GE ENERGY

POWER SYSTEM STUDY
FOR
CORN HYDRO PLANT
CITY OF TALLAHASSEE

GE JOB 30020962

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INTRODUCTION

General Electric Company's Energy Services was contracted to perform short-circuit, protective device evaluation, coordination, and arc-flash hazard studies for Corn Hydro Generating facility in City of Tallahassee, FL. This study has been performed in accordance with City of Tallahassee purchase order number COTLH-0001032866.

The scope of the short-circuit study included the Corn Hydro Generating Plant electrical system from the incoming 4.16 kV Utility down to the largest downstream protective device below each substation feeder breaker. The coordination study included from the utility relays down to the substation feeder breakers. The arc-flash hazard study covered the same scope as the coordination study.

EXECUTIVE SUMMARY

Each aspect of this study and the results and recommendations are summarized here. Detailed discussions appear in each section of this report.

1. The main purpose of the **Short-Circuit Study** was to determine if each protective device was rated to handle the maximum fault current to which it may be subjected. This was done by comparison of the device's published short-circuit current rating to its calculated fault current duty.

   All devices in the main switchgear and panel boards are adequately rated for the available fault current.

   2. The **Coordination Study** has recommended settings for the adjustable protective devices down to the substation feeder breakers. All settings and fuse sizes should be implemented. In fact, these must be implemented before results of the arc-flash hazard study are valid.

   3. The **Arc-Flash Hazard Study** shows the results of the incident energy calculations and the arc-flash protection boundary. Please note that these results are based on the settings found in the coordination study. Any arc-flash hazard labels can only be affixed to equipment after the coordination study recommendations have been implemented.

The complete results and discussion are found in the individual study sections of this report.

SHORT-CIRCUIT STUDY

The purpose of the Short-Circuit Study was to determine if each protective device, within the scope of this study, was rated to handle the maximum fault current to which it may be subjected. This was done by comparison of the device's published short-circuit current rating to its calculated fault current duty. The calculated short-circuit current values were also used to aid in the selection of protective device settings in the Coordination Study.

The Utility short-circuit contribution used in this study is shown below. It was provided by Larry Allen, System Protection Engineer with Bengal 21 Power Solutions.

3Ph SC MVA	3Ph SC X/R	SLG SC MVA	SLG SC X/R
657	2.16	590	5.3

SHORT CIRCUIT ANALYSIS

The results of the short circuit analysis are summarized in Table I of this section. By comparing the calculated short circuit current magnitudes to the specific protective equipment interrupting ratings, any equipment inadequately rated from a short circuit standpoint can be quickly detected.

All devices in the main switchgear and panel boards are adequately rated for the available fault current.

TABLE 1: THREE-PHASE SHORT CIRCUIT DUTY CHECK OF PROTECTIVE DEVICES

Bus		Equipment				Ratings			Duties				Comments
Name	Base kV	ID	Mfg	Style	Standard	1/2 Cyc kA	Int kA	Int Cyc	1/2 Cyc kA	1/2 Cy %	Int kA	Int %	
BUS-1	4.16	52-F1	West	50-DHP-350	ANSI-SYM	78	46.91	5	31.147	39.90%	20.19	43.00%	
		52-B1	West	50-DHP-350	ANSI-SYM	78	46.91	5	27.229	34.90%	17.65	37.60%	
		HP1	West	50-DHP-350	ANSI-SYM	78	46.91	5	53.964	69.20%	35.01	74.60%	
		52-G1	West	50-DHP-350	ANSI-SYM	78	46.91	5	49.716	63.70%	32.24	68.70%	
BUS-2	4.16	52-F2	West	50-DHP-350	ANSI-SYM	78	46.91	5	34.253	43.90%	22.2	47.30%	
		52-B1	West	50-DHP-350	ANSI-SYM	78	46.91	5	27.229	34.90%	17.65	37.60%	
		HP2	West	50-DHP-350	ANSI-SYM	78	46.91	5	54.019	69.30%	35.03	74.70%	
		52-G2	West	50-DHP-350	ANSI-SYM	78	46.91	5	49.716	63.70%	32.24	68.70%	
		52-G3	West	50-DHP-350	ANSI-SYM	78	46.91	5	51.298	65.80%	33.26	70.90%	
PNL-EP-1	0.48	GATE-HOIST	Siemens	HED4	ANSI-SYM	42			6.75	16.10%			
PNL-MP	0.48	PNL-MP-MAIN	ITE	JD6	ANSI-SYM	35			6.906	19.70%			

COORDINATION STUDY

The Coordination Study works cope included the determination of recommended settings for the adjustable protective devices down to the substation feeder breakers. The settings recommended in this study provide a reasonable compromise between the often-conflicting goals of service continuity and equipment protection. Where possible, the minimum amount of equipment is removed from service when the system protective devices operate to isolate a fault or system abnormality. This is known as selectivity. The recommended settings, tabulated according to the device location, are given in this report in Table 2. Time-current curves were drawn illustrating coordination on representative circuits.

The methods used in the course of these studies conform to NEC, ANSI, and other applicable standards and accepted industry practices.

Primary transformer protection was examined to insure avoidance of nuisance outages from inrush currents, as well as providing over-current protection as required by the 2005 National Electrical Code, and fault protection as provided by the American National Standards Institute (ANSI). Coordination with secondary protective equipment was also an objective. This protection was examined by means of time-current curves.

Cables (less than 600V) are required by the NEC to be protected against overcurrent in accordance with their ampacities. All feeders within the scope of this study were examined to confirm that they were properly protecting their cables.

Specifically the coordination study has shown . . .

- All relays and low-voltage breakers should be set and tested at the values recommended by this study; all fuses should be sized per the recommendations of this study; any new equipment recommended should be set and tested to the recommendations of this study to achieve coordination with upstream protective devices, for proper protection of equipment and for the arc-flash hazard conditions found in this report.

ANALYSIS OF TCC'S AND ARC FLASH HAZARD

The hazard presented by arc flash is dependent on the amount of energy produced by the flash. The amount of energy produced by the flash is dependent on the amount of three-phase fault current available and the operating time of the protective device clearing the fault. In general the best type of protection is afforded by instantaneous protective devices such as instantaneous trips of low voltage circuit breakers and fuses and differential relay protection for medium and high voltage systems.

One area of concern in the analysis is the generator switchgear that is prevalent in utility generation plants. Typically overlapping instantaneous differential relaying is applied to both the connecting transformer and the switchgear bus. As a result, the main circuit breaker in the switchgear and the front access of the feeder circuit breakers are protected by instantaneous bus differential and transformer differential relay operation. The operating time of the differential relay is combined with interposing lock out relay and circuit breaker clearing time to produce a total clearing time for the arc fault. A time of 0.2 seconds or 12 cycles is allotted to these locations.

However, the rear of the feeder circuit breakers can connect to either downstream loads or to the generator. If the rear connection of the feeder circuit breaker is connected to the generator the clearing time of the fault depends on the opening time of the generator field circuit breaker and the resultant collapse of the generator field. The combined time for the operation of the field circuit breaker and the collapse of the generator field is more difficult to determine than the operation of the differential relays, lock out relays and switchgear circuit breakers. As a result, a maximum time of 2 seconds as recommended in IEEE 1584 is assigned to these locations.

If the feeder circuit breaker is connected to a load the operating time of the feeder circuit breaker relay determines the arc flash rating for rear access to the circuit breaker.

TCC: 52-F1 AND 52-F2

The instantaneous setting of relays HP-1 and HP-2 has been set above the maximum short circuit let through current of the corresponding transformer. This will allow the relay to trip instantaneously for primary 4.16 kV system faults but not for secondary 480 V faults. The time dial of the relays has been set to be selective with the instantaneous trip characteristic of the downstream PNL-MP-MAIN.

Note that the time dial of the feeder relays HP-1 and HP-2 has been set as low as possible and still be selective with the largest feeder circuit breaker in Panel EP-1. Note that this time dial is selective with the instantaneous characteristic of PNL-MP-MAIN circuit breaker but not the long time characteristic. Thus it is selective for fault currents but not for overloads as fault currents can be seen by either or both devices requiring selectivity to determine fault location and overload currents will be seen by both devices.

TCC: GEN-1-0.25VPU, GEN-2-0.25VPU, GEN-3-0.25VPU

The 51V is a backup to bus and transformer differential relay instantaneous operation. The bus and transformer differential relays operation is added to the operating time of the lock out relay and the circuit breaker clearing time for a total of about 0.2 seconds or 12 cycles total clearing time.

For Generators 1, 2 and 3 the 51V voltage restraint time overcurrent function is shown for a 25% voltage restraint. The actual voltage restraint for a primary system fault would be approximately zero or 0%. However, this characteristic is not in the published curve. The TCC shows the time dial of the 51V would be selective with the instantaneous but not the time dials of the feeder 51 devices if zero restraint were shown. This is necessary to assure the back up operation of the 51V for the short circuit decrement curve shown.

Calculation shows that the actual voltage on BUS-1 and BUS-2 for a secondary 480 V fault is 0.973 V per unit. This would actually be 97.3 % voltage restraint but this curve is not available in the published curve. The 100 % voltage restraint would assure that the 51V would not operate for the given short circuit decrement curve.

The instantaneous of the SEL 351 relays has also been set to operate for primary system faults providing a second back up to the 87B and 87T devices. Note that the pick up of this 50 device is well below the fault current output of the generators.

The combination of the 87T, 87B, and 50 devices assures the fastest operating time possible for faults currents. This in turn results in the lowest arc flash rating.

TABLE 2: RECOMMENDED SETTINGS FOR OVERCURRENT PROTECTIVE DEVICES

NOTE: THE FOLLOWING TABLE IS FROM GEH-5943B AND APPLIES TO SPECTRA SK AND SG TRIP UNITS. THE MVT-PM TRIP UNIT DISPLAYS THE BAND NUMBERS AND EASYPOWER SHOWS THE TIME DELAY NUMBERS

MVT-PM	GEH 5934B
SK, SG	
ST DELAY	ST DELAY
BAND	TIME
TRIP UNIT	EASYPOWER
1	0.10
2	0.20
3	0.30
4	0.40

THE FOLLOWING TABLE IS FROM GES-9890E AND APPLIES TO INSULATED CASE CIRCUIT BREAKERS WITH MVT-PM OR MVT PLUS TRIP UNITS. THE MVT-PM AND MVT-PLUS TRIP UNIT DISPLAYS THE BAND NUMBERS AND EASYPOWER SHOWS THE TIME DELAY DESCRIPTION

