Consultancy Services for the Plant Audit in various Pump Stations and Reservoirs (OP18REFCS03)

Technical Report for Cherry-inline Pump Station

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GHD Ply Ltd.

Preliminary

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Executive Summary

Cherry-inline Pump Station is a station with submersible pumps. Based on preliminary assessment on historical corrective and preventive intervention records, it was agreed between Maynilad and GHD to conduct a number of tests per the submitted ITPs.
This report describes the electrical and FDAS testing results along with a set of recommendations and conclusions. In brief, it can be recommended that the FDAS system shall be improved for safety reason. In addition, from the harmonic and integrity study, it is optimal to keep a close monitoring on VFD1 to detect any future abnormality in its operation so as to have appropriate preventive and corrective action plan.
This report focuses only on electrical and FDAS testing. Results on mechanical test and life cycle cost estimation will be updated in next revision of this report upon the completion of mechanical tests.

Contents

Chapter 1

Preliminary Assessment and Data Gathering

GHD did conduct preliminary assessment on a set of data provided by Maynilad. The data set includes a number of records on daily production and power consumption and intervention reports issued after Maynilad experienced failure/breakdown of assets.

The assessment provided a base for GHD to generate the Inspection Testing Plan (ITP) [4] aiming to gather necessary data for conducting reliability study. The ITP has been reviewed by Maynilad, together with the Work Safety Permit (WSP), prior to execution of visual inspections and testings at the site.

1.1 Maynilad's data

Initial assessment on historical data confirmed that the information for reliability study is not available.

1.1.1 Asset hierarchy

During the bidding phase, Maynilad did provide the first draft of the Asset Registry (AR) that describes a hierarchy of eight (8) levels. Figure 1.1 visualizes the hierarchy with brief description presented in Table 1.1.

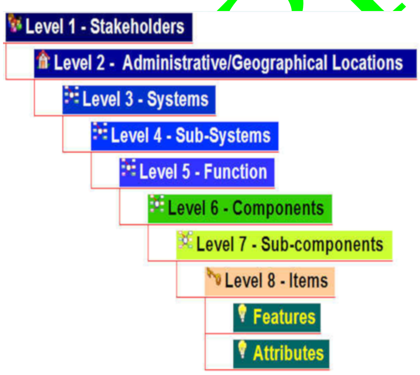


Figure 1.1: Asset Hierarchy

GHD received the latest version of the AR with 101 assets for this PS. The full list of assets is given in the excel file provided by Maynilad in 2018. GHD has developed a MySQL program to convert the data in the excel file to a relational database structure. Per agreement with Maynilad, GHD will only verify level 7 of the AR with the actual site condition for the study [3].

Table 1.1: Condition state definition - Multiple.

Asset hierarchy	Description
Level 1	Stakeholder level. For example, an pump station belongs to MWSI
Level 2	Geographical locations/ or administrative zone (e.g. a pump station belong to Quezon city or Makati)
Level 3	System (e.g. the entire pump stations and reservoir system)
Level 4	Sub-system (e.g. one specific pump station and reservoir such as the Lamesa PSR)
Level 5	Functional system (e.g. booster system or storage system)
Level 6	Component (e.g. Suction line, Reservoir line and Tank)
Level 7	Sub-component (e.g. Suction pipe and fittings, Concrete reservoir, pump)
Level 8	Items (e.g. valve, bearing, motor)

1.2 Preliminary assessment

Assessment on the lastest provided intervention records reveals that the provided pertinent data is incomplete and cannot be used as representative data for a complete reliability study.

It is also confirmed from the provided data that the Client has done regularly check-up on GENSETs to ensure that it provides adequate level of services in case of emergency. To date, no failure records has been observed for the GENSET. Thus, testing on GENSET is not needed. This is also to save cost for Maynilad per unit rate quoted in the Financial Proposal.

Further evaluations and tests have to be conducted to identify the areas for improvement of preventive measures in mitigating corrective measures and study the ways to strengthen preventive measures to improve operating conditions and life of pump components.

Improving the reliability of the pump stations for the next coming years require evaluation of the existing pump station conditions and maintenance practices, particularly assessment of the pump and its components. With that, areas for improvement of operation and maintenance be addressed through action items that come from the resulting recommendations.

In order to capture a relatively good picture on the reliability of the pump system and its associated assets, a number of tests shall be conducted.

1.3 Summary of the inspection test plan (ITP)

A complete write-up on testing shall be referred to the ITP [4], which has been submitted, reviewed, and approved by the Client. This section only provides highlights to help readers keeping abread of the flow of the report.

