Instrument Current Transformer (CT) testing with the PowerMaster®

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When testing instrument transformers in the field using the PowerMaster, there can be confusion whether or not a CT is meeting its specifications. This white paper will discuss in detail basic ratings listed on instrument current transformers and help clarify how the PowerMaster analyzes the data to determine if a CT has either passed or failed a test. This paper also explains user preferences in the PowerMaster so the user can personalize the testing to meet their needs.

In order to understand how a CT will pass or fail a test according to the IEEE C57.13 standard, we must first understand its nameplate specifications. These specifications include the ratio, accuracy class, rating factor, temperature, and burden rating. The ratio of a CT is the amplitude of the primary current in relationship to the amplitude of the secondary current. The accuracy class is rated at 100% of the CT ratio, and most are specified at 0.3% error. The rating factor is a multiplier of the ratio which increases the operating range at its stated accuracy class and temperature range. The burden rating is defined as all resistance in ohms that is present on the secondary connections of the CT. For this paper, we are using a 20:5 CT, accuracy class of 0.3%, rating factor of 2, and a burden rating of 0.5 ohms.

When ratio testing a CT, we are looking at the relationship between the primary and secondary current waveforms for both amplitude and phase. When there is zero phase difference between the two signals, the phase measurement would pass. If there is no phase difference, but the secondary current is ½ of expected, the measurement would fail on amplitude. If the amplitude of the primary and secondary current matches the ratio of the CT, but the phase difference between the two signals is outside the error limits, the measurement would fail on phase. By using the parallelogram in the PowerMaster, the user can visually determine if these test points are within specification.

In addition to errors in the CT itself, probes used to measure amplitude and phase induce additional errors simply by their application and design. Errors can occur depending on how the probe is placed around the conductor, proximity of the probe to other conductors, and accuracy limitations with the probe design. To alleviate some of the restrictions, the PowerMaster allows the user to choose customizable CT error limits and different graphical displays for the IEEE accuracy parallelogram. The parallelogram can be displayed as a standard IEEE C57.13 display, a user defined display, or a combination of the two displays.

When testing instrument transformers, the PowerMaster has the ability to analyze and display the data to the user in a practical format. However, understanding the nature and limitation of a CT becomes paramount when interpreting the data. This paper guides the user on how to analyze, interpret, and configure the PowerMaster to supply the desired results.

The PowerMaster is a highly advanced piece of field test equipment that is capable of testing instrument transformers in the field. CT manufacturers specify their products using a wide range of criteria. Some of this criterion is inter-related, which can cause confusion about whether a CT is meeting its specifications. This white paper will discuss in detail basic ratings listed on instrument current transformers and help clarify how the PowerMaster analyzes the data to determine if the CT has either passed or failed a test. This white paper will also define various user definable preferences so that the operator can personalize their PowerMaster to suit their needs.

The PowerMaster is capable of performing three different types of tests on CTs.

1) Ratio Only Test

A ratio only test measures both the primary and secondary current at a single point and displays the results. Amplitude and phase error will both be calculated.

2) Burden Only Test

A burden only test only measures the secondary current. The PowerMaster will test at several points (as determined in the test setup). The PowerMaster will first measure the amplitude of the secondary current with no extra burden applied. This is the base reading. The PowerMaster will then measure the current as it simultaneously increases the burden on the circuit. The PowerMaster is measuring how much the secondary current drops during the test. The additional burden points available are 0.1 ohms, 0.3 ohms, 0.5 ohms, 1.0 ohms, 2.0 ohms and 4.0 ohms. The user can select the maximum amount of additional ohms maximum they want the test to add. For example, if the user chooses 2.0 ohms, the PowerMaster will measure the current at no additional burden, 0.1 ohms applied, then 0.3 ohms applied, then 0.5 ohms applied, then 1.0 ohms applied, and then finally 2.0 ohms applied. The 4.0 ohm point would not be tested.

3) Burden and Ratio Test

A burden and ratio test combines both aspects of the ratio only test and burden only test. The PowerMaster will test at several points (as determined in the test setup). The PowerMaster will first measure the amplitude and phase of the primary current and secondary current with no extra burden applied. This is the base reading. The PowerMaster will then measure both of these signals as it simultaneously increases the burden on the circuit. The PowerMaster is measuring how the relationship between the primary and secondary current changes as extra burden is applied. The additional burden points available are 0.1 ohms, 0.3 ohms, 0.5 ohms, 1.0 ohms, 2.0 ohms and 4.0 ohms. The user can select the maximum amount of additional ohms maximum they want the test to add. For example, if the user chooses 2.0 ohms, the PowerMaster will make measurements at no additional burden, 0.1 ohms applied, then 0.3 ohms applied, then 0.5 ohms applied, then 1.0 ohms applied, and then finally 2.0 ohms applied. The 4.0 ohm point would not be tested.

Ratio Only CT Testing

In this section of the white paper we will discuss the Ratio Only portion of CT testing. We will also give a basic understanding of CT specifications and what can cause accuracies to fluctuate.

Figure 1.1 CT Test Setup for the PowerMaster

In order to see if the CT passes a test we must first know its nameplate specifications. All CTs will list their ratio which is the amplitude of the primary current in relationship to the amplitude of secondary current. In this example we have chosen a CT with a ratio of 20:5. This means that if there is 20A of current on the primary we should expect 5A of current on the secondary. This is a linear relationship across its operating range, meaning if we have 10A on the primary we should expect 2.5A on the secondary, etc.

The CT will also list its accuracy class. Most metering class instrument CTs in North America are rated at 0.3%. This accuracy is only valid if the CT is operating within its temperature, rating factor, burden, and current limits. It is important to note that operating temperatures affect the rating factor.

The burden of a CT is defined as all the resistance in ohms that is present on the secondary connections of the CT. This is generally the sum of the resistance from all the connections and wiring from the secondary connections of the CT all the way to the connections on the meter. If a CT is overburdened it will cause the secondary current to drop and its accuracy can and most likely will be affected negatively.

The current limits of the CT are related to its ratio and rating factor. For instance, if a CT has a 20:5 ratio and a rating factor of 1, the accuracy is only guaranteed to be 0.3% if the CT is fully loaded (20A on the primary). The CT is only guaranteed to be 0.6% accurate from 10% of its rated load to 100% of its rated load, in this example from 2A to 20A on the primary. Outside of these limits there is no guarantee of the accuracy of the CT.

In order to have a larger range of high accuracy, many utilities install CTs with higher rating factors. The rating factor on a CT is a multiplier of the ratio which allows more operating range at 0.3% accuracy. For instance, if we have a 20:5 CT with rating factor of 2, the CT is guaranteed to be 0.3% accurate from 20A on the primary all the way to 20A x 2 (or 40A) on the primary. As mentioned earlier, as operating temperature rises, the affect on the rating factor can be quite significant. In this instance if the CT is also rated at 30°C, then the rating factor is guaranteed to be 2X at 30°C, but drops to only around 1.5X if the temperature rises to 45°C.

Below are graphical representations of how burden, load, rating factor and temperature can influence CT performance. Figure 1.2 is for a 0.3% CT with rating factor of 2 and burden rating of 1.8 ohms. It illustrates how accuracies are affected by percent rated load of CT operation and existing burden.
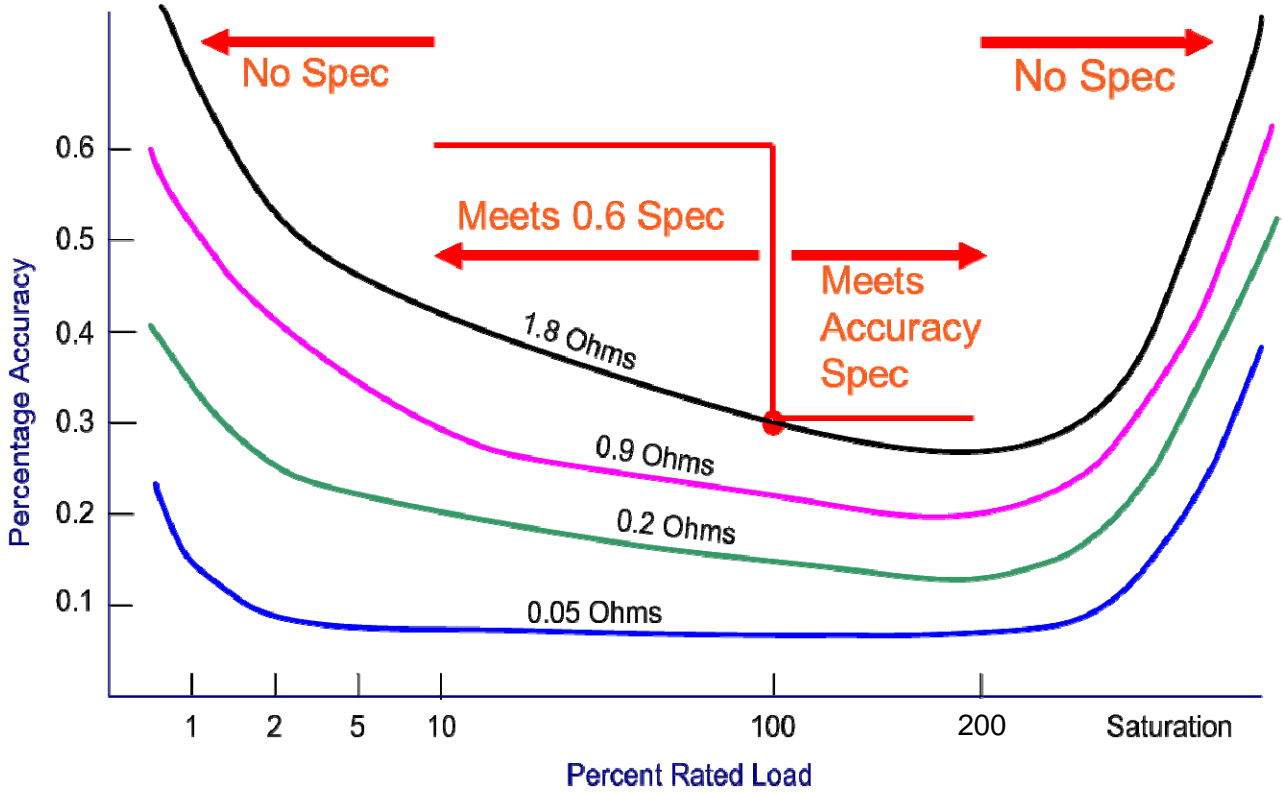