MVT-PM	GES 9890E
ICCB	
GF DELAY	GF DELAY
BAND	DESCRIPTION
TRIP UNIT	EASYPOWER
1	MIN
2	INT
3	MAX

Relay	Manufacturer	Type	Device Function	CT Ratio	Tap	Tap	Tap	Time Dial	Time Dial	Time Dial	Inst	Inst	Inst	Delay
					Range	Setting	(PA)	Curve	Range	Setting	Range	Setting	(PA)	Setting (s)
52-F1	Schweitzer	SEL-351S	51/50	1200/5	0.25 - 16	6	1440	U3, US Very Inverse	0.5 - 15	3				
			51N/50N	1200/5	0.02 - 3.2	1.5	360	U3, US Very Inverse	0.5 - 15	1.5				
52-F2	Schweitzer	SEL-351S	51/50	1200/5	0.25 - 16	6	1440	U3, US Very Inverse	0.5 - 15	3				
			51N/50N	1200/5	0.02 - 3.2	1.5	360	U3, US Very Inverse	0.5 - 15	1.5				
52-G2	Schweitzer	SEL-351S	51/50	600/5	0.25 - 16	6	720	U3, US Very Inverse	0.5 - 15	3	0.25 - 100	15	1800	
			51N/50N	600/5	0.1 - 16	1.5	180	U3, US Very Inverse	0.5 - 15	1.5				
52-G3	Schweitzer	SEL-351S	51/50	600/5	0.25 - 16	6	720	U3, US Very Inverse	0.5 - 15	3	0.25 - 100	15	1800	
			51N/50N	600/5	0.1 - 16	1.5	180	U3, US Very Inverse	0.5 - 15	1.5				
G1-300G	Schweitzer	SEL-300G	51V/50 IEEE	800/5	2 - 16	4	640	U2 25%V	0.5 - 15	2				
			51N/50N IEEE	100/5	0.1 - 3.2	1	20	U2, US Inverse	0.5 - 15	1				
G1-351	Schweitzer	SEL-351S	51/50	600/5	0.25 - 16	6	720	U3, US Very Inverse	0.5 - 15	3	0.25 - 100	15	1800	
			51N/50N	600/5	0.1 - 16	1.5	180	U3, US Very Inverse	0.5 - 15	1.5				
G2-300G	Schweitzer	SEL-300G	51V/50 IEEE	800/5	2 - 16	4	640	U2 25%V	0.5 - 15	2				
			51N/50N IEEE	800/5	0.1 - 3.2	1	160	U2, US Inverse	0.5 - 15	1				

Relay	Manufacturer	Type	Device Function	CT Ratio	Tap	Tap	Tap	Time Dial	Time Dial	Time Dial	Inst	Inst	Inst	Delay
					Range	Setting	(PA)	Curve	Range	Setting	Range	Setting	(PA)	Setting (s)
G3-300G	Schweitzer	SEL-300G	51V/50 IEEE	600/5	2 - 16	5	600	U2 25%V	0.5 - 15	1				
			51N/50N IEEE	600/5	0.1 - 3.2	1	120	U2, US Inverse	0.5 - 15	1				
HP-1	Schweitzer	SEL-351S	51/50	50/5	0.25 - 16	3	30	U4, US Extremely Inv.	0.5 - 15	10	0.25 - 100	100	1000	
			51N/50N	50/5	0.1 - 16	1.1	11	U2, US Inverse	0.5 - 15	2				
HP-2	Schweitzer	SEL-351S	51/50	50/5	0.25 - 16	3	30	U4, US Extremely Inv.	0.5 - 15	10	0.25 - 100	100	1000	
			51N/50N	50/5	0.1 - 16	1	10	U2, US Inverse	0.5 - 15	2				

Thermal Magnetic Breaker	Mfg	Type	Style	Frame	Trip	Inst	Inst
						Setting	Trip (A)
GATE-HOIST	Siemens	(Std)	HED4	125A(30-125AT)	125	Fixed	800
PNL-MP-MAIN	ITE	ET	JD6	400A(350-400T)	400	Low	2000

ARC-FLASH HAZARD STUDY

Introduction

An arc-flash hazard is a dangerous condition associated with the release of energy caused by an electrical arc. An arc-flash hazard study should be performed as part of an overall electrical safety program that determines safety-related work practices before someone approaches exposed live parts. The National Fire Protection Association, Inc. (NFPA®) includes items such as shock hazard analysis, arc-flash hazard analysis, arc-flash hazard and shock hazard labels, safety training, and work permits as part of the requirements of *NFPA 70E Standard for Electrical Safety In the Workplace, 2009 Edition*. The arc-flash hazard study is a continuation of the short-circuit analysis and protective device coordination of an electrical system. The short-circuit analysis is used to determine the momentary duty, interrupting duty and short-circuit (withstand) rating of electrical equipment (*IEEE Std. 141-1993 – Red Book*). Results of the protective device coordination study are used to determine the time required for protective devices to isolate overload or short-circuit conditions (*IEEE Std. 242-2001 – Buff Book*). Both the short-circuit study and the protective device coordination study results are required to perform arc-flash hazard calculations. The outcomes of the arc-flash hazard study include the incident energy at assigned working distances throughout the electrical system and the arc-flash protection boundary (*IEEE Std. 1584-2002, IEEE Guide for Performing Arc-Flash Hazard Calculations* and its Amendment 1, *IEEE Std. 1584a-2004*). The PPE (personal protective equipment) required can then be specified based on the incident energy that was calculated.

Workers can be killed or seriously injured by arcing faults even without direct contact. Arcing involves high temperatures of up to or beyond 35,000 degrees Fahrenheit at the arc terminals, or about four times hotter than the surface temperature of the sun. Tremendous energy can be released in a very brief time at the initiation of the arc. Clothing is ignited at distances of several feet caused by the resulting thermal energy. Severe or fatal burns at distances of 10’ are common.

Arc-Blast: When an arcing fault occurs, thermal escalation of the air and vaporization of metal can create a very loud explosion and tremendous pressures. Conductors can vaporize resulting in ionized gases, hot vapors, molten metal and shrapnel being violently expelled from the arc area. This can result in ruptured eardrums, collapsed lungs, and forces that violently knock workers backwards. Copper expands as it becomes vaporized by the intense heat. Its volume expands to 67,000 times the volume of solid copper.

Personal Protective Equipment (PPE) for shock and arc-flash hazards includes the clothing, gloves and headwear that help to mitigate the effects of an arc-flash event for a worker who is exposed. PPE is generally determined to protect the head and body against thermal effects that would cause severe burn. It does not necessarily protect from the possible impact of any harmful light, sound, or pressure impulses, toxic gas by-products or ejected debris.

NFPA 70E Standard for Electrical Safety in the Workplace, 2009 Edition addresses arc-flash and shock hazards, including these excerpts. Several definitions are provided after these excerpts.

Arc Flash Hazard Analysis. "A study investigating a worker's potential exposure to arc flash energy, conducted for the purpose of injury prevention and the determination of safe work practices, arc flash protection boundary, and the appropriate levels of PPE." Article 130.3 states that "An arc flash hazard analysis shall determine the Arc Flash Protection Boundary and the personal protective equipment that people within the Arc Flash Protection Boundary shall use."

Article 110.8(B)(1) Working Within the Limited Approach Boundary of Exposed Electrical Conductors or Circuit Parts that Are or Might Become Energized addresses the **Electrical Hazard Analysis**. "If the energized electrical conductors or circuit parts operating at 50 volts or more are not placed in an electrically safe work condition, other safety-related work practices shall be used to protect employees who might be exposed to the electrical hazards involved." It goes on to require that work practices protect employees from arc flash and from coming into contact with energized electrical conductors or circuit parts. It states that "Appropriate safety-related work practices shall be determined before any person is exposed to the electrical hazards involved by using both shock hazard analysis and arc flash hazard analysis."

Shock Hazard. "A dangerous condition associated with the possible release of energy caused by contact or approach to energized electrical conductors or circuit parts." Article 110.8(B)(1)(a) states that "A shock hazard analysis shall determine the voltage to which personnel will be exposed, boundary requirements, and the personal protective equipment necessary in order to minimize the possibility of electrical shock to personnel.

FPN (FINE PRINT NOTE)**:** See 130.2 for the requirements of conducting a shock hazard analysis."

130.3(B) Protective Clothing and Other Personal Protective Equipment (PPE) for Application with an Arc Flash Hazard Analysis. Covers the uses and types of personal protective clothing and equipment when working on energized electrical equipment within the Arc Flash Protection Boundary. ". . . employer shall document, the incident energy exposure of the worker (in calories per square

centimeter). The incident energy exposure level shall be based on the working distance of the employee's face and chest areas from a prospective arc source for the specific task to be performed. Arc-Rated FR *(flame-resistant)* clothing and other personal protective equipment (PPE) shall be used by the employee based on the incident energy exposure associated with the specific task."

130.7(C)(5) Body Protection. "Employees shall wear FR clothing whenever there is possible exposure to an electric arc flash above the threshold incident-energy level for a second-degree burn, [5 J/cm^2 (1.2 cal/cm^2)]."

130.7(C)(10) FPN2: "The PPE requirements of this article are intended to protect a person from arc flash and shock hazards. While some situations could result in burns to the skin, even with the protection described in Table 130.7(C)(10), burn injury should be reduced and survivable. Due to the explosive effect of some arc events, physical trauma injuries could occur. The PPE requirements of this article do not address protection against physical trauma other than exposure to the thermal effects of an arc flash."

Definitions from NFPA 70E

Boundary, Arc Flash Protection – "When an arc flash hazard exists, an approach limit at a distance from a prospective arc source within which a person could receive a second degree burn if an electrical arc flash were to occur."
Note: The onset of a second-degree burn is assumed to be when the skin receives 5.0 J/cm^2 (1.2 cal/cm^2) of incident energy (skin temperature remains less than 80 degrees C, 176 degrees F).

Boundary, Limited Approach – "An approach limit at a distance from an exposed energized electrical conductor or circuit part within which a shock hazard exists."

Boundary, Restricted Approach – "An approach limit at a distance from an exposed energized electrical conductor or circuit part within which there is an increased risk of shock, due to electrical arc over combined with inadvertent movement, for personnel working in close proximity to the energized electrical conductor or circuit part."

Boundary, Prohibited Approach – "An approach limit at a distance from an exposed energized electrical conductor or circuit part within which work is considered the same as making contact with the electrical conductor or circuit part."

Qualified Person – "One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved."

Flame-Resistant (FR) – "The property of a material whereby combustion is prevented, terminated, or inhibited following the application of a flaming or non-flaming source of ignition, with or without subsequent removal of the ignition source.

FPN: Flame resistance can be an inherent property of a material, or it can be imparted by a specific treatment applied to the material."

Arc Flash Suit – "A complete FR clothing and equipment system that covers the entire body, except for the hands and feet. This includes pants, jackets, and beekeeper-type hood fitted with a face shield."

Definitions from IEEE Std. 1584-2002

Flash hazard analysis – "A method to determine the risk of personal injury as a result of exposure to incident energy from an electrical arc-flash."

