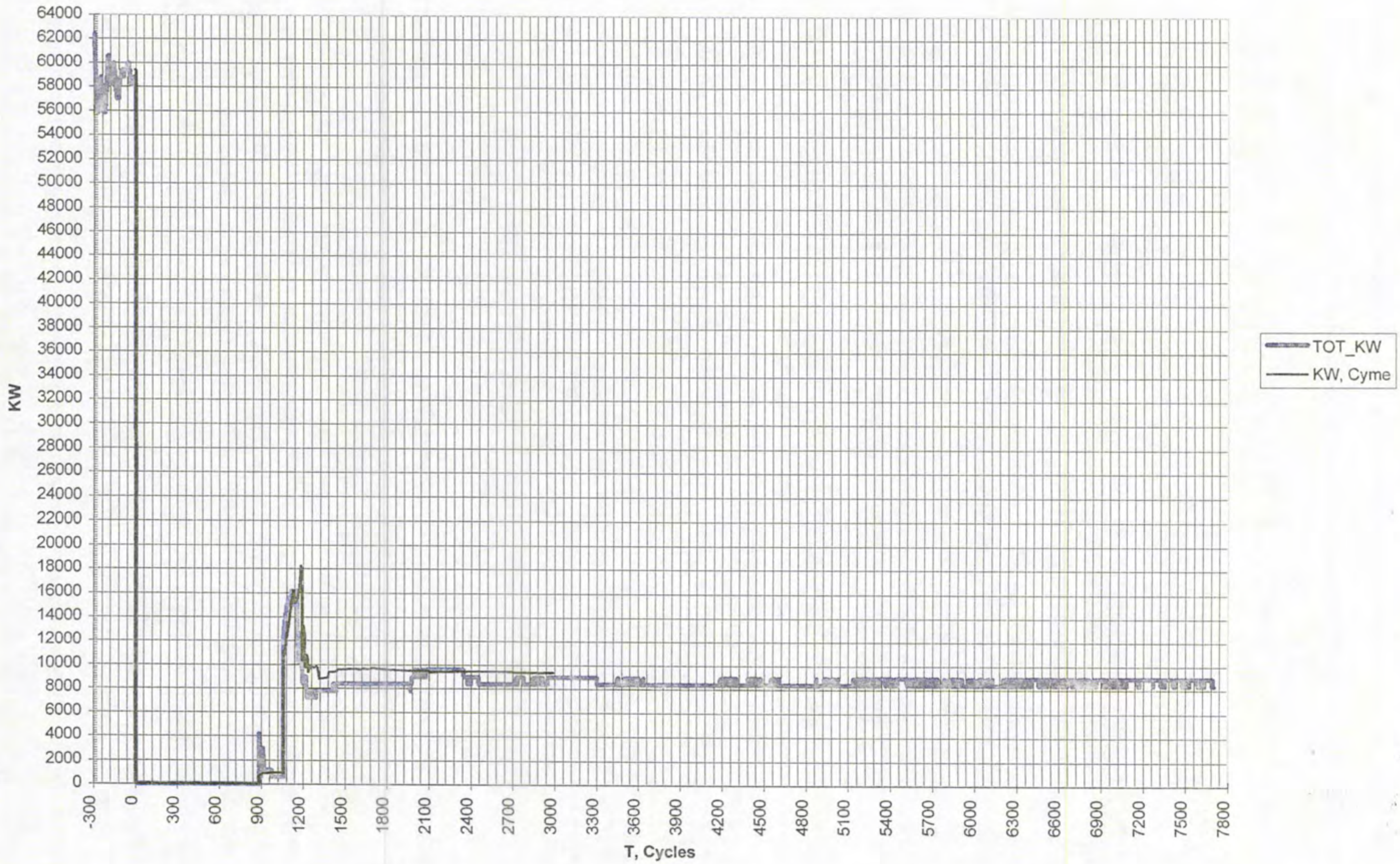


Figure 1-5: Test2, Keowee Frequency

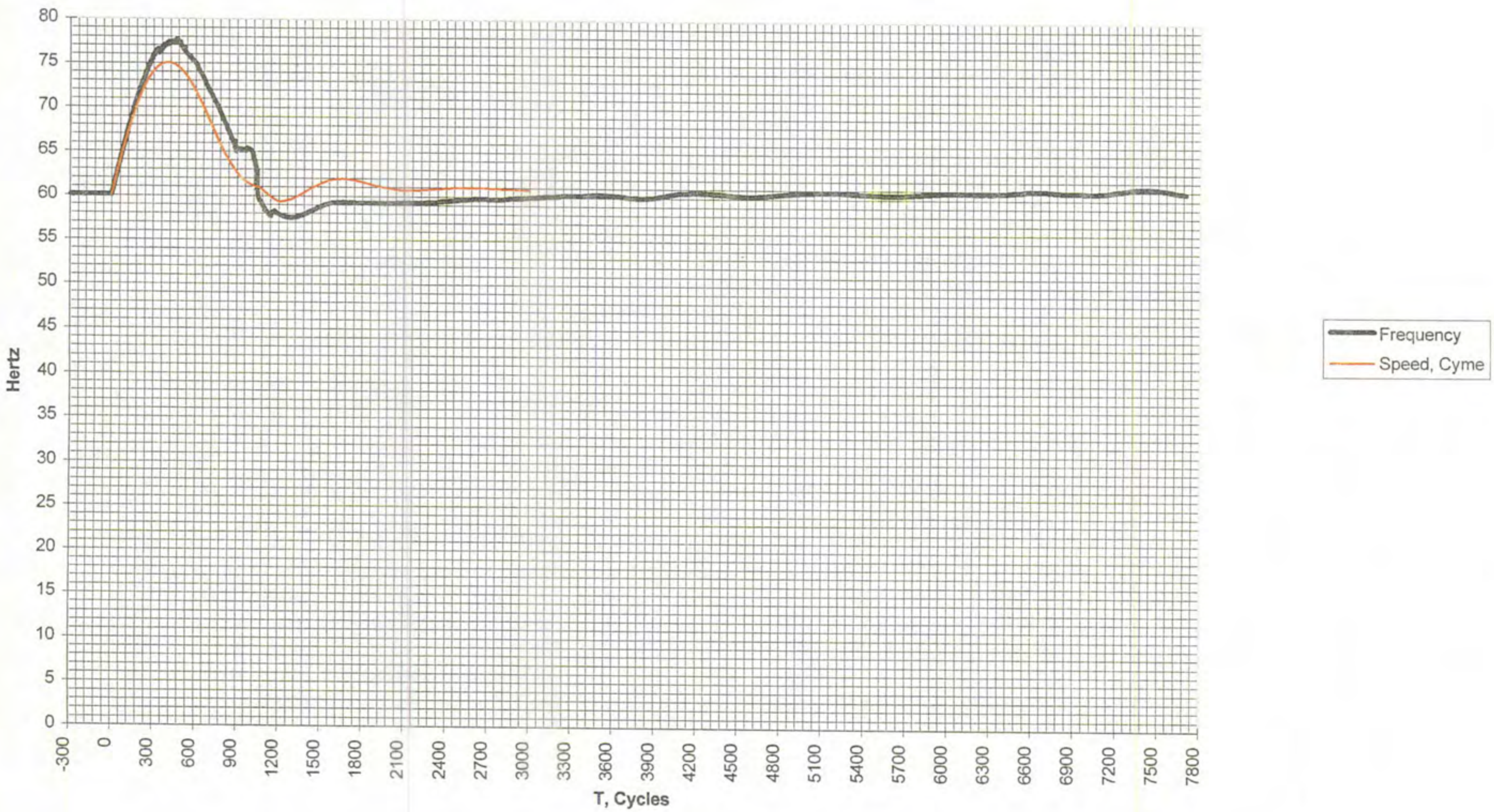


Figure 1-6: Test2, Unit 1 MFB Voltage and Current

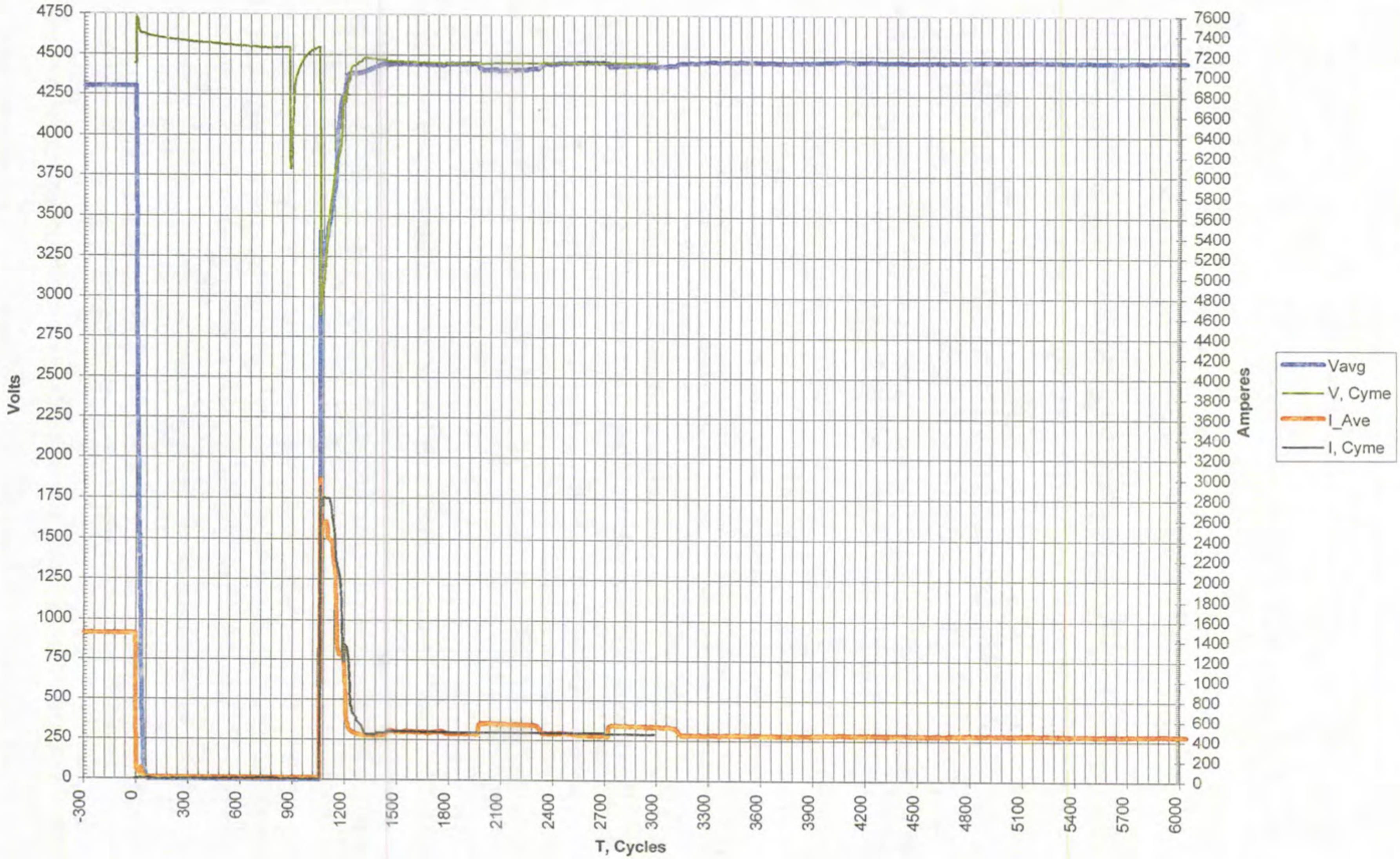


Figure 1-7: Test2, Unit 1 MFB KVA and KW

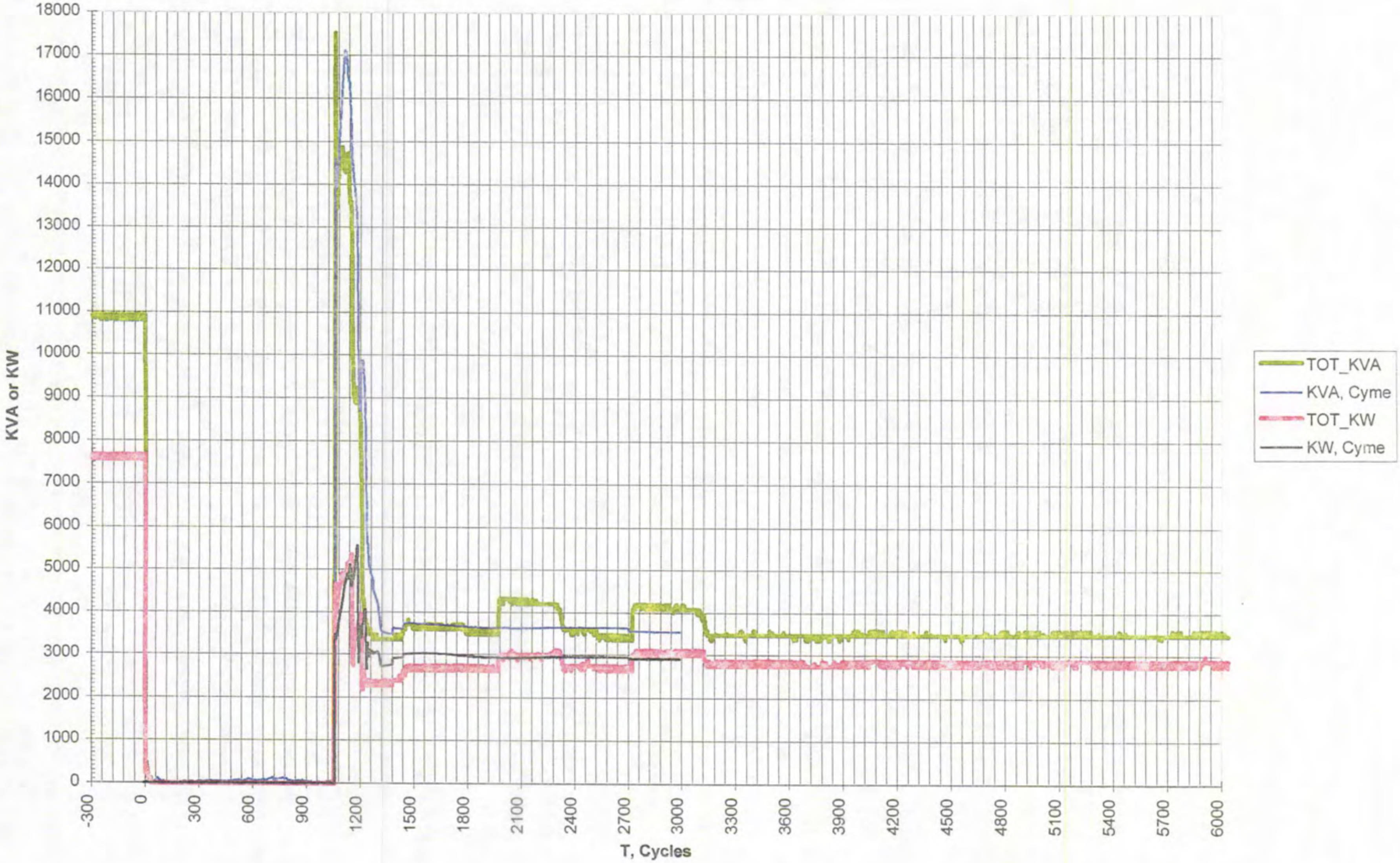


Figure 1-8: Test2, Unit 2 MFB Voltage and Current

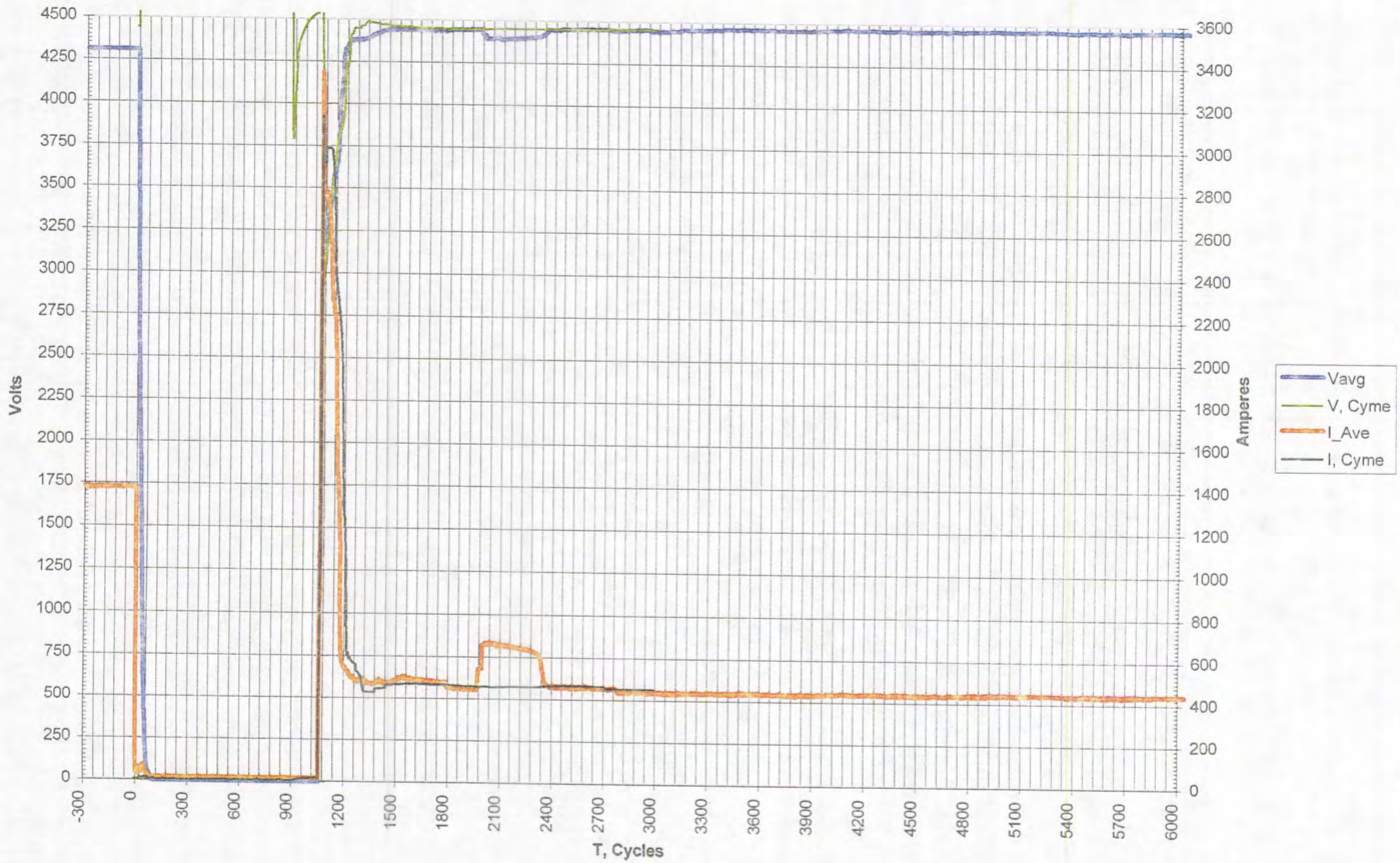


Figure 1-9: Test2, Unit 2 MFB KVA and KW

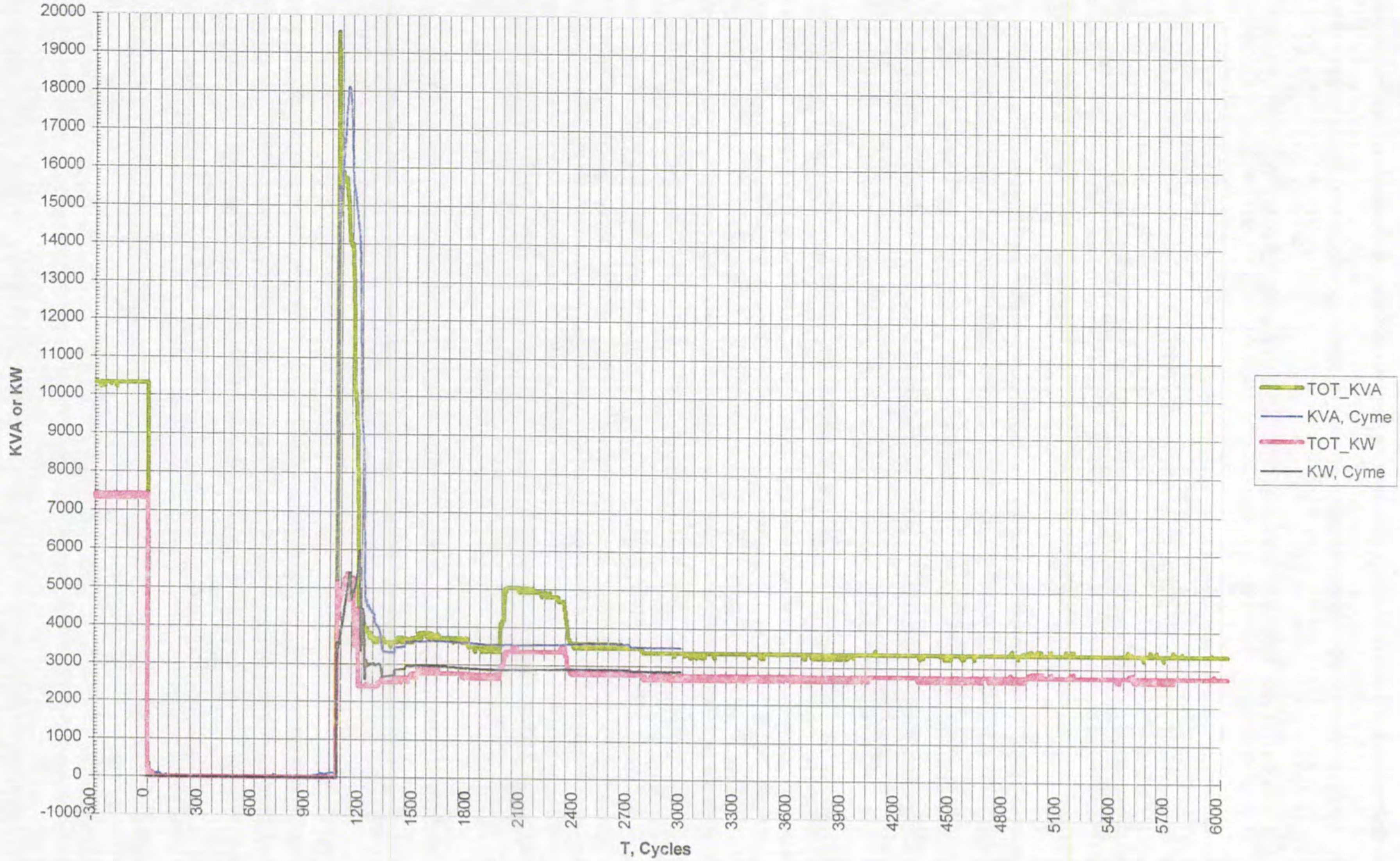


Figure 1-10: Test2, Unit 3 MFB Voltage and Current

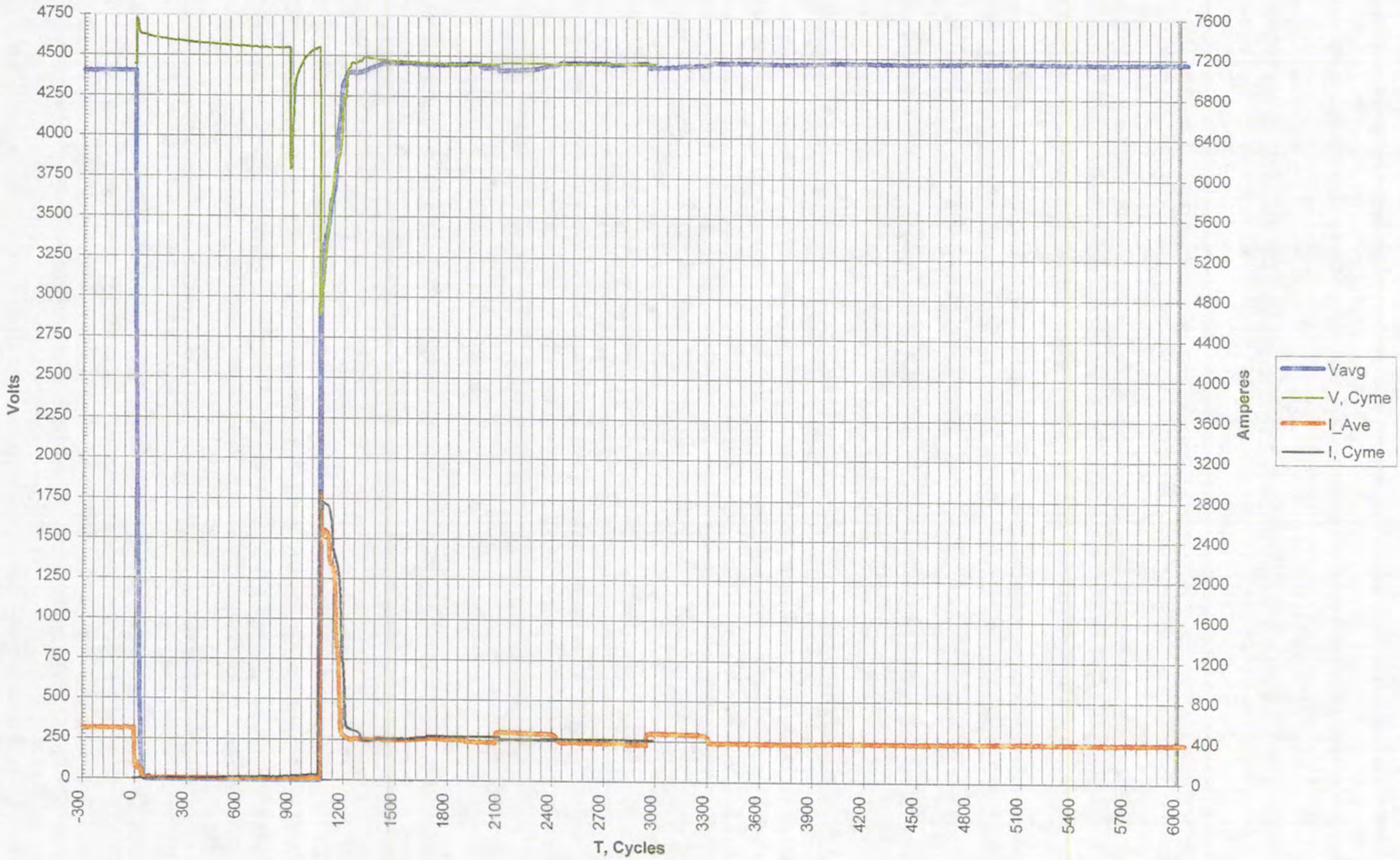


Figure 1-11: Test2, Unit 3 MFB KVA and KW

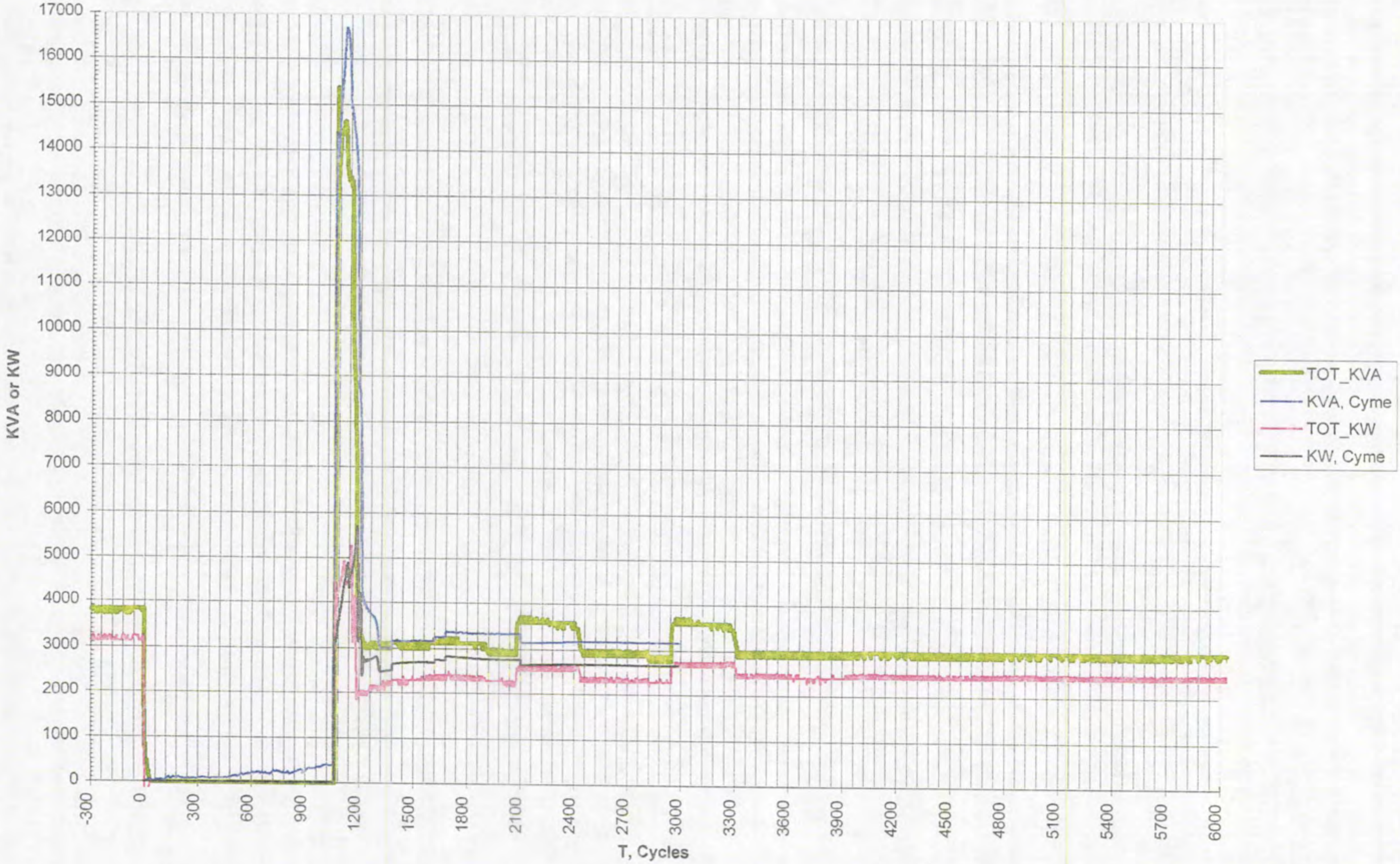


Figure 1-12: Test2, EFW 3B Voltage and Current

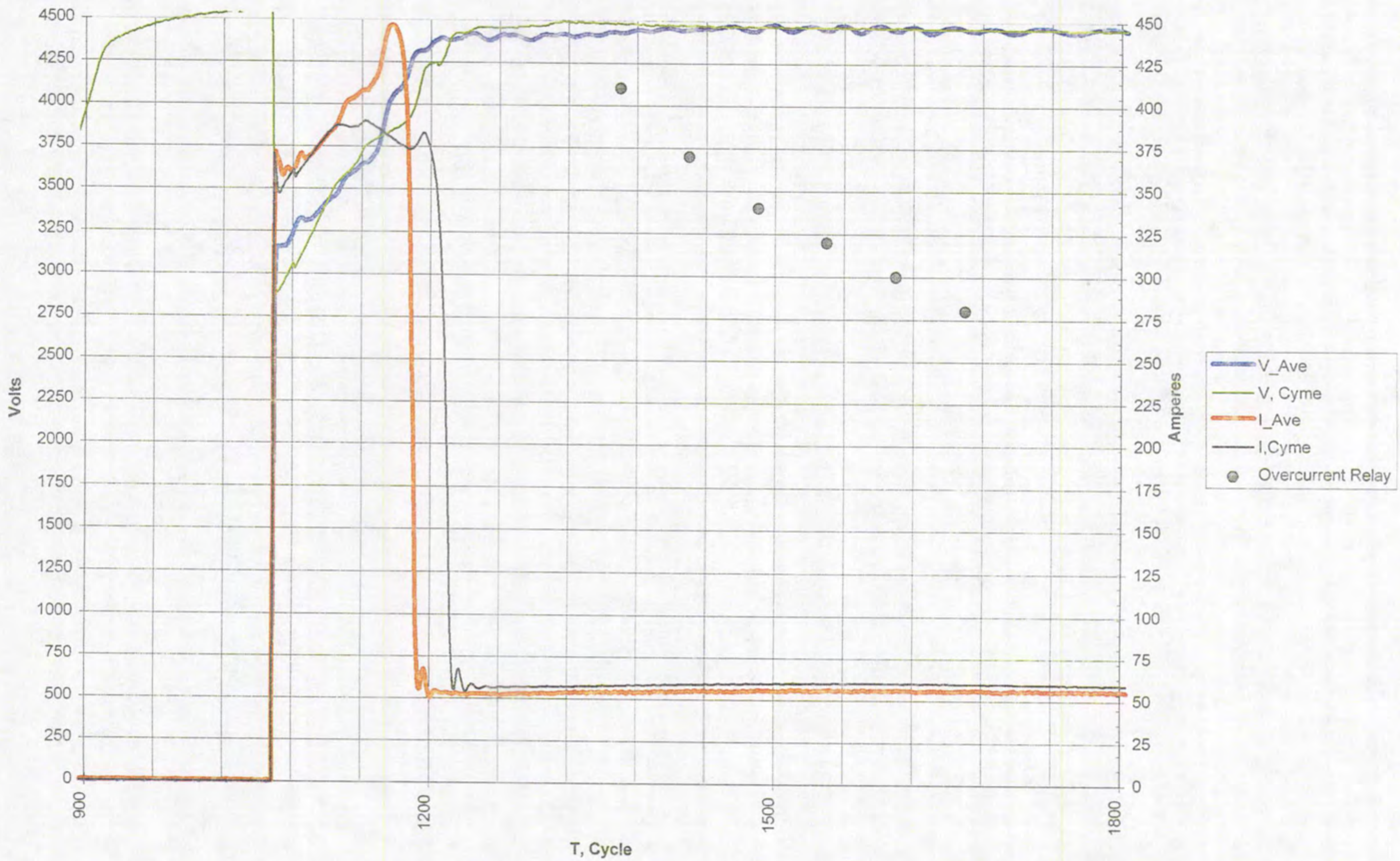


Figure 1-13: Test2, EFW 3B KVA and KW

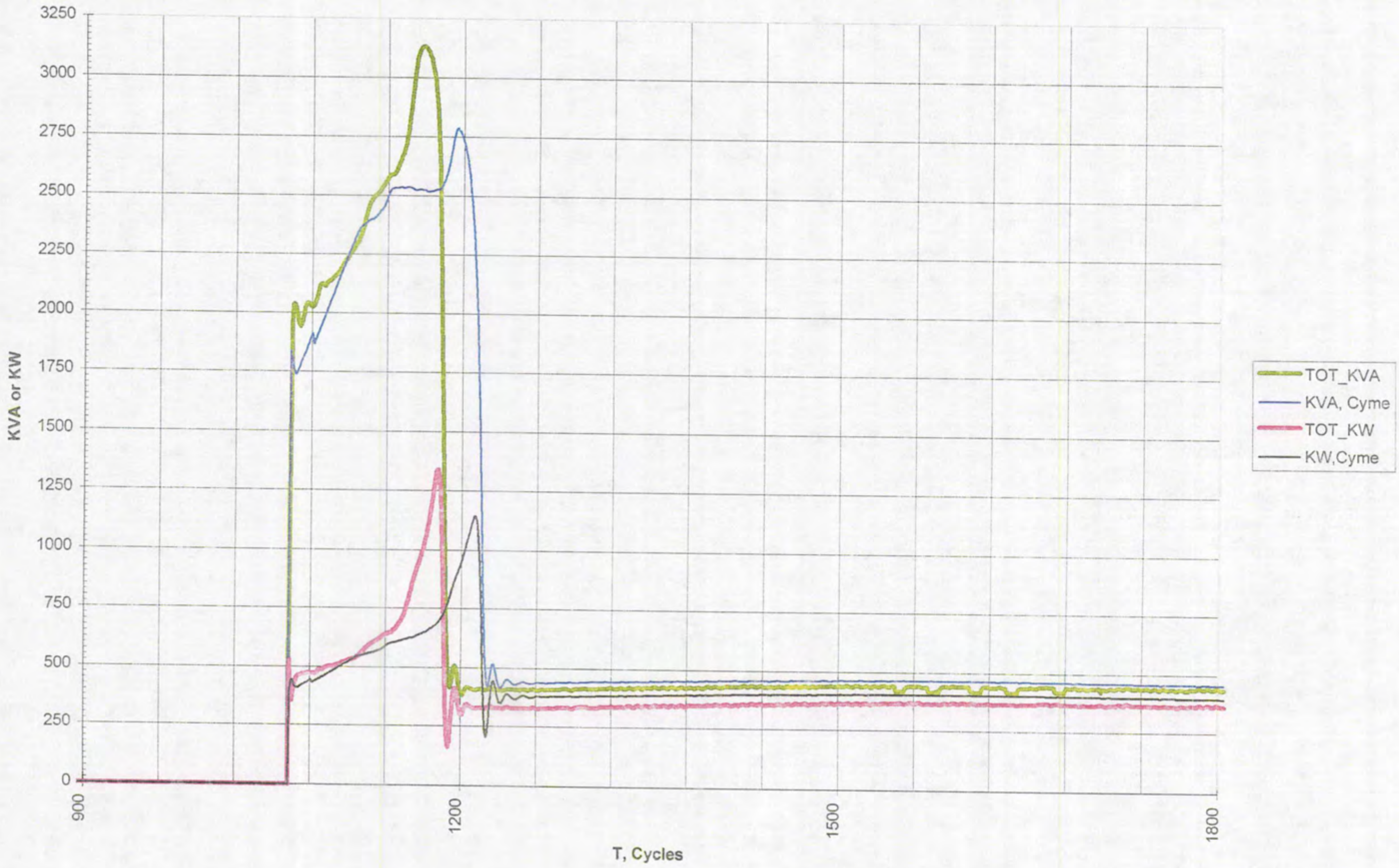


Figure 1-14: Test2, HPI 3B Voltage and Current

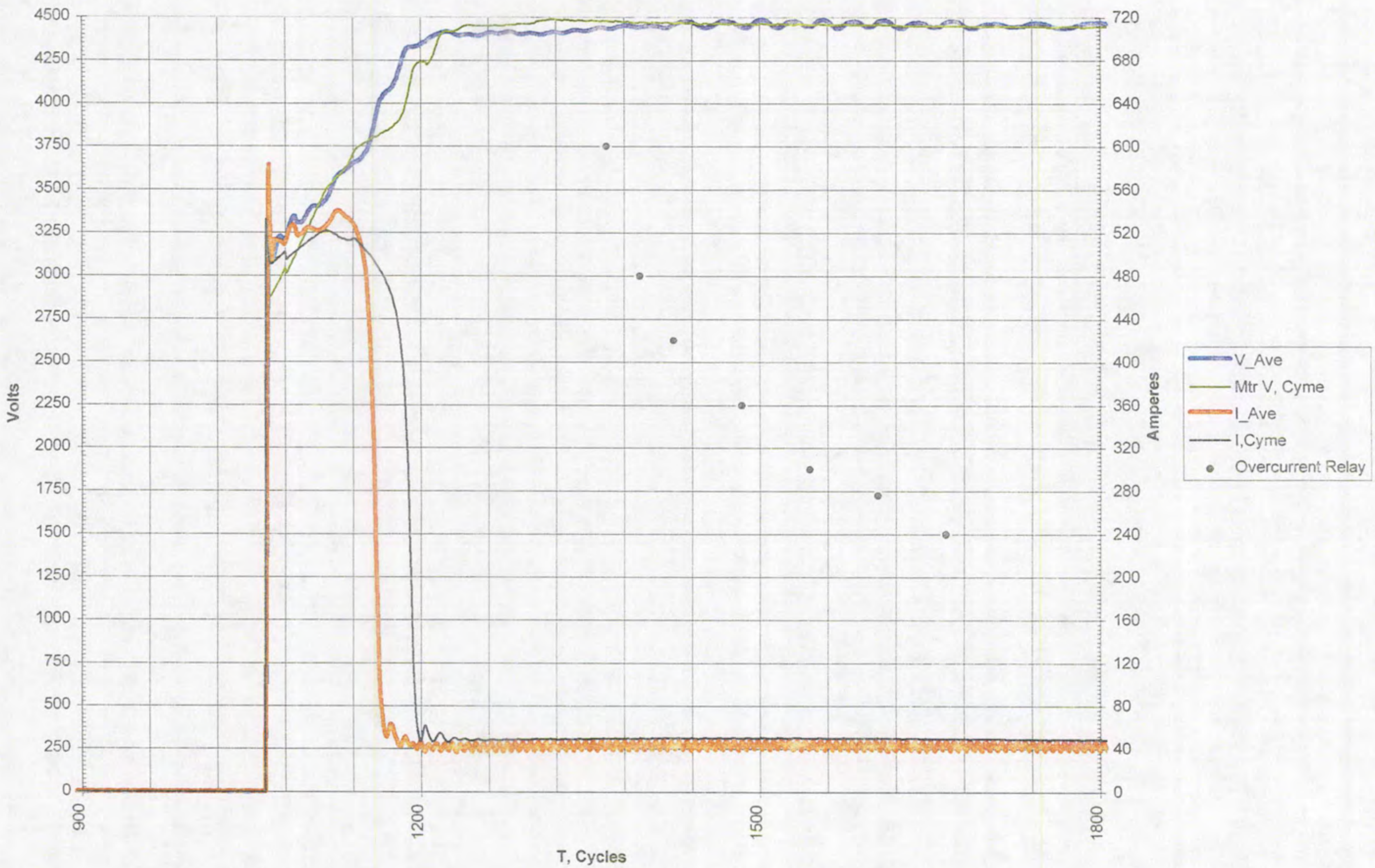


Figure 1-15: Test2, HPI 3B KVA and KW

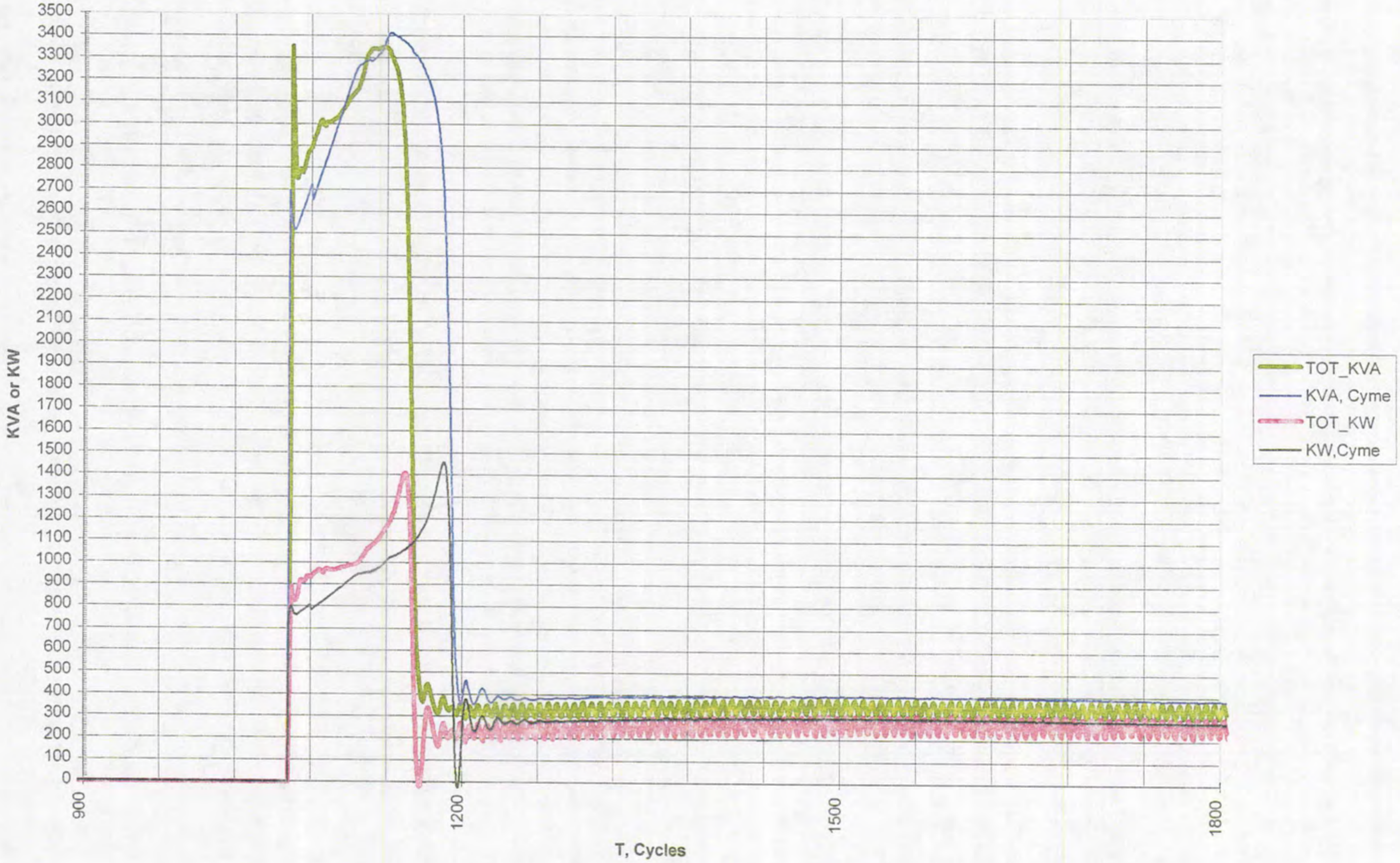


Figure 1-16: Test2, EFW Pump 1A Voltage and Current

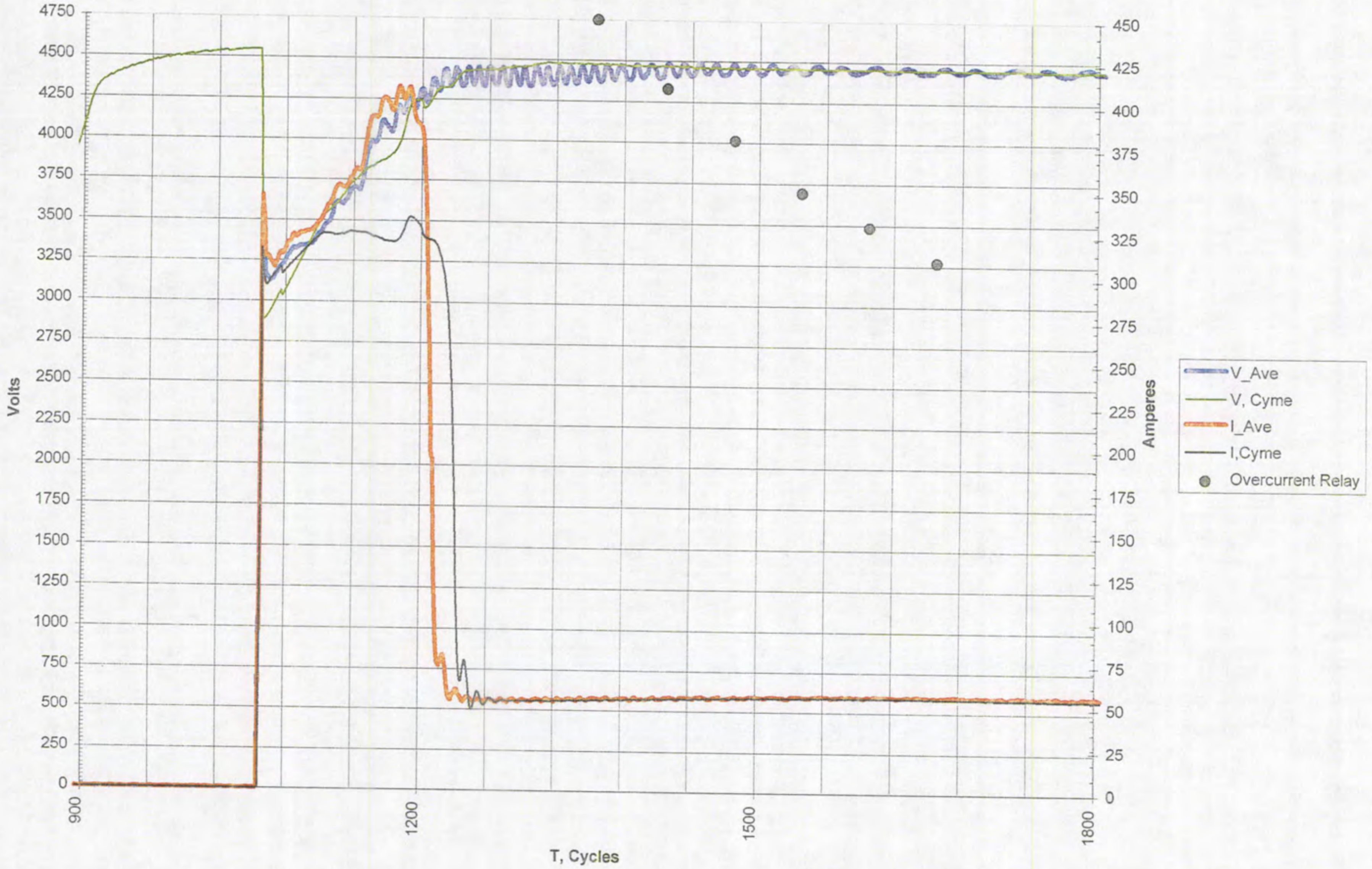


Figure 1-17: Test2, EFW 1A KVA and KW

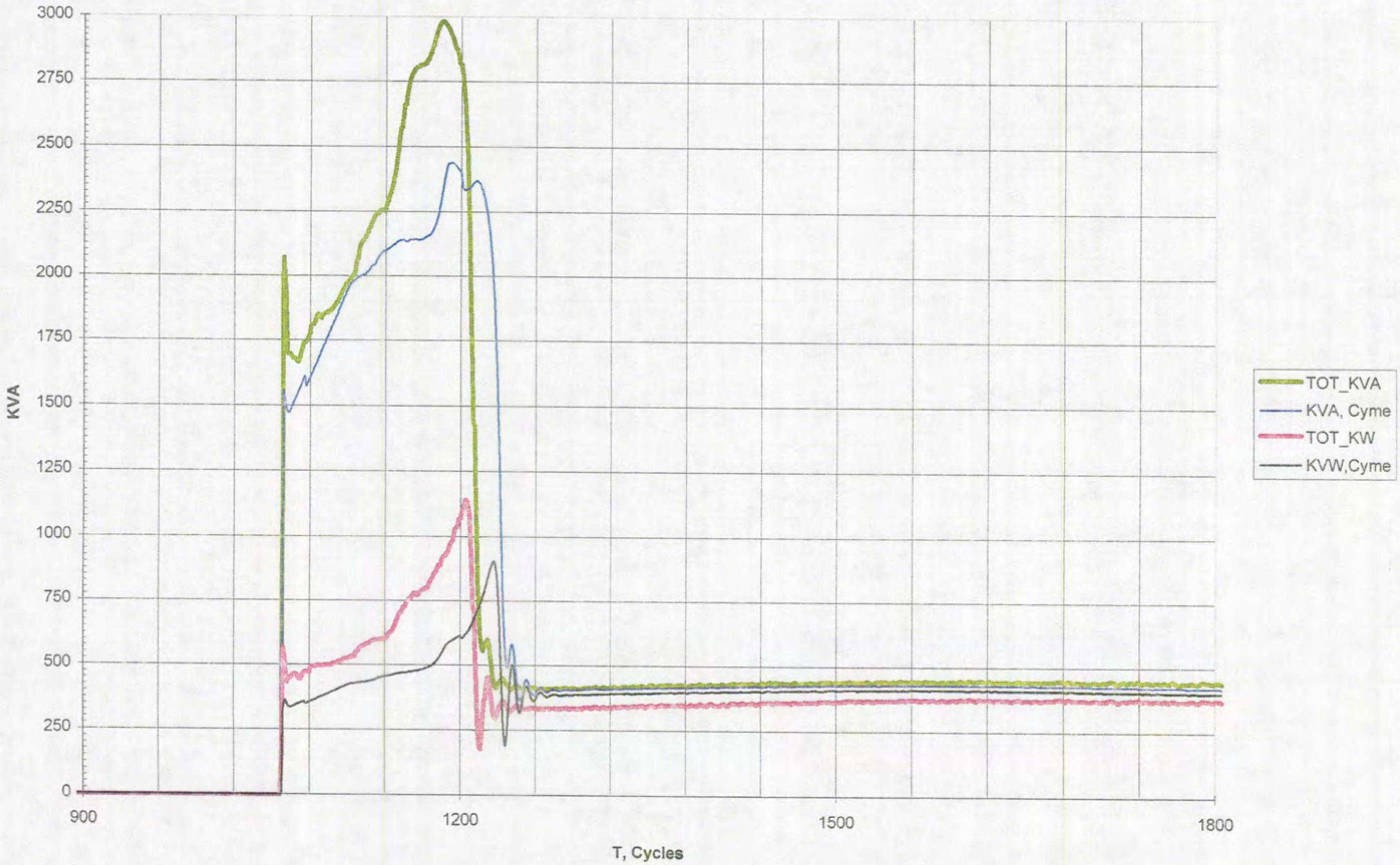


Figure 1-18: Test2, LPSW 3B Voltage and Current

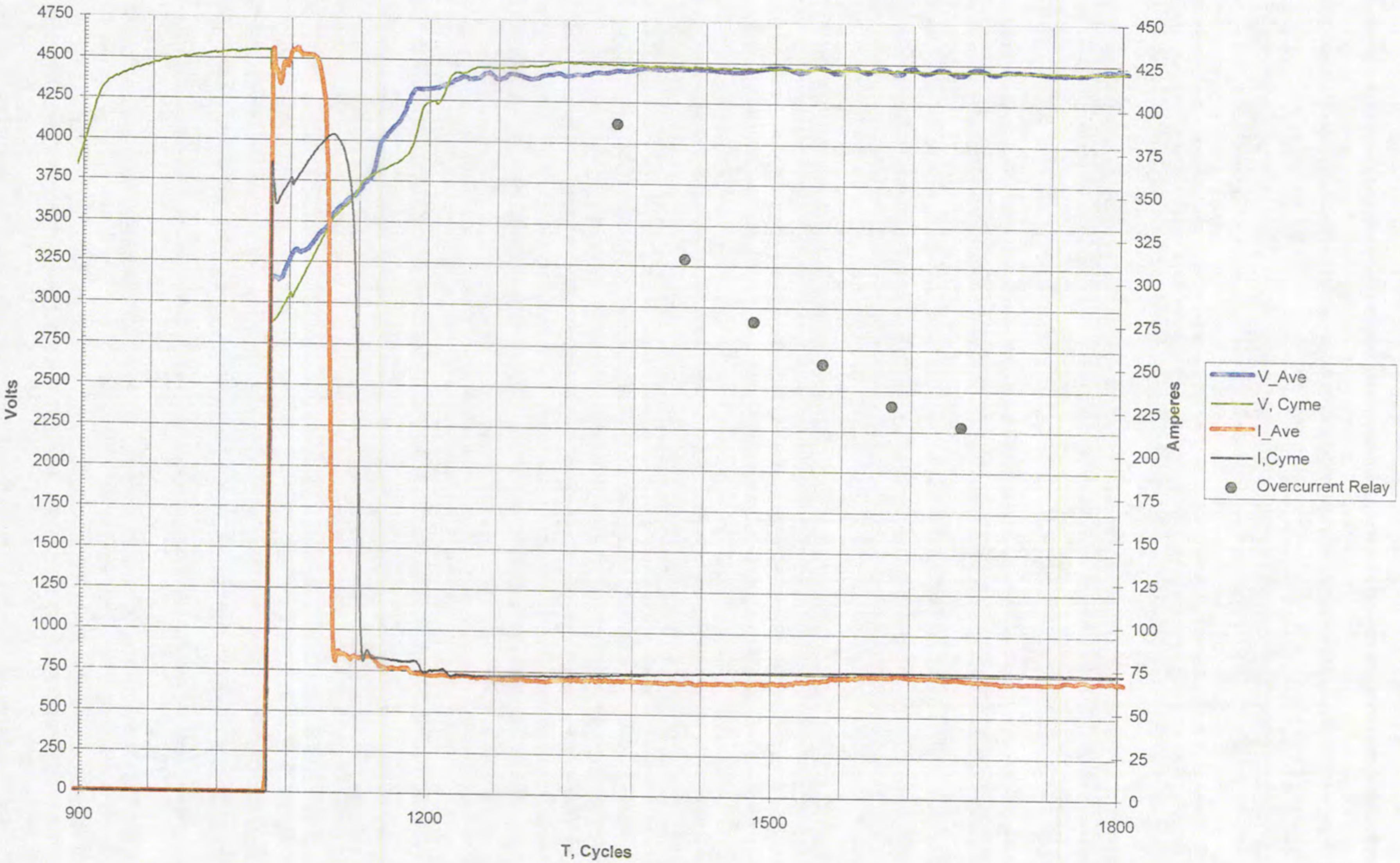


Figure 1-19: Test2, LPSW 3B KVA and KW

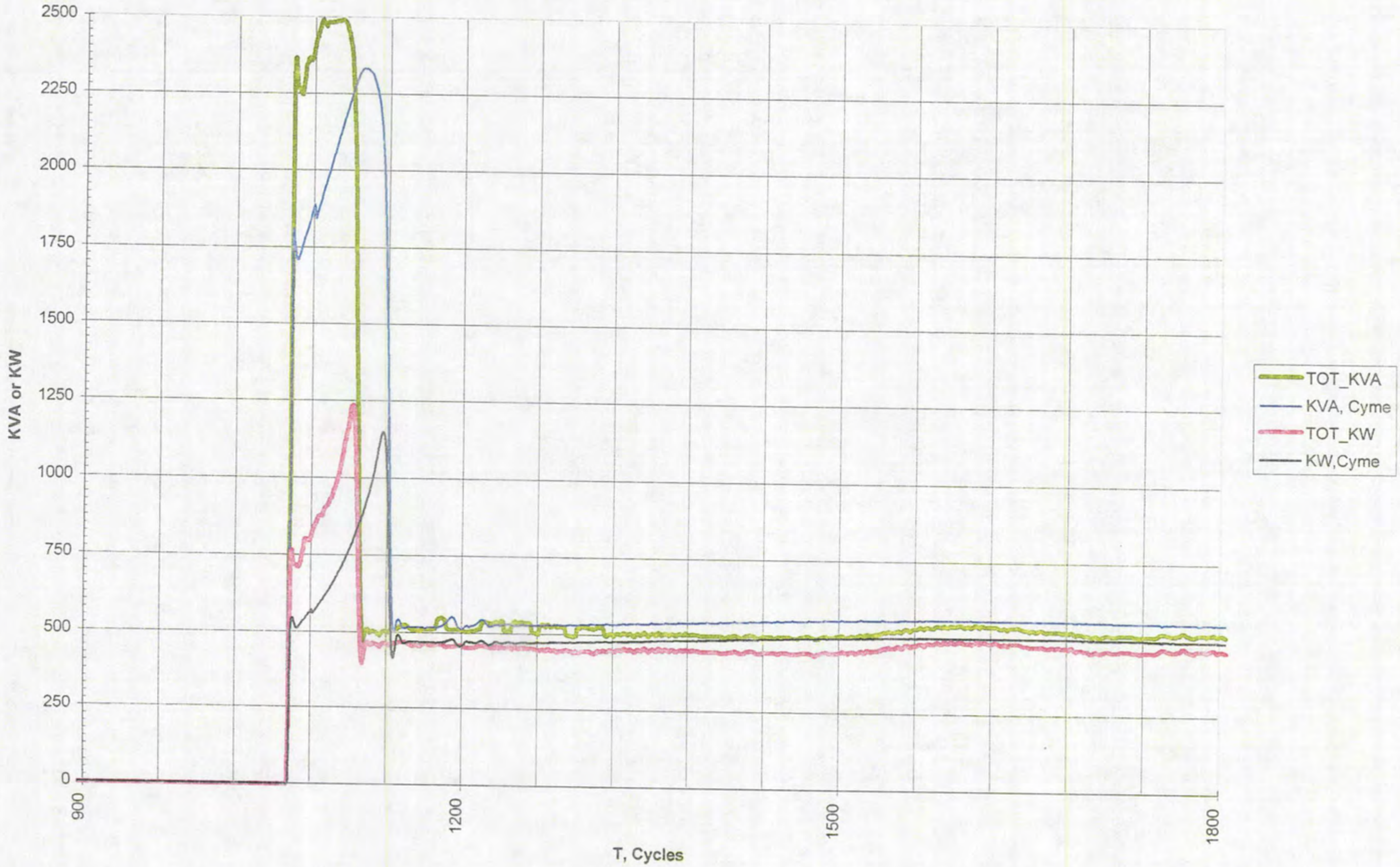


Figure 1-20: Test2, 1X5 Voltage and Current

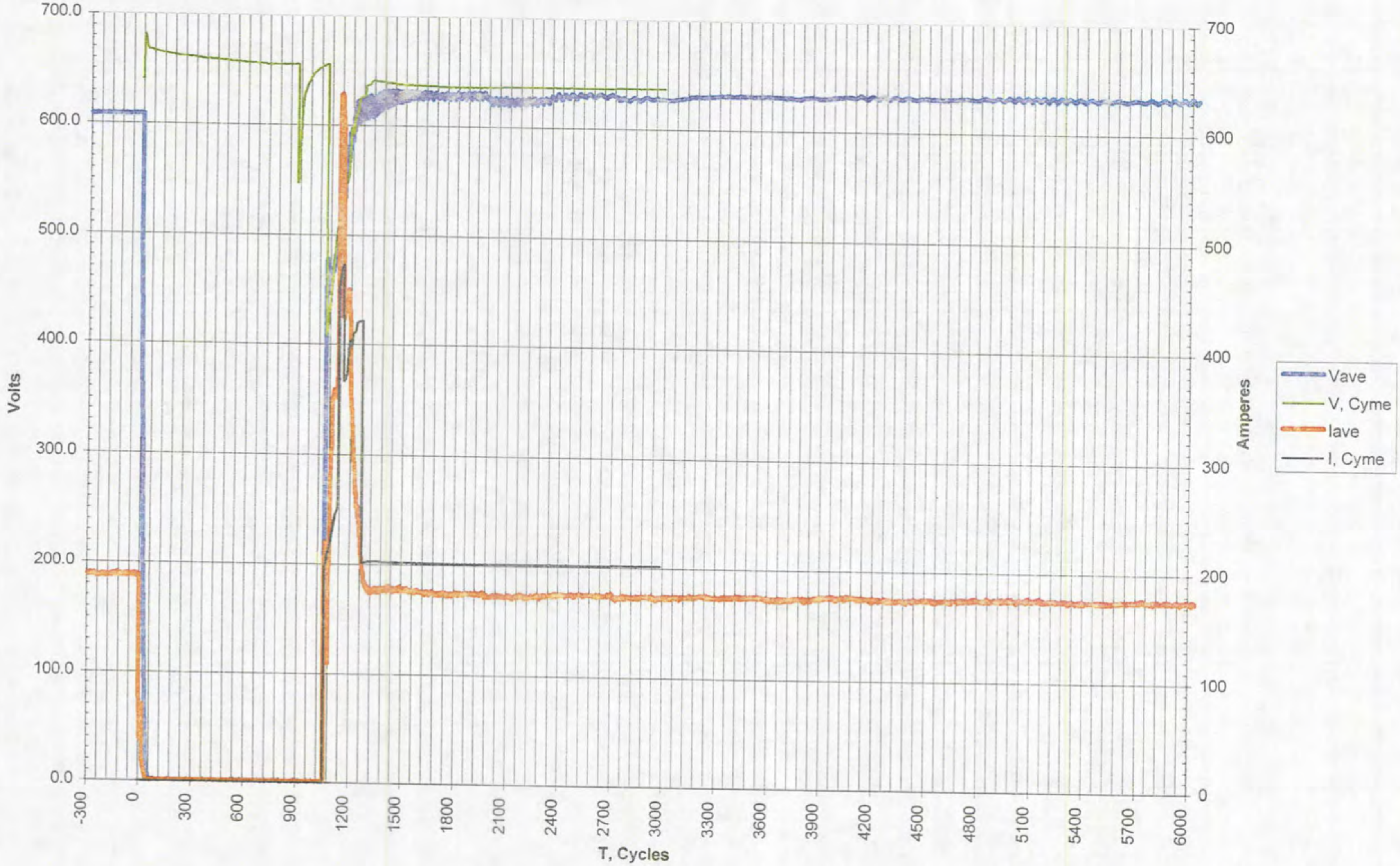


Figure 1-21: Test2, 1X5 KVA and KW

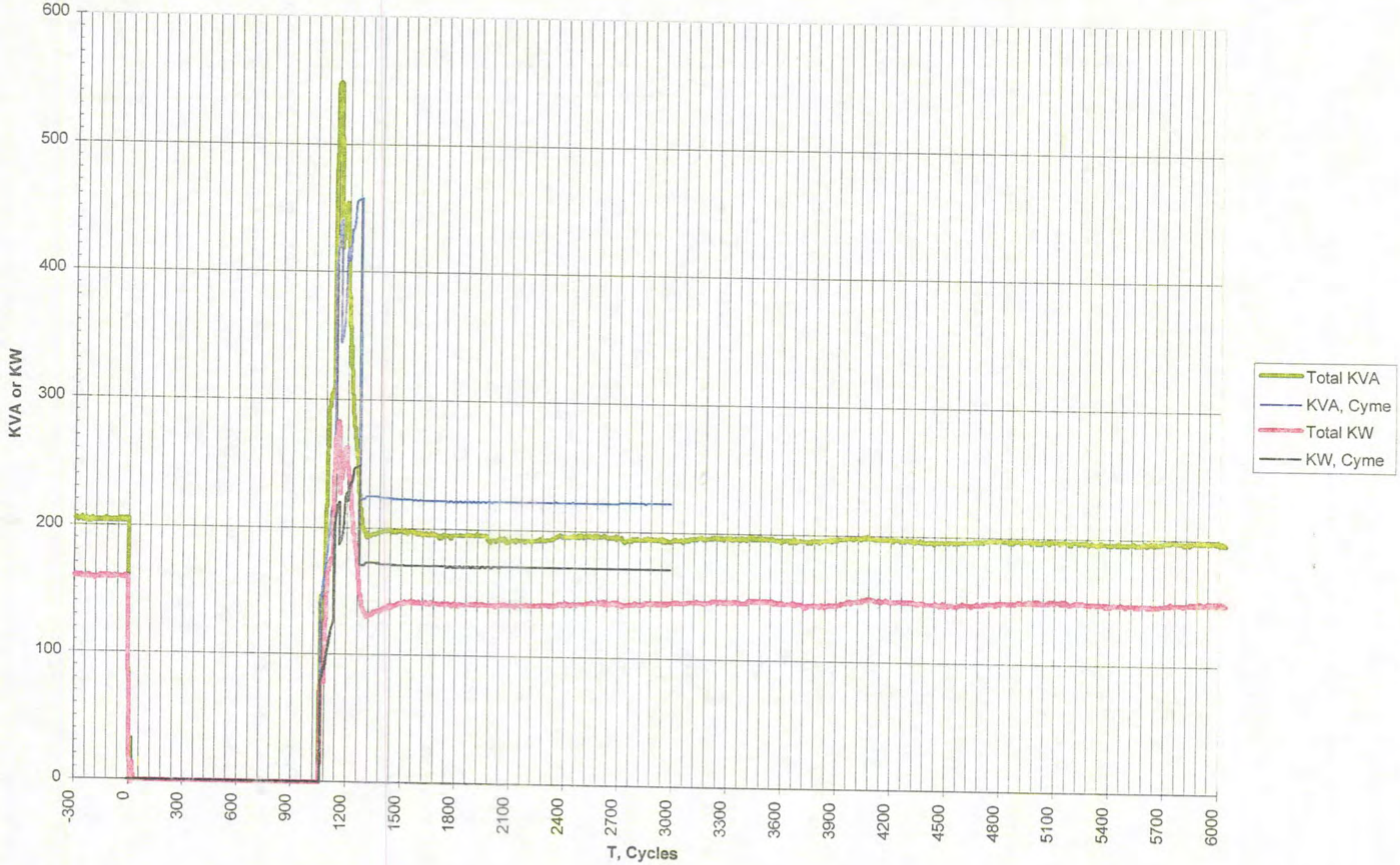


Figure 1-22: Test2, 1X6 Voltage and Current

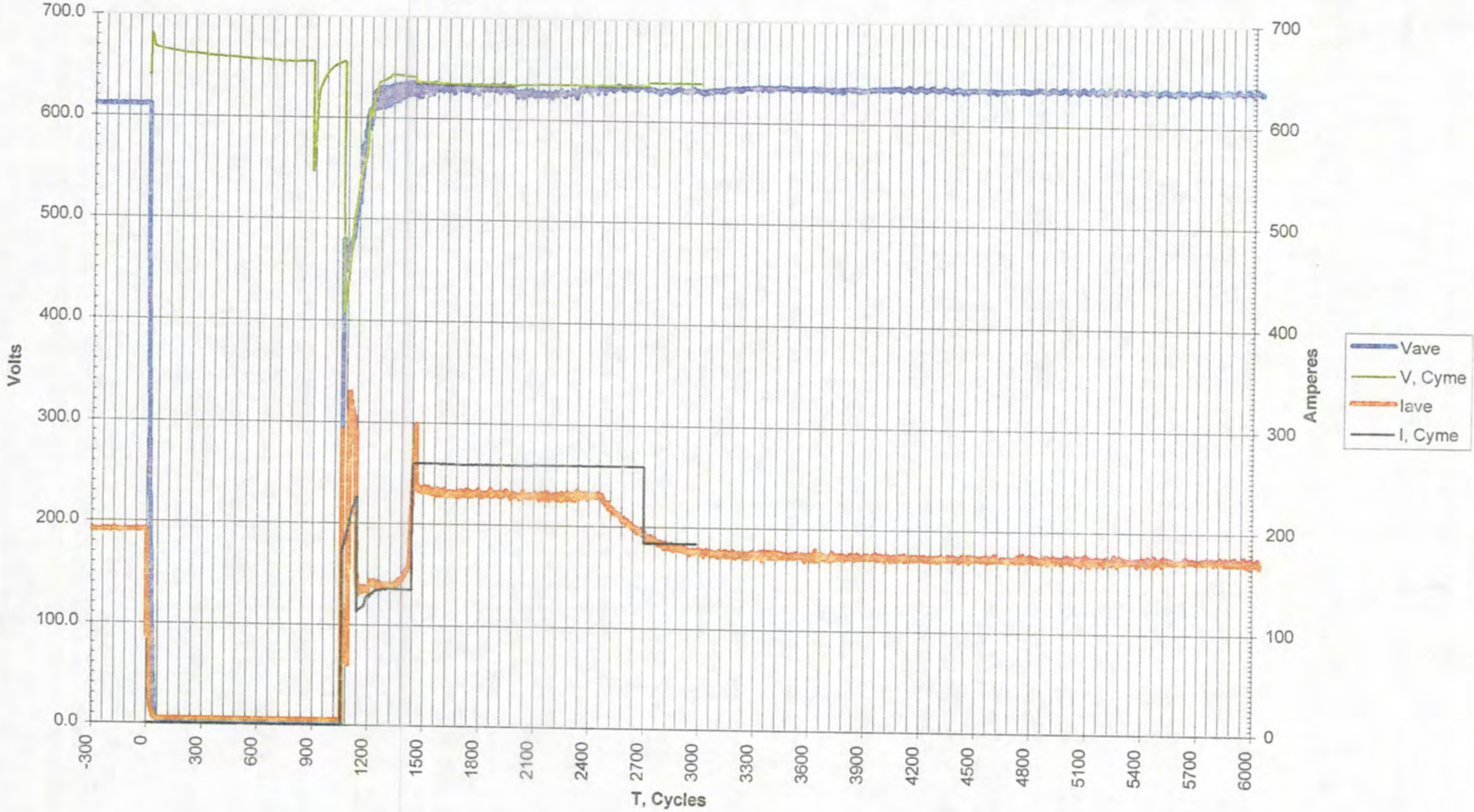


Figure 1-23: Test2, 1X6 KVA and KW

