Statistical Path Analysis Performance Evaluation Of ElectroFlow™

For

Maldon Chicken Hatchery

Maldon,Australia

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PowerFul Corporation
"Legendary Performance"
Columbia - Missouri, U.S.A.

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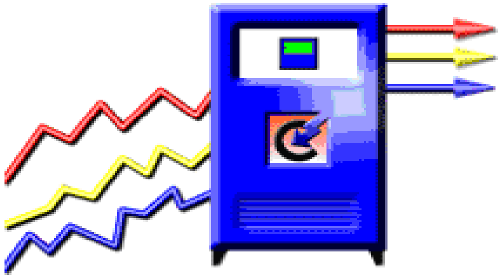
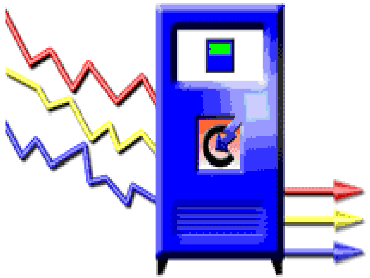
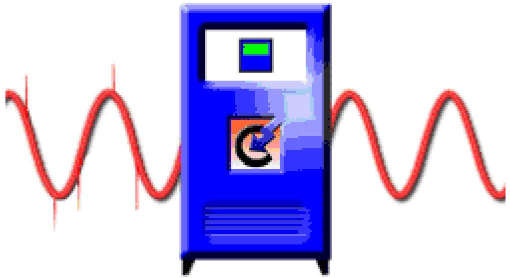
Executive Summary

We are delighted to report that, following the receipt of series of actual data for ElectroFlow™ "OFF", and ElectroFlow™ "ON" conditions. The subsequent comprehensive Statistical Path Analysis (SPA), for the purpose of ElectroFlow™ performance verification, revealed that the actual reduction greatly exceeded those initially projected!

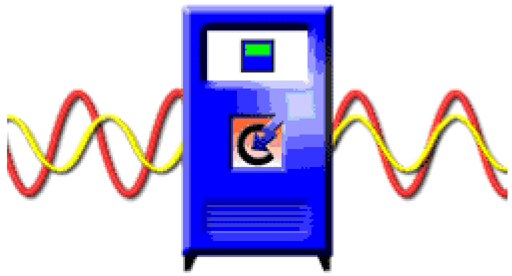
ElectroFlow™ Standard Features

		
1. Voltage Improvement and Stability Improves and stabilizes the voltage supplied to the load, thereby minimizing heat generation, resulting in energy savings, improved production, and increased equipment efficiency and longevity.	2. Three-Phase Balancing Real-time reduction of phase current, and balancing of load over the three phases, based on X/R and Z, thereby reducing negative voltage sequence and circulating currents; resulting in energy savings and reduced equipment maintenance and failure.	3. Surge and Transient Suppression Shields against an infinite number of surges, transients, and spikes, thereby protecting your investment in plant and equipment, while saving money.

ElectroFlow™ Standard Features

4. Broadband Harmonics Mitigation

Mitigation broadband harmonics, resulting in increased equipment longevity, while proportionally reducing the effects of harmonics on monthly electric bills. It is modular in structure and expandable.



5. Power Factor Improvement

Optimizes system power factor to a nominal .95 - unity, at a fraction of standard capacitor bank, but without any deleterious capacitor side effects

6. Releasing KVA capacity

It effectively reduces all three components of power, in a balanced form. It reduces Apparent Power (KVA), Real Power (KW), and Reactive Power (KVAR). Hence, allowing loads to be added without increasing the size of transformer(s), switchgear(s), or cabling.

Savings Projected For :
XFMR MAINS

Transformer Size: 1,500 KVA

Measurement Location: Main

Preliminary projected savings from the Baseline Energy Audit, as reflected in the proposal:

