Final Technical Report
Date of Report June 29, 2012

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Project Period:	01/31/2010 through 03/31/2012
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List of Acronyms

AC	Alternating Current
ARM	Active Rectifier Management
CO2	Carbon dioxide
DC	Direct Current
DSP	Digital Signal Processor
HE	High Efficiency
HVAC	Heating, Ventilation, and Air Conditioning
kWh	kilowatt hours
ICT	Information and Communications Technology
LLC	resonant circuit formed by two inductors and a capacitor
SMR	Switch Mode Rectifier
VAC	volts alternating current

1. Executive Summary

In June of 2009, The U.S. Department of Energy Industrial Technologies Program issued a funding opportunity announcement to develop new technologies to dramatically improve energy efficiency in information and communications technology (ICT) sector. The new technology had to be field tested and commercially available within three to five years. The motivation for this funding opportunity is recognition that worldwide, total energy usage in the ICT industry is estimated at 160 billion kWh with North America consumption at 48 billion kWh. If we assume an average utility cost of $0.10/kWh, $4.8B is spent by the North American ICT industry annually.

Lineage Power and Verizon teamed up to submit a proposal for this opportunity focused on the power conversion chain in telecommunications facilities and data centers. The proposed project had three significant elements: the design and development of high efficiency and high power three-phase rectifiers by Lineage Power, design and development of software to optimize overall plant energy efficiency by Lineage Power, and a field trial in active Verizon telecommunications facilities where energy consumption was measured before and after efficiency upgrades. The proposal was accepted and the project formally awarded in January 2010. Two rectifier designs were needed, one for 208VAC and the other for 480VAC. The first rectifier was completed in December 2010 and the second was completed in September 2011. The software work involved enhancement of a simple energy efficiency feature in the power system controller equipment and this work was also completed in September 2011. This software adjusts the number of rectifiers in standby to force the operating rectifiers to run near the peak of their efficiency curve. The field trial of these developments involved the installation of accurate monitoring equipment and an automatic data collection system as well as the planning, coordination, and installation of the newly designed high efficiency equipment. The major goals of the project were achieved. The new rectifiers achieve an efficiency of 96% and the field trial results validate the expected improvements in overall plant efficiency. The rectifier efficiency improvement means the losses in the new rectifiers are half of the previous generation. If this new high efficiency equipment were to be introduced into the estimated 26 thousand telecommunications facilities in North America, we anticipate 400 million kWh in reduced electricity consumption with a corresponding 300 thousand ton reduction of greenhouse gases.

2. Introduction

The principal objective of this project is to develop, field test and prove-in the commercial feasibility of High-Efficiency Wideband Three-Phase Switched-Mode Rectifiers (HE SMR) utilizing high-efficiency power conversion circuits and an Active Rectifier Management (ARM) efficiency-optimized control system.

A rectifier is a power conversion device that takes the commercial utility AC power delivered to the ICT facility and converts it to 48 volts DC. All power conversions waste some amount of energy which is consumed within the unit and released as heat. The efficiency of a power conversion stage is calculated by dividing the output power output by the input power. Efficiency measures range anywhere from 50% to 99% depending on many design factors of the conversion stage. Older technology used in many ICT facilities has efficiency of 88%. Delivering 100 watts of power to the load equipment would require as much as 113 watts drawn from the source. The extra 13 watts are needed to perform the conversion and are released as heat into the ICT center. More recent rectifiers are capable of 92% efficiency. The units designed as a part of this program had a target of 96% efficiency. For these high efficiency rectifiers, 100 watts delivered to the load would require 104 watts of input power from the source. This is a 3x improvement over the older equipment.

The rectifier improvements focus on a single key power conversion element in an overall DC power plant system. Individual rectifiers are combined into very large systems – up to 0.5 megawatts – by putting them in parallel. The efficiency of an individual rectifier varies, sometimes significantly, over its range of operation. A DC power plant composed of a large number of rectifiers running at a small fraction of their total capacity is generally less efficient than a system with fewer rectifiers running near the peak of their efficiency curves. The Active Rectifier Management (ARM) software takes advantage of this phenomenon and adjusts the number of rectifiers supplying power to the load to optimize overall plant efficiency.

The 48VDC power plant has been a staple of the telecommunications industry from its earliest days. It combines relatively few power conversion stages with the simplest and most reliable battery backup architecture. A study by the Green Grid shows this power plant to be the most efficient power architecture available[1]. There are thousands of telecommunications facilities in the US supporting wire-line and wireless communications. As telecommunications and information technology converge, the potential application of DC power conversion becomes widespread. A recent open standard for information processing[2] calls for efficiencies greater than 95% and illustrates the potential application for the technologies used in these new high efficiency rectifiers.

An important requirement for the DOE grant is rapid commercialization. To help comply with this requirement, the rectifier was designed to match existing product in every way except for the improvement in efficiency. The new units are plug-compatible with a previous generation of lower efficiency units. Replacement of the older, least-efficient rectifier technology is made easier with special purpose cabinets that present the exact same customer external connection points with slots to plug-in the new high efficiency rectifiers. With these approaches, the new rectifiers quickly entered the market directly taking the place of the previous generation and rapidly propagating the high efficiency benefits.

3. Background

The objectives of this project are to

1. Create a next generation true three-phase high power rectifier providing greater than 96% efficiency.
2. Create software technology to optimize overall plant efficiency.
3. Measure typical ICT energy consumption before and after installation of the products created above.
4. Share results at the 2012 INTELEC[3] conference to enhance commercialization.

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[1] "Quantitative Power Distribution Configurations Efficiency Analysis", Lynn Simmons & Pam Lembke, The Green Grid Tech Forum 2009 presentation, http://www.thegreengrid.org

[2] "Server Power Supply Specifications", Pierluigi Sarti, Open Compute Project, http://opencompute.org

[3] "34th International Telecommunications Energy Conference", http://www.intelec.org/intelec2012/

The potential economic benefits of this technology are derived from the reduced losses incurred when converting the commercial AC power into usable DC power. Our approach to reducing losses is to improve the efficiency of the power conversion system elements – rectifiers – and to actively control the elements such that they operate near their peak efficiency. By reducing the losses in the power conversion circuits we reduce the number of incoming kWh's consumed by the plant every year. An additional benefit is gained in reduced air conditioning costs. All incoming power is eventually converted to heat after performing the ICT work. With fewer watts coming into the facility, less heat is generated and less cooling is required. The active rectifier management feature is software loaded into an existing controller to maximize the power plant efficiency by operating the rectifiers at the peak of their efficiency curves.

Much of the DC plant equipment in telecomm centers today date from the 1980's. This technology is based on large magnetics to regulate the voltage and reaches a peak efficiency of 88%. More modern equipment designed in the 1990's and 2000's is based on switch-mode transistor devices and reaches efficiencies near 92%.

The Lineage Power team tasked with this project has a long history of rectifier design. Table 1 describes the skill sets and experience of the key individuals.

