New York Presbyterian Hospital Combined Heat and Power Project Commutating Current Limiter Electric Power Transmission and Distribution (EPTD) Program

Final Report 10-06
February 2010

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Energy Research and
Development Authority

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Final Report

Prepared for the

New York State Energy Research and Development Authority

Albany, NY
www.nyserda.org

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NOTICE

ABSTRACT

Energy users considering implementing synchronous parallel cogeneration in the Con Edison service territory are faced with the prospect of paying for significant substation upgrades. These costs can run into the millions of dollars. As an alternative, NYSERDA co-funded pilot projects that may provide an alternative to substation upgrades and improve the economics of cogeneration projects in Manhattan.

This demonstration project involved using a commutating current limiter (CCL) to protect the Con Edison distribution network from potential faults created by the cogeneration project. The use of the CCL will result in significantly lower costs to the project than the current alternative and help more cogeneration projects move forward.

The NYPH cogeneration project used a G&W "CLiP" as its protection alternative and they were able to secure approval from Con Edison for the use of the CCL. In addition, the device was triggered shortly after start-up of the cogeneration project by a fault on the utility side of the service. The CCL provided the protection anticipated and no equipment failure resulted from the fault.

Upgrading the substation was estimated to cost anywhere from $380 to $1000 per kW. Nevertheless, since the substation upgrade costs are not related to the size of the cogeneration, with a larger number of breakers in the vault, the impact may be much greater. For this 7.5 MW project, the CCL cost approximately $220,000 to implement, or $29 per kW. As a result of this demonstration project, facilities considering synchronous parallel cogeneration now have a viable alternative to substation upgrades.

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SUMMARY

New York Presbyterian Hospital is a full service, teaching medical center located on the East side of Manhattan, New York. The hospital completed a cogeneration study and was considering implementation of a 7.5 MW gas solar turbine with heat recovery and duct firing. Synchronous operation would allow the hospital to operate in the event of power loss on the utility side. Although advantageous to the medical center, this configuration also subjected Con Edison to potential fault currents from the generator. As such, the project was subjected to significant restrictions and requirements from the utility. Among them was the potential of having to upgrade the breaker capabilities of the local substation to handle any fault coming from the generator, at a potential cost of several million dollars.

As an alternative to the substation upgrade, the hospital investigated the use of a commutating current limiter (CCL) to provide the required fault protection. In general, the device uses a notched conductor with small imbedded charges that "explode" when a fault current is indentified. The fault current is then rerouted to a fuse that absorbs the energy and melts. Because of the configuration, the unit has the ability to trigger the explosion and mitigate the fault in an extremely short period of time; satisfying the protection requirements of the utility. Although this device is commonly used in utility distribution applications, it is not common in cogeneration applications.

<u>The project was able to secure authorization from the utility to use the CCL as a fault mitigation device.</u> Numerous factory tests showed the reaction time of the unit to be from 83 to 91 μsec. The unit was installed as part of the switchgear for the cogeneration and was configured to identify both the incoming and outgoing faults on the service entrance. Shortly after system start-up, the facility experienced an incoming fault from the utility. The fault was high enough to trigger fuses at the local substation and the CCL triggered and isolated the fault. The momentary outage to the facility tripped equipment and restarts were required. Nevertheless, there was no damage to the facility, the cogeneration plant, or its ancillary equipment.

Implementing the CCL added approximately $220,000 to the cost of the project.[1] This resulted in a cost to the project of approximately $29 per kW. If the project had to pay the estimated cost of upgrading the substation, the net effect would have been anywhere from $400 to $1000 per kW and would have made the project uneconomic. Since the cost to upgrade a substation is independent of the size of the cogeneration plant, these impacts could be even greater.

[1] The cost of the CCL was integrated into the total cost of the switchgear.

Project Overview

Problem Definition

The New York Presbyterian Hospital is located on the island of Manhattan in the City of New York. Because of the physical characteristics of the Island, it is referred to as a "load pocket." Electricity must be produced on the Island or "transmitted" in across one of two rivers. The "In-City" electrical capacity reserve is currently at or below the recommended margin of 18%. Political obstacles and the "not in my backyard" syndrome have significantly reduced the opportunity to build new generating equipment in the New York City (NYC) and has stifled transmission projects that could import more power.

Distributed Generation (DG) offers a viable solution to resolving the electrical resource issue within NYC. With fuel conversion efficiencies exceeding 60% and significantly lower emissions than traditional coal and oil power plants, promoting DG in NYC can provide significant public benefit to the local and regional community. Installing synchronous, parallel generating equipment offers the added benefit of providing "black-start" generating capacity in the event of a power outage from the local distribution system. The systems do not require operating KVARS from the local distribution company.

However, synchronous parallel generation represents a special problem in Con Edison's network. The potential for fault currents into their substations from the generation equipment may cause significant problems and damage. This is especially true in substations that are near their maximum fault current duty. Many of the company's substations are at their maximum capacity and Con Edison has established policies and procedures for the introduction of DG to protect the distribution system. These procedures have, in some cases, made DG technically and economically unfeasible.

Figure 1 [2] is Con Edison's most recent interconnection map showing areas that may or may not be good candidates for interconnecting synchronous generation equipment. The red areas indicate areas where the breakers in the substation are at capacity and cannot withstand the introduction of additional fault current. Areas in green may have sufficient breaker capacity in the substation for the interconnection of a synchronous generator. However, interconnection is not guaranteed. Each project is studied on a case by case basis to determine the potential impacts on the substation and system. The process can be extremely time consuming. If the project is large enough, the fault current capacity for a given substation may be exceeded and the project would be required to install fault mitigation equipment.

[2] From Con Edison's Web site, ConEdison.com/Distributed Generation

The second issue facing potential projects in green zones is that project applications are queued in the order they are received. The potential impacts of all prior applications are considered when reviewing an application for mitigation purposes.