Figure 1.2

Figure 1.3 shows how operating temperatures can influence the rating factor of a CT. It illustrates that as temperature increases, the rating factor of the CT decreases.
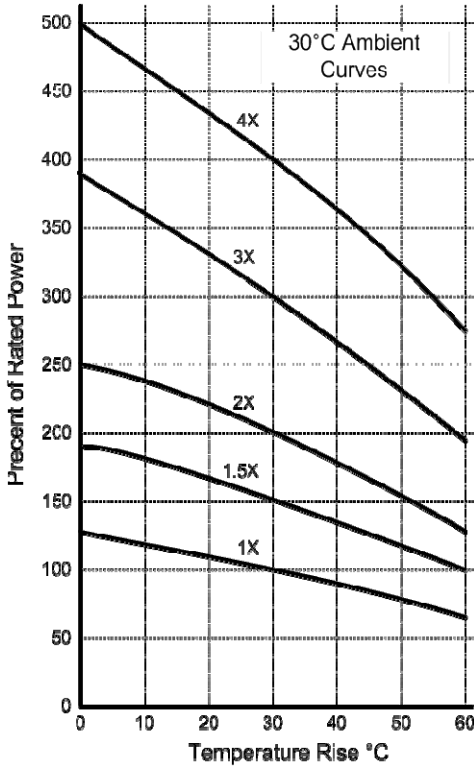

Figure 1.3

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When ratio testing a CT we must also look at the phase relationship between the primary current and secondary current. In a perfect world there should be zero phase difference between these two signals. When determining if a CT passes a ratio test, the PowerMaster follows the IEEE C57.13 Standard which defines what the limits are on phase shift at different amplitude errors. This is graphically represented by the IEEE parallelogram which we will show in detail throughout this white paper.

The PowerMaster accesses its database to pull CT information to see whether the test passes or fails. The user can select a CT already in the database or create a specific CT they need to test (see PowerMaster screen below). Within each CT in the database, the accuracy class, burden class, nameplate ratio, and rating factor are all stored. When the PowerMaster runs a ratio test on the CT it looks at all this information in the database, then calculates the primary and secondary current to see in which IEEE parallelogram the test results must be within before it makes its decision to pass or fail the test.

For all the scenarios in this white paper we have chosen a CT with specifications shown in the screen below.

Figure 1.4 CT Editor for the PowerMaster

Figure 1.5 is an example of the sinusoidal current waveforms expected when performing a CT ratio test. The amplitude of the primary current versus the amplitude of the secondary current matches exactly to the ratio of the CT. There is also zero phase difference between the two signals. When tested with the PowerMaster this CT would PASS.

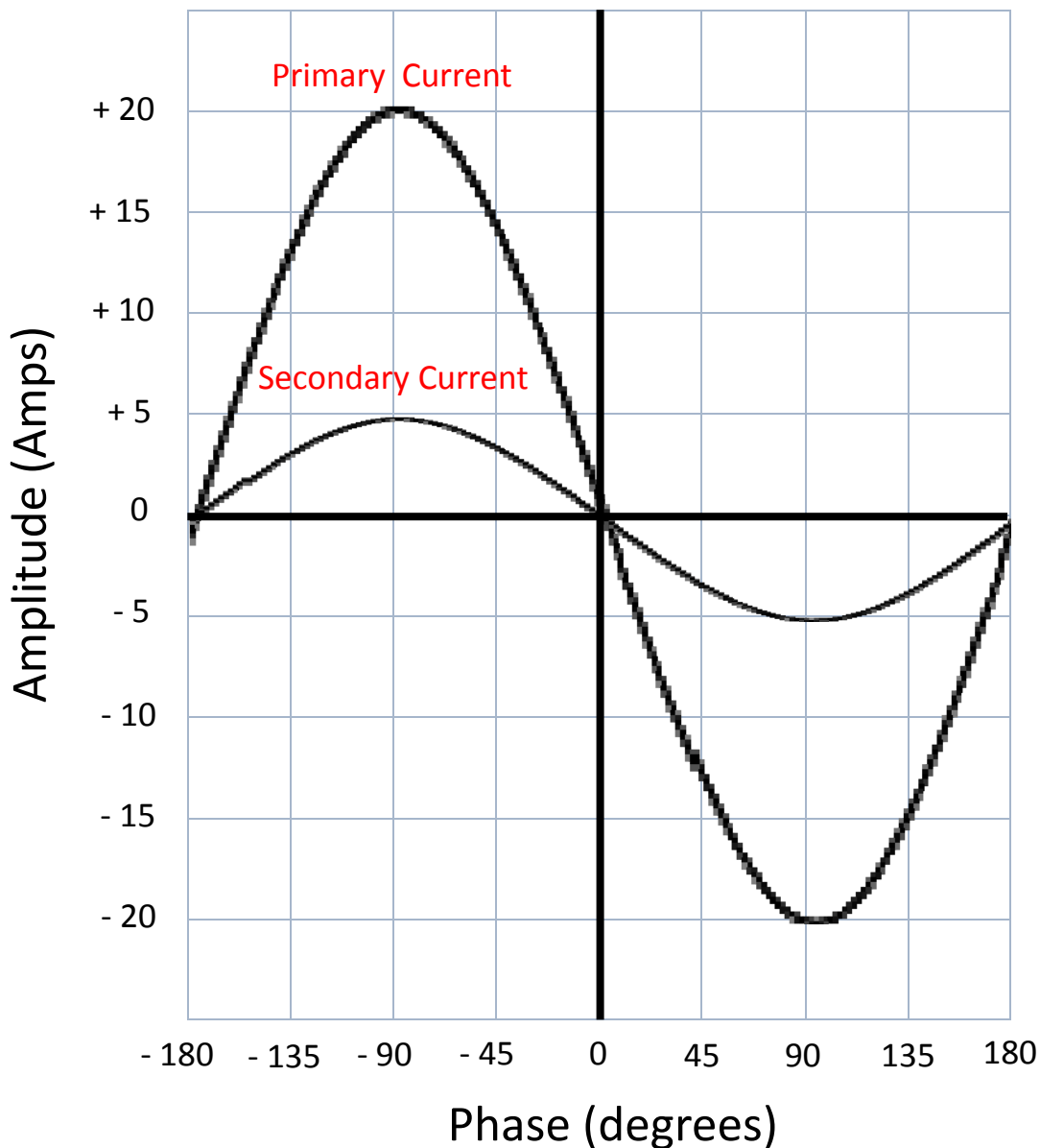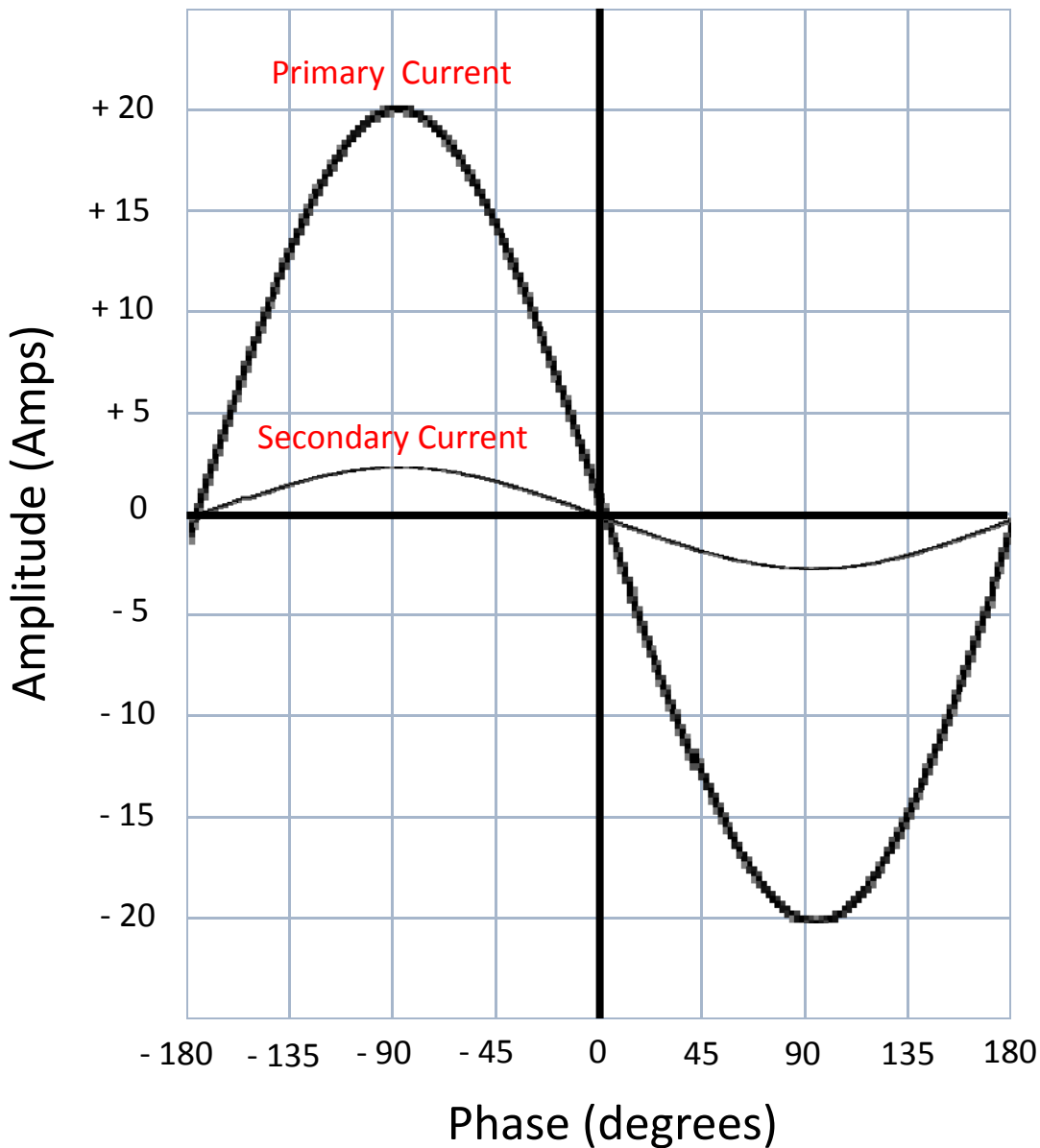CT Specs: Ratio = 20:5   Rating Factor = 2   Accuracy = 0.3   Burden Rating = 0.5

