

SHORT CIRCUIT AND ARC FLASH EVALUATIONS USING AMPSENTRY CAPABILITY

White Paper

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PART 1

Cummins PowerCommand® controls have an overcurrent protection and fault current regulating feature called AmpSentry. AmpSentry is UL listed as a protective relay and is included in SKM software as a motor overload protection device. AmpSentry also has a maintenance mode function which meets the requirements of NEC 240.87 for arc flash mitigation.

The details of the AmpSentry functionality have been discussed in other papers. In this paper we will demonstrate how to incorporate AmpSentry Maintenance Mode into short circuit and arc flash studies with SKM software. We will also show with a simple example how AmpSentry Maintenance Mode reduces arc flash incident energy. This paper assumes the incident energy calculations based on AmpSentry and alternator characteristics only. PowerCommand controls can be configured to shunt trip a breaker in the event of an overcurrent condition. If a circuit breaker has been applied one could use the breaker clearing time to calculate incident energy on the load side of the breaker.

SYSTEM ONLINE

We will start by creating a very simple system consisting only of a generator set, the AmpSentry protective function and a bus. See Figure 1.

First we will model the generator set. Select the Component Editor for the generator set (see Figure 2). On the synchronous generator submenu enter the rated voltage and kW or kVAR for the generator set. Notice that SKM calculates the full load current based on those parameters.

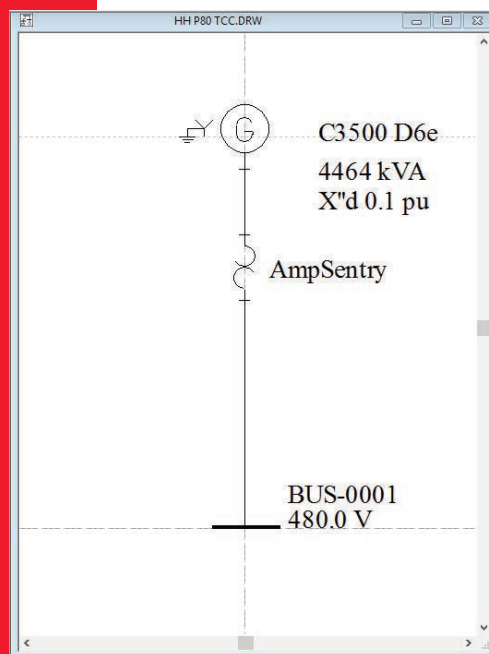


Figure 1 – SKM single line drawing generator set with AmpSentry overcurrent protection

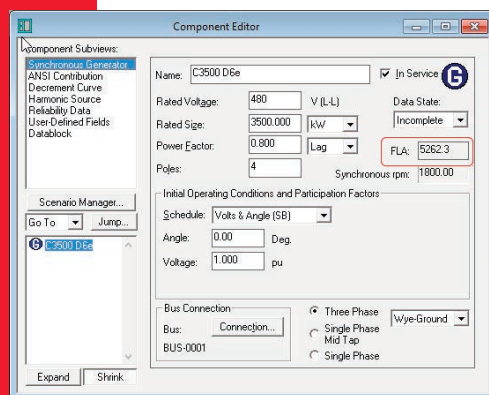


Figure 2 – Generator Set Component Editor



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Select the ANSI contribution submenu.
(See Figure 3.)

Enter the reactances and time constants from the alternator data sheet (see Figure 4). For kVA base make sure that you enter the kVA rating that is used as the basis for the per unit reactances on the alternator data sheet. Notice that the reactances in the spec sheet are based on the 125 C kVA rating so this is the kVA value that should be used in the analysis. Do not select the “Link with Rated” box in the ANSI contribution submenu (Figure 3) because that will cause SKM to use the generator set kW rating as the basis for the per unit reactances.

Select the decrement curve submenu in SKM.
See Figure 5.