Estimated Reduction-Annual Consumption (KWD): 0

Estimated Reduction-Annual Demand (KWH): 123,442

Estimated,Annual,Demand Savings (USD): $ 0

Estimated Annual Consumption Savings (USD): $ 27,009

Estimated Annual Electric Bill Savings (USD): $ 27,009

Baseline Energy Audit

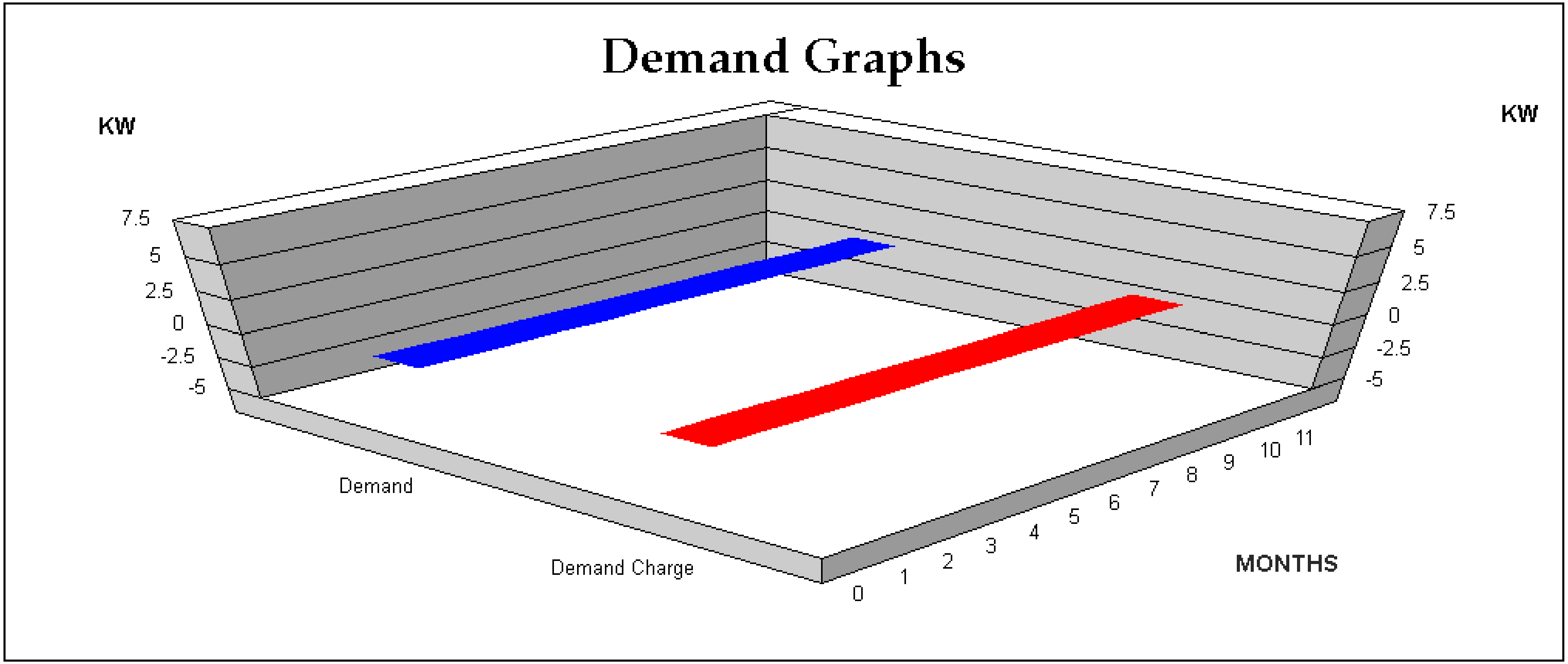
Phase	Voltage		Current		Power Factor	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
A-Phase	426	433	440	480	0.76	0.78
B-Phase	427	432	420	540	0.77	0.79
C-Phase	425	429	416	486	0.76	0.78

Highest Current THD of the Three phases(%):	18.00	For Phase C
Voltage THD of the phase with the highest Current THD (%):	1.90	For Phase C

Power Quality Issues:

Voltage Improvement and Stability
Three-Phase Current Balancing
Power Factor Improvement
Broadband Harmonics Mitigation
Surge and Transient Suppression
Releasing KVA Capacity

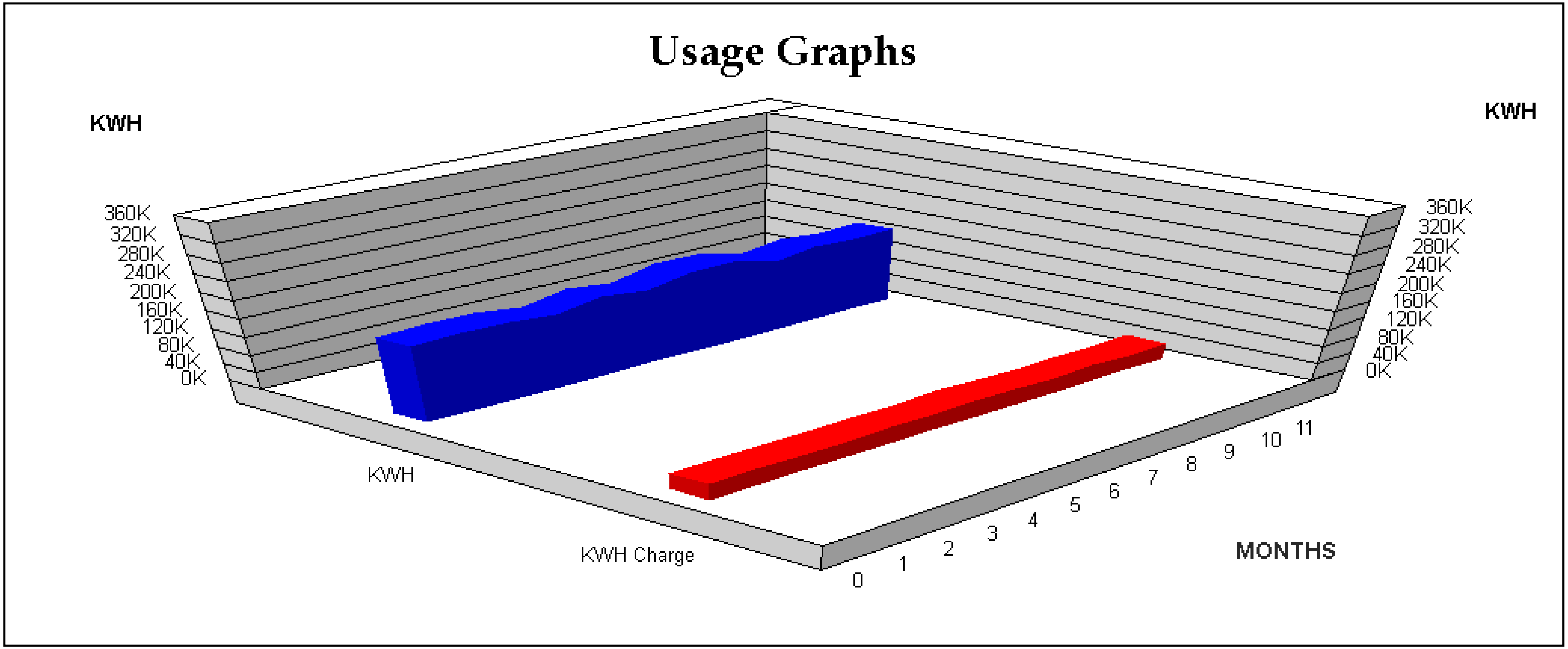
Load Profile -Electric Bill 's Baseline
12-Month Demand Graphs



