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Light Emitting Diode Taxiway Lighting Effects on Constant Current Regulator Stability

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16. Abstract

This study was conducted to determine how light emitting diode (LED) taxiway edge lights affect the operation of Constant Current Regulators (CCR). Some CCRs turn off due to overvoltage or overcurrent because of LED taxiway edge lights.

A test bed was developed to measure and record the voltage and current supplied to an LED taxiway edge fixture as power was applied. The test bed setup consisted of an LED taxiway edge fixture, circuit current control subsystem for constant current to the taxiway edge fixture, and a data acquisition subsystem, which collected the data for analysis. Five types of LED taxiway edge fixtures were used for the testing.

The baseline incandescent taxiway edge fixture had a smooth power curve. Two of the five LED taxiway edge light fixtures showed significant peak power volt ampere (VA) loading after power-up compared to the loading during normal operation. The highest peak power VA was 163% of the nominal VA required.

Based on the results of this study, the following are recommendations for future operation of LED taxiway edge lighting fixtures.

- The peak power VA required by an LED taxiway edge lighting fixture should not exceed the nominal operating power VA by more than 10% for the fixture. When the peak load is limited to 10%, the CCR will have enough reserve capacity to support the load and should easily adjust so that it will not trip off due to an overvoltage condition.

- The LED taxiway edge light fixture should not drop the power VA required at a given step by more than 10%. When the power VA load suddenly drops, the CCR can trip off due to overcurrent. By limiting the power VA drop to 10%, the overcurrent protection function of the CCR should easily adjust so that it will not trip off due to an overcurrent condition.

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LIST OF ACRONYMS

AC	Advisory Circular
CCR	Constant Current Regulator
EUT	Equipment under test
FAA	Federal Aviation Administration
Hz	Hertz
LED	Light emitting diode
NI	National Instruments
RMS	Root mean squared
V	Volt
VA	Volt ampere

EXECUTIVE SUMMARY

This study was conducted to determine how light emitting diode (LED) taxiway edge lights affect the operation of Constant Current Regulators (CCR). Some CCRs turn off due to overvoltage or overcurrent of LED taxiway edge lights.

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INTRODUCTION

PURPOSE.

The Federal Aviation Administration (FAA) Office of Aviation Research Airport Safety Technology Research and Development Section (AJP-6311), in response to a request from the Airport Engineering Division (AAS-100), undertook this project to evaluate how the use of light emitting diode (LED) technology for airport lighting circuits impacts Constant Current Regulator (CCR) operation. This research will assist in the revision of Advisory Circulars (AC) concerning LED fixtures and CCRs.

The purpose of this research is to characterize and investigate the electrical characteristics of LED fixtures that relate to overall performance and compatibility of these products with the existing airfield infrastructure. During this investigation, the electrical behavior of LED fixtures provided an unusual load to an airfield lighting circuit that could cause improper operation of lighting circuit equipment.

BACKGROUND.

LED lighting fixtures are being used in increasing numbers of airports, with the majority of the fixtures used as taxiway edge lights. These fixtures have been the subject of research conducted by the FAA William J. Hughes Technical Center since early 2004. This project was initiated to investigate how the unusual load characteristics of LED fixtures could impact the proper and stable operation of CCRs used to power lighting circuits. In particular, the unusual load from these fixtures during power-up could present difficulties in the operation of CCRs.

SCOPE.

This project involved the development and setup of a test bed and the testing of five different types of LED fixtures. As power was applied to the LED fixtures, the voltage and current were measured and recorded. During power-up, the load presented to the circuit of some LED fixtures changes significantly. This load change was investigated since it impacts the power requirements of the overall series circuit. Five fixtures from different suppliers were tested, and the same test was performed on an incandescent fixture as a control. Immediately after the fixtures were powered up, the measurements were saved to a file where the calculations for the fixtures' power requirements and effective resistance were plotted as a function of elapsed time.

OBJECTIVES.

The specific objectives of this research effort were to

1. capture and measure LED fixture voltage and current during power-up of LED fixtures.

2. calculate apparent power and the effective resistance of the fixture as a function of time.

3. analyze results to determine problems that may be encountered with the interactions between LED fixtures and CCRs.

4. provide specific recommendations for LED fixture standards to address potential compatibility issues between LED fixtures and CCRs found during testing.

5. provide application recommendations specific to this study for designers using LED fixtures.

<u>RELATED DOCUMENTS</u>.

The following documents are related to this project.

- AC 150/5340-30B, "Design and Installation Details for Airport Visual Aids," August 1, 2006

- AC 150/5345-10F, "Specification for Constant Current Regulators and Regulator Monitors," June 24, 2005

- Logan, Alvin, AAS-100, FAA LED Engineering Brief 67, Change 1, "Light Sources Other Than Incandescent and Xenon for Airport and Obstruction Lighting Fixtures," October 2005

- Cyrus, H.M., DOT/FAA/AR-TN05/10, "Light Emitting Diode Taxiway Edge Lights Emissions," March 2005

DISCUSSION

The electrical load presented by an airfield lighting circuit to a CCR impacts the stability and operation of the circuit. CCRs are designed to hold the circuit current at a specific level when switched on. The regulation of the circuit current is accomplished by the CCR sensing the circuit current and correcting its output voltage so the circuit current is equal to the current that is selected.