Select the “Link w/ Contribution” box. This will import the values you entered on the ANSI Contribution sub menu. The value for I_{fg} represents the field current at rated voltage and no load and it can be found on the alternator data sheet. The value for I_f is set to model the fault current regulation function of AmpSentry. When an excitation system has field forcing, as AmpSentry does, SKM software calculates that current as $1/X_d \cdot I_f / I_{fg}$. AmpSentry regulates current to 300% of the generator set rated current. To model this set the value for I_f to $3 \cdot X_d \cdot I_{fg} \cdot (\text{gen kVA rating} / \text{alternator kVA rating})$. Scaling by the ratio of the generator set to alternator kVA ratings accounts for the fact that X_d is based on the alternator kVA rating and AmpSentry regulates current to 300% of the genset kVA rating.

Data for the alternator damage curve may be entered as well and is available from Cummins Power Generation however entering the damage curve is not necessary because the AmpSentry trip curve inherently protects the alternator from thermal damage.

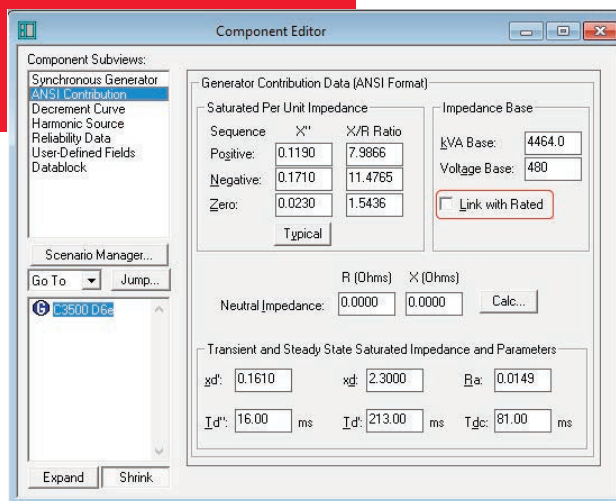
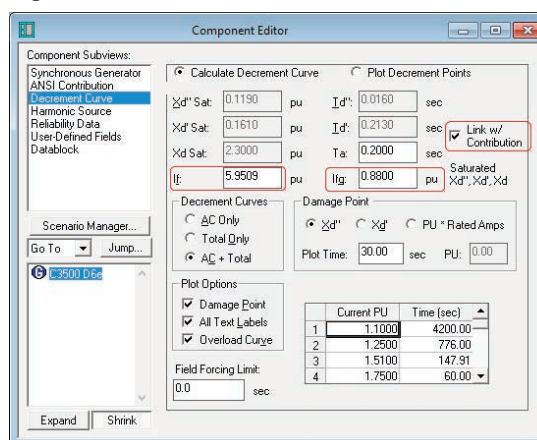


Figure 3 – ANSI Contribution Sub menu

ALTERNATOR DATA SHEET		Frame Size LVSI804X	
CHARACTERISTICS No of Bearings: 2 Stator Assembly: 10141 lb 4600 kg Rotor Assembly: 4184 lb 1888 kg Complete Assembly: 18289 lb 8298 kg			
MAXIMUM SPEED: 2250 RPM EXCITATION CURRENT: 3.94 Amps Full Load: 0.88 Amps No Load: 0.88 Amps			
INSULATION SYSTEM: Class H Throughout			
3 Ø RATINGS (0.8 power factor) (Based on specific temperature rise at 40°C ambient temperature)		60 Hz Voltage (winding no)	
163°C Rise Ratings @27°C		440 (12)	415 (12)
150°C Rise Ratings		3920 (12)	3680 (12)
125°C Rise Ratings		4900 (12)	4600 (12)
105°C Rise Ratings		3816 (12)	3571 (12)
80°C Rise Ratings		4770 (12)	4464 (12)
REACTANCES (per unit ± 30%) (Based on full load at 125°C Rise Rating)		440 (12)	415 (12)
Xd – Synchronous		2.558	2.300
Xd' – Transient		0.176	0.161
Xd'' – Subtransient		0.130	0.119
X2 – Negative Sequence		0.186	0.171
X0 – Zero Sequence		0.025	0.023
MOTOR STARTING Maximum kVA (90% Sustained) Voltage		14781 (12)	14781 (12)
TIME CONSTANTS (Sec)		440 (12)	415 (12)
Td – Transient		0.213	0.213
Td' – Subtransient		0.016	0.016
Td'' – Open Circuit		5.100	5.100
Ta – DC		0.081	0.081
WINDINGS (±20°C)		440 (12)	415 (12)
Stator Resistance (Ω/phase)		0.000256	0.000256
Rotor Resistance (Ω)		1.630	1.630
Number of Leads		6	6

Figure 4 – alternator spec sheet

Figure 5 – SKM decrement curve submenu



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AMPSENTRY SELECTION

Although AmpSentry is an integral part of the PowerCommand control it is modeled as a separate component in SKM software. It is listed in SKM software as a motor overload protective device. See Figure 6.

