Good Morning

My name is Tom Field and I work for Southern Company Services in Alabama.
This is my first time at a Switchgear committee meeting, so you probably don’t know me.
I am here to present some problems that we have encountered in analyzing system needs based on breaker TRV requirements.

Slide 1

The basic problem that we are going to discuss is the new TRV standards that address the requirements of circuit breaker manufacturers, but do not give enough information for utilities to perform TRV studies against a standard. Because of this, we are giving a presentation on the problems with the standards as seen from a utility perspective.

Slide 2

While performing a TRV study on a new generator, we found that C37.013 did not give enough information to perform the study. We then submitted this question to the IEEE to get the information needed to perform future generator TRV studies. We are waiting for the response and have come here to give further background on the problem.

Slide 3

We are going to talk about how we as a utility have applied the TRV standards to our TRV studies using C37.011 as an example, then the problem with C37.013, then the problem with the potential changes to C37.011, and finally some possible solutions to the problems.

Slide 4

Utilities have a three-step process involved in TRV studies. We generate a reference level from a standard, then generate the system response, and finally compare to see if the system is acceptable or if capacitance is needed to make the system response acceptable.

Slide 5

The standard gives an ideal circuit breaker response curve which is the minimum requirements for the circuit breaker manufacturer. Because we may get a breaker with a capability this low, but not lower, we generate this waveshape in a computer program.

Slide 6

The current C37.011 standard gives equations that define this minimum curve which is used in our program to generate it. We use this curve for comparison to our actual system response in a single graph.

Slide 7

The two types of curves which we use most in C37.011 are the three phase bus fault and the short line fault.

Slide 8

The curve for the three-phase bus fault in C37.011 is shown graphically as an exponential and then a 1-cosine waveshape.

Slide 9

The equations for the line shown here are given in the standard.

Slide 10

Data in this table and figure define the variables in the equations. Together, the equations and this information define the minimum breaker TRV capability curve.

Slide 11

This slide shows the program that we use to generate the curve just shown. It is a fairly simple program. We usually use EMTP for circuit analysis, so the logic for this code is in the TACS language of EMTP.

Slide 12

This graph shows the programmed equations output of the breaker capability curve defined in C37.011 for a specific circuit breaker.

Slide 13

A similar set of equations and implementation is given for the Short Line Fault in C37.011.

Slide 14

These are the equations for the short line fault. We have a similar program for generating the output, but those are details beyond the scope of this presentation.

Slide 15

Now, we have shown how we generate a set boundary for the lower limit on circuit breaker capability curve. This is also a boundary for the upper limit on the system response curve. Because of this, we generated and graphed the curve using the equations defining the curve or boundary in the standard. Now, we model the system response in the same simulation program. For the three-phase bus fault, we look at the first pole to open and graph the voltage across it. If it exceeds the minimum boundary after a comparison is made, then capacitance is added to the circuit simulation to bring the system response down below the circuit breaker minimum capability curve. We will discuss the details of the three-phase bus fault circuit simulation now. A similar simulation is performed for the short line fault.

Slide 16

To generate the system response, we use a fairly simple circuit consisting of capacitances and inductances. We fault all three phases and monitor the voltage across the first contact to open.

Slide 17

This is a simplified diagram of the circuit being simulated. The open switch labeled “First Pole to Open” represents the circuit breaker that we are simulating the TRV for. We may have resistance as well depending on the circuit being modeled. The fault current is the current that would be available to the fault before interruption by the circuit breaker.

Slide 18

This shows the circuit simulation program that we would use for the circuit just shown. This particular simulation is in EMTP, so it can be used along with the program for the generator capability curve shown earlier in a single file.

Slide 19

This is the system response for the program just shown.

Slide 20

We make a comparison between the two graphs as shown here.

Slide 21

The problem with C37.013 is that it does not give a specific set of equations defining the lower limit for the circuit breaker capability curve. The range given is useful for manufacturers to know what they must do, but not specific enough for a comparison to a system response. Because of this lack of a clear boundary for the lower limit on the manufacturer's TRV capability curves in C37.013, we are unable to perform system studies to determine whether or not capacitance is needed.