Figure 1.5

Figure 1.6 is an example of an error in the current waveforms when performing a CT ratio test. The amplitude of the primary current versus the amplitude of the secondary current does not match the ratio of the CT. Although there is no phase difference between the two signals, the secondary current is roughly 1/2 what we would expect it to be (2.5A instead of 5A). The CT could be damaged, labeled incorrectly, or the CT could be heavily overburdened among other things. The error would be related to the amplitude, and when tested with the PowerMaster this CT would FAIL.

CT Specs: Ratio = 20:5   Rating Factor = 2   Accuracy = 0.3   Burden Rating = 0.5
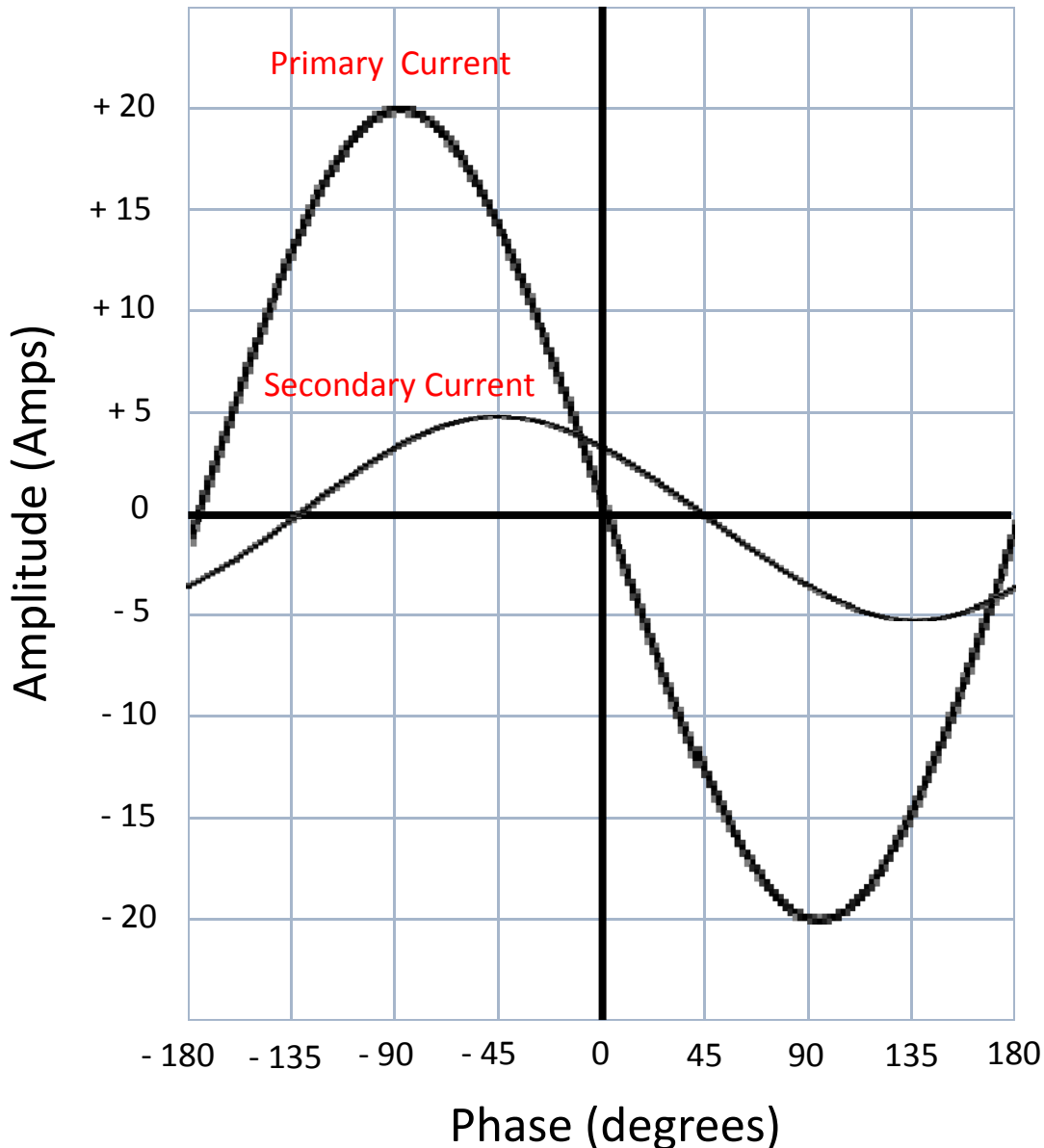

Figure 1.6

Figure 1.7 is another example of an error in the current waveforms when performing a CT ratio test. The amplitude of the primary current versus the amplitude of the secondary current matches exactly the ratio of the CT. However, the phase difference between the two signals is well outside its error limits. The error would be related to the phase, and when tested with the PowerMaster this CT would FAIL.

CT Specs: Ratio = 20:5   Rating Factor = 2   Accuracy = 0.3   Burden Rating = 0.5

Figure 1.7

We will now look at how the accuracy test is graphically represented in the PowerMaster via the IEEE definitions.

Figure 1.8 is the IEEE parallelogram used by the PowerMaster to determine if a CT ratio test passes or fails. This particular parallelogram is based on the 100% RATED LOAD of the CT. In our example, the test must fit within the red area if the primary current of the CT is between 20A and 40A. You will notice that as the amplitude error increases in the positive direction, there is more leeway in the phase error in the positive direction as well. This relationship is true in the negative direction as well. In this IEEE definition the amplitude error is based on the accuracy class of the CT (0.3% in our case).