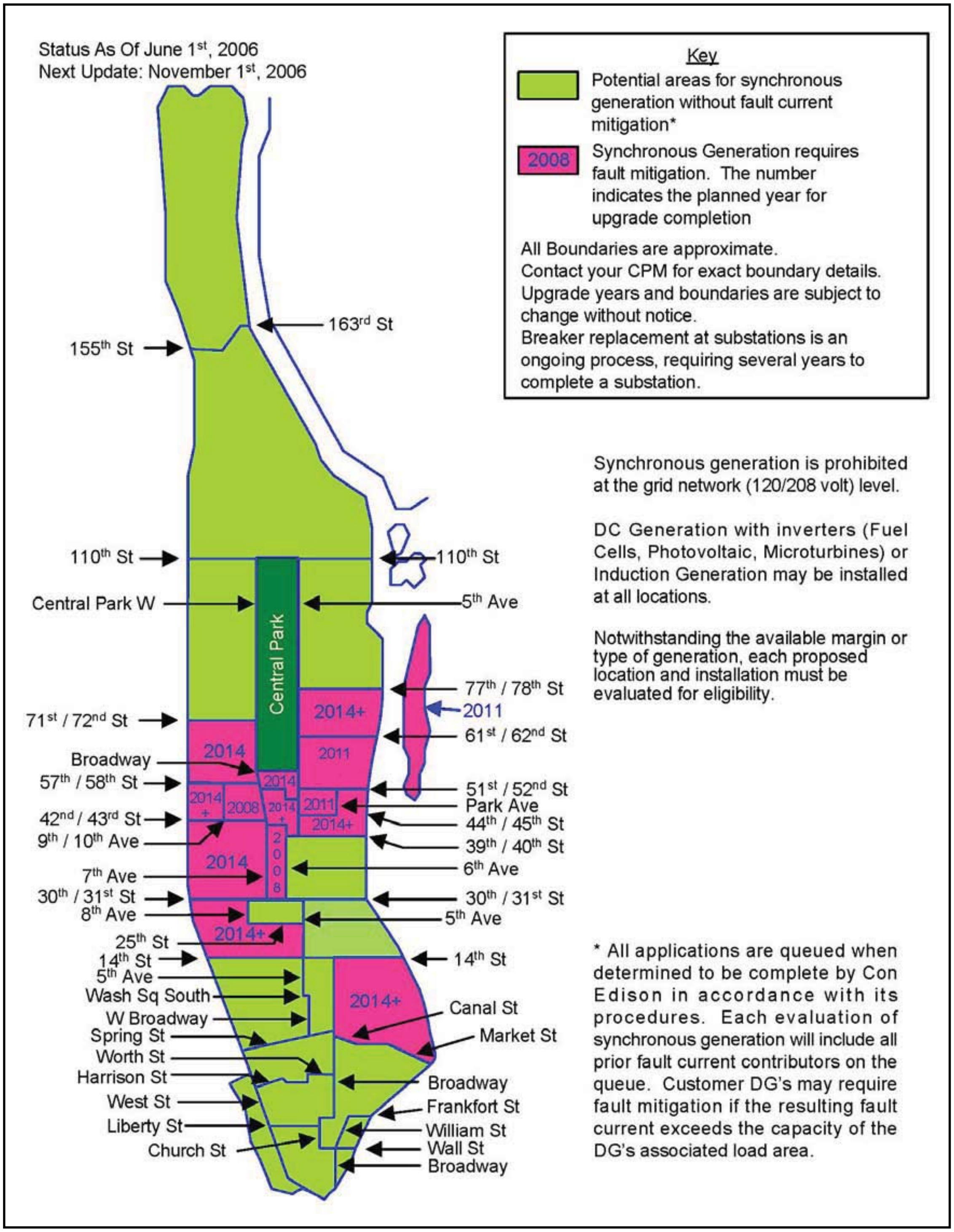
As more and more interest in synchronous DG increases the quantity of applications to Con Edison, the "available" fault current capacity in the Con Edison substations may be used up fairly quickly from the projects in queue. It is unlikely that a project applicant holding a Con Edison interconnection "approval" will readily give up the approval, even if the proposed project is delayed or on-hold. *New York Presbyterian Hospital's DG is located in the red zone between 61st and 77th streets and the upgrade of the substation is not anticipated until 2014.*

Substation upgrades, if required, must also be paid by the applicant if they want to proceed with the project. These upgrade costs easily exceed $1 million. A typical Con Edison substation has 40,000 amp breakers. An upgraded station has 63,000 amp breakers, which have been specially designed and manufactured to meet Con Edison's increased fault requirements. Each breaker costs approximately $100,000. Installation by Con Edison personal is estimated around $20,000 each for a total installed cost of $120,000. A substation normally has 4 to 5 feeders and can have 24 to 60 breakers. In order to "upgrade" the substation, every breaker needs to be replaced. This could cost anywhere from $2.8 million to $7.2 million.[3] Applicants could wait until Con Edison upgrades its sub-station, but many of these projects are years away from completion, and upgraded substations are no guarantee of an interconnection approval.

A readily acceptable, cost effective fault protection mechanism may help simplify and shorten the current Con Edison approval process and facilitate the implementation of synchronous DG in Manhattan. Facilities considering this type of project can simply specify and factor the cost of fault mitigation into the project. This will eliminate much of the uncertainty in the process and reduce the process time and resources required to implement projects.

[3] Based on estimates provided by Con Edison.

Figure 1 Con Edison Interconnection Map



Options for Fault Current Mitigation

Synchronous DG projects have several options for providing fault current mitigation.

1. Install reactors in line with the DG.
2. Install melting element current-limiting fuses
3. Install breakers
4. Install commutating current limiters (CCL)

Although reactors are an effective tool for fault current mitigation, they offer some key drawbacks. The reactor's required impedance may prevent sufficient load current flow or cause excessive voltage drops on the system. In addition, they consume substantial energy while they are in operation. These issues may upset the economics and functionality of a DG system.[4]

Traditional melt-able fuses can operate in ¼ to ½ cycles. However, they do not limit the maximum current to the equipment. In order to trip, the current rating for the fuse must be exceeded which subjects the equipment to extremely high current levels. Traditional breakers typically operate in three- to-five cycles.[5] This would expose their substations to potential damage and would not be fast enough to satisfy Con Edison's requirements.[6]

CCL technology has very high nominal operating currents and will clear a fault very quickly; ¼ to ½ cycles. The clearance methodology limits the actual current through the conductor and the operating time should easily satisfy Con Edison's requirements, protect the system, and avoid damage to any downstream equipment.

Commutating Current Limiters

Commutating current limiters (CCL), also known as Triggered Current Limiters (TCL), are devices that have been used in transmission and distribution systems to provide protection to utility grids for many years. Their primary application has been to provide over-current protection in the high continuous current range (up to 5000A) of medium voltage (1-38kV) equipment where traditional, melting element current-limiting fuses reach their practical limit and generally do not exist.[7]

Traditional Applications of CCL include the following:

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[4] John S. Schaffer, "Triggered Current Limiters for Closing Bus Ties, Bypassing Reactors and Improving Power Quality."
[5] The breakers used by Con Edison were specifically designed to meet the high current requirements.
[6] G&W Electric Company
[7] Ibid.

1. Reactor Bypass - CCL have been used to bypass reactors in utility and industrial applications. The operating current flows through the CCL until a fault occurs. The CCL trips and "commutates" the current through the reactor. This allows the reactor to provide fault protection without a power interruption. This system results in lower operating costs and better voltage control during normal operation.
2. Service Entrance and Substation Equipment - CCL has been used to extend the maximum capacity of service entrance equipment and substations without the need for expensive upgrades to breakers, transformers and other gear.
3. Protection against Catastrophic Failure - CCL have been used to mitigate faults before they reach critical equipment such as oil filled transformers.
4. Bus Tie Closure - In cases where closing a bus tie will allow a distribution system to meet load requirements, the CCL has been used to protect against high fault currents within the systems.
5. Installation of DG - CCL have been used to protect against fault currents from large power plants without the need to replace switchgear or install reactors.