***Shock hazard* – "A dangerous condition associated with the possible release of energy caused by contact or approach to live parts."**

***Exposed (live parts)* – "Capable of being inadvertently touched or approached nearer than a safe distance by a person. It is applied to parts that are not suitably guarded, isolated, or insulated."**

***Electrical Hazard* – "A dangerous condition in which inadvertent or unintentional contact or equipment failure can result in shock, arc-flash burn, thermal burn, or blast."**

***Incident Energy* – "The amount of energy impressed on a surface, a certain distance from the source, generated during an electrical arc event. Incident energy is measured in joules per centimeter squared (J/cm^2)." [Note: A joule is defined as a watt second. J/cm^2 in the SI system is divided by 4.184 to obtain the CGS system unit of calories per centimeter squared (cal/cm^2)]**

Burn Definitions: The skin is made up of two layers, the surface layer called the epidermis, and the more sensitive dermis underneath. Burns that only affect the epidermis are known as first-degree burns and are the least severe type of burns. The area may be red, slightly swollen and sensitive to the touch, but blisters do not form. Within a few days, the skin heals and the damaged layer of sin may peel off. Once the epidermis has been destroyed, the more sensitive lower dermis layer is vulnerable to damage. Damage to both of these two layers is known as a **second-degree burn** and is usually very painful. The skin becomes red and covered with large blisters filled with clear fluid. After about three days the pain usually decreases, and most second-degree burns should be fully healed within 14 days. Third degree burns are the most severe type of burns and extend into deeper tissue. (Burn definitions were taken from *American College of Physicians Complete Home Medical Guide*, 1999)

Systems Covered by IEEE Std. 1584-2002

This arc-flash hazard study was performed utilizing equations from *IEEE Std. 1584-2002, Guide for Performing Arc-Flash Hazard Calculations* and its amendment, *IEEE Std. 1584a-2004.* The guide is based on the use of test data and is designed for systems having:

- Voltages in the range of 208 V – 15,000 V, three phase
- Frequencies of 50 or 60 Hz
- Bolted fault current in the range of 700 A – 106,000 A
- Grounding of all types and ungrounded
- Equipment enclosures of commonly available sizes
- Cable and conductors in air, with gaps between conductors of 13 mm – 152 mm
- Faults involving three phase

Arc-Flash Hazard Analysis Procedure

The process for performing an arc-flash hazard study is as follows:

1. Data collection. **Obtain up-to-date one-line diagram, short-circuit study, protective device coordination study or collect all the necessary data to perform them along with the needed arc-flash data. This data includes but is not limited to all impedance data, i.e. transformers, generators, motors, cables, busways, transmission lines; all protective devices, i.e. circuit breakers, protective relays and their CTs, fuses, switches; specific arc-flash information such as system grounding configuration, conductors enclosed or in open air, class of equipment, and gap distance between conductors (table lookup by voltage). *IEEE Std. 1584-2002* states in Section 4.2 Step 1: "Equipment below 240 V need not be considered unless it involves at least one 125 kVA or larger low-impedance transformer in its immediate power supply." In Section 9.3.2 it states: "The arc-flash hazard need only be considered for large 208 V systems: systems fed by transformers smaller than 125 kVA should not be a concern."**

2. Identify the various operating modes. **Identify utility feeders in/out of service, main and tie breaker positions, Unit Subs and MCCs fed from multiple sources, generators in parallel or in standby mode. Short-circuit study should identify minimum and maximum fault currents for the available switching conditions.**

3. Calculate the bolted fault currents **and X/R ratios at each bus.**

4. Calculate the arcing fault currents **utilizing equations 1 and 2 found in section 5.2 of *IEEE Std. 1584-2002*.**

For applications with a system voltage under 1000V:

$$\lg I_a = K + 0.662 \lg I_{bf} + 0.0966 V + 0.000526 G + 0.5588 V (\lg I_{bf}) - 0.00304 G (\lg I_{bf}) \quad \text{(Section 5.2, Equation 1)}$$

where

- lg is the $\log_{10}$
- I_a is arcing current (kA)
- K is –0.153 for open configurations and is –0.097 for box configurations
- I_{bf} is bolted fault current for three-phase faults (symmetrical RMS) (kA)
- V is system voltage (kV)
- G is the gap between conductors, (mm) (see Table 4 of *IEEE Std. 1584*)

For applications with a system voltage of 1000 V and higher:

$$\lg I_a = 0.00402 + 0.983 \lg I_{bf} \quad \text{(Section 5.2, Equation 2)}$$

The high-voltage case makes no distinction between open and box configurations.

Convert from lg:

$$I_a = 10^{\lg I_a} \quad \text{(Section 5.2, Equation 3)}$$

For application with a system voltage under 1000 V**, calculate a second arc current equal to 85% of I_a, so that a second arc duration can be determined. See the discussion in section 9.10.4 of *IEEE Std. 1584*. It talks about the difficulties in predicting arc current accurately, and that a minor change in current could make a major change in operating time–hence changing the incident energy.

** *IEEE Std. 1584a-2004* change

Table 4 of *IEEE Std. 1584* shows
Factors for equipment and voltage classes[a]

ystem voltage (kV)	:quipment type	›ical gap between conductors (mm)	stance *x* factor
08 – 1	en air	10 – 40	2.000
	tchgear	32	1.473
	C and panels	25	1.641
	›le	13	2.000
– 5	en air	102	2.000
	tchgear	13-102	0.973
	›le	13	2.000
– 15	en air	13-153	2.000
	tchgear	153	0.973
	›le	13	2.000

[a] – The distance *x* factor is used in Section 5.3, equation 6 and Section 5.5, equation 8 as a distance exponent.

5. **Find the** protective device characteristics **and the duration of the arcs. A recent coordination study is best. Fuse clearing times are used. For fuses with average melt times shown, add to that time 15%, up to 0.03 seconds, and 10% above 0.03 seconds to determine total clearing time. If the arcing fault current is above the total clearing time at the bottom of the curve (0.01 seconds), use 0.01 seconds for the time. For relays operating in their instantaneous region, allow 16 milliseconds (60 Hz systems) for operation. The circuit breaker opening time must then be added after consulting the manufacturer's literature.**

6. Document the system voltages and classes of equipment.

Table 2 of *IEEE Std. 1584* shows
Classes of equipment and typical bus gaps

Classes of equipment	ɔical bus gaps (mm)
kV switchgear	152
/ switchgear	104
v-voltage switchgear	32
v-voltage MCCs and panelboards	25
ɔle	13
ıer	Not required

7. Select the working distances.

The incident energy level on the person's face and body at the working distance, not the incident energy on the hands or arms is what is calculated. The degree of injury in a burn depends on the percentage of a person's skin that is burned. The head and body are a large percent of the total skin surface area and injury to these areas is much more life threatening than burns on the extremities.

Table 3 of *IEEE Std. 1584* shows
Classes of equipment and typical working distances

Classes of equipment	Typical working distance[a] (mm)	ıpproximate distance in inches
kV switchgear	910	36"
V switchgear	910	36"
w-voltage switchgear	610	24"
w-voltage MCCs and panelboards	455	18"
ble	455	18"
her	To be determined in field	-

[a]Typical working distance is the sum of the distance between the worker standing in front of the equipment, and from the front of the equipment to the potential arc source inside the equipment.

8. Calculate the incident energy for all equipment.

The basic equations are found in section 5.3 of *IEEE Std. 1584* – equations 4, 5, 6, & 7.

$$\lg E_n = K_1 + K_2 + 1.081 \lg I_a + 0.0011 G \qquad \text{(Section 5.3, Equation 4)}$$

where

- E_n **is incident energy (J/cm²) normalized for time and distance***
- K_1 **is –0.792 for open configuration (no enclosure) and is –0.555 for box configuration (enclosed equipment)**
- K_2 **is 0 for ungrounded and high-resistance grounded systems and is –0.113 for grounded systems**
- G **is the gap between conductors (mm) (see Table 4, *IEEE Std. 1584*)**

**** - measurement utilized in test laboratories was cal/cm²***

Then:

$$E_n = 10^{\lg E_n} \qquad \text{(Section 5.3, Equation 5)}$$

Finally, convert from normalized:

$$E = 4.184 C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{D^x}\right) \qquad \text{(Section 5.3, Equation 6)}$$

where

- E **is incident energy (J/cm²)**
- C_f **is a calculation factor 1.0 for voltages above 1kV, and 1.5 for voltages at or below 1kV**
- E_n **is incident energy normalized**
- t **is arcing time (seconds)**
- D **is distance from the possible arc point to the person (mm)**
- x **is the distance exponent from *IEEE Std. 1584's* Table 4**

Also, the theoretically derived Lee method is utilized for cases over 15kV, or gap is outside the range of the model. Ralph Lee developed a theory-based model of the arc flash that served for many years as the only method available, even though it did not include a method of finding arc current.

Lee Method:

$$E = 2.142\ X\ 10^6\ V\ I_{bf}\left(\frac{t}{D^2}\right) \qquad \text{(Section 5.3, Equation 7)}$$

where

- E **is incident energy (J/cm²)**
- V **is system voltage (kV)**
- t **is arcing time (seconds)**
- D **is distance from the possible arc point to person (mm)**

I_{bf} is bolted fault current

For voltages over 15kV, arc fault current is considered to be equal to the bolted fault current.

9. Calculate the flash-protection boundary for all equipment.

The equations are found in section 5.5 of *IEEE Std. 1584*, equations 8 and 9.

For the *IEEE Std. 1584-2002* empirically derived model:

$$D_B = \left[4.184\, C_f E_n \left(\frac{t}{0.2} \right) \left(\frac{610^x}{E_B} \right) \right]^{\frac{1}{x}}$$ **(Section 5.5, Equation 8)**

For the Lee method:

$$D_B = \sqrt{2.142\ X\ 10^6\ V\ I_{bf} \left(\frac{t}{E_B} \right)}$$ **(Section 5.5, Equation 9)**

where

- D_B **is the distance of the boundary from the arcing point (mm)**
- **Cf is a calculation factor**
  - **1.0 for voltages above 1kV, and**
  - **1.5 for voltages at or below 1kV**
- E_n **is incident energy normalized***
- E_B **is incident energy in J/cm² at the boundary distance**
- t **is time (seconds)**
- x **is the distance exponent from *IEEE Std. 1584*'s Table 4**
- I_{bf} **is bolted fault current**

E_B can be set at 5.0 J/cm² for bare skin (no hood) or at the rating of proposed PPE.**

**** Measurement utilized in test laboratories was cal/cm²***

***** 5.0 J/cm² = 1.2 cal/cm²***

10. Identify the Hazard Risk Categories based on the calculated incident energy.

While this step is not a part of the arc-flash hazard analysis as given in *IEEE Std. 1584-2002*, *NFPA 70E* provides the table showing typical protective clothing systems for the calculated incident energies. The NFPA standard permits the use of Table 130.7(C)(9), which is a hazard risk table based on tasks using assumed short-circuit capacities and assumed fault clearing times. However, GE recommends that an arc-flash hazard study be performed to obtain the actual incident energies to determine the correct PPE rather than a table that is based on assumed values and could call for more or less PPE than is actually required. This study uses Table 130.7(C)(11) Protective Clothing Characteristics from the *NFPA 70E, 2009 Edition*.

Arc-Flash Hazard Study Computer Output Explanation

The computer program used to calculate the arc-flash hazard results (EasyPower®) has the ability to calculate results based on *NFPA 70E, 2009 Edition*; *IEEE Std. 1584-2002*; and *IEEE Std. 1584-2002* enhanced, which is the software vendor's version based on what they believe to be more accurate curve fitting of the actual IEEE test data.

In this study, GE performed the arc-flash hazard calculations using the *IEEE Std. 1584-2002* equations with the *IEEE Std. 1584a-2004 Amendment 1*. This typically results in more conservative results than the other methods, hence requiring greater PPE (personal protective equipment). The proper PPE required is based on the *NFPA 70E, 2009 Edition* that provides for five clothing categories (0, 1, 2, 3, and 4). The "Extreme Danger" notation indicates that it is prohibited to work on the equipment energized because its calculated incident energy is above 40 cal/cm^2.

ARC-FLASH HAZARD STUDY - EXAMPLE OF COMPUTER PRINTOUT

Arc Fault Bus Name	Arc Fault Bus kV	Upstream Trip Device Name	Upstream Trip Device Function	Equipment Type	Gnd	Arc Gap (mm)	Bolted Fault (kA)	Est Arc Fault (kA)	Trip Time (sec)	Opening Time (sec)	Arc Time (sec)	Est Arc Flash Boundary (inches)	Working Distance (inches)	Incident Energy (cal/cm^2)	NFPA Hazard / Risk Category
01-SWITCHYARD	13.800	SWTCHYD MAIN	51/50	Switchgear	X	153	20.926	20.056	0.367	0.083	0.451	401.6	36	12.5	#3
01-SWITCHYARD	13.800	SWTCHYD-FDR1	51/50 ANSI	Switchgear	X	153	21.101	20.221	0.01	0.083	0.093	79.6	36	2.6	#1
20-COMPRESSOR1	4.160	F-COMPRESSOR1		MCC		102	9.996	9.702	0.01	0	0.01	4.3	36	0.2	#0
26-SUB1-2	0.480	SUB 1-2 MAIN		Switchgear	X	32	29.655	*13.237	2.317	0	2	348.8	18	94.5	Ext Danger
40-MCC4	0.480	1-3-3C		MCC	X	25	8.925	5.950	0.19	0	0.19	38.4	18	4.2	#2

* = indicates a reduced arcing current (85%)

Arc Fault Bus Name – Uniquely identifies the system location where the three-phase bolted fault is calculated.