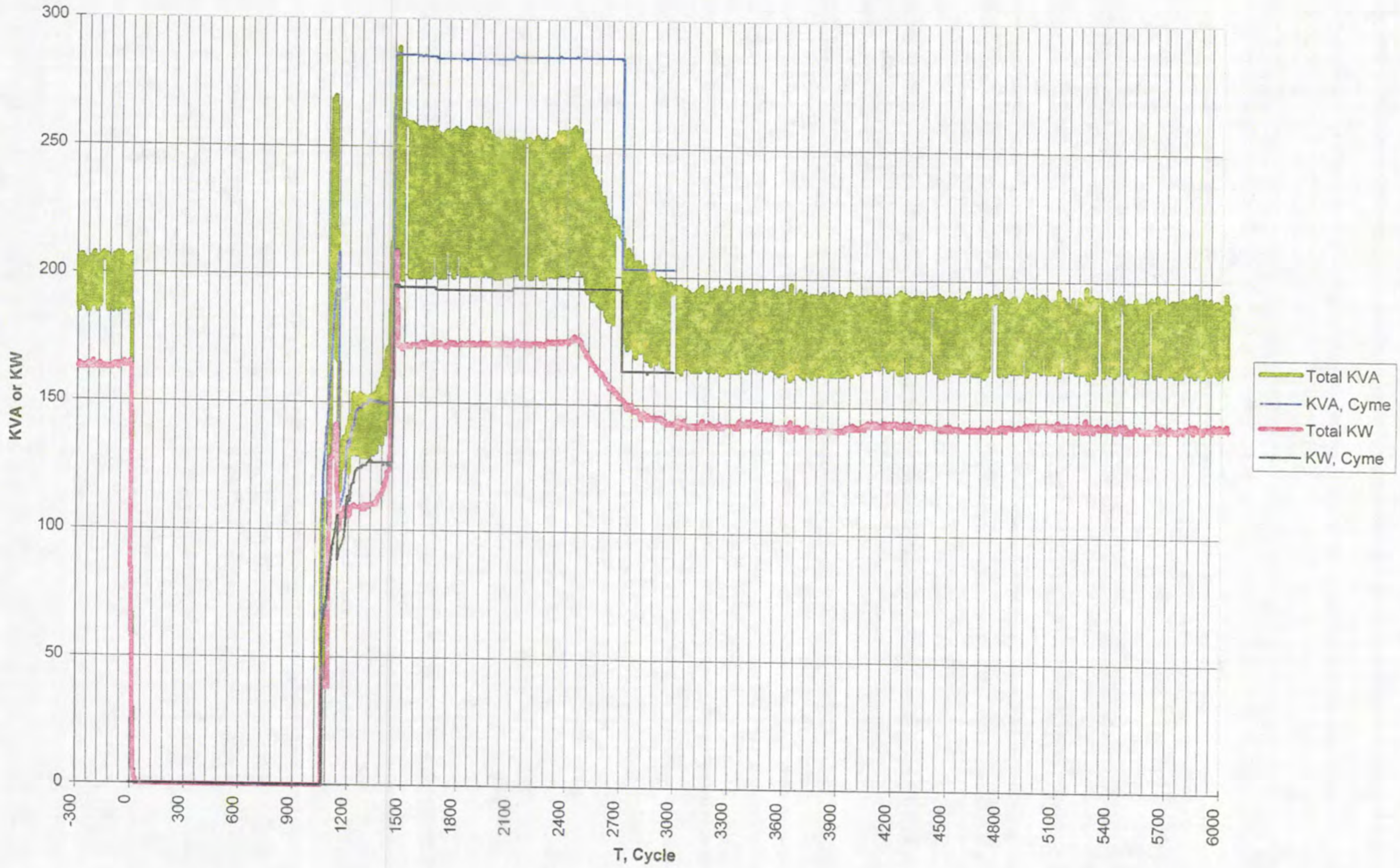


Figure 1-24: Test2, 3X5 Voltage and Current

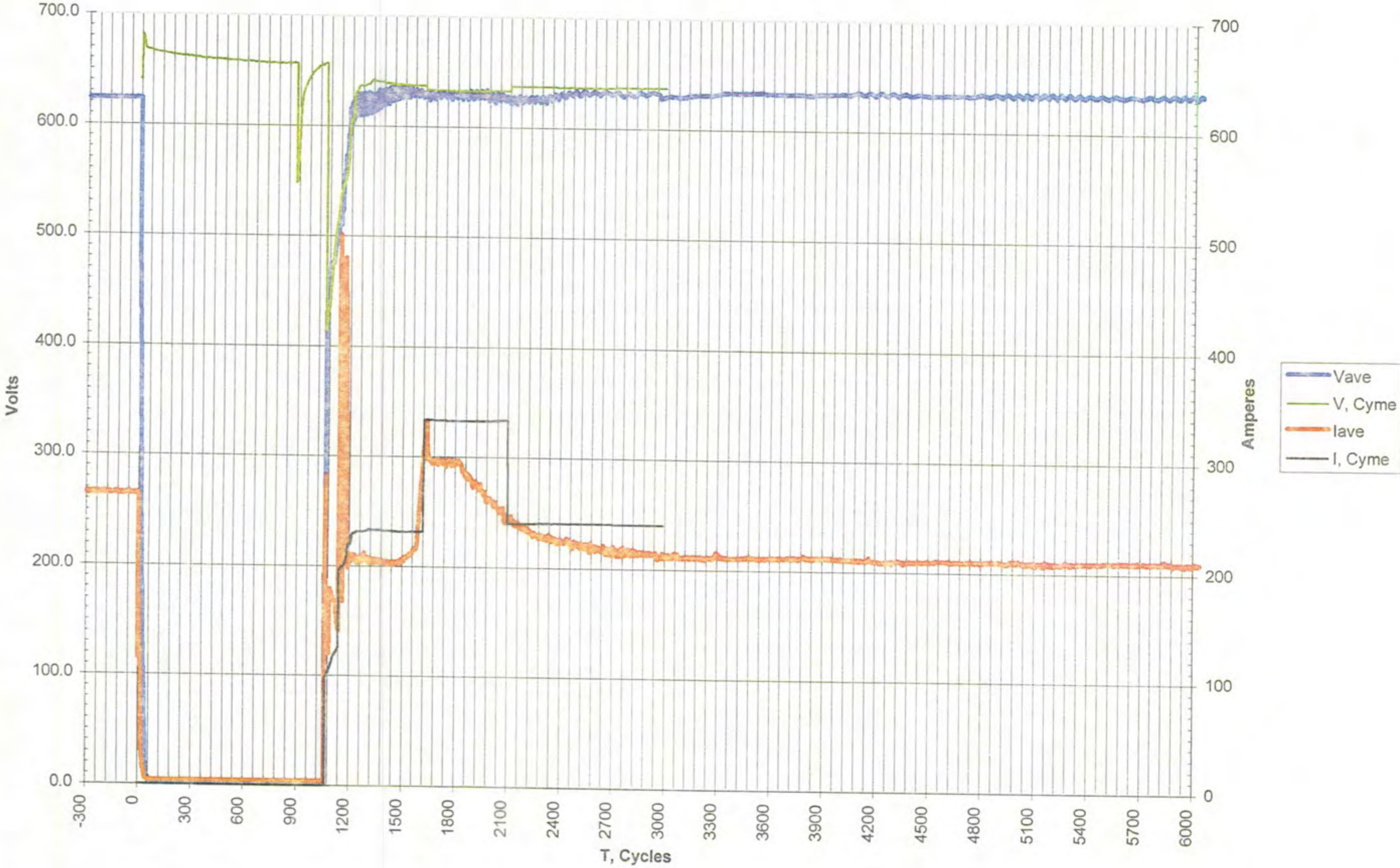


Figure 1-25: Test2, 3X5 KVA and KW

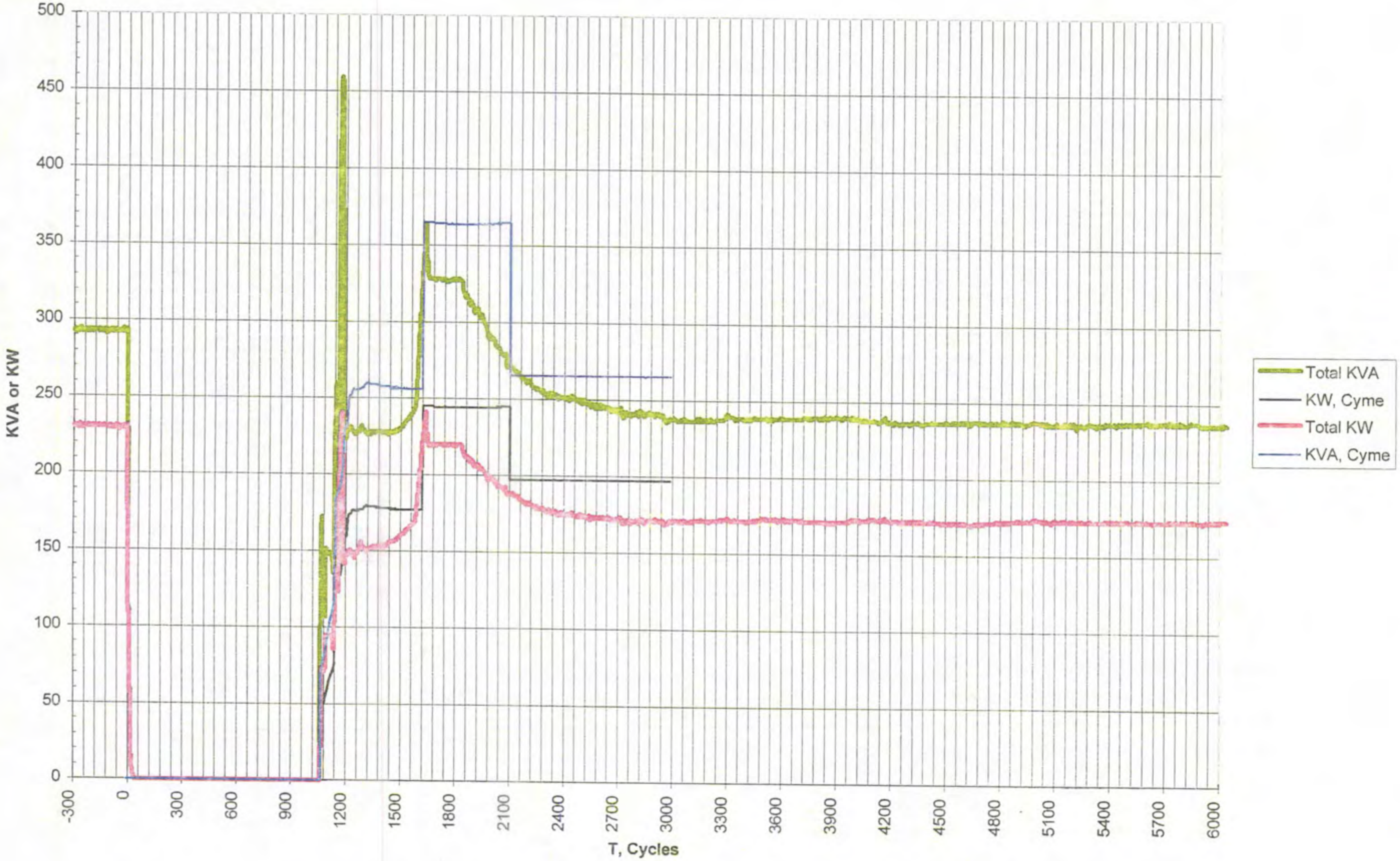


Figure 1-26: Test2, 3X6 Voltage and Current

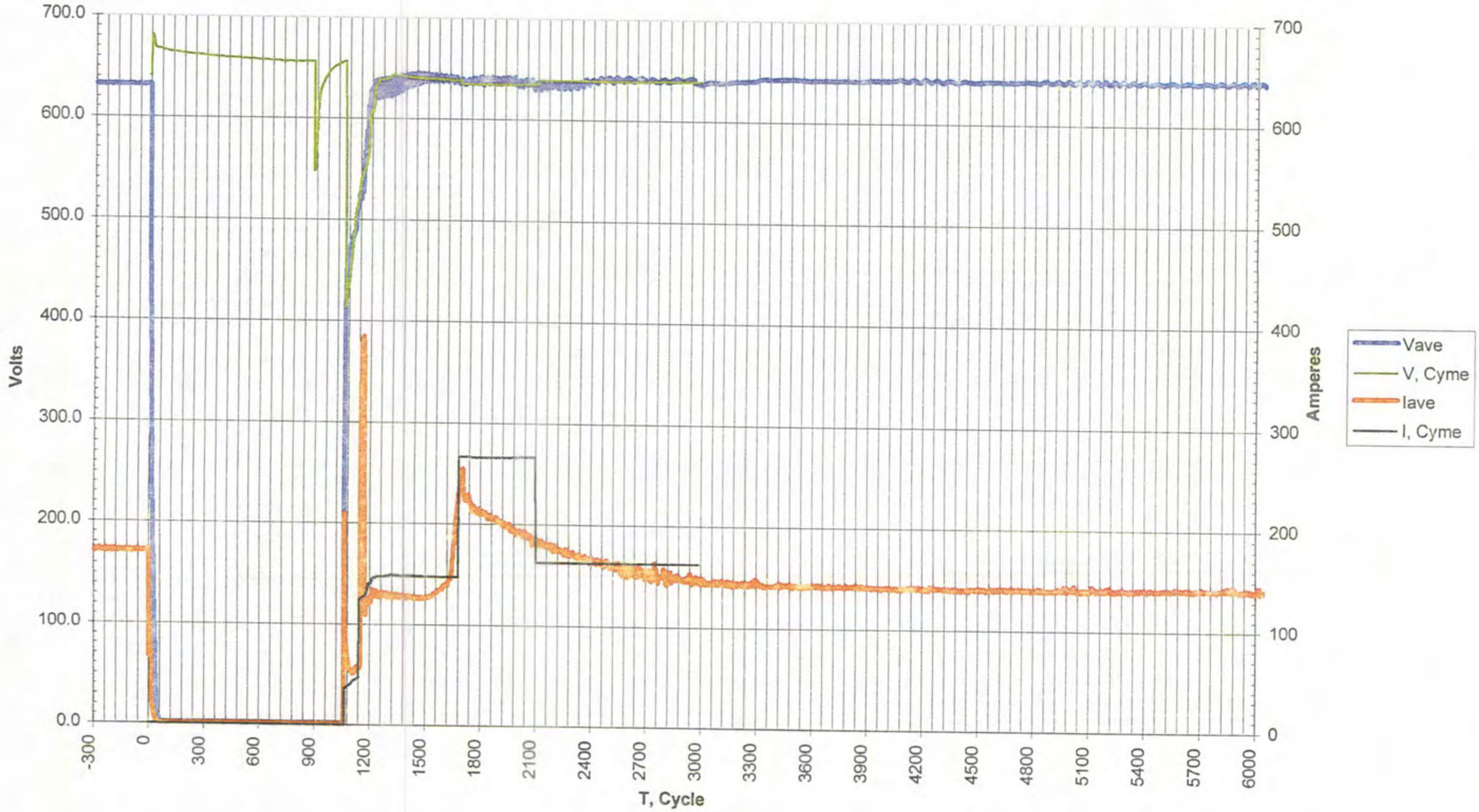


Figure 1-27: Test2, 3X6 KVA and KW

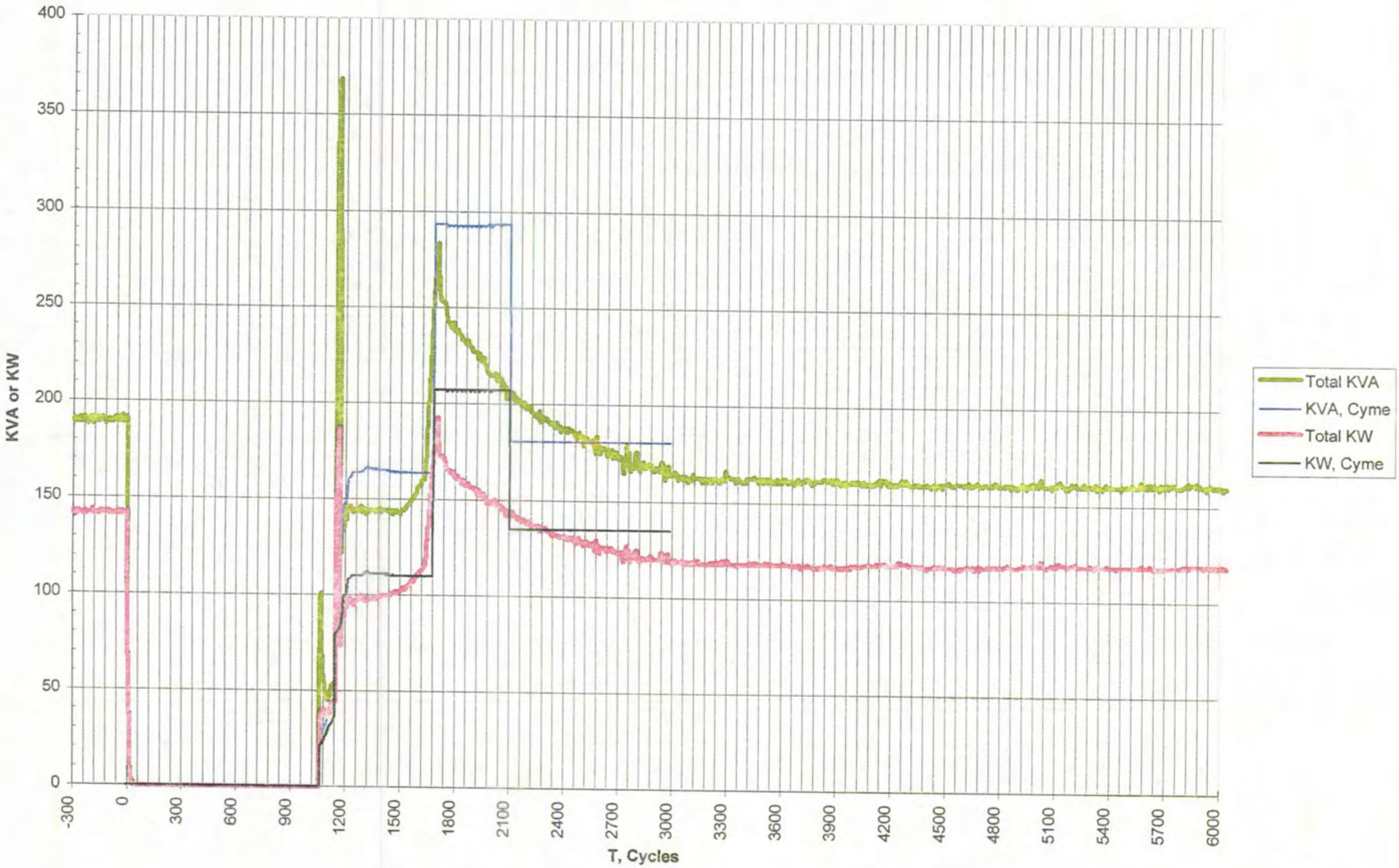


Figure 1-28: Test2, 3X8 Voltage and Current

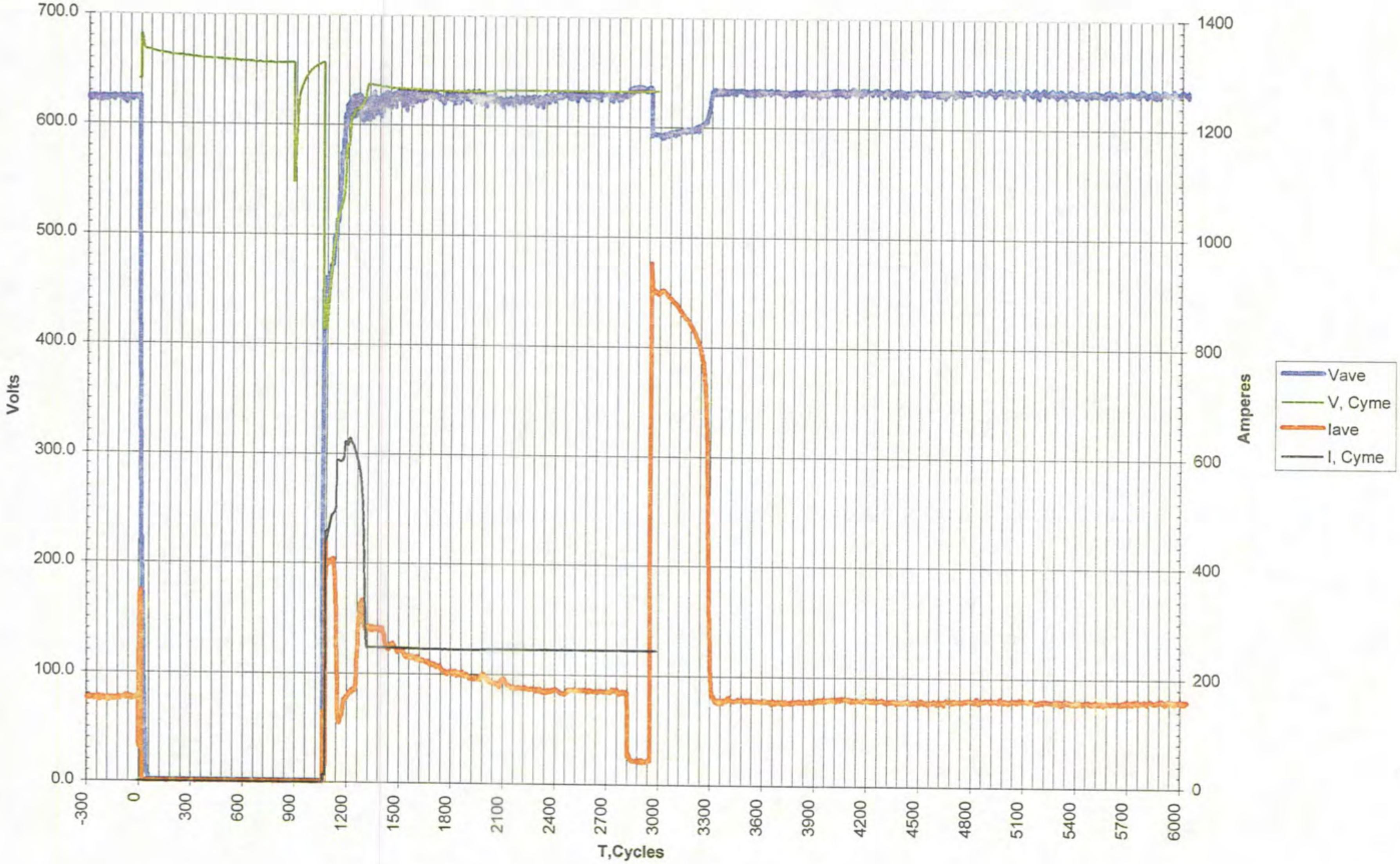


Figure 1-29: Test2, 3X8 KVA and KW

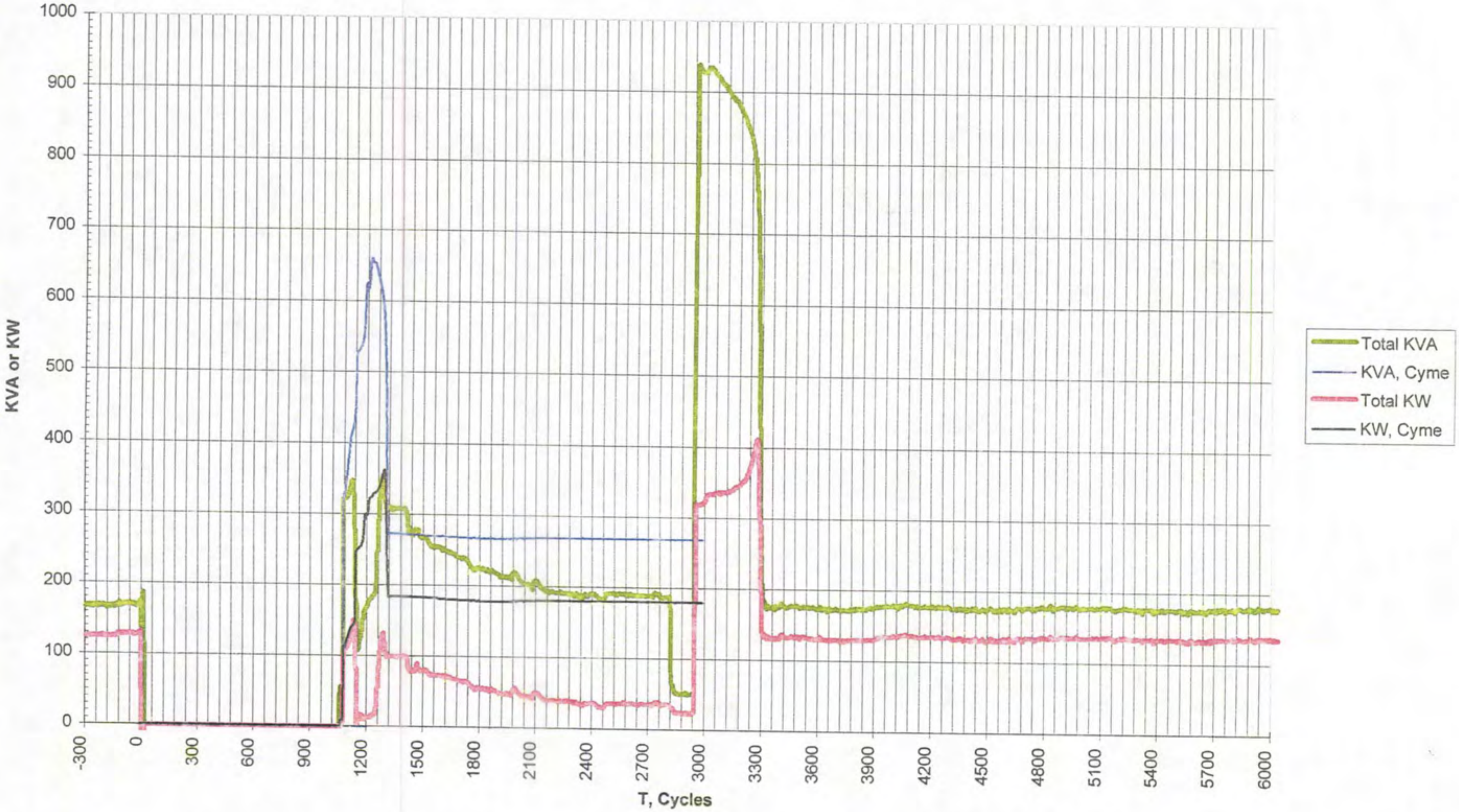


Figure 1-30: Test2, 3X9 Voltage and Current

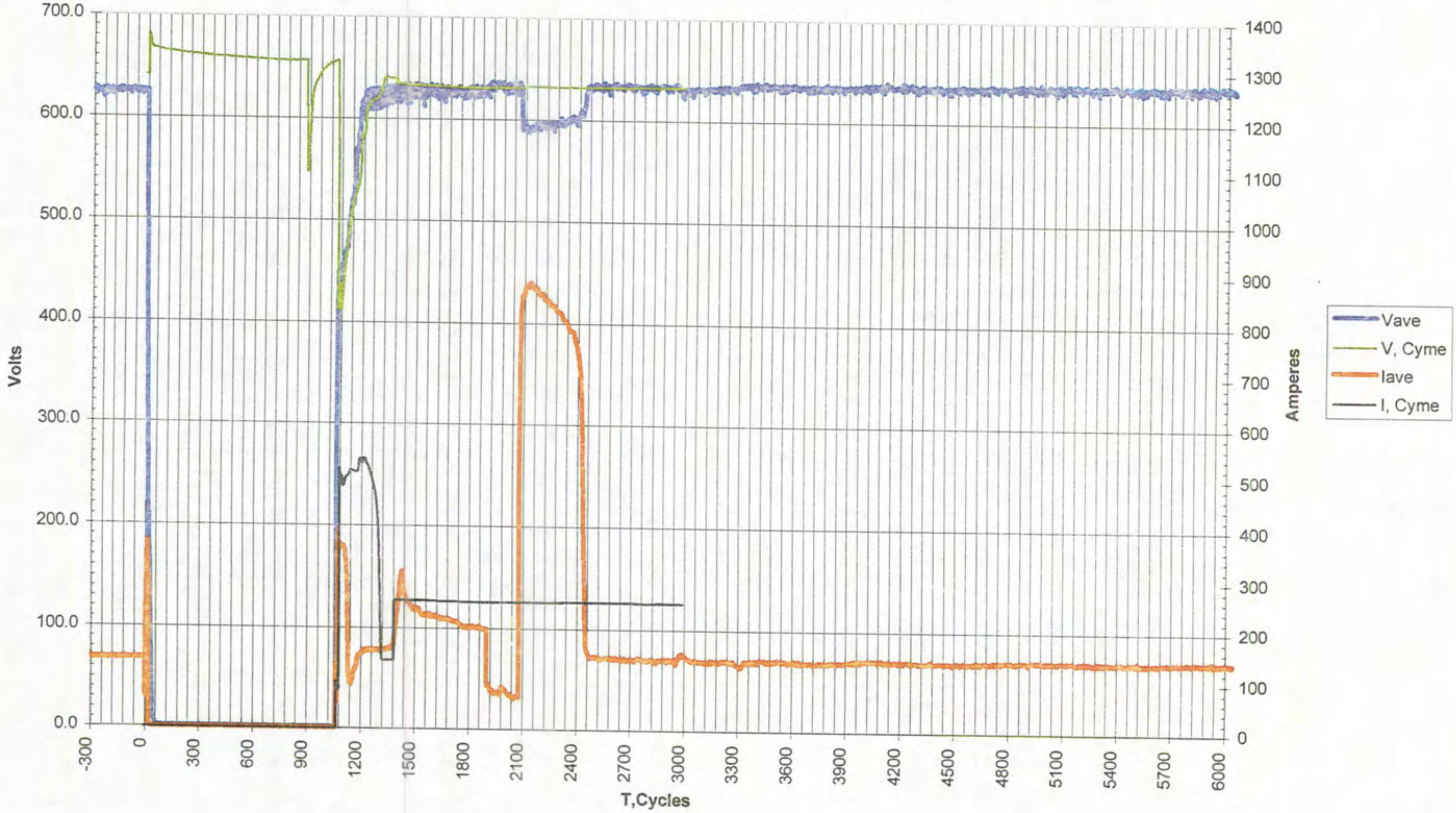


Figure 1-32: Test2, 600V 3XS1 Voltage and Current

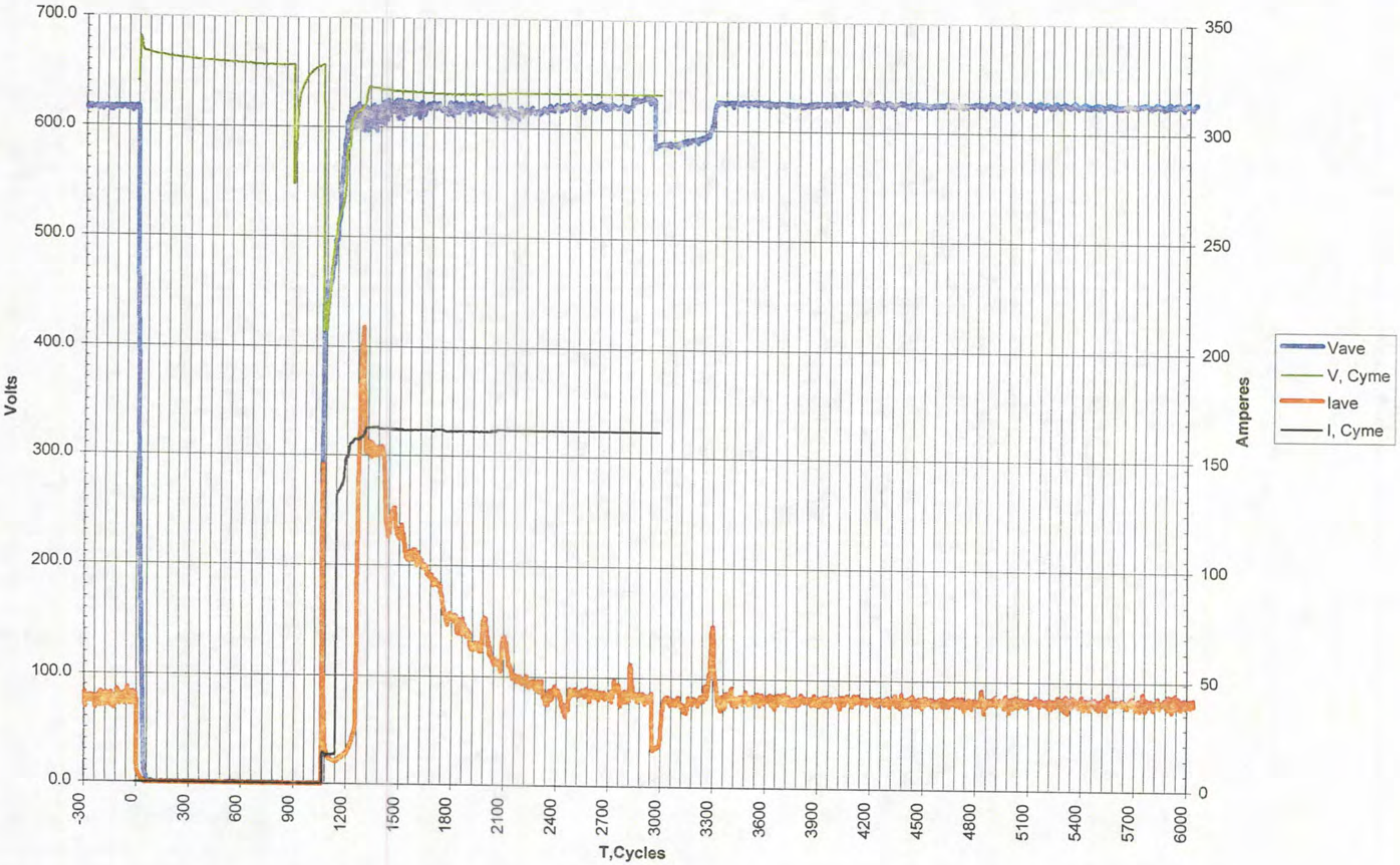


Figure 1-33: Test2, 600V 3XS1 KVA and KW

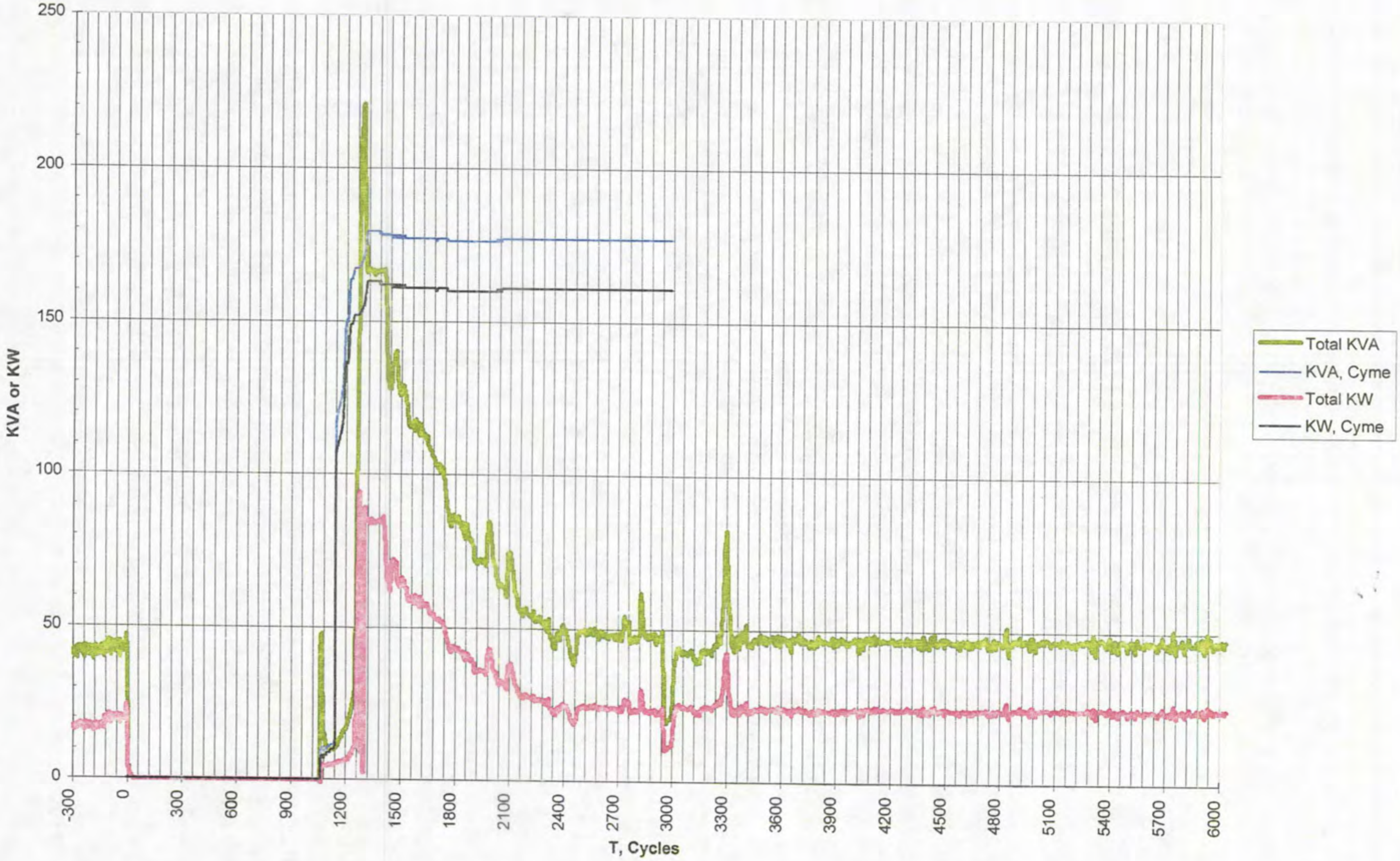


Figure 1-34: Test2, 600V 3XS2 Voltage and Current

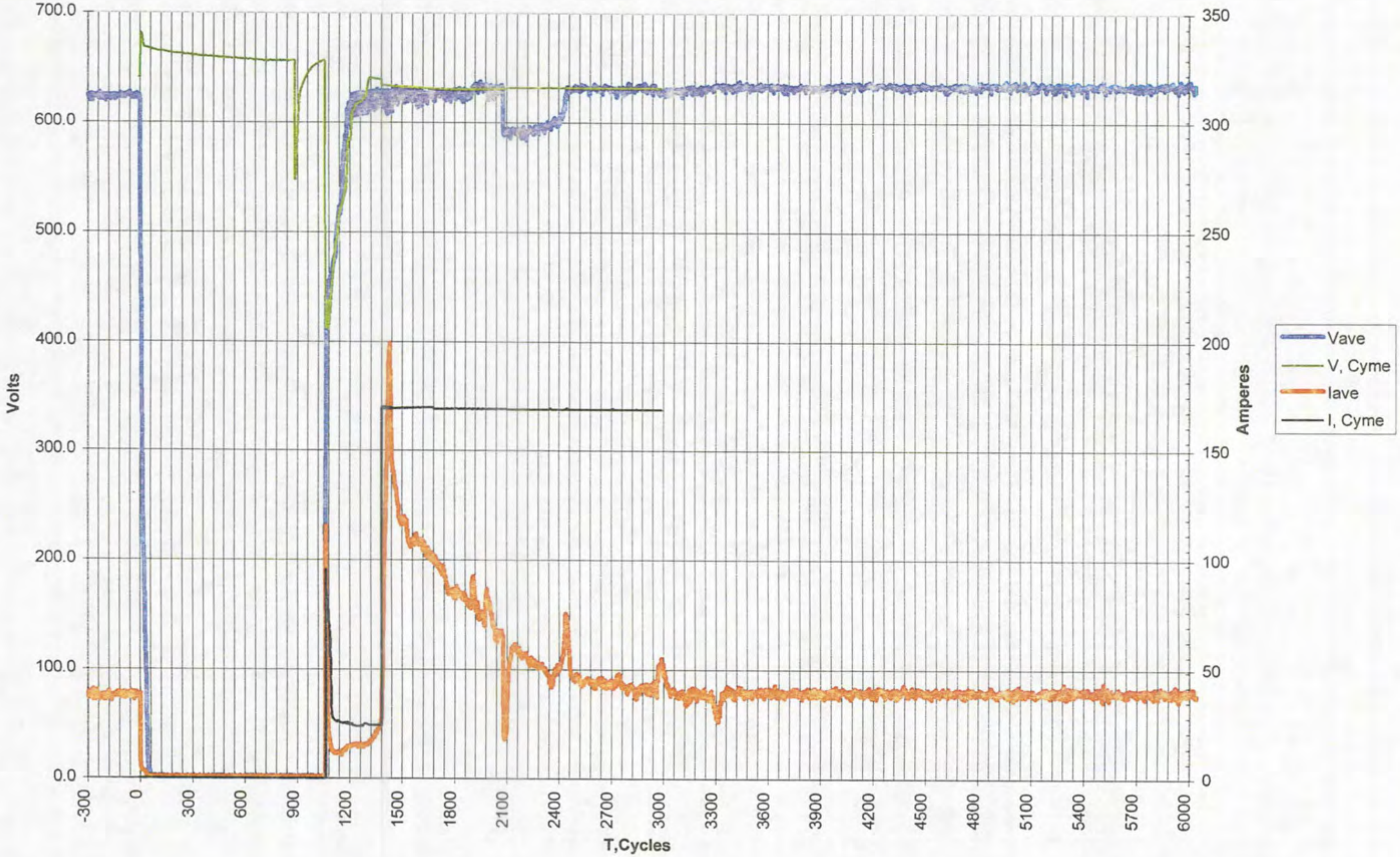


Figure 1-35: Test2, 600V 3XS2 KVA and KW

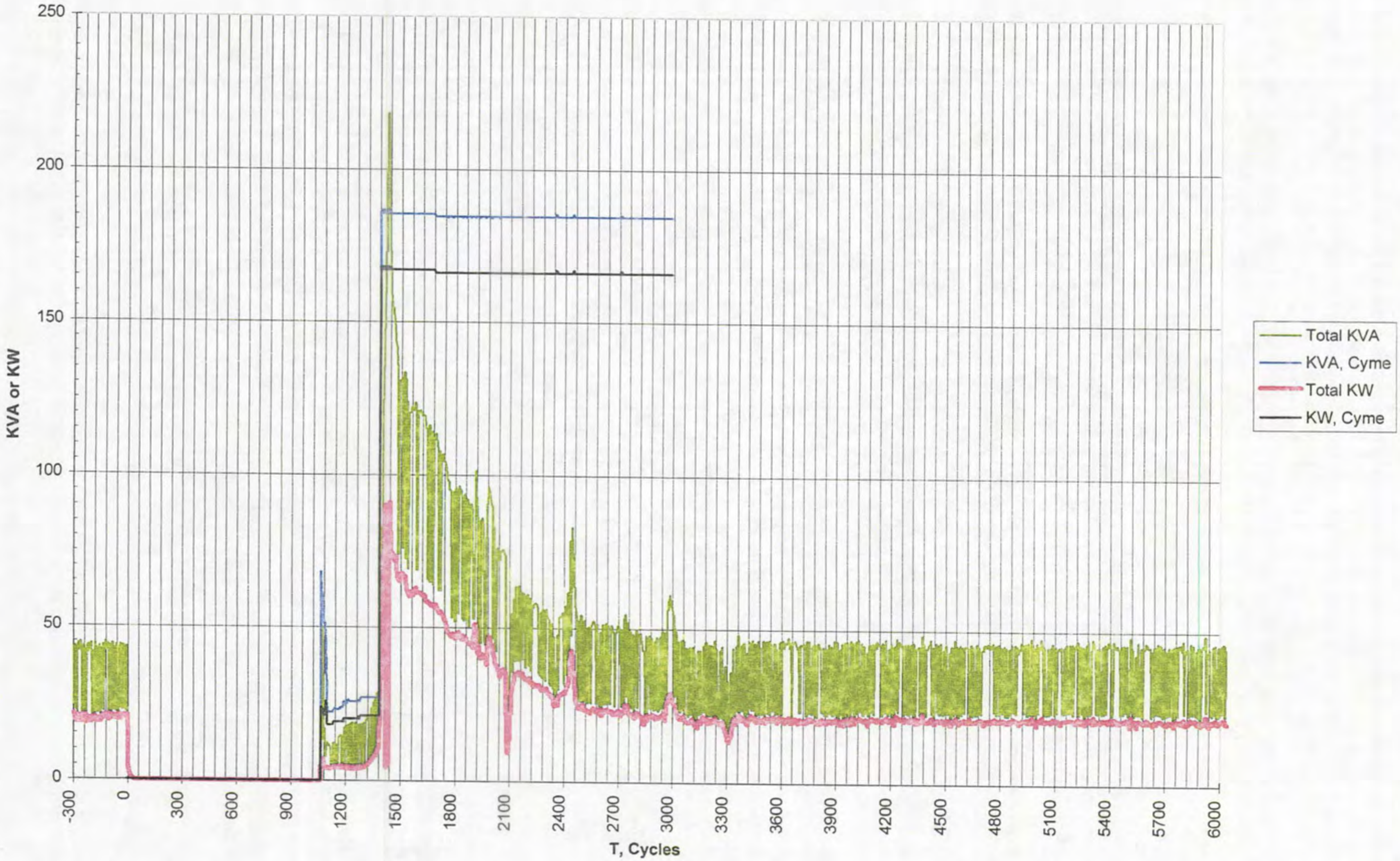


Figure 1-36: Test2, 600V 3XS3 Voltage and Current

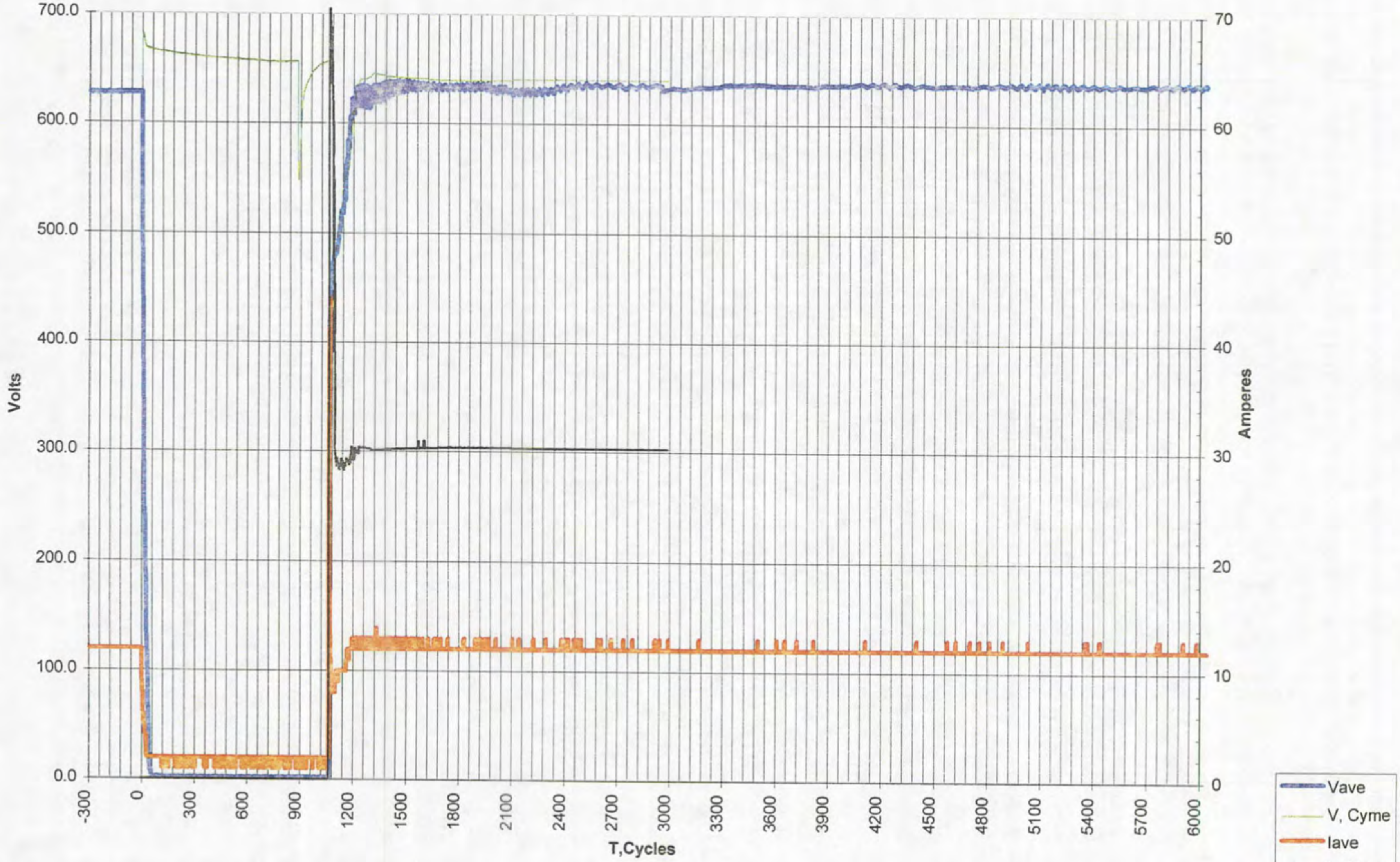


Figure 1-37: Test2, 600V 3XS3 KVA and KW

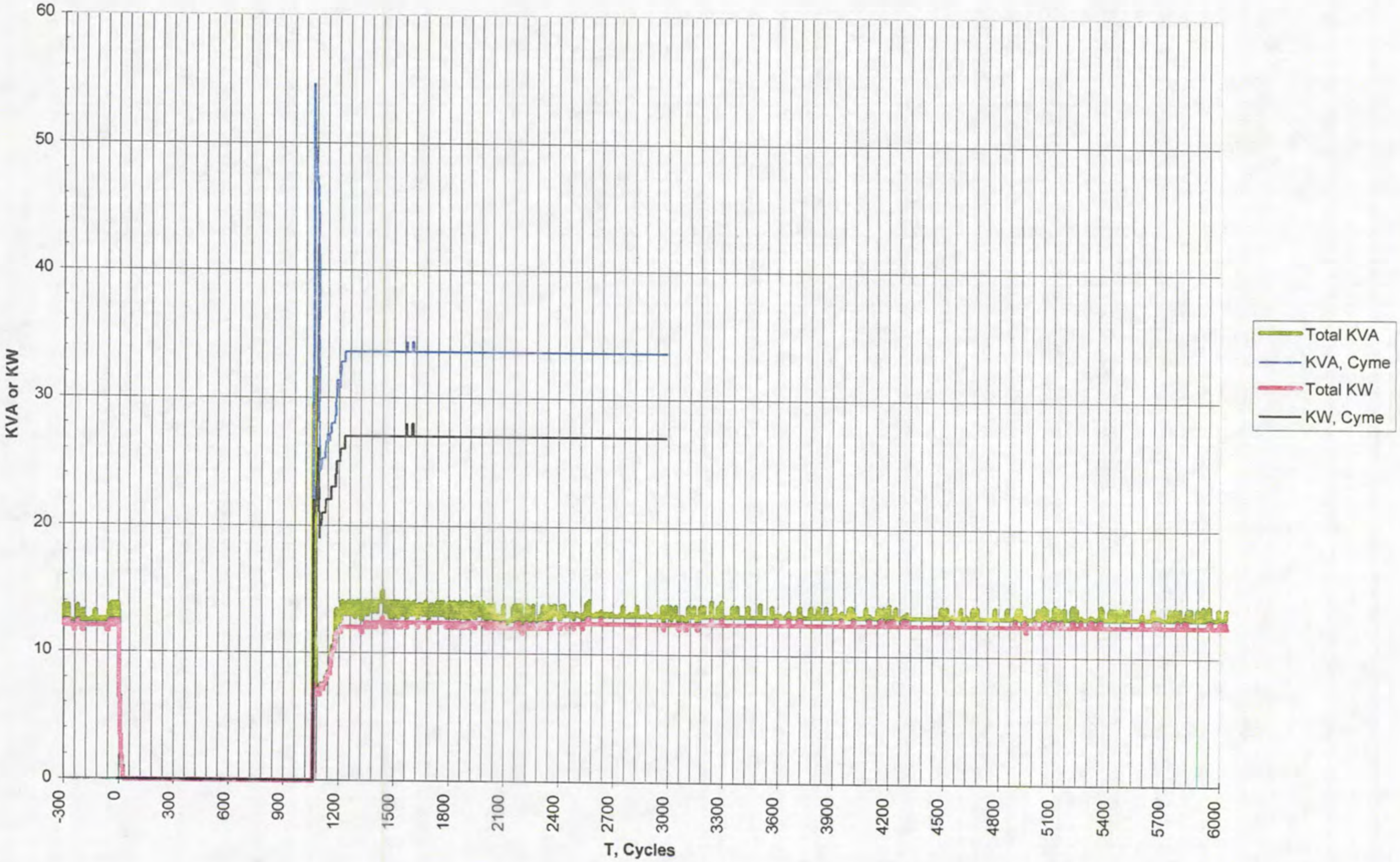


Figure 1-38: Test2, 208V 3XS1 Voltage and Current

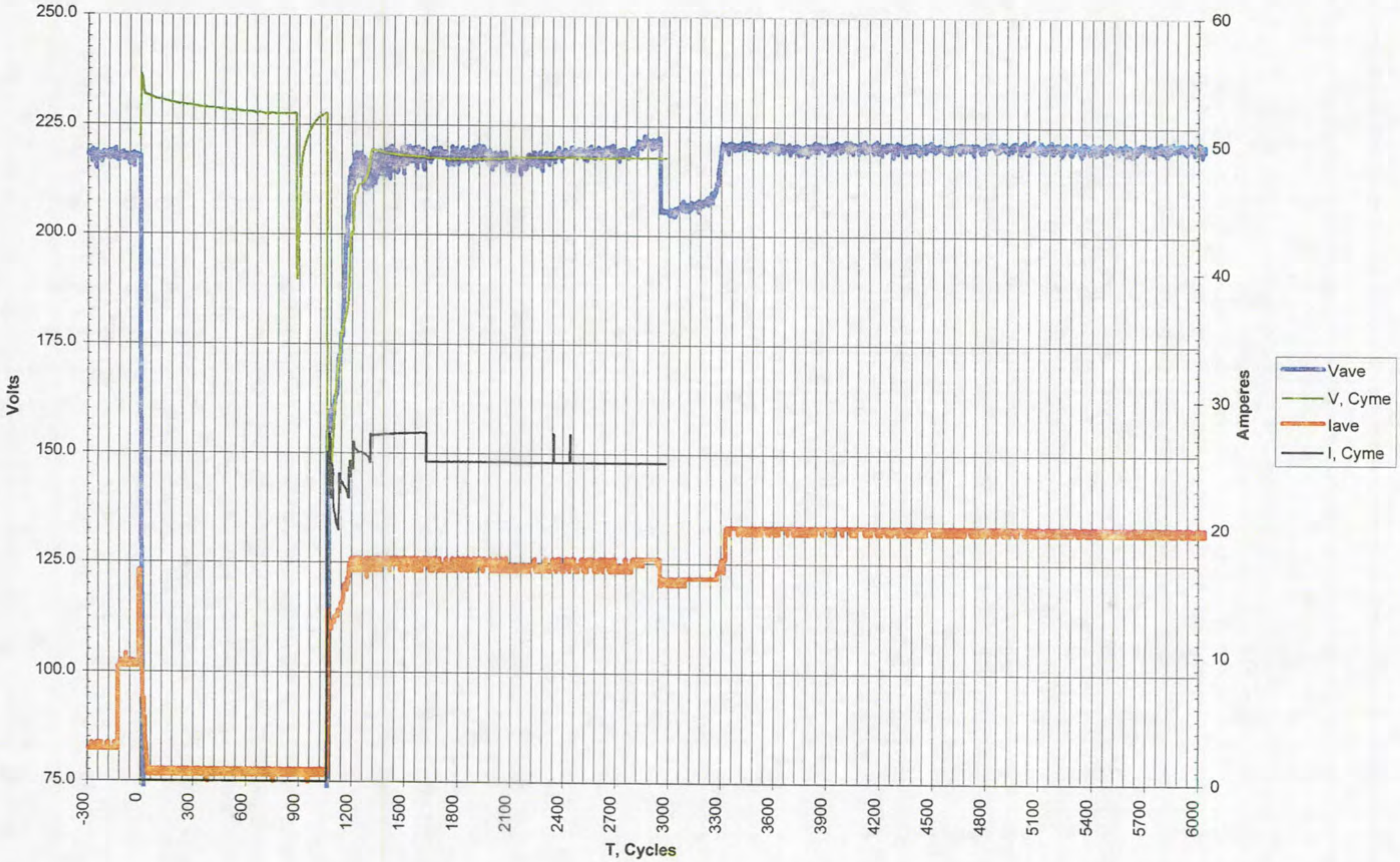


Figure 1-39: Test2, 208V 3XS1 KVA and KW

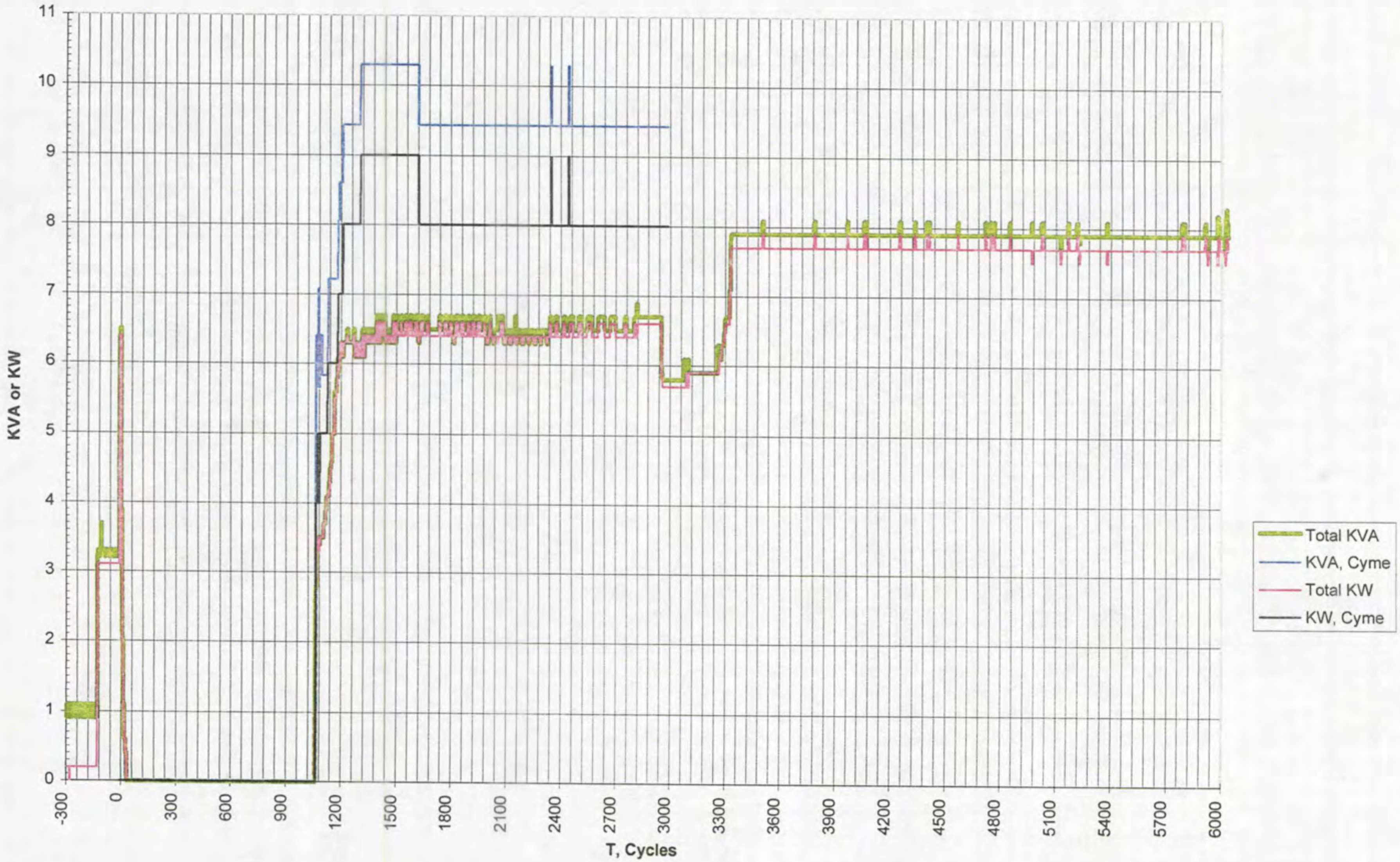


Figure 1-40: Test2, 208V 3XS2 Voltage and Current

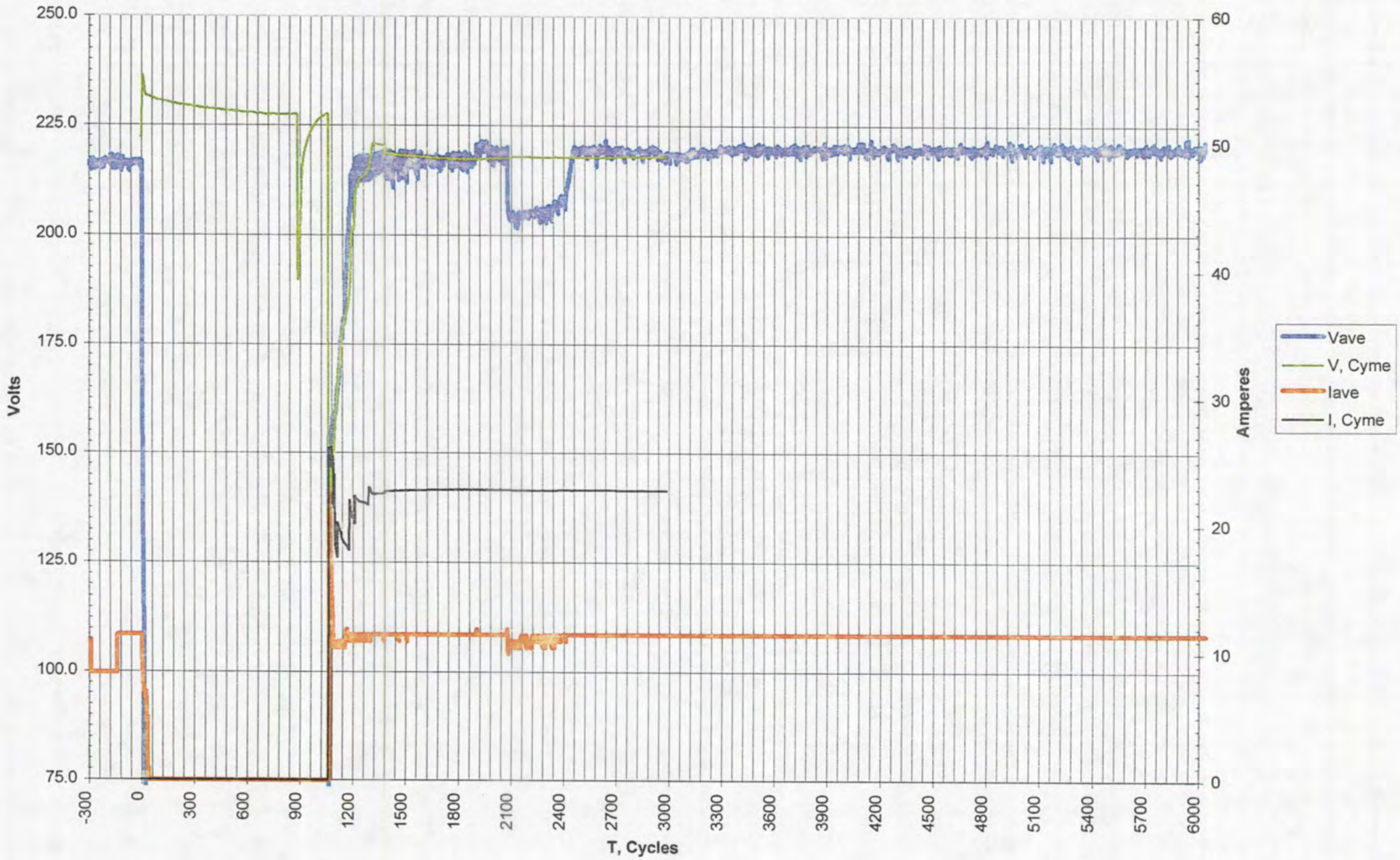


Figure 1-41: Test2, 208V 3XS2 KVA and KW

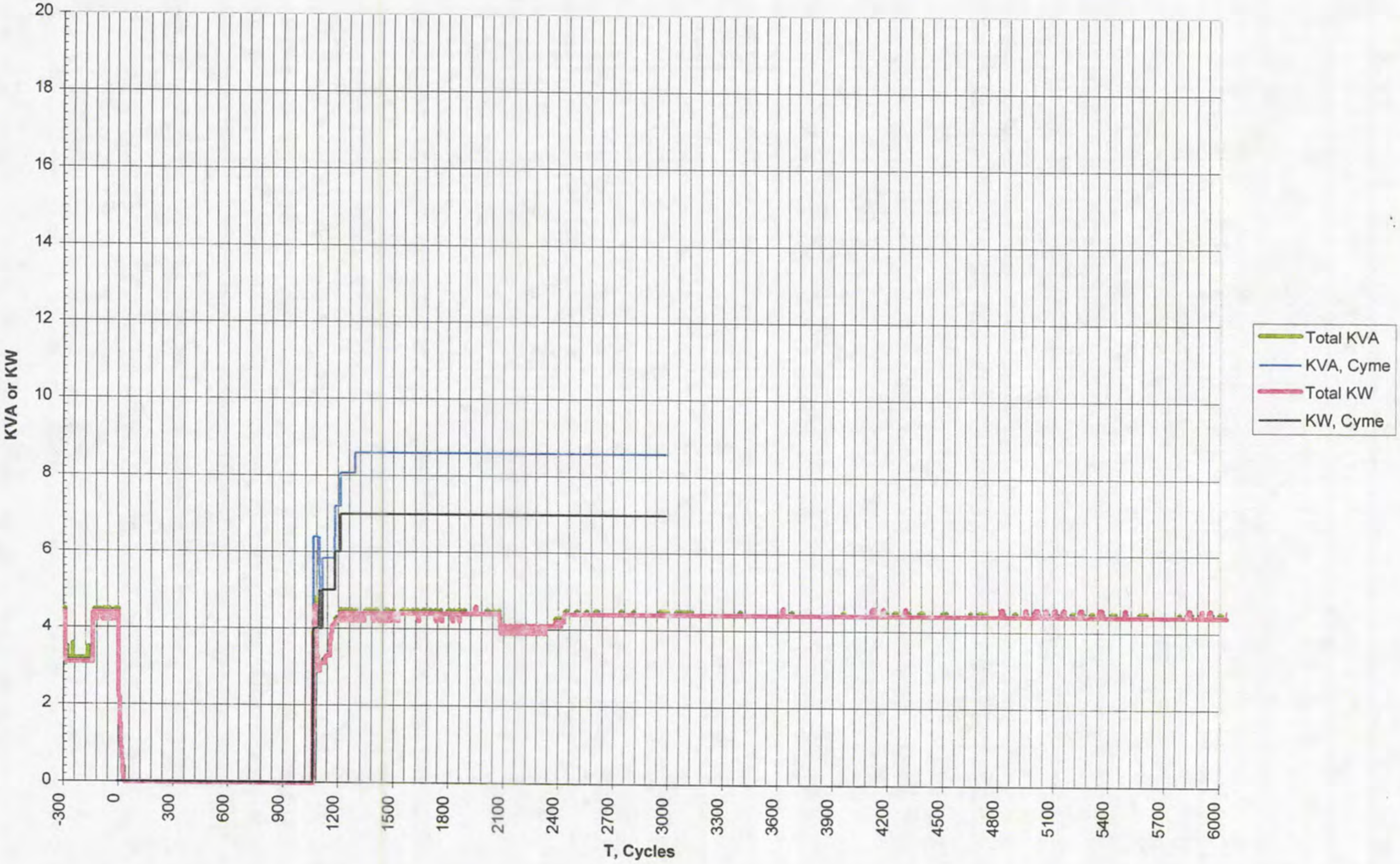


Figure 1-42: Test2, 208V 3XS3 Voltage and Current

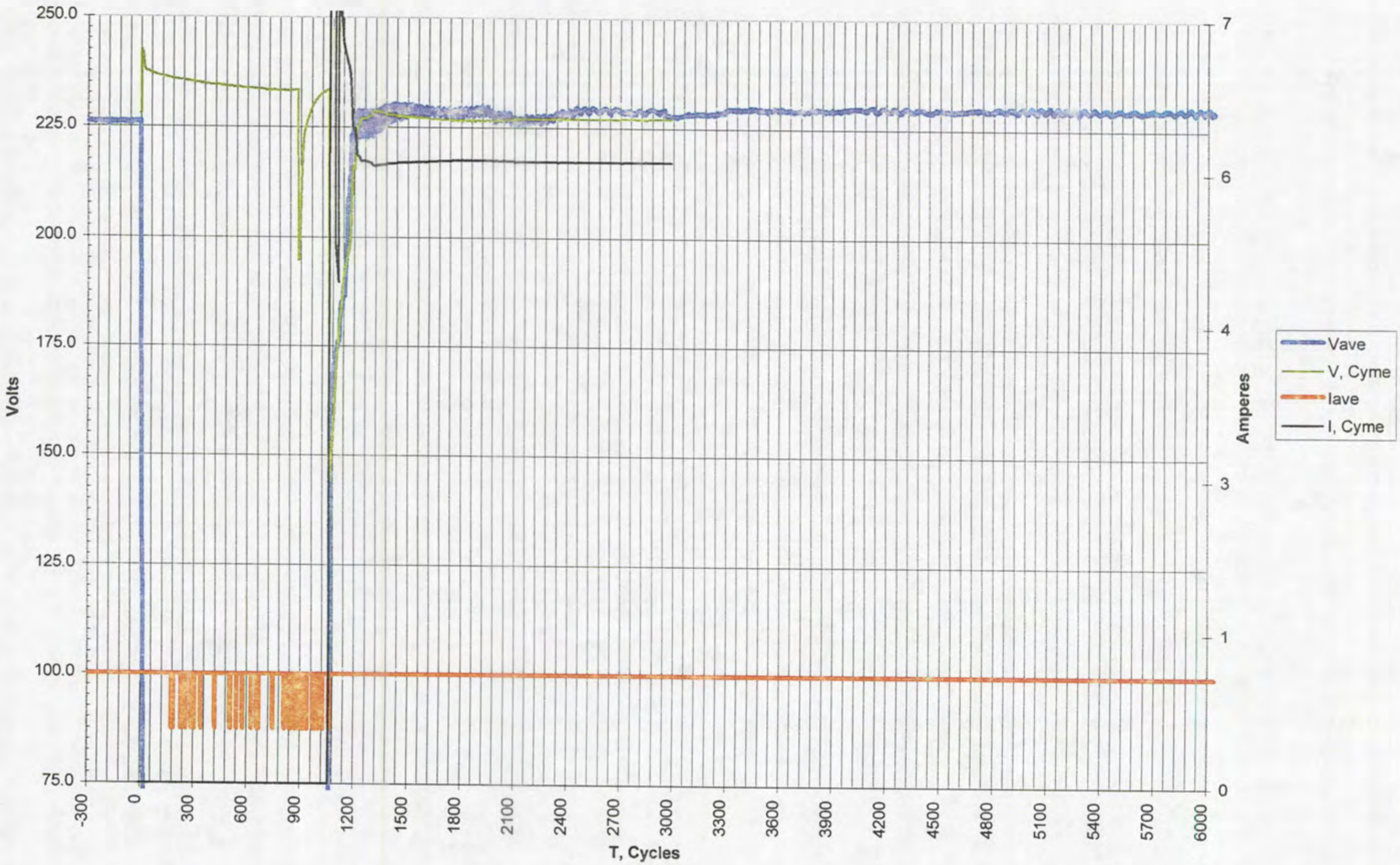
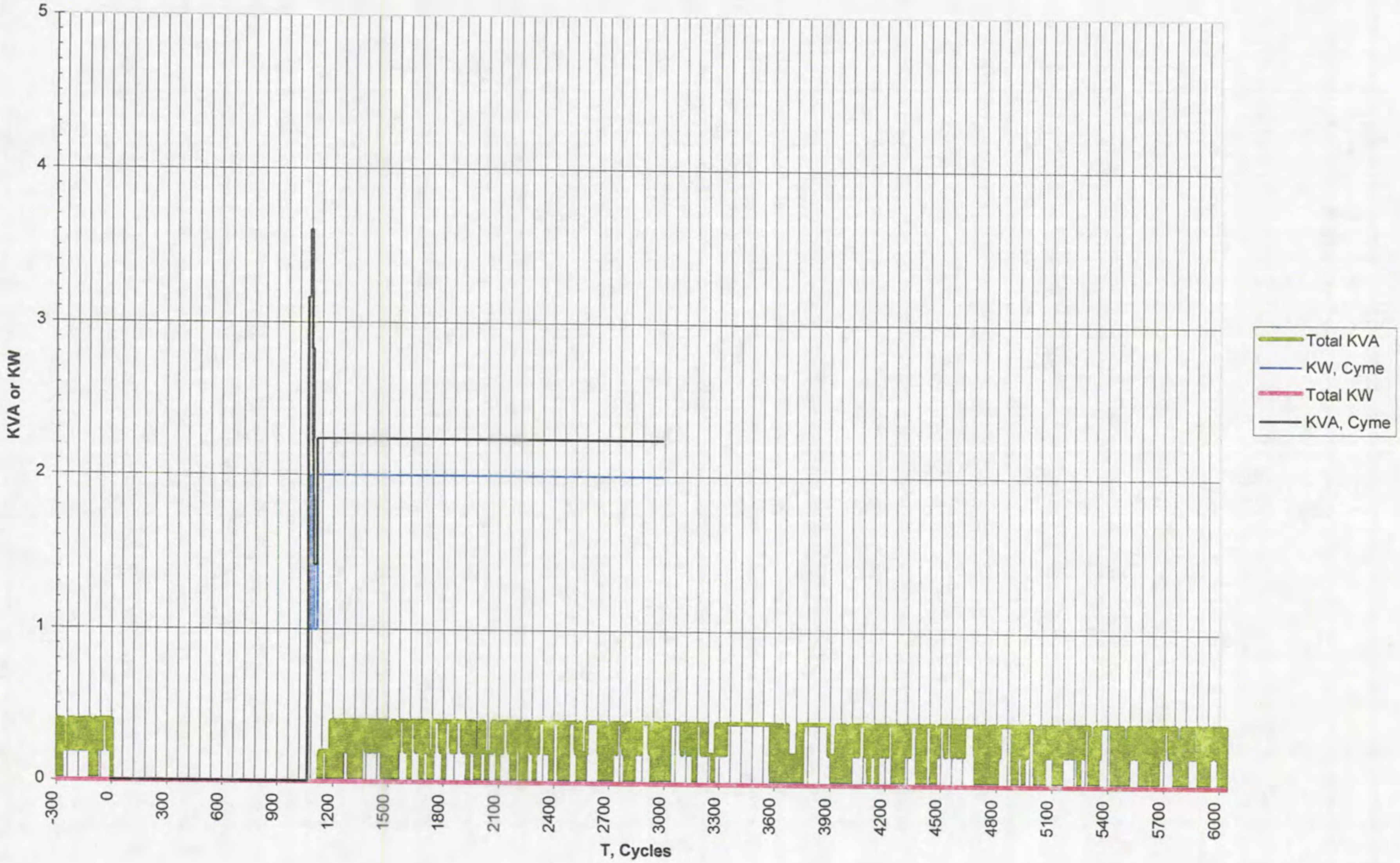