CCL are currently manufactured by G&W (the CLiP), ABB (I_s Limiter) and S&C (Fault Fiter). This demonstration project will involve the G&W CLiP. According to the manufacturer, this will be the first time the device is used to protect the grid from a DG client in Manhattan.

Project Goals

The primary goal of this project was to determine if Con Edison would accept the CCL technology as a viable alternative to a substation upgrade. Acceptance of the technology would provide an economical alternative to implementing synchronous parallel generation in Manhattan. A secondary goal is to demonstrate how implementing the device affected the Con Edison approval process, documents the start-up and commissioning process and collected operating data on the CCL. This project serves as an example for other end users hoping to develop synchronous parallel generation ***anywhere*** in Manhattan and other electrically overloaded areas.

Project Findings

In March 2006, Con Edison provided the hospital with approval to install the G&W CLiP in lieu of upgrading the local substation as shown in Figure 2: Con Edison Approval Letter. The approval came with various caveats that were met by the project during and after installation. The letter suggests that Con Edison is willing to consider the use of this technology as a viable alternative to substation upgrades as long as certain conditions are met. As suggested by a Con Edison Representative in an e-mail at the conclusion of the project:

"… ConEd has agreed that the current-limiting fuse proposal from NYPH, the G&W CLiP, will satisfy our concern about fault current contribution by eliminating the generator contribution within 1/2 cycle. The G&W CLiP was also approved for use on another generator connected in the LIC network and we anticipate that the application would be appropriate for other such DG installations, as long as they are properly specified, tested, and installed."

Figure 2 Con Edison Approval Letter

conEdison

Manhattan Major Services
4 Irving Place 10th Floor South
New York, NY 10003

March 24, 2006

Jennifer Kearney
Energy Programs Manager
New York Presbyterian Hospital
525 East 68th Street AN 108
New York, NY 10021

Re: New York Presbyterian Hospital
Co Gen Project for 525 East 68 Street

Dear Ms. Kearney:

Con Edison has reviewed your G&W clip device and we find it acceptable for use at the location. Our acceptance of this device is with the understanding that the Customer will include the following:

- Use of dual sensing and firing logic.
- Use of inverter, in order to permit a battery to serve as the control power supply. Note the control box uses only AC power.

In addition, we will require the following:

- The CLIP will be tested after installation, by use of the G&W field tester device.
- A procedure should be established to notify Con Ed, whenever the CLIP is disabled. Our concern is that the CLIP can be disabled remotely by removing control power.
- NYPH wire the remote indication contact to an alarm or similar annunciation circuit.

Lastly, NYPH should be aware that the device specifications state "Units are suitable for outdoor as well as indoor applications without need for enclosures or heaters from –40 C thru +40 C." Note that +40 C is only 104 F, which is a very poor rating. This should be verified with G&W and also determined if it has any impact on the application of this device.

Please call me with any questions or inquiries on (212) 460-4998.

Very truly yours,

Joseph Puckart
Customer Project Manager
Manhattan Energy Services

The CLiP was installed as part of the switchgear of the CHP as shown below in Figure 3. The system consists of three CCL, one per phase. Each unit has its own logic system in the event that the fault occurs on only one of the three legs (in a three phase system).

Figure 3 NYPH CHP CLiP Installation

The unit was factory tested to ensure compliance with the specifications on the application. The test results are provided in Appendix A. These tests show that the unit has a "Trigger to Fire Time Delay" of 83 to 93 μsec. The planned field test where a shunt fuse was to be fired was not conducted. Nevertheless, the lab tests were carried out in the field as part of the commissioning process in order to confirm the factory test findings.

The system was commissioned according to the G&W check procedures as shown in Appendix B.

Real-Time Test Fire

In June 2009, shortly after start up of the CHP system and live operation of the system, Con Edison experienced a severe fault on its system. The fault current introduced into the substation and switchgear of the CHP was high enough to trip a substation breaker and the CLiP. This fault resulted in a momentary loss of power that tripped equipment within the central plant and throughout the hospital. All three legs of the CCL were triggered and the fault discharged into the associated fuse. There was no adverse impact to the Solar Turbine CHP or its control panel, switchgear or any other associated ancillary equipment. This incident clearly demonstrated the ability of the CLiP to isolate faults in a manner that protects equipment from harmful faults.

Although the device is designed to absorb a significant fault current by "exploding" charges along the primary conduit and redirecting the current to a "melting" fuse, there is very little outward appearance of an event. A small tip extrudes from within the fuse when it fires. This is one indication that an event has occurred.

The cost to replace the three fuses on the CLiP was $30,000 ($10,000 per leg) and the replacement was done using internal staff. Although originally installed to protect the Con Edison system from internally produced fault currents, the CLiP was also able to protect the system from incoming fault currents as well.

Cost of Installation

The CCL does not come as a standalone unit. It must be integrated into the switchgear of the application. As such, it is difficult to isolate the cost of implementing this technology from the general cost of switchgear and its associated ancillary costs.

The invoices associated with the switchgear are provided in Appendix C and are summarized in Table 1 below. The total cost of the switchgear for the project was approximately $596,694.50. Of this total cost, approximately $220,000 to $250,000 was related to the installation of the CCL (including engineering, materials, manufacturing, etc.). This resulted in a cost to the project of approximately $29 per kW. If the project had to pay the estimated cost of upgrading the substation, the net effect would have been anywhere from $400 to $1000 per kW and would have made the project uneconomic. These findings are summarized below in Table 2.

Table 1 Invoice Summary

Invoice #	Amount
1027286	$ 173,170.00
1027287	$ 121,007.00
1030008	$ 302,517.50
	$ 596,694.50

Table 2 CCL vs Substation Upgrade Comparison

Solar Turbine Capacity	7500	kW
Technology	**Estimated Cost**	**Cost/kW**
Substation Upgrade (low)	$ 2,800,000	$ 373
Substation Upgrade (high)	$ 7,200,000	$ 960
CCL	$ 220,000	$ 29

Conclusion

Projects considering synchronous parallel interconnection of their cogeneration plants with Con Edison's distribution must meet strict standards for protecting the utility's equipment from potential fault currents created by their cogeneration plants. Options include upgrading the utility's substation or installing protective equipment on the client's side of the service entrance. Upgrading the utility substation requires that all of the breakers within the substation serving the client be upgraded with higher amperage breakers. This could cost millions of dollars and will likely make projects uneconomical. Alternatives to this include installing reactors, current limiting fuses, breakers or commutating current limiters (CCL).