Average Monthly Demand : 0.00 KW

Average Monthly Demand Charge: $ 0.00

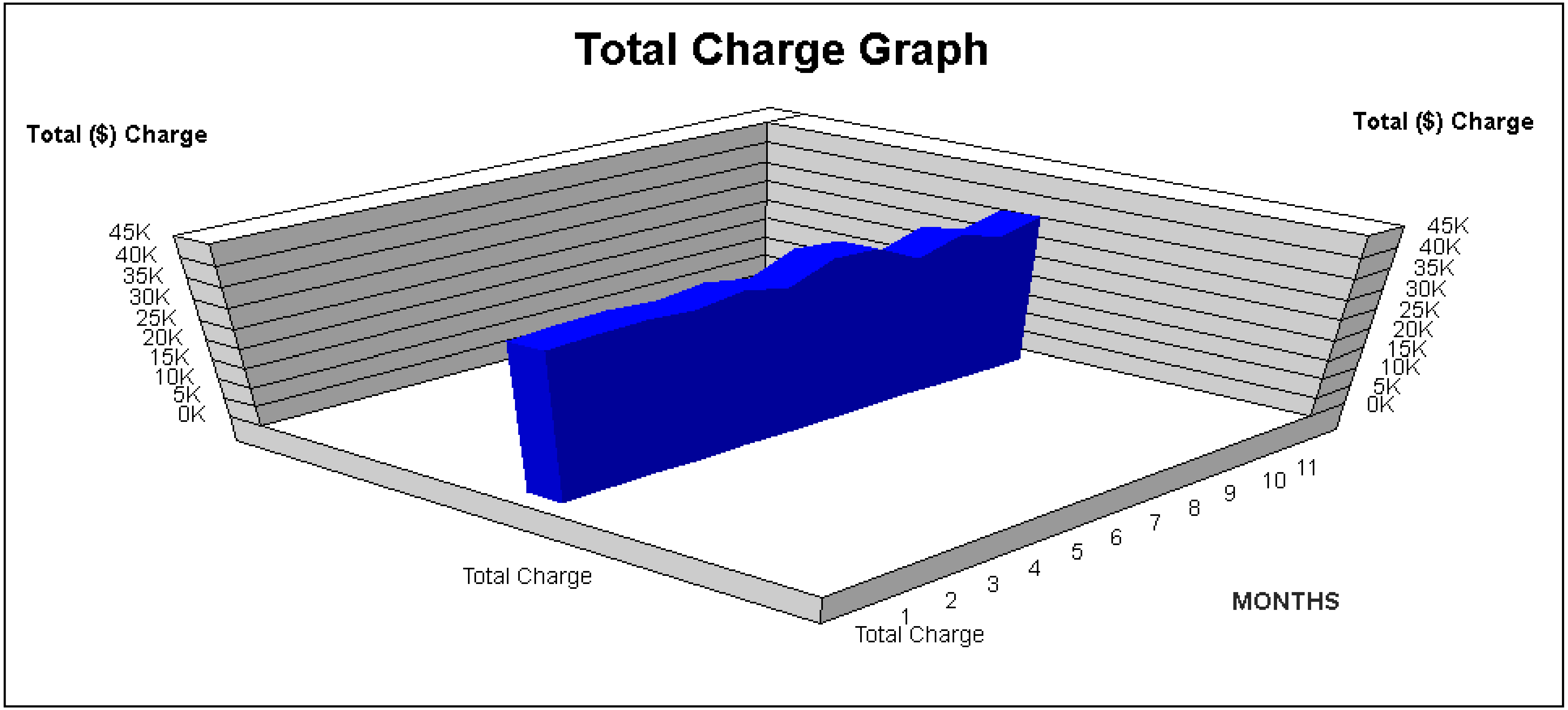
Load Profile -Electric Bill 's Baseline 12-Month Usage Graphs



Average Monthly Consumption: 171,733.75 KWH

Average Monthly Consumption Charge: $ 37,596.25

Load Profile -Electric Bill 's Baseline
12-Month Total Charge Graph



Average Monthly Total Charge: $ 37,596.25

SPA Baseline Methodology

The purpose of the SPA analysis is to answer following two questions?

1. Does ElectroFlow™ address the power quality issue as expected?
2. Does ElectroFlow™ meet or exceed the energy savings projected?

It is very important to establish a baseline methodology for the purpose of answering these two questions.

Hence, the following facts should be used as guidelines for accurately verifying performance of any energy saving devices, including ElectroFlow™:
ElectroFlow™ is a passive system, and does not consume measurable Real Power (KW). This can easily be verified by actual measurements taken at ElectroFlow™ main breaker/disconnect switch.

SPA Baseline Methodology

ElectroFlow™ connects in parallel. As a result, if ElectroFlow™ system fails, it will not affect the facility load. Hence it is guaranteed that the system is fail-safe, in comparison to energy saving devices that connect in series. ElectroFlow™ can easily be turned "ON", or "OFF", to collect data for verification of the effects of ElectroFlow™ on the load.