1.4 Database

GHD developed an MySQL program that functions as a database used to record data collected from visual inspections and testings. The database has been developed using the concept of Relational Database Management System (RDMS), which is a must to record data systematically. The benefits of using the database are

- Eliminate redundancy and repeatition of same data
- Eliminate incorrect data entry that is often found when working with excel files
- Provide linkages among asset hierarchy
- Provide ease for programing (e.g. reliability modeling and life cycle cost analysis)
- Support Maynilad AIM team to learn the benefits of using RDMS in developing an integrated Asset Management System for now and future
- Provide compatibility with any CMMS that is often using other RDMS such as Microsoft SQL Server, Oracle SQL server, or MySQL platform

- Provide ease for compilation of desire tables for further analysis using SQL (Structure Query Language)
- Provide ease for importing/exporting to different extension formats (e.g. flat, csv, xlsx)
- Provide a strong background for Maynilad team to migrate recording practices to Web-based that will be part of GHD's recommendation for future usage.

The program is then migrated into MySQL server, which is a powerful database system that is used also to migrate, compile, and store all production and power consumption data into a single table. Main reasons behind the development of the MySQL server are for statistical computing with R and for faster compilation of queries.

GHD will provide these two sets of database as part of our deliverable and will provide training for Maynilad team to learn how to use the database in an efficient approach.

Chapter 2

Methodology

2.1 The Integrated Asset Management Approach (IAM)

We proposes an Integrated Asset Management (IAM) approach with its framework shown in Figure 2.1 for executing this project. The IAM approach will eventually be beneficial to Clients as it will lay a foundation to build up a systematic asset management plan for the future.

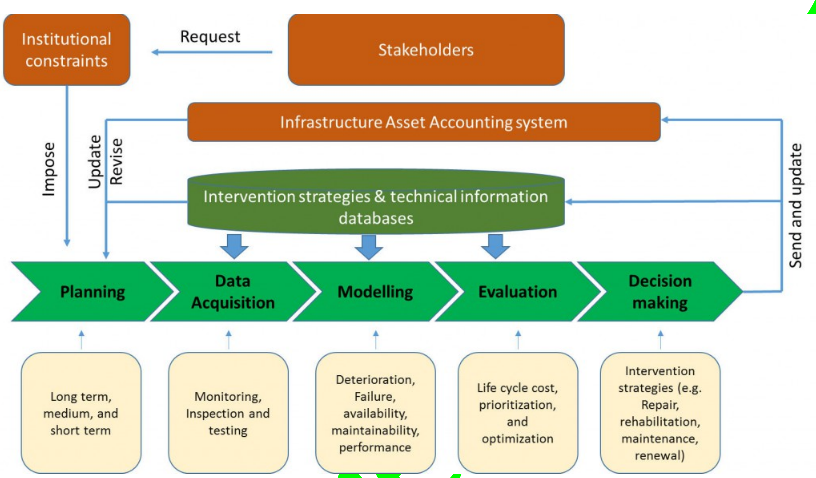


Figure 2.1: Integrated asset management approach (adopted from POM+ http://www.pomplus.vn)

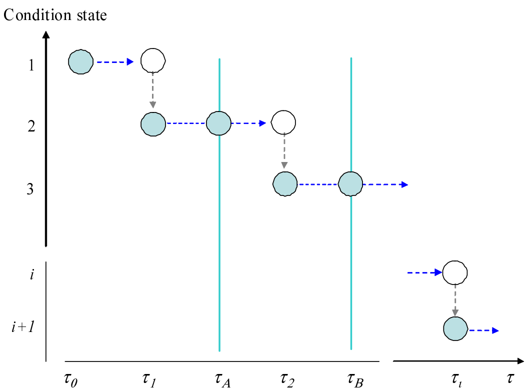
As can be seen in Figure 2.1, we sees the overall picture of works that should be executed in close connection to each other in order to make a full cycle of asset management effectively.

Works associated with auditing equipment and facilities of pump stations and reservoirs, coming up with a preventive maintenance program, tendering, and detailed design can be described explicitly using the framework in Figure 2.1. For example, various type of data concerning physical and operational condition and performance of equipment and facilities will be collected, filtered, and analyzed (Data Acquisition); the data will be further used for modeling purposes (e.g. prediction of failure rate, draw deterioration curve, reliability and efficiency); life cycle cost analysis will be then performed for each equipment and for its system. In this process, either prioritization or optimization technique can be used; finally a set of preventive maintenance intervention strategies will be generated for decision making purposes.