Figure 1-43: Test2, 208V 3XS3 KVA and KW



Appendix 2 - Test 5, Figures of Results

APPENDIX 2: Figures for Test 5

Figure 2-1: Test5, Keowee Voltage and Current

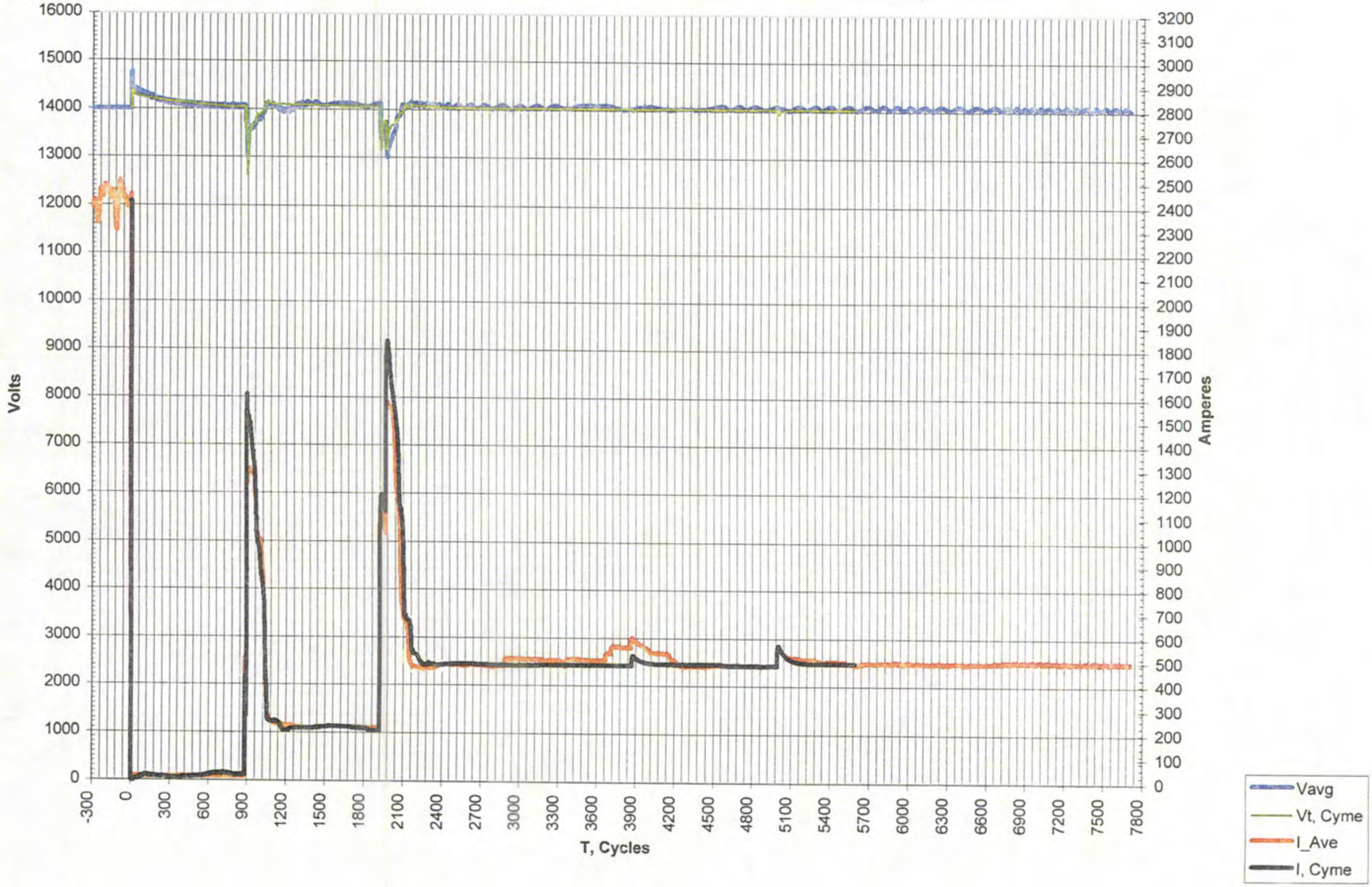


Figure 2-2: Test5, Keowee Voltage

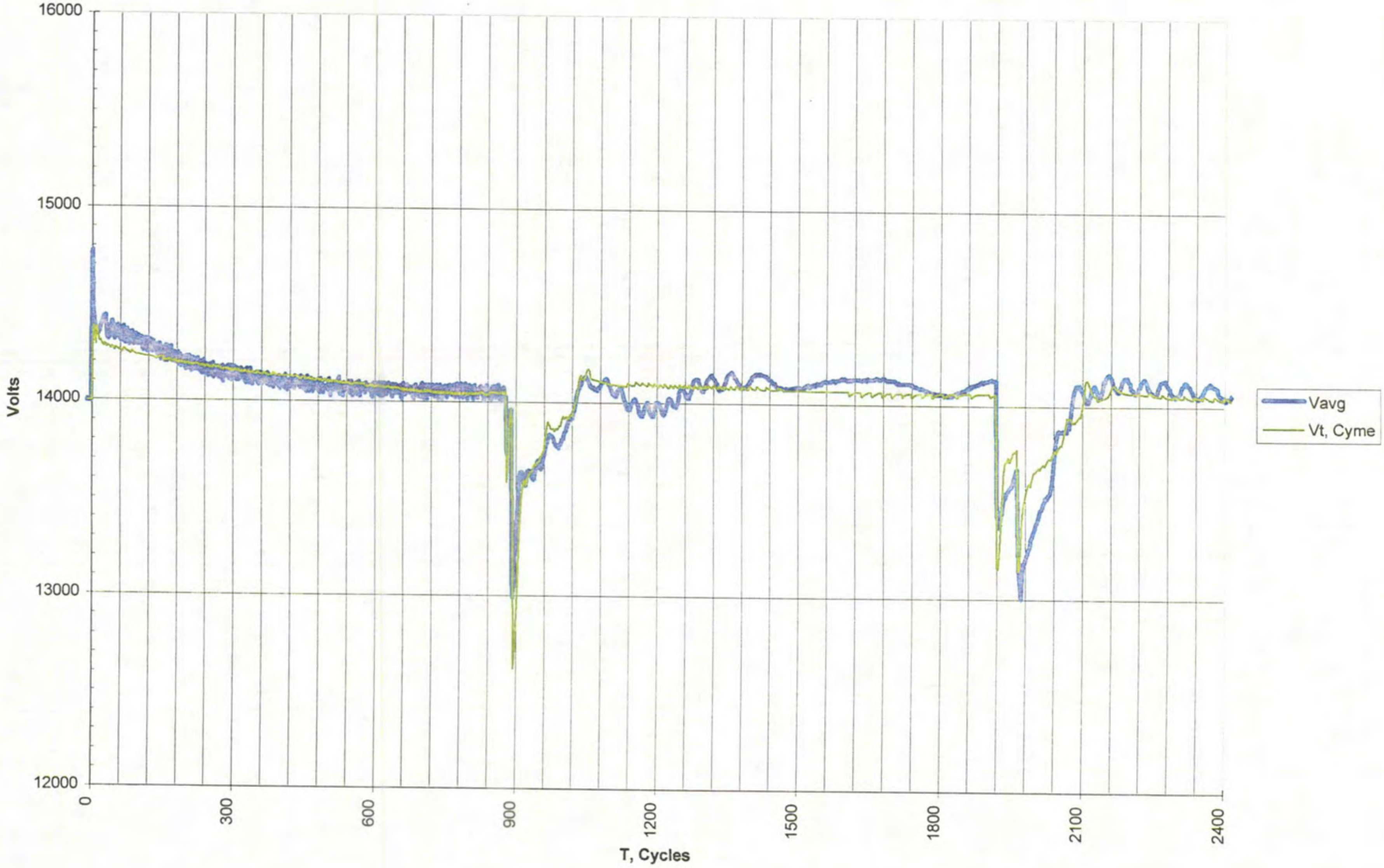


Figure 2-3, Test5, Keowee KVA

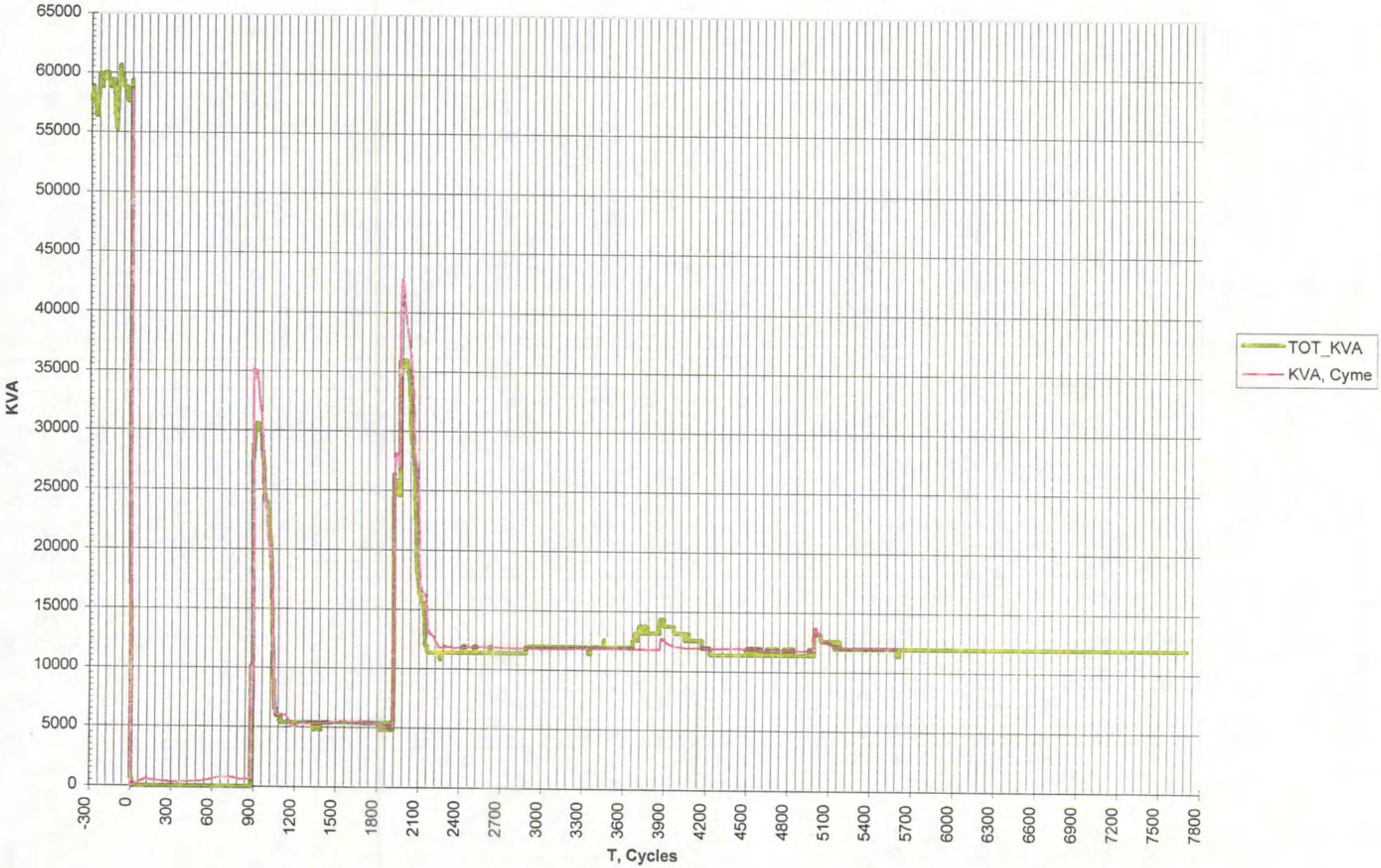


Figure 2-4: Test5, Keowee KW

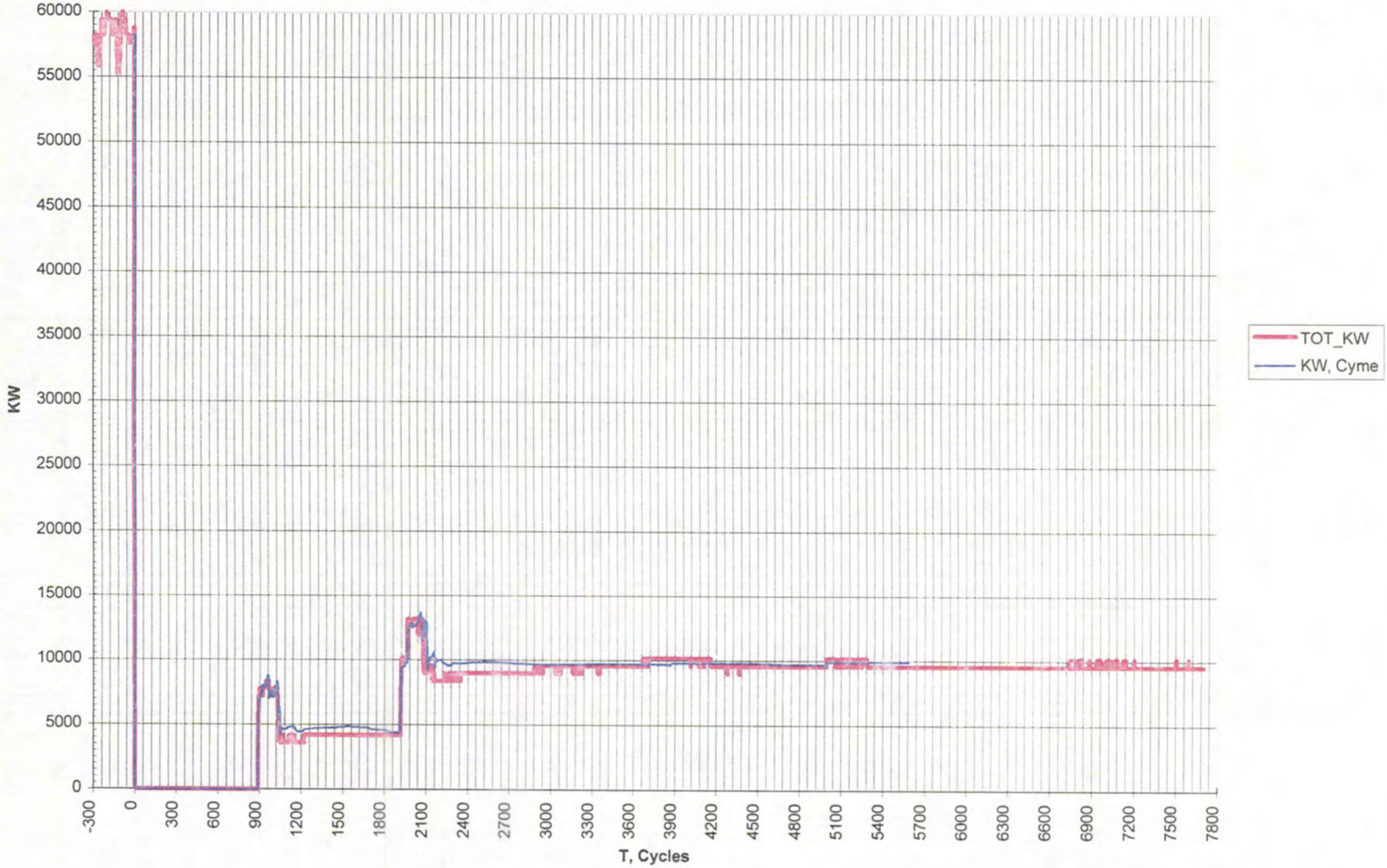


Figure 2-5: Test5, Keowee Frequency

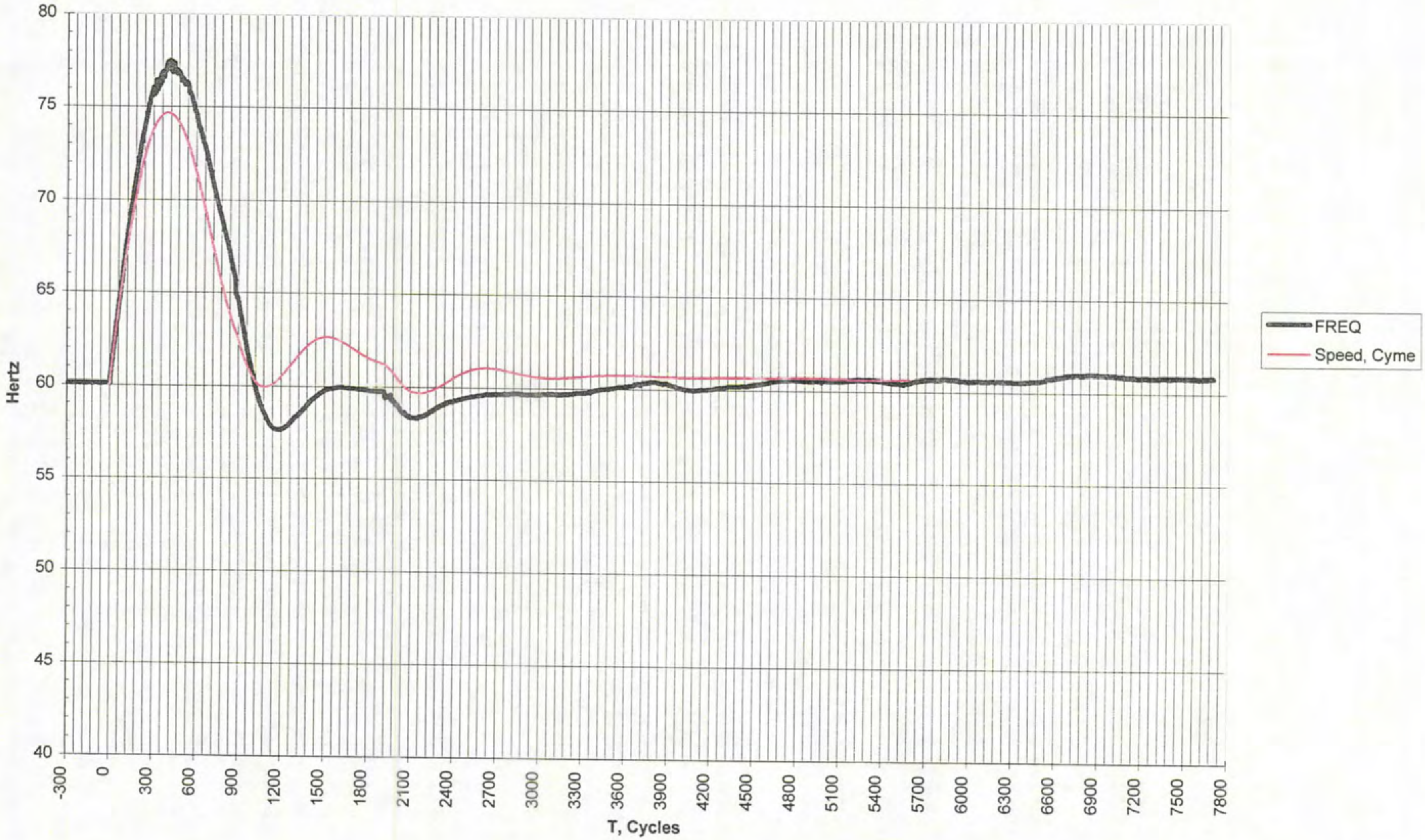


Figure 2-6: Test5, Unit 1 MFB Voltage and Current

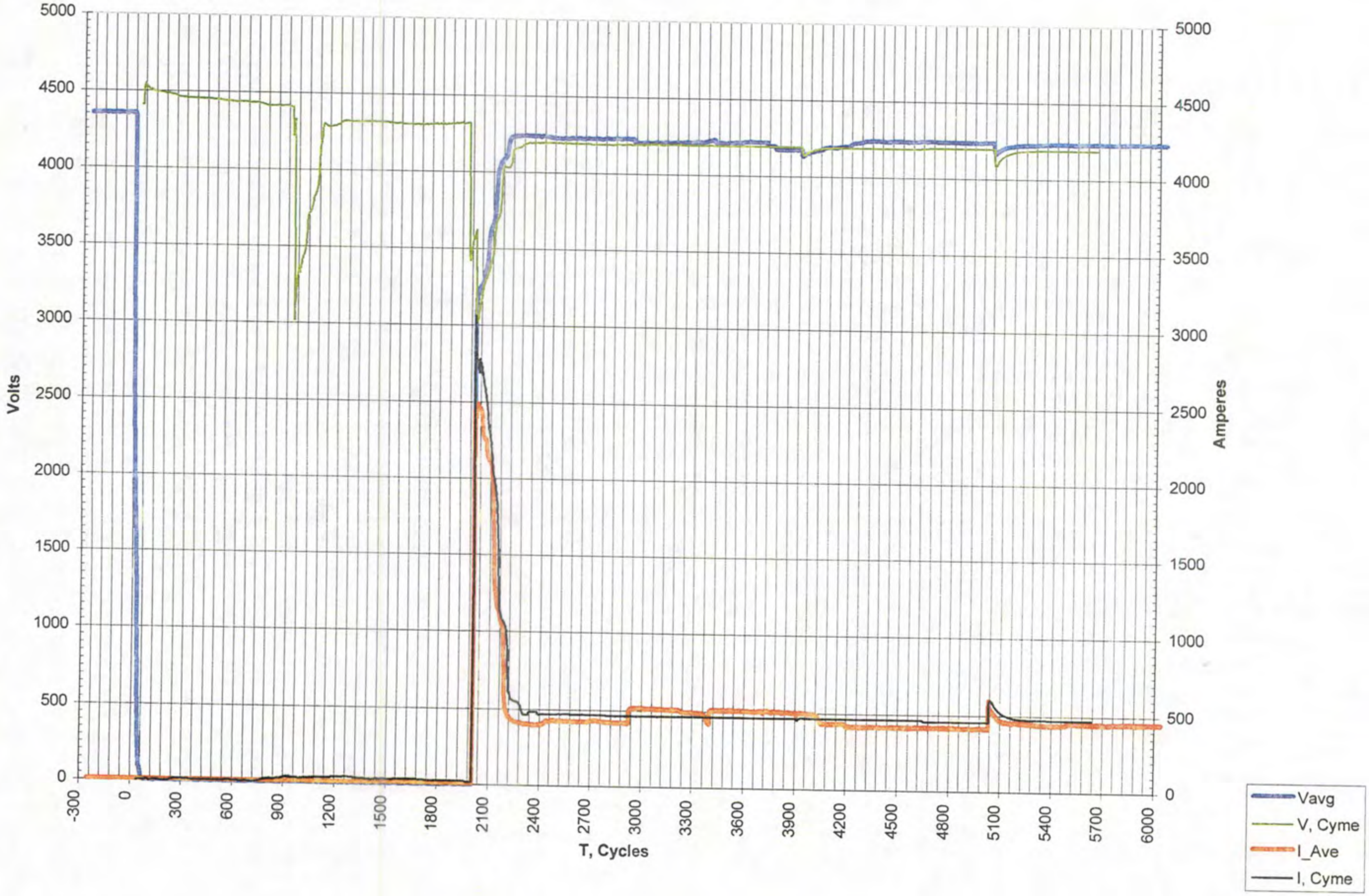


Figure 2-7: Test5, Unit 1 MFB KVA and KW

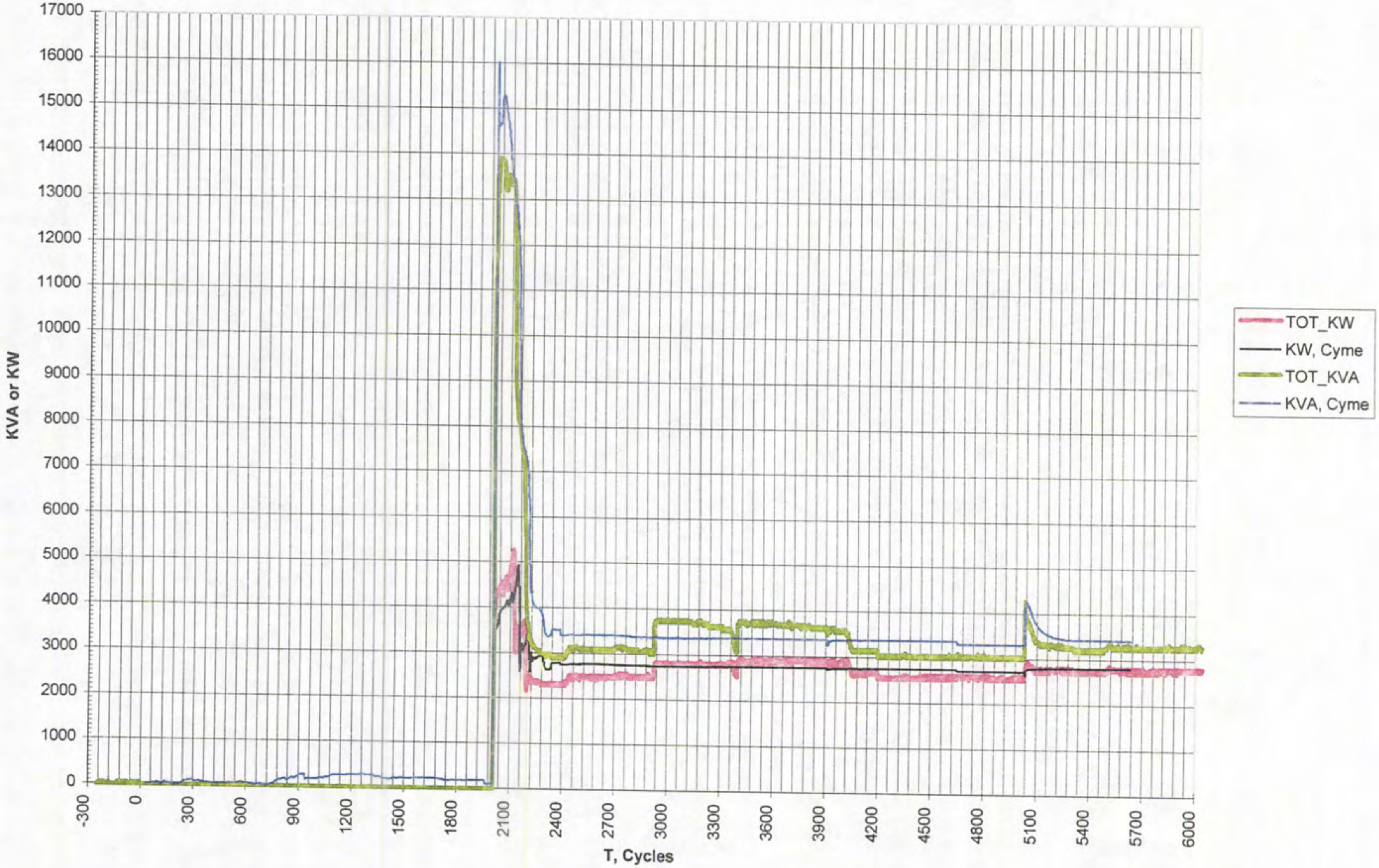


Figure 2-8: Test5, Unit 2 MFB Voltage and Current

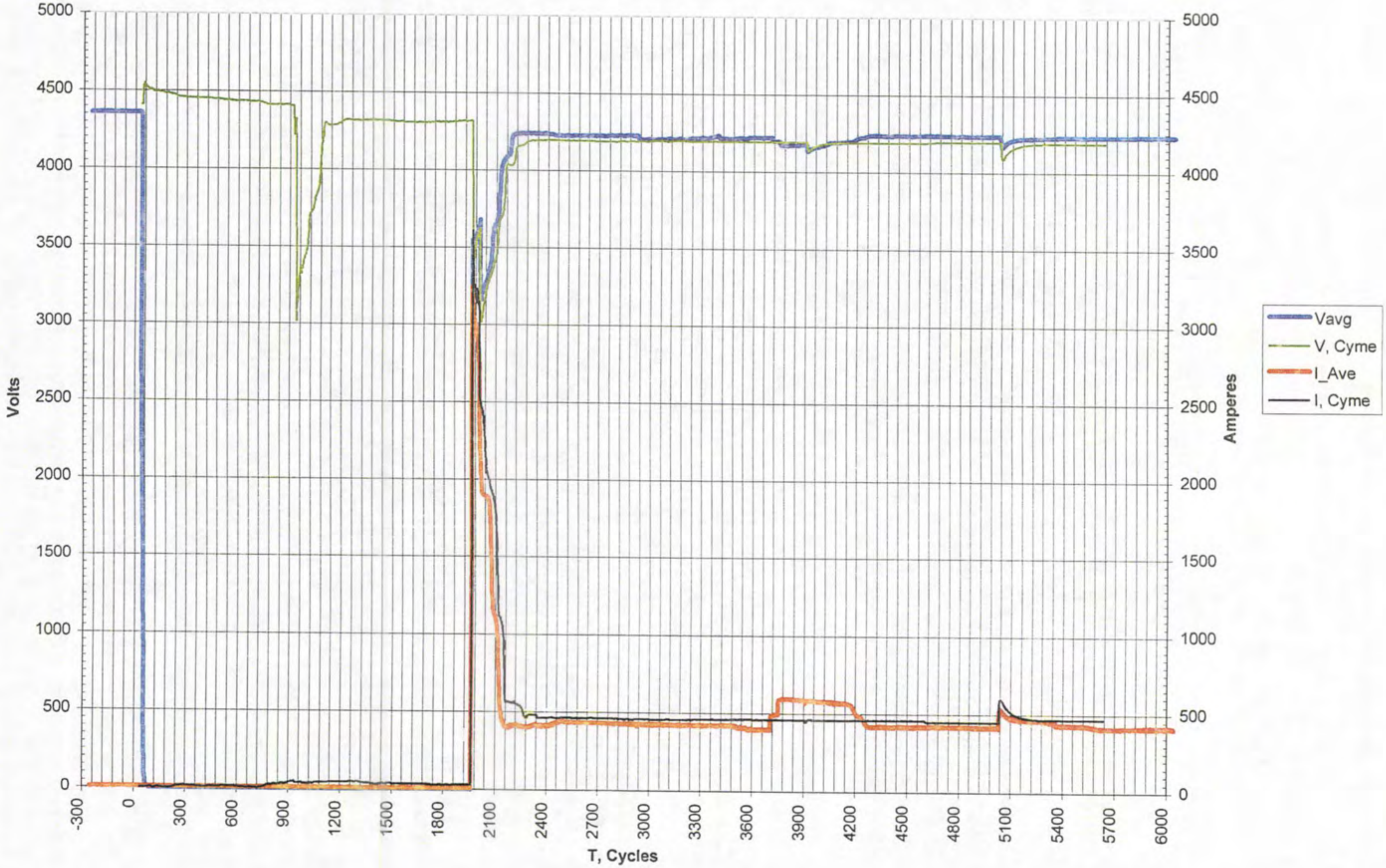


Figure 2-9: Test5, Unit 2 MFB KVA and KW

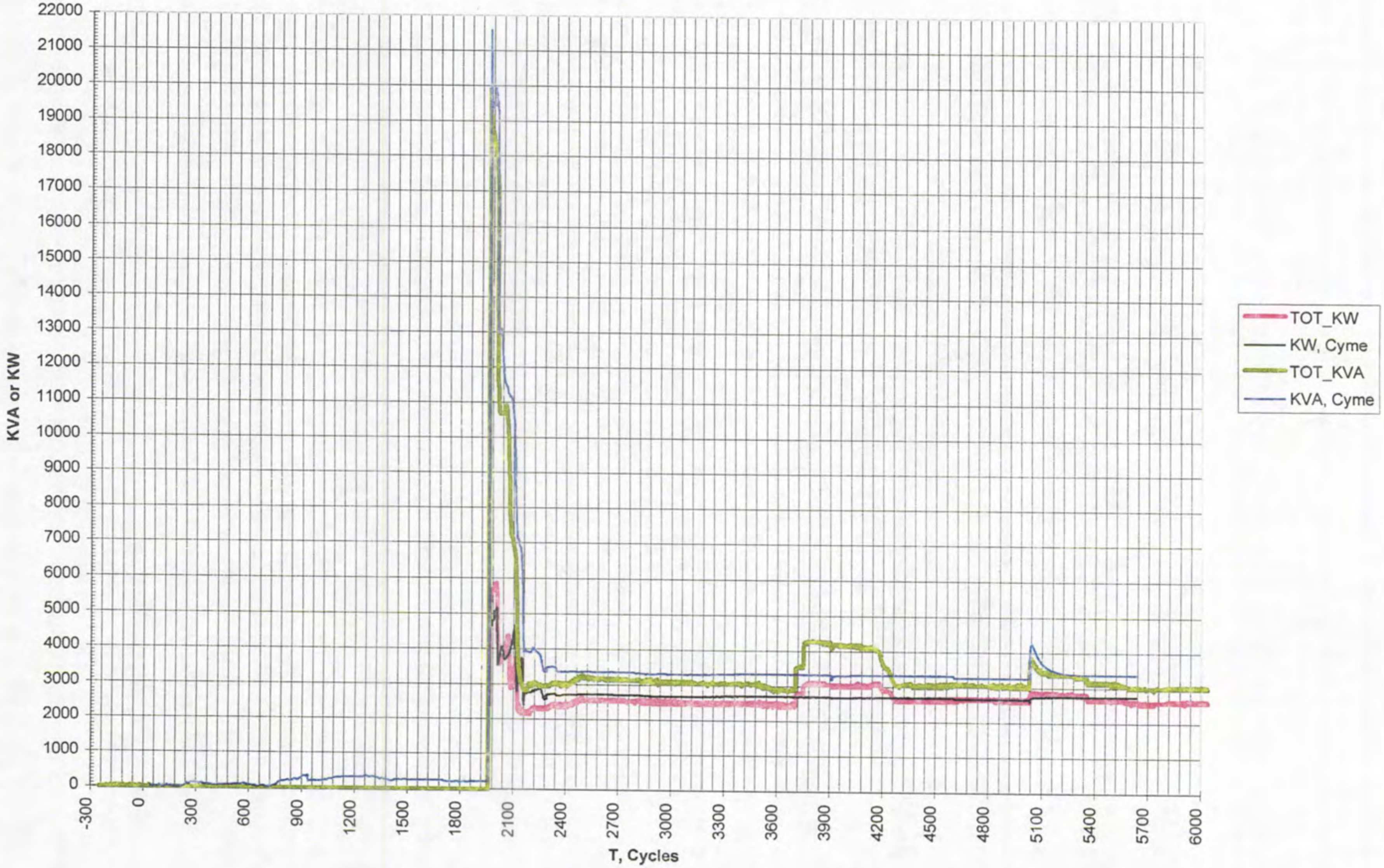


Figure 2-10: Test5, Standby Bus Voltage and Unit 3 MFB Current

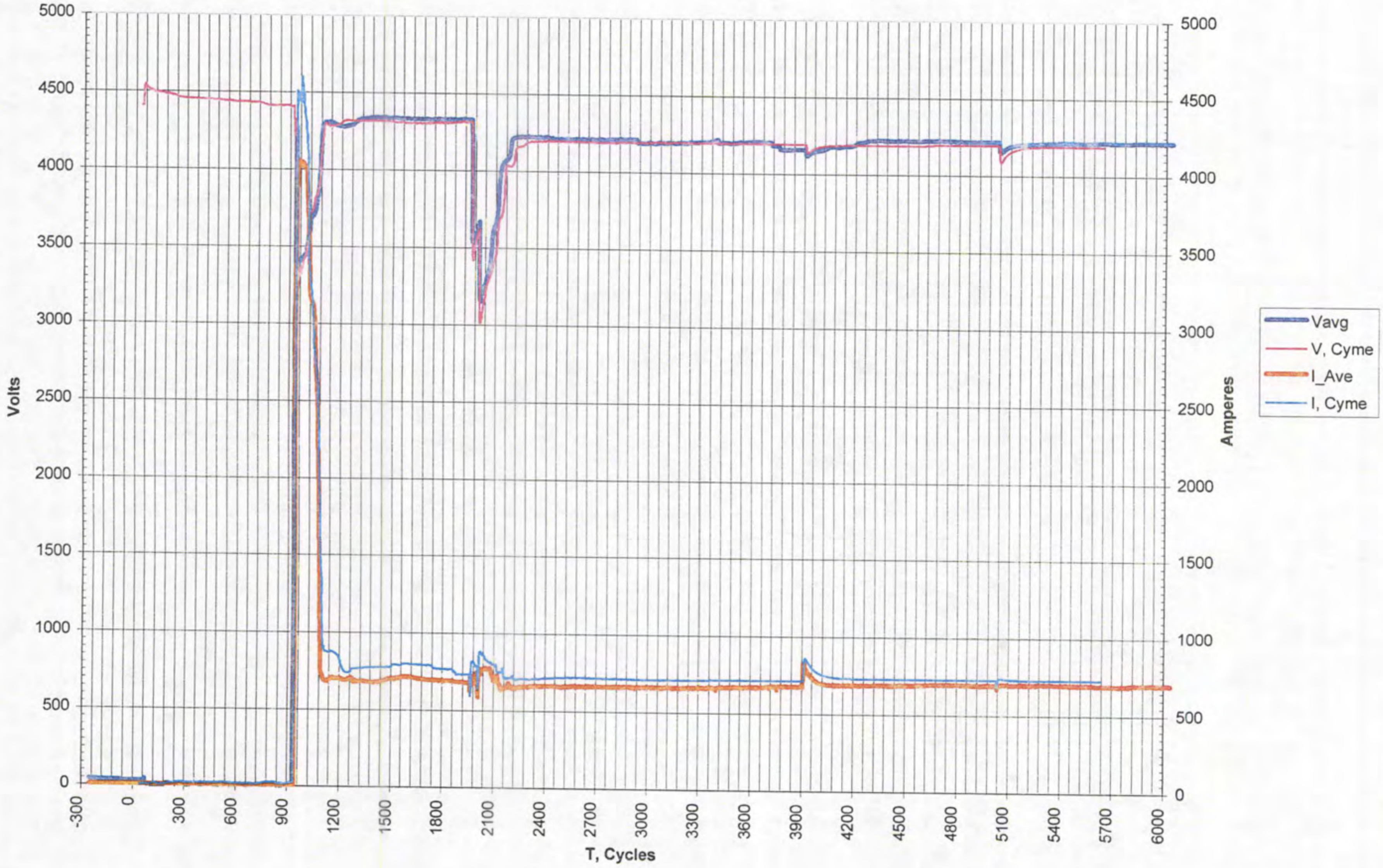


Figure 2-11: Test5, Unit 3 MFB KVA and KW

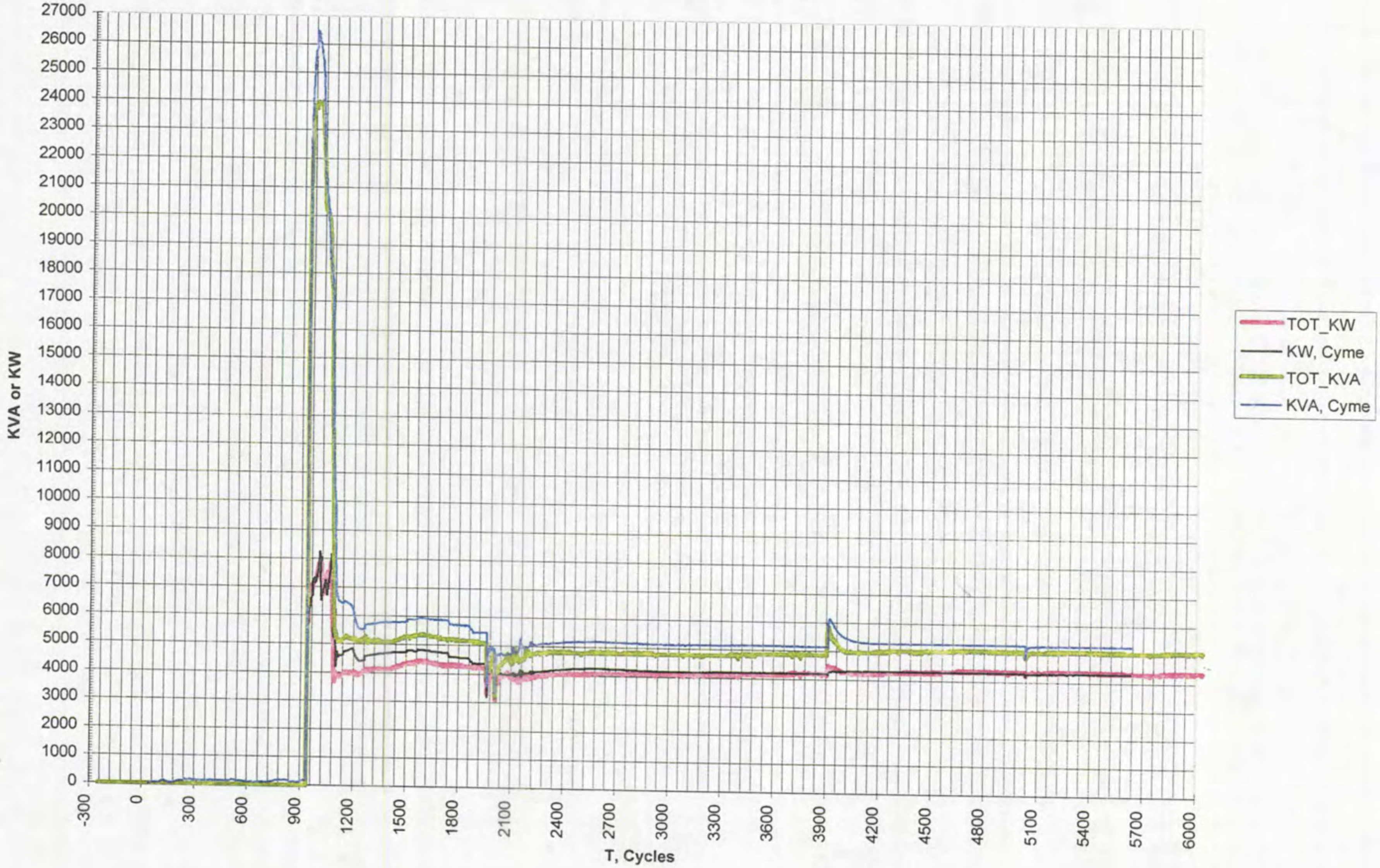


Figure 2-12: Test5, EFW 3B Voltage and Current

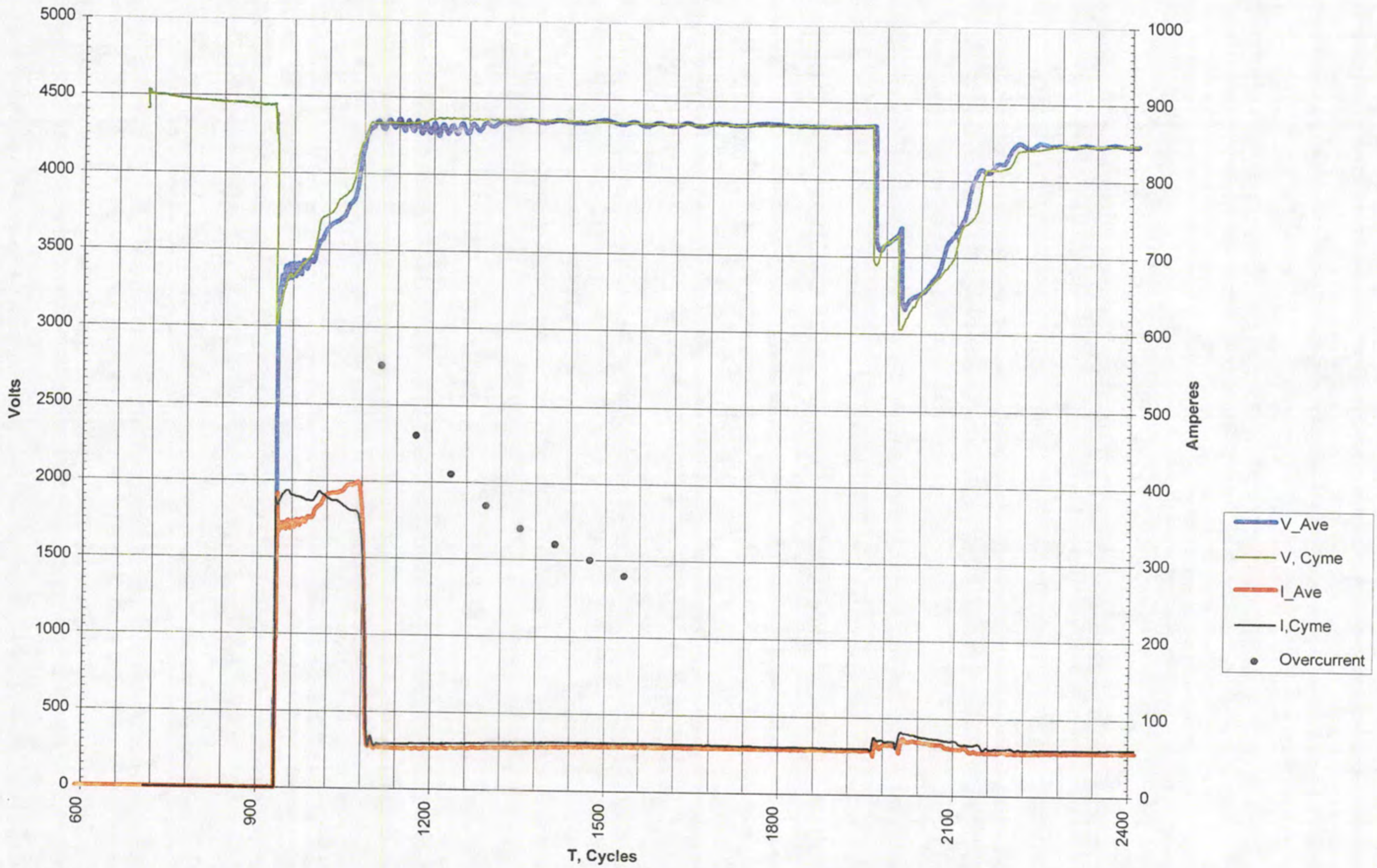


Figure 2-13: Test5, EFW 3B KVA and KW

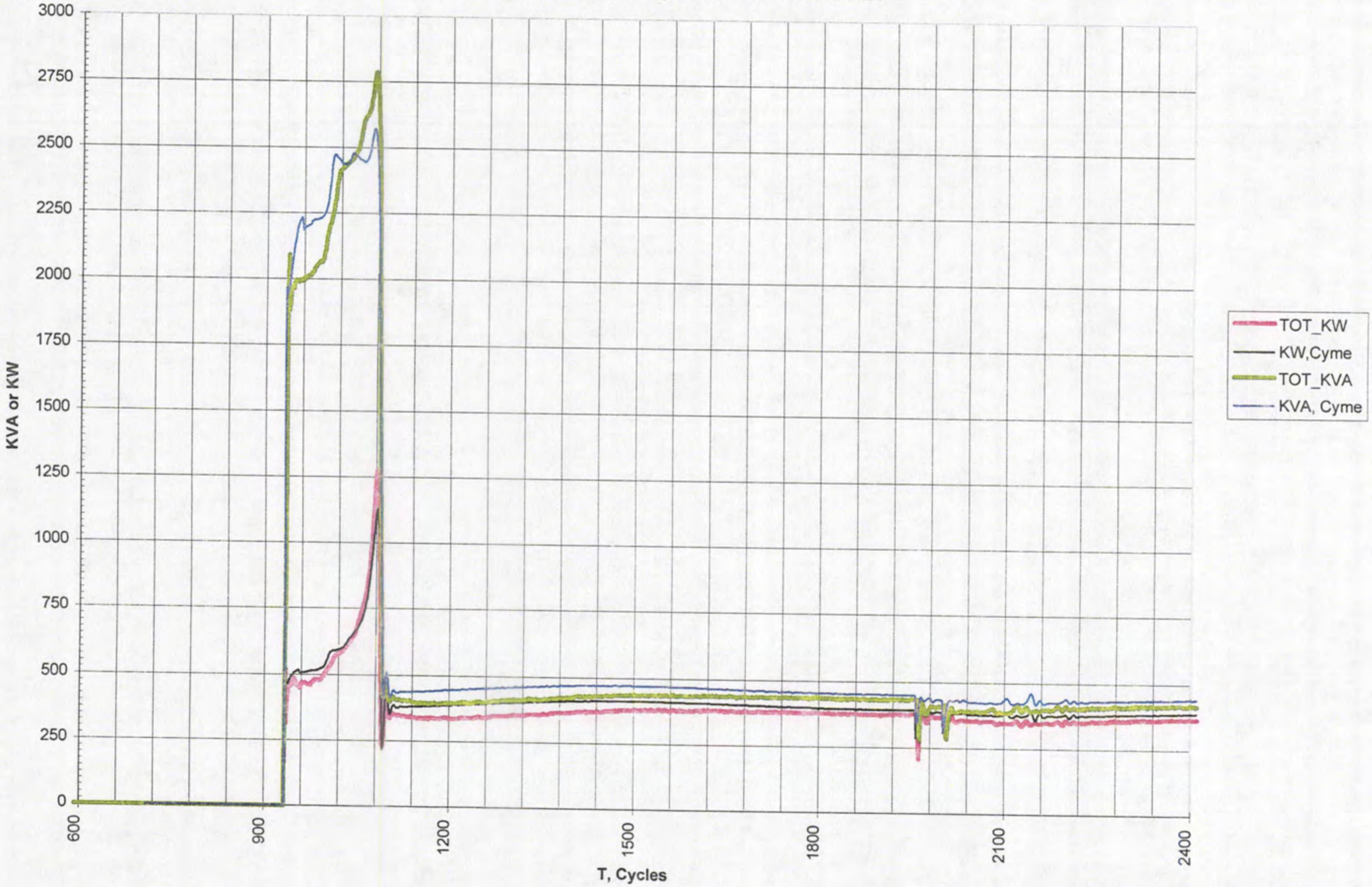


Figure 2- 14: Test5, HPI 3B Voltage and Current

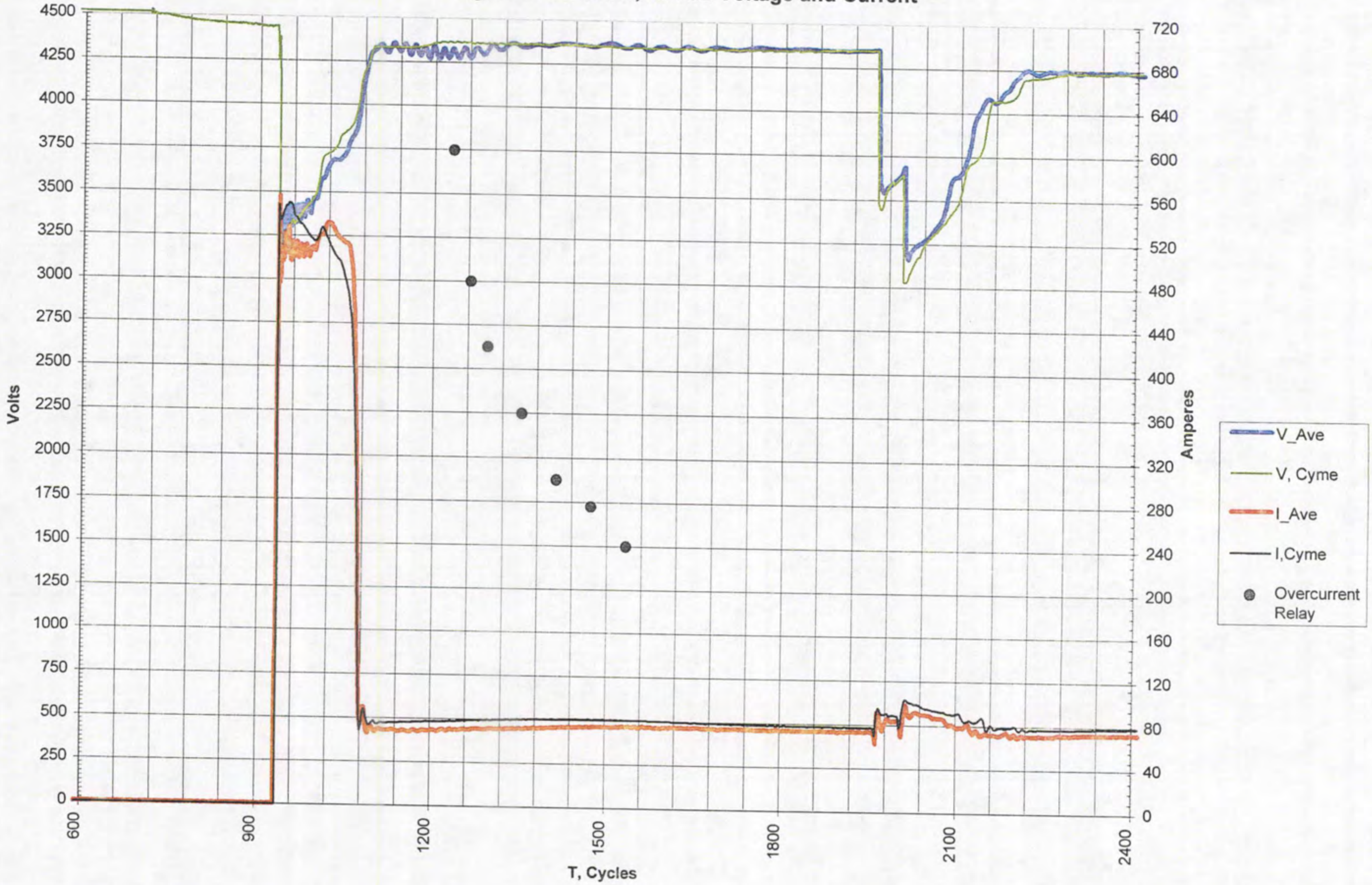


Figure 2- 15: Test5, HPI 3B KVA and KW

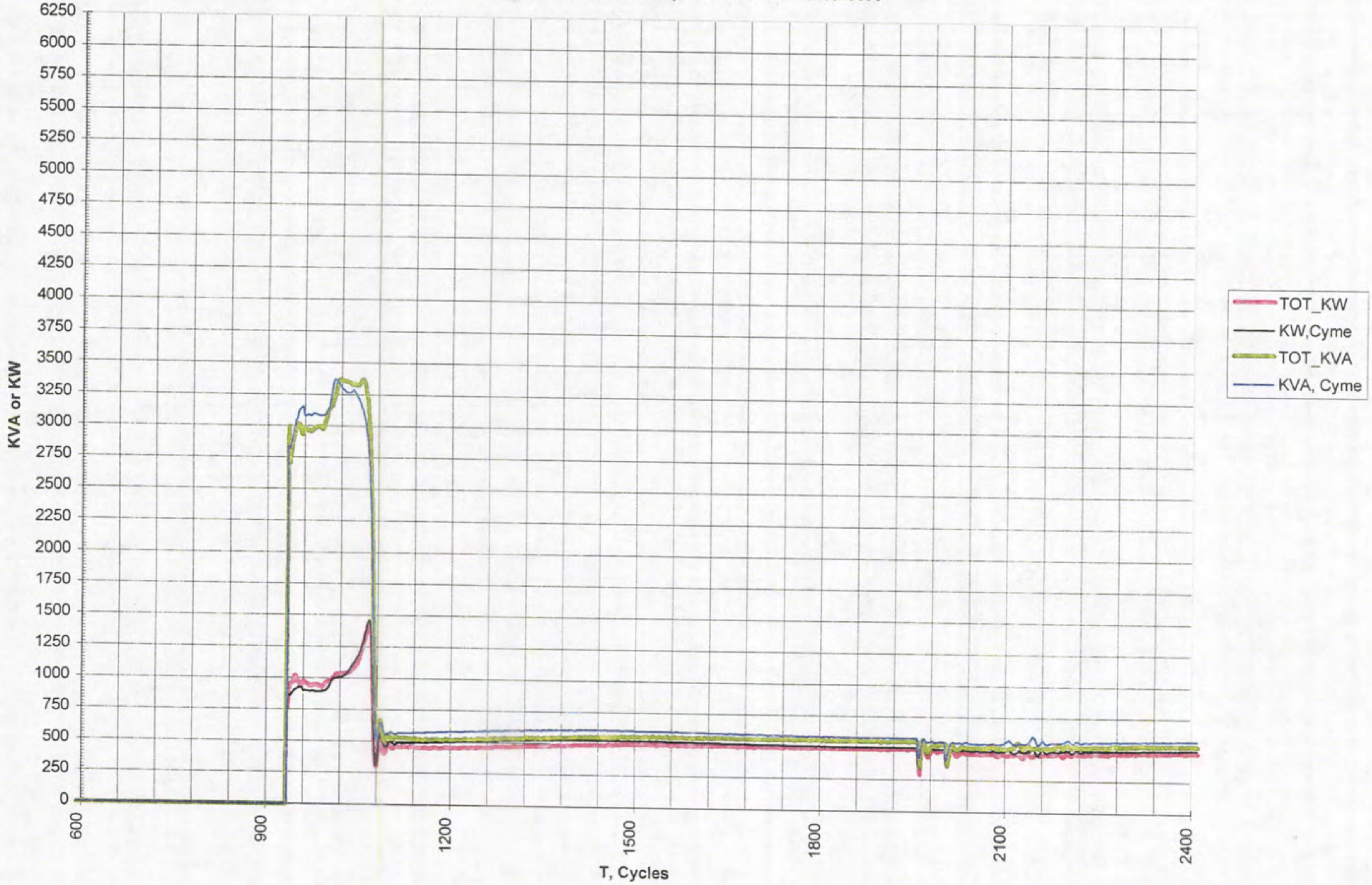


Figure 2- 16: Test5, EFW 1A Voltage and Current