Arc Fault Bus kV – Nominal line-to-line kV rating for the faulted bus.

Upstream Trip Device Name – For each bus at least one and sometimes more data lines will be provided. There will be a unique device name on each line. The arc-flash calculations use the clearing time for the protective device named on this line. There can be more than one device for a given bus since alternate arc-flash calculations may be performed for alternate relay actions. For instance, a bus may have arc-flash calculations for clearing times based on 87B-Bus Differential operation or on 51-Time Overcurrent relay operation of the main breaker. The arc-flash fault current will be the same in each case but the incident energy will be much worse for the latter relay because of its much longer operating time.

Upstream Trip Device Function – ANSI Standard Device Function Number

Equipment Type – *IEEE Std. 1584* arc-flash calculations assume bus separation distances based on the equipment type and voltage rating in four categories. EasyPower® software has additional categories (shown in parenthesis here) with the same values as the 1584 Switchgear category:

1. Open Air
2. Switchgear (Switchboard, NEMA E2 Contactor, Int Switches, VFD, UPS, ATS, Other)
3. MCC, Panel, Panelboard
4. Conductor

ARC-FLASH HAZARD STUDY - EXAMPLE OF COMPUTER PRINTOUT

Arc Fault Bus Name	Arc Fault Bus kV	Upstream Trip Device Name	Upstream Trip Device Function	Equipment Type	Gnd	Arc Gap (mm)	Bolted Fault (kA)	Est Arc Fault (kA)	Trip Time (sec)	Opening Time (sec)	Arc Time (sec)	Est Arc Flash Boundary (inches)	Working Distance (inches)	Incident Energy (cal/cm^2)	NFPA Hazard / Risk Category
01-SWITCHYARD	13.800	SWTCHYD MAIN	51/50	Switchgear	X	153	20.926	20.056	0.367	0.083	0.451	401.6	36	12.5	#3
01-SWITCHYARD	13.800	SWTCHYD-FDR1	51/50 ANSI	Switchgear	X	153	21.101	20.221	0.01	0.083	0.093	79.6	36	2.6	#1
20-COMPRESSOR1	4.160	F-COMPRESSOR1		MCC		102	9.996	9.702	0.01	0	0.01	4.3	36	0.2	#0
26-SUB1-2	0.480	SUB 1-2 MAIN		Switchgear	X	32	29.655	*13.237	2.317	0	2	348.8	18	94.5	Ext Danger
40-MCC4	0.480	1-3-3C		MCC	X	25	8.925	5.950	0.19	0	0.19	38.4	18	4.2	#2

* = indicates a reduced arcing current (85%)

Gnd – Arc-Flash "Ground" Status. Shows an "X" if system is solidly-grounded and an arc-flash reduction is taken (per *IEEE Std. 1584*). The determination used to tell whether an arcing fault is ungrounded is if the average voltage of V_b and V_c is > 1.45 pu for a single-line to ground fault on phase A.

Arc Gap (mm) – This is the arc gap distance derived from Standards based on the equipment type and voltage rating.

Bolted Fault (kA) – The calculated first-cycle symmetrical bolted three-phase fault current in kiloamps (branch current).

Est. Arc Fault (kA) – The estimated first-cycle three-phase arcing fault current in kiloamps. If this value is preceded by an asterisk (*), it indicates that a second arc-flash calculation made with an arcing fault current different from 100% found a worst-case incident energy. Arc-flash calculations are made at 100% of estimated arcing fault current and typically at 85% of estimated arcing fault current for buses less than 1000 V, per *IEEE Std. 1584a*.

Trip Time (sec) – The protective device operating time.

Opening Time (sec) – The circuit breaker operating time. For fuses and low-voltage breakers the operating time will be zero since the fuse timing is already taken into account in the "Trip Time (sec)."

Arc Time (sec) – This is simply the sum of the device tripping time plus the circuit breaker opening time and is the arcing fault duration for purposes of the incident energy calculations.

Est. Arc Flash Boundary (inches) – The Arc-Flash Protection Boundary is an approach limit at a distance from live parts that are uninsulated or exposed, within which a person could receive a second-degree burn. More specifically, this is the distance where the incident energy level equals 1.2 cal/cm^2 (or if a device operates in 0.10 seconds or less, 1.5 cal/cm^2—this is not used in *IEEE Std. 1584* or this study). When live parts are exposed, any personnel which come within this boundary must wear appropriate arc-flash protection clothing.

ARC-FLASH HAZARD STUDY - EXAMPLE OF COMPUTER PRINTOUT

Arc Fault Bus Name	Arc Fault Bus kV	Upstream Trip Device Name	Upstream Trip Device Function	Equipment Type	Gnd	Arc Gap (mm)	Bolted Fault (kA)	Est Arc Fault (kA)	Trip Time (sec)	Opening Time (sec)	Arc Time (sec)	Est Arc Flash Boundary (inches)	Working Distance (inches)	Incident Energy (cal/cm^2)	NFPA Hazard / Risk Category
01-SWITCHYARD	13.800	SWTCHYD MAIN	51/50	Switchgear	X	153	20.926	20.056	0.367	0.083	0.451	401.6	36	12.5	#3
01-SWITCHYARD	13.800	SWTCHYD-FDR1	51/50 ANSI	Switchgear	X	153	21.101	20.221	0.01	0.083	0.093	79.6	36	2.6	#1
20-COMPRESSOR1	4.160	F-COMPRESSOR1		MCC		102	9.996	9.702	0.01	0	0.01	4.3	36	0.2	#0
26-SUB1-2	0.480	SUB 1-2 MAIN		Switchgear	X	32	29.655	*13.237	2.317	0	2	348.8	18	94.5	Ext Danger
40-MCC4	0.480	1-3-3C		MCC	X	25	8.925	5.950	0.19	0	0.19	38.4	18	4.2	#2

* = indicates a reduced arcing current (85%)

Working Distance (inches) – Distance from the possible arc point to the head and body of the worker positioned in place to perform the assigned task. For low voltages, this is typically assumed to be the distance from the fingers to the main body parts such as the face and chest, approximately 18". The working distance varies with equipment operating voltage. Unless the customer provided different working conditions, typical working distances found in *IEEE Std. 1584* Table 3 (up to 15kV) and the IEEE National Electric Safety Code Table 441-1's phase to ground approach distances (in inches) were used in this study. The arc-flash hazard table shows the working distance used for each calculation.

From the 2002 Edition National Electric Safety Code Table 441-1
AC Live Work Minimum Approach Distance
(inches column was added, meter column deleted)
(See Rule 441 in its entirety.)

Voltage in kilovolts phase to phase[1,2]	Distance to employee		
	Phase to ground (ft-in)	(in)	Phase to Phase (ft-in)
0 to 0.050[1]	not specified	not specified	not specified
0.051 to 0.300[1]	avoid contact	avoid contact	avoid contact
0.301 to 0.750[1]	1-0	12	1-0
0.751 to 15	2-2	26	2-3
15.1 to 36.0	2-7	31	2-10
36.1 to 46.0	2-9	33	3-2
46.1 to 72.5	3-3[3]	39	3-11
72.6 to 121	3-2[3]	38	4-3
138 to 145	3-7	43	4-11
161 to 169	4-0	48	5-8
230 to 242	5-3	63	7-6
345 to 362	8-6	102	12-6
500 to 550	11-3	135	18-1
765 to 800	14-11	179	26-0

[1] For single phase system, use the highest voltage available.
[2] For single phase lines off three phase systems, use the phase-to-phase voltage of the system.
[3] The 46.1 to 72.5kV phase-to-ground 3-3 distance contains a 1-3 electrical component and a 2-0 inadvertent movement component while the 72.6 to 121 kV phase-to-ground 3-2 distance contains a 2-2 electrical component and a 1-0 inadvertent movement component.

There is also an altitude correction factor table associated with this approach distance table. It is Table 441-5. Note: The 2007 Edition National Electrical Safety Code's Table

441-1 is the same through 72.5kV. For higher voltages, consult Table 441-2 (phase-to-ground) with various maximum anticipated per unit overvoltage factor T for each voltage level.

Incident Energy (cal/cm²) – The result of the AF calculations needed to identify the Personal Protective Equipment required clothing category. It is the amount of energy impressed on a surface, a certain distance from the source, generated during an electrical arc event.

NFPA Hazard/Risk Category – The *NFPA 70E, 2009 Edition* required protective clothing classification based on the calculated incident energy. The "Extreme Danger" notation indicates that it is prohibited to work on the equipment energized because its calculated incident energy is above 40 cal/cm².

From *NFPA 70E, 2009 Edition* –

TABLE 130.7(C)(11) Protective Clothing Characteristics

Hazard/Risk Category	Clothing Description	Required Minimum Arc Rating of PPE [J/cm² (cal/cm²)]
0	Nonmelting, flammable materials (i.e. untreated cotton, wool, rayon, or silk, or blends of these materials) with a fabric weight at least 4.5 oz/yd²	N/A
1	Arc-rated FR shirt and FR pants or FR coverall	16.74 (4)
2	Arc-rated FR shirt and FR pants or FR coverall	33.47 (8)
3	Arc-rated FR shirt and pants or FR coverall, and arc flash suit selected so that the system arc rating meets the required minimum	104.6 (25)
4	Arc-rated FR shirt and pants or FR coverall, and arc flash suit selected so that the system arc rating meets the required minimum	167.36 (40)

Note: Arc rating is defined in Article 100 and can be either ATPV or E_{BT}. ATPV is defined in ASTM F 1959, *Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing*, as the incident energy on a material or a multilayer system of materials that results in a 50% probability that sufficient heat transfer through the tested specimen is predicted to cause the onset of a second-degree skin burn injury based on the Stoll curve, cal/cm². E_{BT} is defined in ASTM F 1959 as the incident energy on a material or material system that results in a 50% probability of breakopen. Arc rating is reported as either ATPV or E_{BT}, whichever is the lower value.

(ASTM International = Organization formerly known as American Society for Testing and Materials, today provides technical standards for materials, products, systems, and services)

Note: FR = flame resistant

NFPA 70E, 2009 Edition Article 130.7(C)(5) regarding Body Protection for an explanation of Hazard/Risk Category 1's minimum incident energy. **130.7(C)(5) Body Protection.** "Employees shall wear FR clothing whenever there is possible exposure to an electric arc flash above the threshold incident-energy level for a second-degree burn, [5 J/cm^2 (1.2 cal/cm^2)]." Therefore, since Category 1 is the first category to require FR clothing, the minimum incident energy for Category 1 is 1.2 cal/cm^2. See also 130.7(C)(12)(a) for layering requirements.

The arc rating of FR clothing is either the arc-thermal performance value (ATPV—ASTM F 1959) or the energy level (E_{BT}—ASTM F 1959) that caused the breakopen to occur when the fabric was tested.

See *NFPA 70E*, Article **130.7(C)(14)** for details regarding clothing material characteristics–melting. It states that "Clothing made from flammable synthetic materials that melt at temperatures below 315°C (600°F), such as acetate, acrylic, nylon, polyester, polyethylene, polypropylene, and spandex, either alone or in blends, shall not be used."

Arc-Flash Hazard Labels

NFPA 70®, *National Electrical Code® (NEC®), 2008 Edition*, in Article **110.16** on **Flash Protection** requires that equipment be field marked to warn qualified persons of potential electrical arc flash hazards.