During the power-up of incandescent fixtures, the circuit load is essentially passive. When the filaments are cold, they have a small resistance; and resistance slowly increases as they begin to heat until they reach their final value.

Previous research shows that some LED fixtures appear to include internal power supplies that change the load they present to the circuit as power is applied. This investigation measures these fixtures during power-up and analyzes how this impacts CCR operation compares to an incandescent load.

EVALUATION APPROACH

TEST SETUP.

Figure 1 shows the equipment setup that was used to test the taxiway edge LED fixtures, which will be referred to as the equipment under test (EUT). Other types of LED fixtures used on the airfield should behave the same way as taxiway edge LED fixtures. The system consisted of the two major subsystems, the circuit current control that provided constant current to the EUT, and the data acquisition subsystem that recorded the measurements used for the analysis.

CIRCUIT CURRENT CONTROL.

A power level of 120 volts (V) and 60 hertz (Hz) power was fed into the system. The voltage available to the system was controlled and set with a Variac autotransformer. After passing through an isolation transformer and a 4:1 step-down transformer, 30 to 35 V were available for the test circuit. A high degree of isolation from line noise was provided by the use of an electrostatically shielded transformer designed for that purpose.

Voltage from the isolation transformer was converted into a stream of clock pulses by a 60-Hz clock circuit. One clock pulse was created for each positive and negative zero-crossing voltage to synchronize the timing of the current control loop application. A 0.5-ohms sampling resistor was used to develop circuit current for the control loop application, which was measured in true root mean squared (RMS) current. The control loop application then calculated the measured RMS current and compared it to the desired RMS current setting. Then, the control loop provided the triac, which is two opposing silicon controlled rectifiers with both gates paralleled, with a trigger pulse for each half-cycle of current. These pulses provided the proper conduction time duty cycle for the system to maintain the circuit current to the desired level.

Figure 2 shows a screen capture of the control panel for the circuit current control application. The circuit current control application ran on a National Instruments (NI) 8187 PXI controller, which is a single-board computer. This board resides in an instrumentation chassis and is controlled by an NI 6259 Multifunction Data Acquisition board, which provided sampling of current for the control loop. An NI 6602 counter/timer module was also in the instrumentation chassis and was used to provide timing functions for the control loop; it also created the trigger pulses for the optically coupled triac. The application for control was developed using the LabVIEW real-time, run-time software package, version 6.0, to provide the performance needed to operate the control loop. This system provided complete flexibility to set the parameters of the control loop for laboratory use.

DATA ACQUISITION.

For this application, the system also provided the acquisition of the EUT voltage and current. For this test, the rate of 123,000 samples per second was used. Since this application requires sampling of RMS voltage and current of 60-Hz signals, this rate was more than adequate. During a test, the voltage and current samples were collected by the system and, at the end of each half cycle, an RMS calculation was performed for the voltage and current on the previous cycle. The RMS voltage and current was written to a text file, with one RMS voltage and RMS current sample stored each 8.33 milliseconds, or 120 RMS samples per second. This text file was then used for the analysis.

Also provided was a means to consistently trigger the data acquisition at a known time. The same signal conditioning and triggering hardware box was used for the data acquisition system as for the current control system shown in figure 1. This provided a stable, phase-coherent trigger source to ensure that the captured waveforms start at the same place and prevented jitter from noise.

COMPARATIVE RESULTS

<u>INCANDESCENT BASELINE</u>.

The baseline incandescent fixture used a nominal 45 watt rated lamp. Figure 3 shows the VA and the effective resistance when power was applied at 6.6 amps RMS. The effective resistance rose as the filament heated. This dampened the rise in circuit current during the start-up by increasing the resistance relatively slowly. A CCR responds by proportionally increasing the voltage to the load to attain the desired current. The apparent power on the same figure indicates a slow rise in power to about 49 VA, which was near the nominal 45 watt rating for the lamp. Overall, the incandescent fixture provided a stable predictable load characteristic.

<u>FIXTURE 1</u>.

This fixture differed significantly from the incandescent load. As shown in figure 4, for approximately the first 250 milliseconds, the resistance rose to about 0.17 ohms and then settled to about 0.1 ohm. The VA load initially rose to just below 9 VA, and then stabilized at about 5.8 VA. This represents an initial load that is about 155% higher than the final value.

<u>FIXTURE 2</u>.

While this fixture showed some peaks in the effective resistance after power-up, as shown in figure 5, the change in the resistance generally rose to its maximum value of about 0.7 ohms and then settled at about 0.55 ohms. The VA load mimicked that of the incandescent with only a slight peak of about 25 VA and a final value of about 24 VA. The peak is only 105% of the final value.

<u>FIXTURE 3</u>.

The data for Fixture 3 is shown in figure 6. This fixture demonstrated a large, steep rise in resistance and peaked at 0.9 ohms before settling to 0.25 ohms. The VA load also showed a significant peak at about 18 VA, with a final value of about 11 VA. This peak is 163% of the final VA load.

FIXTURE 4.