Although reactors are an effective tool for fault current mitigation, they offer some key drawbacks. The reactor's required impedance may prevent sufficient load current flow or cause excessive voltage drops on the system. In addition, they consume substantial energy while they are in operation. These issues may upset the economics and functionality of a DG system. Traditional meltable fuses can operate in ¼ to ½ cycles. Nevertheless, they do not limit the maximum current to the equipment. In order to trip, the current rating for the fuse must be exceeded, which subjects the equipment to extremely high current levels. Traditional breakers typically operate in three-to-five cycles. This would expose their substations to potential damage and would not be fast enough to satisfy Con Edison's requirements.

CCL technology has very high nominal operating currents and will clear a fault very quickly; ¼ to ½ cycles. The clearance methodology limits the actual current through the conductor and the operating time should easily satisfy Con Edison's requirements, protect the system and avoid damage to any downstream equipment.

This project demonstrated that the CCL technology can be acceptable to the local utility as an alternative to substation upgrades for fault mitigation. In addition, using the technology may be a very cost effective way to implement synchronous parallel cogeneration. The cost impact of the CCL for this project is estimated at around $29 per kW whereas a substation upgrade would have cost anywhere from $400 to $1000 per kW as shown in the table below.

Solar Turbine Capacity	7500	kW
Technology	Estimated Cost	Cost/kW
Substation Upgrade (low)	$ 2,800,000	$ 373
Substation Upgrade (high)	$ 7,200,000	$ 960
CCL	$ 220,000	$ 29

In addition to gaining interconnection approval, the technology proved effective when it mitigated an incoming fault early in the operation of the cogeneration plant. Although the fault current was large enough to trip utility side-substation breakers, the CCL protected the Solar Turbine cogeneration plant, the control panel and other ancillary equipment within the hospital.

As stated in an -mail by a representative of Con Edison to a member of the project team after the successful installation of the CCL for this project,

> "… ConEd has agreed that the current-limiting fuse proposal from NYPH, the G&W CLiP, will satisfy our concern about fault current contribution by eliminating the generator contribution within 1/2 cycle. The G&W CLiP was also approved for use on another generator connected in the LIC network and we anticipate that the application would be appropriate for other such DG installations, as long as they are properly specified, tested, and installed."

Appendix A – CLiP Factory Test Results

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G&W Electric Company
System Protection Division

CLiP® PRODUCTION TEST SHEET

TITLE: **CLiP® SENSING AND FIRING LOGIC**

RESPONSIBILITIES: CLiP ASSEMBLY TECHNICIAN

I.D. CODE: 811- 07-0075 **DRAWING NO.:** C5102 0117000

G&W SHOP ORDER NO.: G 71064 **TRIGGER LEVEL:** 4

TECHNICIAN: L **DATE:** 6-29-07

TEST DATA

1. PROBE CALIBRATION VERIFIED ✓

2. BURDEN RESISTOR VALUE 1.503 OHMS

3. EXCITATION CURRENT OF CURRENT TRANSFORMER
   - 500 : 1 TEST VOLTAGE UP TO 80 VOLTS ~ AMPS
   - 1500 : 1 TEST VOLTAGE UP TO 240 VOLTS .09 AMPS
   - 2000 : 1 TEST VOLTAGE UP TO 150 VOLTS ~ AMPS

   NOTE : SHOULD BE LESS THAN 10 AMPS

4. CURRENT TRANSFORMER RATIO: 1498 : 1

5. SEPARATION OF CURRENT PEAKS FROM STANDARD REFERENCE UNIT (Not to exceed 15.0μSec) +/- 9 μSec

6. MAGNITUDE OF PEAK IS WITHIN 5% OF REFERENCE CT. 1.2 %

7. VOLTAGE ACROSS FIRING CAPACITOR 469 Volts

8. TRIGGER TO FIRE TIME DELAY (80 to 100μSec) 89 μSec

9. CALIBRATION VALUES: Lo (4) Level 3.97 kA; Hi (14) Level 14.27 kA

   CUSTOMERS REQUESTED SETTING 3.97 kA

10. OPEN CIRCUIT VOLTAGE ACROSS FIRING LEADS .071 Volts

11. FIELD TESTER GO/NO-GO VOLTAGES GO 64 NO-GO 60

    OPPOSITE POLARITY GO 62 NO-GO 60

12. TRIGGER LEVEL ADJUSTMENT SCREW SEALED BY: [signature]

Signature of Tester: [signature] Date: 6-29-07

NOTE: ALL OSCILLOSCOPE TEST TRACES MUST BE ATTACHED TO THIS FORM.

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G&W Electric Company
System Protection Division
CLiP® PRODUCTION TEST SHEET

TITLE: **CLiP® SENSING AND FIRING LOGIC**

RESPONSIBILITIES: CLiP ASSEMBLY TECHNICIAN

I.D. CODE: 811- 07- 0074 **DRAWING NO.:** C5102 0117 000

G&W SHOP ORDER NO.: G 71064 **TRIGGER LEVEL:** 4

TECHNICIAN: [signature] **DATE:** 6-29-07

TEST DATA

1. PROBE CALIBRATION VERIFIED ✓

2. BURDEN RESISTOR VALUE 1.500 OHMS

3. EXCITATION CURRENT OF CURRENT TRANSFORMER
   500 : 1 TEST VOLTAGE UP TO 80 VOLTS ~ AMPS
   1500 : 1 TEST VOLTAGE UP TO 240 VOLTS .07 AMPS
   2000 : 1 TEST VOLTAGE UP TO 150 VOLTS ~ AMPS
   NOTE : SHOULD BE LESS THAN 10 AMPS

4. CURRENT TRANSFORMER RATIO: 1497 : 1

5. SEPARATION OF CURRENT PEAKS FROM STANDARD REFERENCE UNIT
(Not to exceed 15.0μSec) +/- 5 μSec

6. MAGNITUDE OF PEAK IS WITHIN 5% OF REFERENCE CT. .15 %

7. VOLTAGE ACROSS FIRING CAPACITOR 465 Volts

8. TRIGGER TO FIRE TIME DELAY (80 to 100μSec) 90 μSec

9. CALIBRATION VALUES: Lo (4) Level 3.98 kA; Hi (19) Level 14.53 kA

   CUSTOMERS REQUESTED SETTING 3.98 kA

10. OPEN CIRCUIT VOLTAGE ACROSS FIRING LEADS .061 Volts

11. FIELD TESTER GO/NO-GO VOLTAGES GO 64 NO-GO 61

    OPPOSITE POLARITY GO 64 NO-GO 62

12. TRIGGER LEVEL ADJUSTMENT SCREW SEALED BY: JdA

Signature of Tester: JdA Date: 6-29-07

NOTE: ALL OSCILLOSCOPE TEST TRACES MUST BE ATTACHED TO THIS FORM.