Table 1 - Project Resources

Role	Skill Set	Education	Experience
Project Manager	Scheduling, time and expense management, R&D project coordination, field project coordination.	PhD EE, Six Sigma Black Belt	26 years
Rectifier Electrical	Hard & soft switched converters. Three level topologies, high frequency magnetics and control loop design. Use of simulation tools like MATLAB, SIMPLIS & PLECS.	MS Electrical Engineering	12 years
Rectifier Mechanical	Mechanical design and analysis of high density electronic packaging in missile guidance units, telecom equipment and power electronics	BS Aeronautical & Mechanical Engineering	20 years
Rectifier Software	Real-time embedded software for digital control of power supplies.	BS and MS in Computer Engineering	20+ years embedded software design
Controller Software	Embedded real time firmware. Protocols, algorithms.	MS Computer Science. BSc Electronic and Electrical Engineering	30 years firmware, 20 years in power

4. Results and Discussion

Our approach to the rectifier design improvements come from four areas:

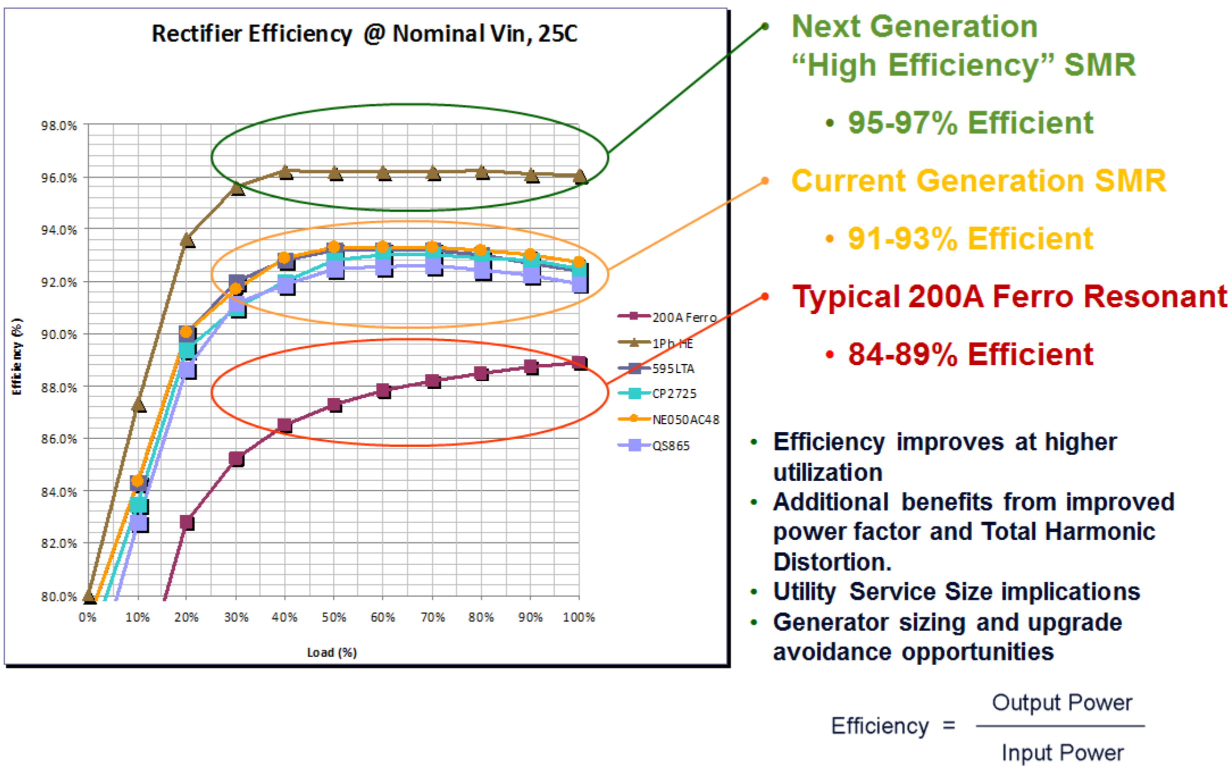
1. Optimization of the power factor correction input circuit to achieve the right balance of conduction and switching losses. This is done using silicon-carbide diodes to minimize switching losses and improved magnetic materials to reduce core losses.
2. The use of new circuit topologies throughout the rectifier design. In the input stage, a three level bridgeless boost eliminates AC commutating diode losses. In the output stage, a LLC resonant topology enables the use of low-loss zero-voltage switching across the entire operating range.
3. The use of DSP control of the power conversion circuits to flatten the efficiency curve for operation from 20% to 100% of load capacity. This is done by continuously adjusting

boost voltage to operate the output stage at peak efficiency and adjusting the boost switching frequency to minimize switching losses.

4. The use of improved packaging to minimize parasitic losses and enable more efficient cooling. These improvements include shorter conductors to reduce I^2R conductor losses, tight switching loops to reduce switching losses, and improved airflow to minimize silicon device conduction losses.

Figure 1 shows the efficiency curves for the two generations of rectifiers in the field and of the new design supported by this grant.

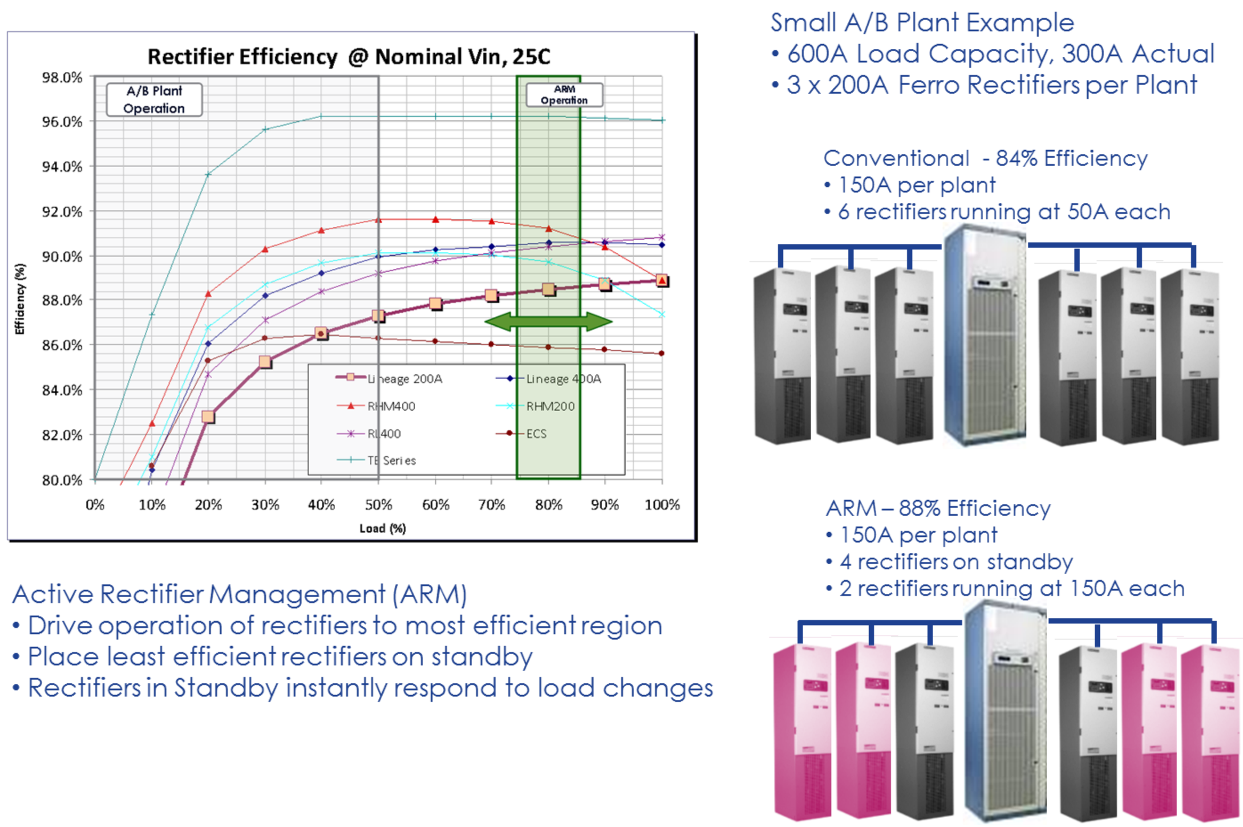
Figure 1 - Rectifier Efficiency



Note the shape of the efficiency curves shown in Figure 1. The older ferro resonant technology has an efficiency that peaks near its max capacity and falls away quickly at lower loading levels. The switch-mode technology shows a peak near 60% of capacity and falls away gradually on either side of that peak. An objective of the new design was to increase overall peak efficiency and to provide as flat an efficiency curve as possible. As you can see from the chart, both objectives were achieved.