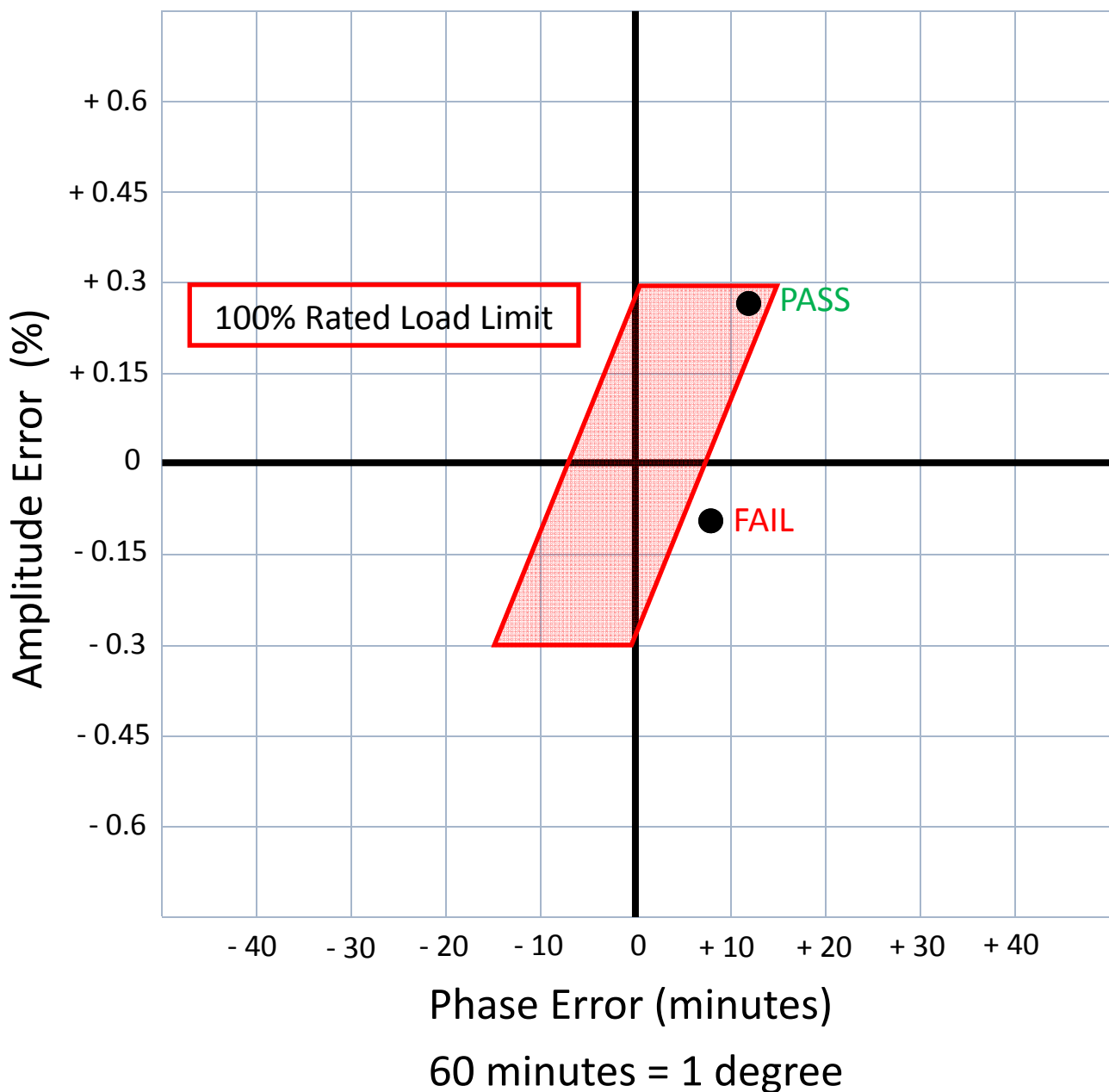CT Specs: Ratio = 20:5   Rating Factor = 2   Accuracy = 0.3   Burden Rating = 0.5

Figure 1.8

Figure 1.9 is based on the same CT, but if it were operating at 10% to 100% RATED LOAD of the CT. Per IEEE, the accuracy limit is doubled (from 0.3% to 0.6% in our case) under these load conditions. In our example, the test must fit within the blue area if the primary current of the CT is between 2A and 20A.

CT Specs: Ratio = 20:5   Rating Factor = 2   Accuracy = 0.3   Burden Rating = 0.5
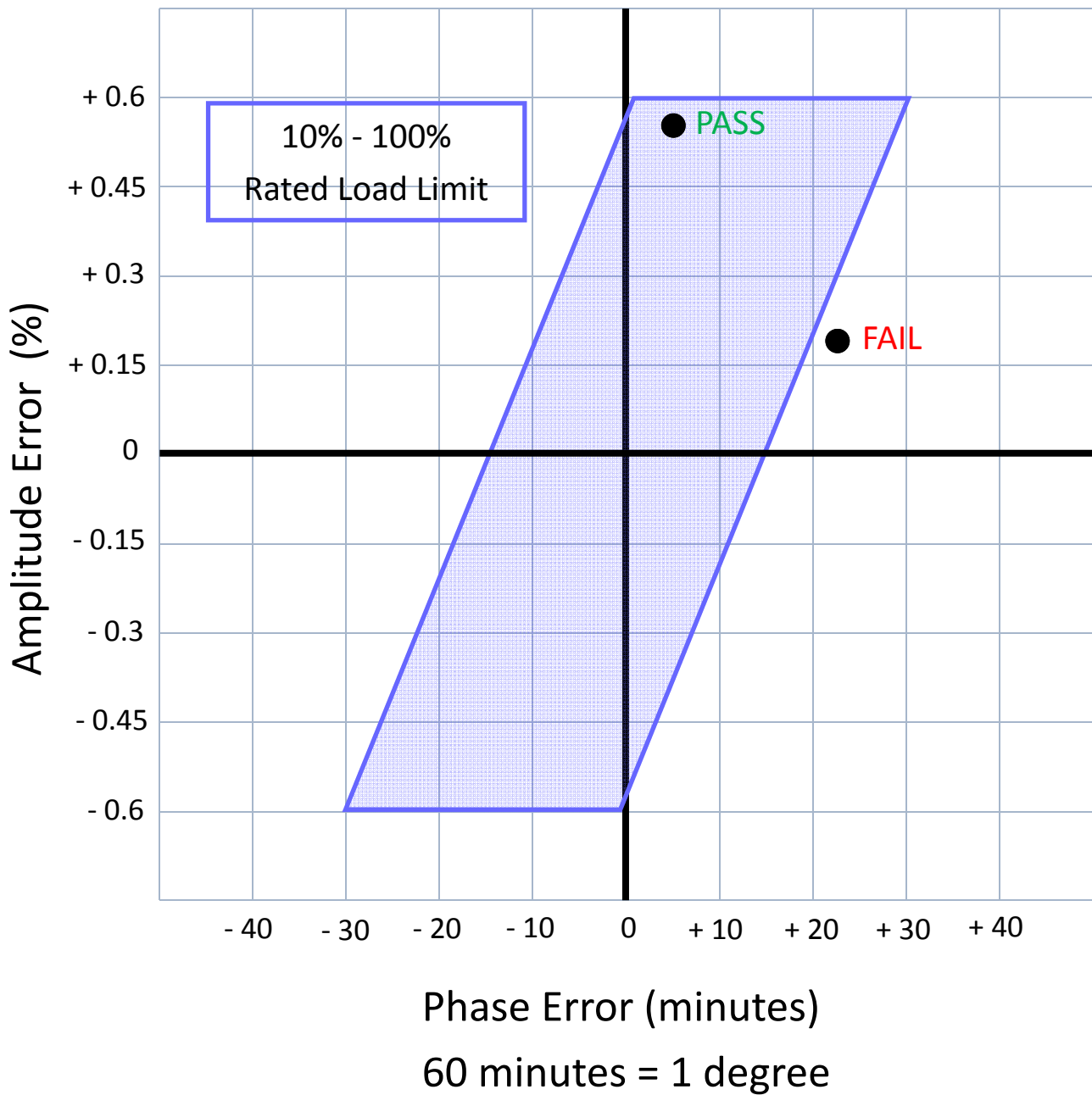

Figure 1.9

Figure 1.10 shows the two separate IEEE parallelograms together that the PowerMaster uses. Depending on the primary current of the CT that the PowerMaster measures, it will use the appropriate parallelogram to determine if the CT ratio test passes or fails. As an example, if the PowerMaster was testing the CT and we were reading 25A on the primary, the sample test points would be classified as pass or fail as shown below.
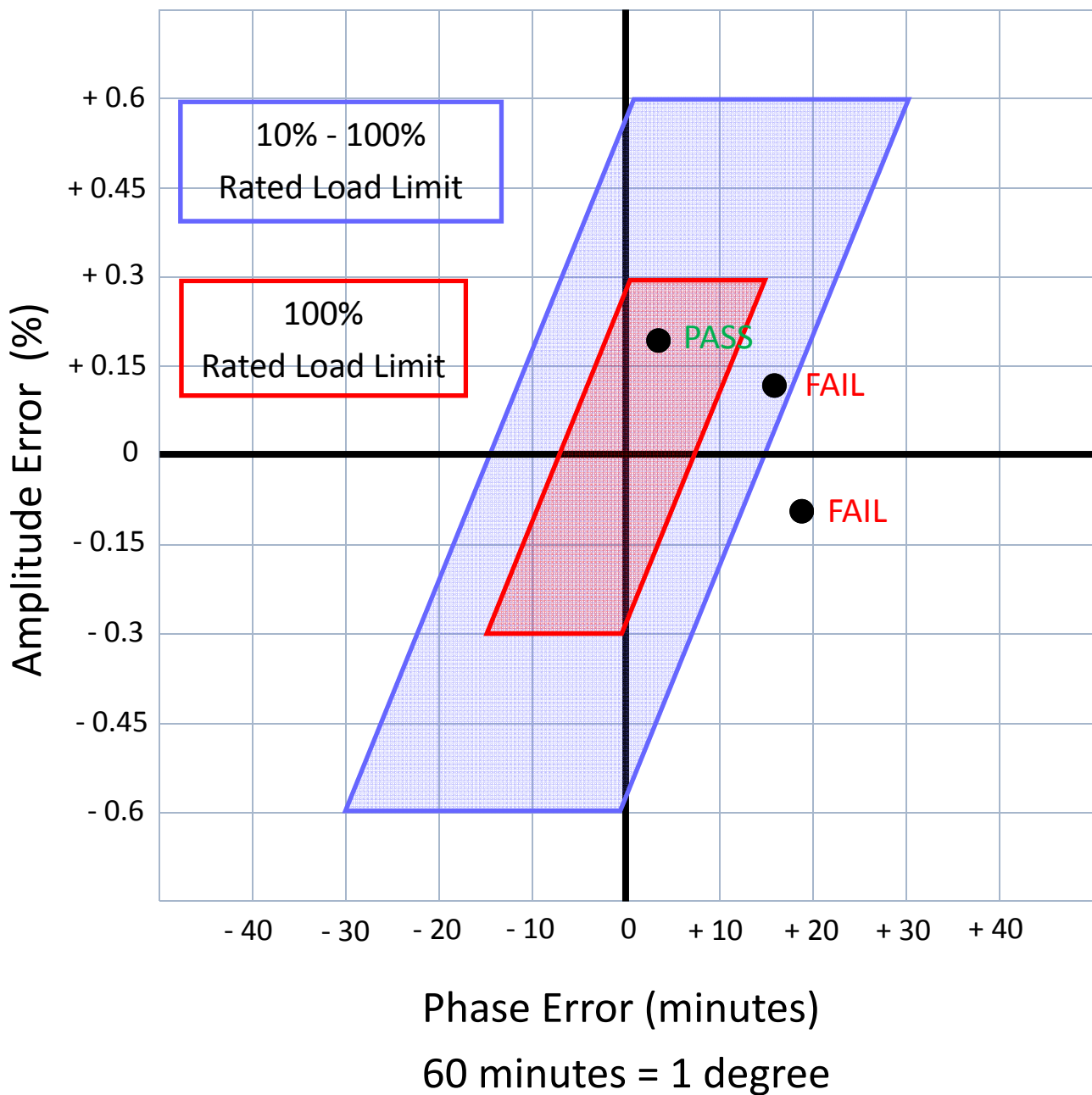
CT Specs: Ratio = 20:5   Rating Factor = 2   Accuracy = 0.3   Burden Rating = 0.5