For both ElectroFlow™ "ON", and ElectroFlow™ "OFF" conditions, it is required to tabulate all of the pertinent Dependent Variables: Demand (KWD), and Consumption (KWH), as well as all of the power quality variables: Voltage, Current, Power Factor, Total Harmonics Distortion for all of the three phases.

The collected data such as Demand (KW), and/or Usage (KWH) should not be simply averaged, added, or subtracted; as means to compare or analyze the variables.

similarly, one must not, for the sake of comparison, simply collect data of ElectroFlow™ "ON " and "OFF" for periods such as : Daily, Weekly, or Monthly!

Because this methodology does not take into account the load variation/load profile, and Load Factor. Such incorrect method completely ignores the "Apples-To-Apples"

SPA Data Collection Methodology

Data collection for performing accurate SPA analysis should be conducted based on the following conditions:

Testing and measurements must be conducted using a three-phase power analyzer capable of data logging at a minimum rate of 128 samples per cycle, which equates to 7,680 times per second at 60 Hz, or 6,400 samples per second at 50 Hz. The three-phase variables to be measured on the per minute basis, for the purpose of power quality as well as energy savings, are: voltage, current, power factor, harmonics, Demand (KW), and Usage (KWH).

All of the three-phase values must be displayed on per-minute or shorter basis, for several consecutive periods of 15 minutes “ON”, and 15 minutes “OFF”. This is practically recommended, because most of utility companies' Demand Meters register Maximum monthly KW Demand, based on the highest sliding 15-minute interval in that month; which is subsequently billed to, and paid by the customer. In addition, such short-duration sampling and comparison, minimizes effects of other independent variables such as: load variation/load profile, unit of production, and change of weather, in such comparison testing.

SPA Data Collection Methodology

For the purpose of this study Harmonitor™ 3000 is used, with sampling rate of 256 samples per cycle, at 60/50 Hz frequency. It collects Voltage, Current, Power Factor, Harmonics, Demand, and Usage for all of the three-phases.

SPA Analysis Methodology

For performing scientific and accurate SPA analysis, following guidelines are set:
In order to correctly analyze effects of ElectroFlow™ "ON", and ElectroFlow™ "OFF", conditions of Demand (KW), and/or Usage (KWH), theoretically speaking, the load should be kept constant. One can then proceed to analyze Demand reduction from the test data of both conditions, where Usage (KWH) reduction can be calculated from the cumulative values for both conditions.
However, practically speaking, it is clear that the load is variable, even on the per-minute basis, which makes "Apples-To-Apples" comparison difficult.
In such a case, the most accurate method is to use linear/non-linear regression method to predict Demand (KW), based on the measured conditions. Such an analysis allows to predict the accurate comparison of Demand (KW), and/or Usage (KWH) with respect to changes in the status of ElectroFlow™ based on the per-minute data collected, and accurately determine its demand and/or energy savings effects; even when the load is fluctuating in a rapidly variable load profile.

SPA Analysis Methodology

$$P = P_{\alpha\beta} + P_0 \qquad (1)$$

$$P_{\alpha\beta} = \bar{P}_{\alpha\beta} + \tilde{P}_{\alpha\beta} \qquad (2)$$

$$\bar{P}_{\alpha\beta} = \sum_{n=1}^{\infty} 3V_{+n} I_{+n} Cos(\phi_{V_{+n}} - \phi_{I_{+n}}) + \sum_{n=1}^{\infty} 3V_{-n} I_{-n} Cos(\phi_{V_{-n}} - \phi_{I_{-n}})$$

$$\tilde{P}_{\alpha\beta} = \sum_{n=1}^{\infty} - 3V_{+n} I_{-n} Cos(2\omega_n t + \phi_{V_{+n}} + \phi_{I_{-n}}) + \sum_{n=1}^{\infty} - 3V_{-n} I_{+n} Cos(2\omega_n t + \phi_{V_{-n}} + \phi_{I_{+n}}) +$$

$$\sum_{\substack{m=1 \\ m \neq n}}^{\infty} \left[\sum_{n=1}^{\infty} 3V_{+m} I_{+n} Cos\left((\omega_m - \omega_n)t + \phi_{V_{+m}} - \phi_{I_{+n}}\right) \right] + \sum_{\substack{m=1 \\ m \neq n}}^{\infty} \left[\sum_{n=1}^{\infty} 3V_{-m} I_{-n} Cos\left((\omega_m - \omega_n)t + \phi_{V_{-m}} - \phi_{I_{-n}}\right) \right] +$$

$$\sum_{\substack{m=1 \\ m \neq n}}^{\infty} \left[\sum_{n=1}^{\infty} - 3V_{+m} I_{-n} Cos\left((\omega_m + \omega_n)t + \phi_{V_{+m}} + \phi_{I_{-n}}\right) \right] + \sum_{\substack{m=1 \\ m \neq n}}^{\infty} \left[\sum_{n=1}^{\infty} - 3V_{-m} I_{+n} Cos\left((\omega_m + \omega_n)t + \phi_{V_{-m}} + \phi_{I_{+n}}\right) \right]$$

$$P_0 = \bar{P}_0 + \tilde{P}_0 \qquad (3)$$

$$\bar{P}_0 = \sum_{n=1}^{\infty} 3V_{0n} I_{0n} Cos(\phi_{V_{0n}} - \phi_{I_{0n}})$$