Figure 1 also provides some insight into the Active Rectifier Management feature of the DC plant controller. A typical DC plant is composed of a collection of rectifiers of varying vintages. For a variety of reasons, the actual load on a DC plant is typically in the 30% to 80% range. If all the rectifiers are running at 30% of their capacity, the overall plant efficiency could be 2% to 4% lower than the ideal state. By selectively placing rectifiers in standby, the DC plant controller can move the operating point of the remaining rectifiers closer to their peak efficiency. This control strategy is illustrated in Figure 2.

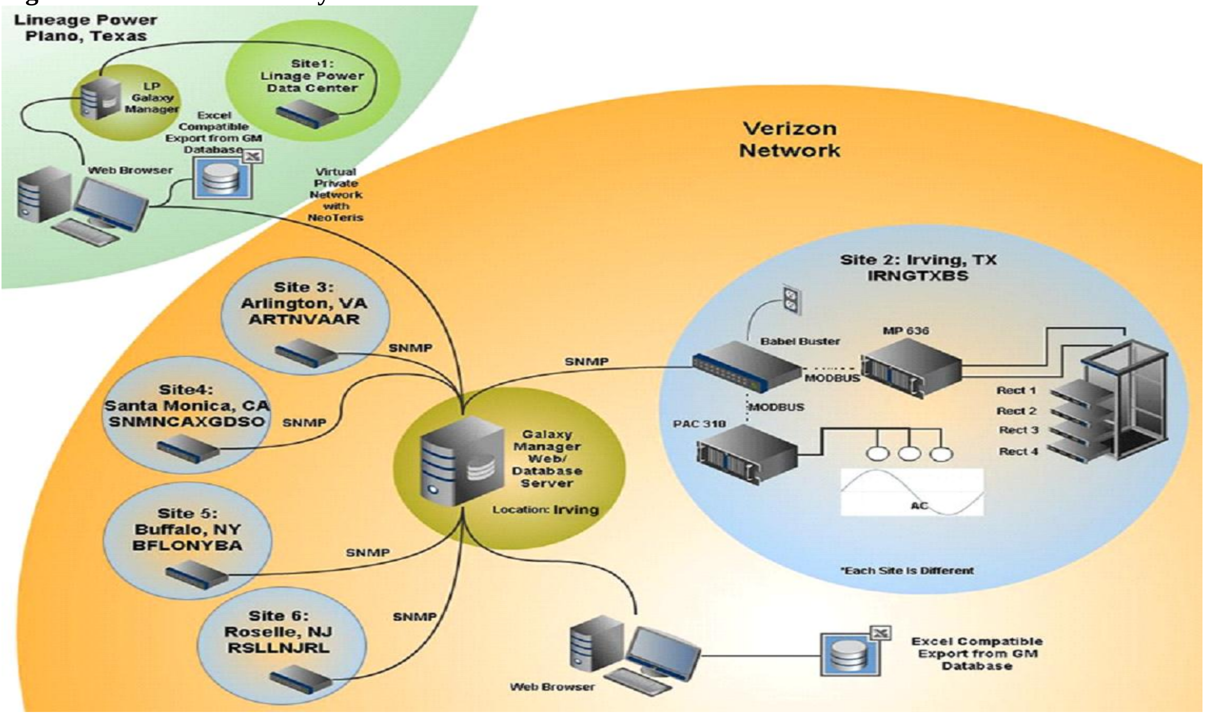
Figure 2 - Active Rectifier Management



The ARM software continuously monitors the average load on each rectifier in the system and places rectifiers on standby based on configuration data. Two thresholds drive the operation of the feature. The first is the target loading as a percentage of rectifier capacity. Rectifiers are gradually placed on standby until the remaining rectifiers are operating at the target capacity. This value is set based on the peak of the system's efficiency curve. For example in Figure 2, a ferro system would set a threshold near 100% whereas a switch-mode system would use a number in the range of 50-70%. The other threshold sets the maximum load on the operating rectifiers that would cause a standby rectifier to be brought back online. For a switch-mode plant in Figure 2, this threshold would be 70-80%. The software employs a number of other techniques to ensure even loading of all rectifiers over time and optimizing which rectifiers are placed on standby. This feature is further described in Appendix C.

To evaluate these new designs, Lineage Power partnered with Verizon to test this new technology in five typical telecommunications facilities. For each of these telecommunications facilities, monitoring equipment was placed to measure the input and output power of each plant and to record the measurements over many months. After three to six months of collecting baseline data, the plants were upgraded to the new equipment and additional measurements were collected. A special purpose monitoring system was designed to facilitate the data collection and is illustrated in Figure 3.

Figure 3 - Data Collection System



The measured improvement from each site is presented in Figures 4 to 8. In these charts, bars are used to show input and output power over time along with an overlaid data point showing plant efficiency. In general, plant output power remains nearly constant while input power reduces and efficiency improves when the upgrade is made. The original equipment and the upgrade strategy for each site are listed in Table 2.

Table 2 - Site Upgrade Plan

Site	Original Equipment	Upgrade
Irving, TX	MCS controller 480vac-208vac transformer (5) 208vac 200A Ferro	Replace controller to Millennium II with new feature. Remove transformer. Replace all rectifiers with (5) 480vac HE Switch-mode.
Arlington, VA	Galaxy SC controller (6) 480vac 400A Ferro	Replace controller with Millennium II with new feature. Replace all rectifiers with (12) 480vac input HE Switch-mode
Santa Monica, CA	Millenium I controller (24) 480vac Switch-mode	Replace controller with Millennium II with new feature. No change to any of the (24) existing rectifiers.
Buffalo, NY	Galaxy SC controller (6) 208vac Switch-mode	Replace controller with Millennium II with new feature. Replace all rectifiers with (6) 208vac HE Switch-mode.
Roselle, NJ	Galaxy SC controller (9) 208vac Switch-mode	Replace controller with Millennium II with new features. Replace half of the rectifiers with (5) 208vac HE Switch-mode.