Phase Error (minutes)

60 minutes = 1 degree

Figure 1.10

Most CTs that don't have internal defects and are not overburdened should pass testing when tested with direct (wire touching wire) connections. When testing in the field with a product like the PowerMaster, however, there are current probes that must be used to measure the primary (and sometimes secondary) current.

These probes have inherent inaccuracies in them simply because of their design. There are many issues that can influence the current probe and cause readings to vary slightly. These issues include placement of the probe around the conductor, the proximity of other probes and conductors, and the specific probe in use. Sometimes the inaccuracy of the probe itself can cause the CT test points to fall outside of the IEEE parallelograms and give fail messages when there is probably no error.

To alleviate this, Powermetrix has given the user an option of choosing different CT test error limits in the user preferences of the PowerMaster (see screen below). The pass/fail criteria will then by calculated in the following manner:

1.0X Specification Accuracy = use IEEE parallelogram definitions

1.5X Specification Accuracy = multiply IEEE parallelogram definitions by 1.5

2.0X Specification Accuracy = multiply IEEE parallelogram definitions by 2

3.0X Specification Accuracy = multiply IEEE parallelogram definitions by 3

User Defined Accuracy = enter multiplier for IEEE parallelogram definitions
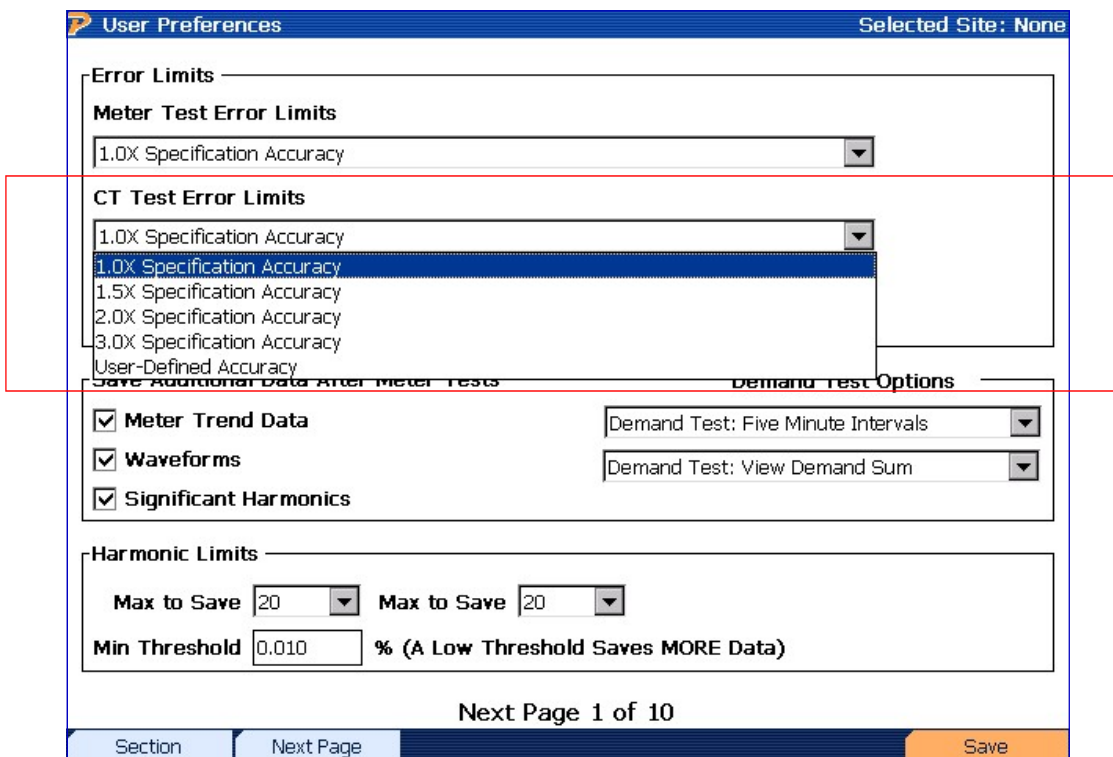

Figure 1.11 User Preferences for the PowerMaster (page 1)

The CT Test Error Limits designate how the PowerMaster will calculate the pass/fail criteria during a CT test. If the user would also like the graphical representation displayed, they must also select the correct designation in the user preferences menu shown below. There are three different options:

1) IEEE Accuracy Parallelogram - this option will only show the graphical representation of the normal IEEE parallelograms. There will be (2) total parallelograms shown - 100% rated load limits, and 10% to 100% rated load limits.

2) User Defined Accuracy Parallelogram - this option will only show the graphical representation of the normal IEEE parallelograms multiplied by the CT Test Error Limit chosen. There will be (2) total parallelograms shown - user defined 100% rated load limits, and user defined 10% to 100% rated load limits.

3) IEEE And User Defined Accuracy Parallelogram - this option will show the graphical representation of both the normal IEEE parallelograms and the IEEE parallelograms multiplied by the chosen CT Test Error Limit. There will be (4) total parallelograms shown - 100% rated load limits, 10% to 100% rated load limits, user defined 100% rated load limits, and user defined 10% to 100% rated load limits.
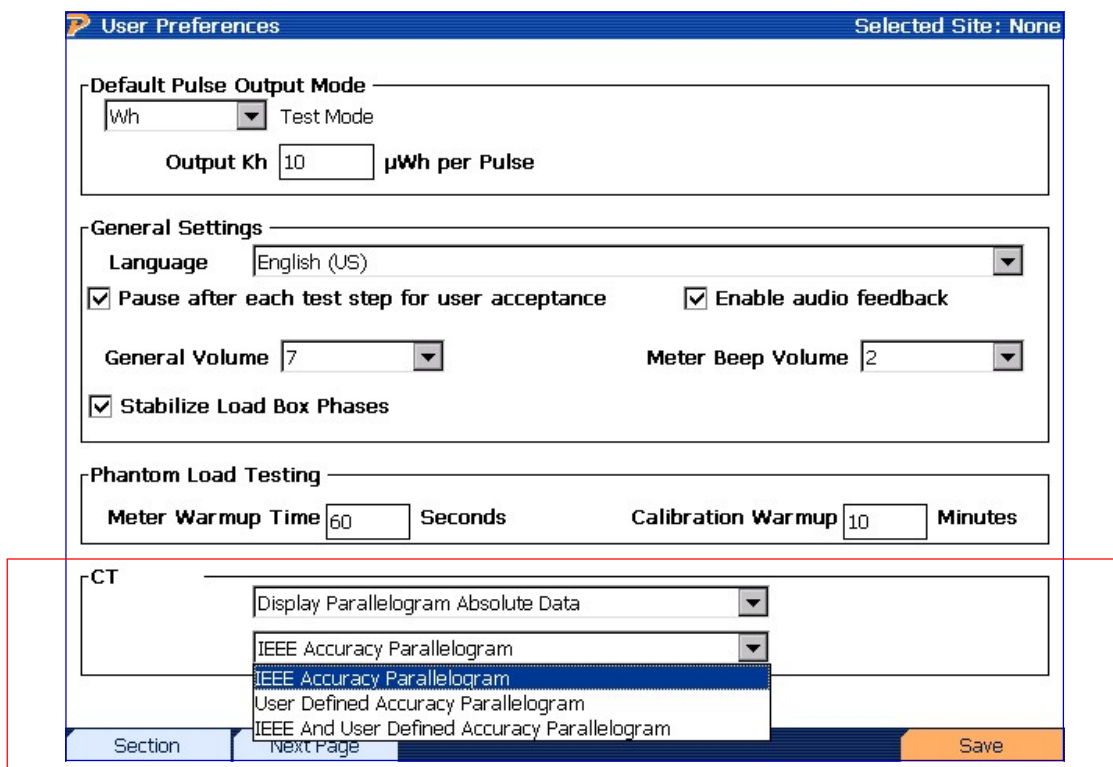