The VA and resistance plots for Fixture 4 are shown in figure 7. While the resistance peaked soon after power-up to about 0.19 ohms, the final value was 0.13 ohms. This change in resistance appeared relatively slow. The resulting fixture VA consumed peaks at about 6.8 VA, and then reduced to about 6 VA. The peak represents 113% of the final load.

FIXTURE 5.

The chart for Fixture 5 is shown in figure 8. The effective resistance quickly peaked at 0.3 ohms, and then settled to 0.13 ohms. The apparent power also peaked rapidly at about 11 VA and then settled to 6 VA. But this fixture included an additional characteristic shown in figure 9. This graph captured the same event as figure 8, but included a longer time frame. The fixture behavior changed at about 2 seconds of elapsed time and again at about 3.75 seconds of elapsed time. Even though the fixture current was held at 6.6 amps, the resistance increased from a low of 0.13 ohms, then to 0.18, and finally to 0.23 ohms. The apparent power after peaking at 11 VA, dropped to 6 VA, stepped to 7.75 VA, and finally rose to 10.2 VA. This results in the peak VA being 108% of the final VA.

SUMMARY

The incandescent baseline fixture showed a slow increase of the load as power was applied. As the filament heated, its resistance increased, which dampened the control loop of the CCR. This effect generally results in stable loop control.

All LED fixtures showed at least some initial peak in the effective resistance and VA. This was due to the start-up of the internal power supply in the fixtures. In particular, Fixtures 1 and 3 showed large initial peak VA loads compared to the final load. Table 1 summarizes the results.

Table 1. Summary of Power Characteristics

Fixture	Initial Peak (VA)	Final (VA)	Peak Percent of Final
Incandescent	Not applicable	49	Not applicable
Fixture 1	9	5.8	155%
Fixture 2	25	24	105%
Fixture 3	11	18	163%
Fixture 4	6.8	6	113%
Fixture 5	11	10.2	108%

To understand the significance of this peak load characteristic, consider the following case using Fixture 3 as an example. A circuit load consisting of 20,000 feet of AWG 8 cable, 250 LED fixtures, 250 isolation transformers, and a typical 5 VA loss in each transformer is shown in the third column of table 2 (250 x 5 VA = 1250).

Table 2. Fixture 3 Circuit VA Load, 250 Fixture Example

Case	Cable Loss (VA)	Isolation Transformer Loss (VA)	Fixture Power (VA)	Total Power (VA)
Peak Initial VA Case	547	1250	4500	6297
Final VA Case	547	1250	2750	4547

If the designer looked at the rated VA load and a 5000 VA CCR was used, the circuit would be initially overloaded by almost 1300 VA. Since many CCRs are provided with overvoltage protection, this situation has the potential for activating this and shutting down the circuit.

If the circuit remained powered during the peak VA time after power-up and the VA demand suddenly dropped from 6297 to 4547 VA, the effective resistance of the load would also drop. This would cause the CCR current to rise to about 9 amps until the CCR could reduce its output. Since CCRs include overcurrent capabilities, this issue also could cause the CCR to trip the overcurrent protection and shut down.

The combination of high initial peak VA followed by the sudden drop in load, can set up an unstable interaction between the CCR and LED fixtures. It must be noted that there are adjustments in CCRs that can set the overcurrent and voltage sensitivity. But the range and time constant of these adjustments is not uniform in all CCRs. The speed of the current control loop in the CCR also has an effect on the sensitivity to overload.

It further must be noted that using a high initial peak VA LED fixture on circuits that share other high initial peak VA components may cause even more instability. This would be true when sharing a circuit.

There are no standards for LED fixtures that require any specific load behavior on the part of the fixture. It is possible for a new product to be certified that is noisier than those that were tested during this study. All tested fixtures were built and certified in accordance with AC 150/5345-46, "Runway and Taxiway Fixtures" and Engineering Brief 67, "Light Sources Other Than Incandescent and Xenon for Airport and Obstruction Lighting Equipment."

CONCLUSIONS

The tests were successful in the capture and measurement of light emitting diode (LED) fixture voltage and current during power-up of the LED fixtures. Apparent power and effective resistance measurements revealed the following circuit start-up issues:

a. Two of the five tested LED fixtures showed significant peak volt ampere (VA) loading after power-up compared to the loading during normal operation. The highest peak VA was 163% of the nominal VA required. This initial peak has the potential for causing a series circuit to be overloaded.

b. After the initial peak, a sudden drop in the load VA of a circuit can cause overcurrent and trip an overcurrent shutdown of the circuit.

c. The combination of high initial peak VA followed by a drop in load that was seen here may, in some cases, set up an instability between the Constant Current Regulators (CCR) and LED fixtures if the timing of the CCR's current control loop is similar to the timing of the peak- and reduced-VA behavior of the LED fixture.

d. If these high peak VA fixtures are used on shared circuits with other components with high peak VA, the combination can cause start-up to be more of a problem.

RECOMMENDATIONS

Based on the test results, the following requirements are recommended for future LED fixtures.

- The peak power VA required by an LED taxiway edge lighting fixture should not exceed the nominal operating power VA by more than 10% for the fixture. When the peak load is limited to 10%, the CCR will have enough reserve capacity to support the load and should easily adjust so that it will not trip off due to an overvoltage condition.