Figure 4 - Arlington, VA

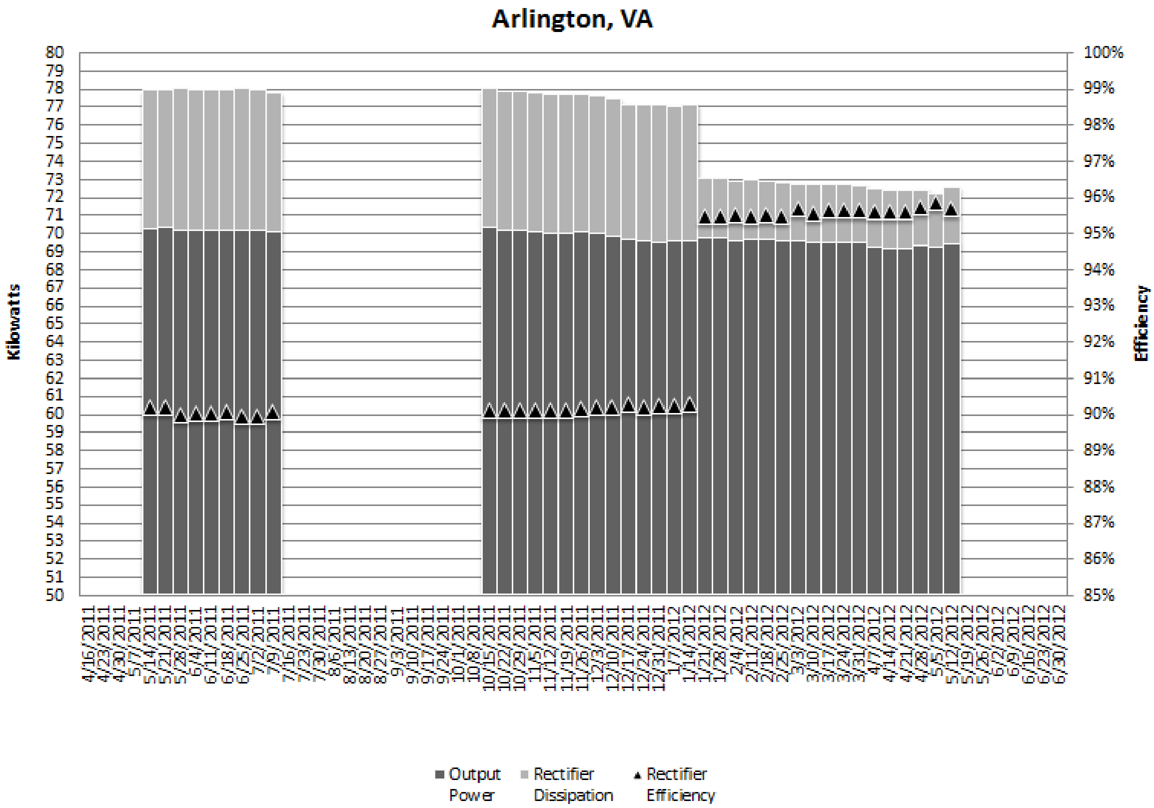


Figure 5 - Buffalo, NY

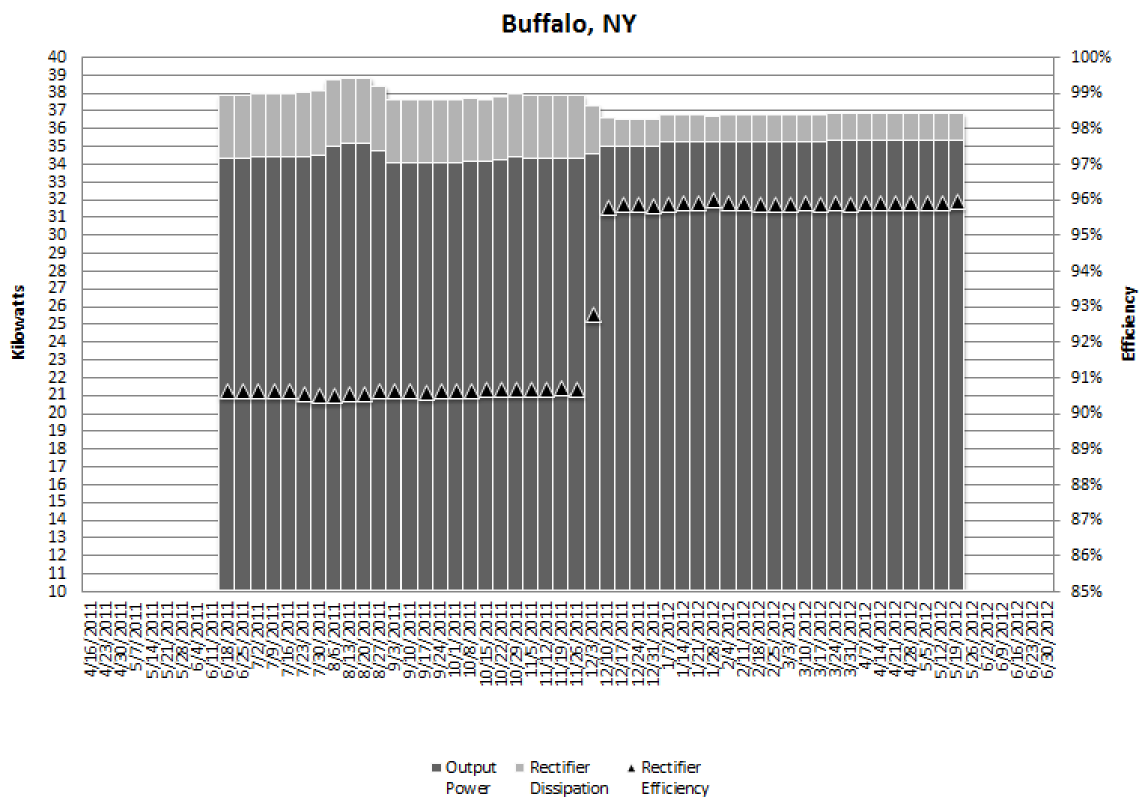


Figure 6 - Irving, TX

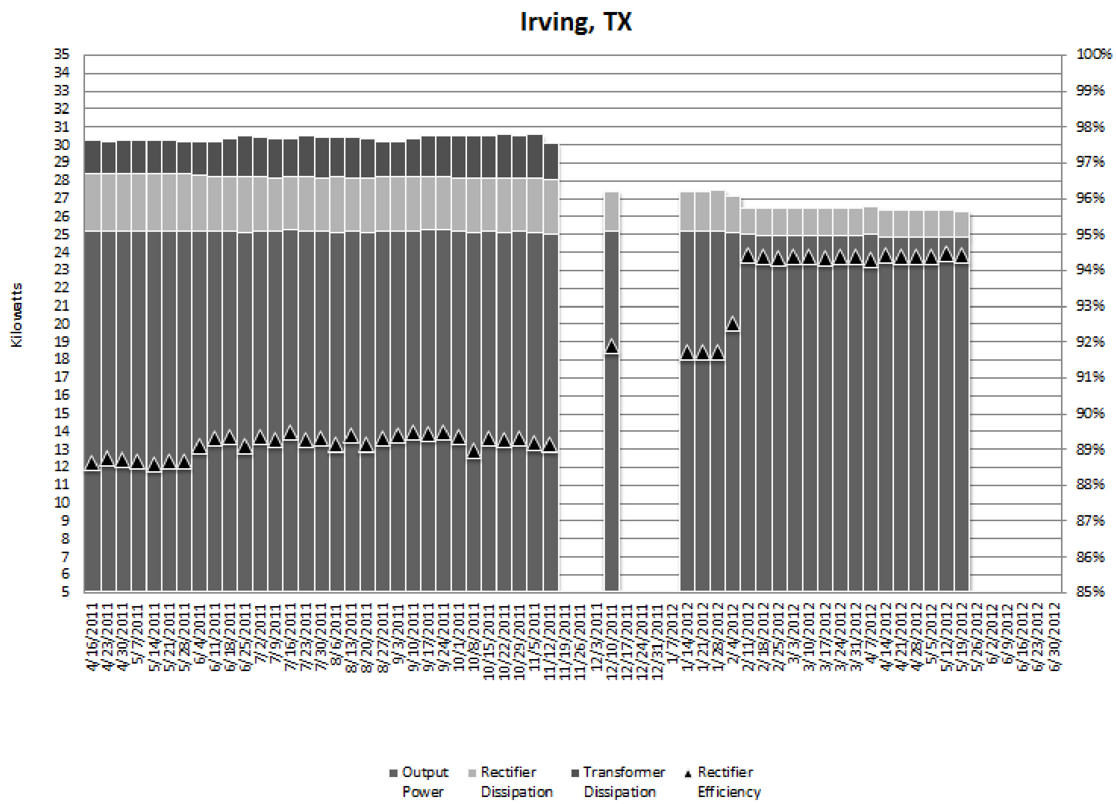


Figure 7 - Roselle, NJ

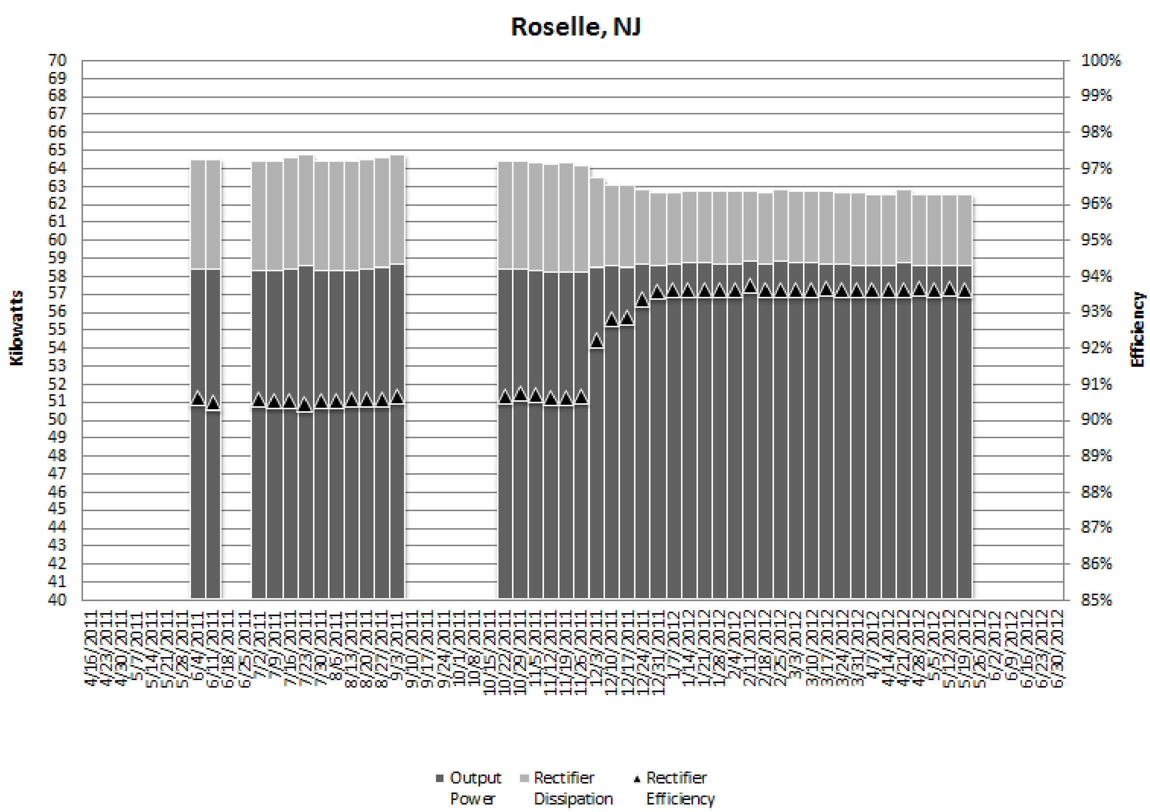
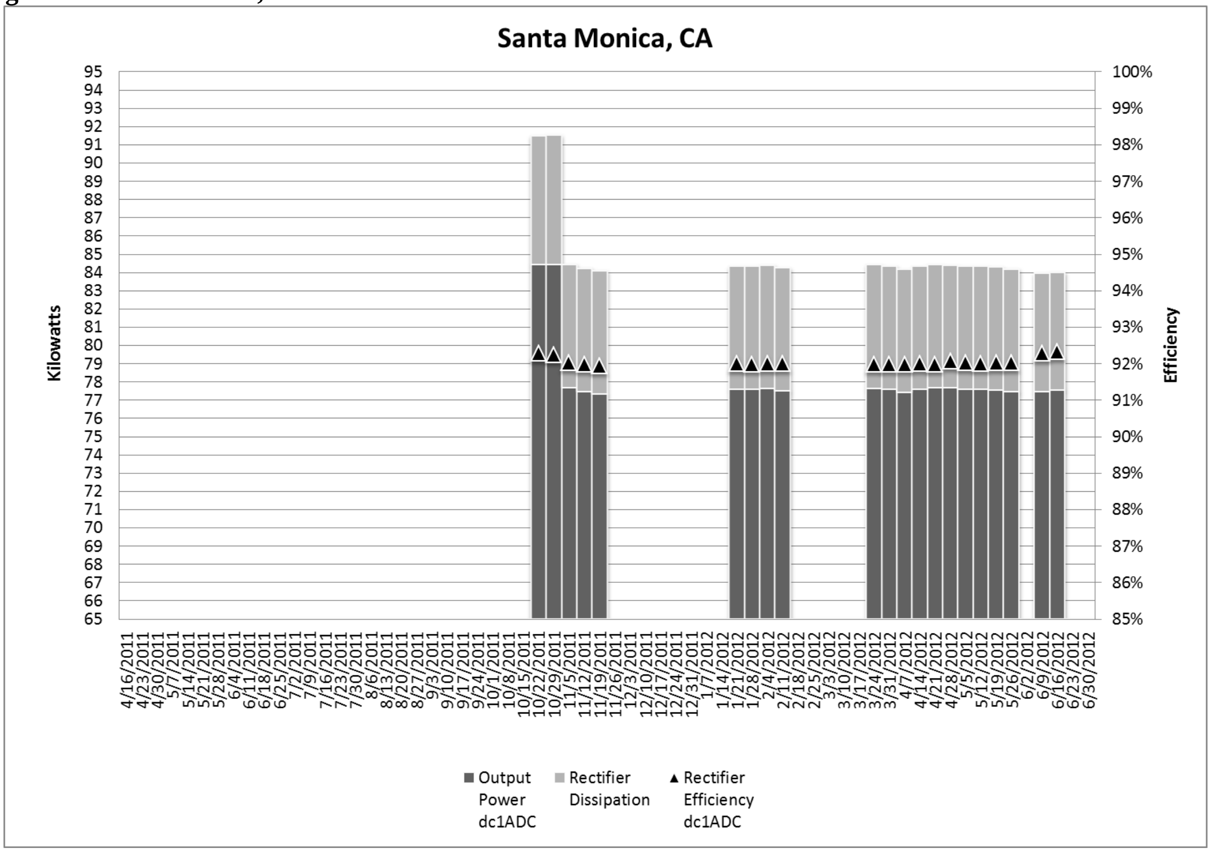


Figure 8 - Santa Monica, CA



The measured results from the field sites validate the assumptions that drove the proposal. Table 3 lists the energy consumption before and after the upgrades and the expected cost savings from the improvements. These cost savings assume $0.10/kWh and include both the direct energy consumption reduction and the indirect reduction from reduced cooling requirements. This indirect savings is estimated at 60% of the direct savings based on an analysis Verizon performed on their typical telecommunications facility.