2.2 Deterioration process and rating index

In order to analyze and forecast the deterioration of assets, it is necessary to accumulate time series data on the CS of the assets. The historical deterioration process of an asset is described in Figure 2.2. This figure shows the deterioration progress of a component that has not been repaired. In reality, there exists uncertainty in the deterioration progress of the asset, and more-over, the CS at each point in the time axis is restricted by the time, at which, visual inspection is carried out.

In this figure, τ represents real calendar time (the expression "time" will be used instead throughout this paper). The deterioration of the asset starts immediately after it begins to operate at time τ_0. The CS of an asset is expressed by a rank J representing a state variable i $(i = 1, \cdots, J)$. For a component in the good or new situation, its condition state is given as $i = 1$, and increasing of CS i describes progressing deterioration. A value of $i = J$ indicates that an asset has reached its service limit. In Figure 2.2, for each discrete time τ_i $(i = 1, \cdots, J-1)$ on the time-axis, the corresponding CS has increased from i to $i+1$. Hereinafter τ_i is referred to the time a transition from a CS i to $i+1$ occurs.



Note) In this example, the deterioration process of a infrastructure component if expressed in terms of calendar time $\tau_1, \tau_2, ..., \tau_i$, and condition state of the section is increased in unitary units.

Figure 2.2: Transition Time of Condition State (adopted from [11]).

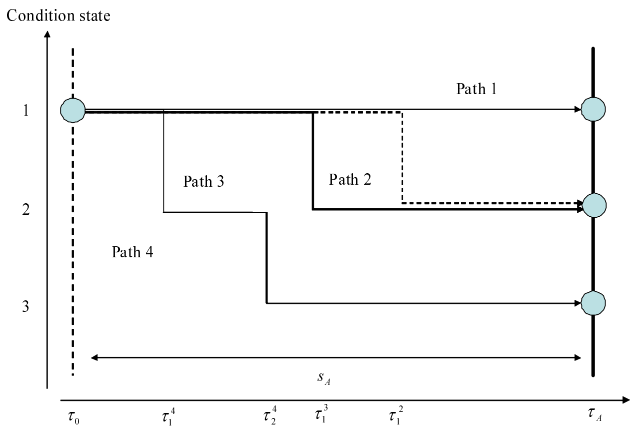
Information regarding the deterioration process of an asset can be acquired through periodical visual inspections. However, information on the CS based on continuous visual inspection is difficult to obtain. In this case, the initial inspections is carried out at times τ_A on the time-axis. It is supposed that at time τ_A the CS observed by inspection is i $(i = 1, \cdots, J-1)$. The deterioration progress in future times is uncertain. Among the infinite set of possible scenarios describing the deterioration process only one path is finally realized.

Figure 2.3 shows four possible sample paths. Path 1 shows no transition in the CS 1 from initial time τ_0 to first inspection time τ_A. In paths 2 and 3, CS has advanced to one upper CS at the calendar times τ_1^2 and τ_1^3 respectively. The CS of these two paths observed at time τ_A become 2. In a periodical inspection scheme, the point times τ_1^2 and τ_1^3 in which the CS has changed from 1 to 2 are not determined. In addition, path 4 shows transitions in the CS at times τ_i^4 and τ_{i+1}^4 during the inspection interval. The CS observed at time τ_A becomes 3. That is, in spite of the transitions in the CS are observable at the time of periodical inspection, it is not possible to obtain information about the times in which those transitions occur.

Figure 2.4 further describes the deterioration process inferring the inspection approach and how the CS is assumed. In this figure, it is assumed that the CS at the calendar time τ_{i-1} has changed from $i-1$ to i. The calendar time τ_{i-1} is assumed to be equivalent to $y_i = 0$. The time represented by the sample time-axis is referred from now on as a "time point", and differs from "time" on the calendar time axis. The times τ_A and τ_B correspond to the time points y_A and y_B on the sample axis. It can be seen that $y_A = \tau_A - \tau_{i-1}$, $y_B = \tau_B - \tau_{i-1}$.

Information on the CS i at the beginning of the calendar time τ_{i-1} cannot be obtained in a periodical inspection scheme. Therefore, time points y_A and y_B on the sample time-axis cannot be correctly obtained either. For convenience of description, it is assumed that the information at the time a point is known in order to develop the model, despite this assumption is not necessarily essential. The following paragraph discusses that even without information at time points y_A and y_B an exponential hazard model can be estimated.