Slide 22

The standard gives a rate of rise, a time delay, and a time to the maximum voltage E2 as well as the maximum voltage. It states that the curve should be tangent to the Rate of Rise (ROR) line at some point, but does not define that point. It states that there is a curve near the top, but does not specify the equation for the curve nor the time range for the curve. Basically, there is not a set of equations defining the minimum required TRV capability for circuit breakers in the current version of C37.013.

Slide 23

This is the graph of the curve given in C37.013. You can see a range is given at the beginning, but no time is give for when the range between the time delay and the ROR line ends. After this, we can see that it is tangent at some point, but where and when is not defined. We can see that the ROR line intersects the maximum value at some time T3, but the actual curve hits the maximum at T2. There is no equation or time given for the curve between the tangent point on the ROR line and the maximum at T2.

Slide 24

This gives a description of the graph just shown. Again, what we just discussed is described here. It is stated that the curve "has approximately a 1-cosine waveshape" between some tangent point and T2, but as will be shown in a little bit it is not a 1-cosine waveshape that is defined.

Slide 25

The standard defines a System Source Fault and a Generator Source Fault with different sets of parameters for the curve range. The System Source Fault has a long delay and a short T2 time which gives a large window for the system response. Because of this, a 1-cosine waveshape can fit between the ROR line and the delay line.

Slide 26

This is the table in the standard for the system source fault which gives the time T2, rate of rise, and time delay in the note below the table. This is the only data given for defining the curve in definite details.

Slide 27

This is the graph of an actual system response, the ROR line for the circuit breaker, the delay line, and the E2-T2 point and then a 1-cosine waveshape. The black line is the system response which you can see fits inside the window (this response is similar to a 1-cosine wave).

Slide 28

The generator source fault has a short time delay and a long T2, so it generates a small window which does not allow a 1-cosine curve to fit in.

Slide 29

This shows the data in the standard for the generator source fault. Again, this is the only definite data available for the circuit breaker capability curve.

Slide 30

This is a simulation of the generator source fault for the same circuit, the ROR and delay line, and the E2-T2 point and then a 1-cosine waveshape. You can see the narrower window in this graph. One problem is in this graph where the circuit breaker and the system response curve leave the delay line near the top.

Slide 31

This shows the problem a little better. You can see that the 1-cosine curve crosses the system response curve past the delay line. However, since this area is not clearly defined, it cannot be determined whether or not this system response is acceptable from the standard.

Slide 32

We have shown how we perform TRV studies with C37.011, the problem in C37.013 which prevents us from performing these studies, and now we will show a potential problem with the proposed changes to C37.011. This may give the same problem to C37.011 that we have with C37.013.

The IEC is harmonizing with the IEEE, so the IEC standard 56 waveshapes are being used to replace the defined functions in IEEE C37.011. The IEC standard gives a 2 parameter and a 4 parameter function. These functions provide some limits for the circuit breaker manufacturers by providing ranges, but do not address the needs of utilities.

Slide 33

This shows the 2 Parameter function of IEC 56. You can see that this is similar to C37.013.

Slide 34

This shows the 4 Parameter function of IEC 56. A 4 parameter function is being proposed for C37.011. If it is not implemented carefully, the same problems that utilities have with C37.013 will appear in C37.011.

PAUSE

QUESTION TO VERIFY NO SOLUTION BEFORE CONTINUING ON TO PROPOSED SOLUTION
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Slide 35

Some possible solutions are the IEC reference waveshape which is not a good solution because some of the curve can drop below in undefined regions. The Delay Line to E2 is another possibility, but E2 will be reached before T2 in some cases and the breaker will drop below this in the current standard. The delay line to some percentage of T2 and then a jump to the ROR line could be used. A slope between the end of the delay and another percentage of T2 at the tangent point could be added. Finally, a curve from the tangent point to the T2 point could be defined.

Slide 36

This shows the problem with only specifying the end of the delay line and then going to the ROR line. You can see that the circuit breaker curve continues below the ROR line until the tangent point.