Open the Component Editor for AmpSentry and enter the full load current based on the genset standby kW rating. See Figure 7. Remember that SKM calculated this value when the genset voltage and kW rating were entered on the Synchronous Generator submenu.

From the data entered a time current curve graph can be created. This graph displays the decrement curve and AmpSentry trip curve. See Figure 8.

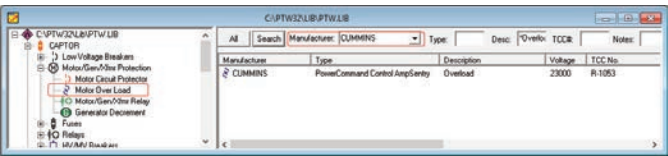


Figure 6 – Locating AmpSentry in SKM

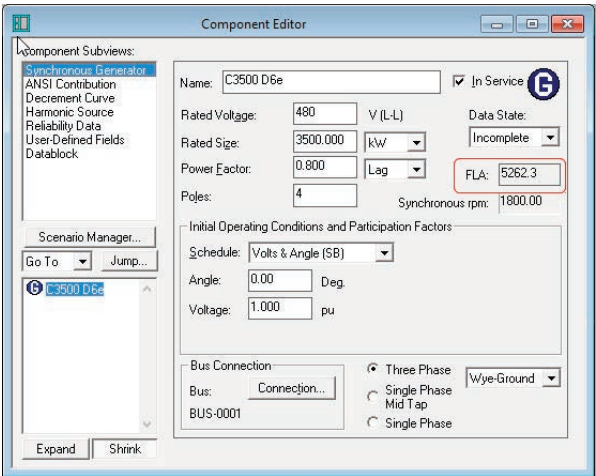


Figure 7 – Entering generator set full load current in the SKM component editor

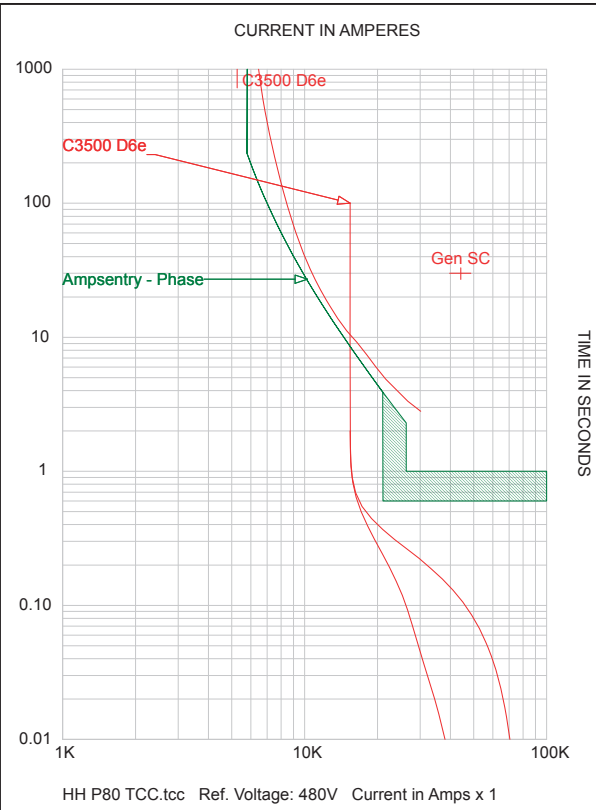


Figure 8 – Time Current Curve showing AmpSentry trip curve and alternator decrement curve

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ARC FLASH EVALUATION

SKM software uses the decrement curve to model the short circuit current to use in the arc flash calculation. SKM software has an option that allows the user to account for the fact that, unlike a transformer, fault current from a generator set decays exponentially. SKM software assumes a step change from the initial fault current to reduced value and models this by dividing the arc flash event into two time periods, calculates the arc flash incident energy in both periods and then adds the two calculations. Figure 9 illustrates this concept.