In the case the CS of an asset at time τ_i (time point y_C) is assumed to change from i to $i+1$, the period length in which the CS has remained at i (referred as the life expectancy of a CS i) is represented by $\zeta_i = \tau_i - \tau_{i-1} = y_C$. The life expectancy of a CS i is assumed to be a stochastic

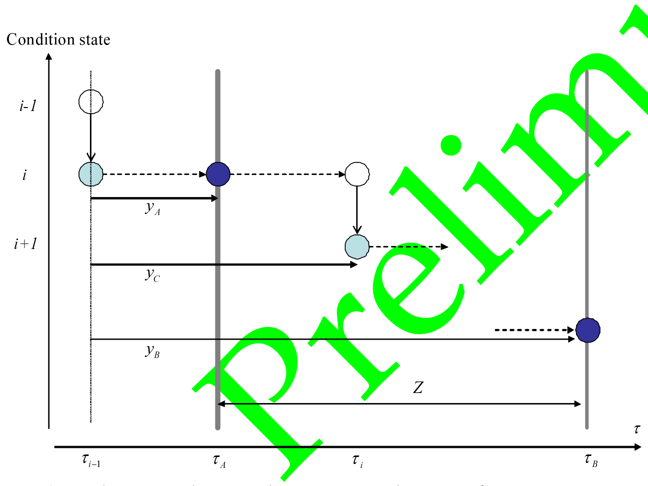


Note) In this example, the deterioration process of an asset is expressed in terms of four different sample paths. In paths 2 and 3 the CS has advanced to one upper CS at the calendar times τ_1^2 and τ_1^3 respectively. In path 4, the CS has increased one state at each time τ_1^4 and τ_2^4. However, in the case of a periodical inspection carried out at times τ_A the CS at any point in time between inspections cannot be observed.

Figure 2.3: Transition Pattern of Condition State.

variable ζ_i with probability density function $f_i(\zeta_i)$ and distribution function $F_i(\zeta_i)$. Random variable ζ_i is defined in the domain $[0, \infty]$. The distribution function is defined as

$$F_i(y_i) = \int_0^{y_i} f_i(\zeta_i) d\zeta_i. \tag{2.1}$$



Note) In the case the condition state changes from $i-1$ to i at the calendar time τ_{i-1} the inspections carried out at times τ_A and τ_B will also correspond to the points in time y_A and y_B when using τ_{i-1} as the time origin. The figure shows a sample deterioration path in which the condition state has advanced in one unit to y_c in the interval time $\tau_{i-1} - y_C$. However, observations at time τ_{i-1} are not possible in a periodical inspection scheme, so there is no way to obtain observation at y_A, y_B and y_C. Nevertheless, it is possible to use the information contained in $z = y_C - y_A \in [0, Z]$.

Figure 2.4: Model of Deterioration Process.

The distribution function $F_i(y_i)$ represents the cumulative probability of the transition in the CS from i to $i+1$. CS i is assumed to be observed at initial time $y_i = 0$(time τ_A). The time interval measured along the sample time-axis until the time point y_i is $\tau_{i-1} + y_i$. Therefore, using the cumulative probability $F_i(y_i)$, the probability $\tilde{F}_i(y_i)$ of a transition in the CS i during the time points interval $y_i = 0$ to $y_i \in [0, \infty]$ is defined by $\tilde{F}_i(y_i)$:

$$\text{Prob}\{\zeta_i \geq y_i\} = \tilde{F}_i(y_i) = 1 - F_i(y_i). \tag{2.2}$$

The conditional probability that the CS of an asset at time y_i advances from i to $i+1$ during the time interval $[y_i, y_i + \Delta y_i]$ is defined as

$$\lambda_i(y_i)\Delta y_i = \frac{f_i(y_i)\Delta y_i}{\tilde{F}_i(y_i)}, \tag{2.3}$$

where the probability density $\lambda_i(y_i)$ is referred as the hazard function.

2.3 Condition State (CS) definition

Condition of an asset can be described either by a range of discrete condition state (CS) or by continuous values of one or more than one parameters such as cracking, thickness, and corrosion. In asset management practice, discrete range of CS is often for the following reasons:

- It can be converted/mapped from continuous value of monitoring data;
- It is convenient for non-technical persons and managers;
- It is suitable for determination of intervention strategy and thus for life cycle cost modeling.

Assets in pump stations are different in category and functionality, thus it is not easy to define a universal range of CSs. However, it is possible that a generic range of CSs can be used to map appropriately different type of assets. In this project, following definitions are used for multiple CSs (Table 2.1) and binary state (Table 2.2) systems.