$$\tilde{P}_0 = \sum_{n=1}^{\infty} - 3V_{0n} I_{0n} Cos(2\omega_n t + \phi_{V_{0n}} + \phi_{I_{0n}}) + \sum_{\substack{m=1 \\ m \neq n}}^{\infty} \left[\sum_{n=1}^{\infty} 3V_{0m} I_{0n} Cos\left((\omega_m - \omega_n)t + \phi_{V_{0m}} - \phi_{I_{0n}}\right) \right] + \sum_{\substack{m=1 \\ m \neq n}}^{\infty} \left[\sum_{n=1}^{\infty} - 3V_{0m} I_{0n} Cos\left((\omega_m + \omega_n)t + \phi_{V_{0m}} + \phi_{I_{0n}}\right) \right]$$

SPA Analysis Methodology

Formula **(1):** This represents the Real Power components, including the balanced/symmetrical Real Power, and the imbalanced/Asymmetrical Real Power, as well as the zero sequence.

Formula **(2):** The non-zero sequence components of Real Power are accurately considered. The balanced three-phase Real Power, and imbalanced components of Real Power, as well as Positive, and Negative sequence harmonics can be integrated in the same formula, and may be accurately calculated and accounted for, based on the direction of harmonics; in the formula. Furthermore, the negative voltage sequence, as well as the positive voltage sequence can be calculated and accounted for using the same methodology.

SPA Analysis Methodology

Formula **(3):** The zero-sequence components of Real Power are accurately considered. The balanced three-phase zero-sequence Real Power, as well as imbalanced components of zero-sequence Real Power are accounted for.

The regression analysis is performed on the Statistical Path Analysis (SPA) data collected at the facility with ElectroFlow™ "ON", and "OFF", as compared against the load data previously collected at the Audit stage, and the pertinent information supplied about the electrical distribution layout.

MATLAB software, which is the standard software used by the scientific community and professionals for this purpose, is used to perform the mathematical analysis.

Data collected For ElectroFlow™ 'ON' Period

KW	V(A)	V(B)	V(C)	I(A)	I(B)	I(C)	PF(A)	PF(B)	PF(C)	I_{THD} (A)	I_{THD} (B)	I_{THD} (C)
246.27	416.17	417.66	416.50	408.65	368.19	365.96	0.97	0.98	0.97	4.44	6.18	6.51
246.96	416.46	416.25	416.51	402.88	365.17	362.59	0.97	0.97	0.97	4.25	7.40	6.58
261.98	417.81	416.48	415.16	406.34	364.42	362.60	0.97	0.98	0.98	5.94	6.21	6.36
238.57	416.53	415.23	416.90	395.03	389.12	392.23	0.97	0.97	0.97	7.10	7.58	6.23
226.00	415.35	415.25	417.59	416.64	382.62	389.86	0.97	0.98	0.97	6.87	8.09	7.38
226.97	415.71	417.83	415.40	403.12	367.10	365.65	0.97	0.98	0.97	7.35	7.66	6.63
244.55	417.81	417.44	416.09	405.26	367.69	364.86	0.98	0.97	0.97	8.71	6.37	6.70
233.72	418.02	416.96	415.76	396.27	365.34	364.00	0.97	0.98	0.97	7.73	6.82	6.57
232.27	416.01	415.96	416.06	409.82	365.53	362.22	0.97	0.98	0.97	6.05	7.58	6.86
226.28	417.77	415.15	417.07	393.06	368.49	369.07	0.97	0.98	0.98	7.69	8.36	26.25
231.13	417.39	417.91	416.30	391.73	365.55	361.62	0.97	0.98	0.97	6.87	7.27	6.68
226.72	416.88	416.04	416.07	392.56	366.30	360.90	0.97	0.98	0.97	7.27	6.80	27.25
214.65	416.00	416.52	417.20	394.70	370.61	366.35	0.97	0.98	0.97	8.79	7.60	6.20
218.54	417.09	415.51	416.48	404.47	376.53	369.50	0.97	0.98	0.98	7.74	6.44	6.57
232.76	417.51	415.20	417.77	412.64	365.09	366.63	0.97	0.97	0.97	7.21	7.25	6.05

Data collected For ElectroFlow ™ 'OFF' Period

KW	V(A)	V(B)	V(C)	I(A)	I(B)	I(C)	PF(A)	PF(B)	PF(C)	I_{THD} (A)	I_{THD} (B)	I_{THD} (C)
287.14	419.00	421.10	418.78	509.91	439.21	439.81	0.88	0.85	0.83	14.07	17.94	19.14
277.61	421.15	423.56	421.56	488.93	419.87	422.20	0.88	0.85	0.83	14.11	18.22	19.34
278.24	420.98	423.05	420.56	490.41	420.03	423.56	0.88	0.86	0.83	14.02	18.27	19.25
277.62	421.25	422.45	421.03	483.35	424.69	422.23	0.88	0.86	0.83	14.29	18.10	19.76
277.84	420.58	422.11	420.13	492.73	420.45	420.99	0.88	0.85	0.83	14.19	18.44	19.82
280.16	421.47	423.25	421.82	496.42	418.62	422.55	0.88	0.86	0.83	13.82	18.21	19.37
277.76	420.91	423.56	421.16	493.20	417.60	420.26	0.88	0.85	0.83	13.89	18.41	19.45
277.31	421.28	423.56	421.53	487.11	420.44	421.63	0.88	0.85	0.83	14.27	18.29	19.58
282.44	420.08	423.12	420.28	495.57	428.98	429.93	0.88	0.85	0.84	13.93	17.78	18.98
299.43	420.57	423.19	420.29	521.47	457.46	454.37	0.88	0.86	0.84	13.72	17.19	18.46
289.69	420.36	421.60	420.12	510.87	442.87	442.52	0.88	0.85	0.83	13.79	17.75	18.85
278.30	419.74	420.90	419.78	489.03	423.36	424.03	0.88	0.86	0.83	14.47	18.43	19.63
276.05	420.97	422.87	420.98	484.51	421.82	421.73	0.88	0.85	0.83	14.76	18.98	20.44
277.55	420.97	422.39	420.82	492.27	419.32	420.41	0.88	0.86	0.83	14.41	18.76	19.96
298.91	420.03	422.74	420.07	518.63	455.42	456.49	0.88	0.86	0.84	13.69	17.16	18.23