- The LED taxiway edge light fixture should not drop the power VA required at a given step by more than 10%. When the power VA load suddenly drops, the CCR can trip off due to overcurrent. By limiting the power VA drop to 10%, the overcurrent protection function of the CCR should easily adjust so that it will not trip off due to an overcurrent condition.

The following additional design and installation related measures can be taken by designers, engineers, and maintenance personnel to reduce the likelihood of compatibility problems with CCRs.

a. When designing circuits that include LED fixtures, the peak and nominal VA loads should be considered to assure adequate margins.

b. The CCR behavior, speed of current control capabilities, and adjustments for overvoltage and overcurrent should be taken into account when selecting LED and CCR components.

c. The designer should discuss the specifics of the circuit design methodology with the manufacturers of these fixtures and CCRs.

d. Extreme care should be taken when considering the use of LED fixtures on circuits that share other high initial peak VA components.

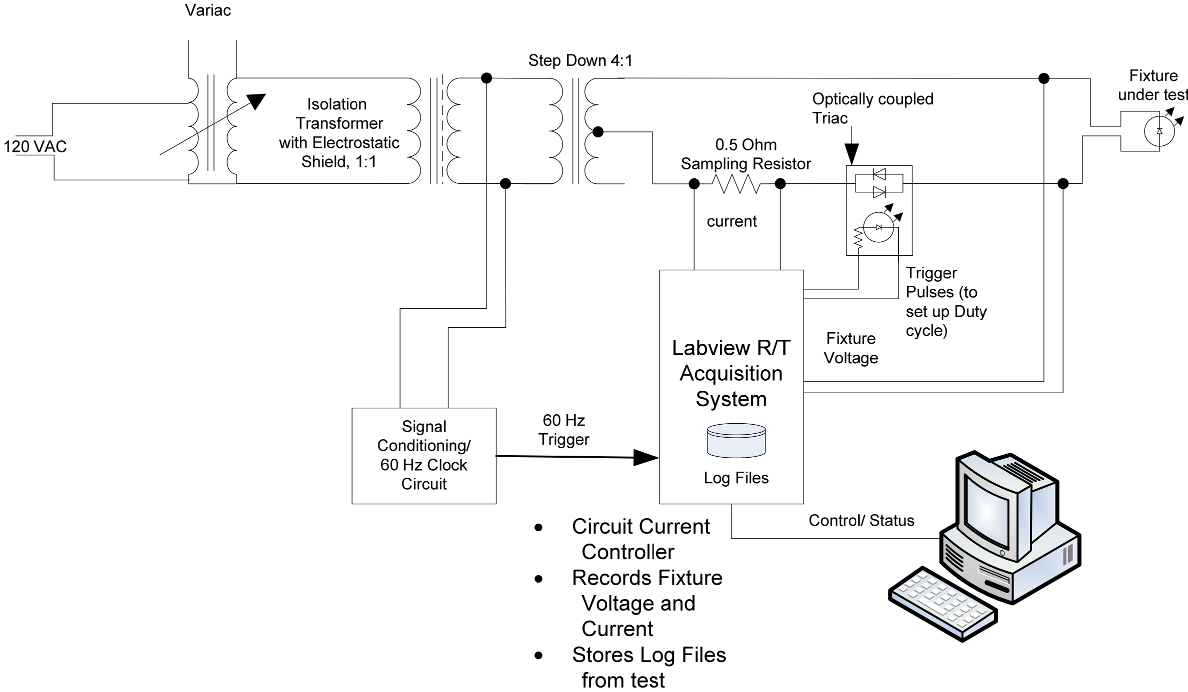