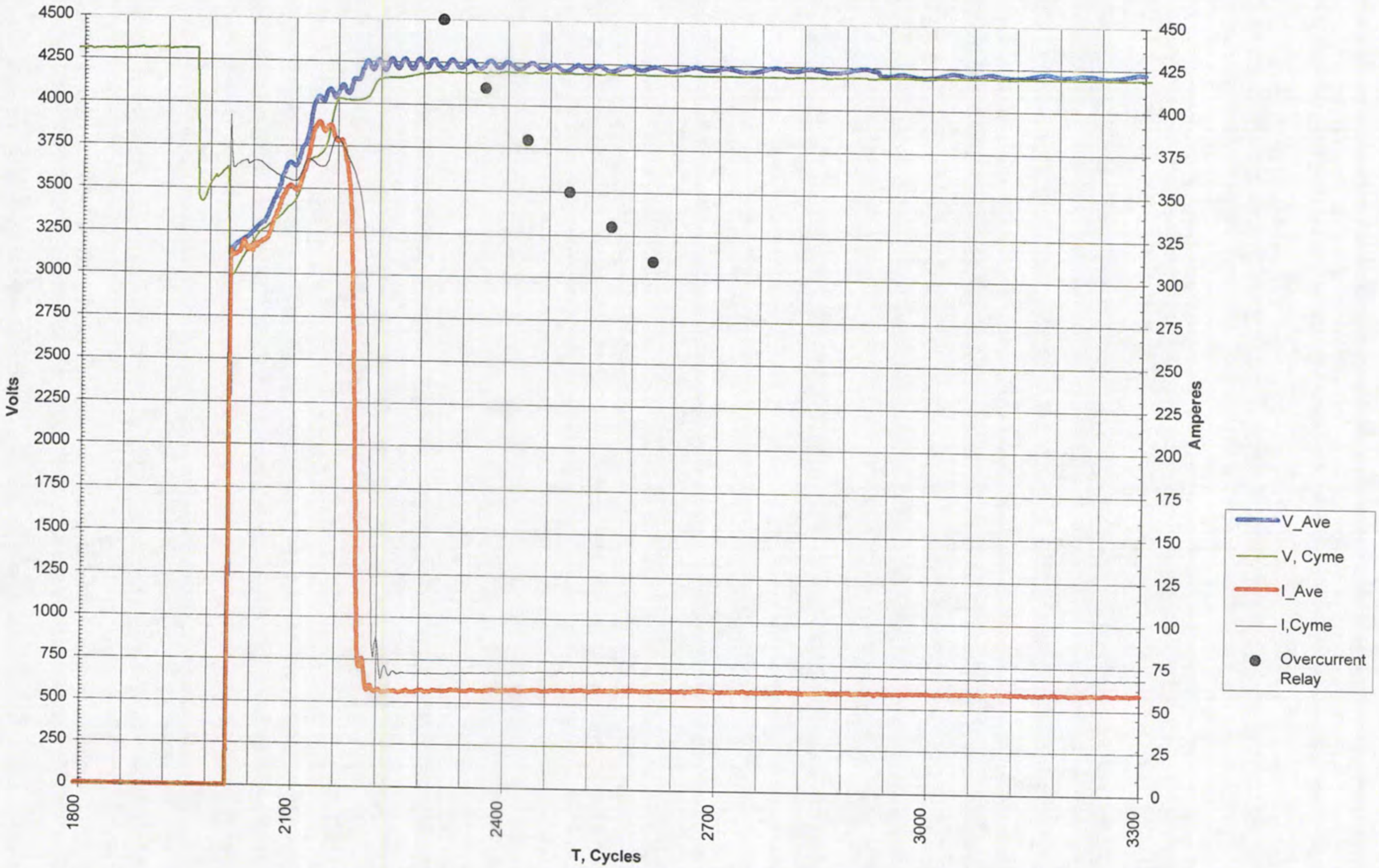


Figure 2- 17: Test5, EFW 1A KVA and KW

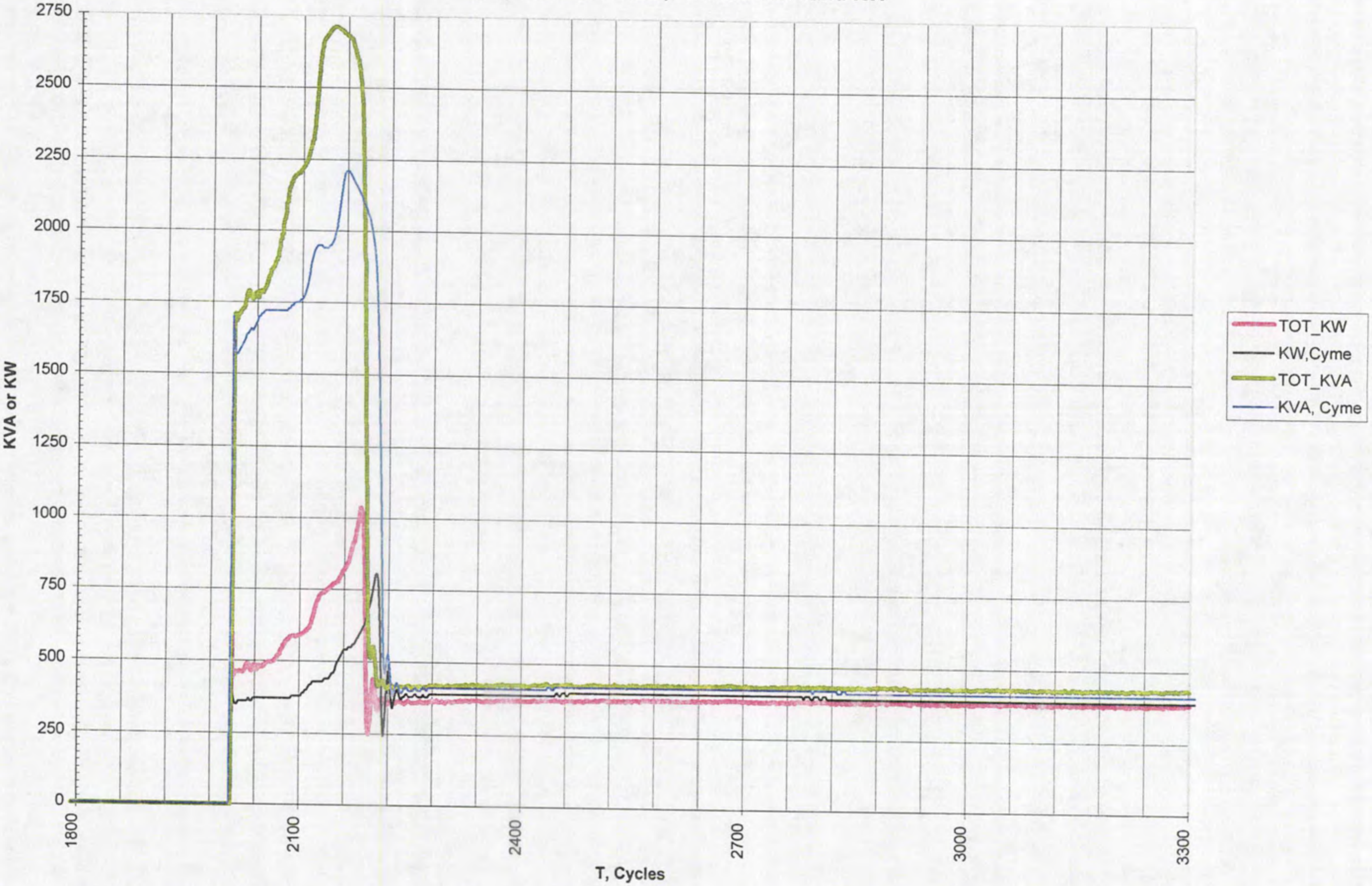


Figure 2- 18: Test5, LPSW 3B Voltage and Current

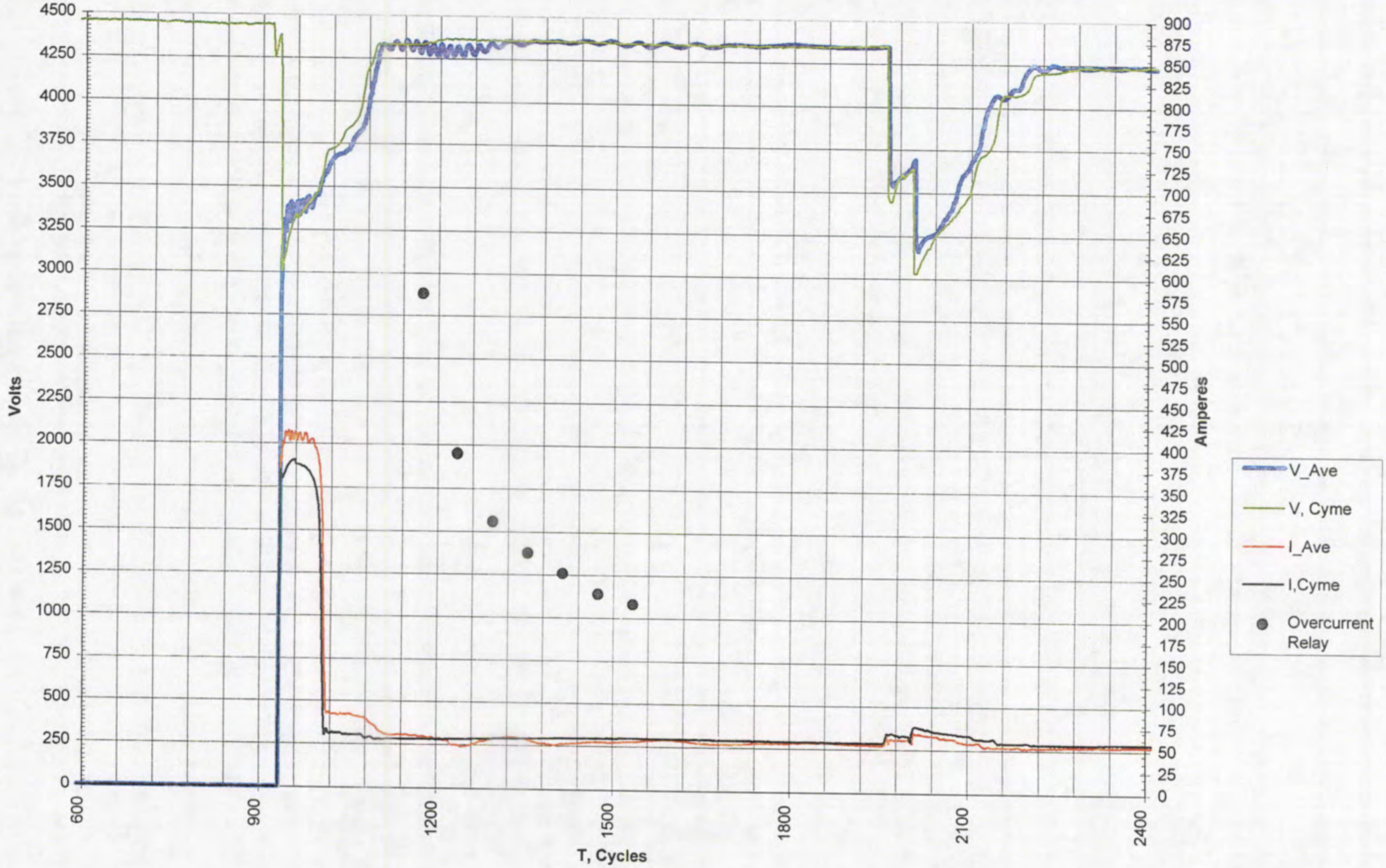


Figure 2- 19: Test5, LPSW 3B KVA and KW

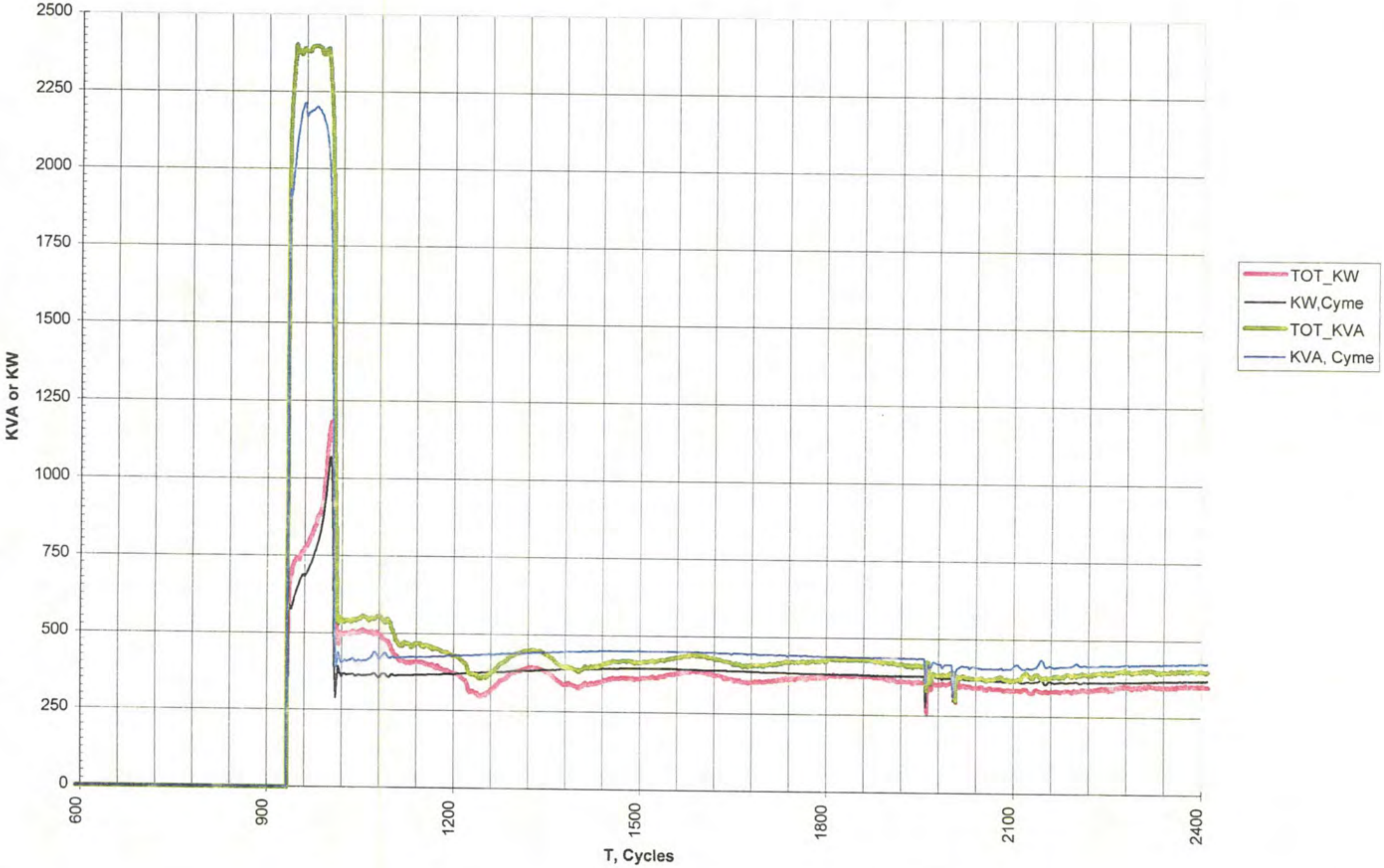


Figure 2- 20: Test5, LPI 3B Voltage and Current

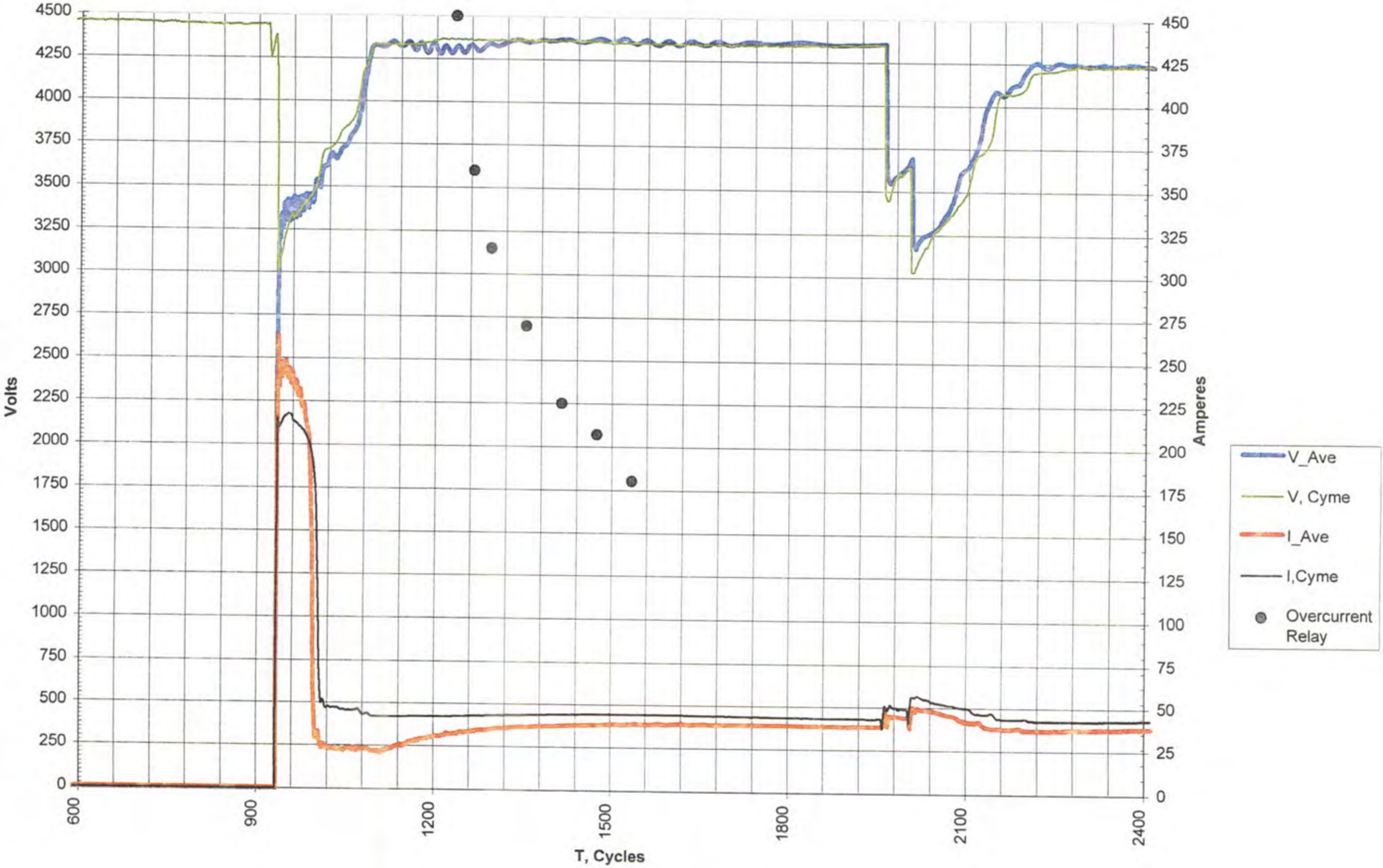


Figure 2- 21: Test5, LPI 3B KVA and KW

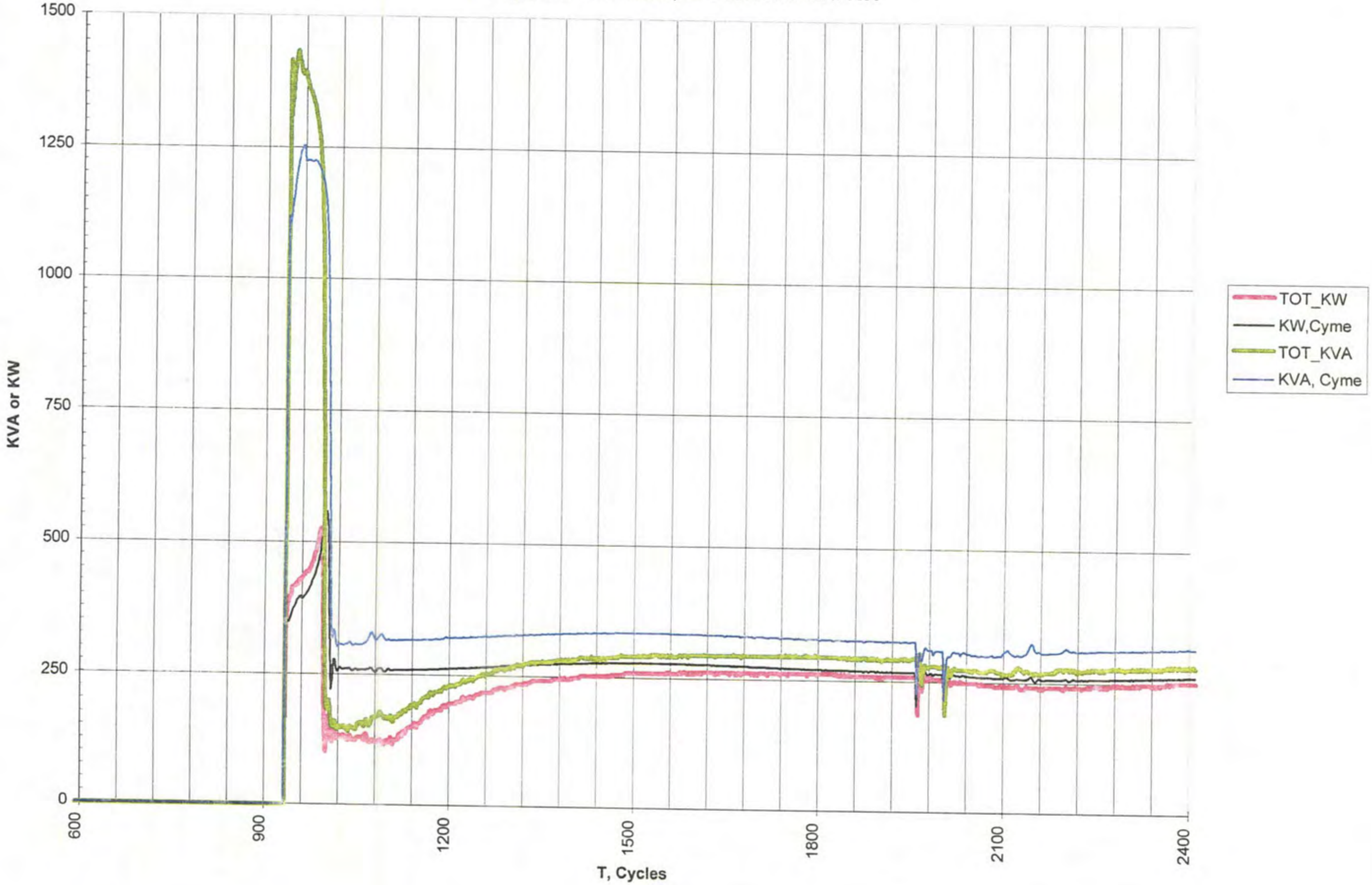


Figure 2- 22: Test5, RBS 3B Voltage and Current

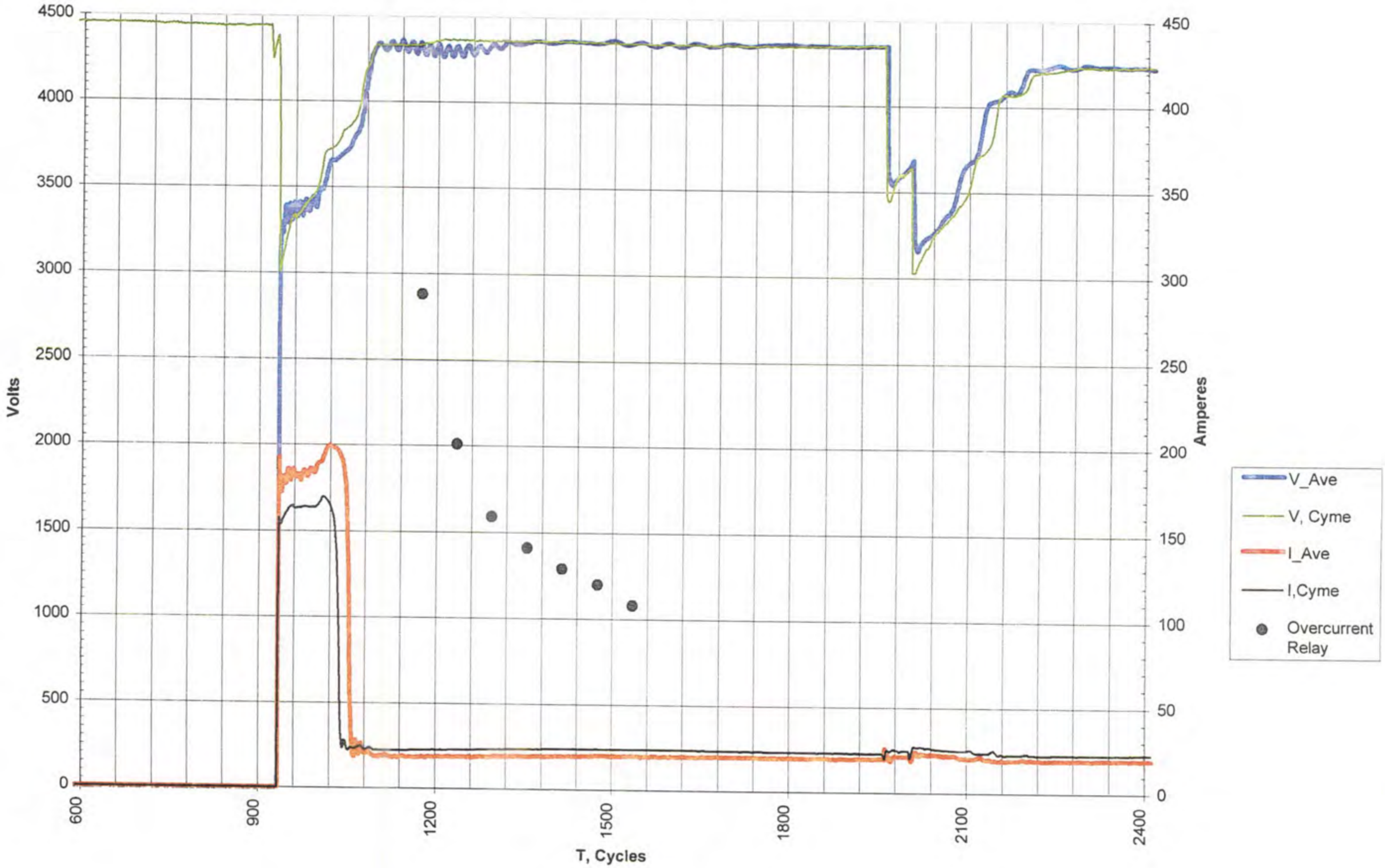


Figure 2- 23: Test5, RBS 3B KVA and KW

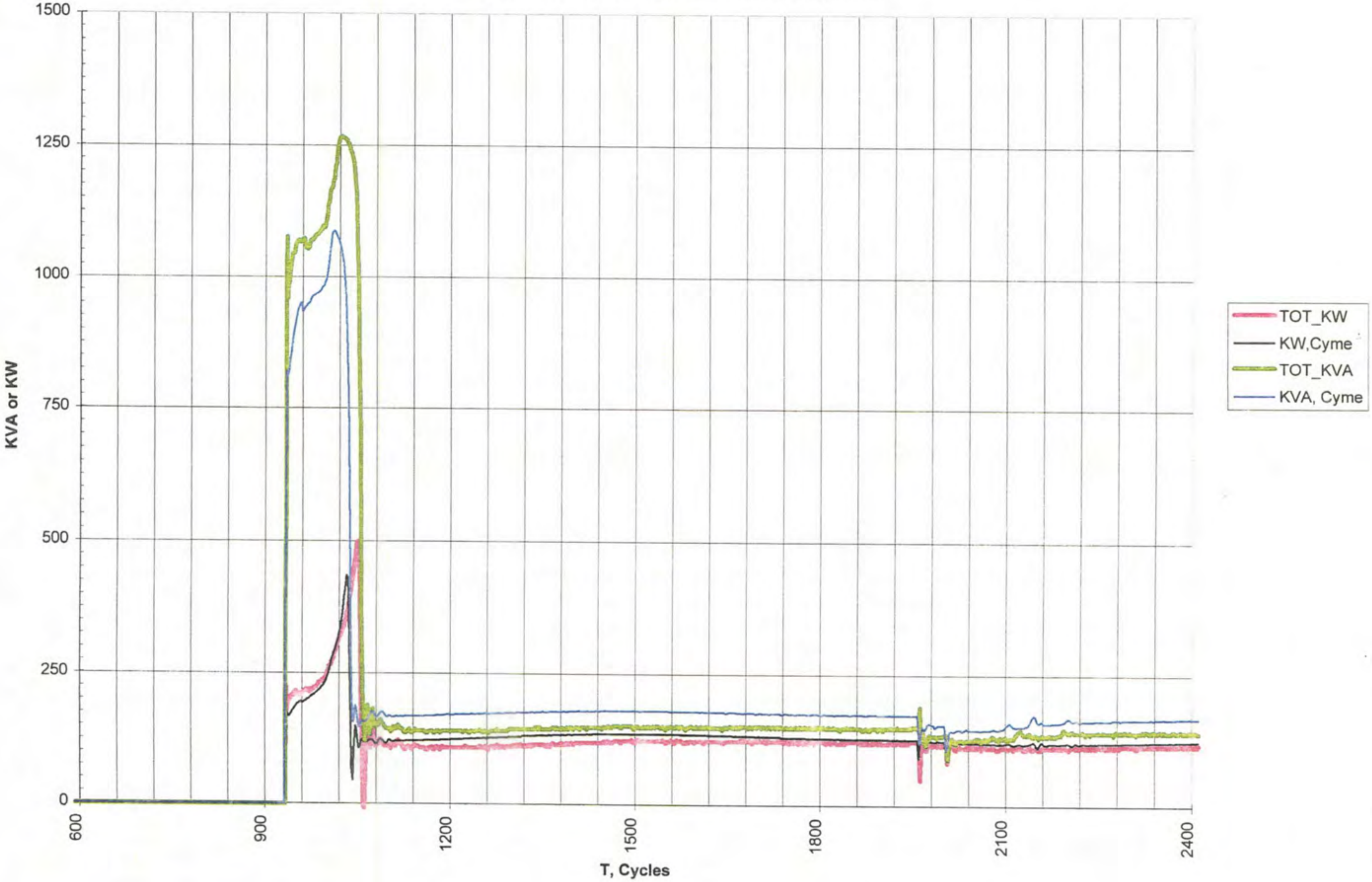


Figure 2- 24: Test5, RBCF 3B Voltage and Current

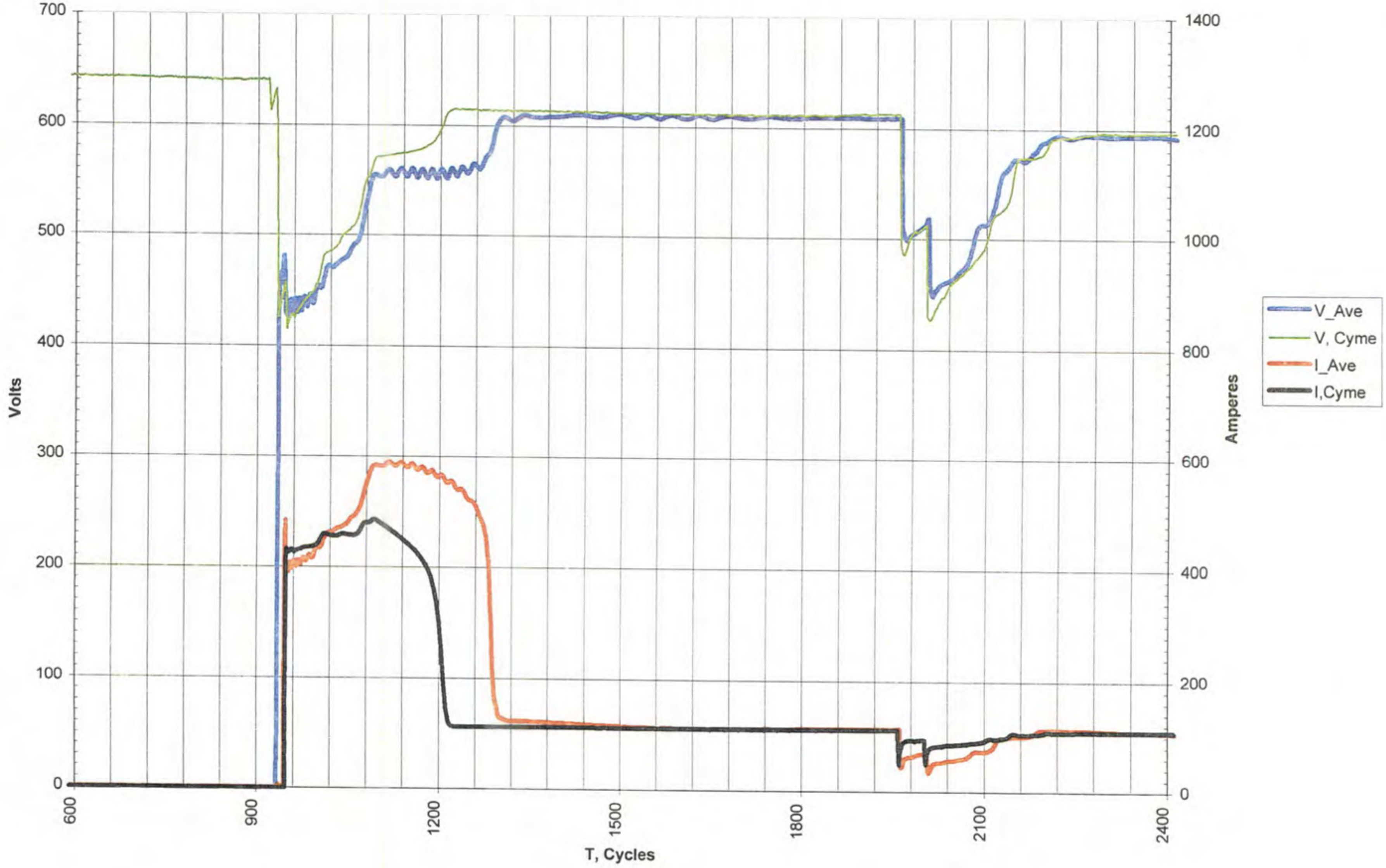


Figure 2- 25: Test5, RBCF 3B KVA and KW

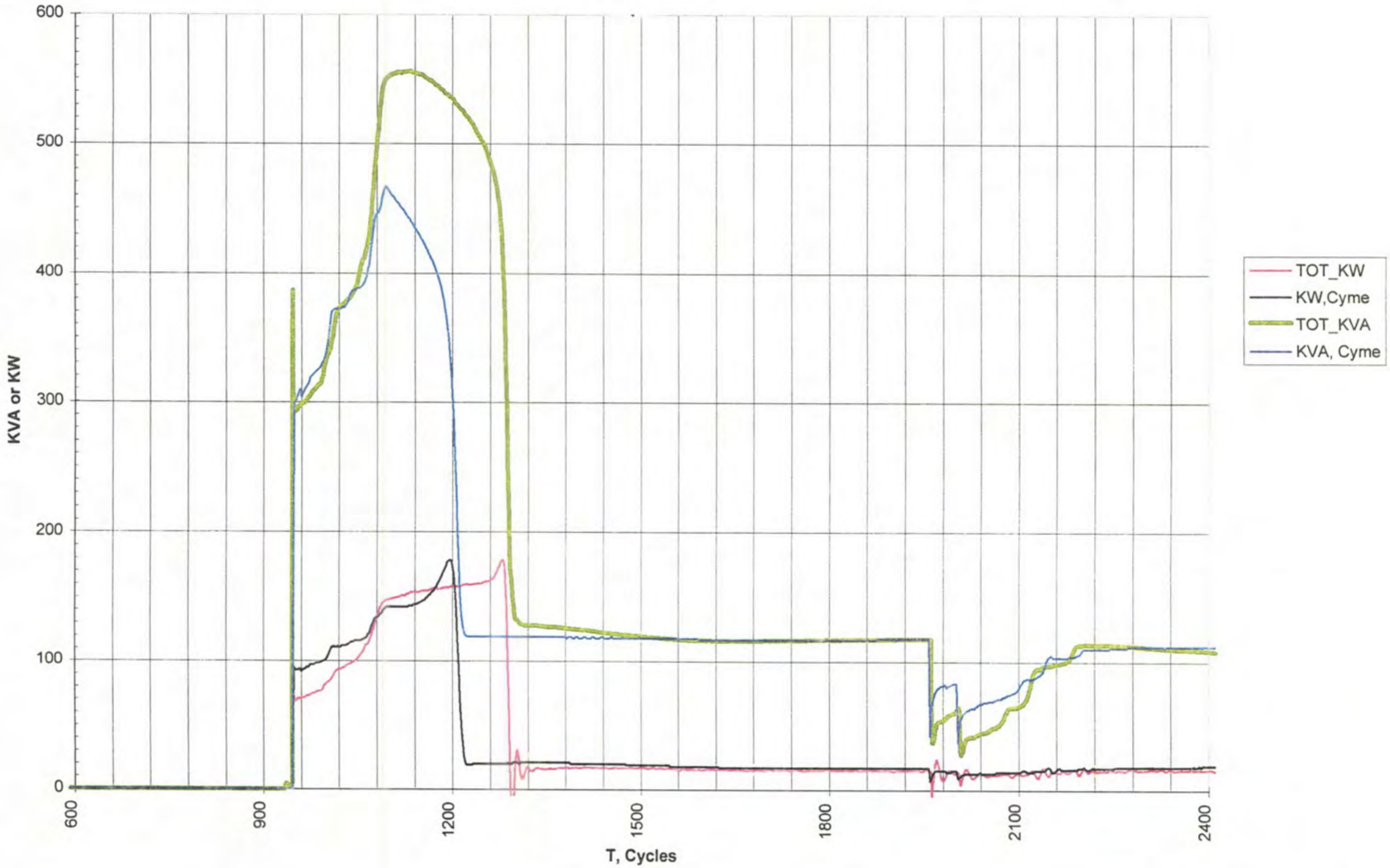


Figure 2-26: Test5, 1X5 Voltage and Current

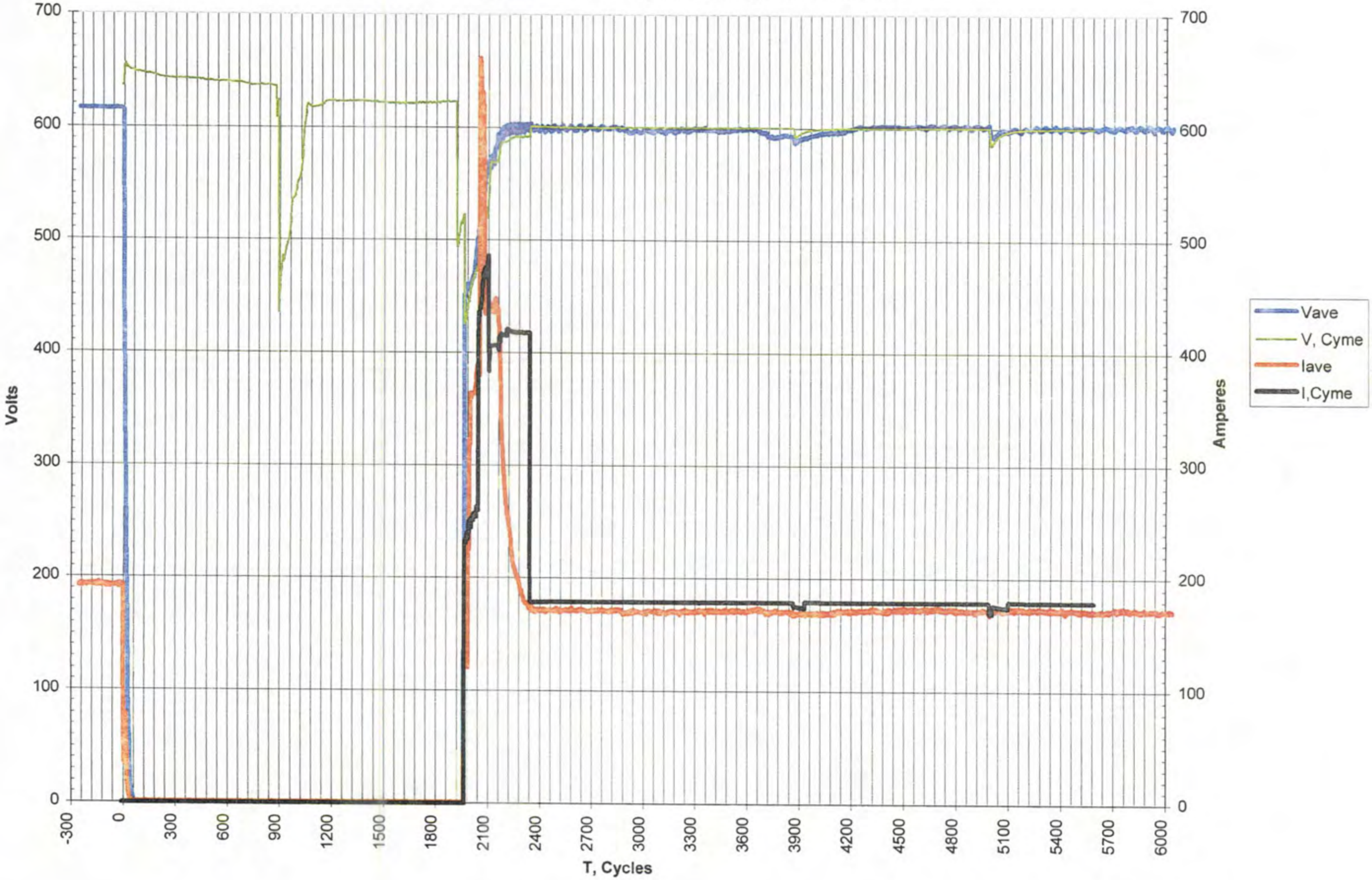


Figure 2-27: Test5, 1X5 KVA and KW

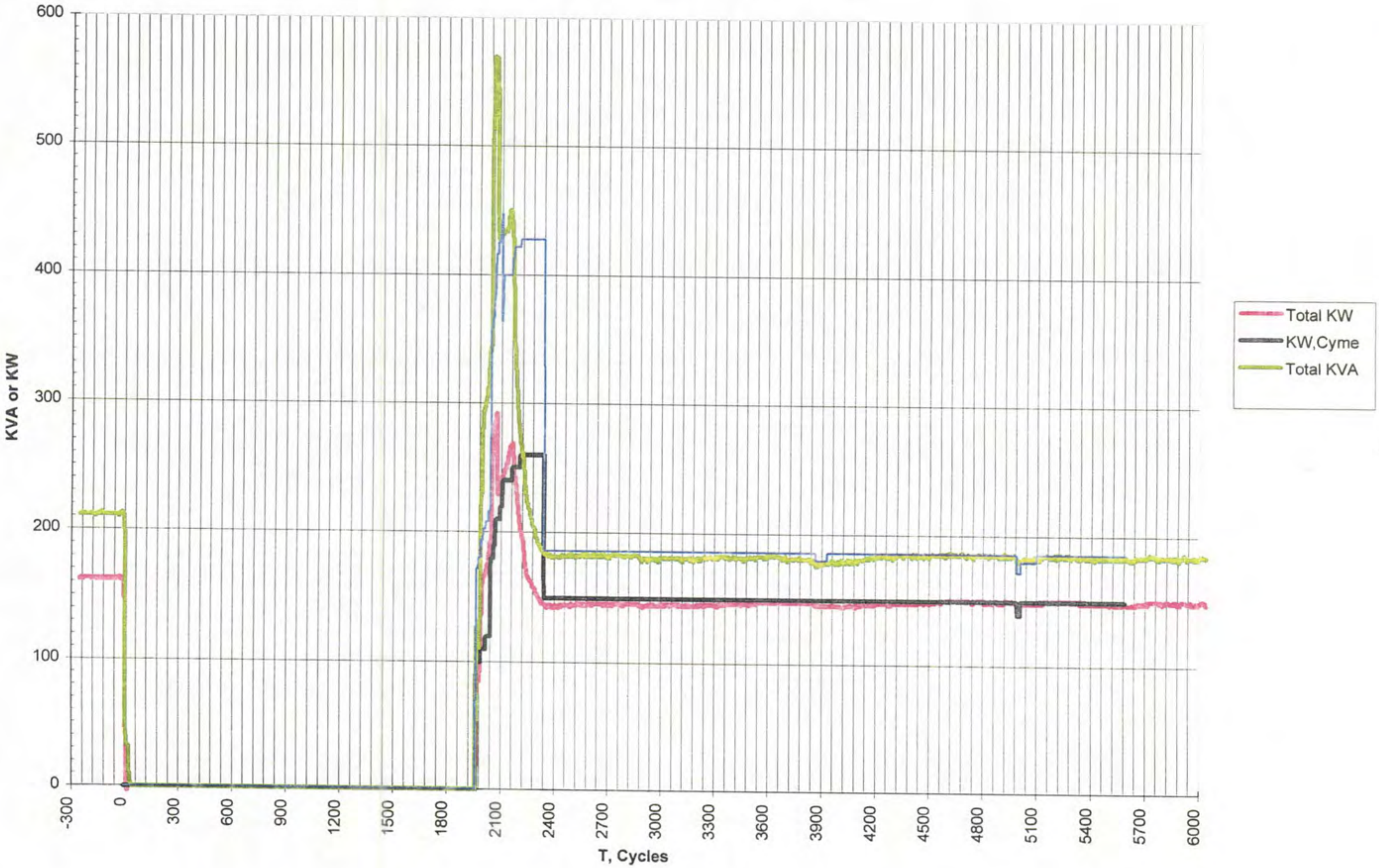


Figure 2-28: Test5, 1X6 Voltage and Current

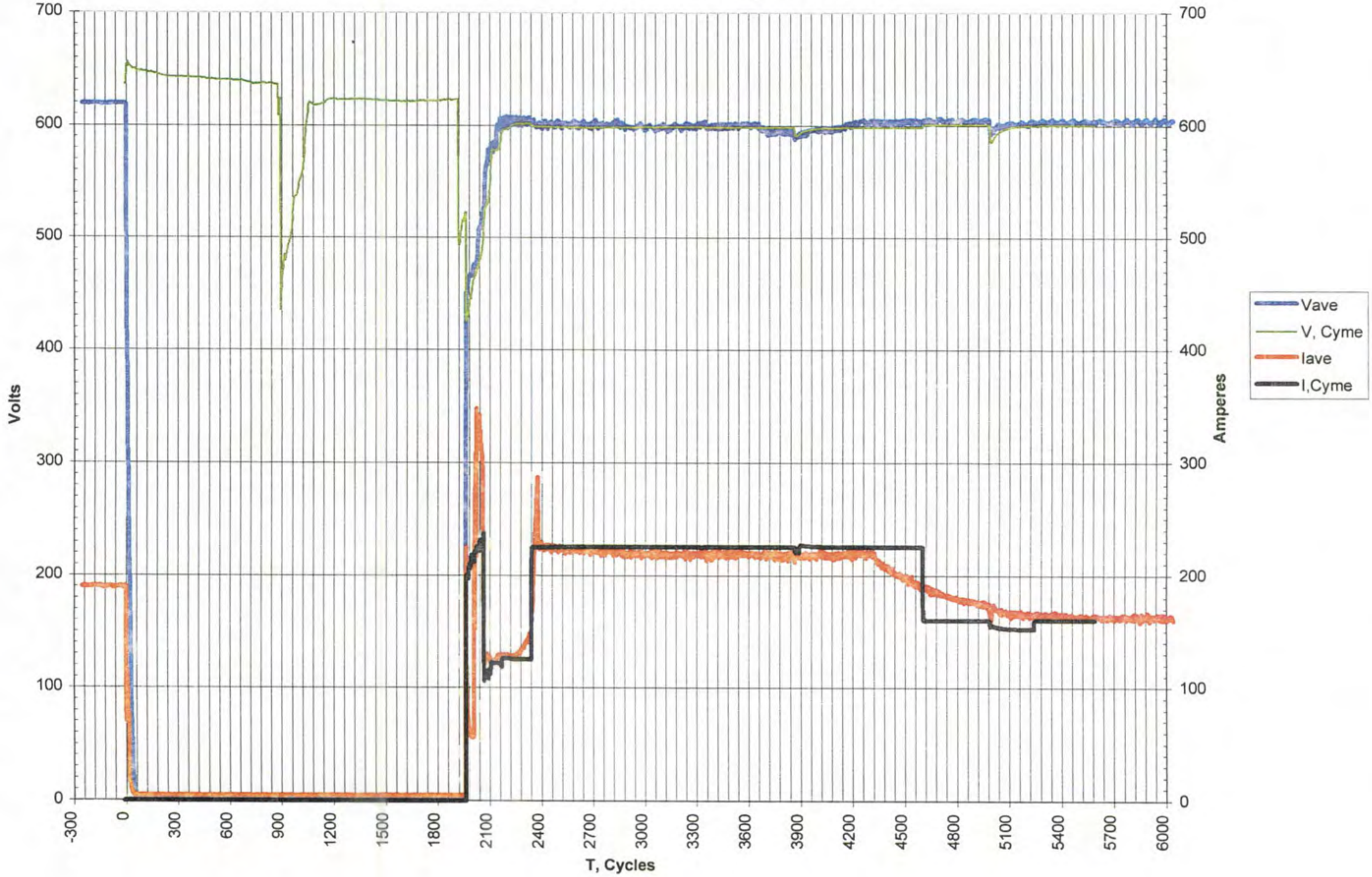


Figure 2-29: Test5, 1X6 KVA and KW

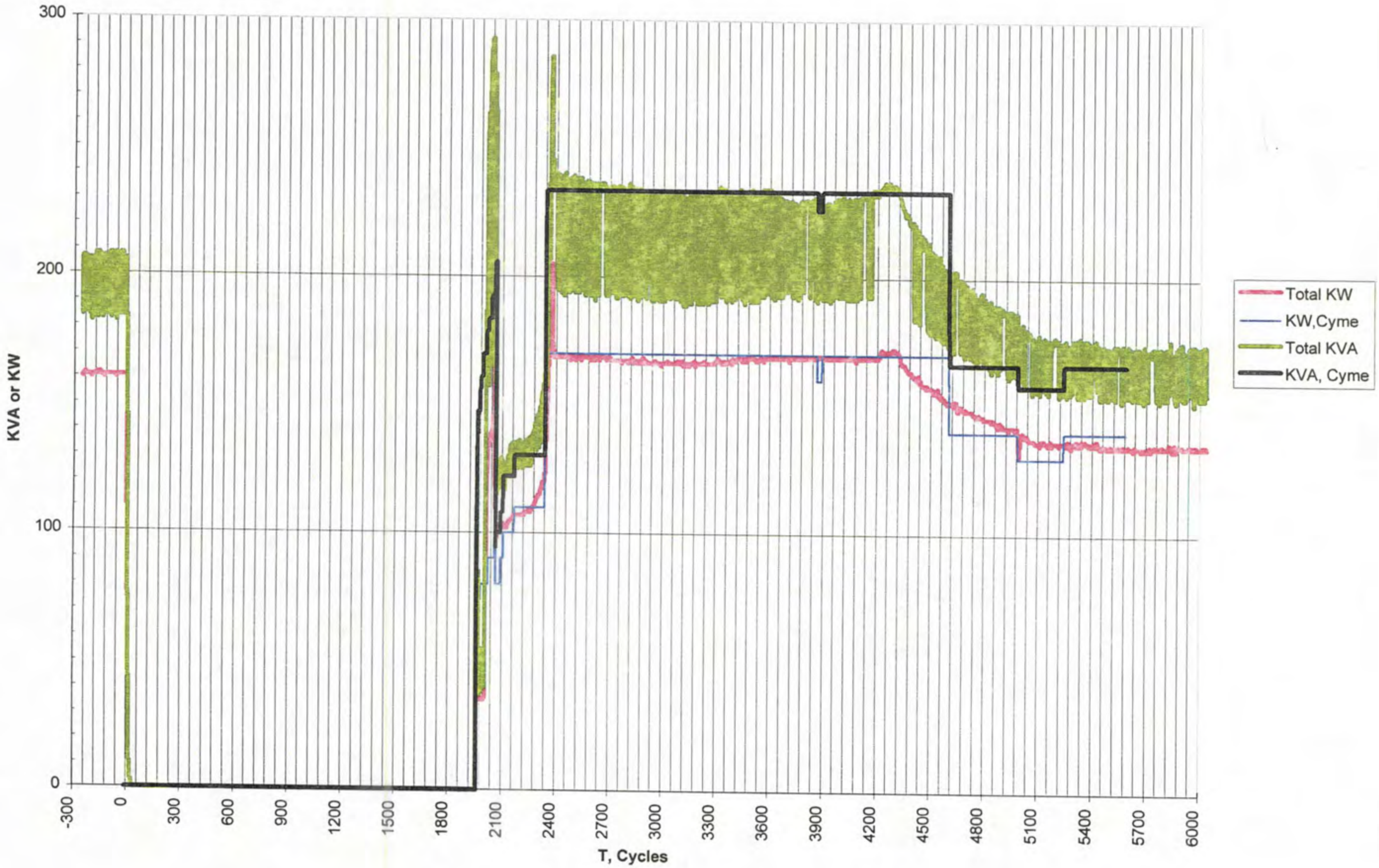


Figure 2- 30: Test5, 3X5 Voltage and Current

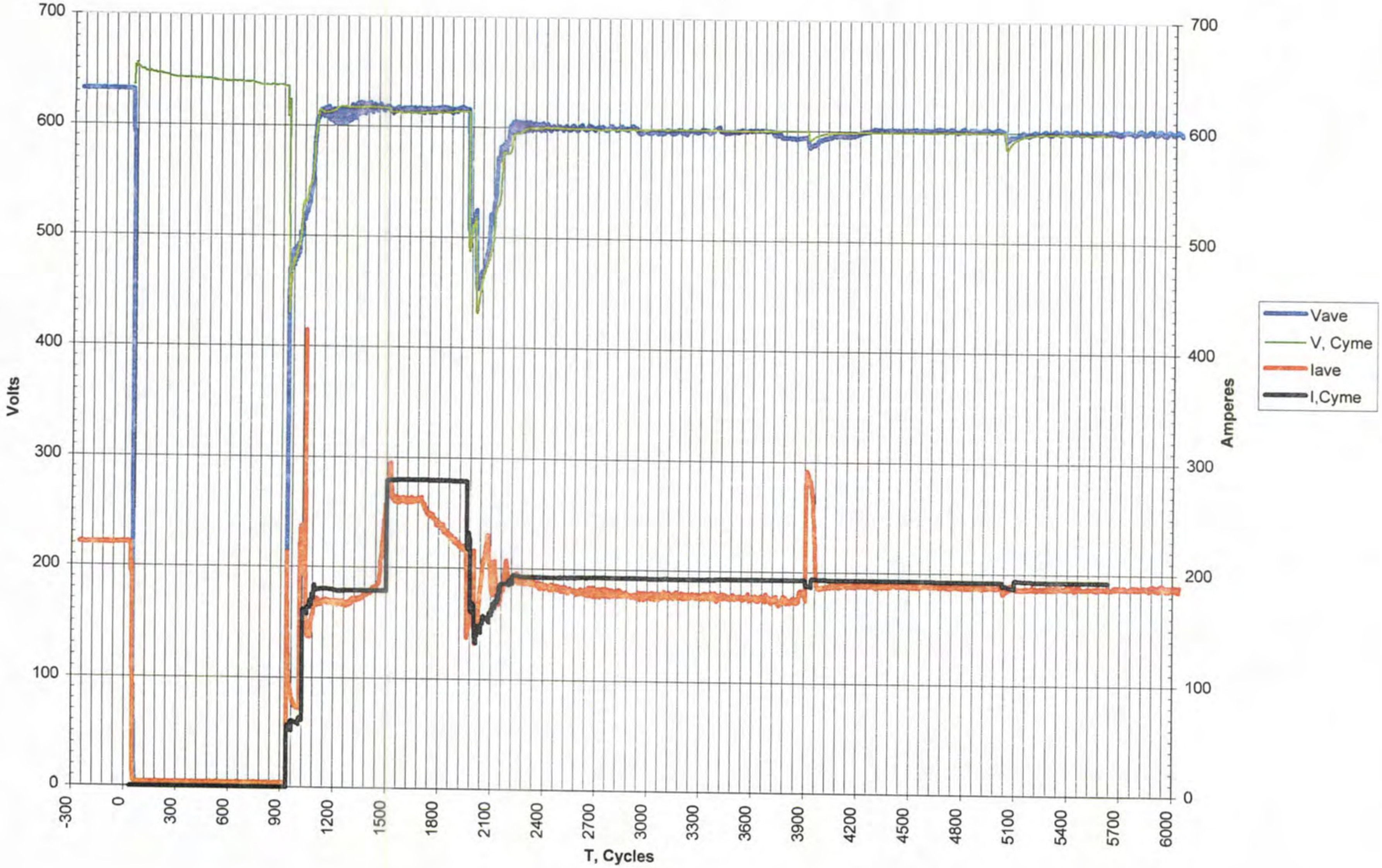


Figure 2- 31: Test5, 3X5 KVA and KW

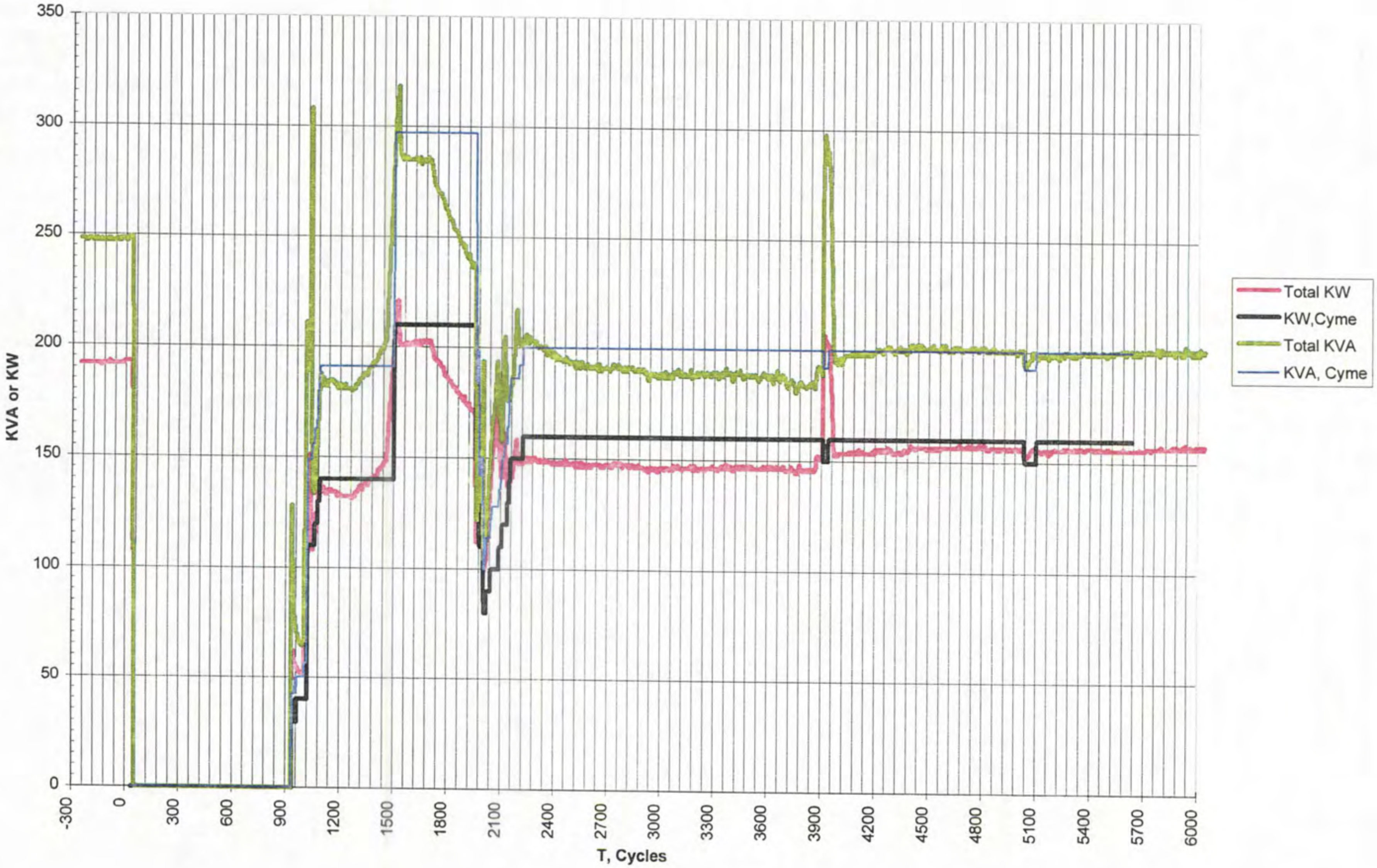


Figure 2- 32: Test5, 3X6 Voltage and Current

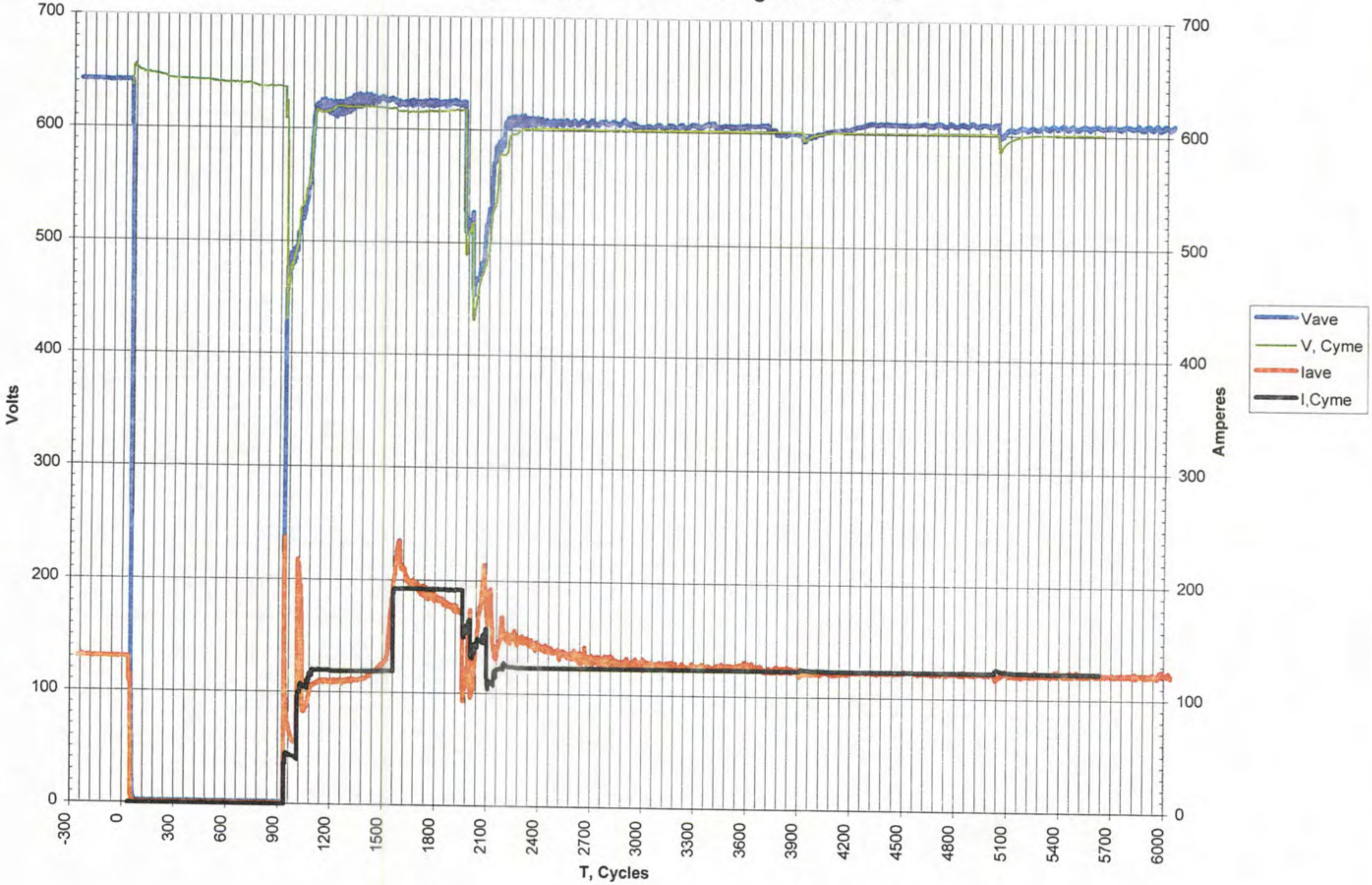