Table 3 - Upgrade Results

Site	kW before	Upgrade	kW after	Estimated Annual Savings
Irving	30.4	208 ferro to 480 HE SMR	26.4	56,064 kWh / $5,606
Arlington	77.9	480 ferro to 480 HE SMR	72.8	71,482 kWh / $7,148
Santa Monica	84.3	Software upgrade	84.0	4205 kWh / $420
Buffalo	37.9	208 SMR to 208 HE SMR	36.7	16,819 kWh / $1,682
Roselle	64.5	50/50 mix HE and std SMR	62.7	25,229 kWh / $2,523

5. Benefits Assessment

The results from the five trial sites indicate good savings from reduced energy consumption in both the power equipment and the HVAC equipment cooling the heat generated from the power equipment. Replacing the older ferro resonant technology with the high efficiency rectifier is the most appealing upgrade from a return-on-investment payback perspective. If this upgrade was completed at all suitable Verizon telecommunications facilities, an internal Verizon analysis indicates potential reduction in direct energy consumption of 63 million kWhs per year and a potential savings of $10 million per year when both direct and indirect savings are considered. If the analysis of the Verizon sites is extended to the entire ICT industry, savings of 700 million kWhs are possible. This reduction in energy consumption also means a reduction of 500 thousand metric tons of CO_2 released into the atmosphere annually by fossil fuel based energy production facilities. See Appendix D for details on these calculations. Finally, replacement of aging power infrastructure equipment significantly enhances the reliability of the ICT network.

6. Commercialization

A key requirement in the design of the new rectifiers was to maintain full backward compatibility with existing product in the field. The form, fit, and function of the new high efficiency rectifiers exactly matches its previous generation. Customers can easily unplug the original equipment and slide in the new equipment without interruption to ICT operations. Figure 9 shows a typical installation. This easy replacement backward compatibility eases the commercialization of the new equipment.

Figure 9 - Ease of SMR Upgrade

When considering replacements of the older ferro resonant technology, the plug-and-play strategy must be applied at the frame level due to the large size of the older technology. Figure 10 shows a before-and-after installation of high efficiency rectifiers replacing a ferro resonant frame. The design of the new frame is done in such a way that the incoming AC and outgoing DC connection touch-points are in exactly the right configuration to speed installation and maintain expensive wiring.

Figure 10 - Ease of Ferro Upgrade

7. Accomplishments

This project achieved all of its objectives as documented in the original Statement of Project Objectives (SOPO). The project plan and completion dates are shown in Table 4.

Table 4 – Task/Milestone Schedule

Task/ Milestone SOPO Number	Title or Brief Description	Task/Milestone Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
1	HE SMR – Concept Development 208V Unit 480V Unit	1/1/2010 4/1/2010		1/1/2010 4/1/2010	100 100	
2	HE SMR – Initial Prototype (P0) Design, Build and Test 208V Unit 480V Unit	4/30/2010 8/30/2010		4/30/2010 12/30/2010	100 100	
3	HE SMR – Intermediate Prototype (P1) Rectifier Design, Build and Test 208V Unit 480V Unit	6/30/2010 10/30/2010		6/30/2010 2/1/2011	100 100	480V P1 stage was delayed due to Field issue with current 480V rectifier
4	HE SMR – Final Prototype (P2) Design, Build and Test 208V Unit	8/30/2010		12/30/2010	100	See Power loss comparison data below

	480V Unit	12/30/2010		9/30/2011	100	
5	ARM – Concept Development (P0)	6/30/2010		7/9/2010	100	Task was delayed due to SW designer work load
6	ARM – Initial Prototype (P1) Development	8/30/2010		6/30/2011	100	
7	ARM – Final Software Design (P2)	12/30/2010		9/30/2011	100	
8	FOA – Baseline Data Collection	12/30/2010	7/30/2011	11/30/2011	100	
9	FOA – Installation of HE SRM and ARM	3/31/2011	12/30/2011	12/30/2011	100	5 Verizon offices are being monitored
10	Project Management and Reporting	6/30/2011	3/31/2012	3/31/2012	100	Application for Paper for presentation at Intelec 2012

New rectifiers were designed that met their targets of 96% efficiency. A new controller software feature was designed to implement the Active Rectifier Management feature. All these products were deployed in actual Verizon telecommunications facilities to validate their performance. The rectifiers passed all their qualification tests and are now generally available. A paper describing the Verizon telecommunications facility energy efficiency study performed as a part of this project was accepted for presentation at the INTELEC 2012 conference[4]. This internationally recognized conference addresses issues and concerns of the telecommunication power industry. Our presentation to this body is a key element of the commercialization of our work.

Five patent applications were made as a result of this work focused on inventions within the rectifiers.

- "LLC Converter Active Snubber Circuit and Method of Operation Thereof" by Raghothama Reddy, November 2010, USPTO Application 12/950,545
- "Interleaved LLC Converter Employing Active Balancing" by Rick Barnett and Raghothama Reddy, August 2011, USPTO Application 13/218,938
- "A Multilevel Power Converter and Methods of Manufacturing and Operation Thereof" by Raghothama Reddy, June 2011, USPTO Application 13/170,559.
- "Optimization of a Power Converter Employing an LLC Converter" by Raghothama Reddy, June 2011, USPTO Application 13/170,614.
- "Insulating Boot for Electrical Components" by Khanh Nguyen, October 2011, USPTO Application 61/579,099.

8. Conclusions

The project successfully delivered on its promise of improved power conversion. The losses in the new rectifier design are nearly half of its previous generation and three times better than commonly deployed older technology. A simple software algorithm provides an additional minor improvement in overall plant efficiency. The new design was verified in actual customer

[4] "DC Power Plant Rectifier Efficiency – A Case Study"; Mark A. Johnson, James M. Hill, Tab Walter, J. Bill Swink, and Roy Davis; INTELEC 2012 Conference Proceedings, Scottsdale AZ, 30 September 2012.

telecommunications facilities and moved smoothly into widely available production. These improvements are due to better devices, components, and circuits coupled with novel system control approaches enabled by software.

Many lessons were learned during this program. We knew our greatest challenge would be the design and development of the high efficiency rectifiers. Fully dedicated teams were assigned and the rectifier development proceeded at a good pace. Those parts of the program that we considered somewhat easier – the ARM feature and the field monitoring of the Verizon telecommunications facilities – turned out to be more difficult than anticipated. Because of our early assumptions, action on these parts of the program were delayed or lightly staffed. Finding a good system to accurately monitor the AC supply to the DC plants was difficult. Collecting the data and reliably transmitting it to a centralized server for long term storage required significant effort. We would have been better served with a less sophisticated scheme of collection equipment with integrated storage and occasional site visits to retrieve the data. The lesson learned is that all elements of any project must be fully staffed and project managed to ensure prompt completion.

9. Recommendations

The demand for ever more efficient power conversion devices continues. As efficiency goes up, it gets increasingly more difficult to remove the last few watts out of the conversion process. Just recently, a large Internet search and storage company approached us with a desire for 98% efficient power conversion products. These levels of performance will require significant research. We recommend that DOE continue to support work on the power supply chain to achieve further improvements in ICT energy consumption.

10. Appendix A – Rectifier Specifications

GE Energy

595LT-TE Rectifiers

- Provides high power density
- Plug and Play – installation of the rectifier in a shelf connected to a compatible system controller initializes all set up parameters automatically. No adjustments are needed.
- Digital meter, Rectifier state and on/off/standby indicators
- Extended service life – parallel operation with automatic load sharing ensures that parallel units are not unduly stressed even when a unit fails or is removed.
- Monitoring / control – the built in microprocessor controls and monitors all critical rectifier functions and communicates with the system controller using the built in Galaxy Protocol serial interface.
- Fail safe performance – hot insertion capabilities allow for converter replacement without system shutdown; soft start and inrush current protection prevent nuisance tripping of upstream breakers.