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G&W Electric Company
System Protection Division

CLiP® PRODUCTION TEST SHEET

TITLE: CLiP® SENSING AND FIRING LOGIC

RESPONSIBILITIES: CLiP ASSEMBLY TECHNICIAN

I.D. CODE: 811- 07-0073   **DRAWING NO.:** C5102 0117000

G&W SHOP ORDER NO.: G 71064   **TRIGGER LEVEL:** 4

TECHNICIAN: [signature]   **DATE:** 6-29-07

TEST DATA

1. PROBE CALIBRATION VERIFIED ✓
2. BURDEN RESISTOR VALUE 1.501 OHMS
3. EXCITATION CURRENT OF CURRENT TRANSFORMER
   500 : 1 TEST VOLTAGE UP TO 80 VOLTS ~ AMPS
   1500 : 1 TEST VOLTAGE UP TO 240 VOLTS .11 AMPS
   2000 : 1 TEST VOLTAGE UP TO 150 VOLTS ~ AMPS
   NOTE : SHOULD BE LESS THAN 10 AMPS
4. CURRENT TRANSFORMER RATIO: 1497 : 1
5. SEPARATION OF CURRENT PEAKS FROM STANDARD REFERENCE UNIT (Not to exceed 15.0μSec) +/- 8 μSec
6. MAGNITUDE OF PEAK IS WITHIN 5% OF REFERENCE CT. .22 %
7. VOLTAGE ACROSS FIRING CAPACITOR 467 Volts
8. TRIGGER TO FIRE TIME DELAY (80 to 100μSec) 89 μSec
9. CALIBRATION VALUES: Lo (4) Level 3.97 kA; Hi (14) Level 14.46 kA
   CUSTOMERS REQUESTED SETTING 3.97 kA
10. OPEN CIRCUIT VOLTAGE ACROSS FIRING LEADS .083 Volts
11. FIELD TESTER GO/NO-GO VOLTAGES GO 63 NO-GO 62
    OPPOSITE POLARITY GO 62 NO-GO 58
12. TRIGGER LEVEL ADJUSTMENT SCREW SEALED BY: [initials]

Signature of Tester: [signature]   Date: 6-29-07

NOTE: ALL OSCILLOSCOPE TEST TRACES MUST BE ATTACHED TO THIS FORM.

(26)

G&W Electric Company
System Protection Division
CLiP® PRODUCTION TEST SHEET
TITLE: **CLiP® SENSING AND FIRING LOGIC**

RESPONSIBILITIES: CLiP ASSEMBLY TECHNICIAN

I.D. CODE: 811-07-0072 **DRAWING NO.:** C5102 0117 000

G&W SHOP ORDER NO.: G 71064 **TRIGGER LEVEL:** 4

TECHNICIAN: [signature] **DATE:** 6-29-07

TEST DATA

1. PROBE CALIBRATION VERIFIED ✓

2. BURDEN RESISTOR VALUE 1.495 OHMS

3. EXCITATION CURRENT OF CURRENT TRANSFORMER
500 : 1 TEST VOLTAGE UP TO 80 VOLTS ~ AMPS
1500 : 1 TEST VOLTAGE UP TO 240 VOLTS .07 AMPS
2000 : 1 TEST VOLTAGE UP TO 150 VOLTS ~ AMPS
NOTE : SHOULD BE LESS THAN 10 AMPS

4. CURRENT TRANSFORMER RATIO: 1497 : 1

5. SEPARATION OF CURRENT PEAKS FROM STANDARD REFERENCE UNIT
(Not to exceed 15.0μSec) +/- 10 μSec

6. MAGNITUDE OF PEAK IS WITHIN 5% OF REFERENCE CT. .22 %

7. VOLTAGE ACROSS FIRING CAPACITOR 471 Volts

8. TRIGGER TO FIRE TIME DELAY (80 to 100μSec) 91 μSec

9. CALIBRATION VALUES: Lo (4) Level 3.97 kA; Hi (14) Level 14.43 kA

CUSTOMERS REQUESTED SETTING 3.97 kA

10. OPEN CIRCUIT VOLTAGE ACROSS FIRING LEADS .062 Volts

11. FIELD TESTER GO/NO-GO VOLTAGES GO 64 NO-GO 61

OPPOSITE POLARITY GO 63 NO-GO 61

12. TRIGGER LEVEL ADJUSTMENT SCREW SEALED BY: [signature]

Signature of Tester: [signature] Date: 6-29-07

NOTE: ALL OSCILLOSCOPE TEST TRACES MUST BE ATTACHED TO THIS FORM.

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G&W Electric Company
System Protection Division
CLiP® PRODUCTION TEST SHEET

TITLE: **CLiP® SENSING AND FIRING LOGIC**

RESPONSIBILITIES: CLiP ASSEMBLY TECHNICIAN

I.D. CODE: 811- 07- 0071 **DRAWING NO.:** C5102 0117000

G&W SHOP ORDER NO.: G 71064 **TRIGGER LEVEL:** 4

TECHNICIAN: JSA **DATE:** 6-29-07

TEST DATA

1. PROBE CALIBRATION VERIFIED ✓

2. BURDEN RESISTOR VALUE 1.499 OHMS

3. EXCITATION CURRENT OF CURRENT TRANSFORMER
500 : 1 TEST VOLTAGE UP TO 80 VOLTS ~ AMPS
1500 : 1 TEST VOLTAGE UP TO 240 VOLTS .06 AMPS
2000 : 1 TEST VOLTAGE UP TO 150 VOLTS ~ AMPS
NOTE : SHOULD BE LESS THAN 10 AMPS

4. CURRENT TRANSFORMER RATIO: 1497 : 1

5. SEPARATION OF CURRENT PEAKS FROM STANDARD REFERENCE UNIT
(Not to exceed 15.0μSec) +/- 10 μSec

6. MAGNITUDE OF PEAK IS WITHIN 5% OF REFERENCE CT. .9 %

7. VOLTAGE ACROSS FIRING CAPACITOR 470 Volts

8. TRIGGER TO FIRE TIME DELAY (80 to 100μSec) 90 μSec

9. CALIBRATION VALUES: Lo (4) Level 3.98 kA; Hi (14) Level 14.43 kA

CUSTOMERS REQUESTED SETTING 3.98 kA

10. OPEN CIRCUIT VOLTAGE ACROSS FIRING LEADS .069 Volts

11. FIELD TESTER GO/NO-GO VOLTAGES GO 63 NO-GO 61

OPPOSITE POLARITY GO 62 NO-GO 61

12. TRIGGER LEVEL ADJUSTMENT SCREW SEALED BY: JSA

Signature of Tester: JSA Date: 6-29-07

NOTE: ALL OSCILLOSCOPE TEST TRACES MUST BE ATTACHED TO THIS FORM.