> "Electrical equipment, such as switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers, that are in other than dwelling occupancies, and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment."

NFPA 70E, 2009 Edition in Article **130.3** requires **Equipment Labeling**.

> "Equipment shall be field marked with a label containing the available incident energy or required level of PPE."

Note that if arc-flash and shock hazard labels are provided in this workscope, only equipment within the scope of this study had labels provided. *NFPA 70E* requires labels at all locations that have an arc-flash hazard (Hazard/Risk Category 1 or

greater). The Table Method (*NFPA 70E 2009 Edition* Table 139.7(C)(9) should be used with writable labels to audit and label the remaining system locations that have an arc-flash hazard that were not within the scope of this study.

Occupational Safety and Health Administration (OSHA)

OSHA has not specifically addressed arc-flash hazards, however, there exists adequate safety requirements for employers to follow to ensure the safety of the worker in the workplace (General Duty clause).

OSHA 29 CFR 1910.269(l)(6)(iii) states that "The employer shall ensure that each employee who is exposed to the hazards of flames or electric arcs does not wear clothing that, when exposed to flames or electric arcs, could increase the extent of injury that would be sustained by the employee."

OSHA 1910.132(d)(1) — The employer shall assess the workplace to determine if hazards are present, or are likely to be present, which necessitate the use of personal protective equipment (PPE). If such hazards are present, or likely to be present, the employer shall:

> **OSHA 1910.132(d)(1)(i)** — Select, and have each affected employee use, the types of PPE that will protect the affected employee from the hazards identified in the hazard assessment;
>
> **OSHA 1910.132(d)(1)(ii)** — Communicate selection decisions to each affected employee; and,
>
> **OSHA 1910.132(d)(1)(iii)** — Select PPE that properly fits each affected employee. Note: Non-mandatory Appendix B contains an example of procedures that would comply with the requirement for a hazard assessment.

In response to an inquiry on OSHA's stand on arc-flash hazard, Richard S. Terrill, the Regional Administrator for Occupational Safety and Health, US Department of Labor for the Northwest Region at Seattle, concluded as follows:

> "Through OSHA does not, per se, enforce the NFPA standard, 2004 Edition, OSHA considers NFPA standard a recognized industry practice. The employer is required to conduct assessment in accordance with CFR 1910.132(d)(1). If an arc-flash hazard is present, or likely to be present, then the employer must select and require employees to use the protective apparel. Employers who conduct the hazard/risk assessment, and select and require their employees to use protective clothing and other PPE appropriate for the task, as stated in the *NFPA 70E standard, 2004 Edition*, are deemed in compliance with the Hazard Assessment and Equipment Selection OSHA standard."

Of course, the safest course of action is to deenergize the equipment first as the following OSHA regulation limits the situations in which work is performed near or on equipment or circuits that are or may be energized.

OSHA 1910.333(a)(1) — "Deenergized parts." Live parts to which an employee may be exposed shall be deenergized before the employee works on or near them, unless the employer can demonstrate that deenergizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations.

Methods for Decreasing Arc-Flash Incident Energies

There are measures which can be taken to lower the incident energy and decrease the arc-flash boundary distance at a given system location. These include:

1. **Lower the available fault current** at that location. On systems equipped with differential relaying, which will operate in the same amount of time for a reduced magnitude fault, arc-flash incident energies will be reduced. While this can be a consideration when designing a new electrical distribution system, it normally is not practical to consider reducing fault current available on an existing system. In addition to the relatively high cost of changing out transformers for higher impedance units or adding current limiting reactors, increasing impedance will degrade voltage regulation performance within the system. In new systems, consideration should be given to reducing the transformer sizes, thereby reducing available fault current. Additional transformers would need to be purchased for the same loads. Limit the ampere rating sizes of new mains and feeders where possible, i.e. split large feeders into two feeders.

2. **Raise the available fault current** at that location. This is not a contradiction to point 1. There may be locations in an electrical system which would have had a lower NFPA Hazard/Risk Category if there were a higher fault current present sufficient to operate a fuse in its current limiting region or sufficient to operate a short-time or instantaneous trip device. On longer circuit lengths, this could involve adding parallel conductors to the circuit to raise the downstream fault levels.

Discussion of Arc-Flash Results

IEEE Std. 1584-2002 equations were used in all arc-flash hazard calculations. *IEEE Std. 1584a-2004–Amendment 1* requires that the second arc current equal to 85% of the original arc current be calculated *only* for system voltages under 1000V. The larger of the two incident energies calculated was used in this study.

The following assigned working distances were used in this study for each of the following voltage levels:

Voltage	Working Distance
69.000 kV	39 "
46.000 kV	33 "
34.500 kV	31 "
13.800 kV	36 "
4.160 kV	36 "
2.400 kV	36 "
0.480 kV	18 "
0.208 kV	18 "

1. Annex B of *IEEE Std. 1584-2002* states "If the time is longer than two seconds, consider how long a person is likely to remain in the location of an arc flash. It is likely that the person exposed to an arc flash will move away quickly if it is physically possible and two seconds is a reasonable time for calculations. A person in a bucket truck or a person who has crawled into equipment will need more time to move away." For this study, **a 2 second maximum time was used** in the arc-flash calculations.
2. The Arc Flash Protection Boundary is the distance at which the incident energy equals 1.2 cal/cm^2. *NFPA 70E* permits the Arc Flash Protection Boundary to be calculated at a different incident energy level (1.5 cal/cm^2) for situations where the fault-clearing time is 0.1 second (or faster). *IEEE Std. 1584-2002* is silent on this topic. **This study uses the more conservative calculation where the Arc Flash Protection Boundary is the distance at which the incident energy equals 1.2 cal/cm^2 for all fault-clearing times.**

By setting some of the instantaneous settings lower than their maximum settings, lower incident energies were realized. However, there were still locations where the incident energy was calculated to be above 40 cal/cm^2. This is referred to in the report's arc-flash hazard table as "Extreme Danger," meaning there is no Category of PPE that can be used to work on this location while it is energized. The most typical location in a system is the secondary of a transformer before its secondary main breaker. This area is only protected by the upstream fuse or breaker/relay.

Two arc-flash hazard tables appear in the results. The first table, **TABLE AF – Arc-Flash Hazard Table**, shows *every* system bus in the model with its arc-flash calculations, unless it was purposefully not calculated according to *IEEE Std. 1584*, it was the first bus in the system (utility bus), or it was overdutied or caused an upstream protective device to be overdutied. The second table, **TABLE AFL – Arc-Flash Hazard Label Table**, shows only those buses needing arc-flash hazard labels with just the values provided on each equipment label (one label per line). This table shows the comment line that appears at the bottom of each label and must be approved by the customer before the labels are printed.

Note: The arc-flash hazard and shock hazard labels supplied as part of this project can not be affixed to equipment until the recommendations of this study are implemented, (i.e. all relay and breaker settings are set and tested at the values recommended by this study; all fuses are sized per the recommendations of this study; any new equipment recommended has been set and tested to the recommendations of this study; etc.)

It is recommended that this study be repeated whenever any system changes are made that would affect the fault current levels or the protective device opening times, or in five years as required by *NFPA 70E*, whichever occurs sooner.

TABLE 3A: ARC FLASH HAZARD CALCULATION

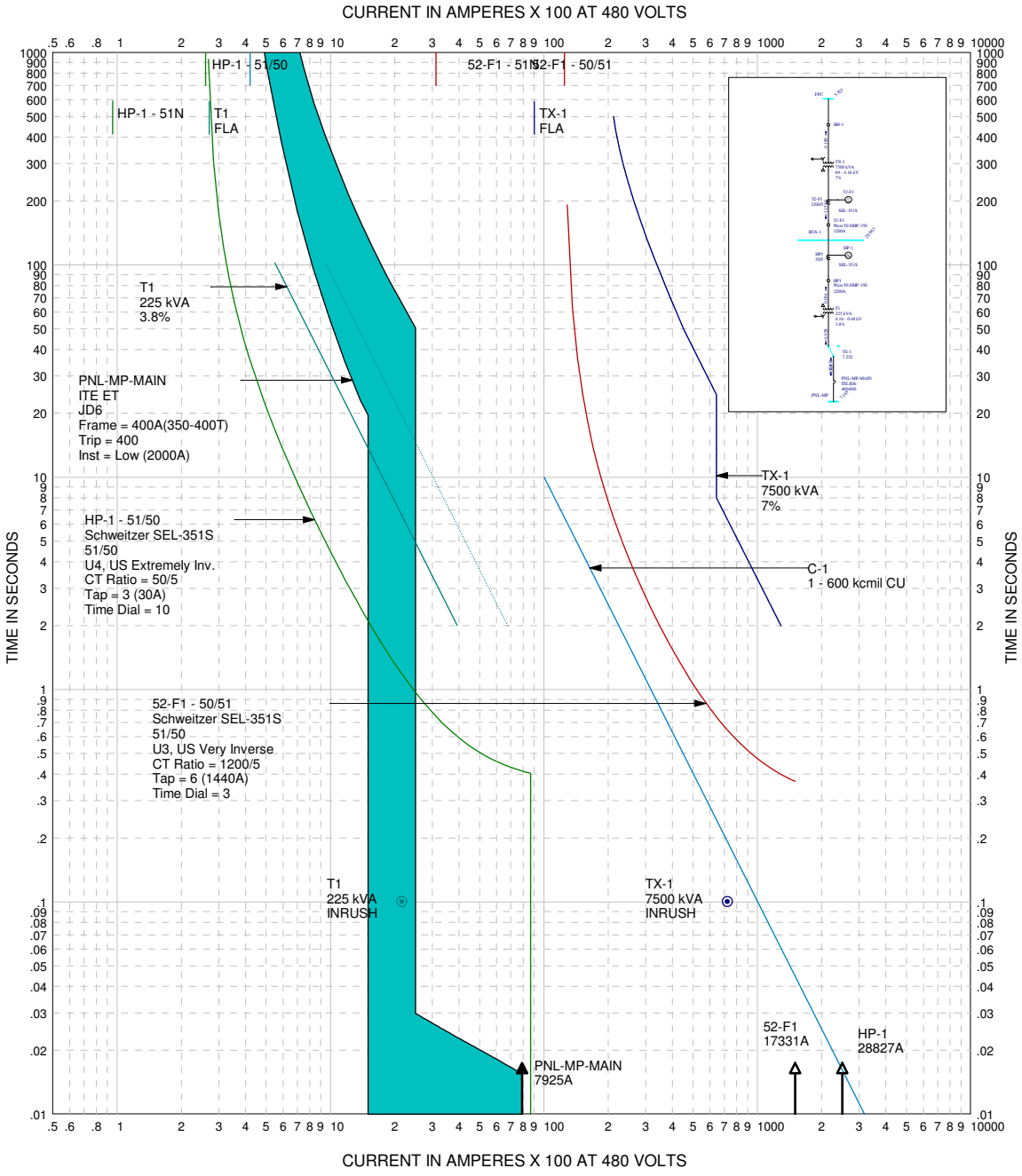
Arc Fault Bus Name	Arc Fault Bus kV	Upstream Trip Device Name	Upstream Trip Device Function	Equipment Type	Gnd	Arc Gap (mm)	Bolted Fault (kA)	Est Arc Fault (kA)	Trip Time (sec)	Opening Time (sec)	Arc Time (sec)	Est Arc Flash Boundary (inches)	Working Distance (inches)	Incident Energy (cal/cm2)	NFPA Hazard / Risk Category
BUS-1	4.160	87T, 87B	87	Switchgear	X	102	28.863	27.513			0.2	212.4	36	6.7	#2*
BUS-1	4.160	87T, 87B	87	Switchgear	X	102	28.863	27.513			0.2	212.4	36	6.7	#2*
BUS-1	4.160	87T, 87B	87	Switchgear	X	102	28.863	27.513			0.2	212.4	36	6.7	#2*
BUS-2	4.160	87T, 87B	87	Switchgear	X	102	28.863	27.513			0.2	212.4	36	6.7	#2*
BUS-1	4.160	87T, 87B	87	Switchgear	X	102	28.863	27.513			0.2	212.4	36	6.7	#2*
BUS-1	4.160	40, 41	40	Switchgear	X	102	28.863	27.513			2	2264.4	36	67.5	Ext Danger
BUS-2	4.160	87T, 87B	87	Switchgear	X	102	28.863	27.513			0.2	212.4	36	6.7	#2*
BUS-2	4.160	40, 41	40	Switchgear	X	102	28.863	27.513			2	2264.4	36	67.5	Ext Danger
BUS-2	4.160	87T, 87B	87	Switchgear	X	102	28.863	27.513			0.2	212.4	36	6.7	#2*
BUS-2	4.160	40, 41	40	Switchgear	X	102	28.863	27.513			2	2264.4	36	67.5	Ext Danger
BUS-1	4.160	87T, 87B	87	Switchgear	X	102	28.863	27.513			0.2	212.4	36	6.7	#2*
BUS-2	4.160	87T, 87B	87	Switchgear	X	102	28.863	27.513			0.2	212.4	36	6.7	#2*
BUS-1	4.160	87T, 87B	87	Switchgear	X	102	28.863	27.513			0.2	212.4	36	6.7	#2*
BUS-1	4.160	HP-1	51/50	Switchgear	X	102	28.827	27.479	0.016	0.083	0.099	103.5	36	3.4	#1
BUS-2	4.160	87T, 87B	87	Switchgear	X	102	28.863	27.513			0.2	212.4	36	6.7	#2*
BUS-2	4.160	HP-2	51/50	Switchgear	X	102	28.863	27.513	0.016	0.083	0.099	103.5	36	3.4	#1
PNL-EP-1	0.480	PNL-MP-MAIN		Panel	X	25	6.716	4.667	0.021	0	0.021	8	18	0.3	#0
PNL-MP	0.480	HP-1	51/50	Panel	X	25	0.793	0.549	0.522	0.083	0.605	63.1	18	9.4	#3
TS-1	0.480	HP-1	51/50	ATS	X	32	0.799	0.535	0.531	0.083	0.614	70.6	18	9	#3
TS-2	0.480	PNL-MP-MAIN		ATS	X	32	6.776	4.553	0.021	0	0.021	7.1	18	0.3	#0