Applications

- Telecommunications networks
- Digital subscriber line (DSL)
- Indoor/outdoor wireless
- Routers/switches
- Fiber in the loop
- Transmission
- Data networks
- PBX

Key Features

- Digital load sharing
- Hot pluggable
- Front panel meter
- System State - LED indicators
- Hi power density
- 3-Phase, 3-wire input
- RoHS 5/6 compliant
- -48V input

Specifications

Input	595LTA TE Rectifier	595LTB TE Rectifier
Voltage Range	320 – 530 Vac	176 – 275 Vac
Input Current (Specified) Rated Maximum Typical Maximum	20A at 480V 25A at 380V 30A 22A at 320Vac 19A at380Vac 15A at 480Vac	40A at 208Vac 35A at 240Vac 50A 41A at 176Vac 36A at 200Vac 33A at 208Vac 30A at 240Vac
Input Frequency	44 – 63Hz	44 – 63Hz
Power Factor	0.99 at>50% to 100% load	0.99 at>50% to 100% load
Efficiency (from 100Adc to 220Adc)	96%	95.5%
Total Harmonic Distortion		<5% from 50 – 100% load
Output		
Voltage Adjust Range	44-58Vdc float/boost	44-58Vdc float/boost
Voltage Nominal	52Vdc	52Vdc
Regulation (with controller)	±0.5%	±0.5%
Ripple	100mVrms	100mVrms
Output Current - 0 C to 37 C -0 C to 40 C 50 C	 NA 220A 200A	 220A NA 200A
Heat Release 54Vdc – 160Adc 54Vdc – 200Adc 54Vdc – 220Adc	 270W (920BTW/hr) 450W (1,550 BTU/hr) 560W (1,930 BTU/hr)	 360W (1,240 BTU/hr) 510W (1,750 BTU/hr) 630W (2,150 BTU/hr)

GE Energy

Environmental	
Operating Temperature	-5°C to +55°C (23F to 131°F)
Storage Temperature	-40°C to +85°C (-40 to 185°F)
Humidity	< 95% non-condensing
Altitude	-50 to 4000 meters (Altitudes above 1500 meters, de-rate the temperature by 0.656C per 100 meters

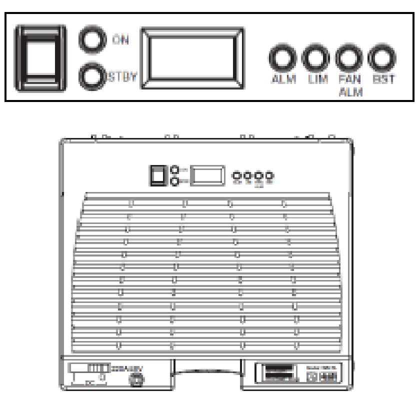
Mechanical	
Length (inch/mm)	18.2/470
Width (inch/mm)	10.40/265
Height (inch/mm)	8.25/210
Weight (lb/Kg)	LTA – 37/17 LTB – 33/15

Safety and Standards Compliance	595LT TE Rectifier
NEBs Level 3	Evaluated by independent NRTL test lab to Telcordia GR63, Issue 3 & GR 1089, Issue 5
Safety	UL Recognized (US & Canada) and VDE UL 1950, EN60950/IEC950 CSA 234/950 (tested for SELV output)
RoHS	Compliant to RoHS EU Directive 2002/95/EC; RoHS 5/6
Electromagnetic Compliance: Emission and Immunity	EN55022 (CISPR22) Radiated/conducted emission Class; IEC/EN61000-4-2 ESD levels 3 & 4 IEC/EN61000-4-3 Radiated Immunity. 10Vm IEC/EN61000-4-4 Electrical Fast Transients/Burst, level 4 IEC/EN61000-4-5 Lightning Surge, level 4 FCC Part 15, Class A; GR1089-CORE, Issue 5

Outline Drawing

Rectifier Control and Feature Panel

- 3 Position Power Switch
- On and Stand by LED lamps
- Current Display Meter
- Status LED's
  - ALM (red): Thermal/Comm.
  - LIM (yel.): Current Limit
  - FAN ALM (red): Fan Fail
  - EQL (yel.): Equalize mode



11. Appendix B – Ferro Retrofit Specifications

LINEAGE POWER®

PRODUCT OVERVIEW

Ferro / SCR Retrofit Power Solution

Cost Effective Energy Efficiency Upgrade

- Preserves distribution and cabling investments
- Retrofits legacy ferro or SCR rectifiers
- Modern Galaxy SC and Millennium II controllers
  - Adaptive Rectifier Management (efficiency management)
  - Thermal compensation and battery management features
- Efficiency approaching 97%

Lineage Power offered stand-alone 200A and 400A ferro-resonant rectifiers throughout the 1980s and 1990s. These legacy ferro-resonant rectifiers have since been discontinued. The Ferro / SCR Retrofit Power Solution allows Lineage and third party legacy ferro-resonant or SCR rectifiers to be upgraded to modern energy-efficient switched mode rectifiers and controller technology while preserving existing cabling and distribution investments. Bolting patterns remain the same as well.

The Ferro / SCR Retrofit Power Solution (RPS) utilizes 595LT Total Efficiency™ rectifiers to improve energy efficiency and deliver centralized management visibility and control. The 595LT TE rectifiers offer next generation efficiency approaching 97% with the proven reliability heritage of 595 rectifiers deployed in telecom networks for the past 20 years. The 595LT TE rectifiers are managed by the modern Galaxy SC or Millennium II controllers.

The RPS cabinet is designed to accommodate four 220A (880A total) rectifiers within the same floorspace of an existing ferro-based telecom energy system. The top section of each RPS cabinet is carefully designed to offer the AC and DC connection points at the same physical location as the ferro being replaced, enabling the existing AC and DC cabling infrastructure to be re-used. RPS configurations enable back-to-back or side-by-side deployments. If a Galaxy SC controller is not already present, either a Millennium 2 or Galaxy SC controller must be installed.

Lineage Power has designed RPS cabinets to replace many combinations of ferro and SCR rectifiers manufactured by Emerson/Lorain (RL and RHM series), Delta Electronics (HDS and MCS), Lineage Power and PECO II (128/129/143).

The Ferro / SCR Retrofit Power Solution provides a cost-effective upgrade for the installed base of legacy telecom power systems. The design of the RPS cabinet is optimized to minimize installation time and effort by avoiding any cabling or distribution changes. For most applications the retrofit process can be completed in a single work shift.

Benefits

Reliability

- Delivers decades of service
- Proven field performance
- Controller continuity

Intelligence

- Industry leading controller features
- Ethernet interface for remote access
- Centralized network management

Investment Protection

- Energy efficiency improvement
- Seamless integration with ferro plants
- Re-certify and re-warranty whole plant

On Time Delivery

- Turn-key retrofit service option including plant assessment
- Fast track deployment
- 24/7 support

Total Efficiency

The Lineage Power Total Efficiency™ (TE) architecture reduces energy loss and lowers cooling costs by 50-70%. TE products will prioritize sustainable energy sources like solar, wind, water and fuel cells over traditional utility grid or diesel generator sources – and they will intelligently respond to smart grid information to reduce consumption during peak demand periods. Active Rectifier Management (ARM) and Battery Charging Optimization (BCO) features increase efficiency on current and legacy power infrastructures. The Total Efficiency architecture addresses issues end-to-end based on our proven experience and expertise in batteries, power distribution, DC energy systems, AC-DC power supplies, and DC-DC board mounted power to deliver a solution that is more safe, reliable and energy efficient than alternatives from our competitors.