Figure 1. Diagram of the Project Test Setup

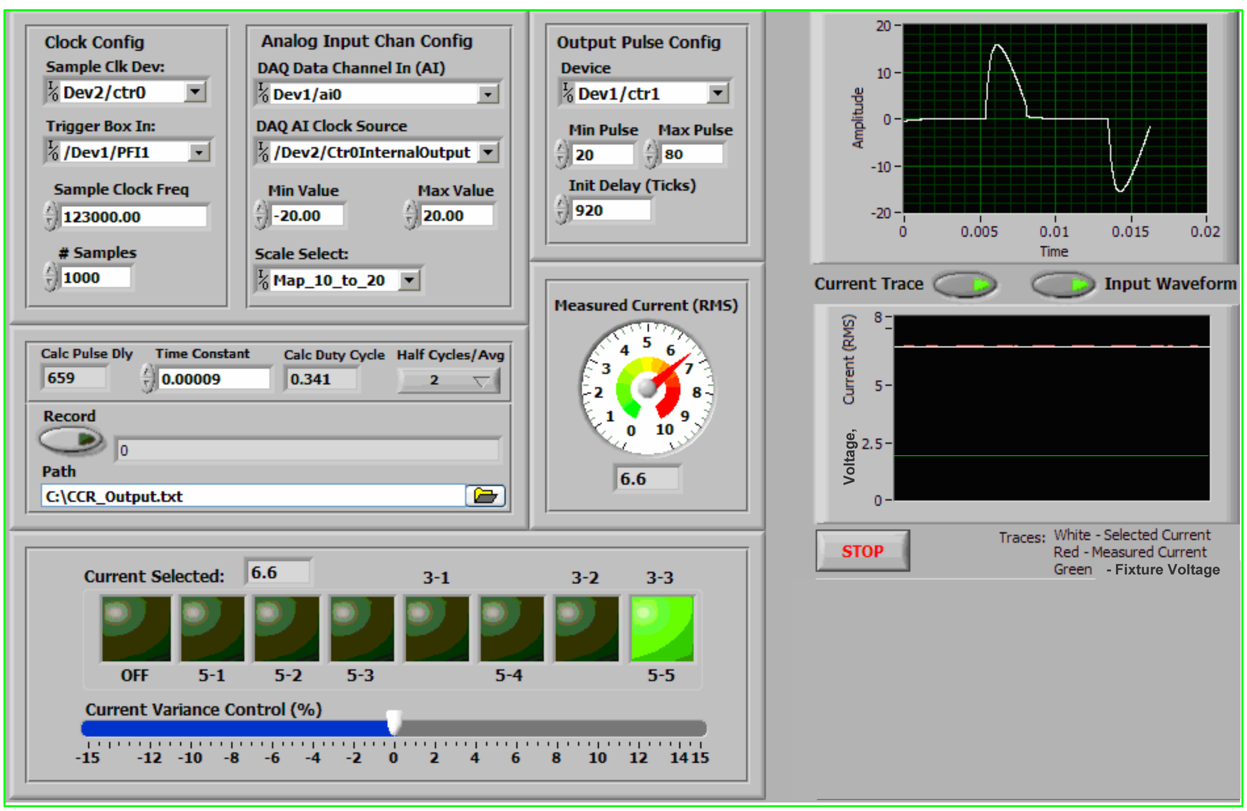

Figure 2. Circuit Control Screen

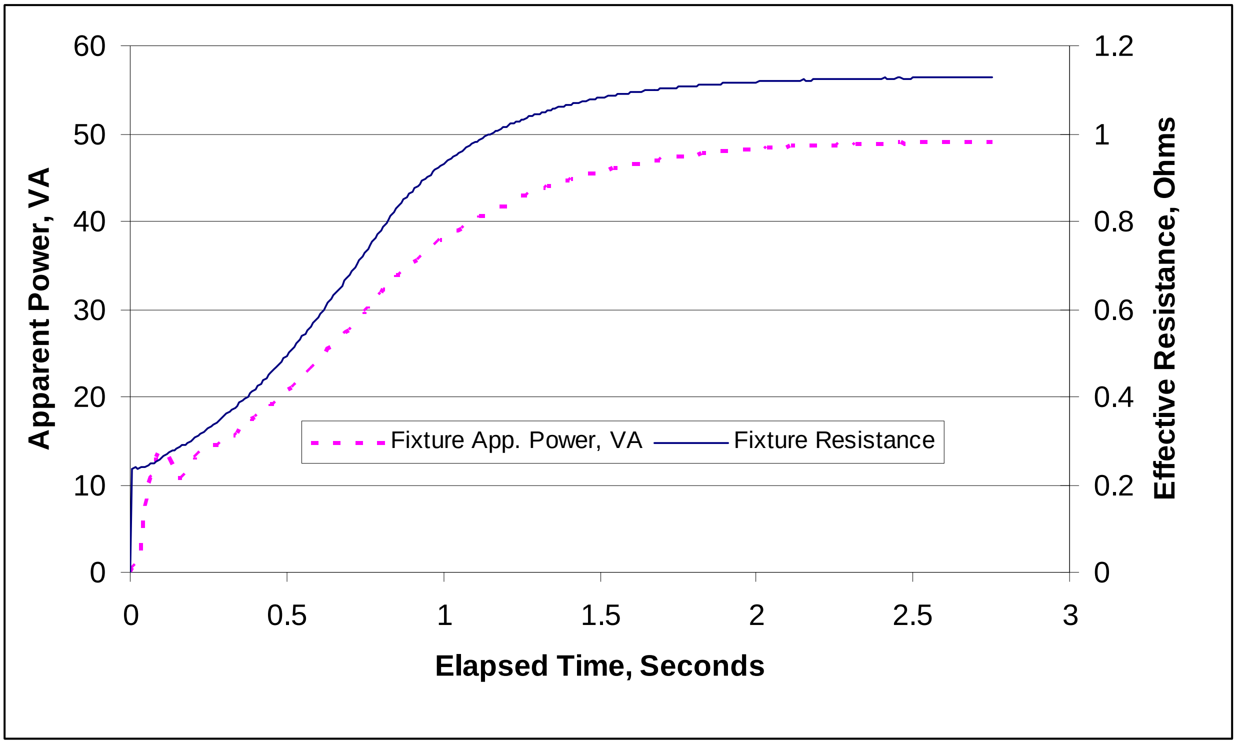

Figure 3. Baseline Incandescent Apparent Power and Resistance

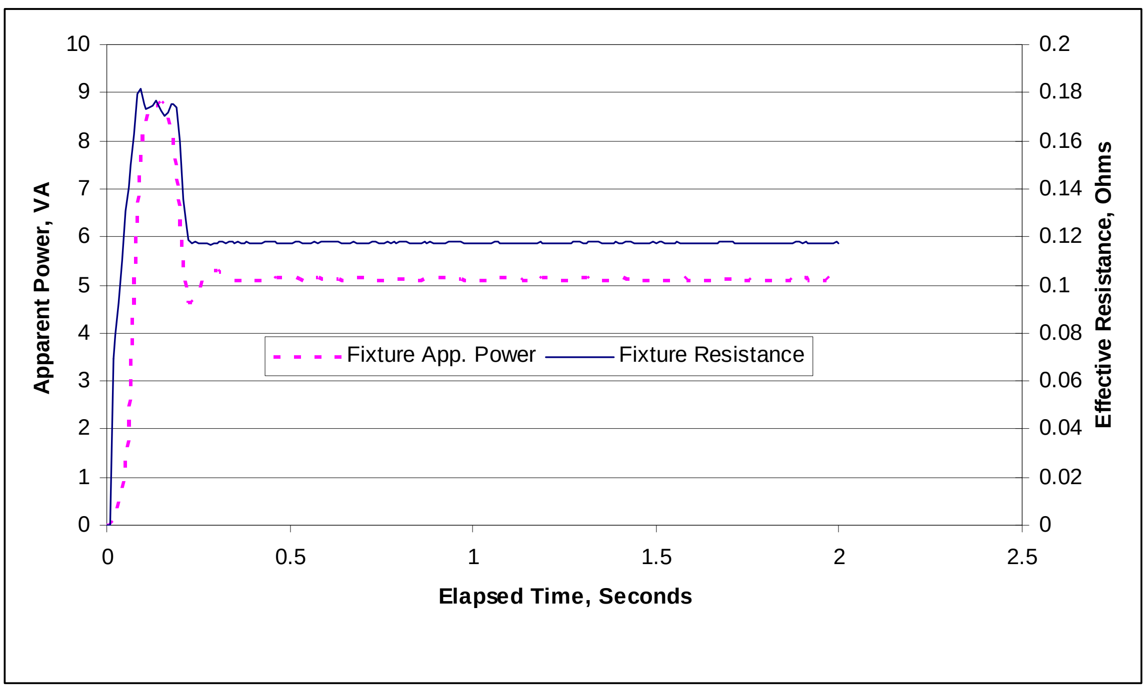

Figure 4. Fixture 1 Apparent Power and Resistance

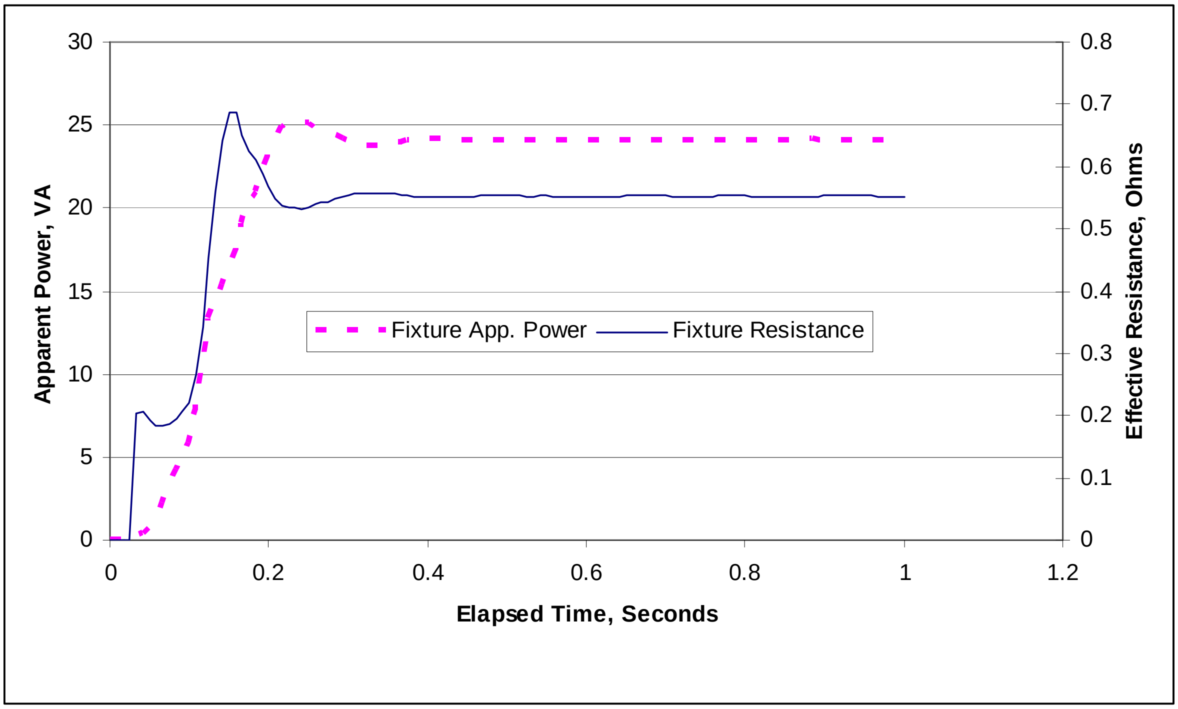

Figure 5. Fixture 2 Apparent Power and Resistance