Figure 1.12 User Preferences for the PowerMaster (page 2)
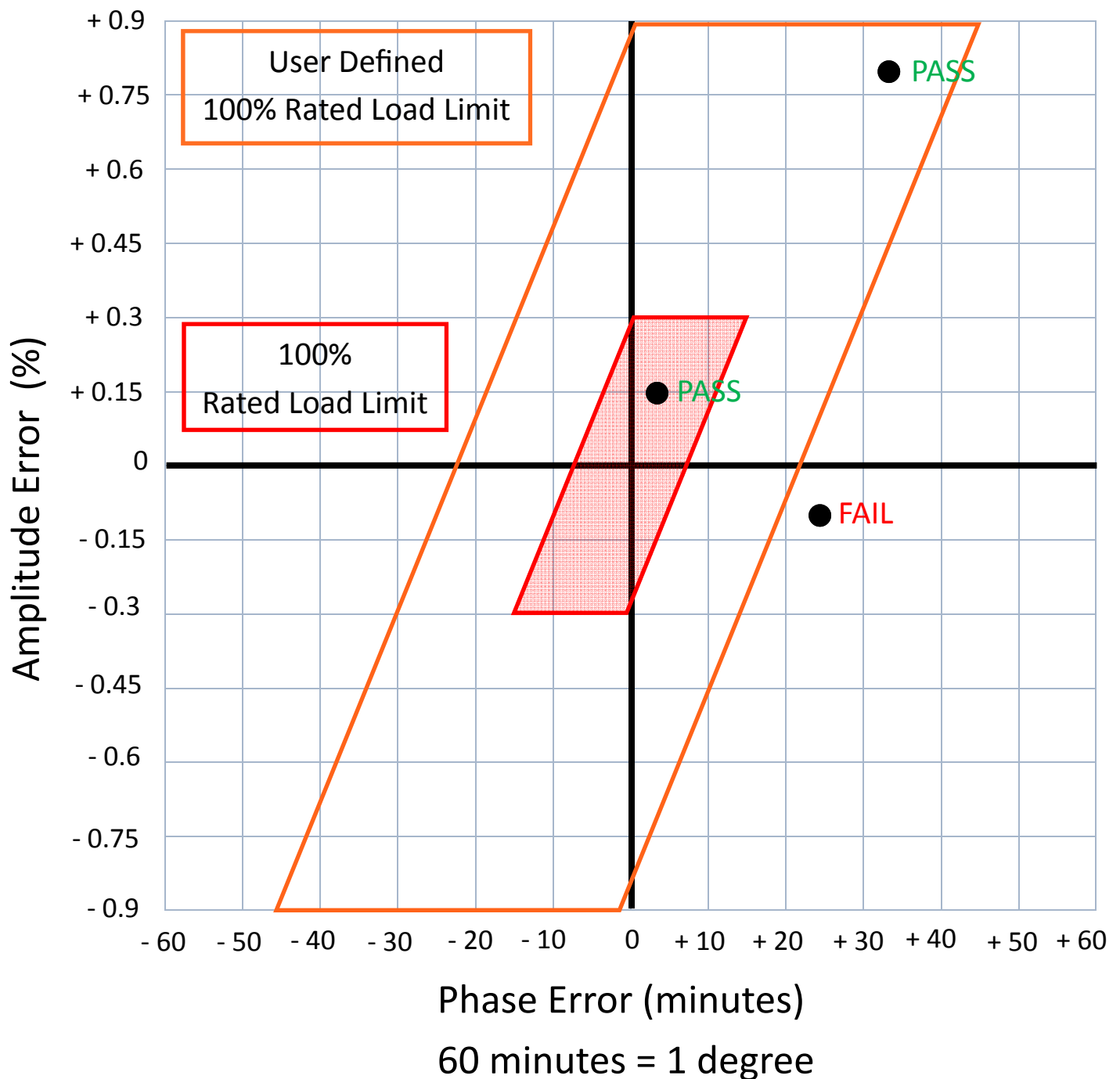
In Figure 1.13 we have chosen the 3.0X Specification Accuracy. If we consider that the 100% rated load accuracy of the CT is normally 0.3%, we can see that the 3.0X specification takes this number up to 0.9%, and the parallelogram expands accordingly in both the amplitude and phase error allowed. Therefore, if the CT is operating in that condition (primary current between 20A and 40A) the following examples of test points will have the corresponding pass/fail designations.

CT Specs: Ratio = 20:5   Rating Factor = 2   Accuracy = 0.3   Burden Rating = 0.5
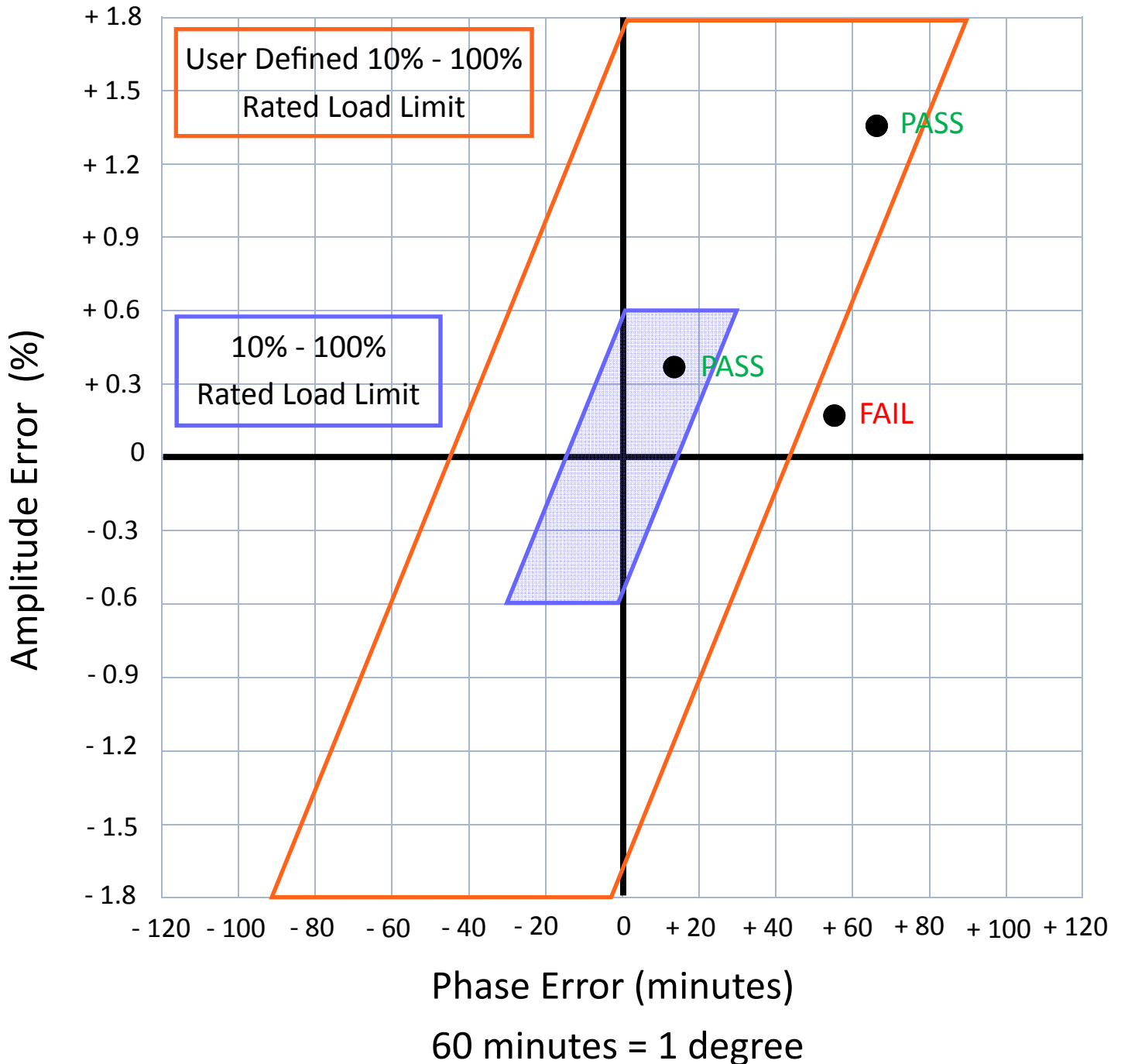

Figure 1.13

In figure 1.14 we are continuing with the 3.0X Specification Accuracy. If we consider that the 10% to 100% rated load accuracy of the CT is normally 0.6%, we can see that the 3.0X specification takes this number up to 1.8%, and the parallelogram expands accordingly in both the amplitude and phase error allowed. Therefore, if the CT is operating in that condition (primary current between 2A and 20A) the following examples of test points will have the corresponding pass/fail designations.