The first period, represented by the blue line in Figure 9, models the instantaneous or sub-transient period. Current during this period is a function of the sub-transient reactance ($1/X_d''$). The second period, represented by the green line, models the sustained short circuit value. The current is a function of field forcing or fault current regulation properties of the excitation system. Although the current is decaying exponentially between these two periods this method of doing two separate arc flash energy calculations and adding the two values to get the result is considered a reasonable approximation of the arc flash energy.

To perform these calculations SKM prompts the user for two values, as illustrated in Figure 10.

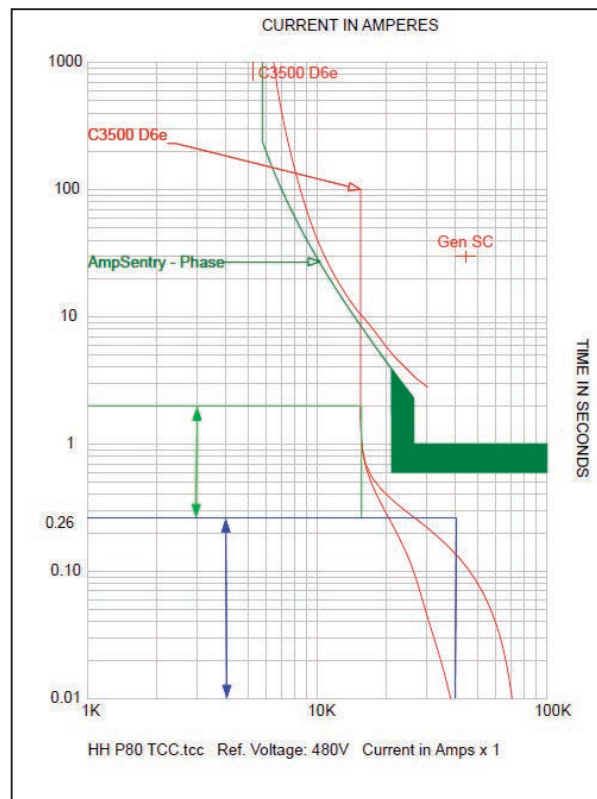


Figure 9 – Arc Flash energy calculation from an onsite generator source

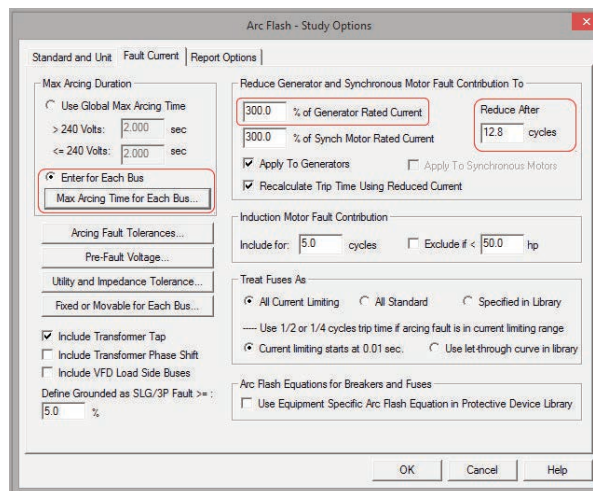


Figure 10 – SKM Arc Flash Options Screen

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In the upper right corner of Figure 10, SKM prompts the user to enter the sustained short circuit current as a percentage of rated current and the point in time, stated in cycles, at which SKM will transition to using the sustained short circuit value rather than the instantaneous short circuit value in the arc flash incident energy calculation. SKM software uses these two values to define the boundaries of the instantaneous and sustained fault period in figure 9 for the arc flash incident energy calculation.