30

G&W Electric Company
System Protection Division

CLiP® PRODUCTION TEST SHEET

TITLE: **CLiP® SENSING AND FIRING LOGIC**

RESPONSIBILITIES: CLiP ASSEMBLY TECHNICIAN

I.D. CODE: 811- 07-0076 **DRAWING NO.:** C5102 011000

G&W SHOP ORDER NO.: G 71064 **TRIGGER LEVEL:** 4

TECHNICIAN: [signature] **DATE:** 6-29-07

TEST DATA

1. PROBE CALIBRATION VERIFIED ✓

2. BURDEN RESISTOR VALUE 1.496 OHMS

3. EXCITATION CURRENT OF CURRENT TRANSFORMER
500 : 1 TEST VOLTAGE UP TO 80 VOLTS ~ AMPS
1500 : 1 TEST VOLTAGE UP TO 240 VOLTS .11 AMPS
2000 : 1 TEST VOLTAGE UP TO 150 VOLTS ~ AMPS
NOTE : SHOULD BE LESS THAN 10 AMPS

4. CURRENT TRANSFORMER RATIO: 1496 : 1

5. SEPARATION OF CURRENT PEAKS FROM STANDARD REFERENCE UNIT
(Not to exceed 15.0μSec) +/- 10 μSec

6. MAGNITUDE OF PEAK IS WITHIN 5% OF REFERENCE CT. .07 %

7. VOLTAGE ACROSS FIRING CAPACITOR 512 Volts

8. TRIGGER TO FIRE TIME DELAY (80 to 100μSec) 83 μSec

9. CALIBRATION VALUES: Lo (4) Level 3.97 kA; Hi (14) Level 14.40 kA

CUSTOMERS REQUESTED SETTING 3.97 kA

10. OPEN CIRCUIT VOLTAGE ACROSS FIRING LEADS .070 Volts

11. FIELD TESTER GO/NO-GO VOLTAGES GO 61 NO-GO 59

OPPOSITE POLARITY GO 60 NO-GO 58

12. TRIGGER LEVEL ADJUSTMENT SCREW SEALED BY: [signature]

Signature of Tester: [signature] Date: 6-29-07

NOTE: ALL OSCILLOSCOPE TEST TRACES MUST BE ATTACHED TO THIS FORM.

Appendix B – G&W CLiP Checkout Procedure

SYSTEM PROTECTION DIVISION

CLiP® COMMISSIONING CHECK-OUT PROCEDURES

G&W ELECTRIC CO.

CUSTOMER NY [illegible] DATE [illegible]

CUSTOMER CONTACT Chung Wong PHONE ____

TIME IN ____ TIME OUT ____ SIGNATURE ____

INCOMING POWER:

INVERTER POS/NEG ✓, INVERTER INPUT 126.5

AC BOARD INPUT 121.6, XFMR OUTPUT 7.99

OUTGOING POWER:

PHASE A 7.91, PHASE B 7.91, PHASE C 7.91

I.T. A 7.31, I.T. B 7.33, I.T. C 7.32

REMOTE INDICATION:

STD OR HI-SPEED HS, DISARMING RELAY (Y/N) Y

PHASE A ✓, PHASE B ✓, PHASE C ✓

CUSTOMER RESPONSE TO REMOTE INDICATION None is 4by

FIELD TESTER: (std./redundant)

	GO (std./redundant)		NO GO (std./redundant)
PHASE A^+	70 / 70	PHASE A^+	60 / 60
PHASE A^-	70 / 70	PHASE A^-	60 / 60
PHASE B^+	70 / 70	PHASE B^+	60 / 60
PHASE B^-	70 / 70	PHASE B^-	60 / 60
PHASE C^+	70 / 70	PHASE C^+	60 / 60
PHASE C^-	70 / 70	PHASE C^-	60 / 60

SIMULATORS:

USED? No, TIME –, OK? –

CONDITIONS TESTED ____

Procedure #:CLP-F-13 Issue Date: 8/6/03 Revision: 1 Page: 1 of 1

CLiP components have been tested at the factory for dielectric integrity. The overall system should also be verified for dielectric integrity by hipot or similar means before applying system voltage. For these tests, the short yellow control cables (300mm), between the Sensing and Firing Logic and the Isolation transformers, must be connected. The yellow, 30 meter cables from the ground potential end of the Isolation Transformer to the control box must also be connected. The control box must have grounds with continuity to the base of the Isolation Transformer.

Before beginning the commissioning process, the CLiP should be ready for energization of control power. CLiP high voltage portions must be de-energized and grounded per applicable safety codes. Ensure that CLiP trigger wires are not connected.

The interrupters may or may not be installed at this time. If they are installed, the two gray triggering leads should not be connected to the triggering terminals of the Sensing and Firing Logic. They should be shorted, tightly twisted, and pulled back parallel to the interrupter body. The yellow remote indicating cable, between the interrupter and the Isolation Transformer, should not be connected. It should be pulled back and restrained next to the interrupter body.

The following instructions are a general guide to assist the installer in checkout of the CLiP installation. This does not preclude any specific details provided in the main installation instructions, or in the use of the field tester or simulators, and their appropriate instructions.

INCOMING POWER:

1. For A.C. control power supplies, skip to item 3 below. For D.C. control power one must verify the polarity of the supply before energizing the controls. Terminal 1 is Positive. Terminal 2 is negative. Isolate one of the input wires from the control box terminal strip before checking.

2. Energize D.C. control power. Record DC input voltage (terminals 1 & 2).

3. If A.C. control power is supplied, energize the source and measure the voltage between terminals 1 & 2. For a D.C. control power system, the A.C. output of the inverter to the controls can be measured at terminals 17 & 18 on the Printed Circuit Board. The A.C. voltage should be 110-125VAC unless an optional 220-250V A.C. supply option has been ordered. Record the A.C. voltage.

4. Record the stepdown transformer output voltage from terminals 3 & 4. It should be from 6.5-8VAC (typically around 7.5V).

5. De-energize and re-energize the control power supply. Verify proper operation of the Loss of Voltage relay and its contacts at the terminal strip. Check user's alarm circuits for function.

OUTGOING POWER:

6. Record output voltages to the isolation transformers. They will be slightly lower than the voltages recorded in step 4. Control power must be enabled. Note, the black and white control power leads are not polarized. [If the jumper between terminals 11 & 12 is removed for connection of the remote disable relay or other disabling function, the output voltage will be zero and the yellow LED will be illuminated. The control power must be enabled for further tests.]

7. Remove the caps on the control power elbow fitting at the high-voltage side of the isolation transformer. This is where the remote indicating cables will later plug in. Record the output voltage of each transformer. It should be below that recorded in step 6, but at or above 6.0VAC (5.75VAC for 27kV units and above.

REMOTE INDICATION:

8. Virtually all CLiP units after year 2000 have standard hi-speed remote indication using a printed circuit board in the control box. Record the indication type.