Figure 2- 33: Test5, 3X6 KVA and KW

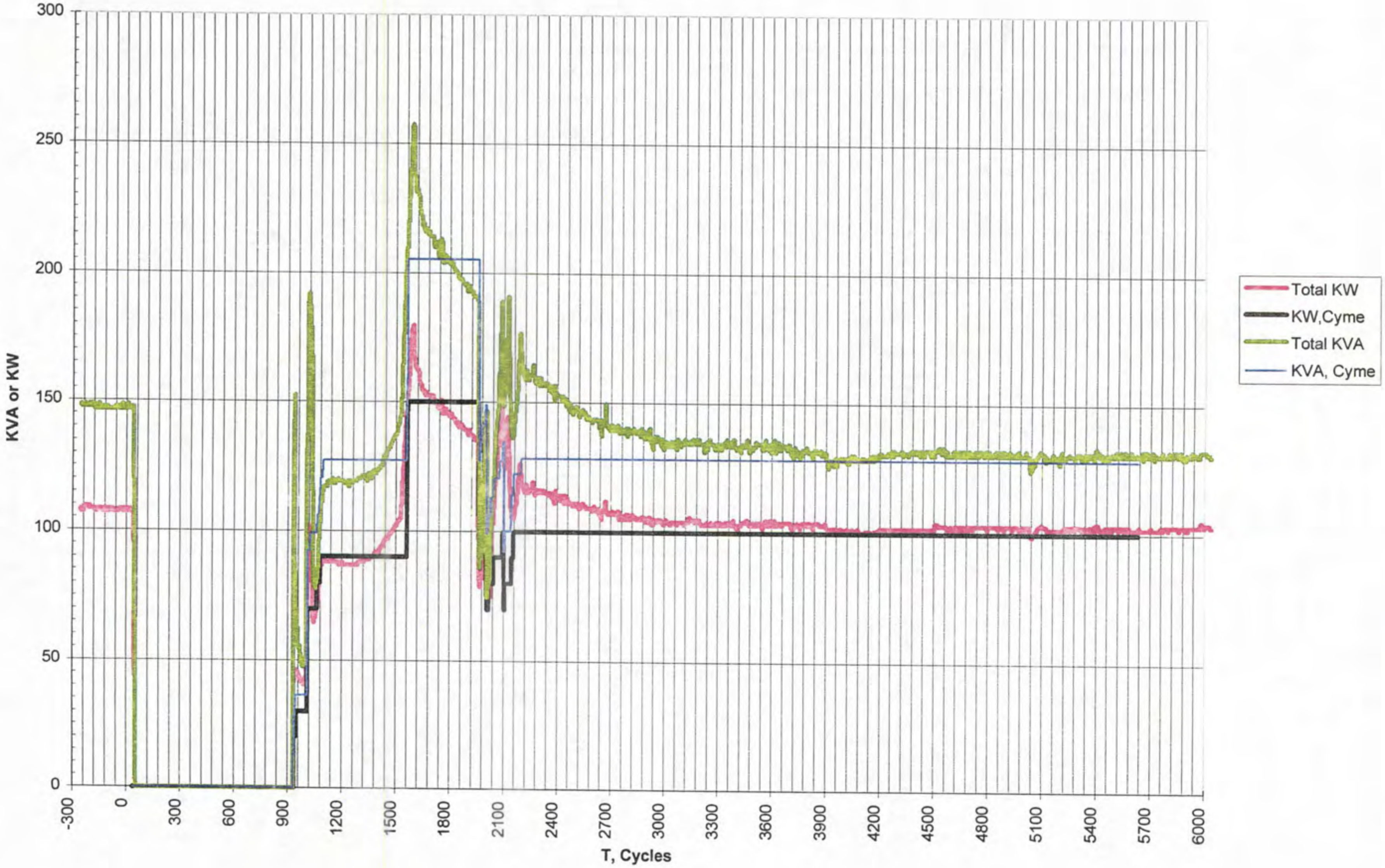


Figure 2- 34: Test5, 3X8 Voltage and Current

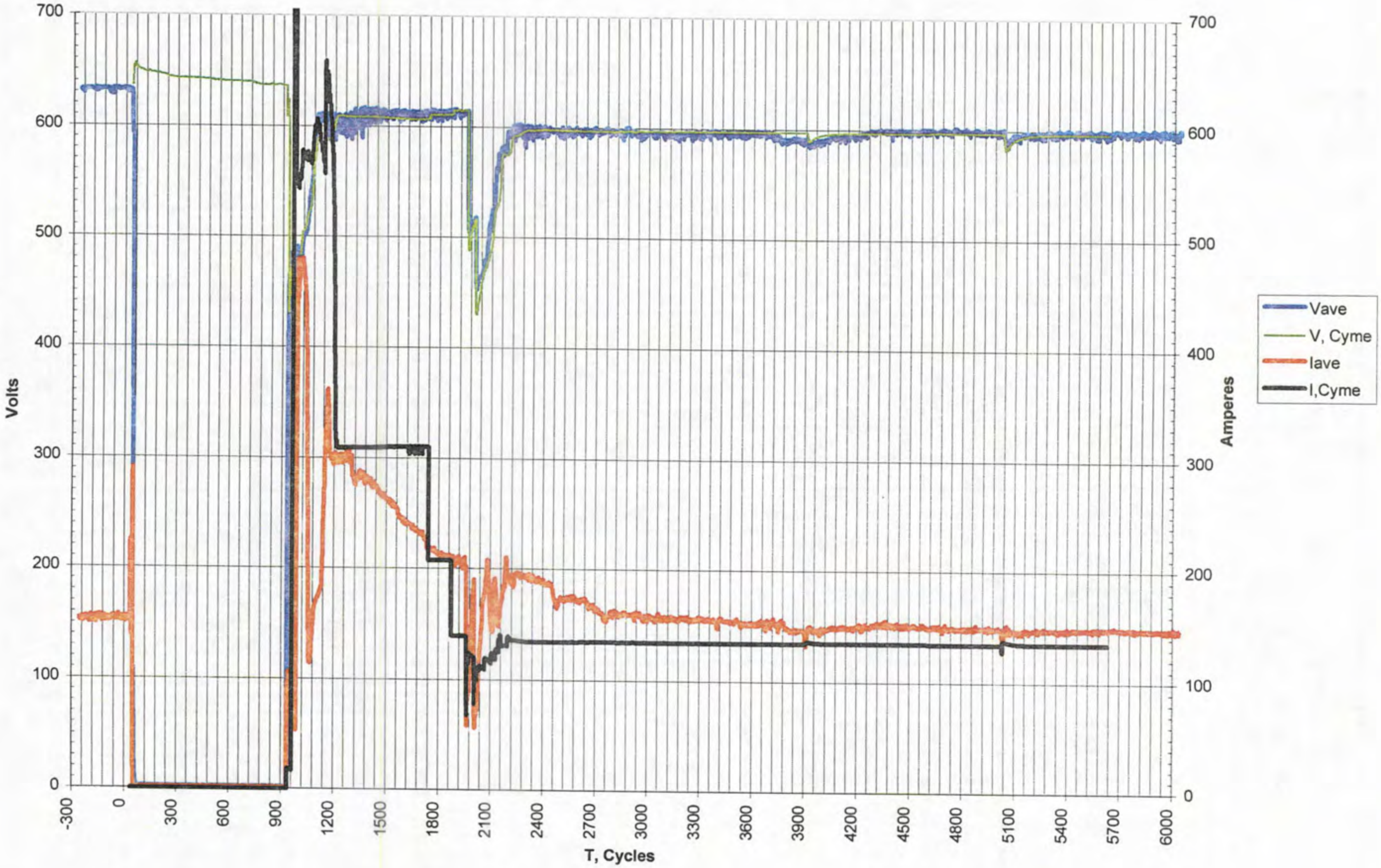


Figure 2- 35: Test5, 3X8 KVA and KW

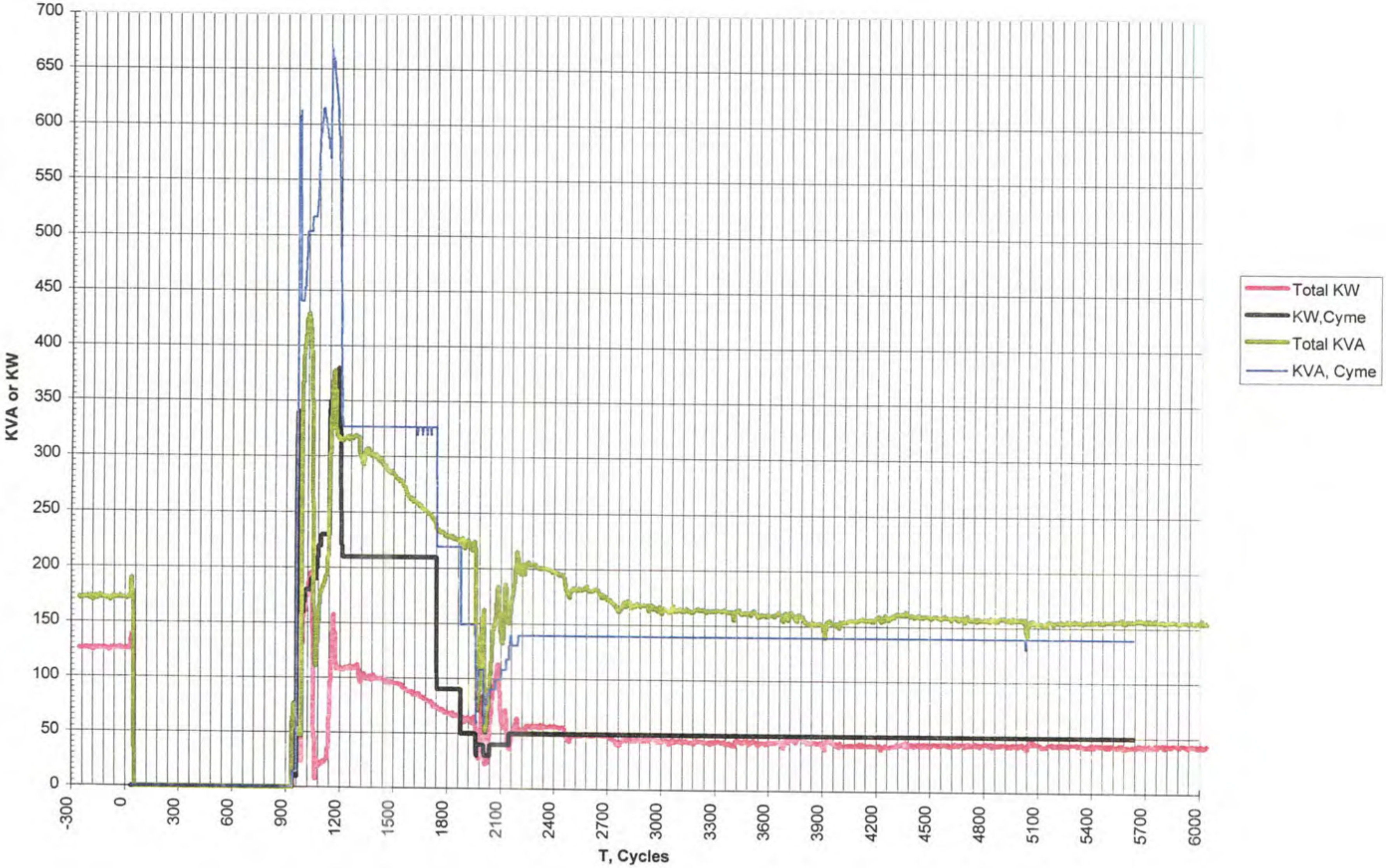


Figure 2- 36: Test5, 3X9 Voltage and Current

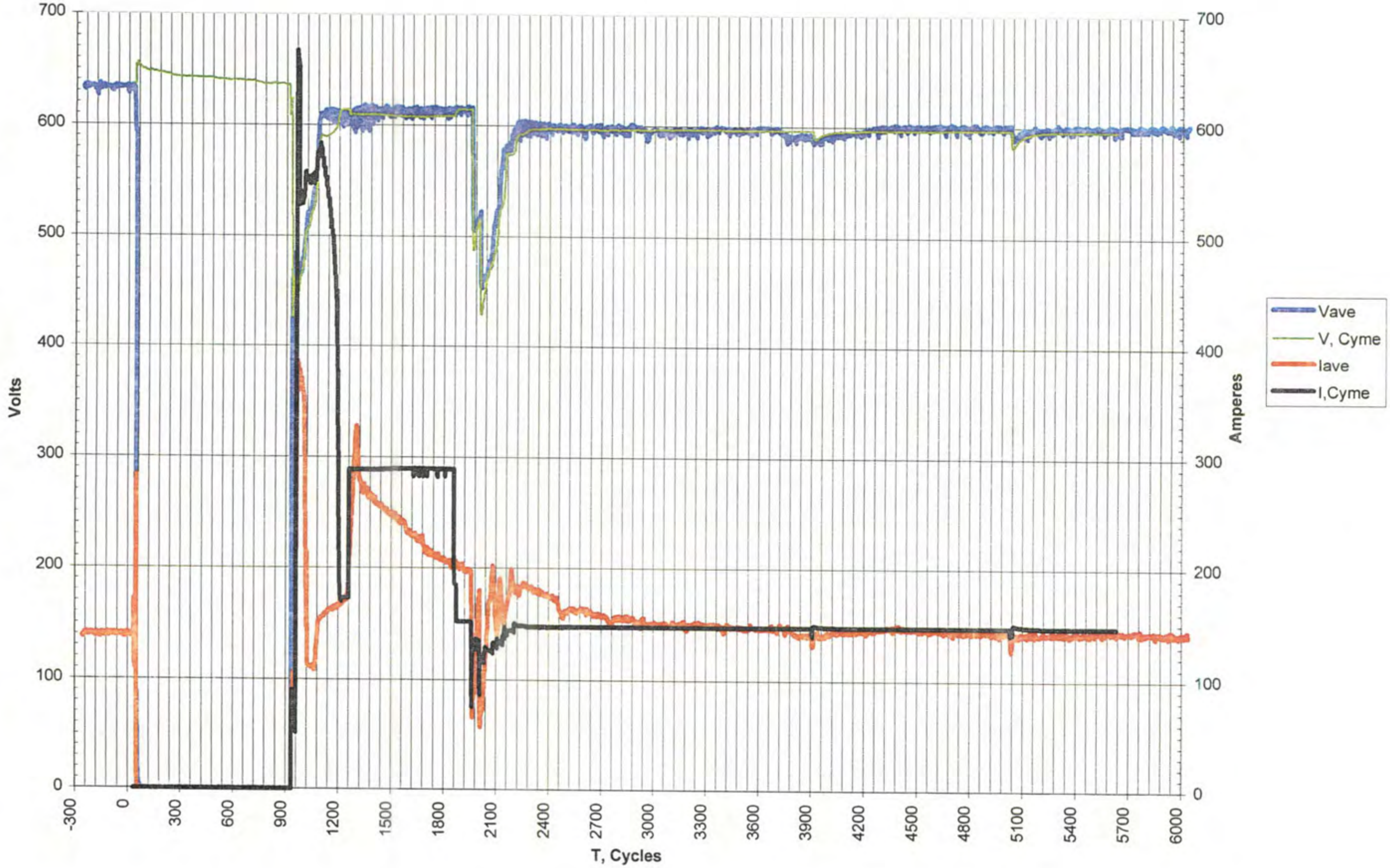


Figure 2- 37: Test5, 3X9 KVA and KW

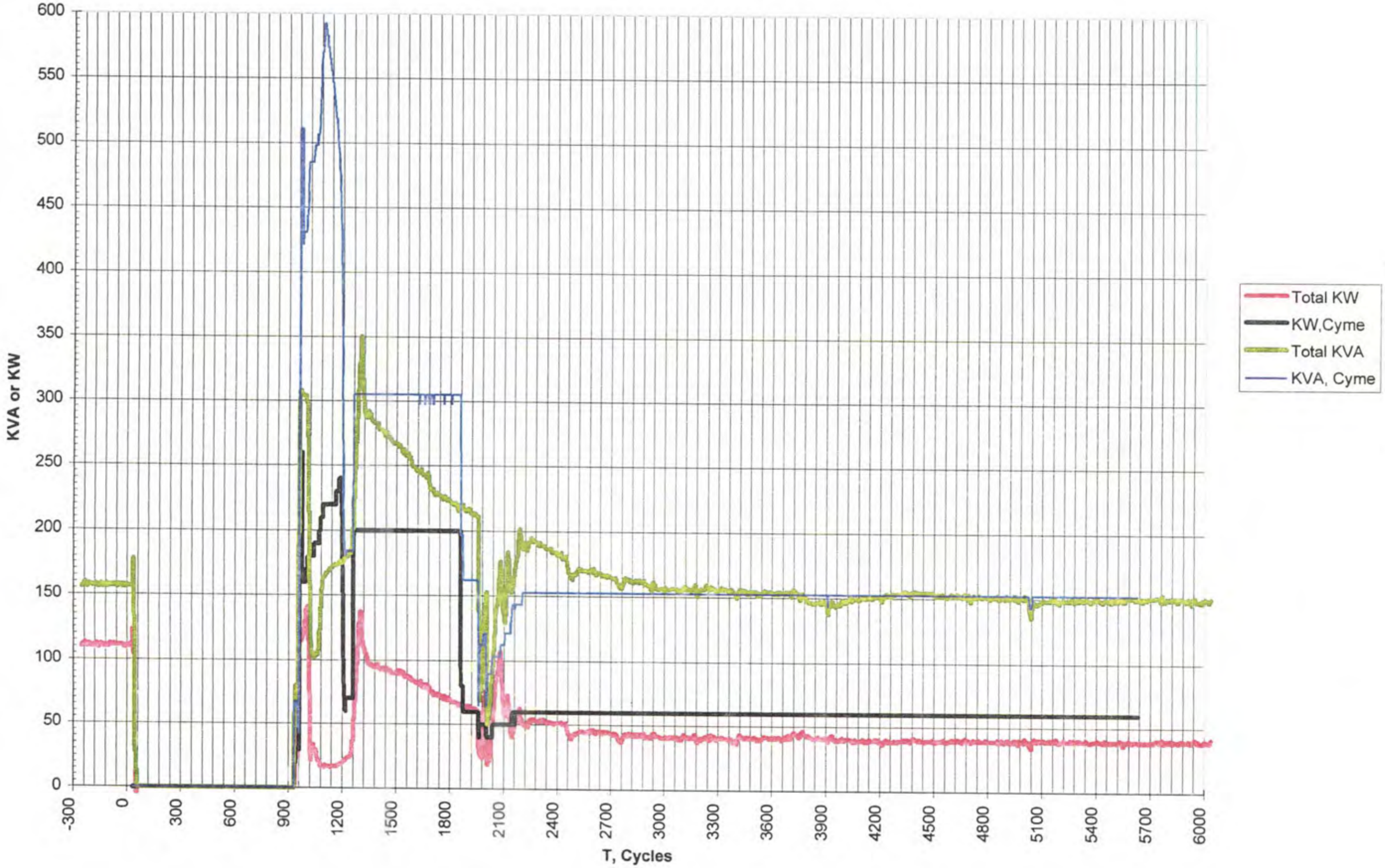


Figure 2- 38: Test5, 600V 3XS1 Voltage and Current

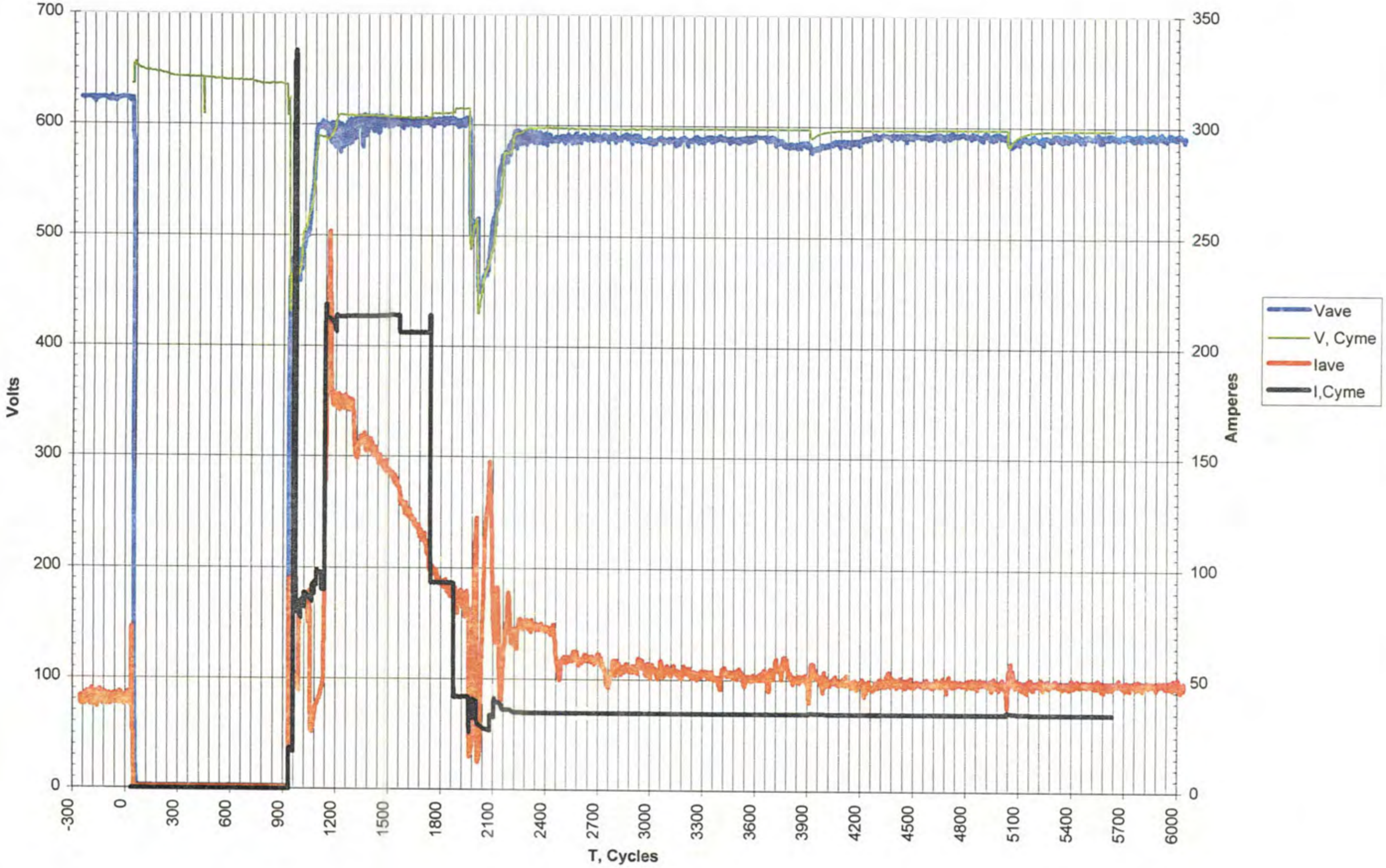


Figure 2- 39: Test5, 600V 3XS1 KVA and KW

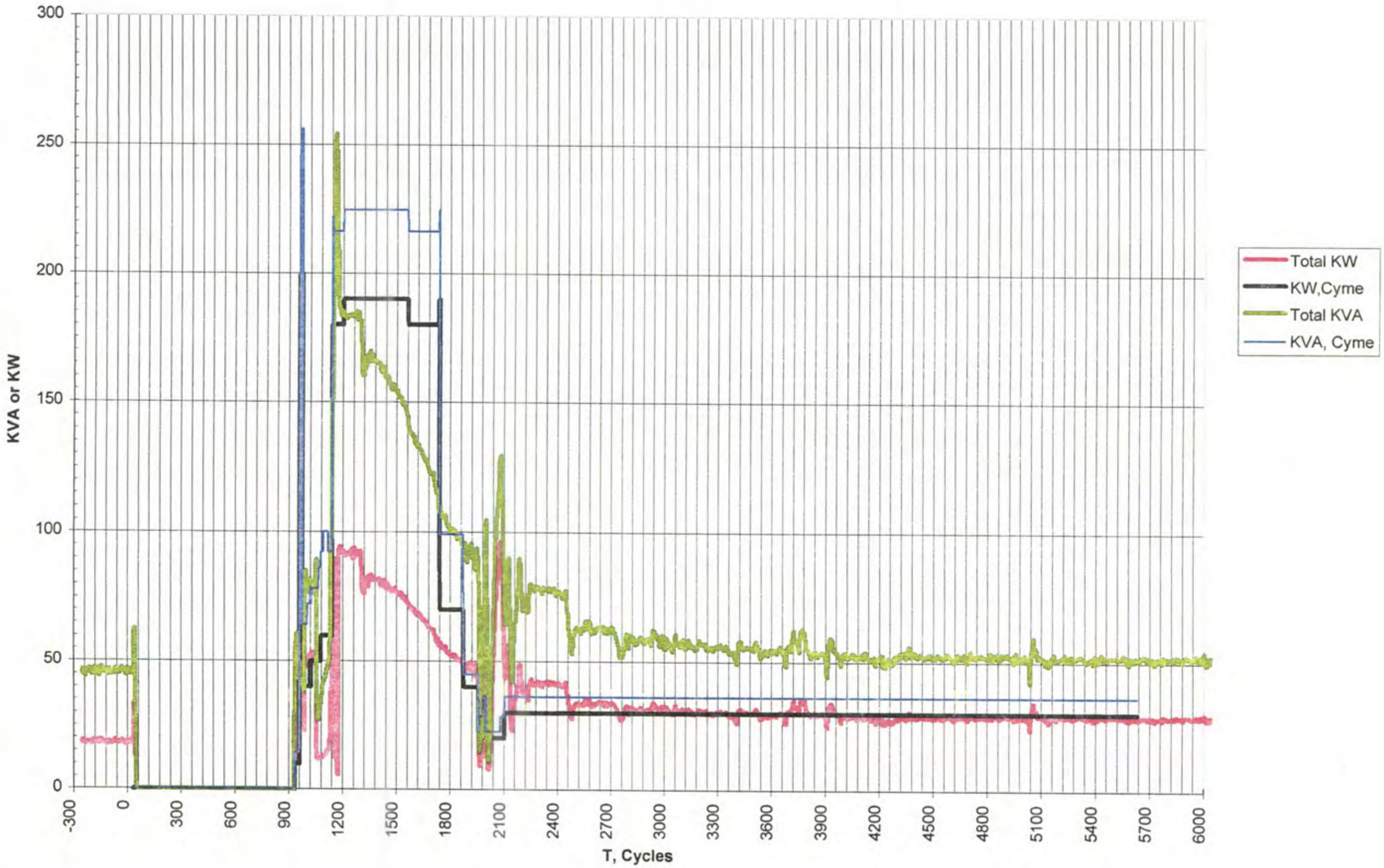


Figure 2- 40: Test5, 600V 3XS2 Voltage and Current

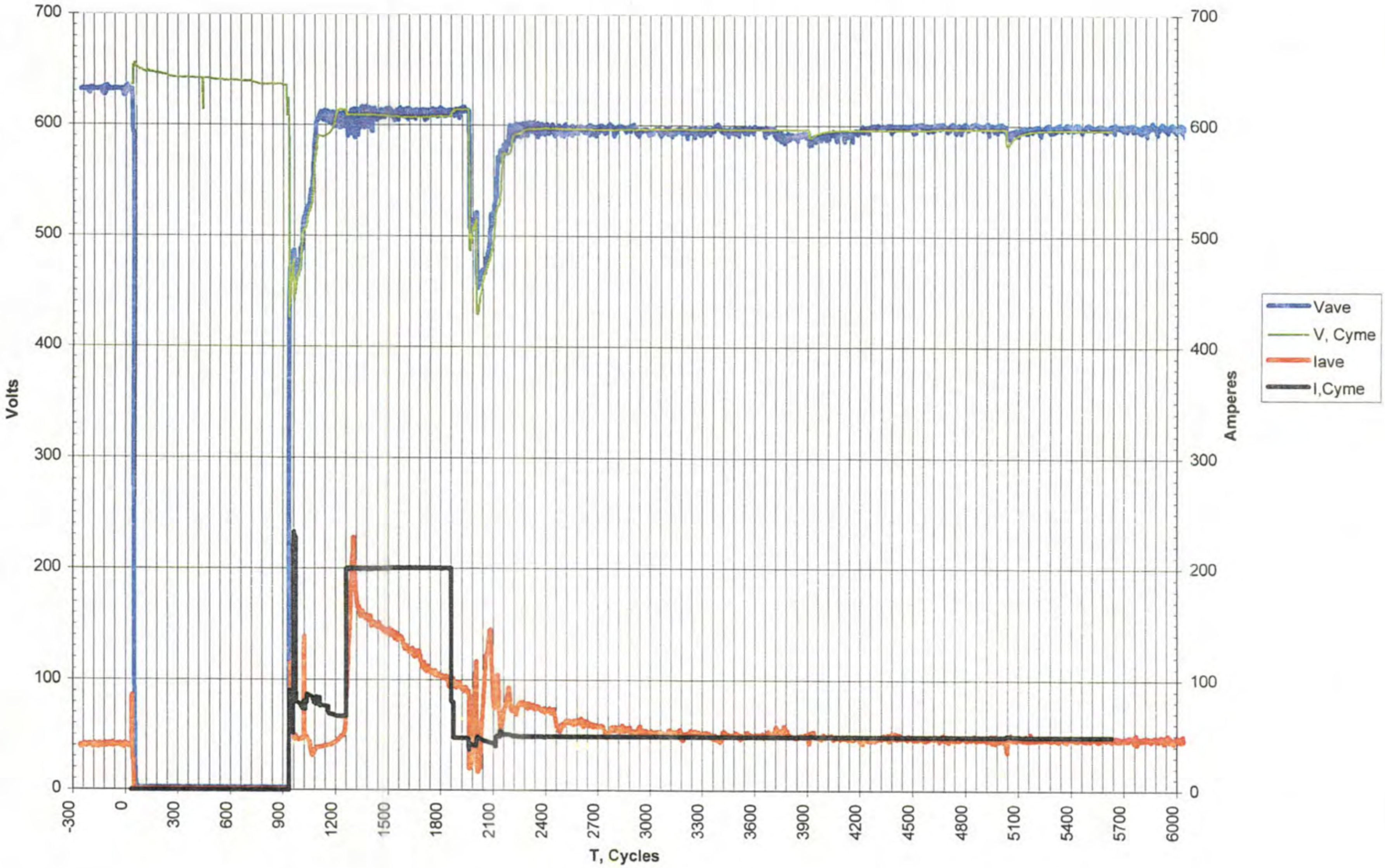


Figure 2- 41: Test5, 600V 3XS2 KVA and KW

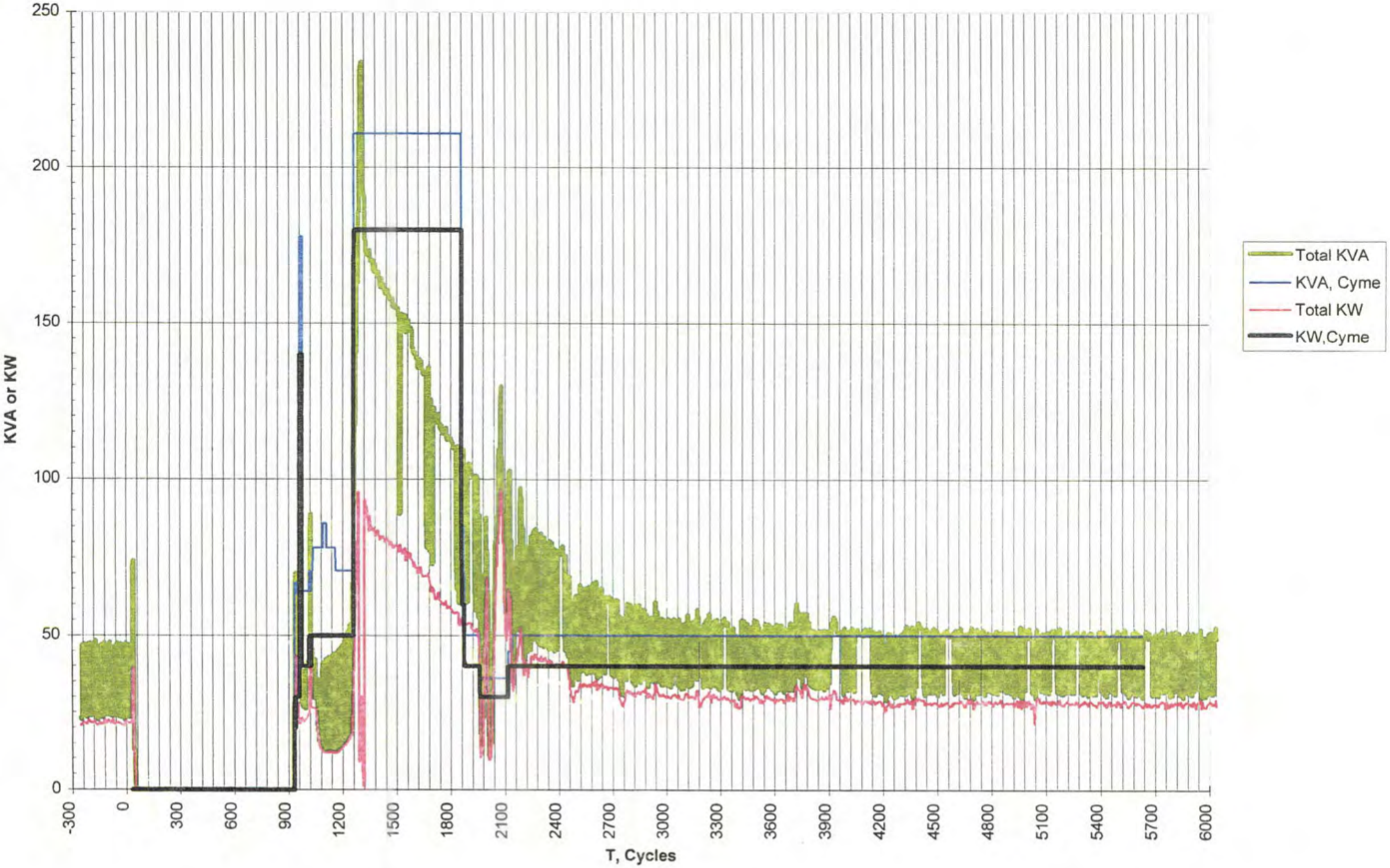


Figure 2- 42: Test5, 600V 3XS3 Voltage and Current

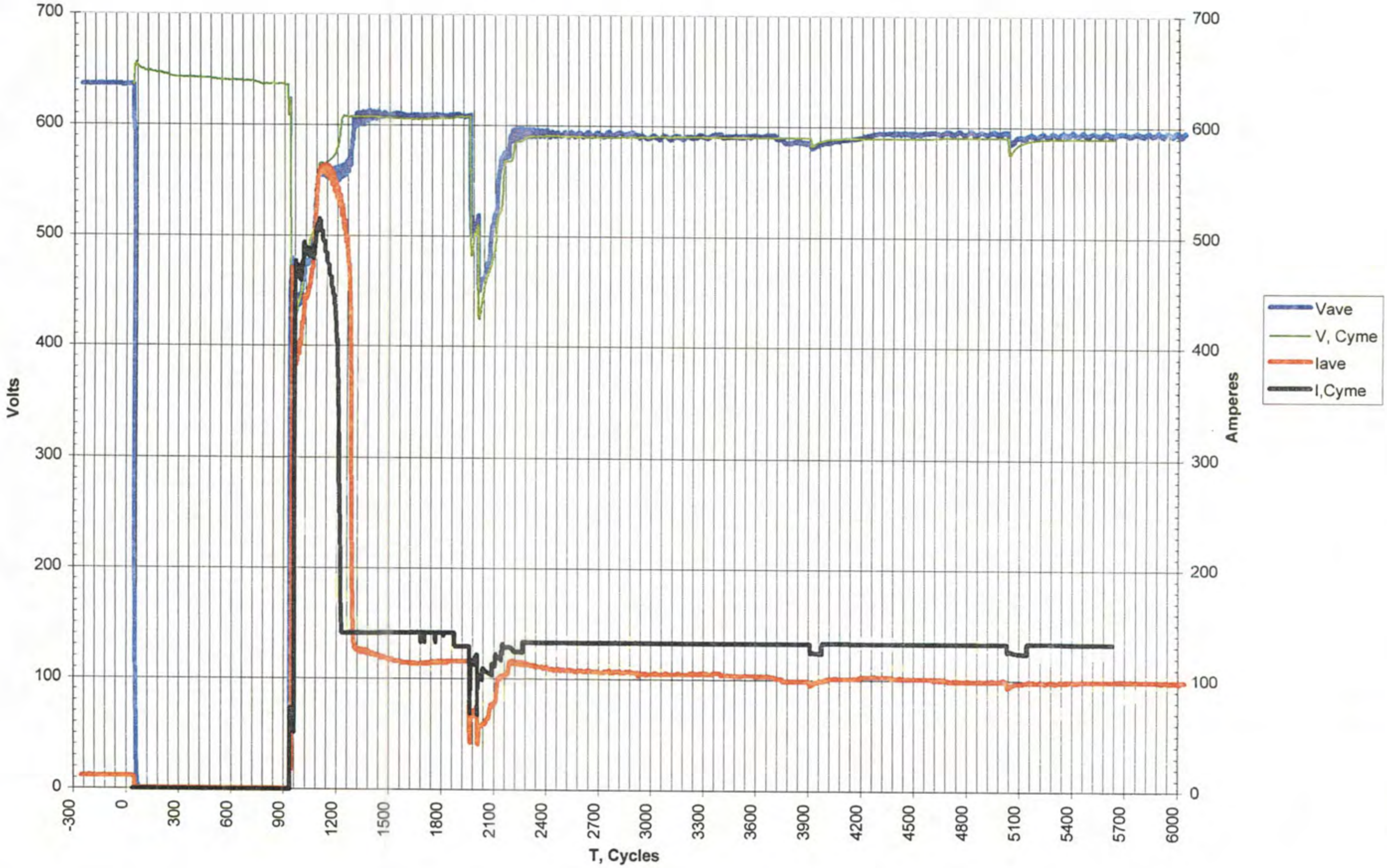


Figure 2- 43: Test5, 600V 3XS3 KVA and KW

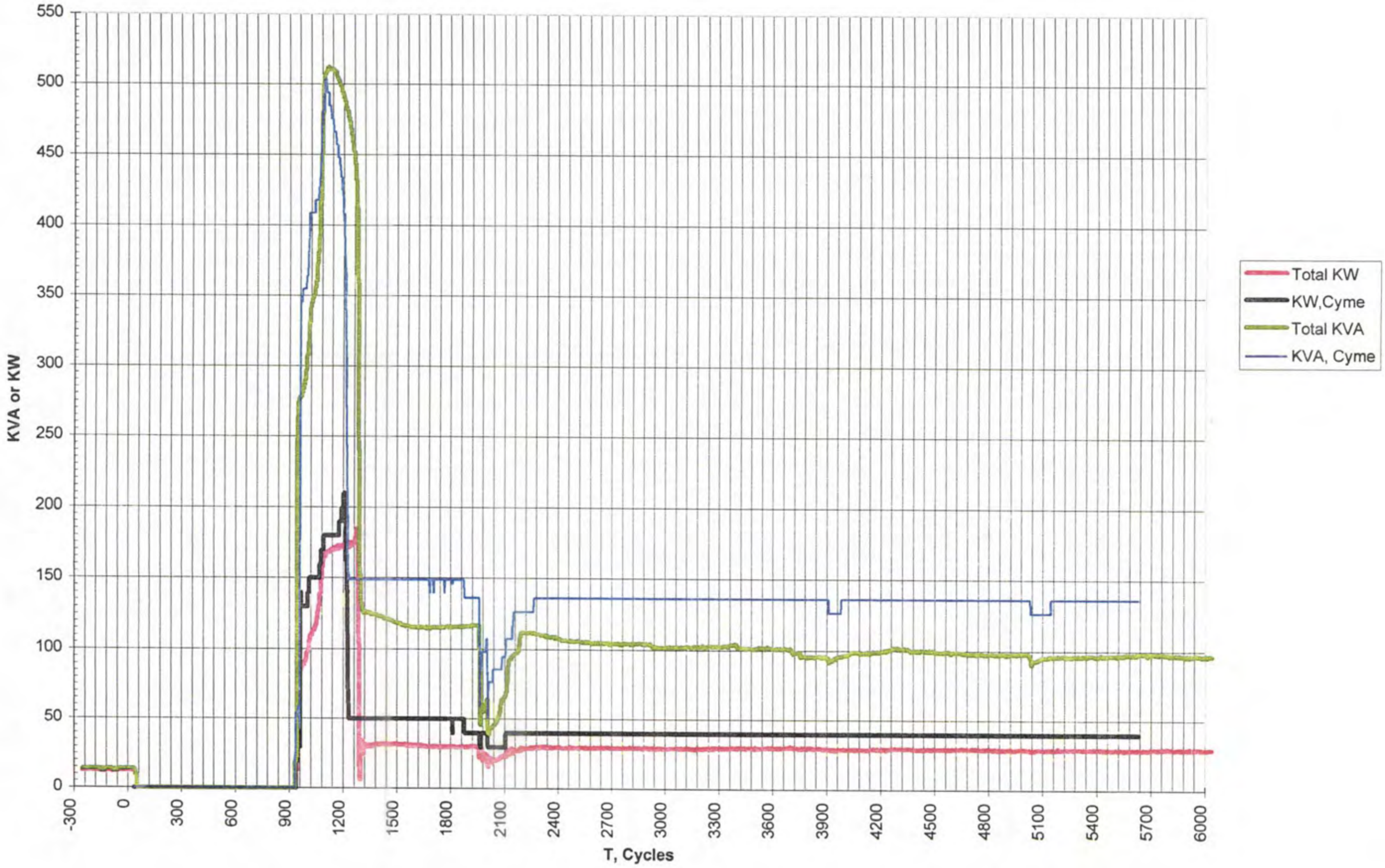


Figure 2- 44: Test5, 208V 3XS1 Voltage and Current

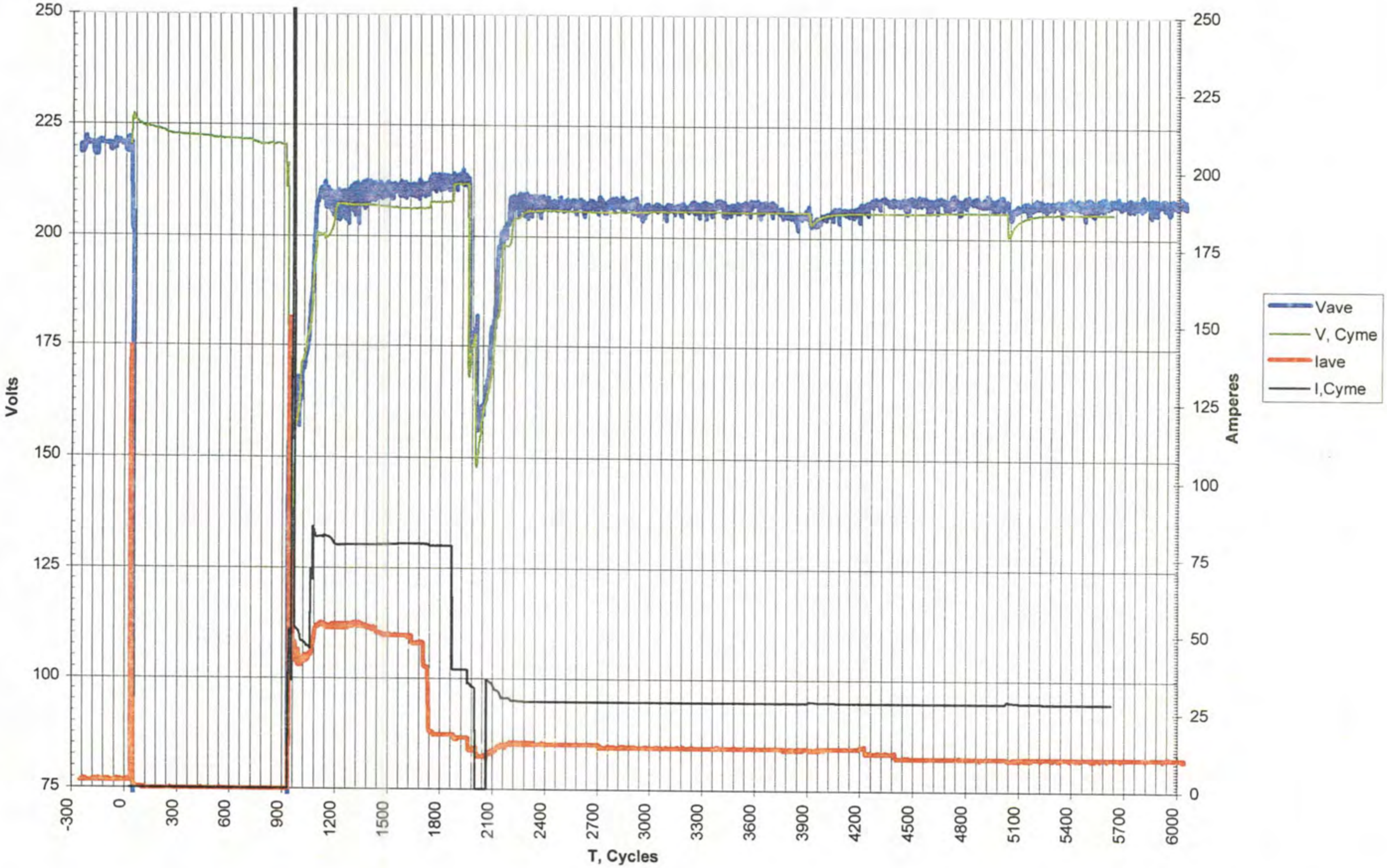


Figure 2- 45: Test5, 208V 3XS1 KVA and KW

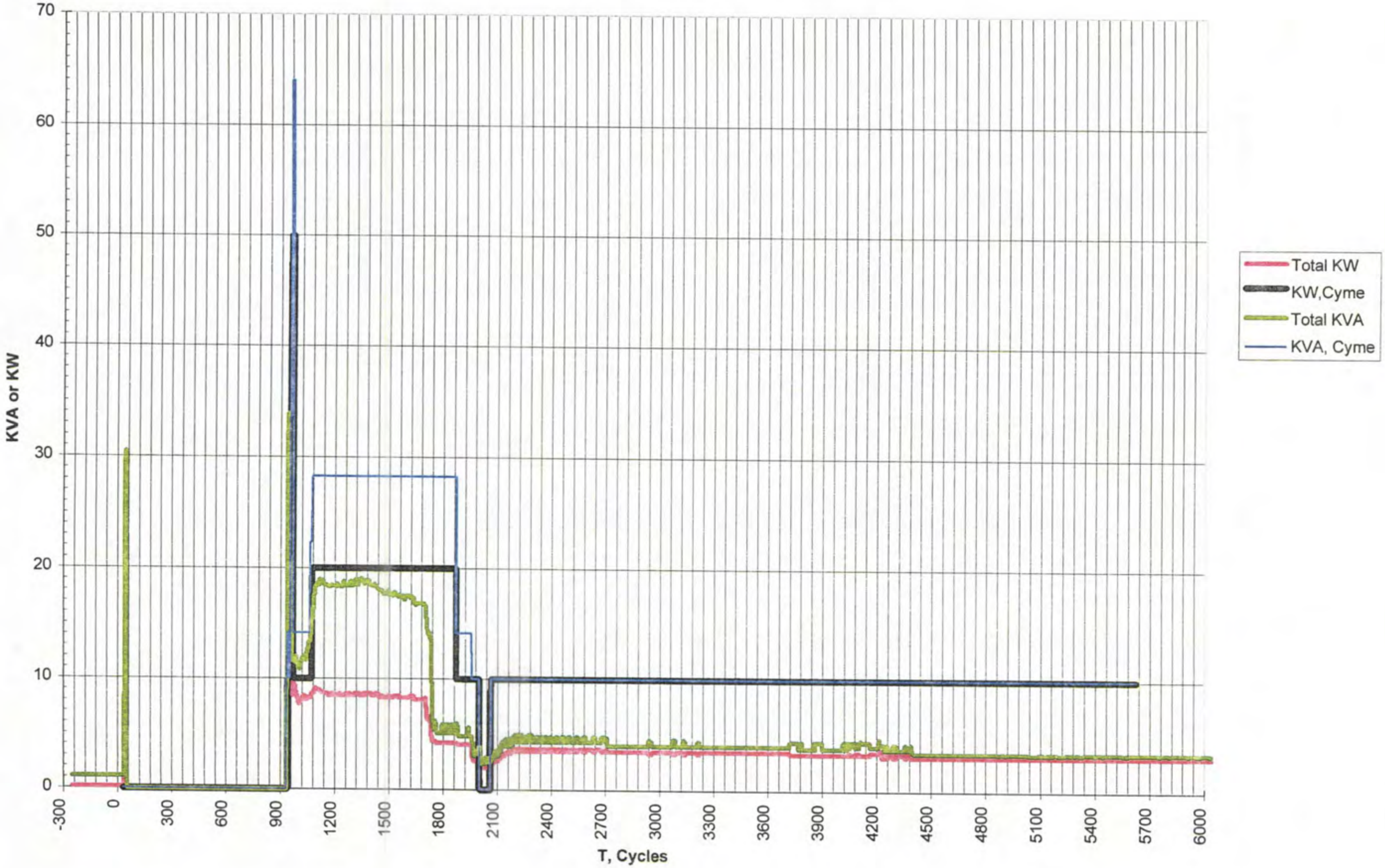


Figure 2- 46: Test5, 208V 3XS2 Voltage and Current

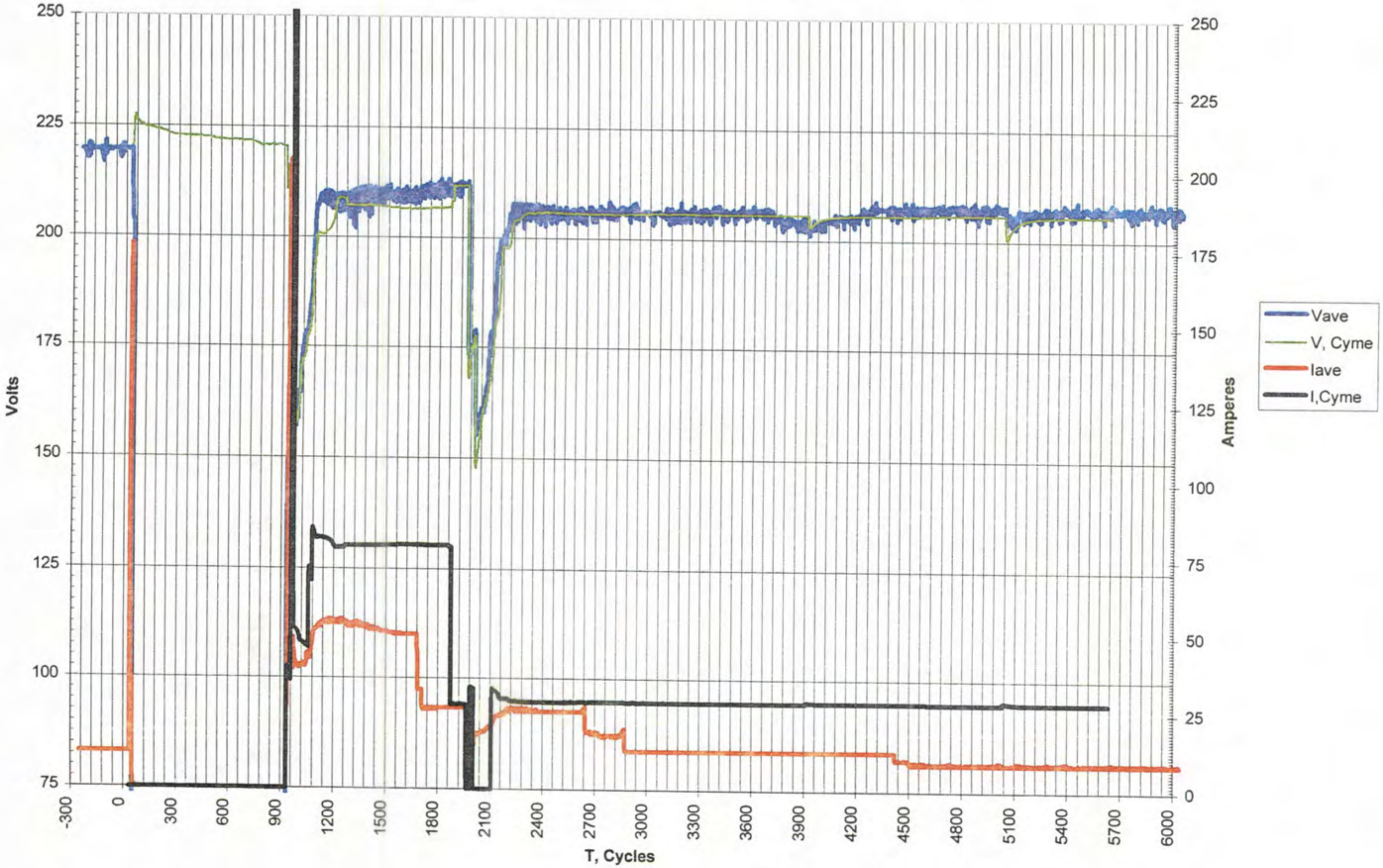


Figure 2- 47: Test5, 208V 3XS2 KVA and KW

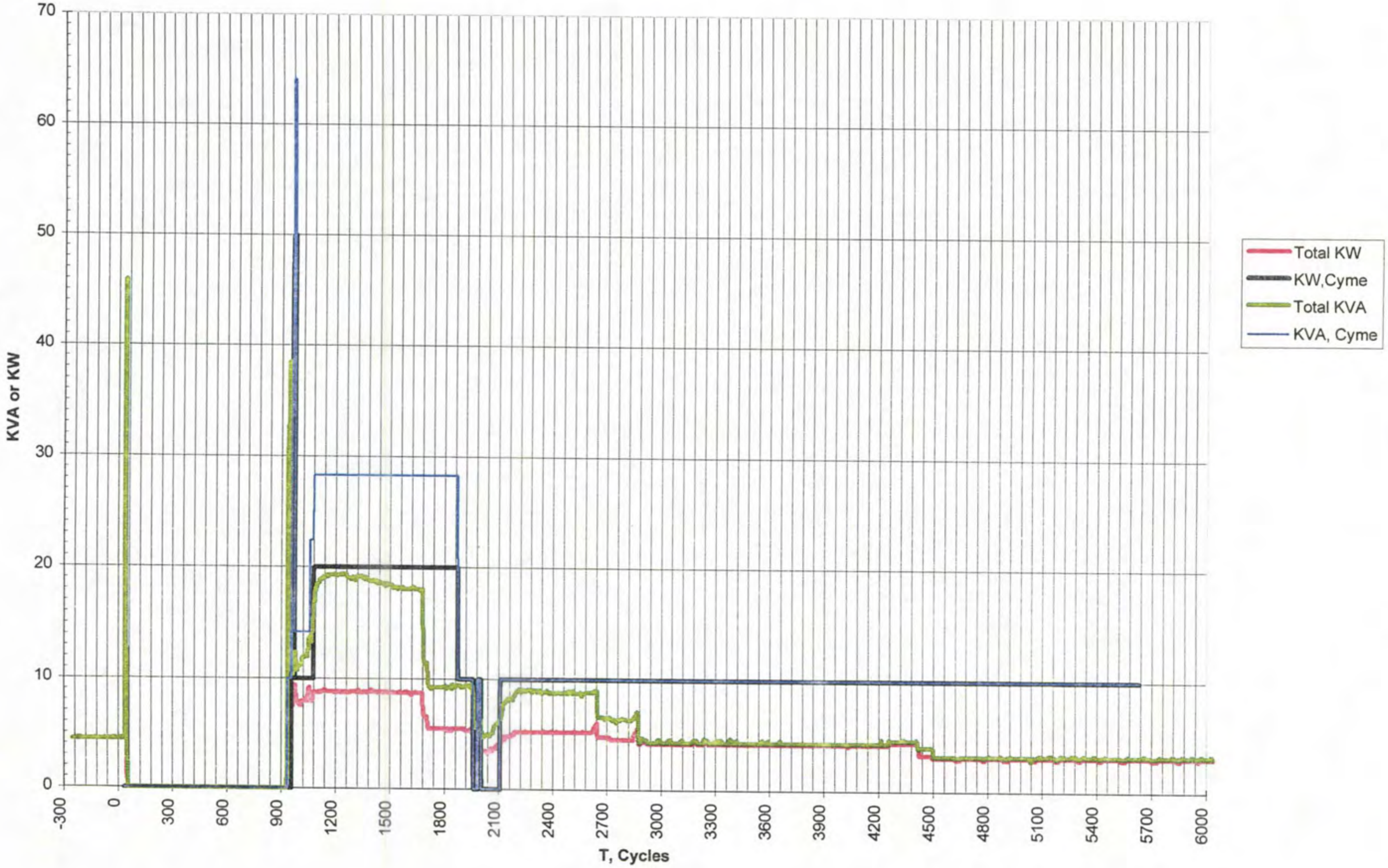


Figure 2- 48: Test5, 208V 3XS3 Voltage and Current

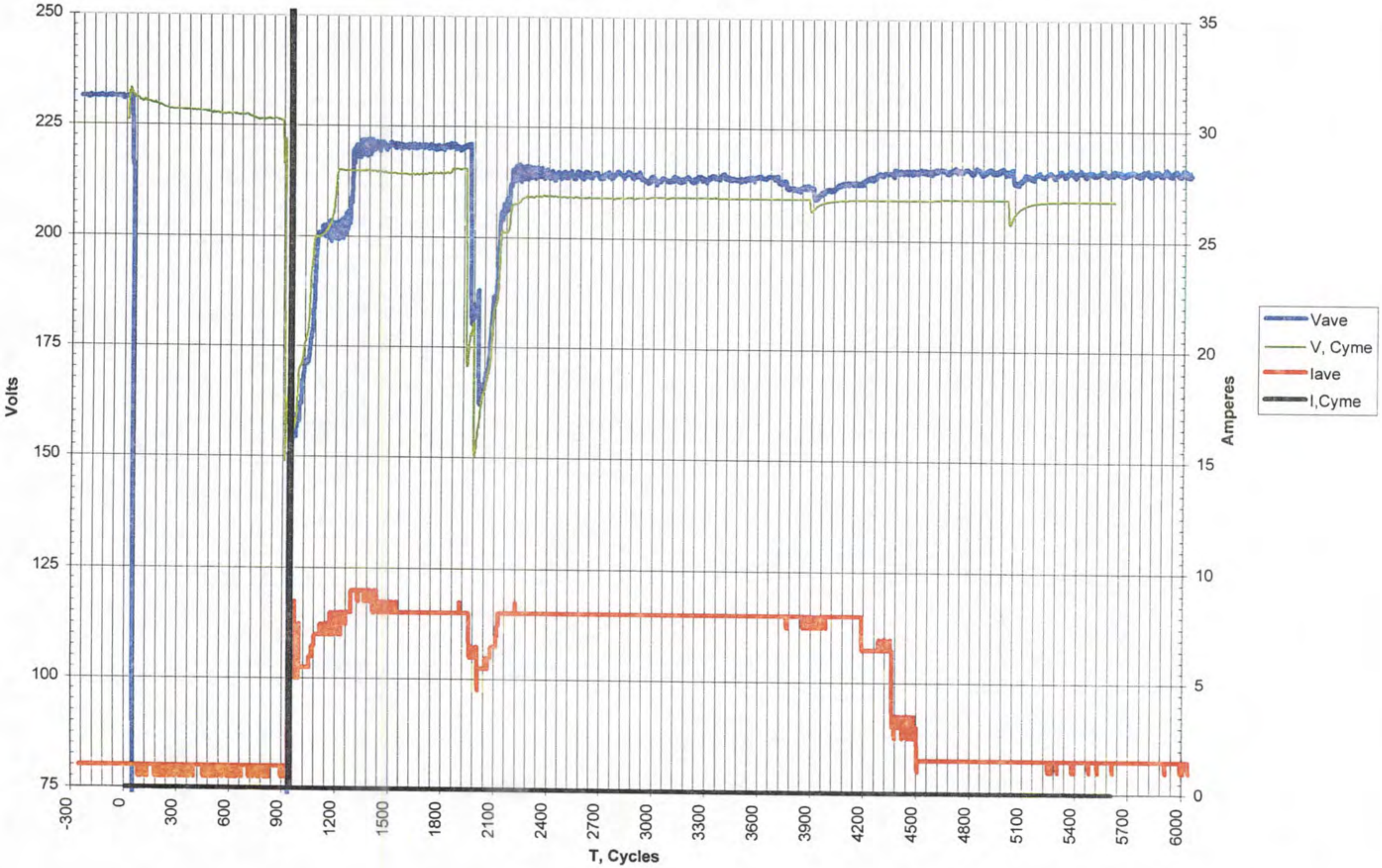
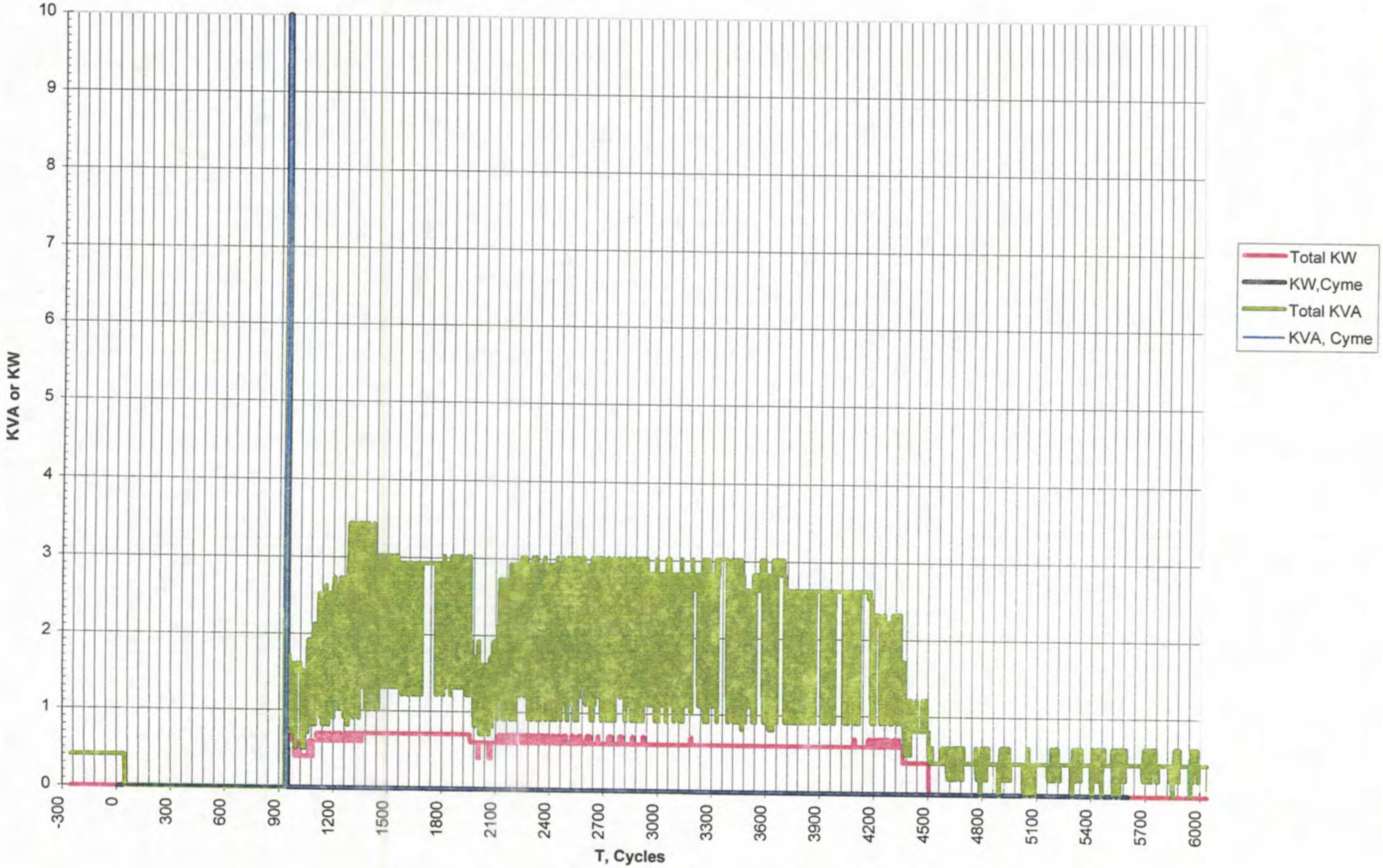