CT Specs: Ratio = 20:5   Rating Factor = 2   Accuracy = 0.3   Burden Rating = 0.5

60 minutes = 1 degree

Figure 1.14

In figure 1.15 we are continuing with the 3.0X Specification Accuracy. If we have chosen only IEEE Accuracy Parallelograms to be displayed, the following would be shown on the PowerMaster screen.

CT Specs: Ratio = 20:5   Rating Factor = 2   Accuracy = 0.3   Burden Rating = 0.5
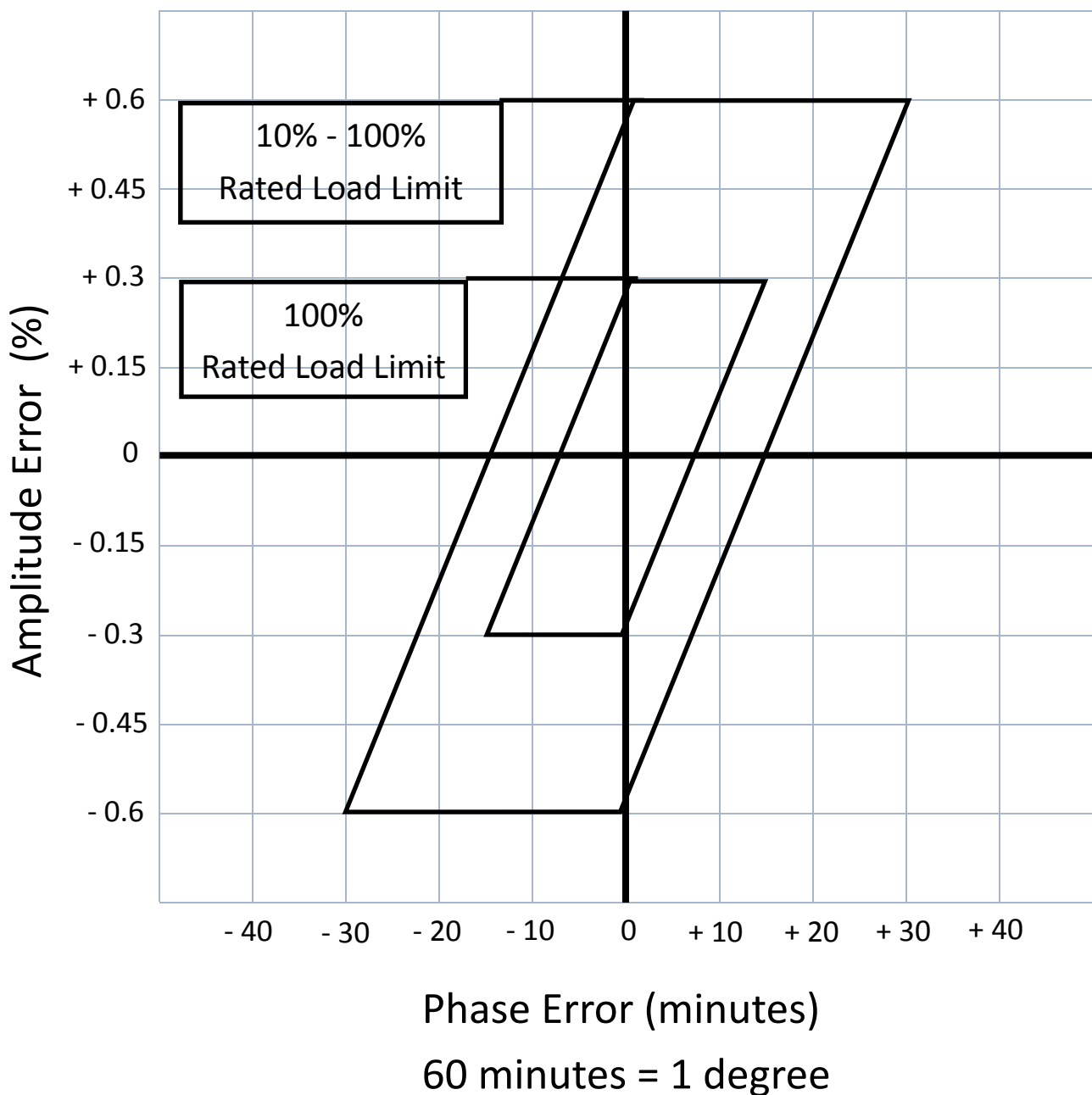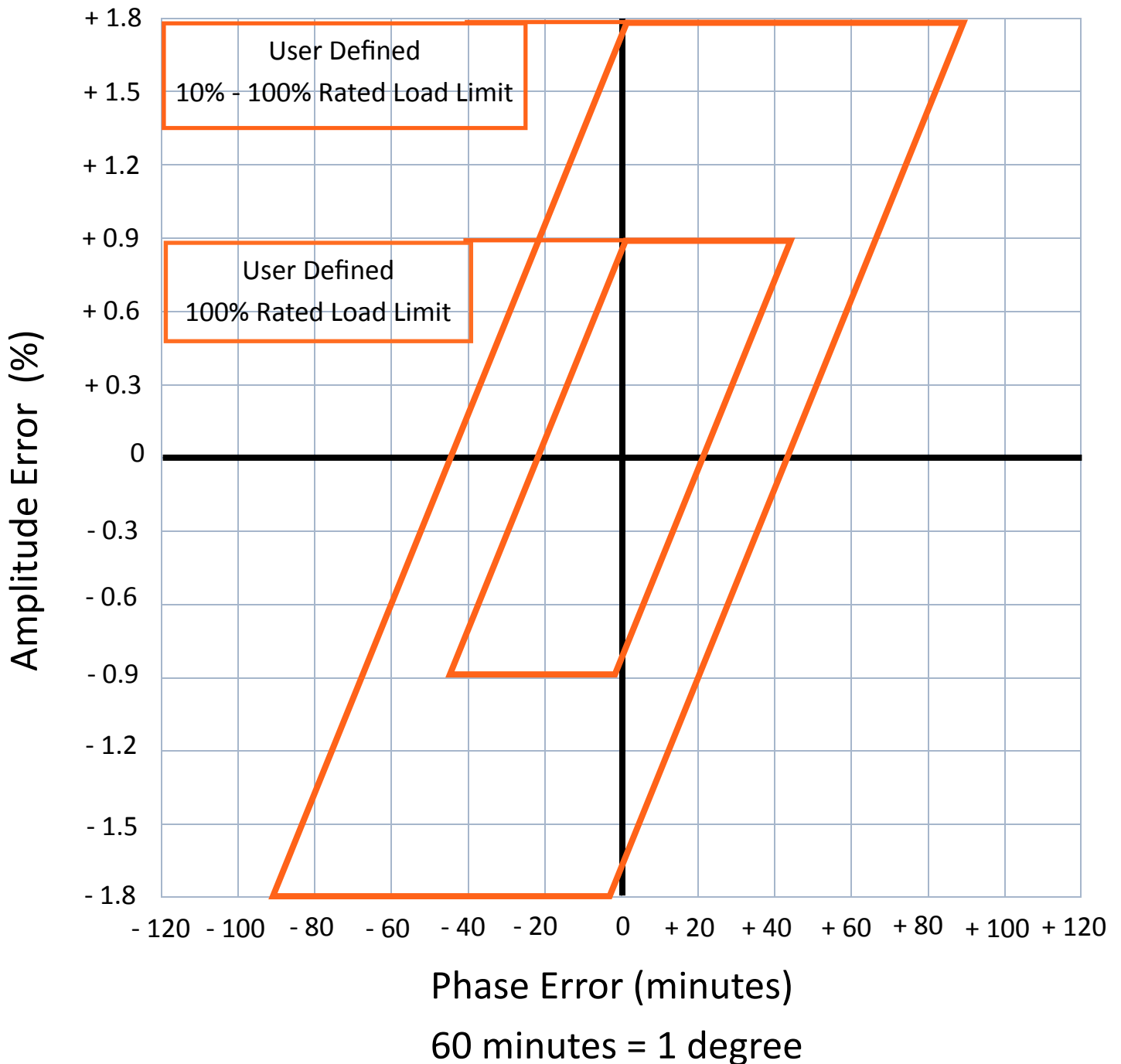

Phase Error (minutes)

60 minutes = 1 degree

Figure 1.15

In figure 1.16 we are continuing with the 3.0X Specification Accuracy. If we have chosen only User Defined Accuracy Parallelograms to be displayed, the following would be shown on the PowerMaster screen.

CT Specs: Ratio = 20:5   Rating Factor = 2   Accuracy = 0.3   Burden Rating = 0.5

Figure 1.16

In Figure 1.17 we are continuing with the 3.0X Specification Accuracy. If we have chosen both IEEE And User Defined Accuracy Parallelograms to be displayed, the following would be shown on the PowerMaster screen.

CT Specs: Ratio = 20:5   Rating Factor = 2   Accuracy = 0.3   Burden Rating = 0.5

Phase Error (minutes)

60 minutes = 1 degree

Figure 1.17

Burden Only CT Testing

In this section of the white paper we will discuss the Burden Only portion of CT testing.