The percent of rated current during the sustained short circuit period is a function of the voltage regulator and the excitation system. Cummins AmpSentry function regulates fault current to 300% of rated current during this period so 300% is the appropriate value to use in this calculations. With a conventional voltage regulator this value will correspond to the maximum field forcing capability of the excitation system as in such systems the voltage regulator will maximize excitation to attempt to recover voltage.

Use the alternator transient time constant (T_d') to set the transition between using the sub-transient fault current and the regulated or field-forced fault current. For the alternator in this example that time constant is 0.213 seconds (see Figure 4) which corresponds to 12.8 cycles.

MAXIMUM ARC DURATION

The upper left corner of the arc flash options screen (Figure 10) has a max arcing duration section. This allows an operator to specify a maximum duration of the arc in scenarios where an overcurrent device does not operate to interrupt fault current. That value typically can be set to 2 seconds, as NFPA 70E recognizes 2 seconds as a reasonable

maximum time for a person to move away from an arc if physically possible. In scenarios where the current is not high enough to clear an overcurrent protection device within 2 seconds it is appropriate to use 2 seconds as a maximum arc duration in arc flash energy calculations.

The Maximum Arc Duration setting may be used to model AmpSentry's maintenance mode function. To model arc flash energy while maintenance mode is enabled we recommend setting the max arc duration to 50ms plus the time equivalent of one alternator transient time constant (T_d'). Tests have shown that when in maintenance mode AmpSentry will recognize the fault and shut off the generator set within 50 ms. Shutting off excitation to the generator set doesn't instantly interrupt arcing current however. The alternator, like a motor, has energy stored in the windings and will feed a fault in a manner similar to motor contribution. To model this period our recommendation is to use the alternator transient time constant. For the alternator in the example from data sheet in Figure 4, the transient time constant is 213ms.

If there is more than one source that can feed the fault, such as a generator set and a utility transformer, select the “Enter for Each Bus”

option in the “Max Arcing Duration” section. This will enable the “Max Arcing Time for Each Bus” button. Clicking that button opens the window where the maximum arcing duration can be entered for each bus. See Figure 11.

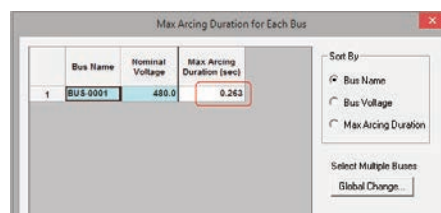


Figure 11 – Max Arcing Duration for each bus

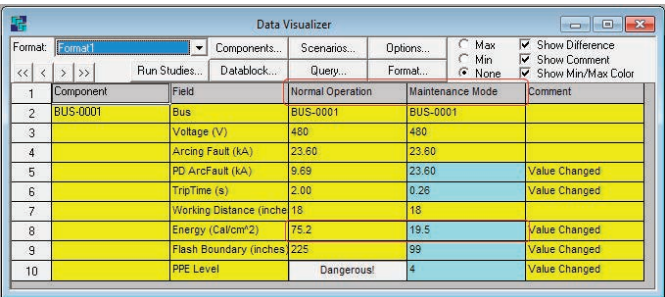
ARC FLASH ENERGY REDUCTION
EXAMPLE

To illustrate the arc energy reducing capabilities of maintenance mode we will show a simple example using the simple system represented by the single line drawing in Figure 1. This system consists of a generator set equipped with AmpSentry (although AmpSentry is shown as a separate component on the drawing) and a bus. We didn't include any cable in this example so the bus represents the terminals of the generator set.

SKM software calculates arc flash incident energy using the method defined by IEEE 1584 and approved by NFPA 70E. In this method incident energy is directly proportional to the arc clearing time. We calculated incident energy twice using two different scenarios, once with the generator set under normal operation and once with the generator set in maintenance mode. The only difference in the calculations is the max arc duration settings. For the normal operation case we set that time to 2 seconds to represent a case where the fault is not cleared by an overcurrent protective device. For the maintenance mode case we set the time to 0.263 seconds which corresponds to 50 msec for the control to sense the fault and 0.213 sec (the alternator transient time constant) to allow for contribution to the fault from the stored energy in the alternator windings. Figure 12 shows the results of the two calculations side by side. Notice that using the maintenance mode reduces arc flash incident energy from 75.2 cal/cm² to 19.5 cal/cm².