Regression Model

The regression model to be used for accurately predicting Demand is as described below:

$$KWD = \beta_1 P_a(t) + \beta_2 P_b(t) + \beta_3 P_c(t) + \beta_4 P_{asymmetric}(t) + \beta_5 P_{Harmonic}(t) + \beta_6 P_n(t) + \alpha$$

Where

$P_{a,b,c}$ is computed for each phase using V, I, PF for the respective phase, per Sample data collected of Voltage, Current, and Power Factor

$P_{Harmonics}$ is computed using V_{THD}, and I_{THD} for each phase, per sample data collected .

$P_{Asymmetrical}$ is computed using V, I, PF for each phase, per sample data collected, of Voltage, Current, Power Factor; respectively .

Regression Model

P_n is computed using V, I_n for the three phase imbalance, per sample data collected.

Coefficient β_1, β_2, β_3, β_4, β_5, β_6 α and are estimated by the

Based on the regression analysis performed on the data, the model is as shown below :

β_1	14.95
β_2	7.49
β_3	5.60
β_4	1,298.02
β_5	6,289.56
β_6	1,590.20
α	2,080,626.97

Regression Model

The Statistical indices used to evaluate regression models in accordance to the following

:

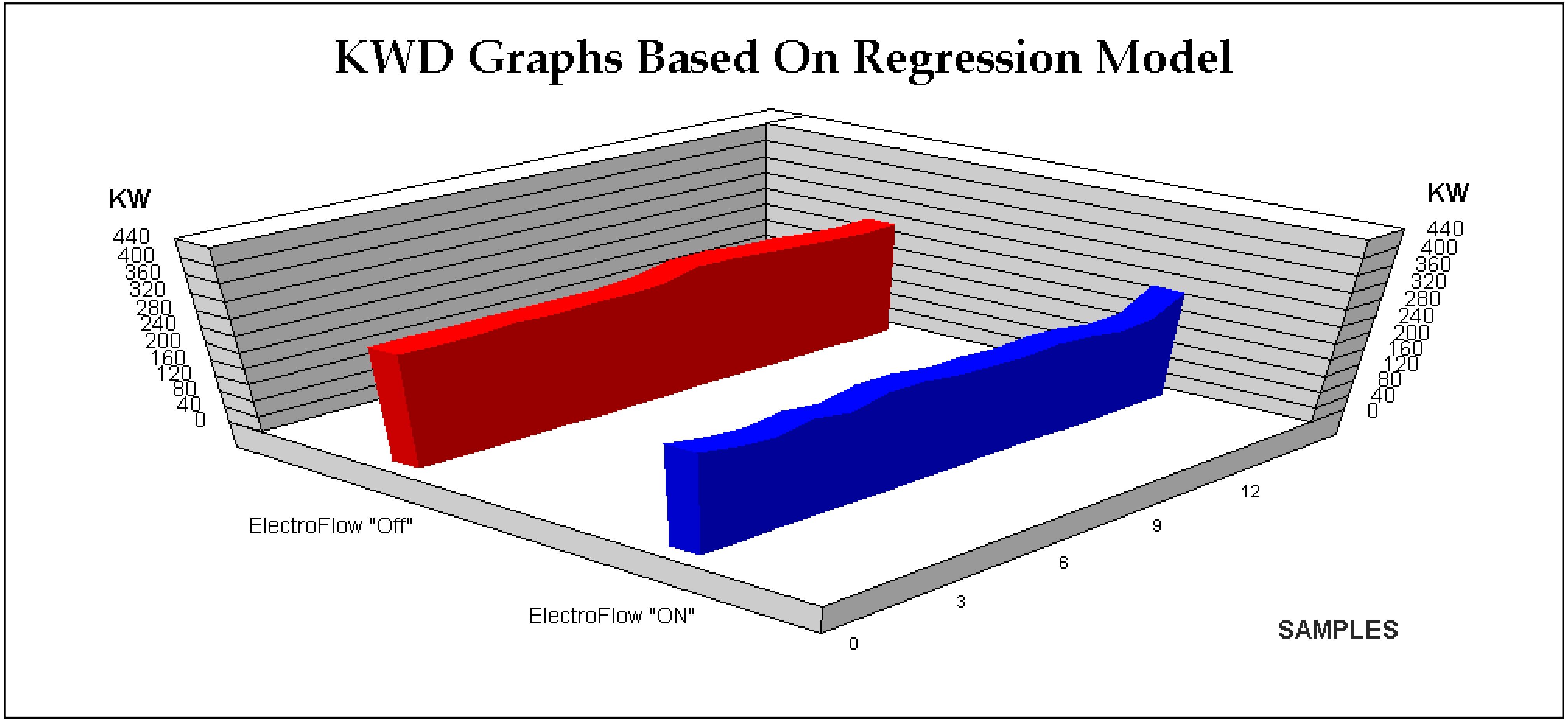
= (%) Coefficient of Determination R2 0.49

Mean Bias Error, MBE (%)=0.37

As can be seen, the model is therefore a very close representation of the facility's real conditions, and subsequent power quality effects on the load is clearly identified.