When selecting a Burden Only test the user has the ability to choose the maximum burden applied during the test.

Figure 1.18 CT Test Setup for the PowerMaster

When performing a CT Burden only test, the PowerMaster must have a direct connection to the secondary terminals of the CT. This can be accomplished by shorting the CT via the bypass bar and connecting directly to the secondary terminals or by connecting to a test switch.

In this example, the user chose to perform a burden only test up to 0.5 ohms. Figure 1.19 is the graphical representation of how the secondary current dropped as burden was added.
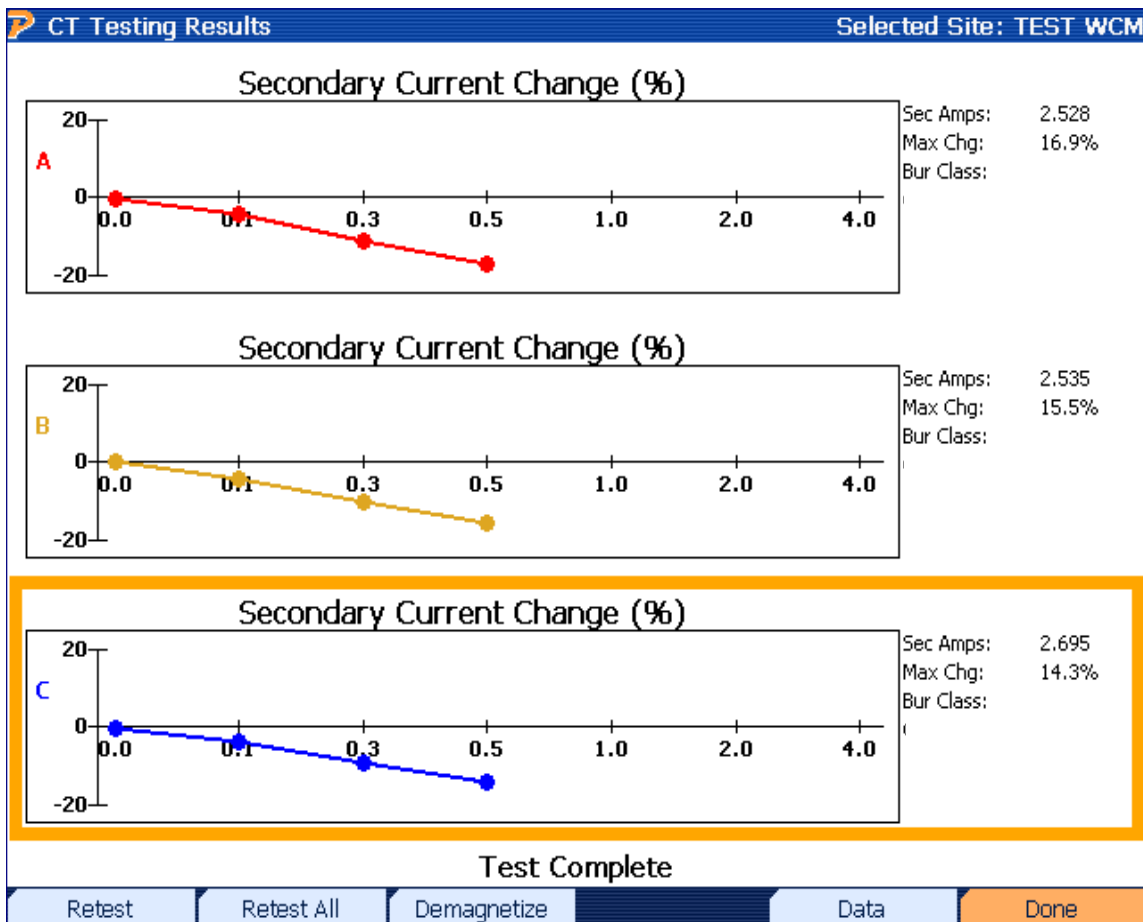

Figure 1.19 CT Burden Test Results for the PowerMaster

Burden and Ratio CT Testing

In this section of the white paper we will discuss the Burden and Ratio portion of CT testing. This is the most accurate and complete way to test CTs in the field.

When selecting a Burden and Ratio CT test the user has the ability to choose the maximum burden applied during the test.

Figure 1.20 CT Test Setup for the PowerMaster

The graphical representations for the burden and ratio test follow all the same rules as we defined earlier in the ratio only portion of this white paper. The only difference is that there will be multiple test points depending on the maximum burden the user has selected. For example, if the user selected 1.0 ohms as the maximum burden, the test points would correspond to the multiple test points as shown in Figure 1.21. This illustrates that as the secondary current drops (because of extra applied burden), the ratio can also change in amplitude and phase error. All pass/fail designations are based on the FIRST test point.

CT Specs: Ratio = 20:5 Rating Factor = 2 Accuracy = 0.3 Burden Rating = 0.5
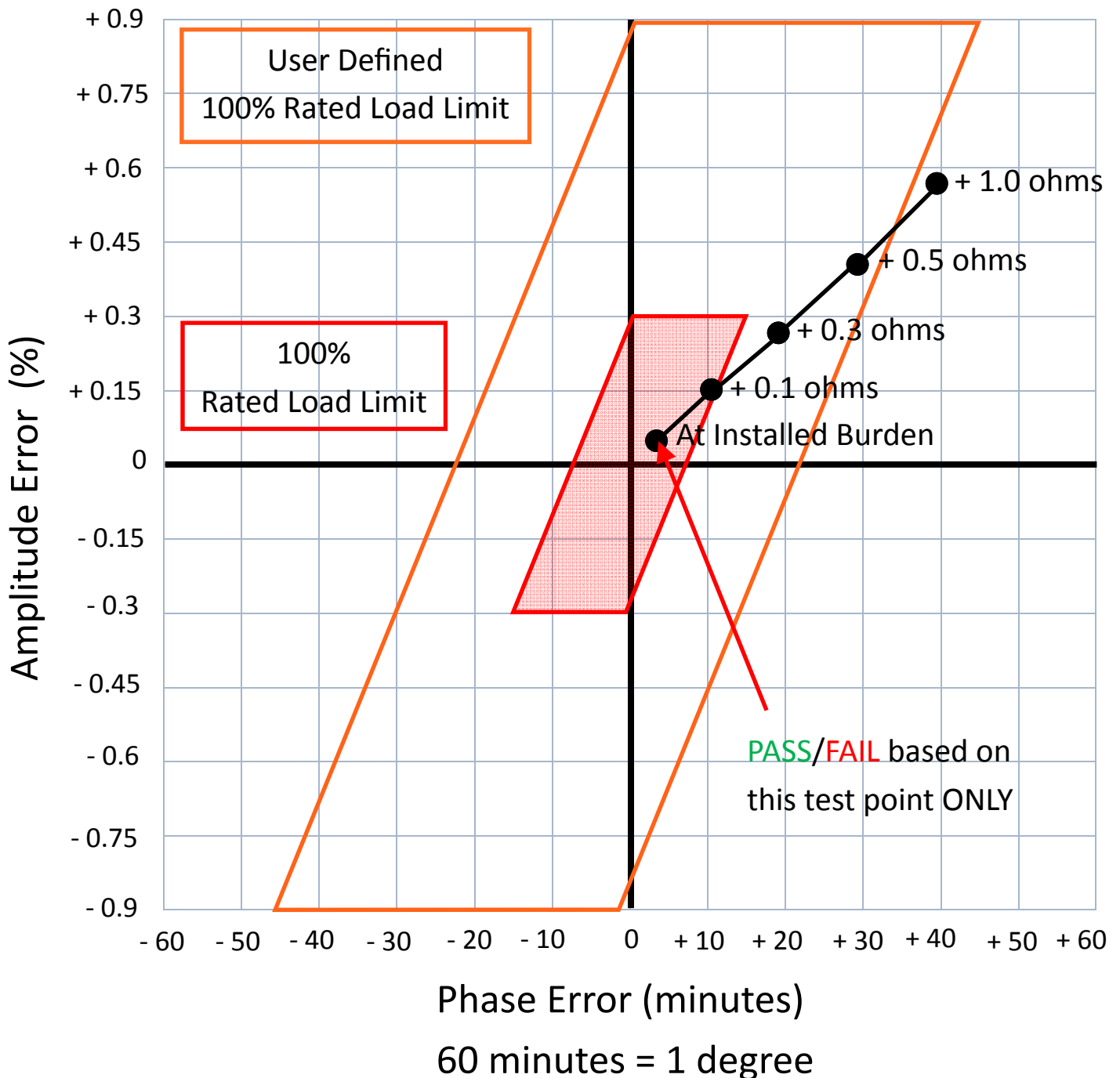

Phase Error (minutes)

60 minutes = 1 degree

Figure 1.21

Conclusion

When testing instrument transformers, the PowerMaster has the ability to analyze and display the data to the user in a practical format. However, understanding the nature and limitation of a CT becomes paramount when interpreting the data. This paper should now educate the user on the functional aspects of a CT and what results should be expected when certain attributes are present. This paper should also guide the user on how to configure the PowerMaster to yield expected results that can be presented in a fully educated manner.