Figure 2- 49: Test5, 208V 3XS3 KVA and KW



Appendix 3 - Test 6, Figures of Results

APPENDIX 3: Figures for Test 6

Figure 3-1: Test6, Lee Voltage and Current

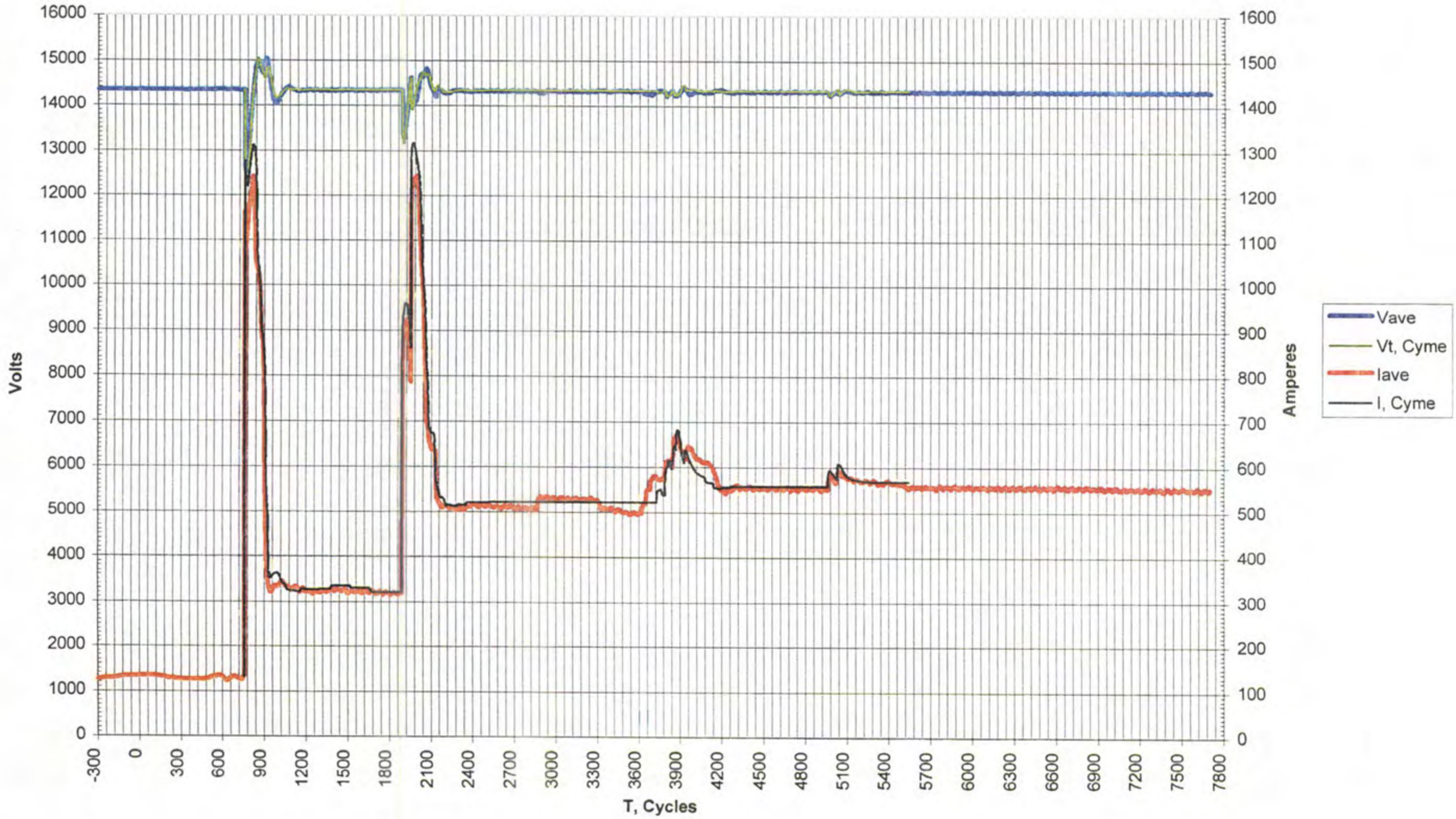


Figure 3-2: Test6, Lee Voltage

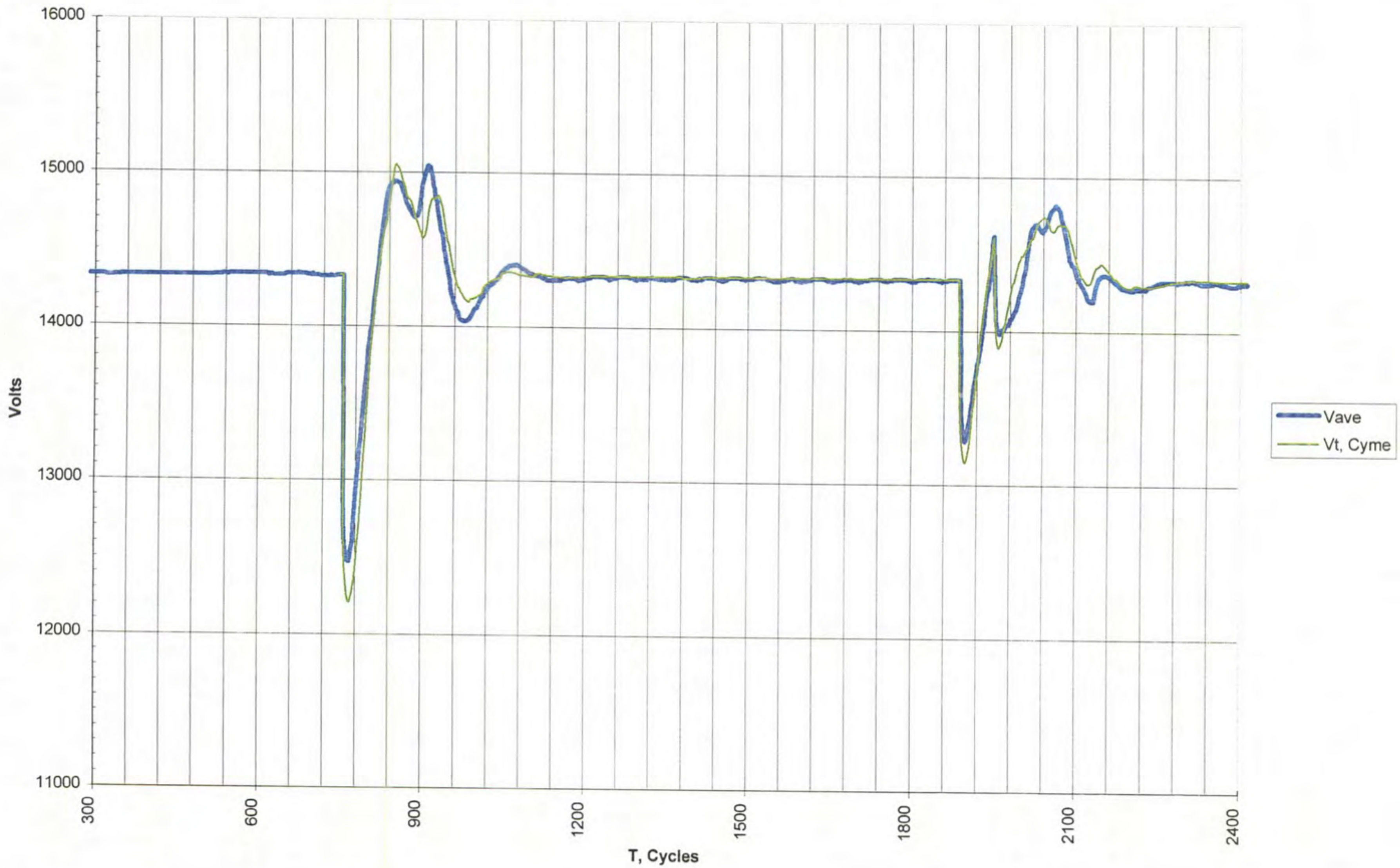


Figure 3-3, Test6, Lee KVA

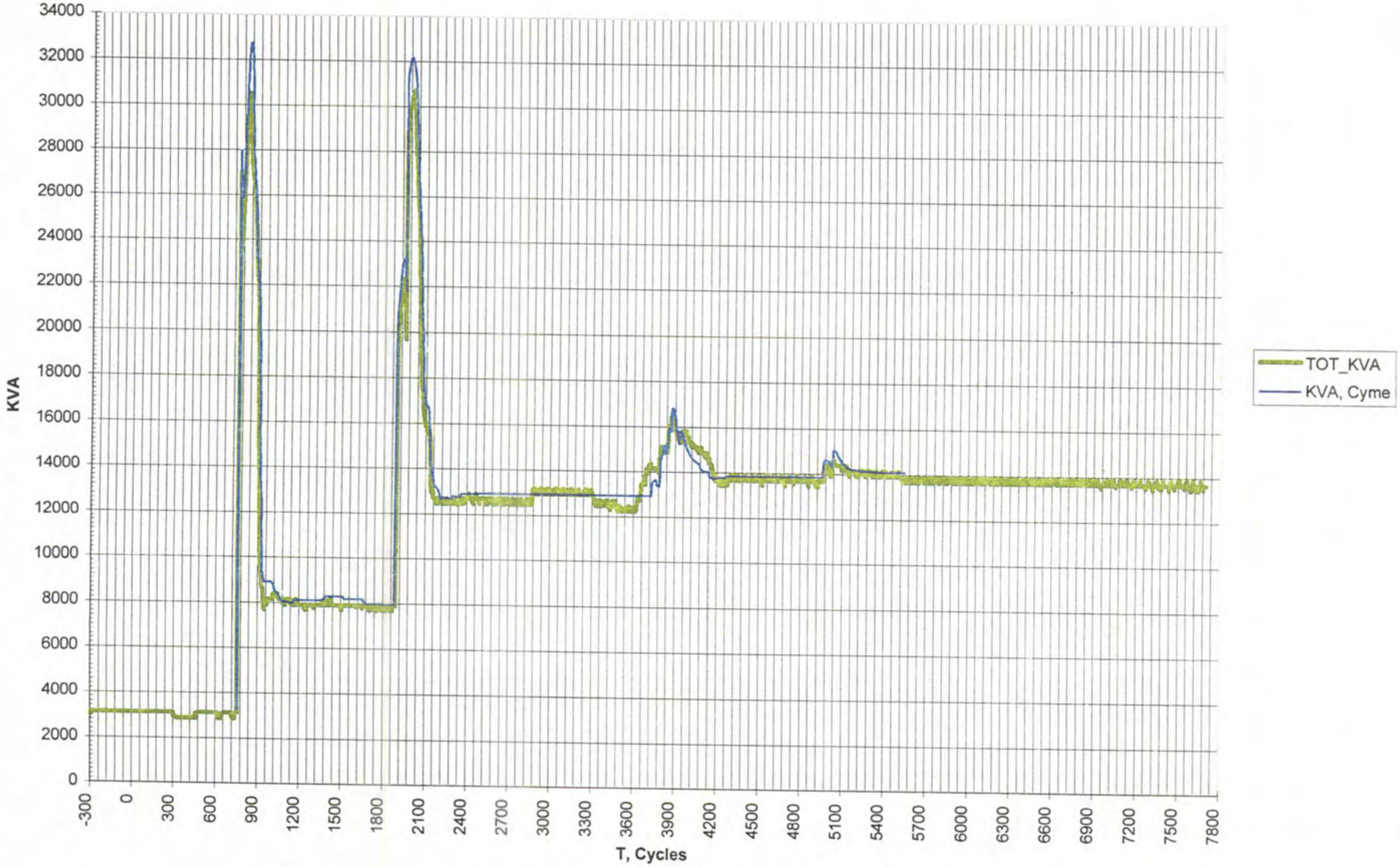


Figure 3-4: Test6, Lee KW

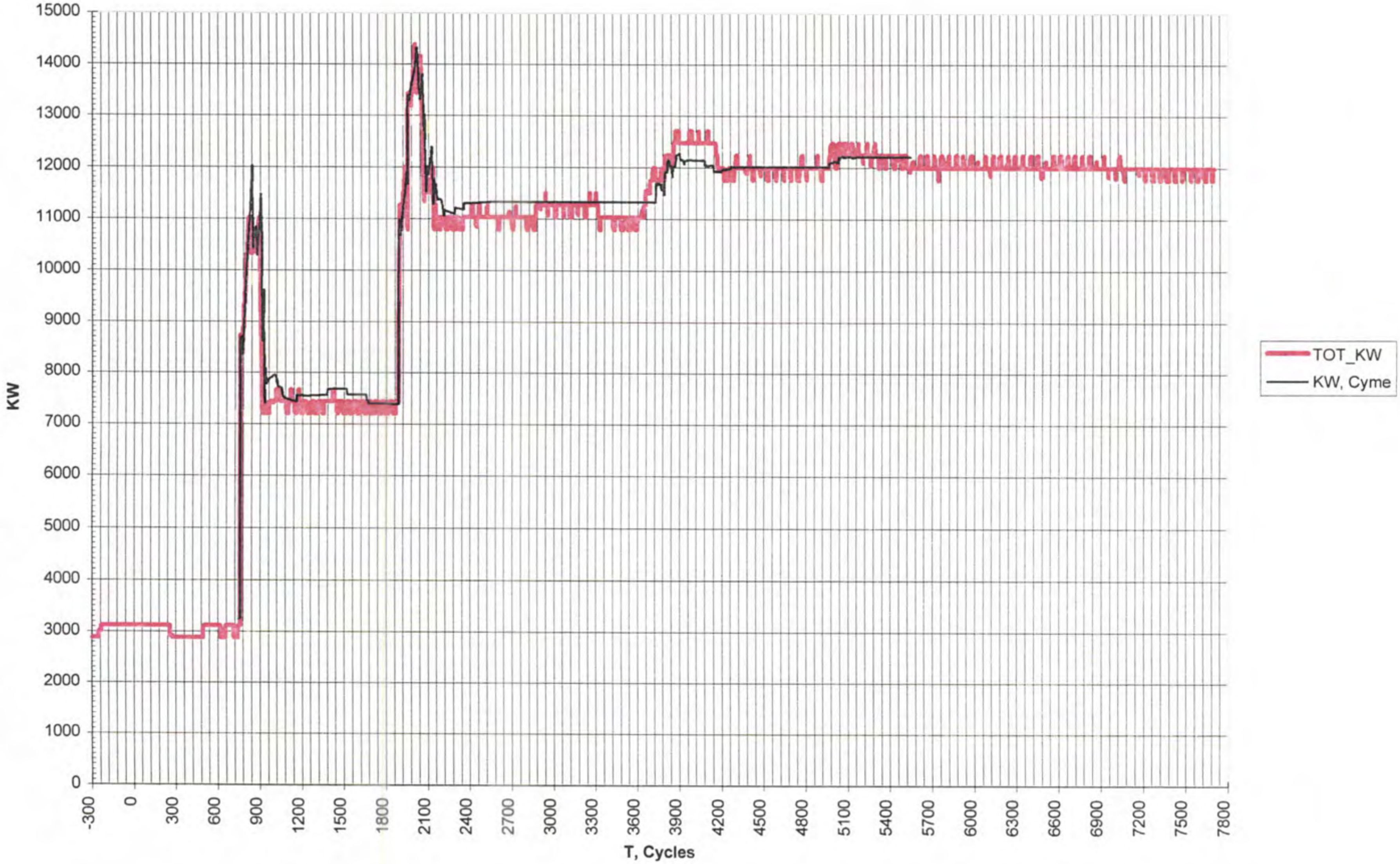


Figure 3-5: Test6, Lee Frequency and Current

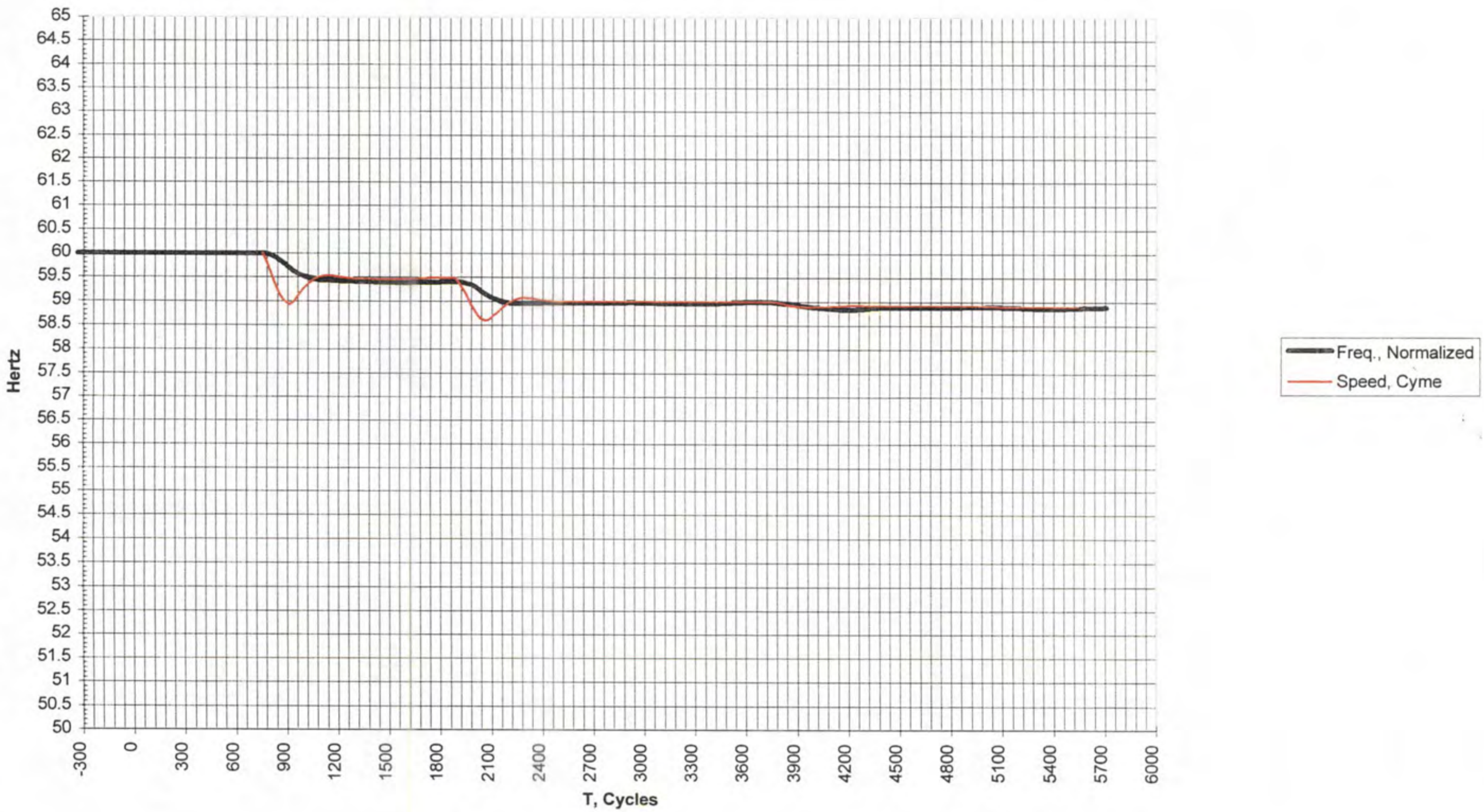


Figure 3-6: Test6, Unit 1 MFB Voltage and Current

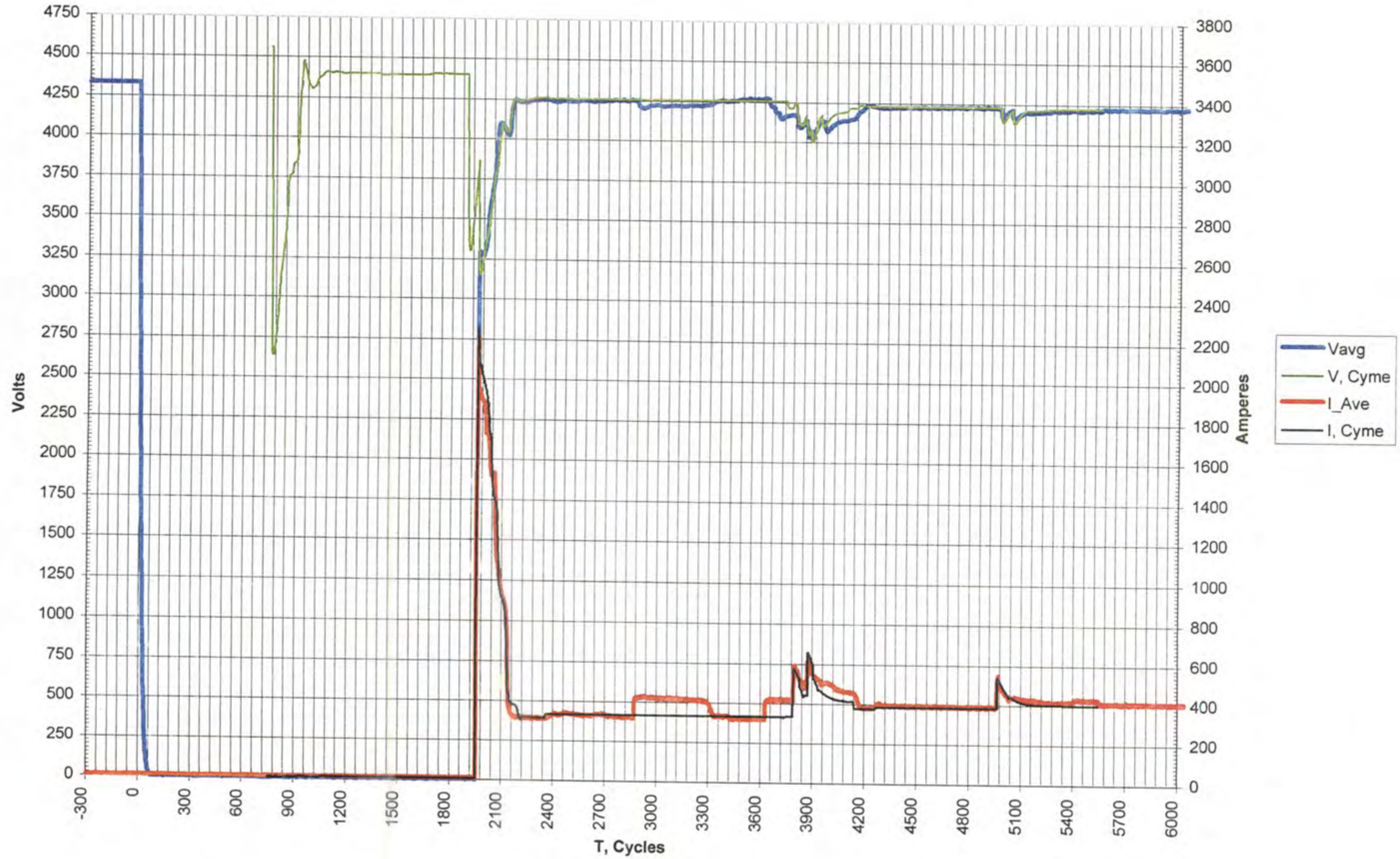


Figure 3-7: Test6, Unit 1 MFB KVA and KW

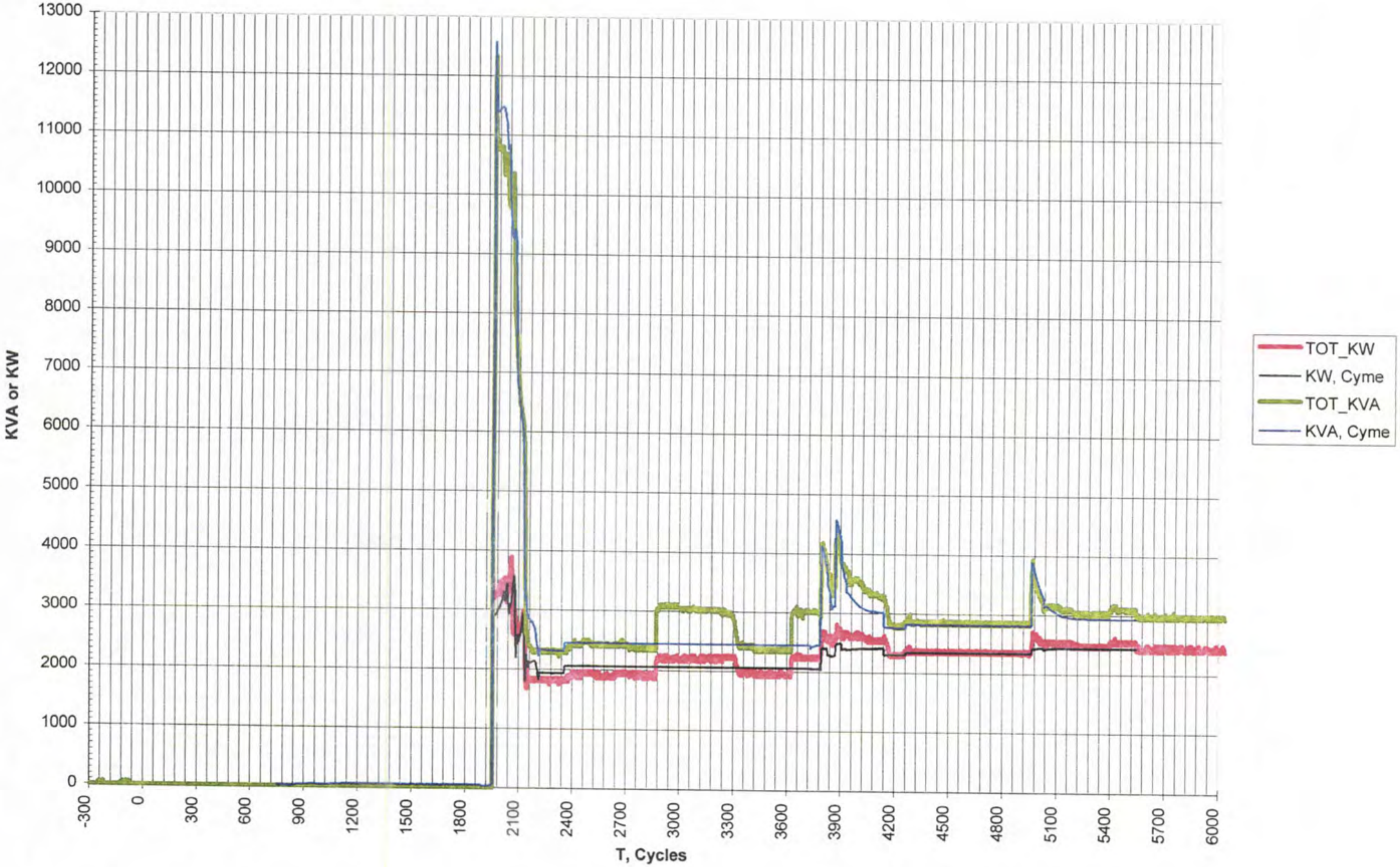


Figure 3-8: Test6, Unit 2 MFB Voltage and Current

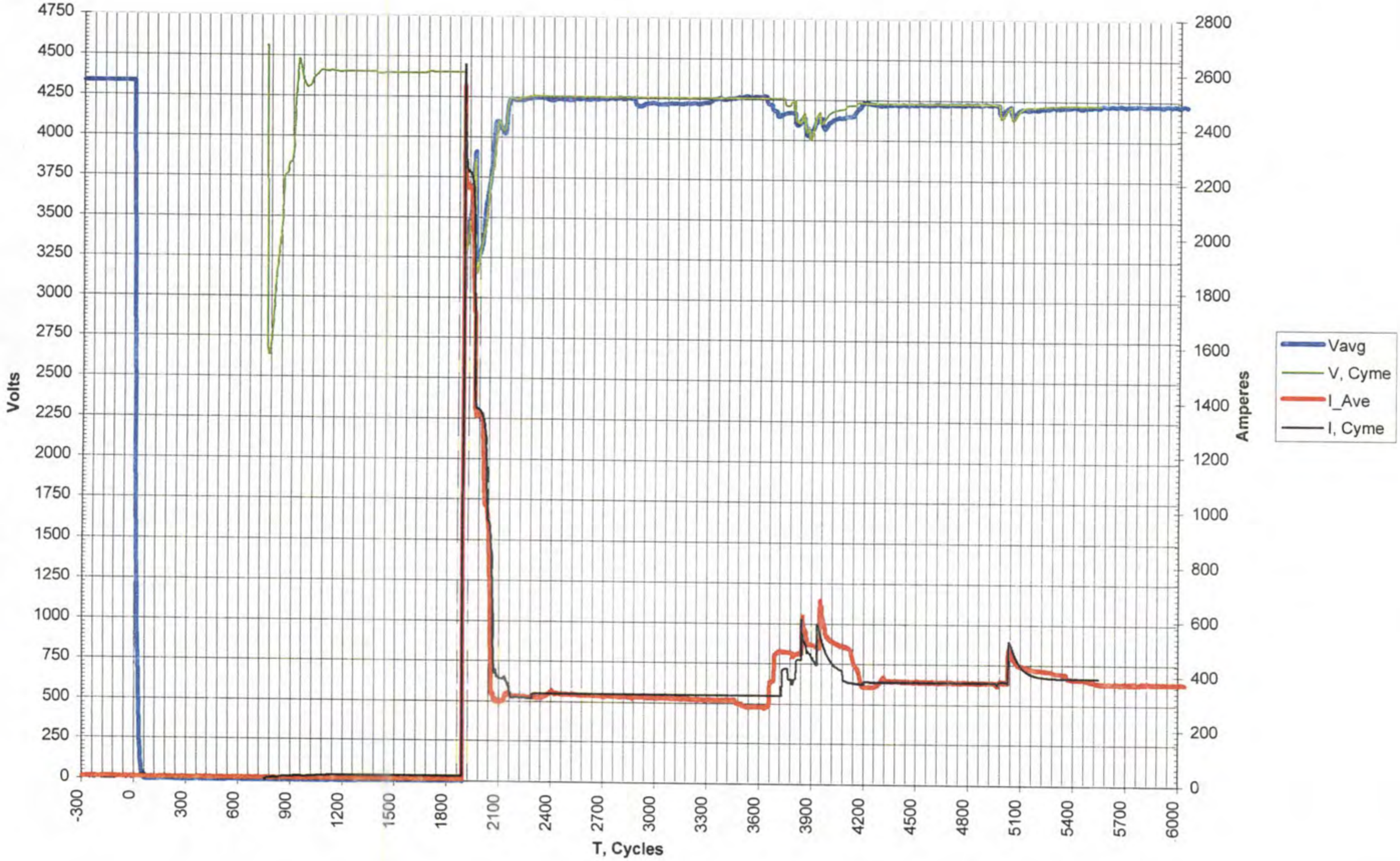


Figure 3-9: Test6, Unit 2 MFB KVA and KW

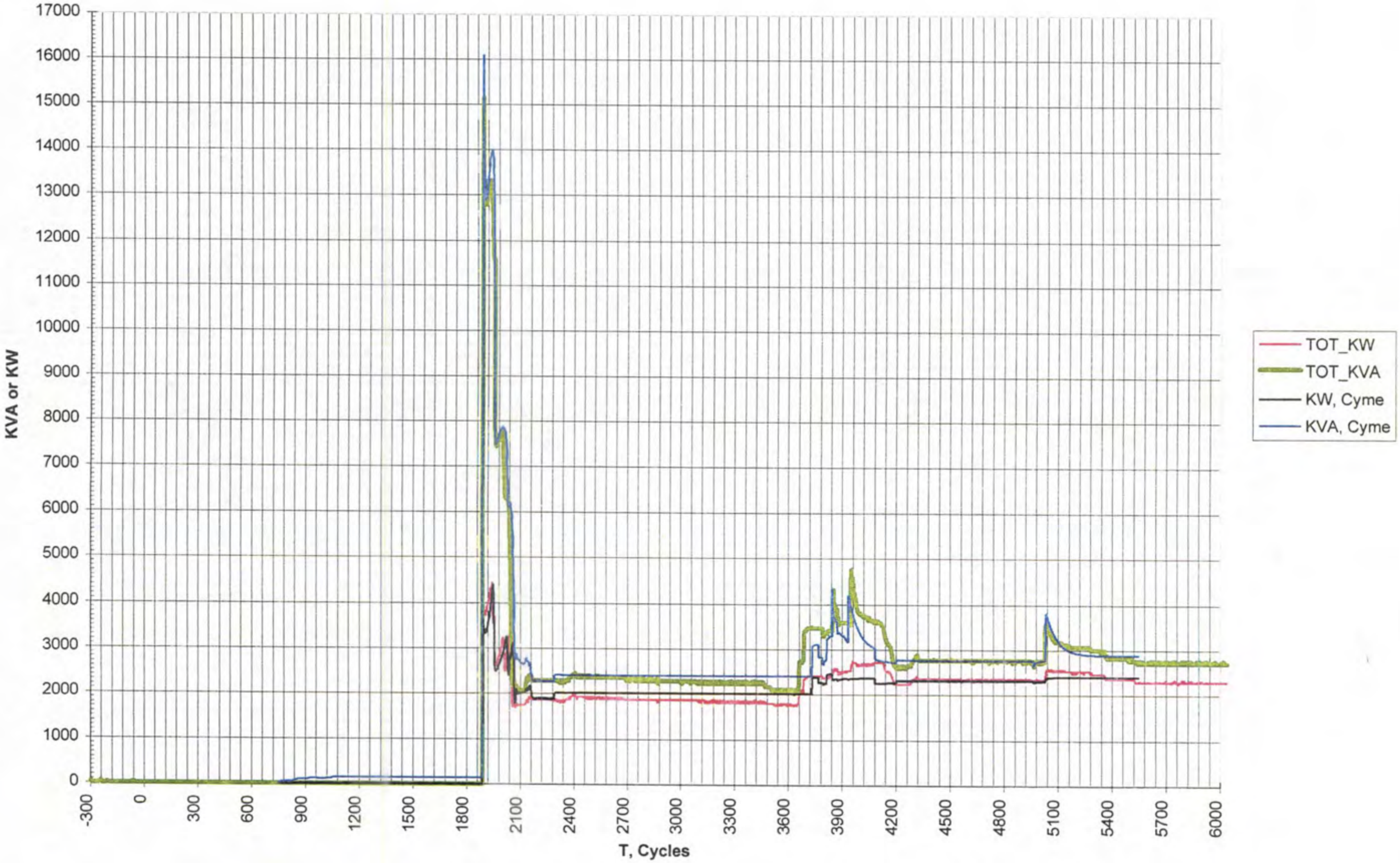


Figure 3-10: Test6, Standby Bus Voltage and Unit 3 MFB Current

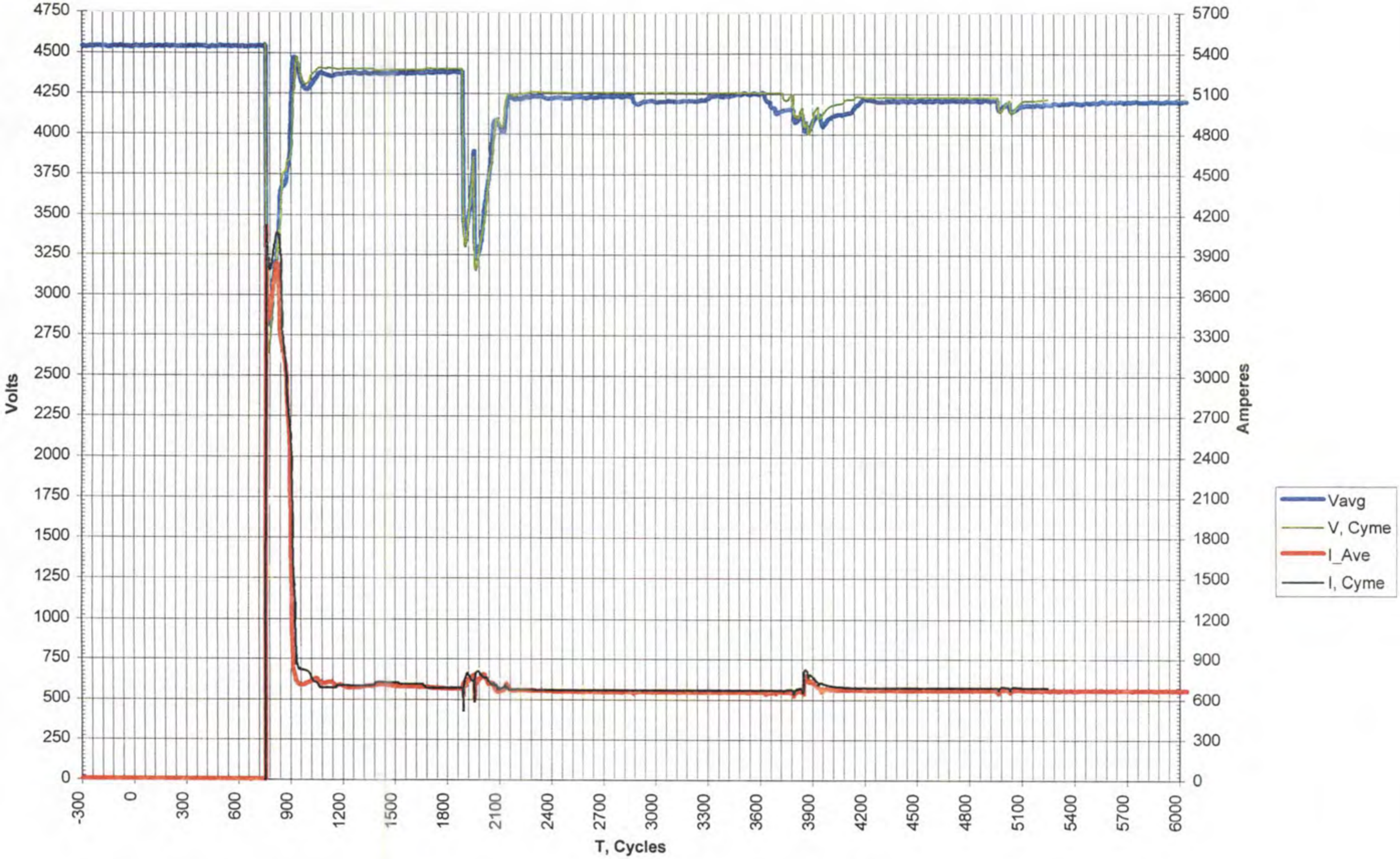


Figure 3-11: Test6, Unit 3 MFB KVA and KW

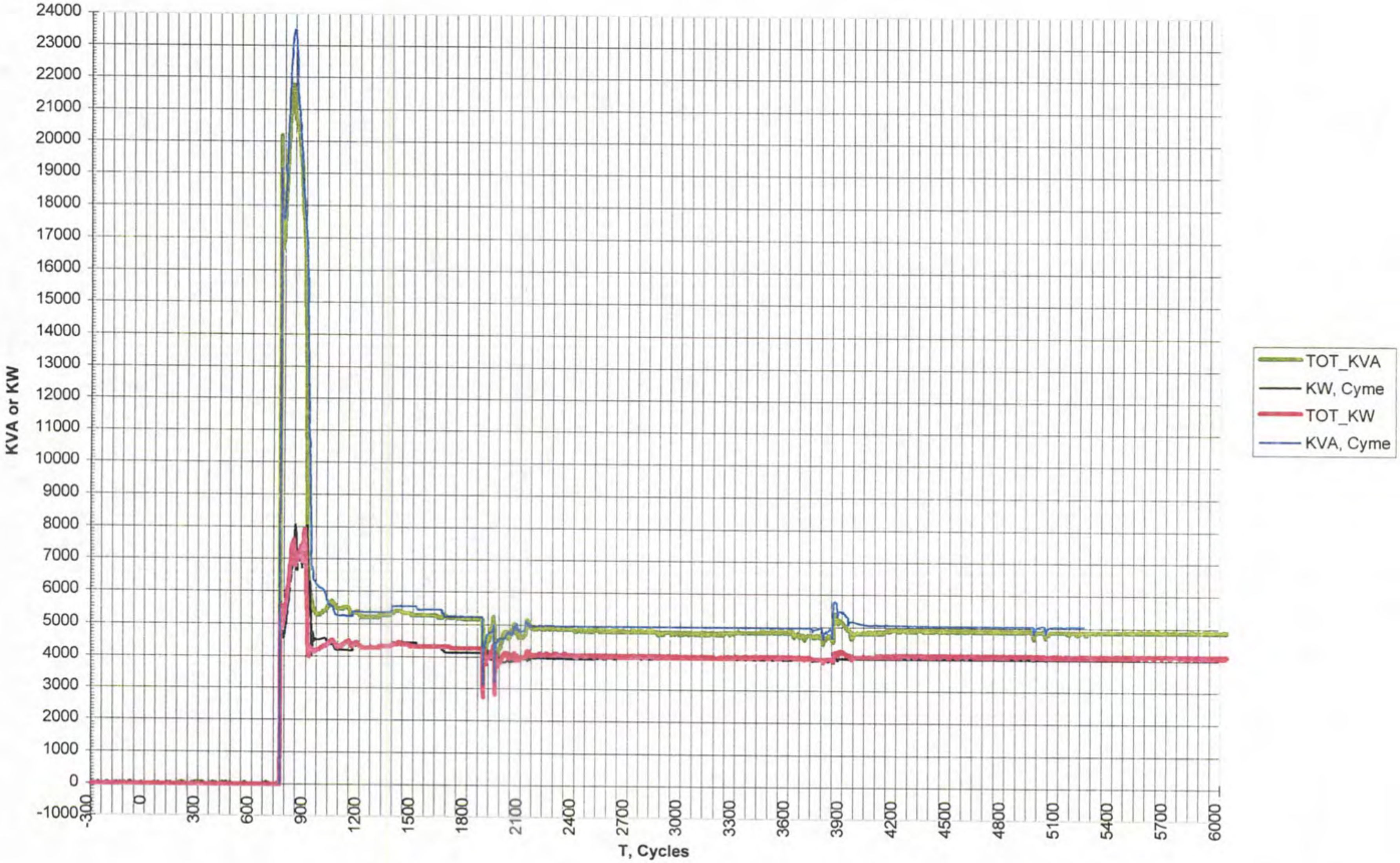


Figure 3-12: Test6, EFW 3B Voltage and Current

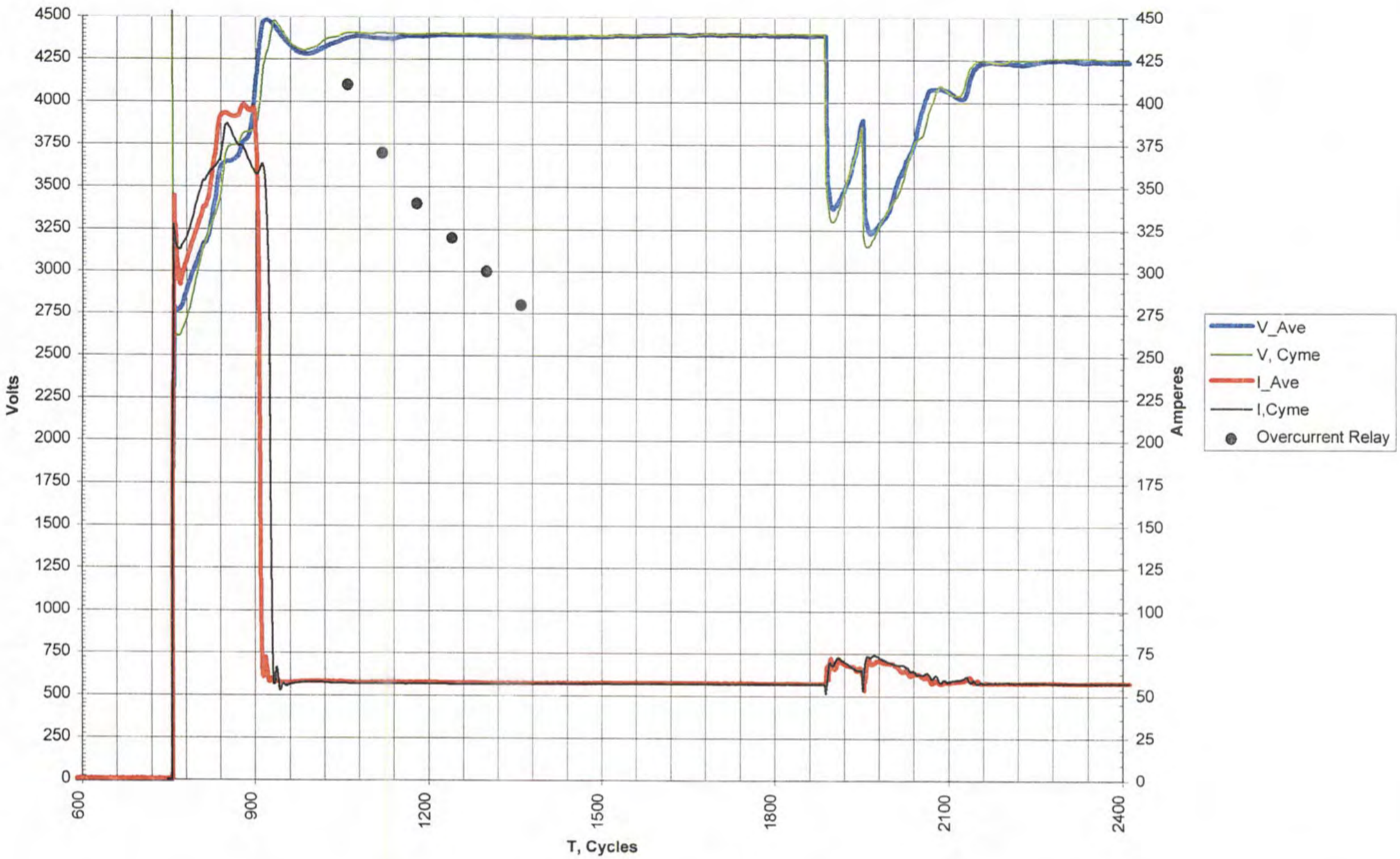


Figure 3-13: Test6, EFW 3B KVA and KW

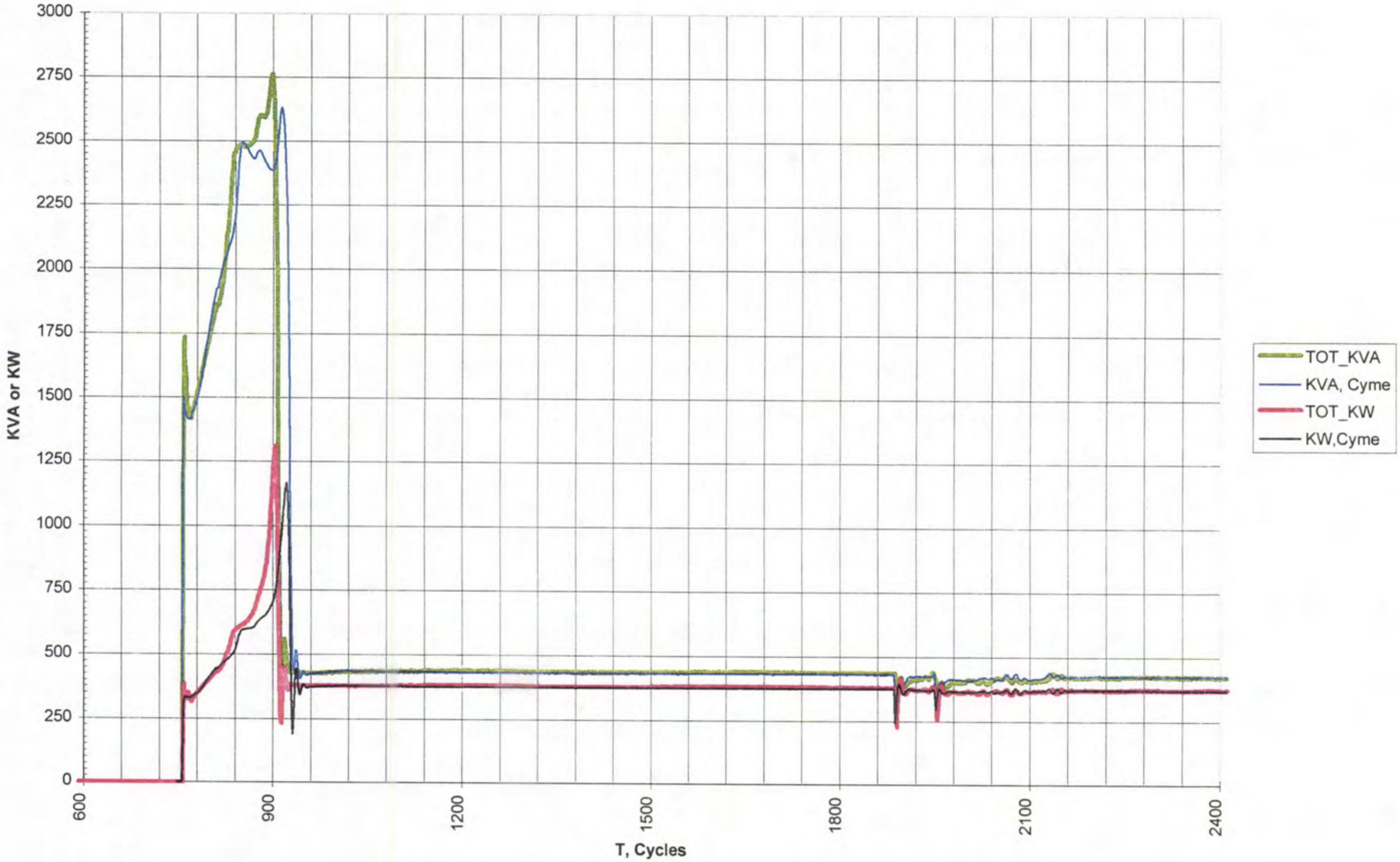


Figure 3-14: Test6, HPI 3B Voltage and Current

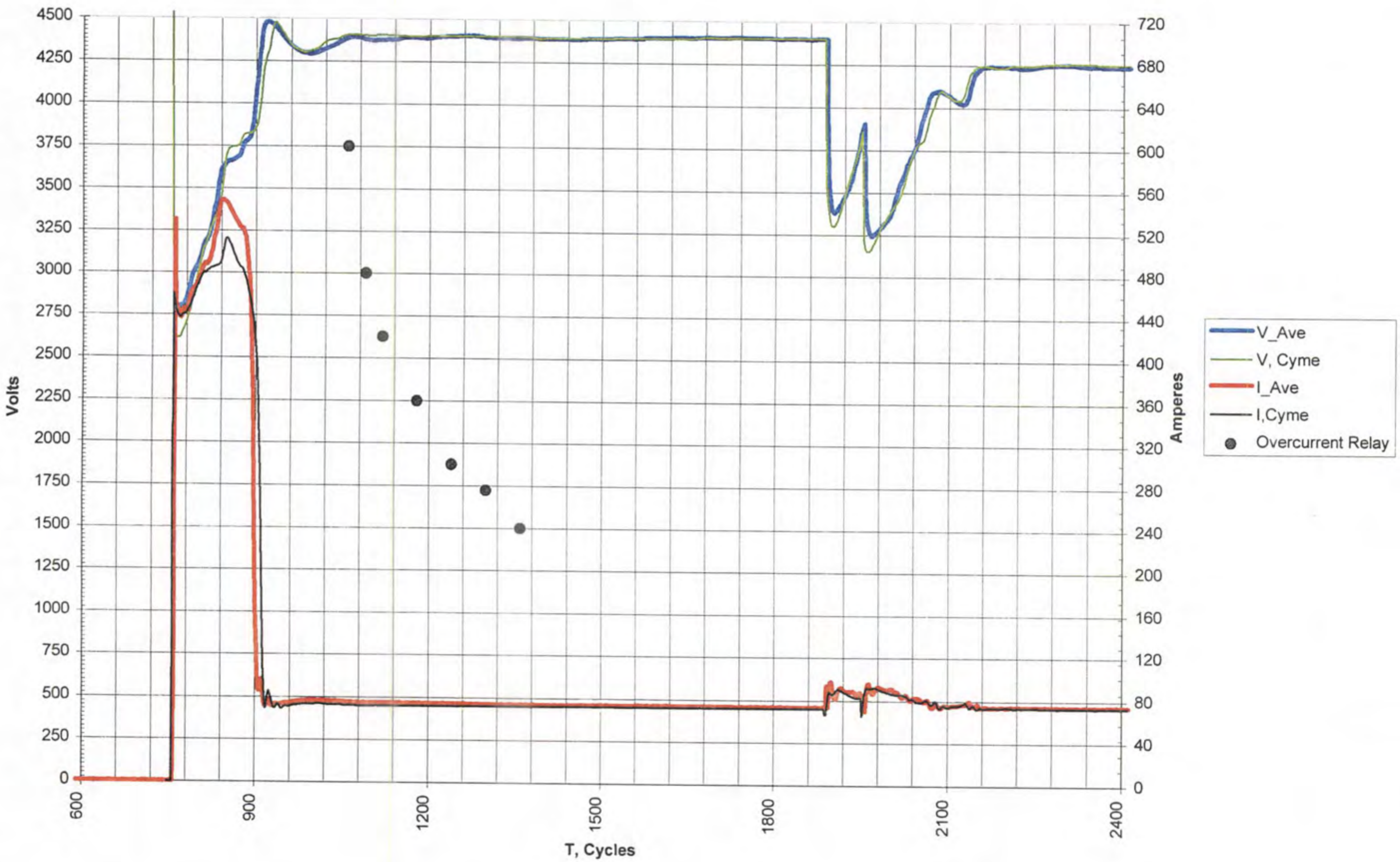


Figure 3-15: Test6, HPI 3B KVA and KW