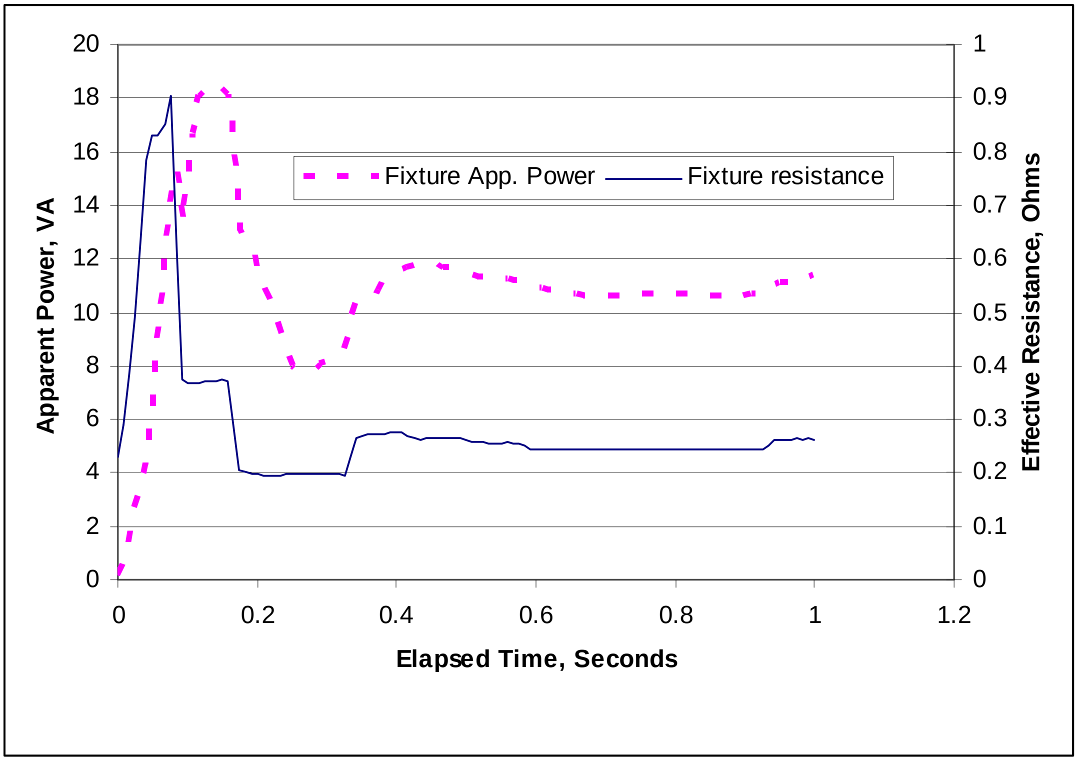

Figure 6. Fixture 3 Apparent Power and Resistance

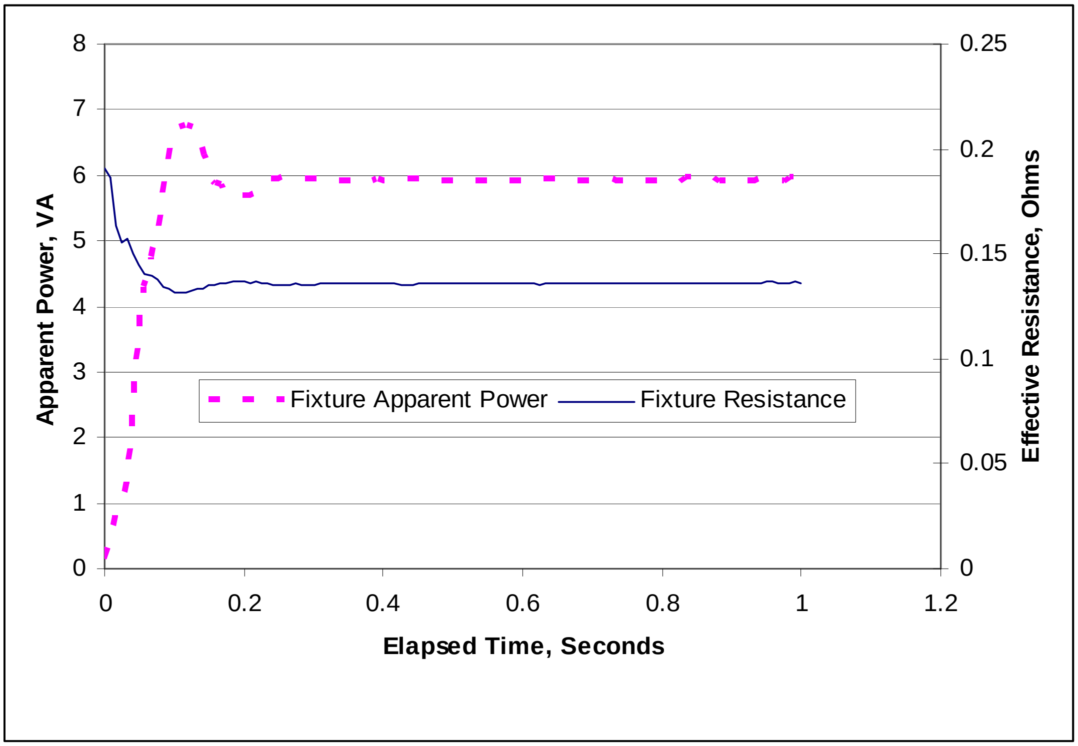

Figure 7. Fixture 4 Apparent Power and Resistance

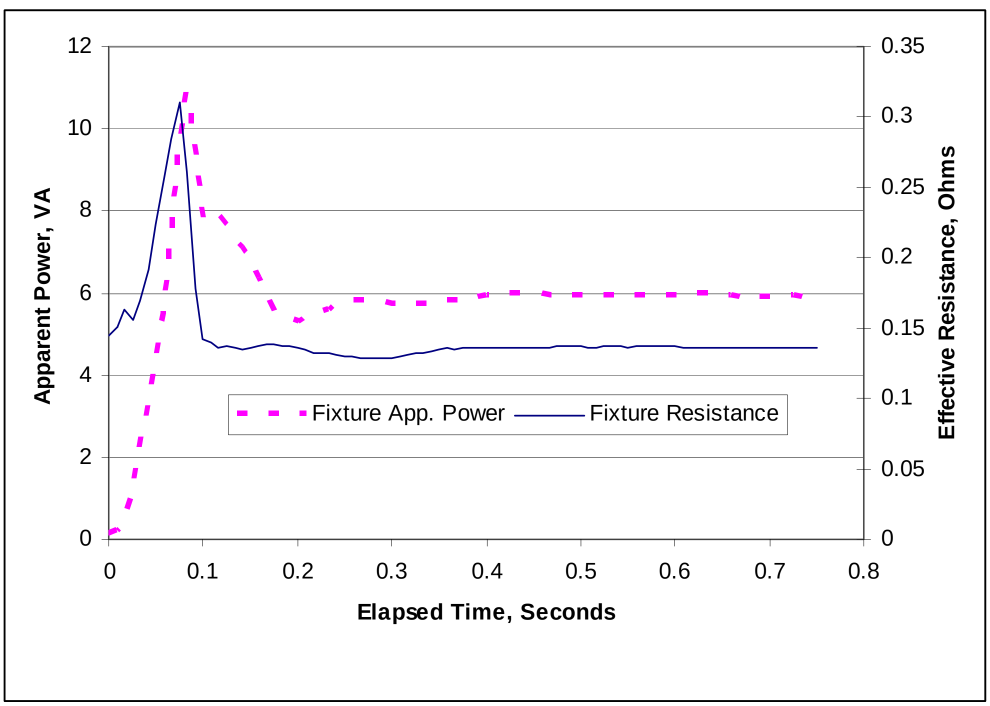

Figure 8. Fixture 5 Apparent Power and Resistance

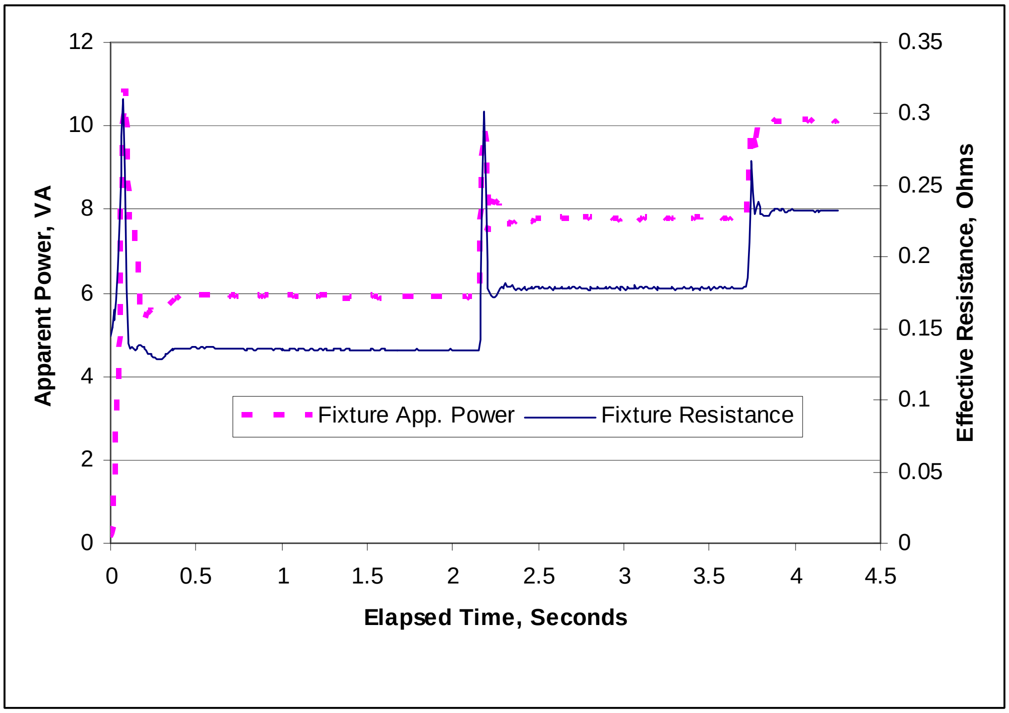

Figure 9. Longer View of Fixture 5 Apparent Power and Resistance