9. Using a bare wire (a paper clip will work), short-circuit the terminals where the voltage check in step 7 was made. This is about 7.5VAC at 8 amperes maximum. The associated fault sensing circuit breaker in the control box will trip, the fault sensing relay will pick up, and the red LED will illuminate. If the short is maintained, the green LED will not illuminate. If the short is removed while the breaker is tripped, both red and green LEDs may illuminate.

10. Remove the short and reset the circuit breaker. Check the other phases in the same manner. Verify satisfactory operation of any user-installed remote indication alarm and/or breaker trip circuits connected to the terminal strip.

FIELD TESTER:

11. If the CLiP is provided with the optional Redundant Sensing and Firing Logic system, temporarily disconnect the redundant sensing tie wire at the high voltage (insulated) triggering terminal on one SFL unit.

12. Mount the field tester across the top of the isolation transformer and turn thumbscrews to clamp it to the bus. Verify

that the high voltage (insulated) triggering post does not contact the legs of the field tester. Connect the red clip-lead to the high voltage (insulated) triggering terminal. Plug the other end of the red lead in the "banana" jack. Follow specific instructions for field tester operation.

The test is essentially a matter of charging a large capacitor in the tester to a level where, upon discharging, the current is sufficient to trigger the CLiP Sensing & Firing Logic (SFL). When the SFL triggers, the green LED on the field tester will illuminate. Record the charge voltage (from the meter) at which the SFL triggers, and another value, below which it does not trigger. A spread of 10-15V is sufficiently close. Record values.

13. Perform and record the above checks on each SFL and on all phases. Thresholds within 20V for different phases are acceptable.

14. Then reverse orientation of the tester and check all phases with the opposite discharge polarity (opposite current flow).

15. Reconnect the redundant sensing tie wire.

SIMULATORS:

Use of the simulators is at customer discretion. High voltage will need to be energized for use of the simulators. During these tests, there is no protective capability from the CLiP interrupters. Interrupters must be installed without connection of triggering leads or the remote indication cable. The high-voltage system should have previously passed all dielectric integrity test requirements.

As there is no protection from the CLiP interrupters, the system available fault power must be limited to within equipment ratings. If this is not possible, the customer is advised to not perform this test. All sources of fault power should not be connected during this test.

The use of the simulators is an attempt to induce an undesirable triggering, due to system conditions that were not predicted during earlier stages of design or analysis. It must be recognized that the user's staff, consultants or G&W personnel can not predict all pertinent system characteristics or phenomena. Operation of a simulator is quite rare; however, they are a useful tool during startup or where unknown phenomena are an issue. The simulator has the same initiation characteristic as the interrupter. Use of the simulators may prevent an undesired (and more costly) interruption of a CLiP interrupter.

Some CLiP users may choose not to use the simulators. They may not be able to energize and de-energize the system repeatedly. They may not be able to reduce available fault power to within system ratings; or other reasons may preclude their use. Tests with the simulators are at customer discretion. If the customer chooses not to use the simulators, the system is ready for final connections of interrupters prior to full activation. Ensure that the control power is OFF when connecting triggering leads of interrupters or simulators. Ensure that control power is re-energized following connection of triggering leads.

16. Disable control power to the CLiP.

17. Connect simulator triggering leads to the SFL triggering terminals. Twist the leads of the simulator.

18. Temporarily support the simulator body (of each phase) adjacent to the triggering terminals with electrical tape, cable ties or similar means. Ensure that the simulator or its wires do not reduce the electrical clearance between phases or to ground.

19. Disconnect and separate the quick-connect terminals that short the lead wires. Energize control power.

20. At this time the system should be prepared for high voltage energization by removal of grounds, closure of enclosure doors (if applicable), etc.

21. Testing is performed by closure of system switchgear to energize the CLiP and incite a transient response. These may include transformer energization, capacitor bank or stray capacitance inrushes, motor starting, de-energized system pickup, tie closure and other items. Repeated closure is recommended, as responses are often statistically random in nature. Ensure that transformers, if energized, are given sufficient time for transient inrush currents to decay before de-energization. Three to five close-open operations are typical. Multiple switches or breakers may be operated in order to verify multiple conditions.

22. Following tests, de-energize the high voltage system. Isolate and apply grounds per applicable safety codes.

23. De-energize CLiP control power.

24. Access simulators and re-connect the shorting wires.

25. Check simulators for signs of operation. Operation is typically indicated by a marking of the interior of the simulator body in the translucent portion of the tube. It appears as a line or skip mark of lighter color. Shaking the tube will result in a rattle of loose components. Record tests made and the results.

26. It is preferred that the simulator does not operate. If an operation has occurred, consult personnel of the G&W Electric Company System Protection Division.

27. If an operation has not occurred, the system is ready for final preparations before energization. Follow primary installation instructions. Ensure that the triggering leads are connected, shorting wires removed and control power is re-energized before applying high voltage.

Consult G&W Electric Company System Protection Division personnel if there are any questions or concerns.

Appendix C – Switchgear Costs

GE Energy

and its affliated companies

ORIGINAL INVOICE

INVOICE NUMBER	INVOICE DATE	PAGE
1027286	16-JUL-07	1 of 1

DUE DATE	PAYMENT TERMS
15-AUG-07	NET 30

SEND PAYMENT SHOWING INVOICE NO. & INVOICE DATE TO

BY MAIL: GE ENERGY
P.O. BOX # 281997
ATLANTA GA 30384-1997

BY WIRE: DEUTSCHE BANK TRUST COMP
ACC# 50280397
ABA# 021001033
NEWYORK, NY
Swift Code: BKTRUS33

SHIP TO: NEW YORK PRESBYTERIAN HOSPITAL
512 E 71st St
NEW YORK NY 10021-4803

BILL TO: ACCOUNTS PAYABLE
NEW YORK PRESBYTERIAN HOSPITAL
PO BOX 156
NEW YORK NY 10021

GE Tax ID# 14-0689340

We now accept: Master Card, Visa and American Express. Call Phone# listed below for processing

CURRENCY: USD

CUSTOMER ORDER NUMBER	GE REFERENCE NUMBER	GE CUSTOMER NUMBER	BILLING PERIOD
89906284-0-C	30014747	5206537	16-JUL-07

LINE	SVC.DATE	PRODUCT/SERVICE PROVIDED	TAX	QUANTITY	UOM	UNIT PRICE	EXTENDED AMOUNT
1		SUPPLY RELAY PANELS AND TOPHATS PER GE PROP 1-1EMASG RELAY PANEL REV 2 DTD 1/17/07 Project Name: CORNELL-RELAY PANEL Project Manager: WONG, Mr. CHUNG	N	1		173,170.00	173,170.00

OKAY TO PAY
Date 8-28-2007
PO# 89906284
Cost Center 07-7623
Account#
Inv# 1027286
Apprvd Amt $173,170.00
Proj Mgr [signature] 8-27-2007
Director [signature] 8/30/07
VP Facilities [signature] 8/31/07
CEO/CFO