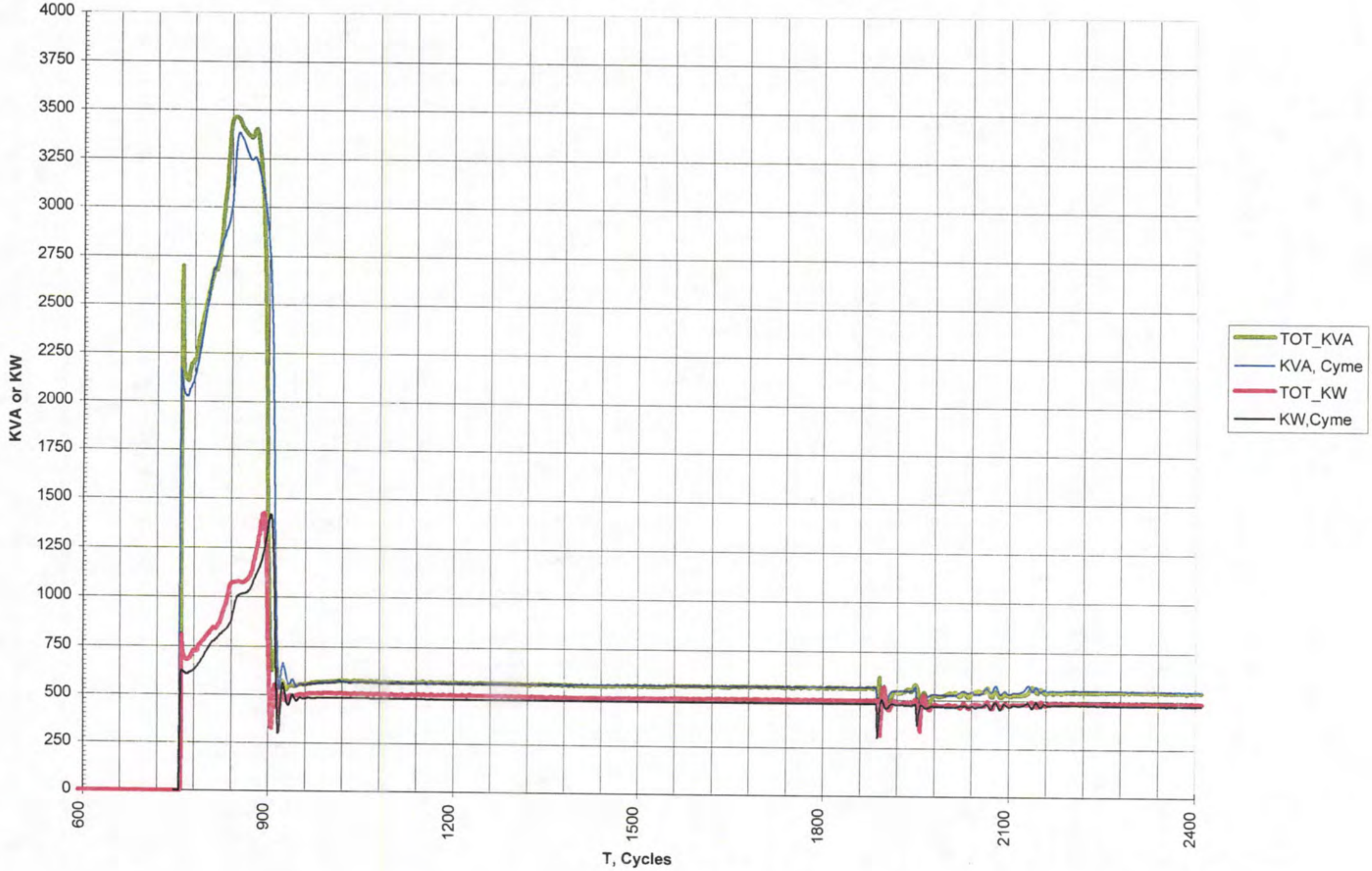


Figure 3-16: Test6, EFW 1A Voltage and Current

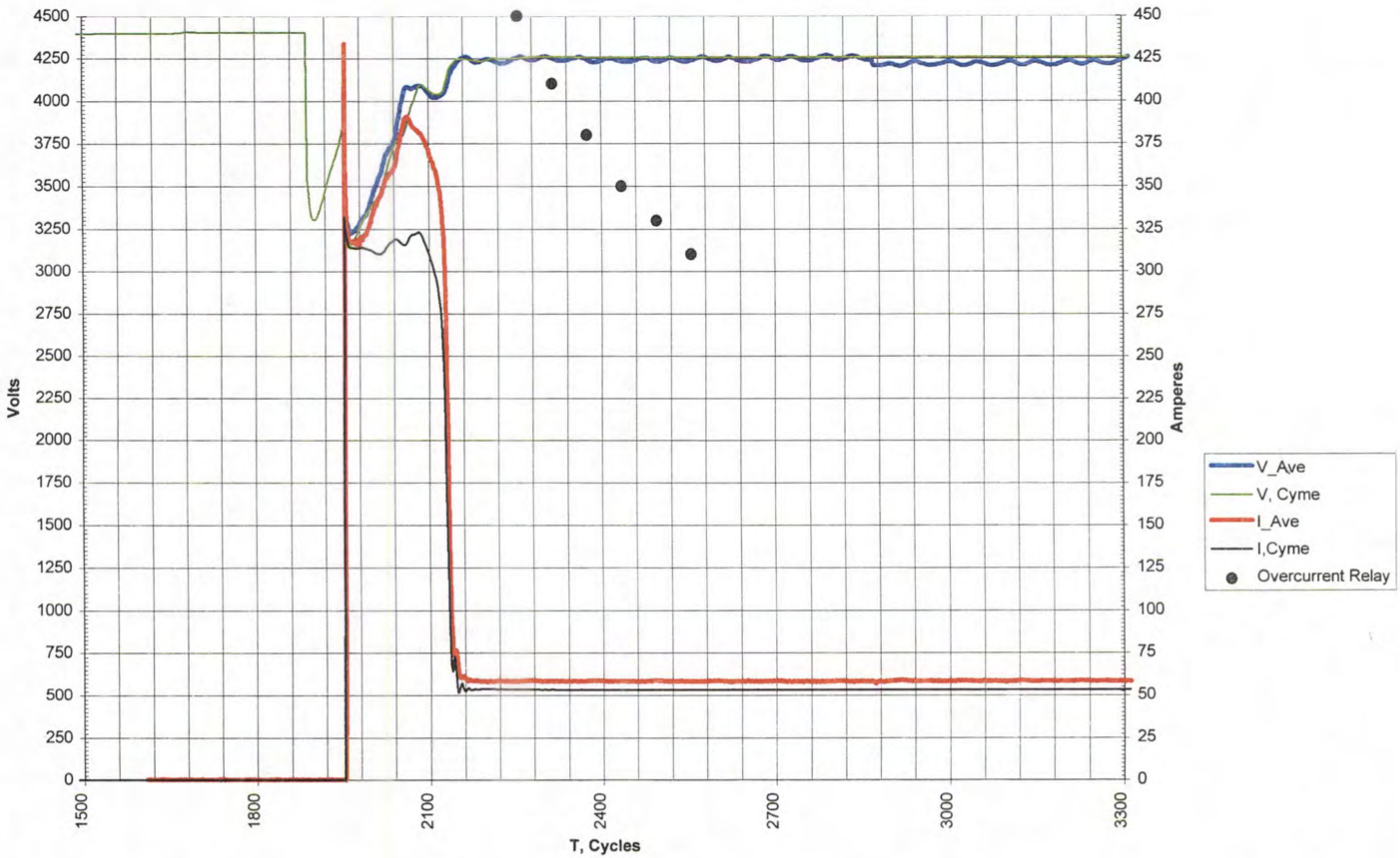


Figure 3-17: Test6, EFW 1A KVA and KW

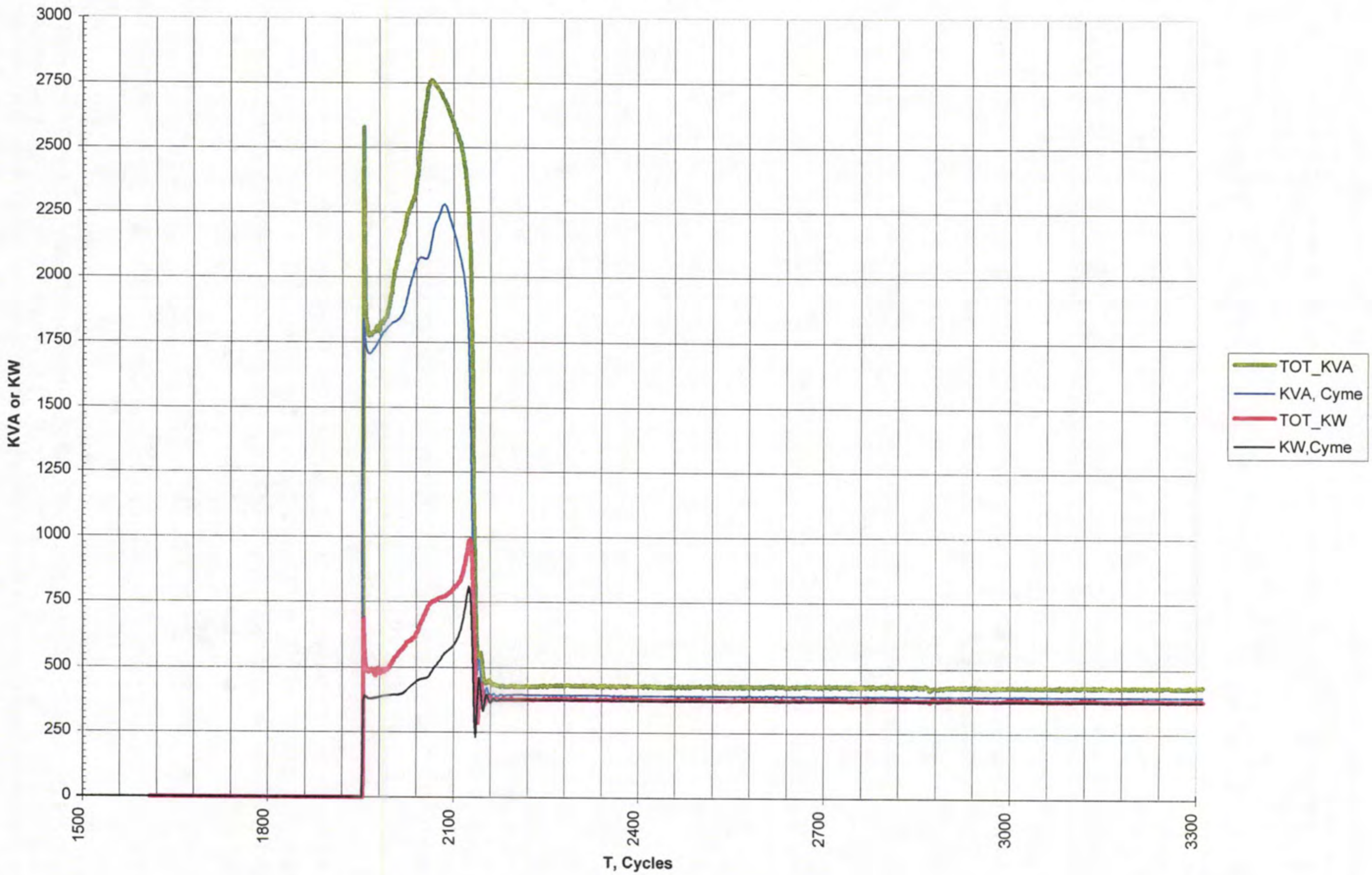


Figure 3-18: Test6, LPSW 3B Voltage and Current

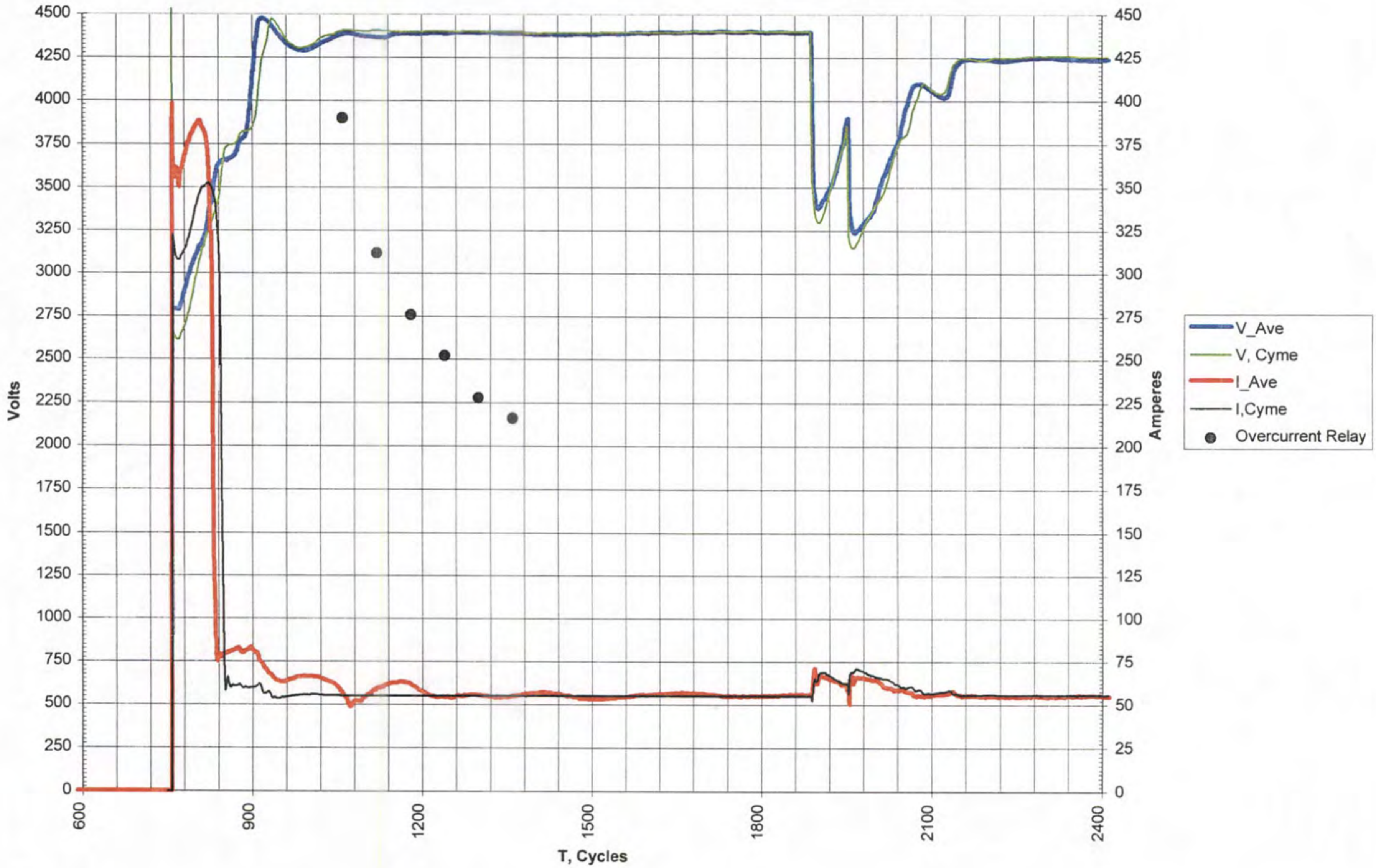


Figure 3-19: Test6, LPSW 3B KVA and KW

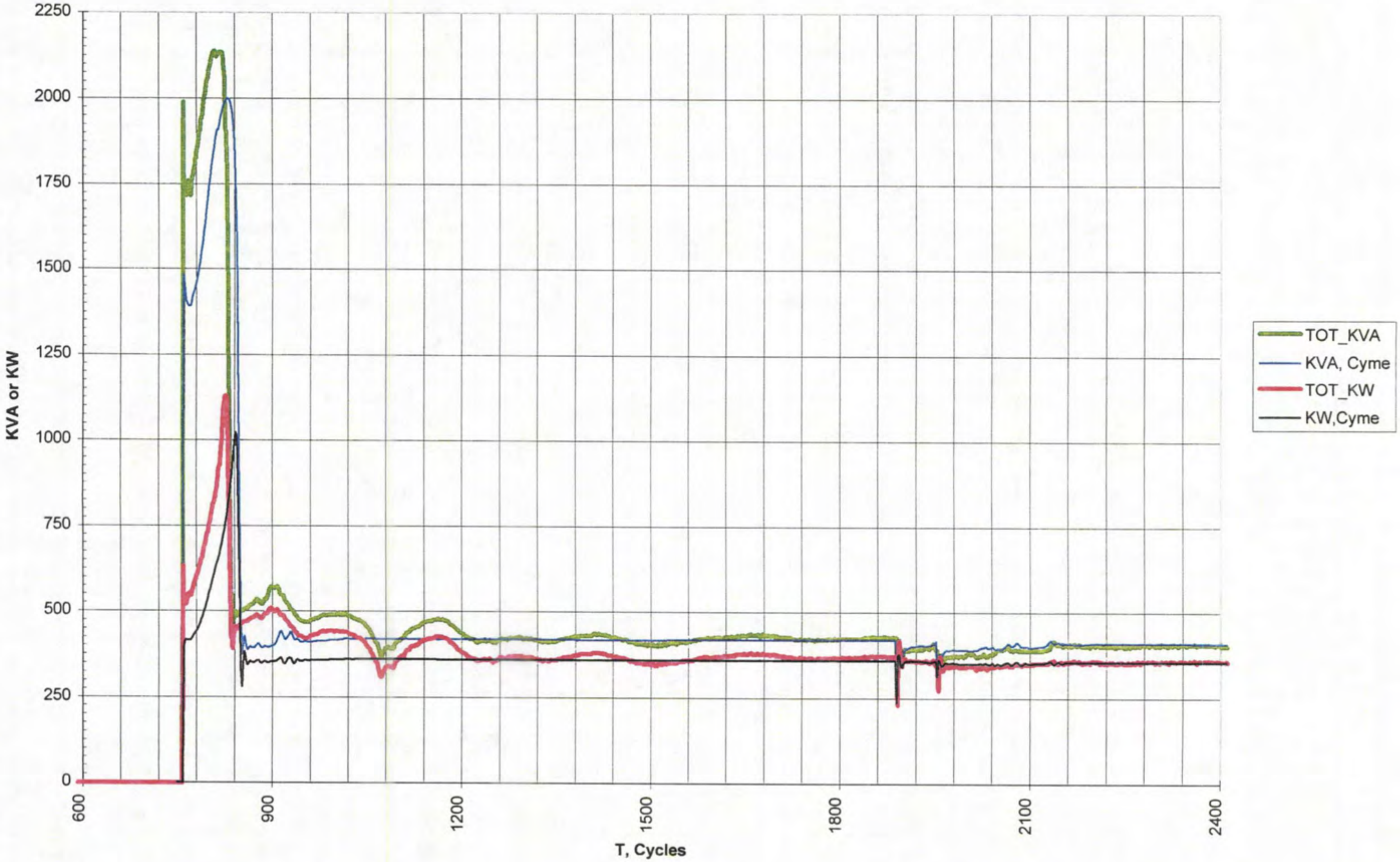


Figure 3-20: Test6, LPI 3B Voltage and Current

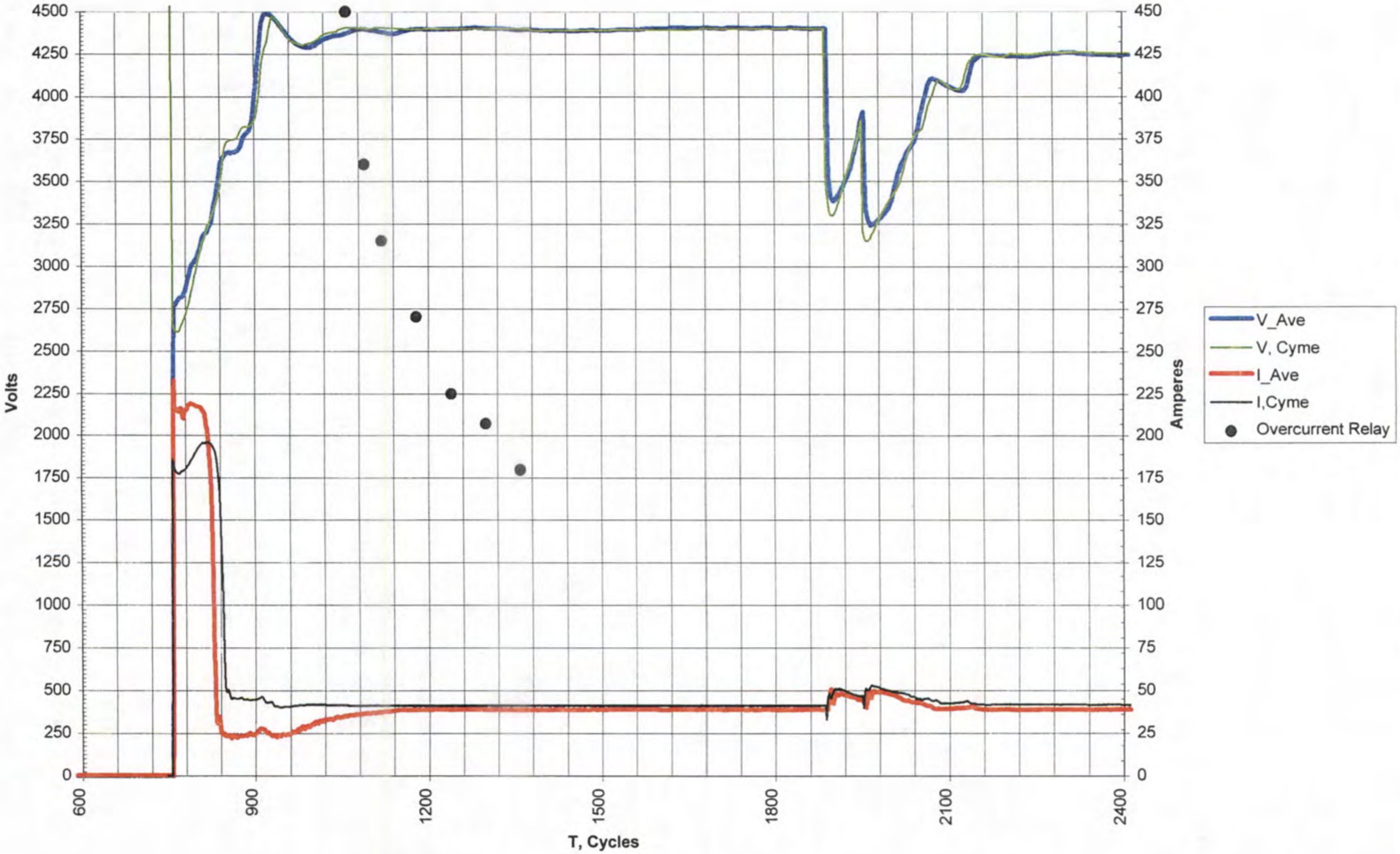


Figure 3-21: Test6, LPI 3B KVA and KW

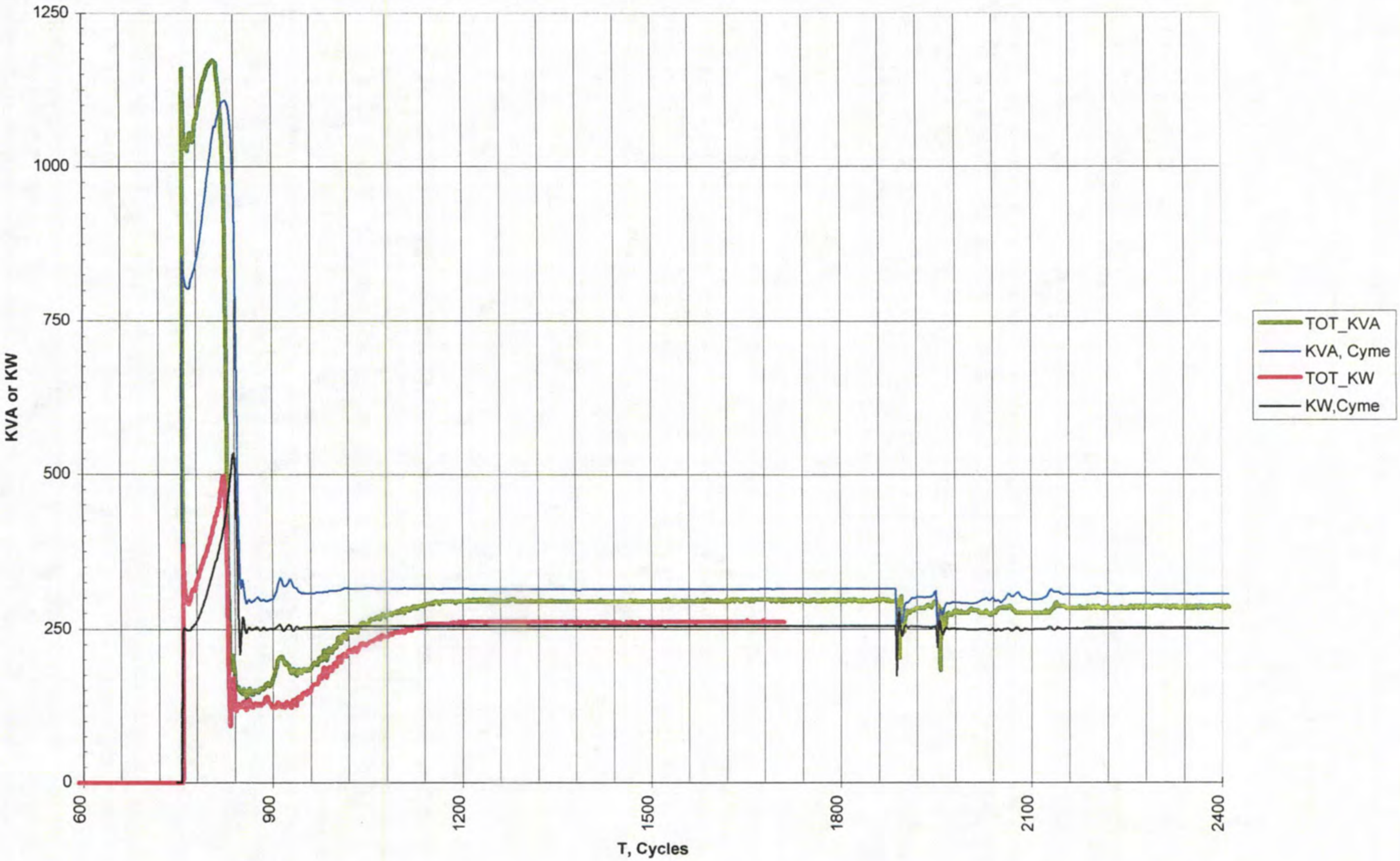


Figure 3-22: Test6, RBS 3B Voltage and Current

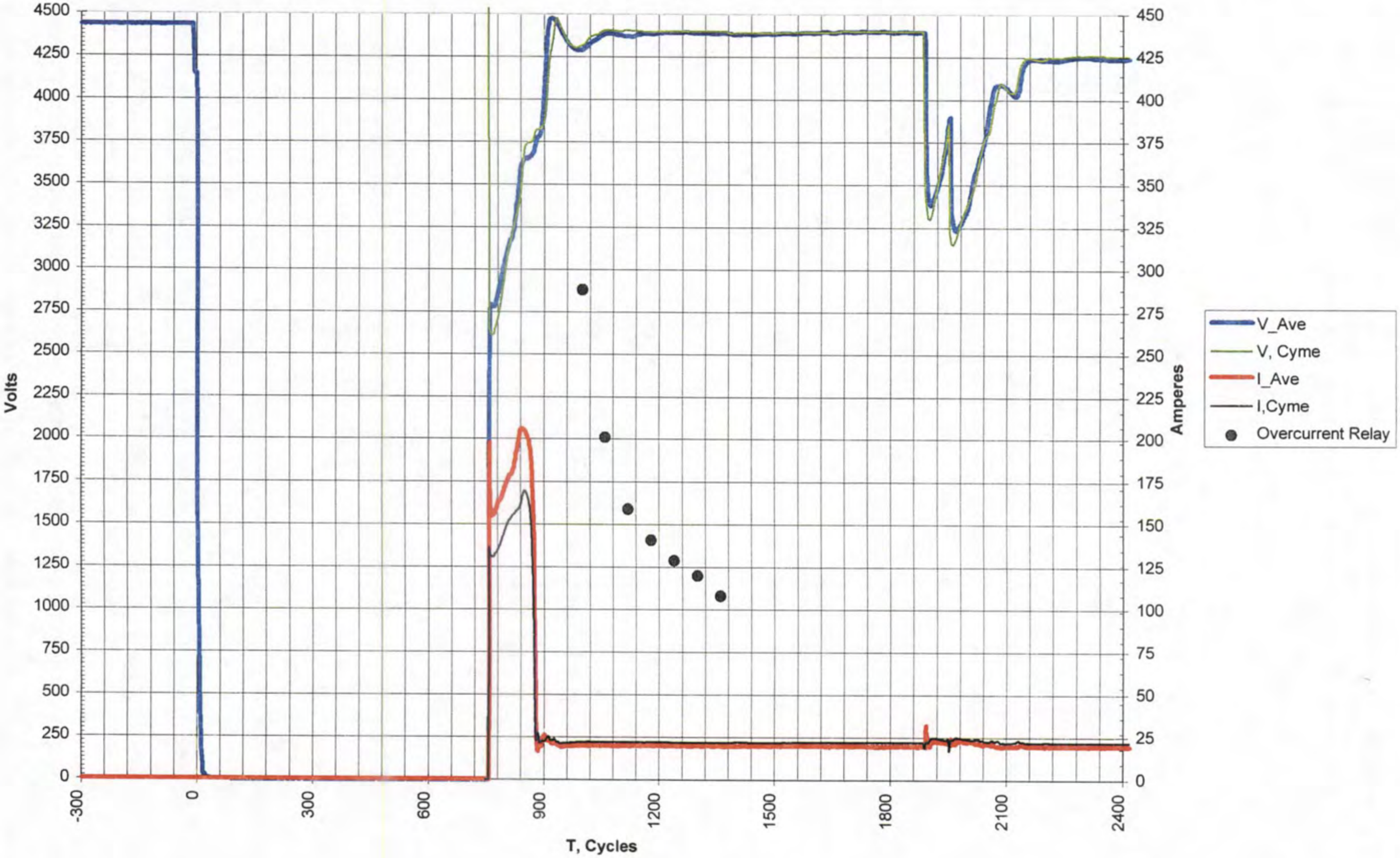


Figure 3-23: Test6, RBS 3B KVA and KW

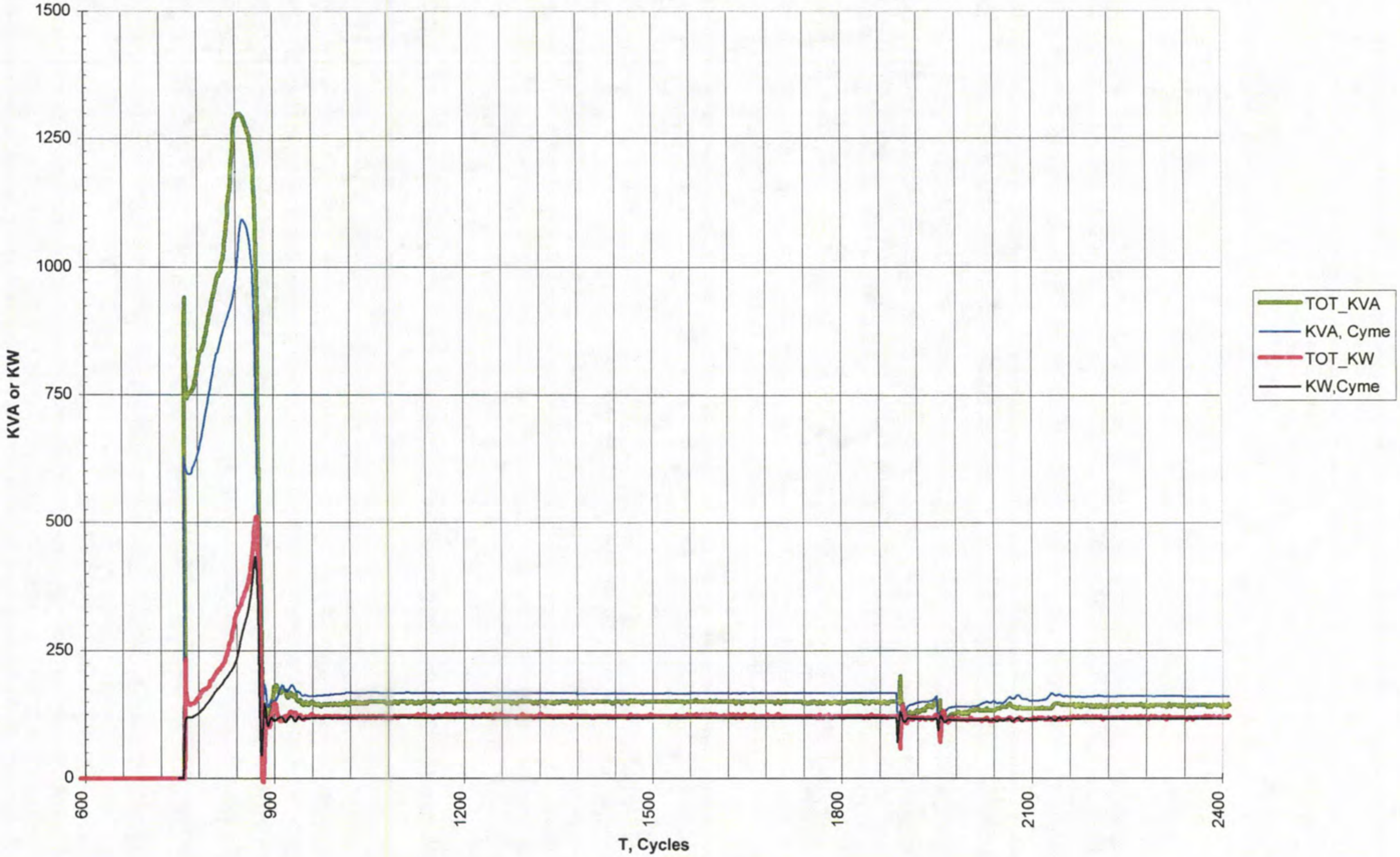


Figure 3-24: Test6, RBCF 3B Voltage and Current

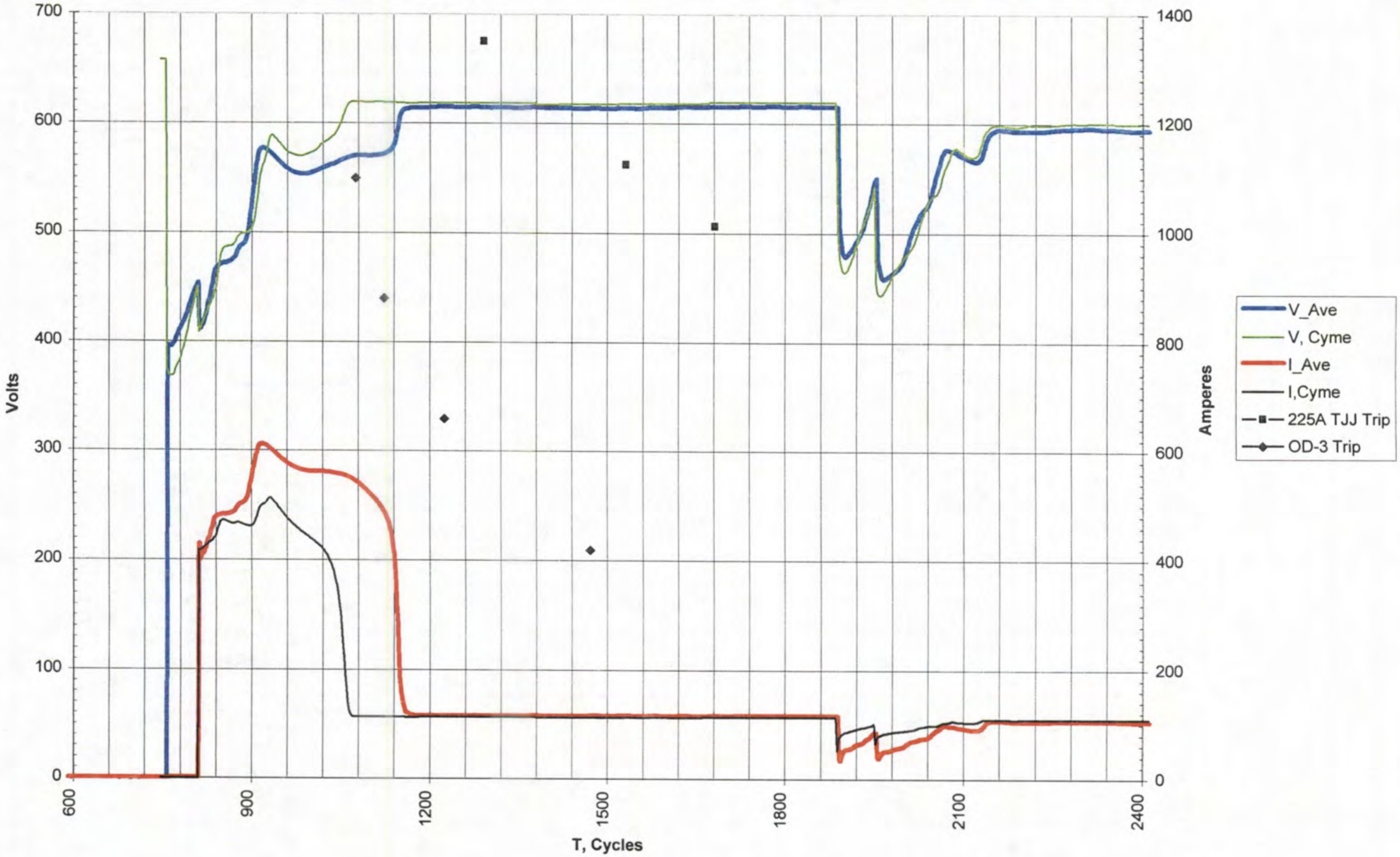


Figure 3-25: Test6, RBCF 3B KVA and KW

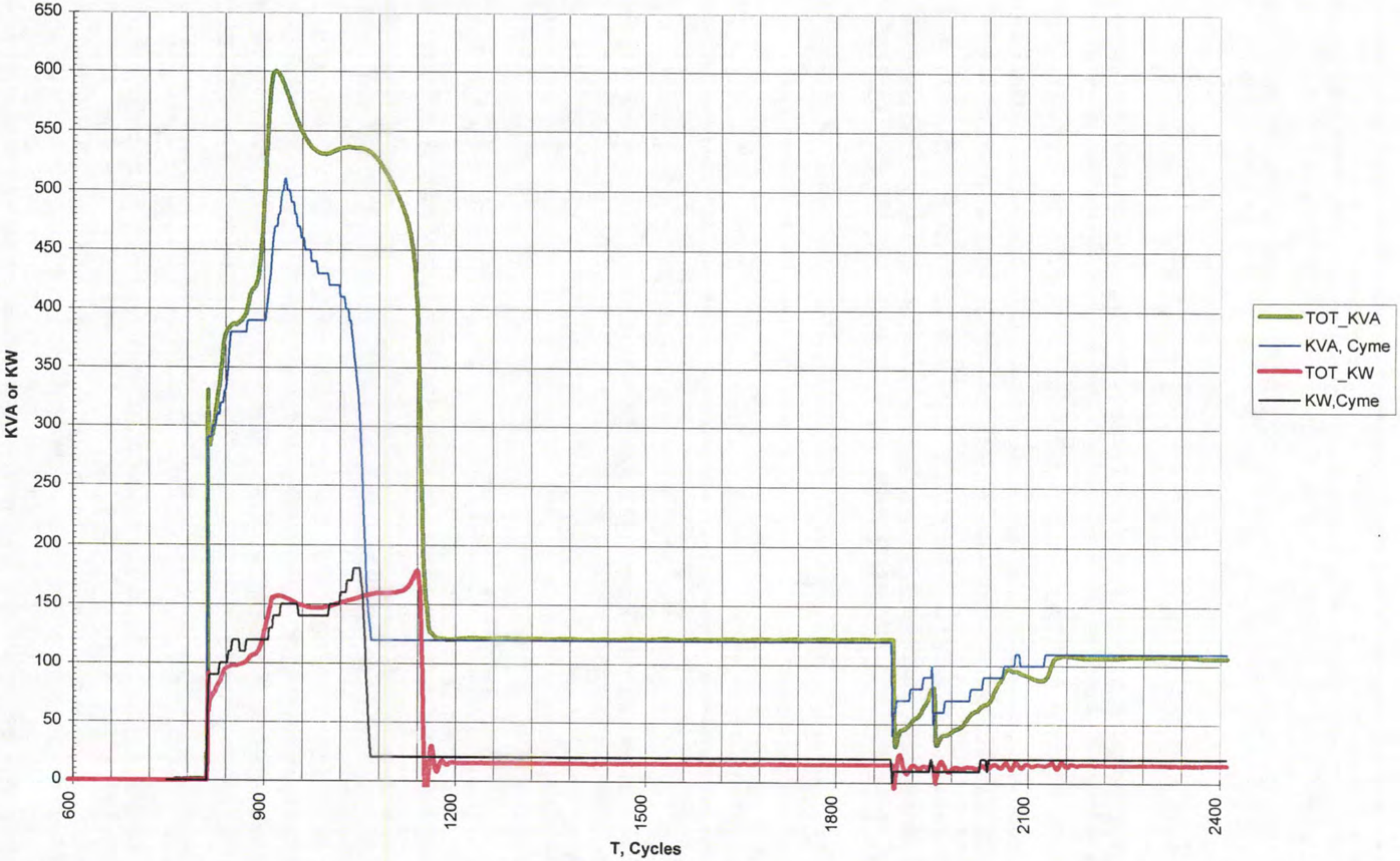


Figure 3-26: Test6, 1X5 Voltage and Current

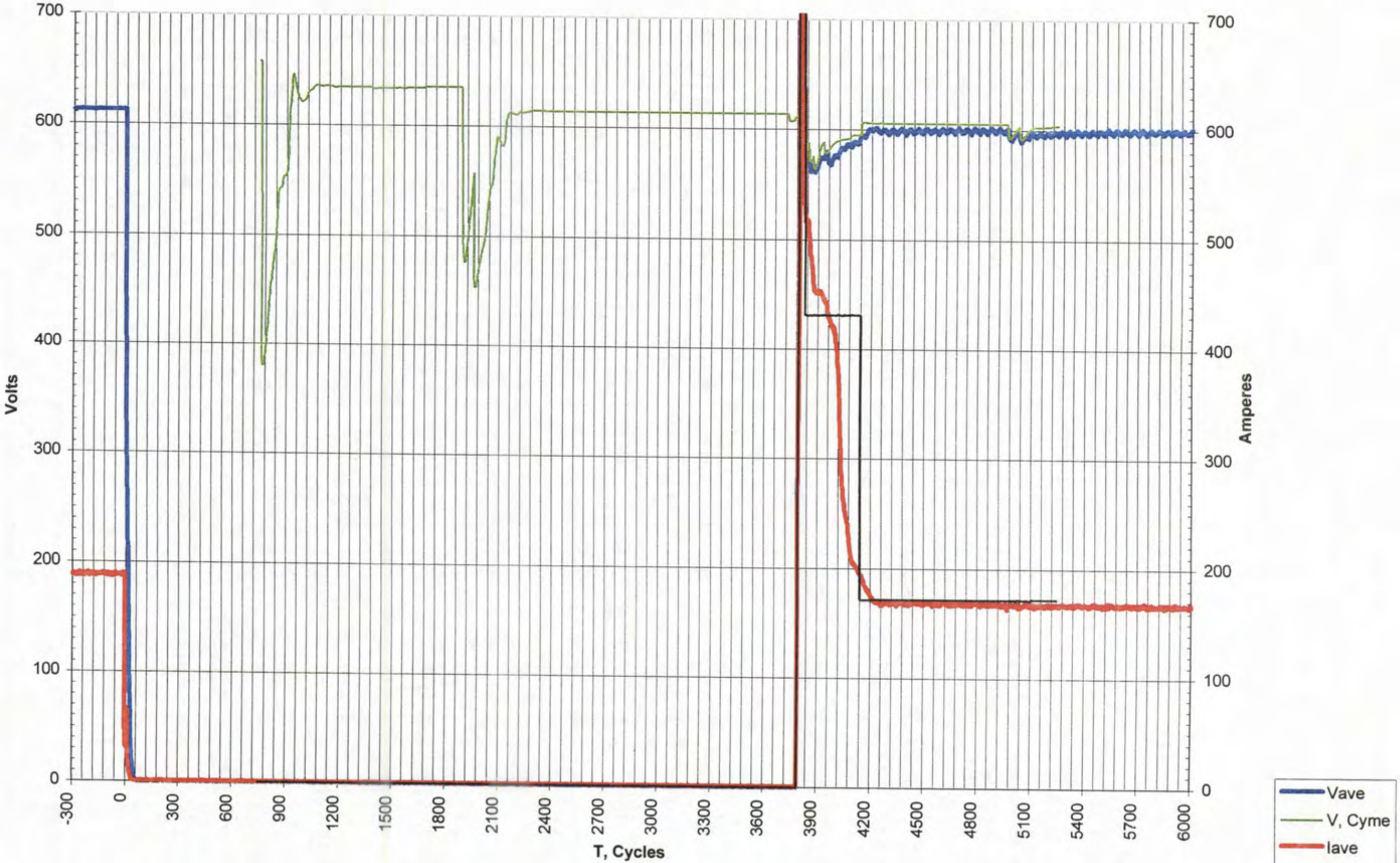


Figure 3-27: Test6, 1X5 KVA and KW

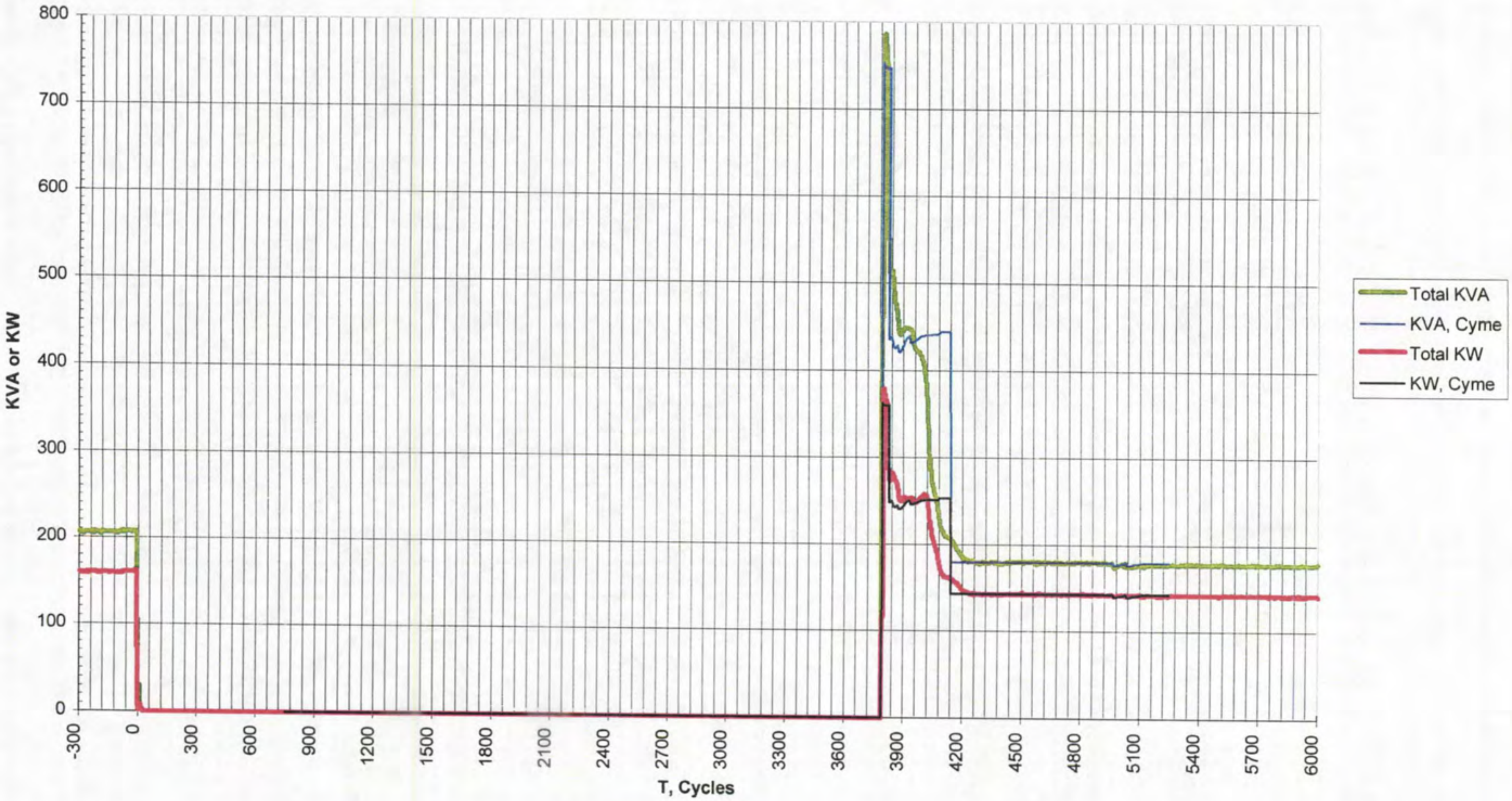


Figure 3-28: Test6, 1X6 Voltage and Current

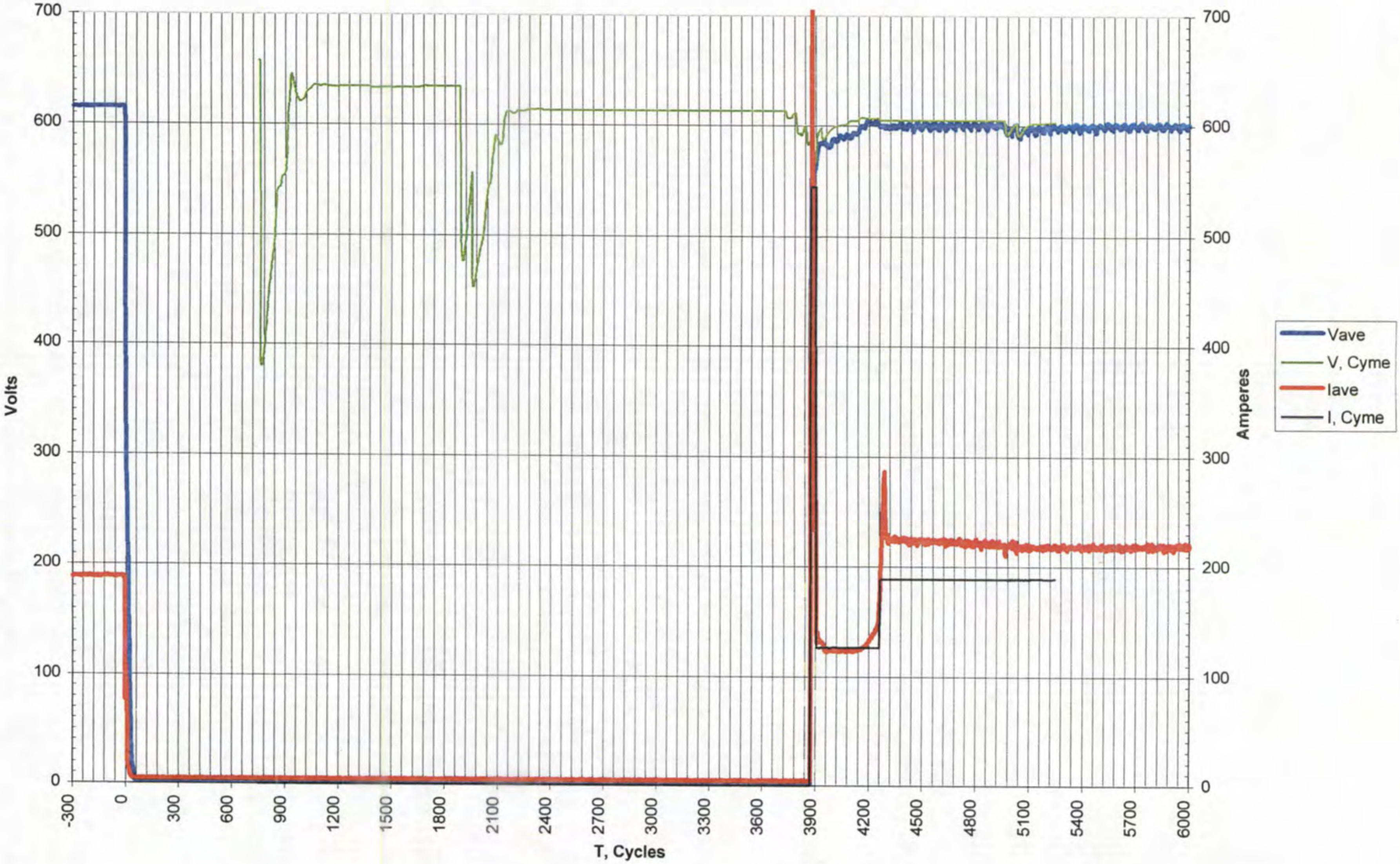


Figure 3-29: Test6, 1X6 KVA and KW

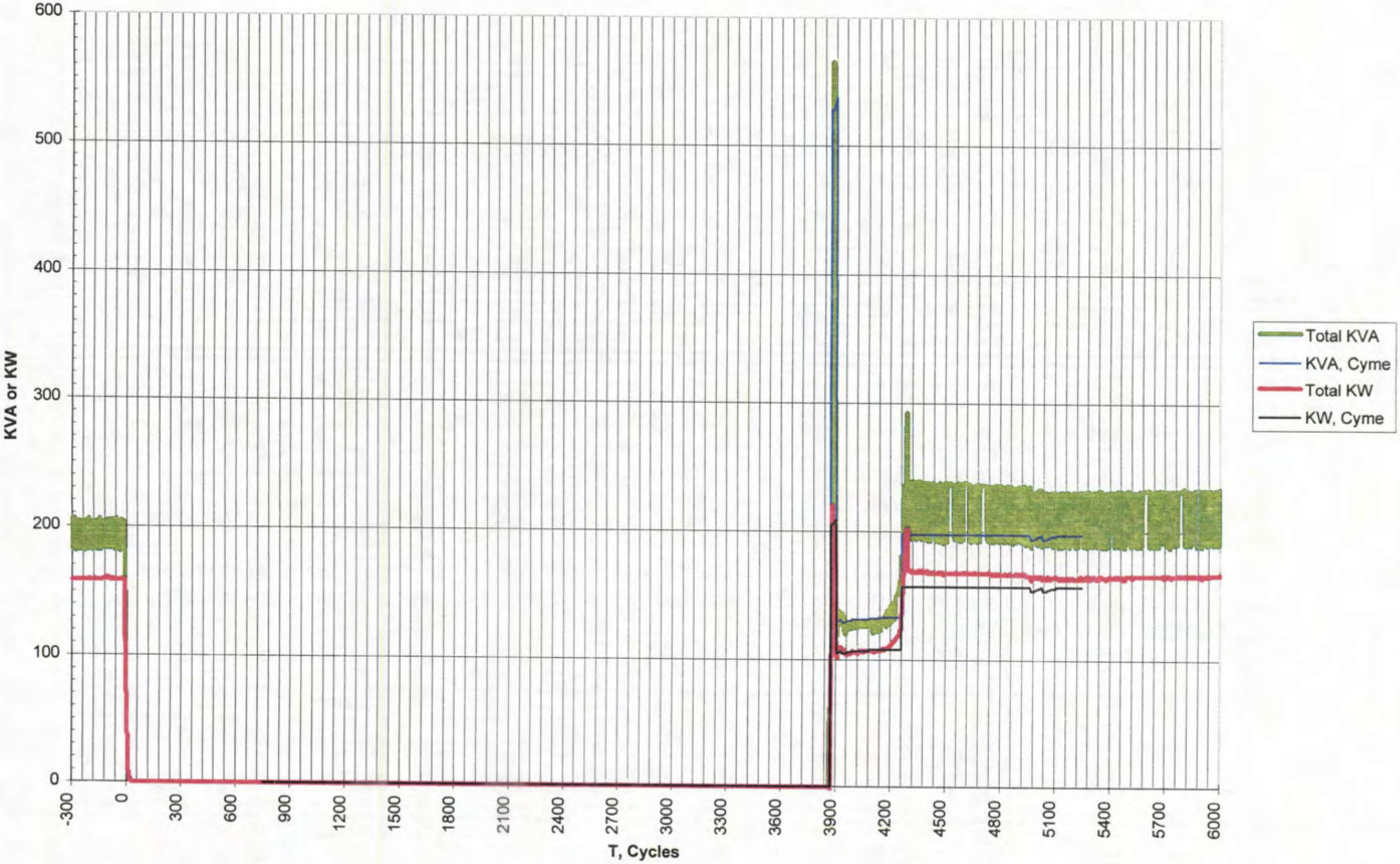


Figure 3-30: Test6, 3X6 Voltage and Current

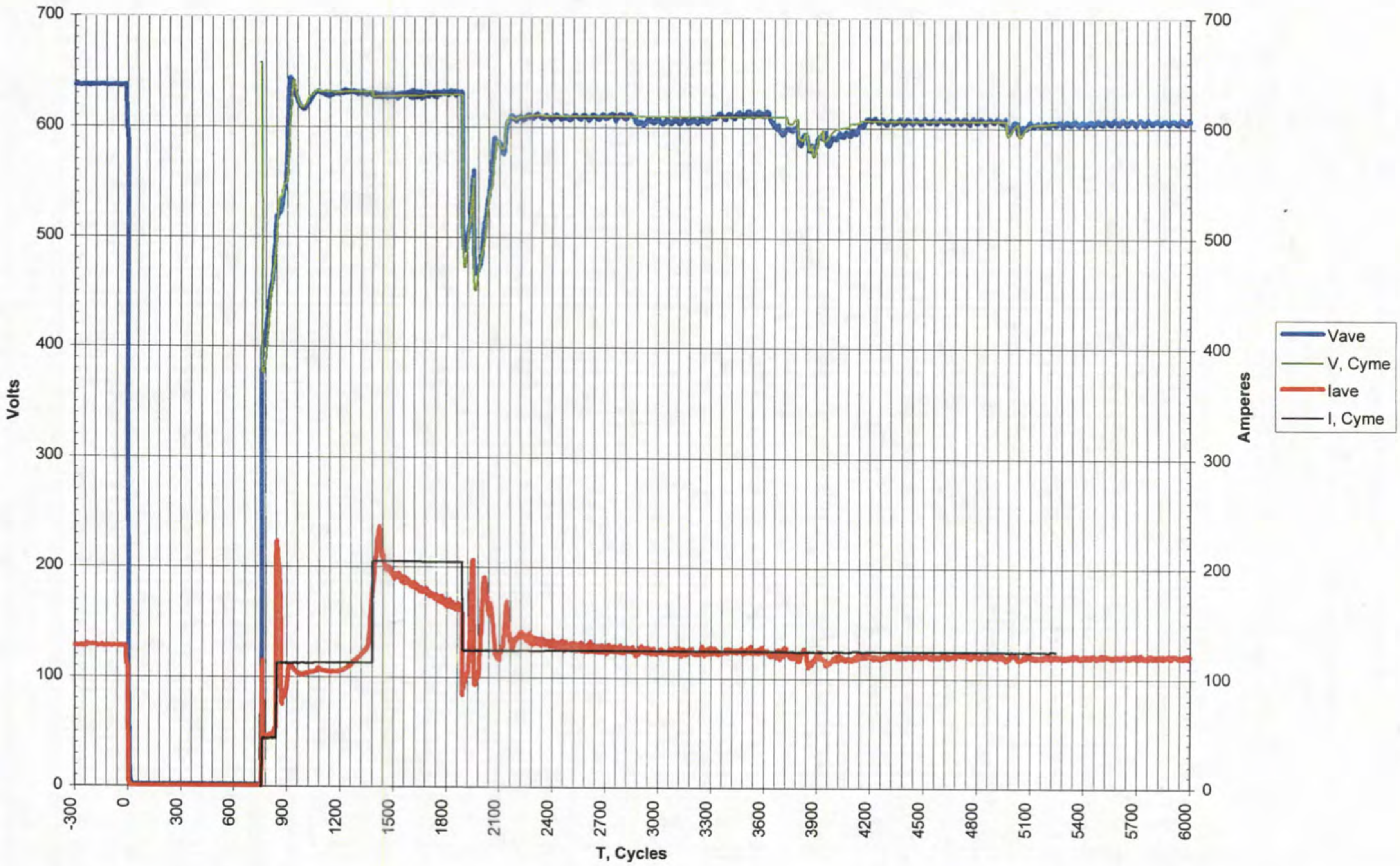


Figure 3-31: Test6, 3X6 KVA and KW

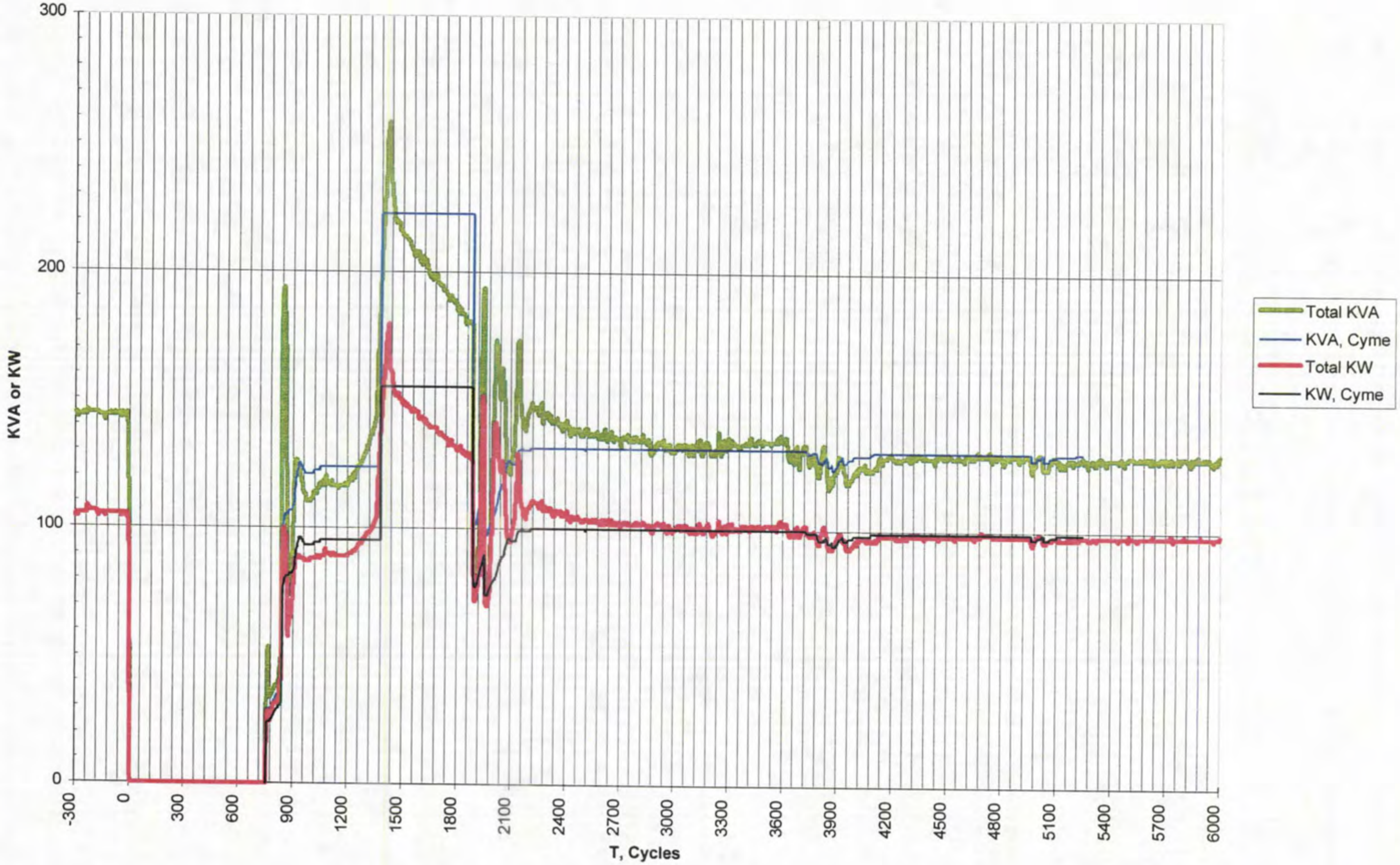