TABLE 3B: ARC FLASH HAZARD LABEL TABLE

Arc Fault Bus Name	Arc Fault Bus kV	Est Arc Flash Boundary (inches)	Working Distance (inches)	Incident Energy (cal/cm2)	NFPA Hazard / Risk Category	Case No.	Label No.	LABEL LOCATION	Study Date
BUS-1	4.160	212.4	36	6.7	#2*	2	0001	52-B1 FRONT ACCESS	12/2009
BUS-1	4.160	212.4	36	6.7	#2*	2	0002	52-B2 FRONT ACCESS	12/2009
BUS-1	4.160	212.4	36	6.7	#2*	2	0003	52-F1 FRONT ACCESS	12/2009
BUS-2	4.160	212.4	36	6.7	#2*	2	0004	52-F2 FRONT ACCESS	12/2009
BUS-1	4.160	212.4	36	6.7	#2*	2	0005	52-G1 FRONT ACCESS	12/2009
BUS-1	4.160	2264.4	36	67.5	Ext Danger	2	0006	52-G1 REAR ACCESS	12/2009
BUS-2	4.160	212.4	36	6.7	#2*	2	0007	52-G2 FRONT ACCESS	12/2009
BUS-2	4.160	2264.4	36	67.5	Ext Danger	2	0008	52-G2 REAR ACCESS	12/2009
BUS-2	4.160	212.4	36	6.7	#2*	2	0009	52-G3 FRONT ACCESS	12/2009
BUS-2	4.160	2264.4	36	67.5	Ext Danger	2	0010	52-G3 REAR ACCESS	12/2009
BUS-1	4.160	212.4	36	6.7	#2*	2	0011	BUS-1 INCOMING BUS	12/2009
BUS-2	4.160	212.4	36	6.7	#2*	2	0012	BUS-2 INCOMING BUS	12/2009
BUS-1	4.160	212.4	36	6.7	#2*	2	0013	HP-1 FRONT ACCESS	12/2009
BUS-1	4.160	103.5	36	3.4	#1	2	0014	HP-1 REAR ACCESS	12/2009
BUS-2	4.160	212.4	36	6.7	#2*	2	0015	HP-2 FRONT ACCESS	12/2009
BUS-2	4.160	103.5	36	3.4	#1	2	0016	HP-2 REAR ACCESS	12/2009
PNL-EP-1	0.480	8	18	0.3	#0	2	0017	PNL-EP-1 FRONT	12/2009
PNL-MP	0.480	63.1	18	9.4	#3	2	0018	PNL-MP FRONT	12/2009
TS-1	0.480	70.6	18	9	#3	2	0019	TS-1 FRONT	12/2009
TS-2	0.480	7.1	18	0.3	#0	2	0020	TS-2 FRONT	12/2009

TIME-CURRENT COORDINATION CURVES

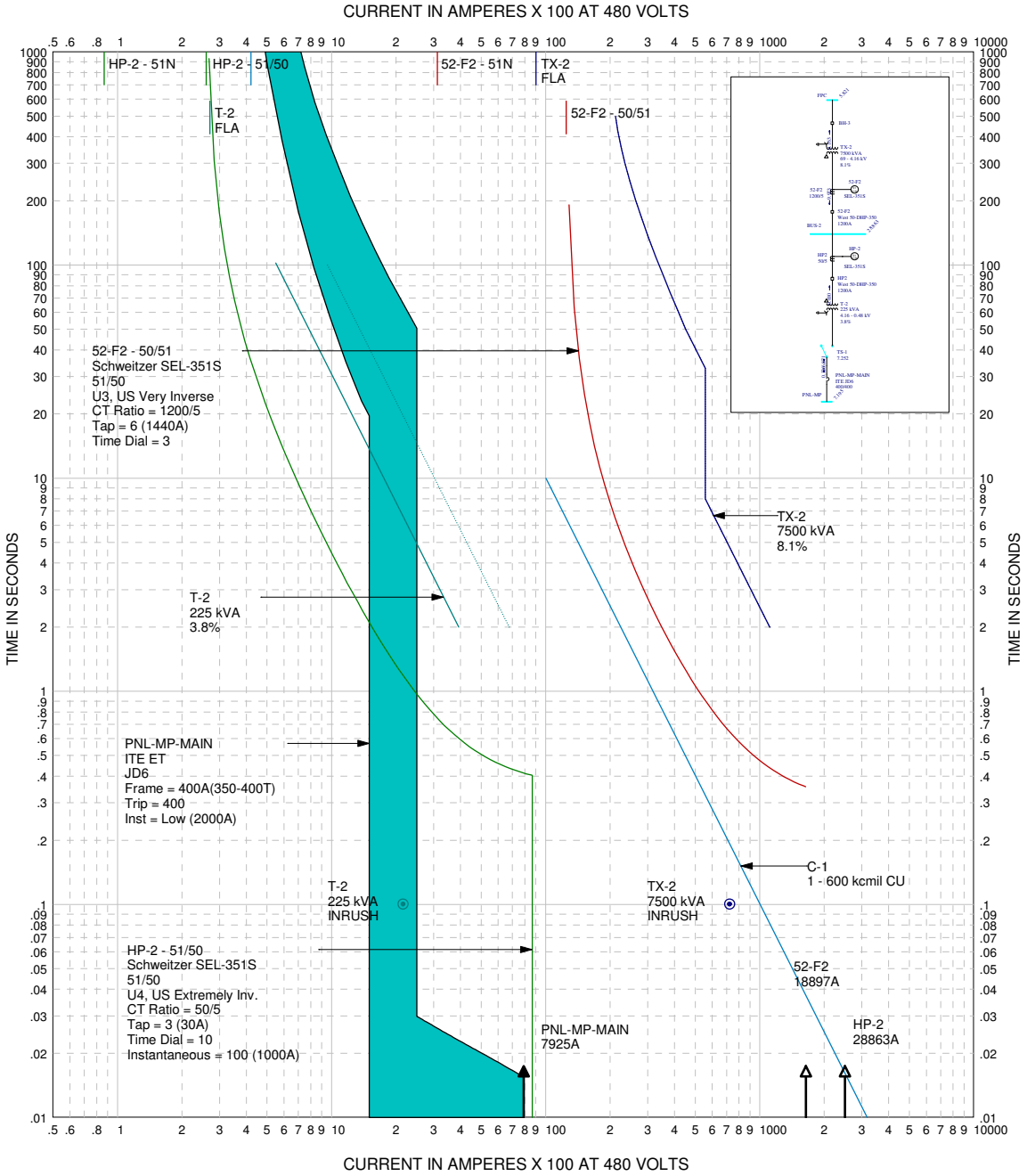
52-F1



GE	***EasyPower*** ® **TIME-CURRENT CURVES**	52-F1
	CORN HYDRO GENERATING STATION' CITY OF TALLAHASSEE, FL GE JOB #30020962	FAULT: THREE-PHASE DATE: Dec 01, 2009 BY: RHS REVISION: 1