Slide 37

This shows a slow between the end of the delay line and the tangent point on the ROR line. In this particular graph, voltages instead of percentages of time were used. The delay line was specified to end at 30% E2 and the tangent point was specified as 40% E2.

Slide 38

This shows the problem between the tangent point and T2. You can see that the ROR line to E2 is above the circuit breaker response. A 1-cosine waveshape is below the breaker response and does not touch the ROR line. Another curve is shown below the circuit breaker response from the tangent point to T2. This is a curve that has to be defined.

Slide 39

This shows one possible solution to the problem in C37.013. This consists of defining the point at the end of the delay line, the tangent point (a constant slope line between the end of the delay line and the tangent point), and a curve function between the tangent point and E2 at T2. However, it is up to the committee members to determine the solution and then return their answer to our question. Thank you for your time.

Slide 40

We have shown the method of analysis used by utilities, the possible problems, the IEC waveshapes, and a possible solution. We'll go through some work done on a generic solution which could be used in the IEC and IEEE standards. We will start with a 5 segment solution which can be altered to the 4 segment line just discussed by removing L3.

Slide 41

These are the equations which define the generic solution.

Slide 42

These are the parameters which are needed. You will notice that a column for a, b, and c need to be inserted into the tables. You will also notice that the rate of rise currently in the table is not needed because E2 and T3 derived from T2 are already specified by the tables.

Slide 43

Here we see the graph using values of 10% for a, 30% for b, and 50% for c. You will notice that the 1-cos waveshape is greater than the rate of rise line at the beginning.

Slide 44

We have altered the algorithm to use the rate of rise line as the lower boundary when the 1-cos is greater.

Slide 45

Here is the program which is used to generate this generic solution.

Slide 46

Here is a graph using 30% for a and 50% for b similar to the earlier discussion of problems with a suggested solution. We have added a point at 70% for c.

Slide 47

This shows the same waveshape out in time a little to see that the 1-cos is centered around cE2.

Slide 48

To go back to the 4 parameter line which was the suggested solution earlier, the equations can be slightly modified as shown in this graph. Basically, L3 was removed and the lower limit on L4 is now T4 instead of T5. However, T5 was left in the equations as a parameter to specify where the 1-cos argment is centered. This is still specified by c and b specifies where L2 ends and L4 begins.

Slide 49

Here we see the output similar to the graph in C37.013. We have used 10% for a, 60% for b, and centered the cosine wave around 67.5% for c.

Slide 50

Here is the modified program.

Slide 51

A final proposal for a solution is obtained by looking at an actual TRV curve. You see the short delay, a slope with rate of rise higher than rate of rise line, a segment along rate of rise line, and an oscillation around some point.

Slide 52

For a final set of equations to define the minimum TRV capability curve, the standard should specify break points a, b, and c for the 5 segment line. We standard should also specify the point that the waveshape will oscillate around. Finally, the last segment of the curve should be calculated based on the starting point.

Slide 53

We will modify the time in segment L4 and the equation of L5. We will add a parameter d for the point that the 1-cosine waveshape is centered around. We will calculate a starting point in the curve, Tx, by setting the point where line segment 4 is equal to line segment 5 by setting the two equations equal with t replaced by T5.

Slide 54

These are the equations that will be used.

Slide 55

These are the parameters to specify in the standard.

Slide 56

This is the equation from the standard generated by this method. You will notice that L4 and L3 do not meet. It is believed that roundoff error in TACS has caused L5 to start at 93% instead of 90%.

Slide 57

This is the program used to generate the previous graph.

Slide 58

We have shown the methods that utilities need to analyze waveshapes, the problems with the new methods from the IEC, and some possible solutions which could be used by both the IEC and IEEE for C37.013. We have also pointed out that similar problems and solutions will be needed for the proposed changes to the C37.011 TRV standard. If you would like any of the programs used in this presentation, please let me know and I will send them to you or give to the committee to post on the internet after the meeting.

I am not from a manufacturing background and may not be able to answer your questions, but please feel free to ask me any questions on what I have just presented.