OK TO PAY
P.O.# 89906284-0-C

State tax status require a copy of the tax-exempt certificates be maintained in our records, otherwise we must collect tax on sales invoiced. If applicable, please return a copy of your valid tax-exempt certificates to the following address, to ensure accurate invoicing: General Electric, PO Box 4090. Duluth, GA 30096. Fax (770) 441-7434

	UNIT TOTAL	TAX TOTAL	SHIP HNDL TOTAL	INVOICE TOTAL
ANY QUESTIONS CONCERNING THIS INVOICE PLEASE CONTACT MAURICE BROWN @ 518-385-5264	173,170.00	0.00	0.00	173,170.00

GE Energy
and its affiliated companies

Finance
#20 Technology Park Ste 200
Norcross, GA 30092

ORIGINAL INVOICE

INVOICE NUMBER	INVOICE DATE	PAGE
1027287	16-JUL-07	1 of 1

DUE DATE	PAYMENT TERMS
15-AUG-07	NET 30

SEND PAYMENT SHOWING INVOICE NO. & INVOICE DATE TO:

By Mail:
GE ENERGY
P.O. BOX #281997
ATLANTA, GA 30384-1997

By Wire:
DEUTSCHE BANK TRUST COMP
ACC# 50280397
ABA# 021001033
NEW YORK, NY
Swift Code: BKTRUS33

GE Tax ID# 14-0689340

We now accept: Master Card, Visa and American Express. Call Phone # listed below for processing

BILL TO:

1

ACCOUNTS PAYABLE
NEW YORK PRESBYTERIAN HOSPITAL
PO BOX 156
NEW YORK NY 10021-0012

SHIP TO:
NEW YORK PRESBYTERIAN HOSPITAL
512 E 71st St
NEW YORK NY 10021-4803

CURRENCY
USD

CUSTOMER ORDER NUMBER	GE REFERENCE NUMBER	GE CUSTOMER NUMBER	BILLING PERIOD
89906484-O-C	30014892	5206537	16-JUL-07

LINE	SVC DATE	PRODUCT/SERVICE PROVIDED	TAX	QUANTITY	UOM	UNIT PRICE	EXTENDED AMOUNT
1		20%-UPON SUBMISSION OF APPROVAL DWGS TO NYPY PER GE PROP 1-EMAUO, REV 2 DTD 1/17/07 Project Name: CGS SWITCHGEAR & TR Project Manager: WONG, Mr. CHUNG		1		121,007.00	121,007.00

OKAY TO PAY
Date 8-14-2007
PO# 89906484
Cost Center 05-5000
Account#
Inv# 1027287
Apprvd Amt $121,007.00
Proj Mgr [signature] 8/14/07
Director [signature]
VP Facilities [signature]
CEO/CFO

[signature] 8/14/07

2007 JUL 24 P 3:38
NY PRESBYTERIAN HOSPITAL
ACCOUNTS PAYABLE

State tax statutes require that a copy of the tax-exempt certificate be maintained in our records, otherwise we must collect tax on sales invoiced. If applicable, please return a copy of your valid tax-exempt certificate to the following address, to ensure accurate invoicing:
General Electric. PO Box 4090. Duluth, GA 30096 Fax: (770)441-7434

	UNIT TOTAL	TAX TOTAL	SHIP HNDL TOTAL	INVOICE TOTAL
any questions concerning this invoice please contact maurice brown @ 518-385-5264	121,007.00	0.00	0.00	**121,007.00**

25732.2007070708201.00001

GE Energy

and its affliated companies

SHIP TO: NEW YORK PRESBYTERIAN HOSPITAL
512 E 71st St
NEW YORK NY 10021-4803

BILL TO: ACCOUNTS PAYABLE
NEW YORK PRESBYTERIAN HOSPITAL
PO BOX 156
NEW YORK NY 10021

ORIGINAL INVOICE

INVOICE NUMBER	*INVOICE DATE*	*PAGE*
1030008	26-JAN-08	1 of 1

DUE DATE	*PAYMENT TERMS*
25-FEB-08	NET 30

SEND PAYMENT SHOWING INVOICE NO. & INVOICE DATE TO

BY MAIL: GE ENERGY
P.O. BOX # 281997
ATLANTA GA 30384-1997

BY WIRE: DEUTSCHE BANK TRUST COMP
ACC# 50280397
ABA# 021001033
NEWYORK, NY
Swift Code: BKTRUS33

GE Tax ID# 14-0689340

We now accept: Master Card, Visa and American Express. Call Phone# listed below for processing

CURRENCY: USD

CUSTOMER ORDER NUMBER	*GE REFERENCE NUMBER*	*GE CUSTOMER NUMBER*	*BILLING PERIOD*
89906484-O-C	30014892	5206537	26-JAN-08

LINE	SVC.DATE	PRODUCT/SERVICE PROVIDED	TAX	QUANTITY	UOM	UNIT PRICE	EXTENDED AMOUNT
1		25%-UPON RECEIPT OF EQUIPMENT BY NYPH PER GE PROP 1-EMAU0, REV 2 DTD 1/17/07	N	1		151,258.75	151,258.75
2		25%-UPON APPROVAL & RELEASE FOR MANUFACTURING PER GE PROP 1-EMAUO, REV 2 DTD 1/17/07	N	1		151,258.75	151,258.75

Project Name: CGS SWITCHGEAR & TR

Project Manager:
WONG, Mr. CHUNG

OKAY TO PAY
Date 3/5/2008
PO# 89906484
Cost Center 05-5000
Account# 9004
Inv# 1030008
Apprvd Amt $302,517.50
Proj Mgr
Director
VP Facilities
CEO/CFO

3/5/08

State tax status require a copy of the tax-exempt certificates be maintained in our records, otherwise we must collect tax on sales invoiced. If applicable, please return a copy of your valid tax-exempt certificates to the following address, to ensure accurate invoicing: General Electric, PO Box 4090, Duluth, GA 30096. Fax (770) 441-7434

	UNIT TOTAL	TAX TOTAL	SHIP HNDL TOTAL	INVOICE TOTAL
ANY QUESTIONS CONCERNING THIS INVOICE PLEASE CONTACT MAURICE BROWN @ 518-385-5264	302,517.50	0.00	0.00	302,517.50

For information on other
NYSERDA reports, contact:

New York State Energy Research
and Development Authority
17 Columbia Circle
Albany, New York 12203-6399

toll free: 1 (866) NYSERDA
local: (518) 862-1090
fax: (518) 862-1091

info@nyserda.org
www.nyserda.org

New York Presbyterian Hospital Combined Heat and Power Project Commutating Current Limiter Electric Power Transmission and Distribution (EPTD) Program

Final Report 10-06

State of New York
David A. Paterson, Governor

New York State Energy Research and Development Authority
Vincent A. DeIorio, Esq., Chairman
Francis J. Murray, Jr., President and Chief Executive Officer

Energy. Innovation. Solutions.