CORNHYDRO

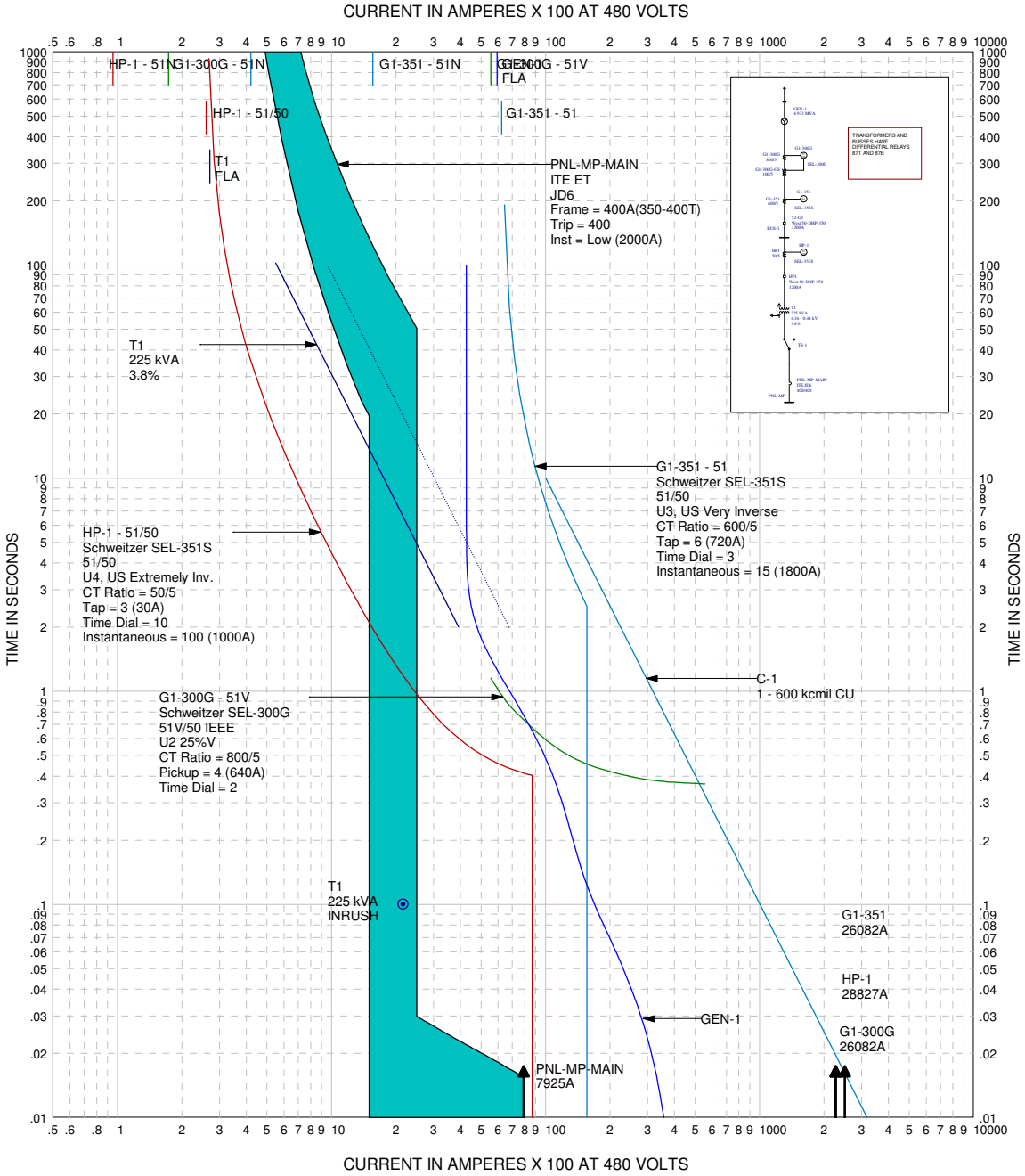
52-F2



GE	***EasyPower*** ® **TIME-CURRENT CURVES**	52-F2
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CORNHYDRO

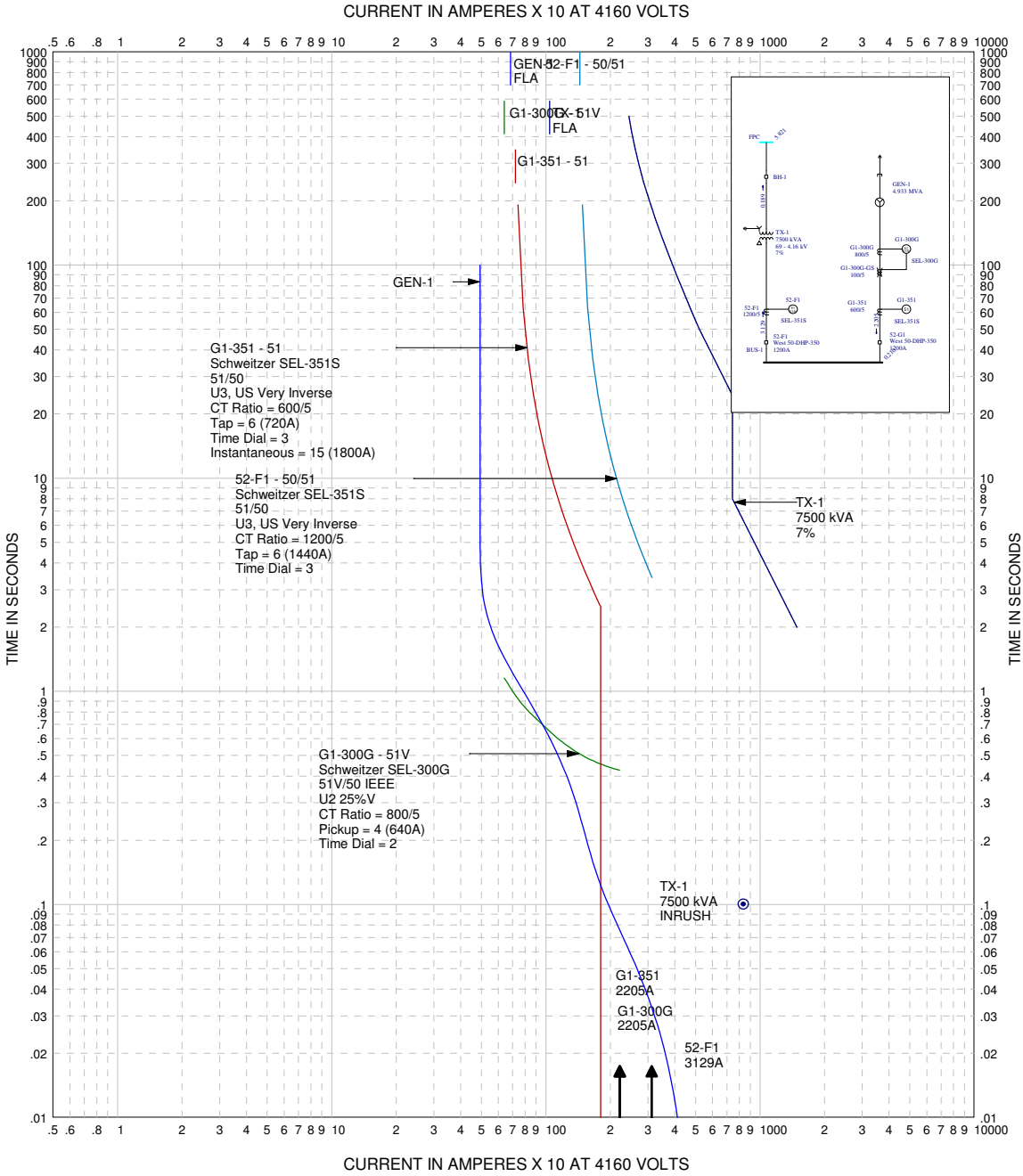
GEN-1-0.25VPU



GE	***EasyPower*** ® **TIME-CURRENT CURVES**	GEN-1-0.25VPU
	CORN HYDRO GENERATING STATION' CITY OF TALLAHASSEE, FL GE JOB #30020962	FAULT: THREE-PHASE DATE: Dec 01, 2009 BY: RHS REVISION: 1

CORNHYDRO

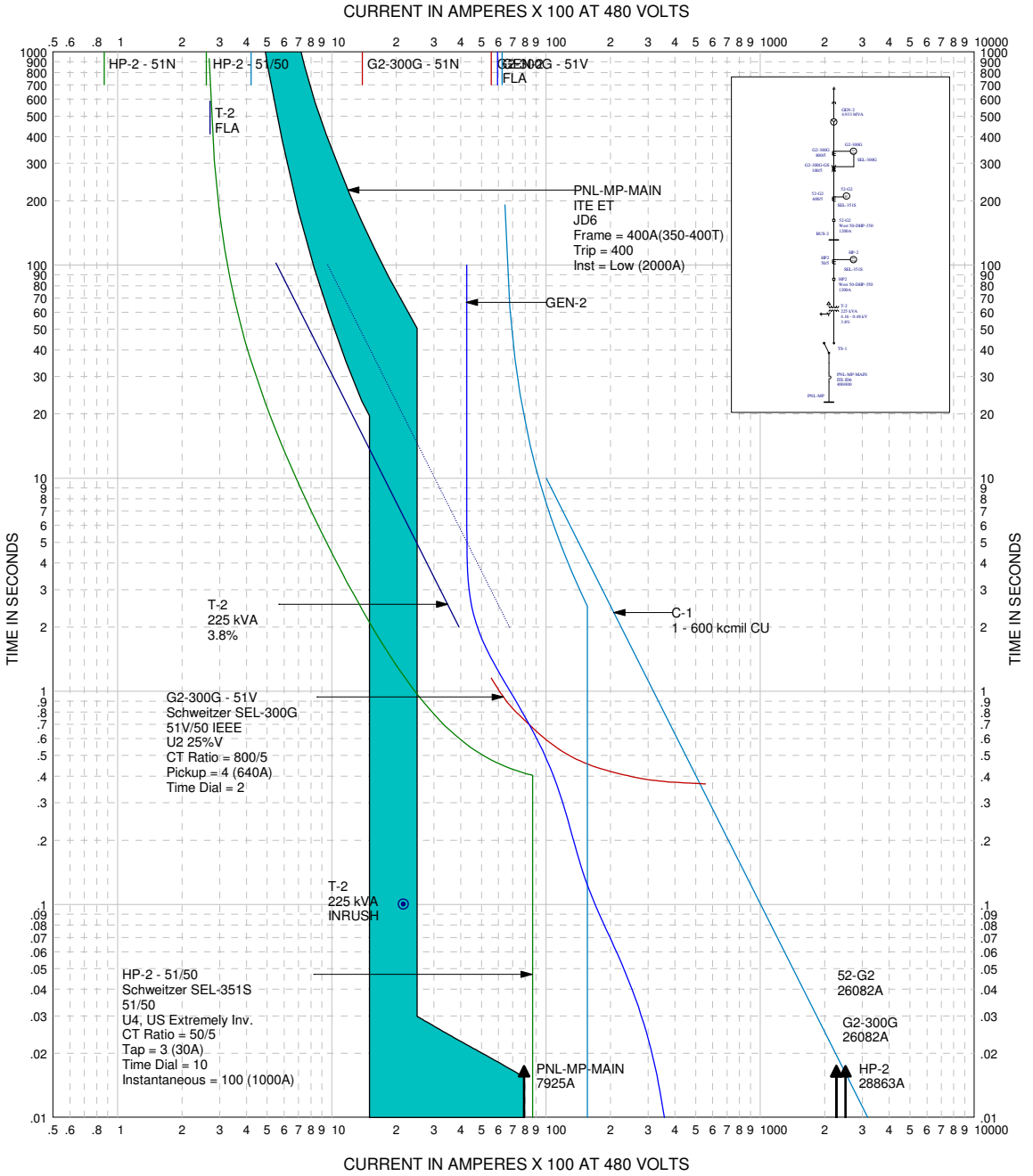
GEN-1-52-F1



GE	***EasyPower*** ® **TIME-CURRENT CURVES**	GEN-1-52-F1
	CORN HYDRO GENERATING STATION' CITY OF TALLAHASSEE, FL GE JOB #30020962	FAULT: THREE-PHASE DATE: Dec 01, 2009 BY: RHS REVISION: 1