The regression model is then applied based on the data collected for ElectroFlow™ "ON", and ElectroFlow™ "OFF" conditions, in order to verify the exact magnitude of savings.

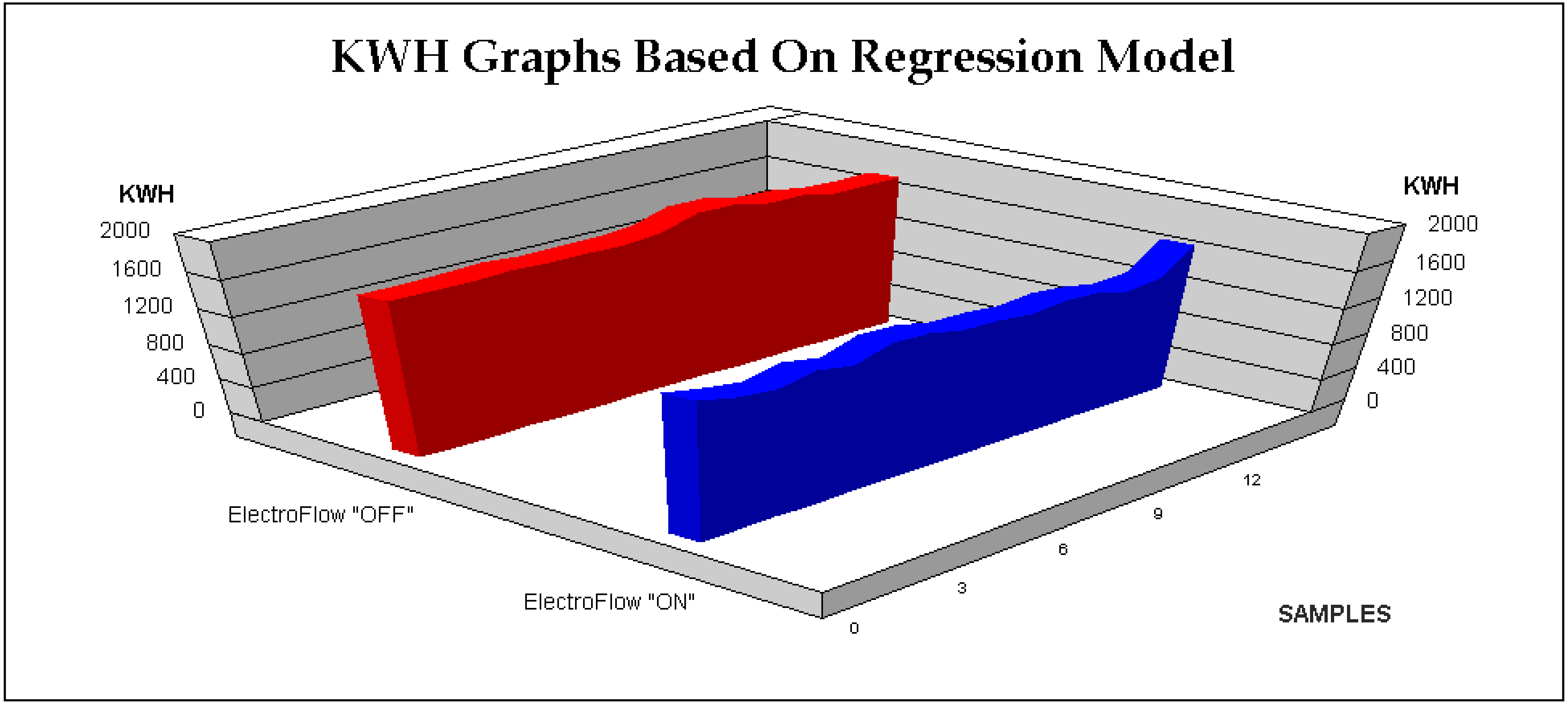
KWD Graphs Based On Regression Model



Average KWD ElectroFlow "ON": 217 KW

Average KWD ElectroFlow "OFF": 287 KW

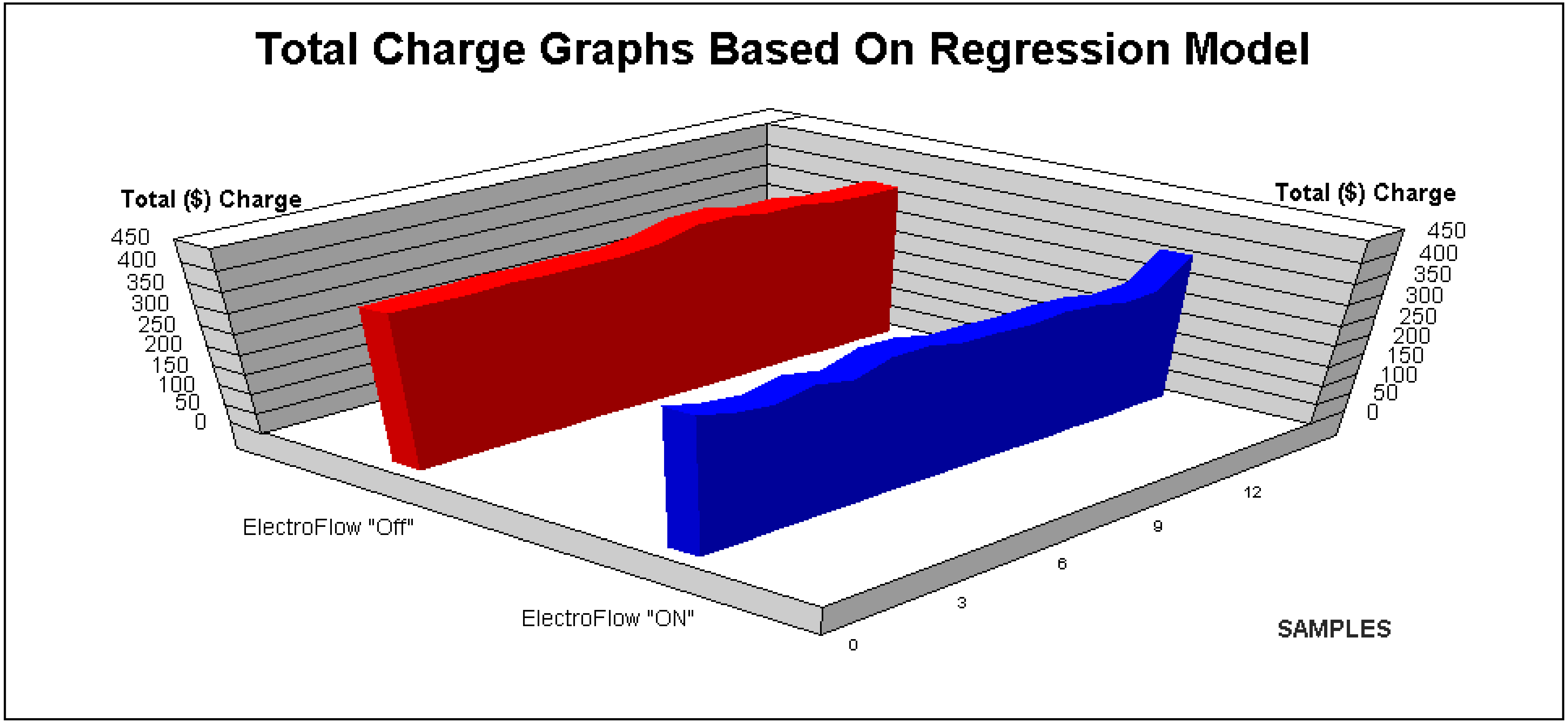
KWH Graphs Based On Regression Model



Average KWH ElectroFlow "ON": 1,459.07 KWH

Average KWH ElectroFlow "OFF": 1,762.20 KWH

Total Charge Graphs Based On Regression Model



Average Total Charge ElectroFlow "ON": $ 320.01

Average Total Charge ElectroFlow "OFF": $ 386.49

Power Quality Effects

	Before ElectroFlow			After ElectroFlow		
Parameter	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
Voltage (v)	421.00	425.90	423.78	418.02	417.91	417.77
Current (A)	521.47	457.46	456.49	391.73	364.42	360.90
Power Factor	0.88	0.85	0.83	0.98	0.98	0.98
Vthd (%)	1.80	1.60	1.50	0.80	0.70	0.60
Ithd (%)	14.76	18.98	20.44	22.10	21.58	24.23

Resultants Of Regression Analyses

Based on the regression model, it is concluded that:

Demand (KWD) with ElectroFlow™ "OFF"	287	KW
Demand (KWD) with ElectroFlow™ "ON" =	217	KW

Hourly Demand (KWD) Savings =