10/11 Ferro / SCR Retrofit Power Solution

LINEAGE POWER®

Specifications

Input	
Nominal Input Voltage - 595A/LTA - 595B/LTB	380 Vac/400 Vac/480 Vac, 3-wire plus ground 208 Vac/220 Vac/240 Vac, 3-wire plus ground
Input Current - 595A/LTA - 595B/LTB	15.7A @ 480Vac Nominal 36.3A @ 208Vac Nominal
Input Voltage Range (per phase-phase): - 595A/LTA - 595B/LTB	320 Vac to 530 Vac 176 Vac to 260 Vac
Input Frequency Range	47-63 Hz
Power Factor	>0.97 at >50% load
Total Harmonic Distortion	<5% at >50% load

Output	
Voltage Nominal	-48 Vdc
Voltage Adjust Range	-44 Vdc to -58 Vdc
Output Current (system maximum)	880A
Regulation (line and load range)	±0.5%
Ripple	<100 mVrms
Psophometric Noise	<2 mV

Mechanical	
Height (cabinet only)	72.0 in. (1,829 mm)
Width (cabinet only)	23.6 in. (600 mm) (List 102) 26 in. (660.4 mm) (List 112) 26 in. (660.4 mm) (List 113) 26 in. (660.4 mm) (List 201) 48 in. (1219.2 mm) (List 202) 24 in. (609.6 mm) (List 301) 24 in. (609.6 mm) (List 302) 24 in. (609.6 mm)
Depth (cabinet only)	23.6 in. (600 mm) (List 102) 32 in. (812.8 mm) (List 112) 32 in. (812.8 mm) (List 113) 32 in. (812.8 mm) (List 201) 23.5 in. (596.9 mm) (List 202) 30 in. (762 mm) (List 301) 35 in. (889 mm) (List 302) 35 in. (889 mm)
Weight for 72.0" cabinet (approximate)	485 lb (220 kg)

Environmental Specifications	
Operating Temperature	0ºC to +50ºC (32ºF to 122ºF)
Storage Temperature	-40ºC to +85ºC (-40 to 185 ºF)
Operating Relative Humidity	5-95% non-condensing
Input Frequency Range	47-63 Hz
Power Derating	3% per ºC from +55ºC to +65ºC
Altitude	4000M max

Safety and Standards Compliance	
NEBS	Evaluated by independent test lab with NRTL status to Telcordia GR63 and GR1089 (including level 3 testing)
Safety	UL Listed (US and Canada): UL Subject 1801 with applicable sections of UL1950/CSA3 950 Applicable sections of IEC950/EN60950 CE mark meets 72/23/EEC and 93/68/EEC directives
RoHS	Compliant to RoHS EU Directive 2002/95/EC
EMC	FCC and EN 55022, Class B; FCC, Class B
ESD	EN61000-4-2, Level 4

12. Appendix C – Active Rectifier Management

The Active Rectifier Management feature has a long history dating back to controller product released in the late 1980's. This appendix provides a historical view of the feature and its enhancement.

MCS (Microprocessor Controlled System controller)

When enabled, firmware in the MCS matches the number and ampacities of all available battery plant rectifiers to the actual plant load requirements. The shutdown of smaller, less-efficient rectifiers occurs when the plant load requirements are low enough. The goal of the algorithm is to maintain the battery plant at maximum efficiency without sacrificing reliability or creating nuisance alarms. The MCS continuously monitors the number of connected rectifiers, their individual ampacities, the output current being delivered by each of the rectifiers, and the office load-current demand. The MCS algorithm strives to maintain the following relationship:

$$\Sigma\, C_{Ron} \geq \max\,(I_{Load}, \Sigma I_{Ron}) \text{ X } 1.04$$

Where,

C_{Ron} = ampacities of all rectifiers turned on; ΣI_{Ron} = sum of outputs of all rectifiers turned on

The efficiency algorithm compares the total plant load current ILoad with the sum of the individual output currents being delivered by all connected "On" rectifiers. It multiplies the larger of the two values by 1.04. It then shuts down the unneeded rectifiers to meet the terms of the above equation with the sum of the ampacities of the remaining rectifiers that are left running. It assumes that the larger rectifiers are more efficient and leaves them running near maximum load.

To insure that all rectifiers are operational when called upon the algorithm exercises all rectifiers on a monthly basis such that every connected rectifier is operated for at least 24 hours per month. Turning off rectifiers due to short-term swings in a plant load are eliminated by restricting shutdown of rectifiers in 10-minute intervals. Upon initially powering up, an MCS plant's unneeded rectifiers are shut down one at a time at 10-minute intervals. Sudden large increases in plant loads will cause standby rectifiers to be immediately turned back on. During the 10 second walk-in period of that rectifier being turned back on any BD alarm event is inhibited. To reduce Turn-on/Turn-off stress on the rectifiers, no rectifier is permitted more than four On/Off cycles per day.

Galaxy Millennium II System Controller - Efficiency Algorithm

The Galaxy Millennium II (M2) is the latest generation of large plant system controllers. The energy efficiency algorithm is modeled after the MCS with these enhancements:

- A configurable *Efficiency Target Capacity* added - the capacity percentage that the system controller tries and maintains all system rectifier outputs. This value can be set from 20% to 95%. Factory default is 70%.
- A configurable *Efficiency Turn On Capacity* added -the capacity percentage of a system rectifier when reached that the system controller will take a rectifier out of Standby/Off and places it into service/On. The value can be set from 25% to 100% with a factory default of 76%.
- A configurable *Inter-Rectifier Delay* added - The value of time the controller will take before placing the second or additional system rectifiers into the standby mode of operation. This value can be set between 1 and 30 minutes with a factory default setting of 10 minutes.
- A configurable *Initial Delay* added - The value of time the controller will monitor and take before placing the first system rectifier into the standby mode of operation. This value can be set between 1 and 30 minutes with a factory default of 10 minutes.

13. Appendix D – Energy Benefit Calculation

Typical Site

673	output amps	private communication, Jay Hill (Verizon)
52	plant voltage	industry standard for flooded cell batteries
34,996	watts output power delivered to the load	calculated
60%	HVAC factor (energy needed to cool a watt of excess heat)	private communication, Jay Hill (Verizon)

	Input power			kWh savings		
	efficency	input kW	kWh/yr	direct	hvac	combined
Ferro	88%	39,768	348,369	29,031	17,418	46,449
SMR	93%	37,630	329,640	10,301	6,181	16,482
HE SMR	96%	36,454	319,339	(upgrade to HE SMR)		

EPA Greenhouse Gas Conversion

0.00069	tons of greenhouse gas per kWh generated	EPA website, http://www.epa.gov/ cleanenergy/energy-resources/refs.html

Verizon Sites

6,578	total plants	private communication, Jay Hill (Verizon)
33%	sites powered by ferro equipment	private communication, Jay Hill (Verizon)

		kWh savings		
	plants	direct	combined	GHG
Ferro	2,171	63,018,260	100,829,215	69,528
SMR	4,407	45,400,252	72,640,402	50,090
Total	6,578	108,418,511	173,469,618	119,618

North American Telecomm Sites

33%	sites powered by ferro equipment	assumption based on Verizon experience
25%	Verizon market share	Telecomm Market Analysis, http://www4.gsb.columbia.edu/ null/download?&exclusive=filemgr.download&file_id=739241

		kWh savings		
	plants	direct	combined	GHG
Ferro	8,683	151,243,823	403,316,861	104,292
SMR	17,629	108,960,604	290,561,610	75,135
Total	26,312	260,204,427	693,878,471	179,427