CORNHYDRO

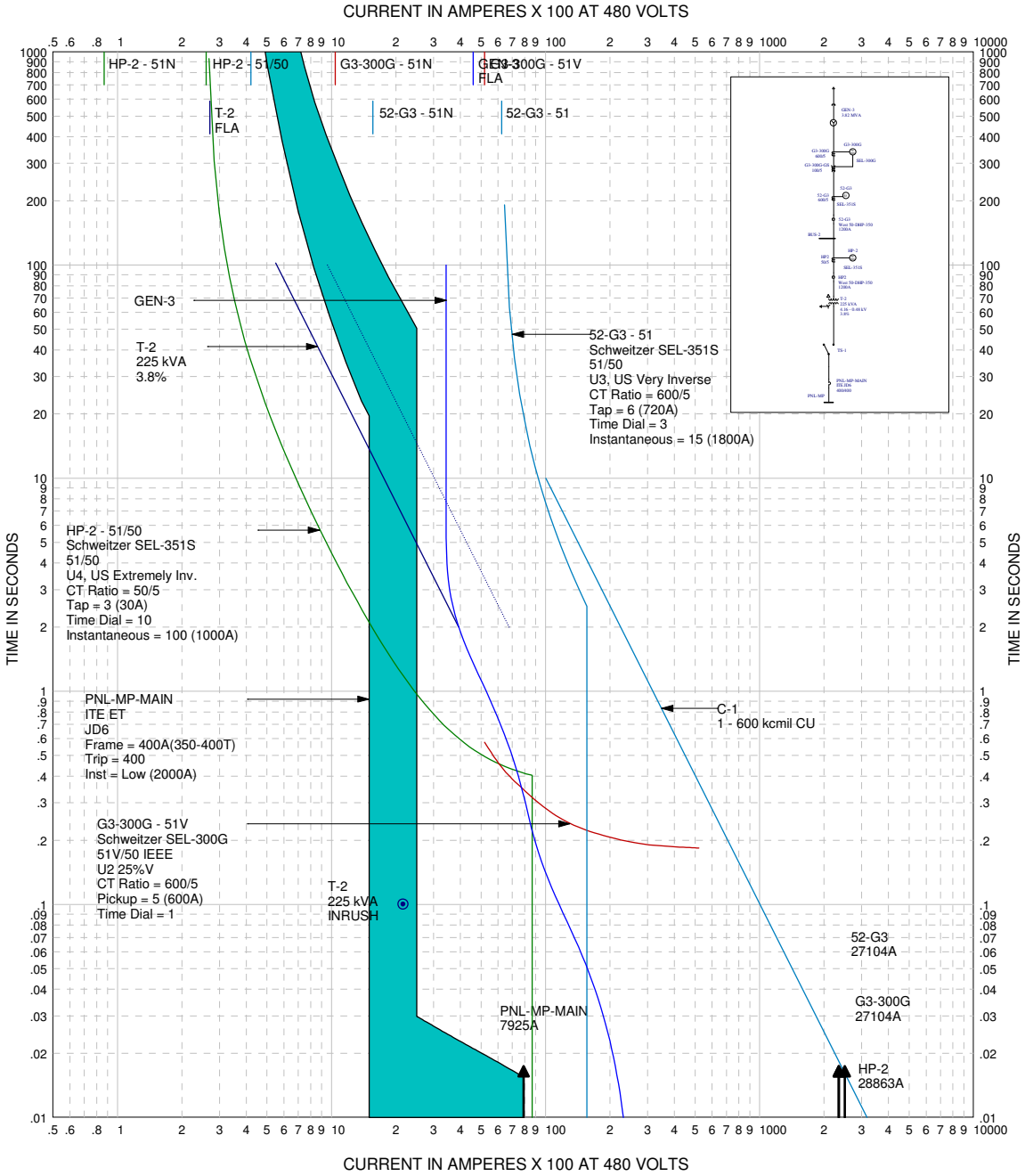
GEN-2-0.25VPU



GE	***EasyPower*** ® **TIME-CURRENT CURVES**	GEN-2-0.25VPU
	CORN HYDRO GENERATING STATION' CITY OF TALLAHASSEE, FL GE JOB #30020962	FAULT: THREE-PHASE DATE: Dec 01, 2009 BY: RHS REVISION: 1

CORNHYDRO

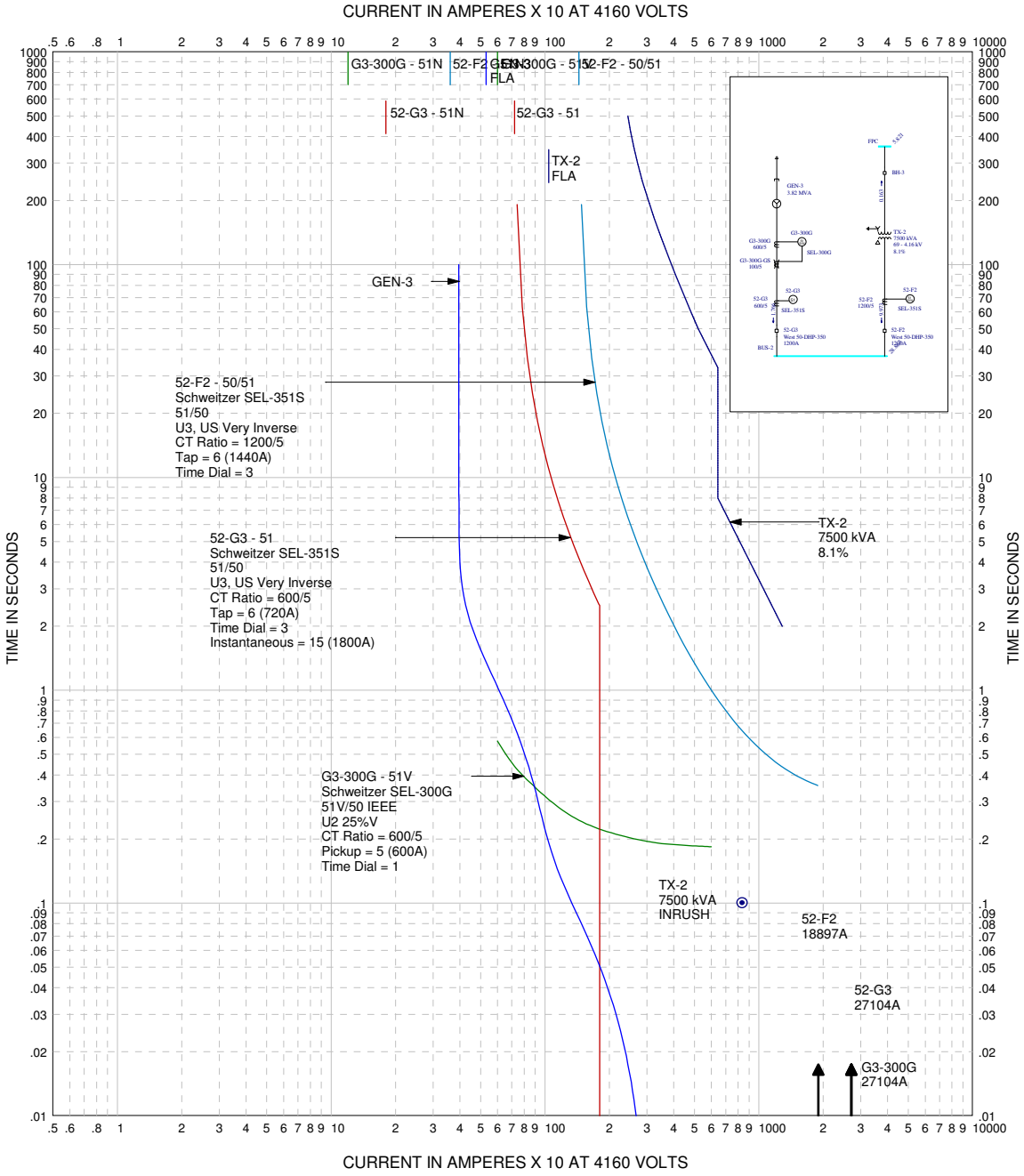
GEN-3-0.25VPU



GE	***EasyPower*** ® **TIME-CURRENT CURVES**	GEN-3-0.25VPU
	CORN HYDRO GENERATING STATION' CITY OF TALLAHASSEE, FL GE JOB #30020962	FAULT: THREE-PHASE DATE: Dec 01, 2009 BY: RHS REVISION: 1

CORNHYDRO

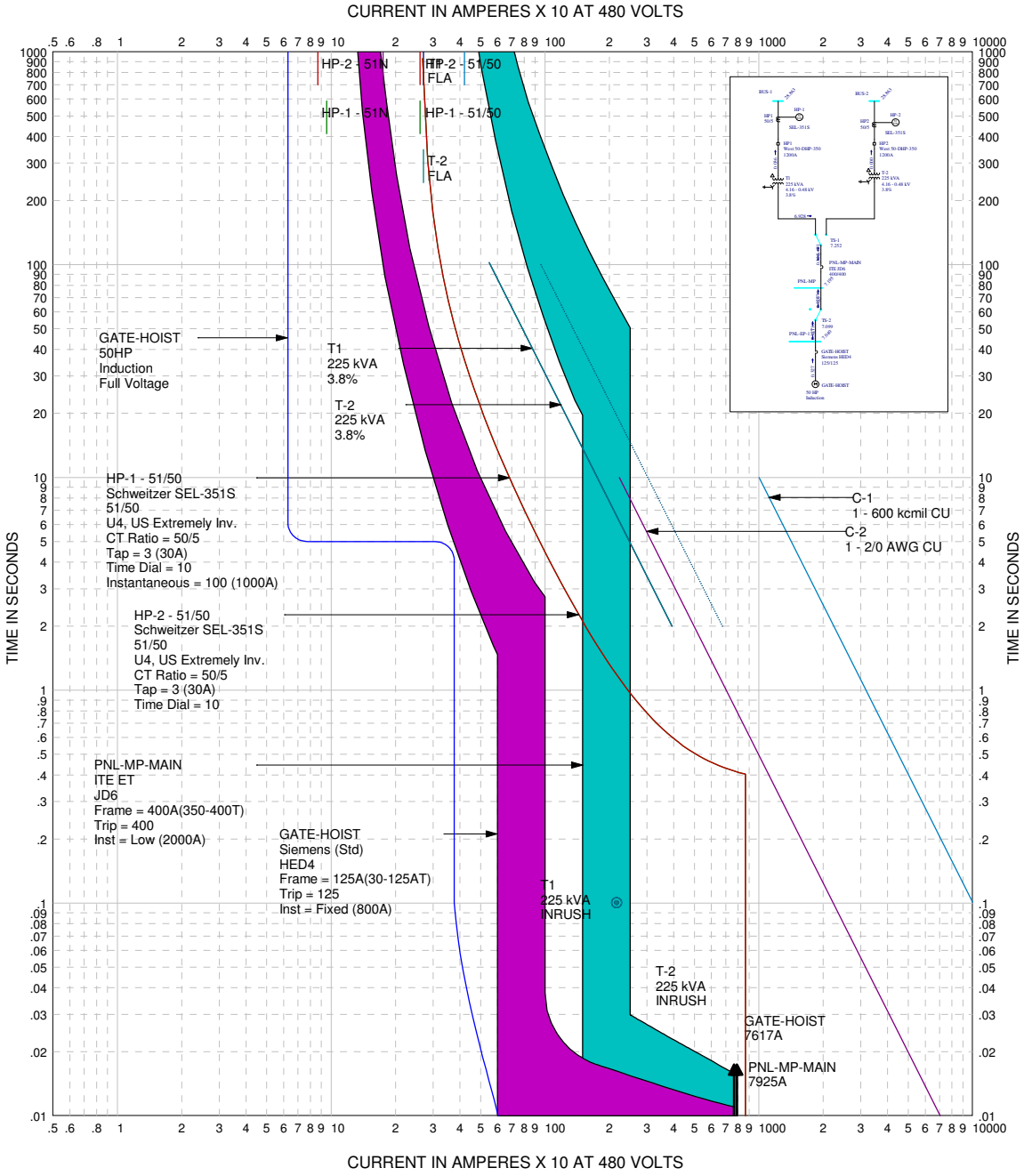
GEN-3-52-F2



GE	***EasyPower*** ® **TIME-CURRENT CURVES**	GEN-3-52-F2
	CORN HYDRO GENERATING STATION' CITY OF TALLAHASSEE, FL GE JOB #30020962	FAULT: THREE-PHASE DATE: Dec 01, 2009 BY: RHS REVISION: 1

CORNHYDRO

HP-1 AND HP-2



GE	***EasyPower*** ® **TIME-CURRENT CURVES**	HP-1 AND HP-2
	CORN HYDRO GENERATING STATION' CITY OF TALLAHASSEE, FL GE JOB #30020962	FAULT: THREE-PHASE DATE: Nov 30, 2009 BY: RHS REVISION: 1

CORNHYDRO