Figure 3-32: Test6, 3X8 Voltage and Current

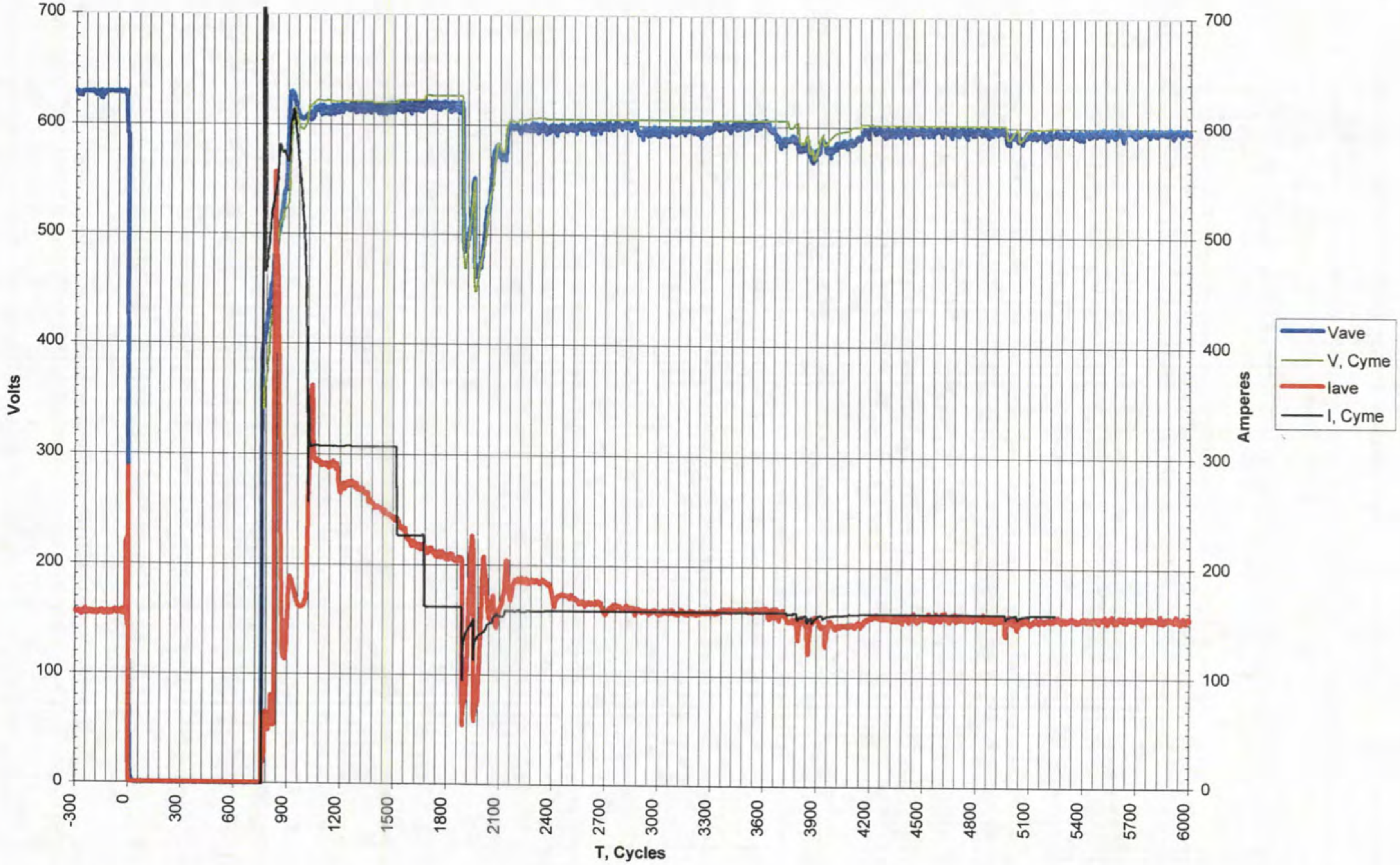


Figure 3-33: Test6, 3X8 KVA and KW

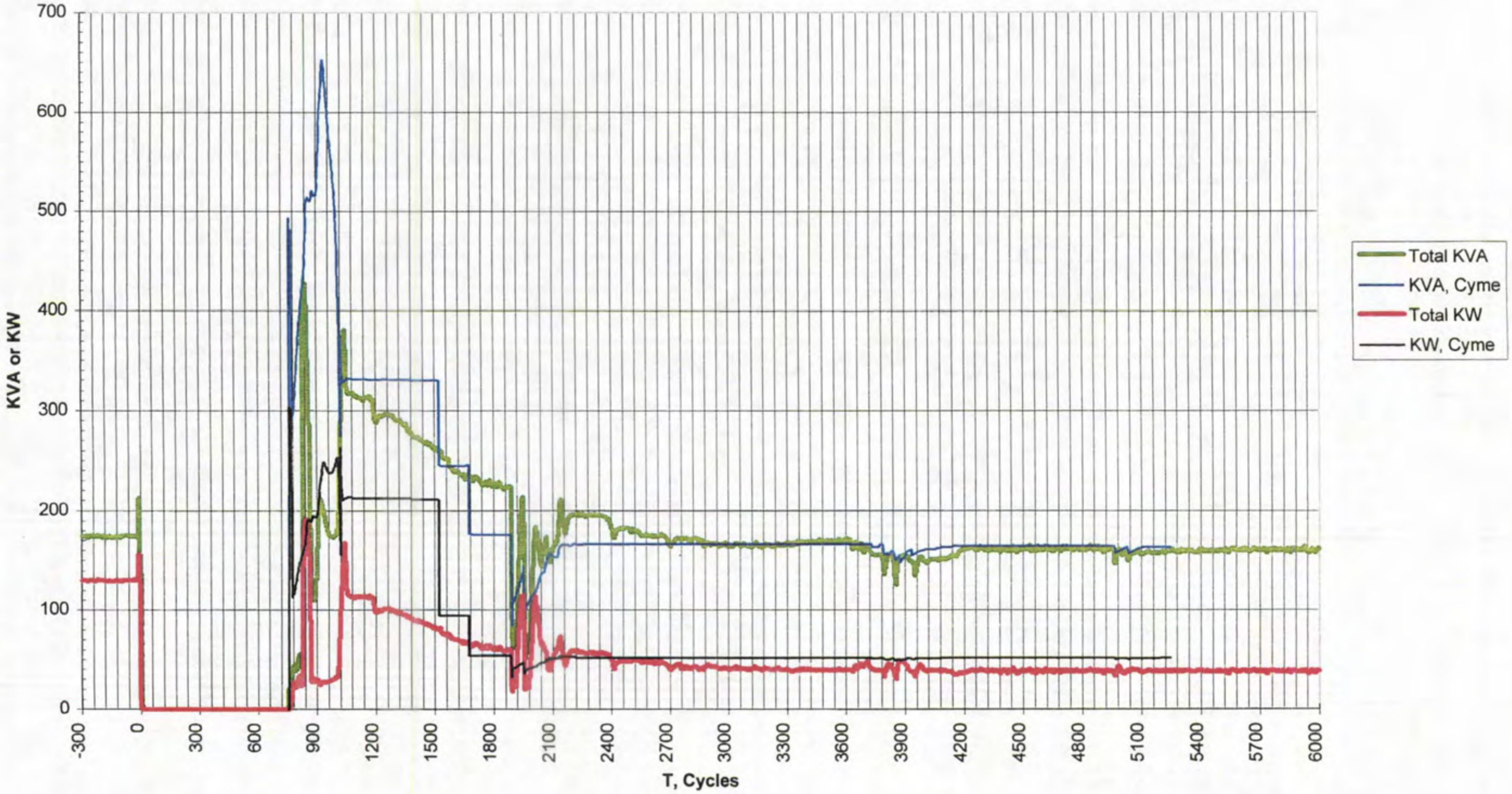


Figure 3-34: Test6, 3X9 Voltage and Current

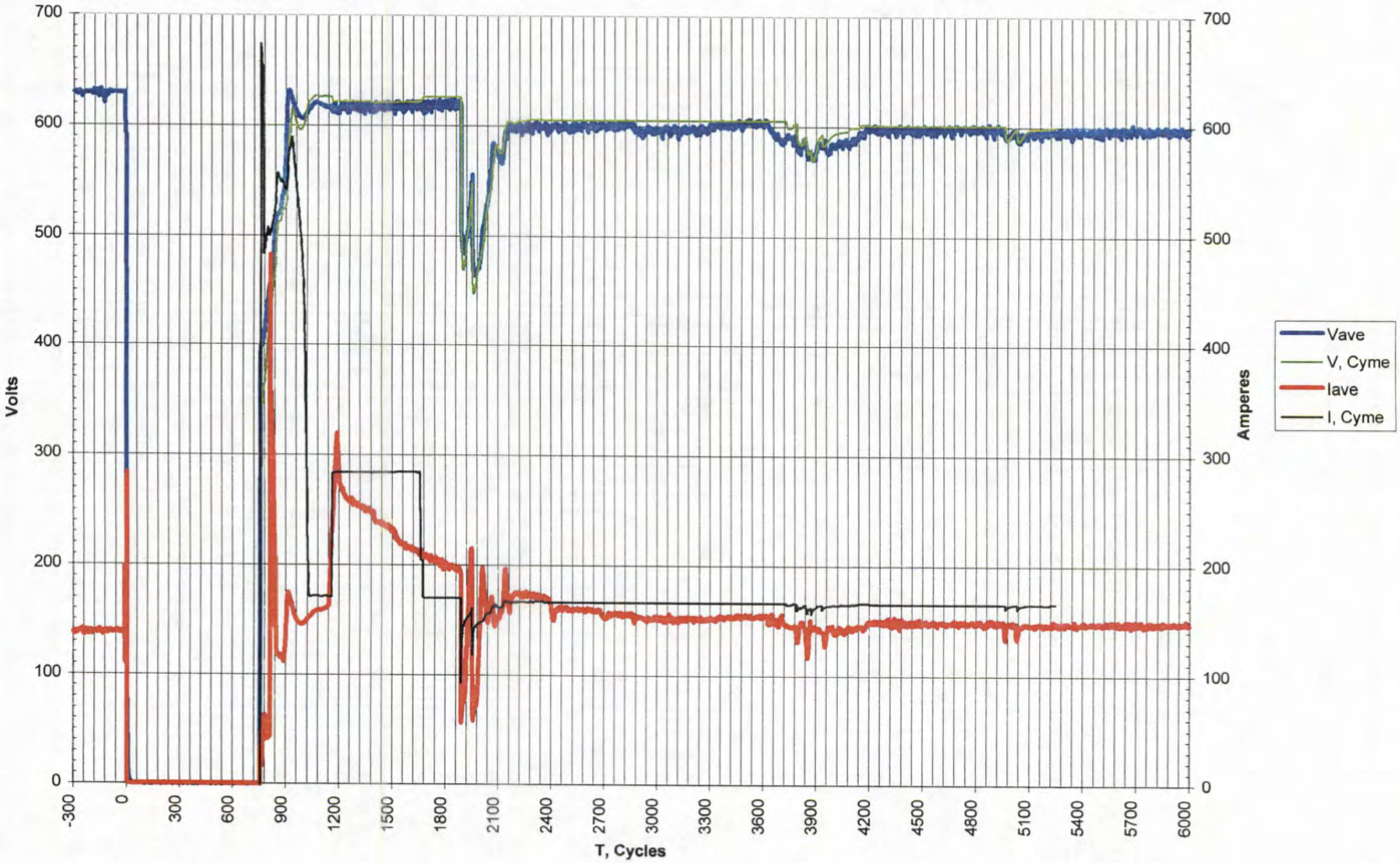


Figure 3-35: Test6, 3X9 KVA and KW

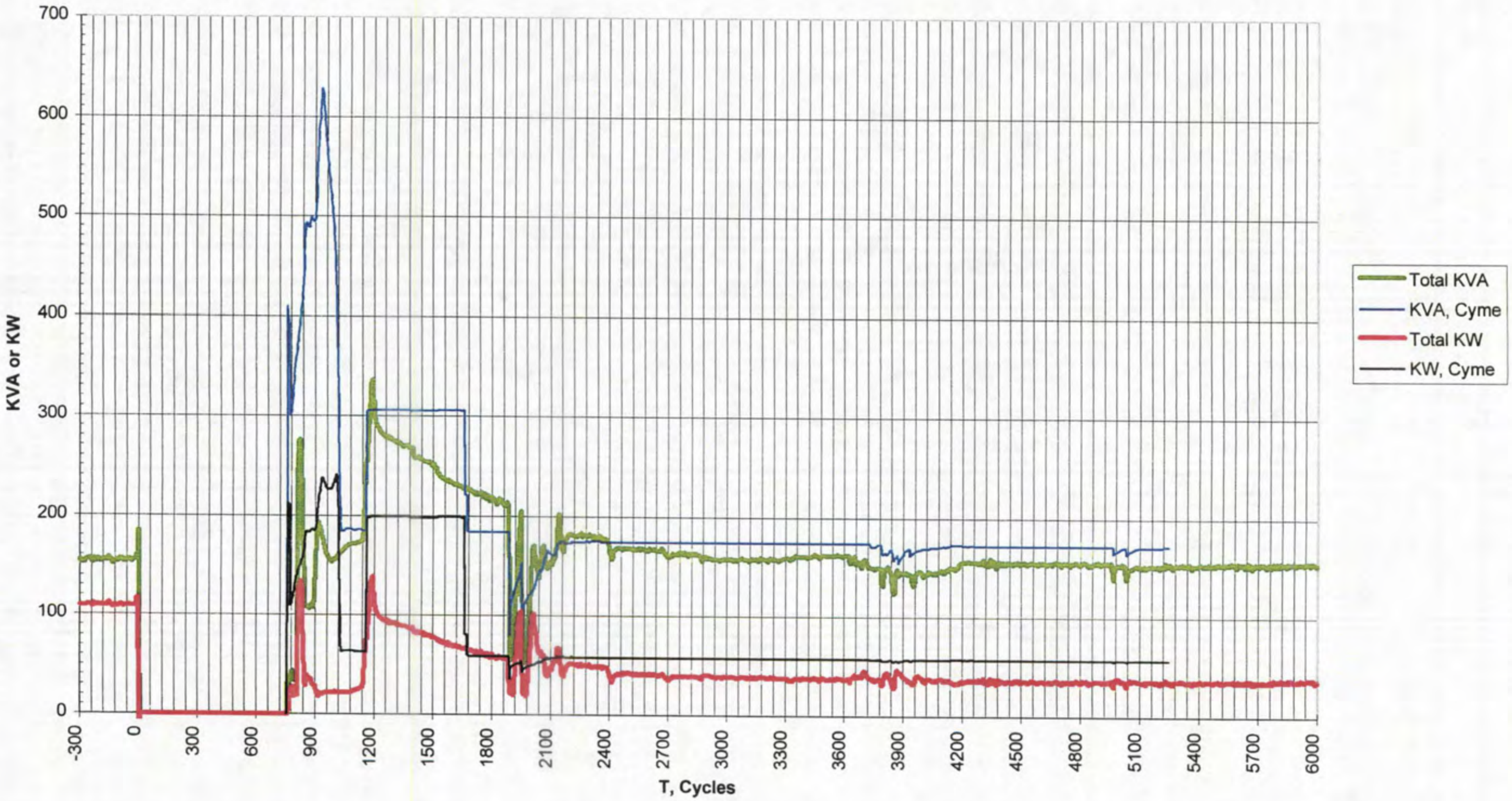


Figure 3-36: Test6, 600V 3XS1 Voltage and Current

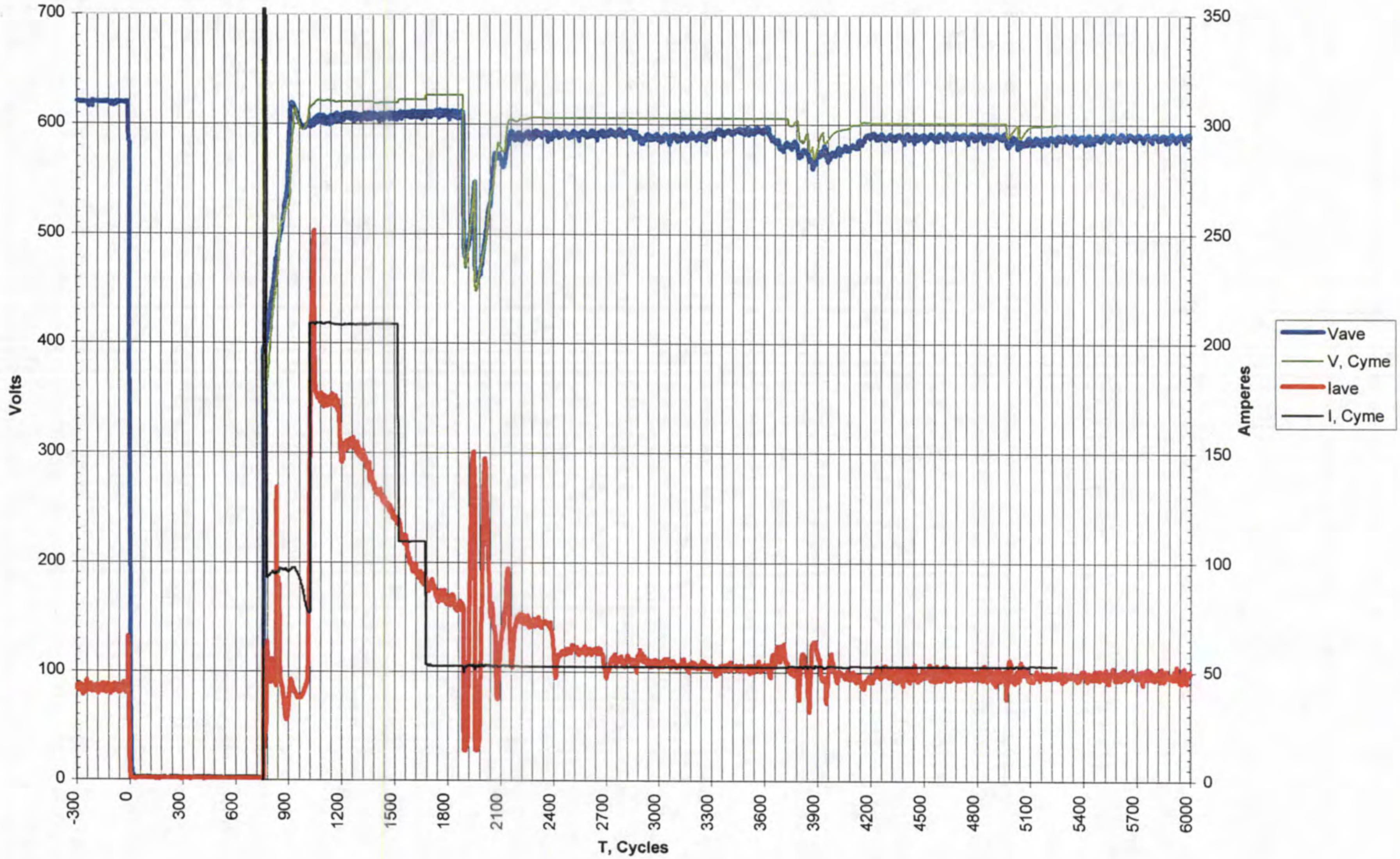


Figure 3-37: Test6, 600V 3XS1 KVA and KW

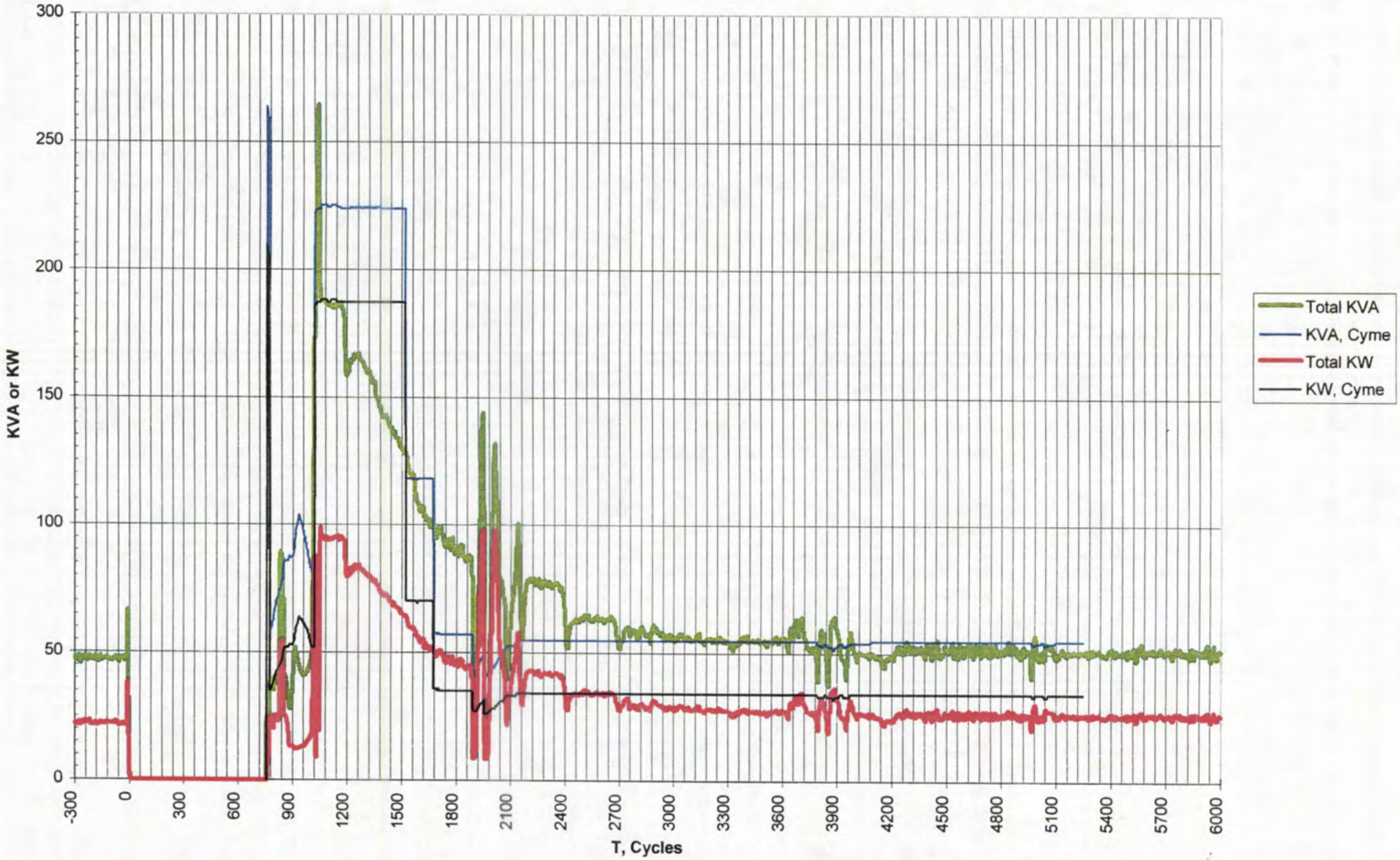


Figure 3-38: Test6, 600V 3XS2 Voltage and Current

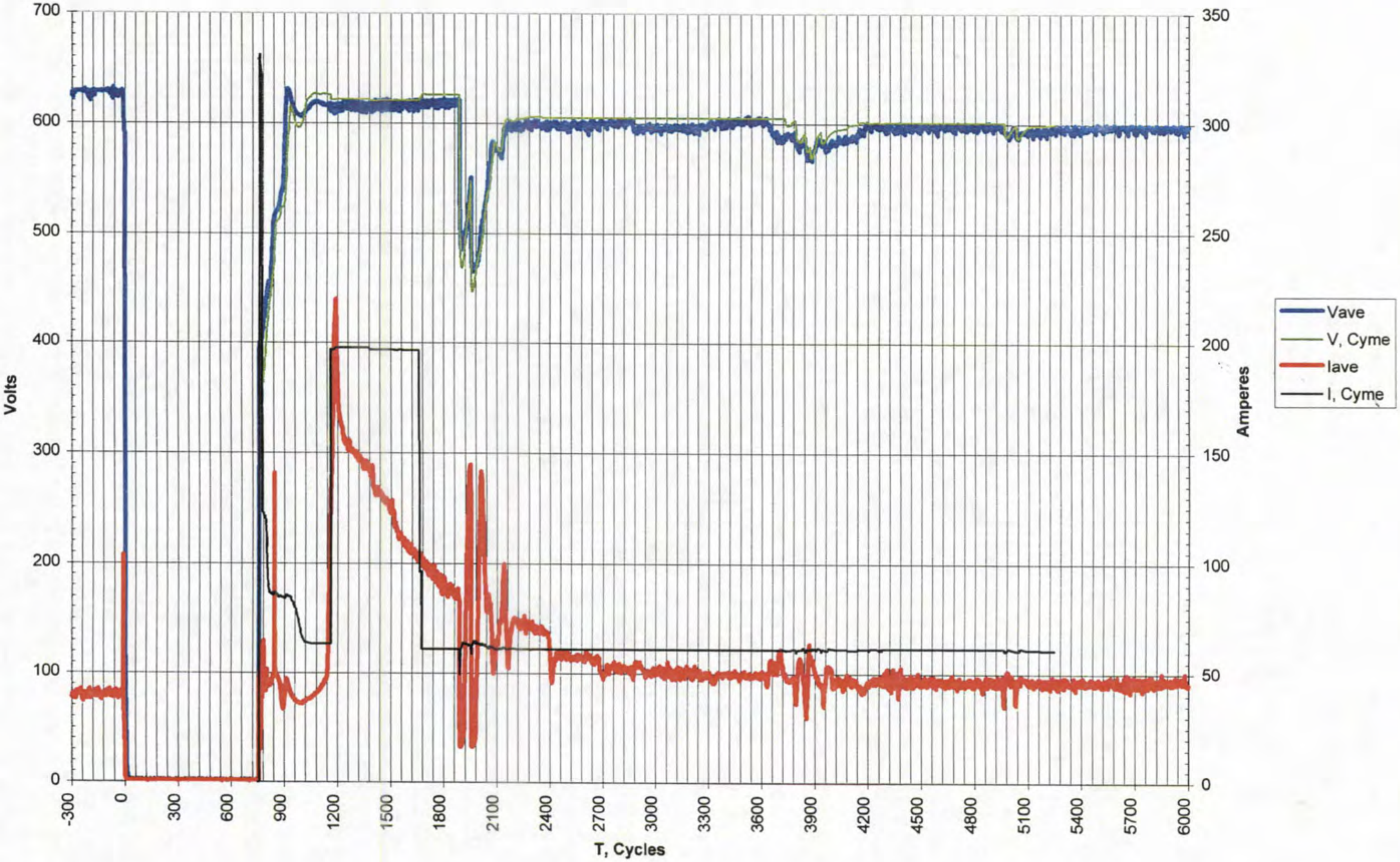


Figure 3-39: Test6, 600V 3XS2 KVA and KW

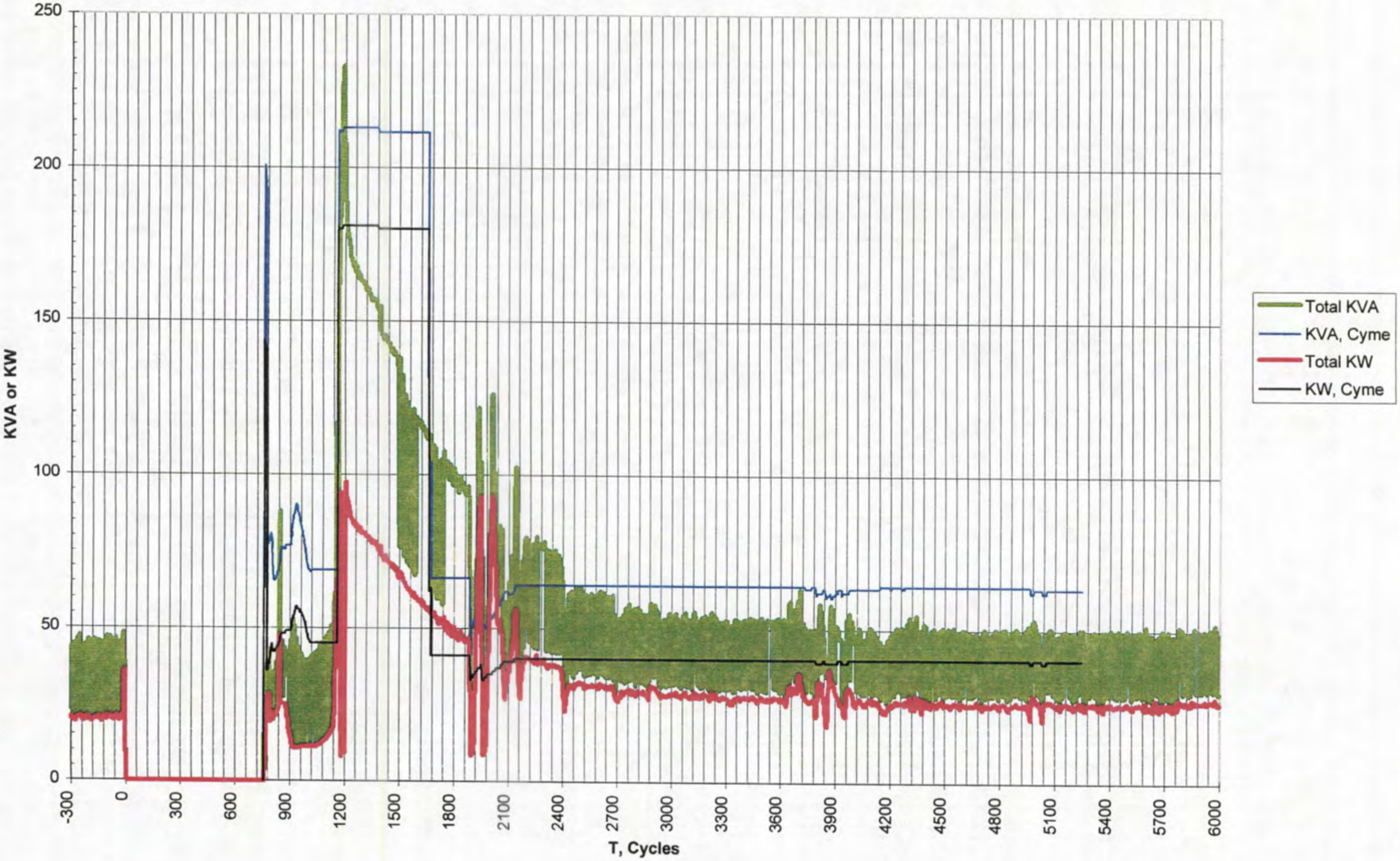


Figure 3-40: Test6, 600V 3XS3 Voltage and Current

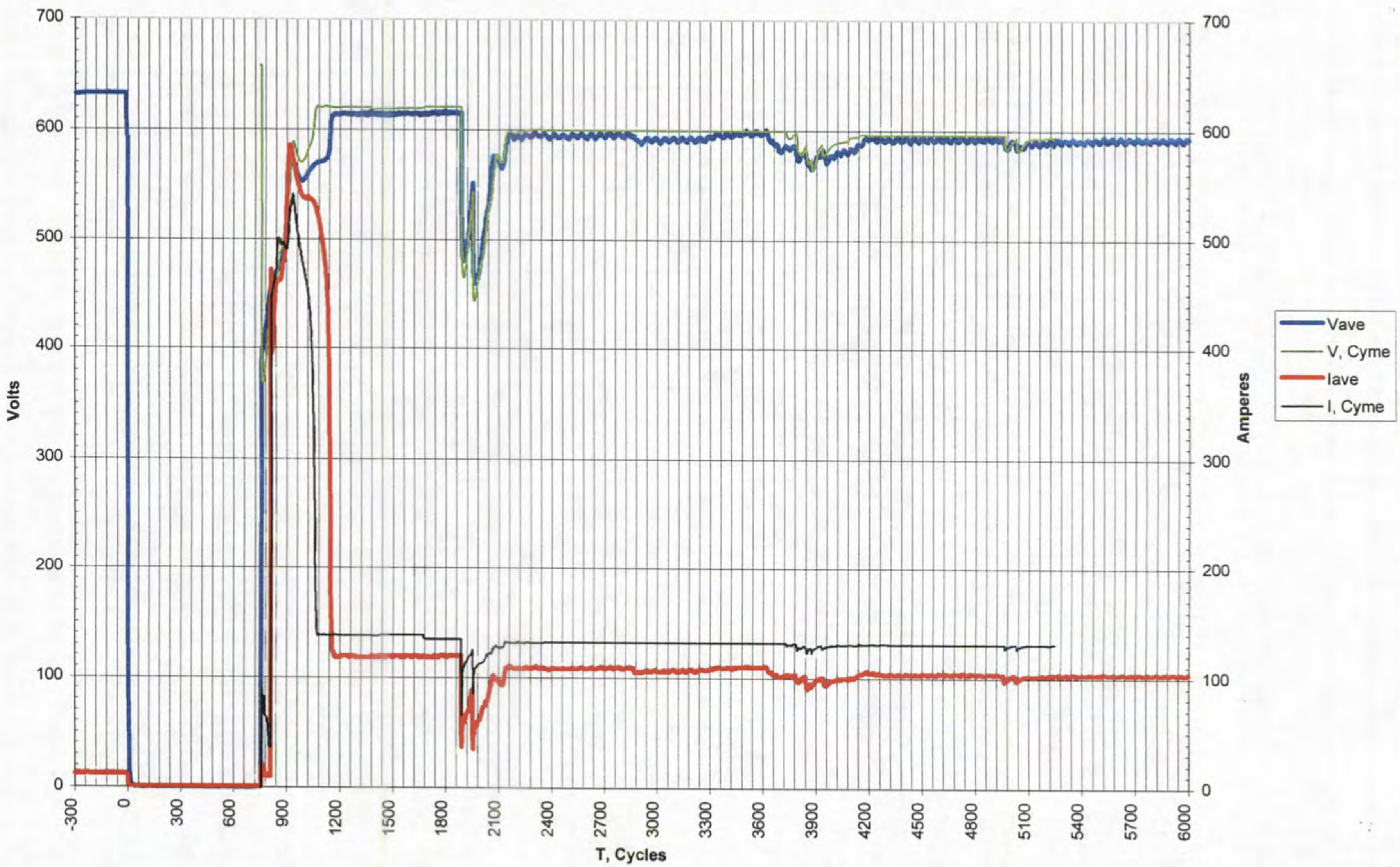


Figure 3-41: Test6, 600V 3XS3 KVA and KW

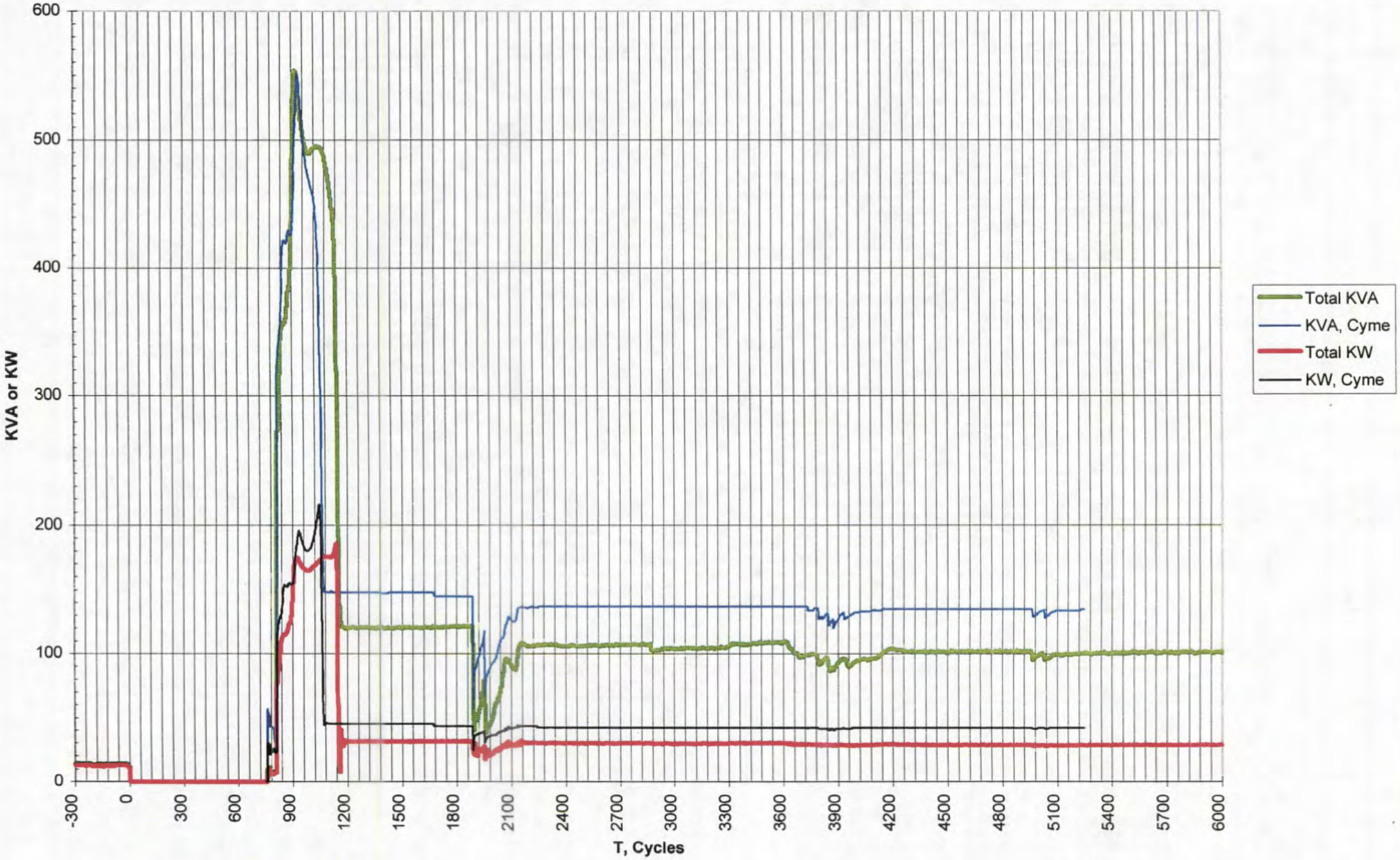


Figure 3-42: Test6, 208V 3XS1 Voltage and Current

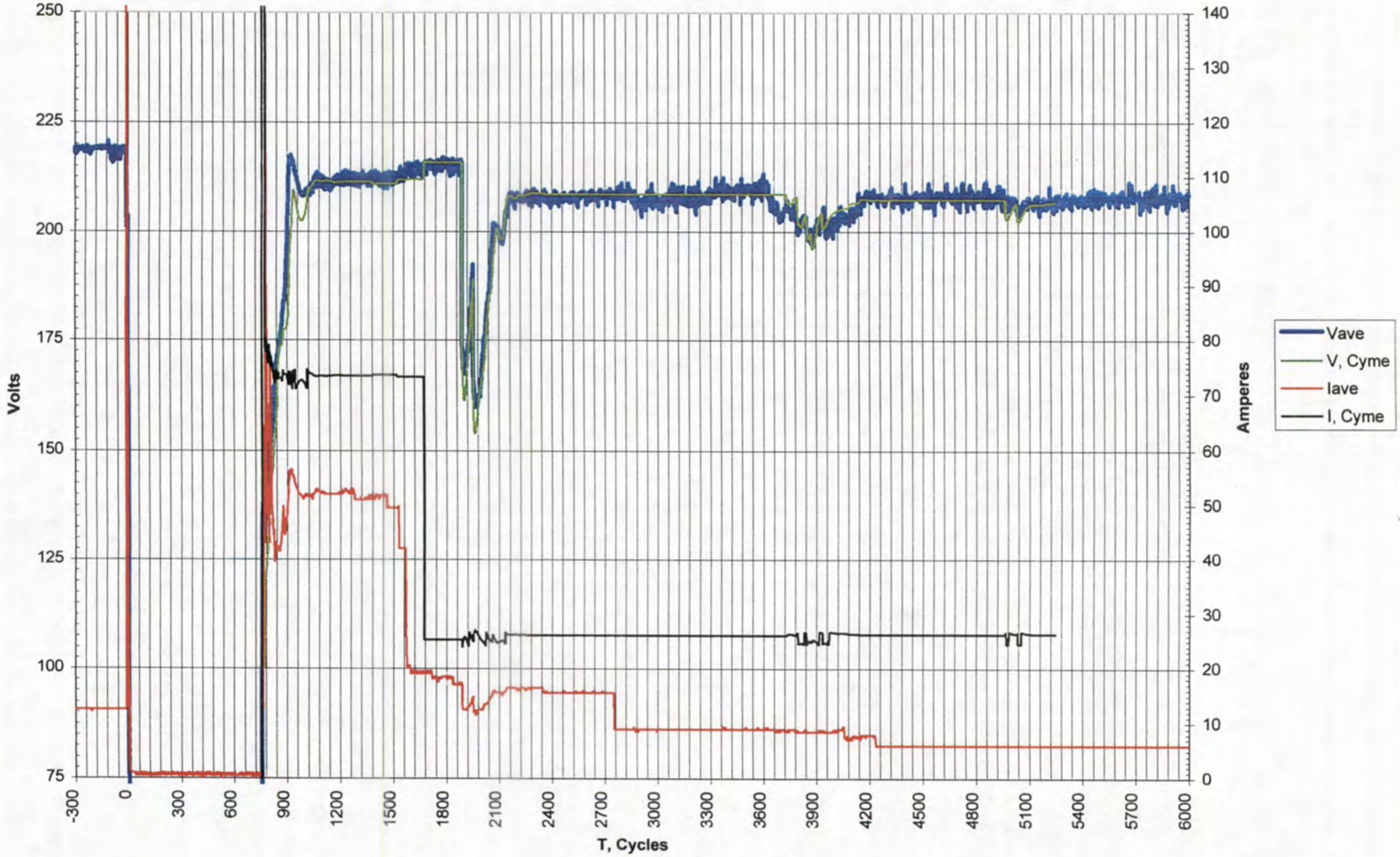


Figure 3-43: Test6, 208V 3XS1 KVA and KW

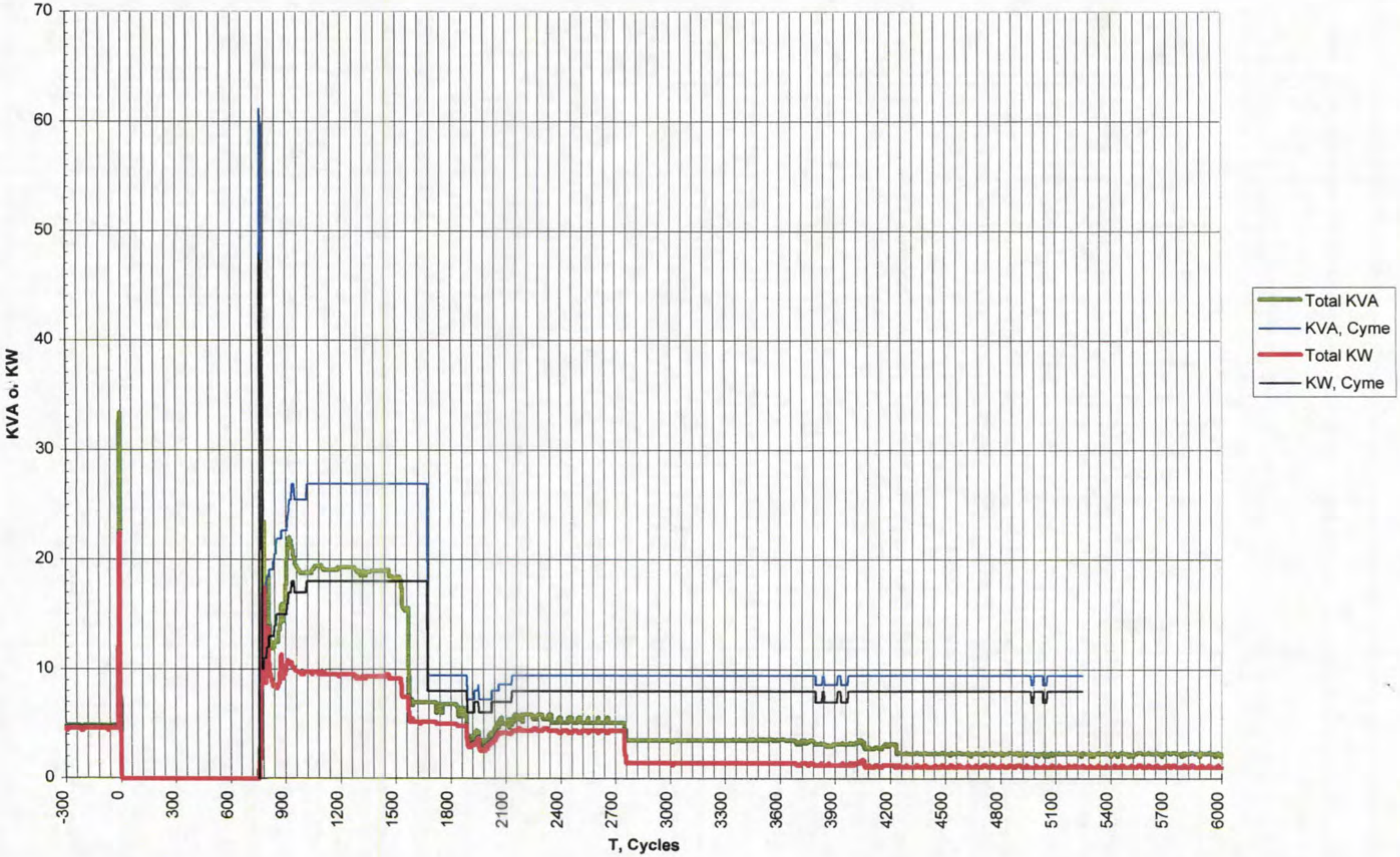


Figure 3-44: Test6, 208V 3XS2 Voltage and Current

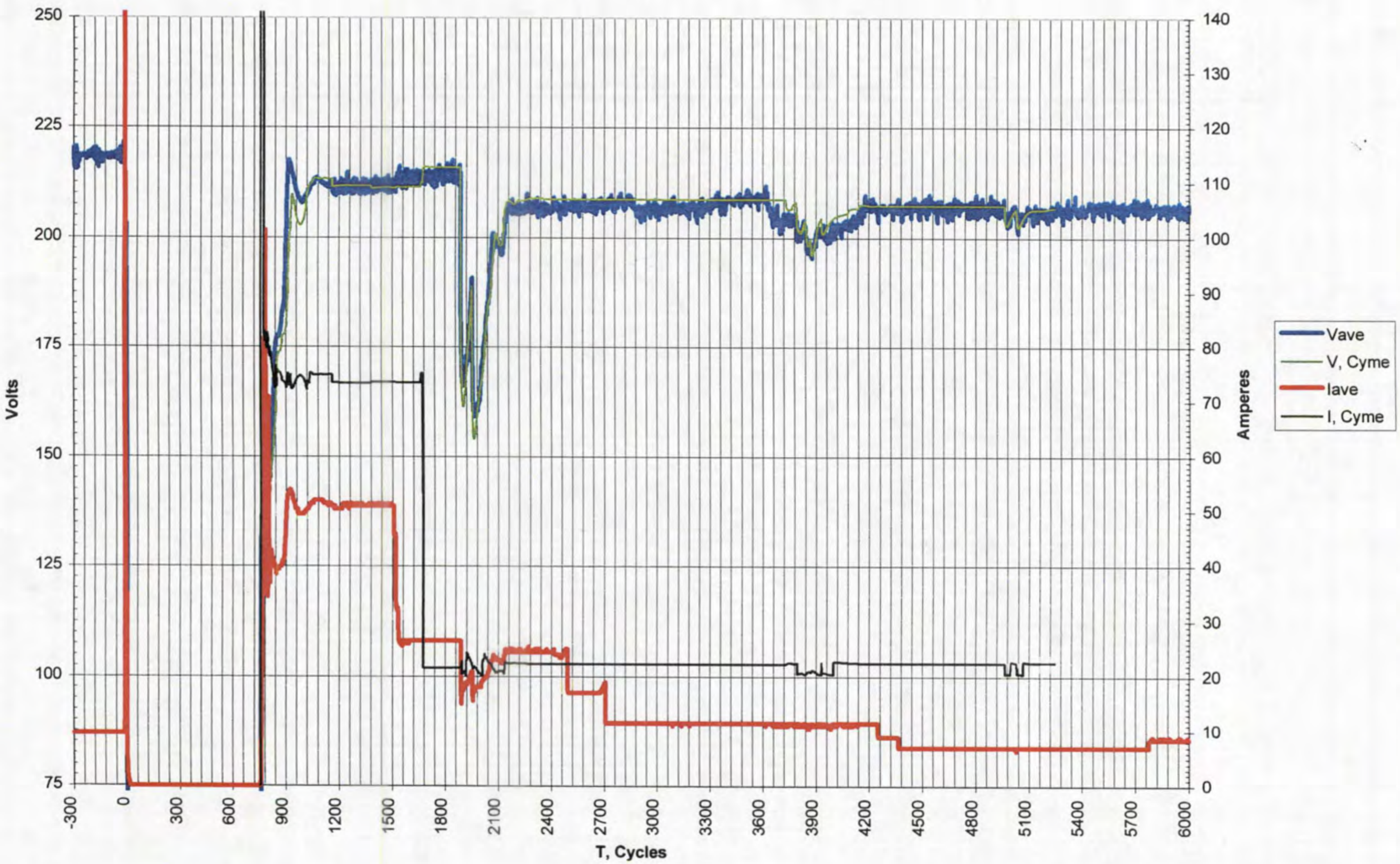


Figure 3-45: Test6, 208V 3XS2 KVA and KW

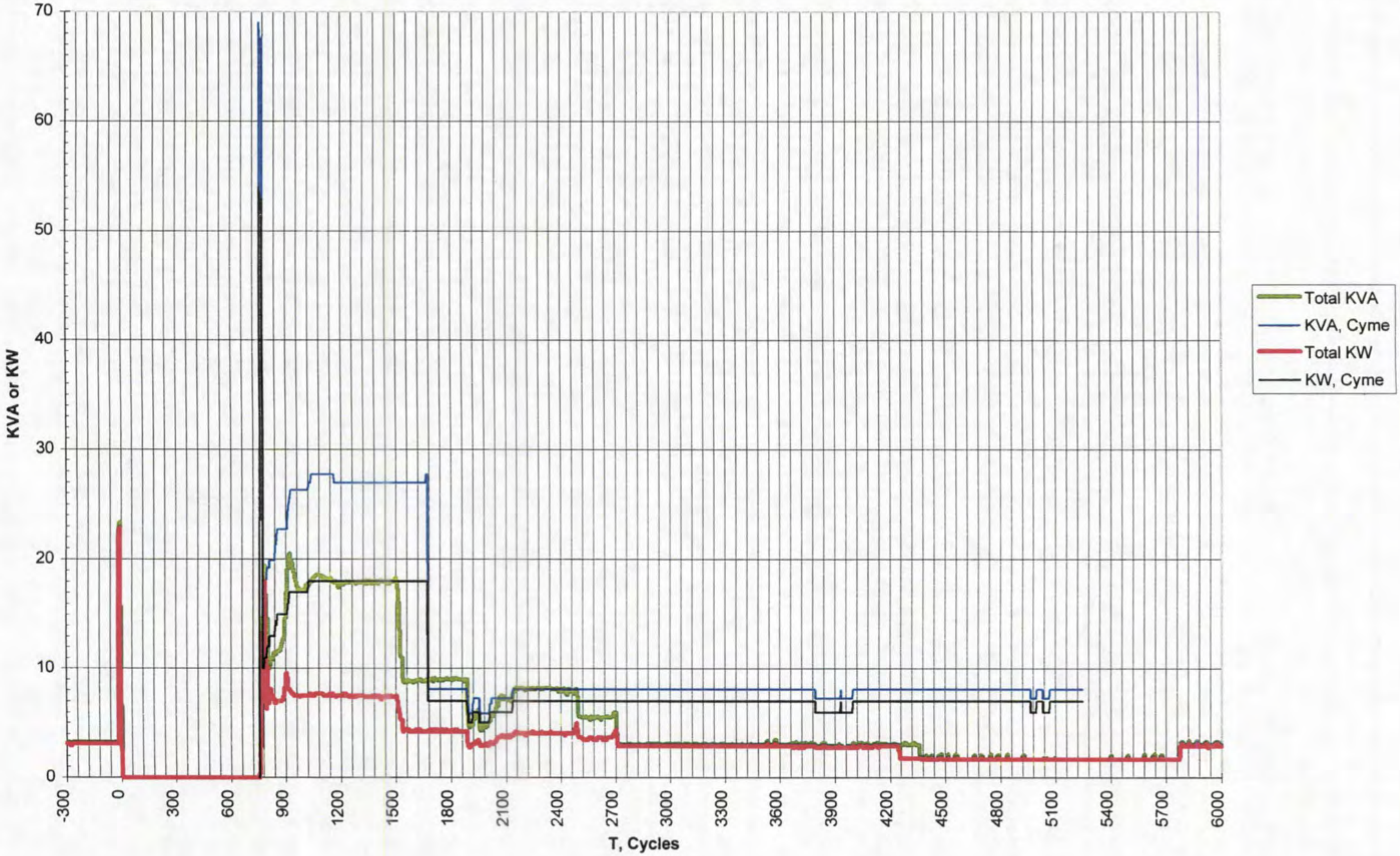


Figure 3-46: Test6, 208V 3XS3 Voltage and Current

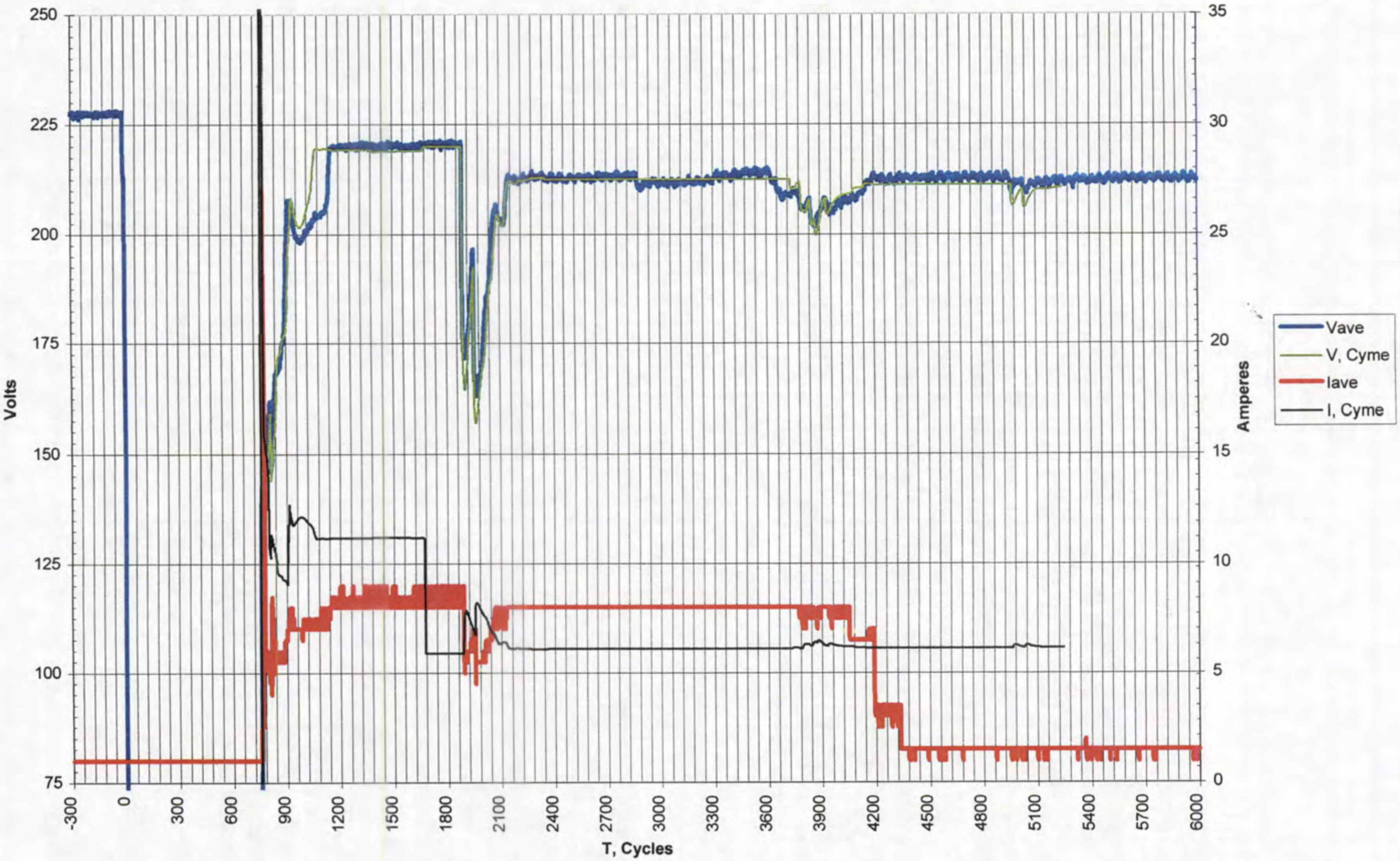


Figure 3-47: Test6, 208V 3XS3 KVA and KW