(Demand (KWD) with ElectroFlow™ "OFF" - Demand (KWD) with ElectroFlow™ "ON") x Adjustment based on Baseline Energy Audit

Adjustment based on Baseline Energy Audit = Demand (KWD) based on Baseline Energy Audit / Demand (KWD) with ElectroFlow "OFF"

Hourly Demand (KWD) Savings =

(287 - 217) =70

Annual Demand (KWD) Savings = Hourly Demand (KWD) Savings x 12

Annual Demand (KWD) Savings = 70 KW x12= 840

Resultants Of Regression Analyses

Based on the regression model it is concluded that:
Annual Usage (KWH) savings = Hourly Demand (KWD) Savings x Hours of Operation of Facility per week x 52 weeks

Hours of Operation of Facility per week = 120 hours/week (Based on Baseline Energy Audit)

Annual Usage (KWH) savings = 70 x 120 x52 = 436800 Kwh

Resultants Of The SPA Study

	Projected		Actual	
	Value	%	Value	%
Annual KWD	0	0	840	0
Annual KWD ($)	0	0	0	0
Annual KWH	123442	6	436800	21.23
Annual KWH ($)	27009	6	95571	21.18
Total ($)	27009	6	95571	21.18

Project Realization Rate

Realization Rate (%) = (Verified Savings/Expected Savings) x 100

KWD Savings Realization Rate(%) = 840 / 0)x 100= 0

KWH Savings Realization Rate(%) = (436800 / 123442)x 100= 354

Total Charge Savings Realization Rate(%) = (95571 / 27009)x 100= 354.00