This example calculates incident energy at the generator set terminals. Energy at a panel or switchgear that the generator set is feeding would be lower due to the resistance of the cable. The generator set control can be configured to shunt trip a breaker using a configurable output which would eliminate the contribution of the alternator windings after excitation is shut off, further limiting the arc flash incident energy downstream of the breaker. It should be noted however that a breaker does not limit arc flash energy within its own enclosure unless the line side terminals of the breaker are isolated by a barrier. The reason for this is that the line side terminals will still be live and could be arcing. Shunt tripping a breaker only limits arc flash energy to downstream equipment.

Arc Flash Evaluation in the example above was done creating two scenarios utilizing the scenario manager function of SKM Power tools, one as Normal mode with Max Arcing Duration of 2 sec and another as Maintenance mode with the Max Arcing Duration of 0.263. Another method to evaluate the Arc flash for the two different scenarios is to add Maintenance Mode for a particular generator set to the Library as shown in the paper "Short Circuit and Arc Flash Evaluation using AmpSentry-Part 2".



Data Visualizer					
Format: Format1	Components...	Scenarios...	Options...	☐ Max	☒ Show Difference
<< < > >>	Run Studies...	Datablock...	Query...	☐ Min	☒ Show Comment
			Format...	☒ None	☒ Show Min/Max Color
1	Component	Field	Normal Operation	Maintenance Mode	Comment
2	BUS-0001	Bus	BUS-0001	BUS-0001	
3		Voltage (V)	480	480	
4		Arcing Fault (kA)	23.60	23.60	
5		PD ArcFault (kA)	9.69	23.60	Value Changed
6		TripTime (s)	2.00	0.26	Value Changed
7		Working Distance (inches)	18	18	
8		Energy (Cal/cm ²)	75.2	19.5	Value Changed
9		Flash Boundary (inches)	225	99	Value Changed
10		PPE Level	Dangerous!	4	Value Changed

Figure 12 – Arc Flash Calculation

LABELING REQUIREMENTS

NFPA 70E requires equipment to have a label indicating arc flash incident energy under worst case conditions. Figure 13 is an example of an arc flash label.

NFPA 70E does not give clear guidance on how to account for reduced levels of incident energy when arc flash mitigation methods such as maintenance mode are used. Many engineers are producing two sets of labels, one for normal operation mode and one for maintenance mode. In situations where maintenance mode is used to reduce the PPE requirement it is important that work procedures clearly call out putting the equipment into maintenance mode before proceeding with work. Using a lockable switch to put a system in maintenance mode, similar to a lock out tag out provision, is one method for making sure that a system is in maintenance mode before proceeding with work at the reduced level of PPE.

SUMMARY

Cummins PowerCommand® AmpSentry overcurrent protection function is available in SKM Power Tools software and can be used for coordination and arc flash studies. AmpSentry also has a maintenance mode function which meets the arc flash mitigation requirements of NEC 240.87. In this paper we showed how to model a generator set with AmpSentry in SKM and how to model the arc flash mitigation effects of maintenance mode. This method we’ve shown for modeling arc flash incident energy from a generator set with the maintenance mode function can be used with any arc flash evaluation tool. Visit cummins.com to learn more.

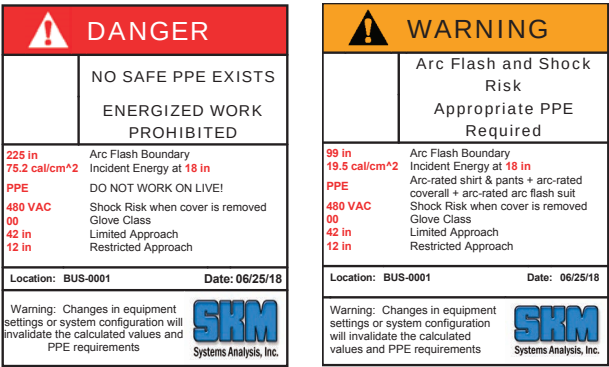


Figure 13 – Arc Flash Hazard labels.

ABOUT THE AUTHORS

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