Table 2.1: Condition state definition - Multiple.

CS i	Definition	Require Intervention	Remarks
1	New/likely new and provide adequate LOS	No	Good (None/Insignificant)
2	Install <=5 years, provide adequate LOS	No	Acceptable (Minor)
3	Moderate aging, not provide adequate LOS, observed moderate breakdown	Yes	Damaged (Significant)
4	Moderate aging, not provide adequate LOS, require frequent CI and PI	Yes	Poor (Extensive)
5	Aging and not provide adequate LOS	Yes	Safety is endangered

Table 2.2: Condition state definition - Binary.

CS i	Definition	Require Intervention	Remarks
0	Not provide adequate LOS	No	
1	Provide adequate LOS	Yes	

2.4 Technical efficiency

Technical efficiency is a coefficient measured as the ratio of actual parameter value and expected/design parameter value. In case of PSs, TE is often discussed around the value of pump efficiency (η), which is a factor that accounts for the kinetic energy lost during the operation [5]. The PE is a product of the followings:

- Hydraulic efficiency (primarily, disk friction against the liquid with impeller shrouds). This efficiency is contributed by the speed and impeller geometry. Shock losses during rapid changes in direction along the impeller and volute can also resulted in additional shock losses;
- Volumetric efficiency (recirculation losses at wear rings, interstage bushes and other);
- Mechanical efficiency (friction at seals or gland packing and bearings)

Hydraulic efficiency and volumetric efficiency are used at the design stage of PS when there is a need to determine suitable pump or group of pumps that satisfies the designed LOS. Whilst, mechanical efficiency is used to determine operational efficiency once pumps are in used.

The mechanical efficiency (η_m) is estimated based on the equation 2.4

$$\eta_p = \frac{P_W}{P_B} \tag{2.4}$$

Where P_W and P_B are water power and brake power, respectively.

Following equations are used to calculated the P_W and P_B:

$$P_{W(kW)} = \gamma \times H \times Q \tag{2.5}$$

$$P_{B(kW)} = P_E \times e_m \tag{2.6}$$

where

P_W *Water power (kW);*
P_B *Brake power (kW);*
P_E *Electric power (kW);*
Q *Water flow rate (m^3/s);*
H *Head produced by pump (m_{H_2O});*
η_e *Motor efficiency (%);*
γ *specific weight of fluid (water) (kN/m^3).*

2.5 Reliability

2.5.1 Qualitative and Operational Analysis

2.5.1.1 Failure Mode and Effects Analysis (FMEA)

An FMEA is often the first step of a system reliability study. It involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects. FMEA is an inductive reasoning (forward logic) single point of failure analysis and is a core task in reliability engineering, safety engineering and quality engineering.

A successful FMEA activity helps identify potential failure modes based on experience with similar products and processes—or based on common physics of failure logic. It is widely used in development and manufacturing industries in various phases of the product life cycle.

Functional analyses are needed as an input to determine correct failure modes, at all system levels. The FMEA is in principle a full inductive (forward logic) analysis, however the failure probability can only be estimated or reduced by understanding the failure mechanism. Hence, FMEA may include information on causes of failure (deductive analysis) to reduce the possibility of occurrence by eliminating identified (root) causes.

2.5.1.2 Reliability Centered Maintenance (RCM)

Reliability-centered maintenance (RCM) is a process to ensure that systems continue to do what their user require in their present operating context. It is generally used to achieve improvements in fields such as the establishment of safe minimum levels of maintenance. Successful implementation of RCM will lead to increase in cost effectiveness, reliability, machine uptime, and a greater understanding of the level of risk that the organization is managing. It is defined by the technical standard SAE JA1011, Evaluation Criteria for RCM Processes.

Reliability centered maintenance is an engineering framework that enables the definition of a complete maintenance regimen. It regards maintenance as the means to maintain the functions a user may require of machinery in a defined operating context. As a discipline it enables machinery stakeholders to monitor, assess, predict and generally understand the working of their physical assets. This is embodied in the initial part of the RCM process which is to identify the operating context of the machinery, and write a Failure Mode Effects Analysis (FMEA). The second part of the analysis is to apply the "RCM logic", which helps determine the appropriate maintenance tasks for the identified failure modes in the FMEA. Once the logic is complete for all elements in the FMEA, the resulting list of maintenance is "packaged", so that the periodicities of the tasks are rationalised to be called up in work packages; it is important not to destroy the applicability of maintenance in this phase. Lastly, RCM is kept live throughout the "in-service" life of machinery, where the effectiveness of the maintenance is kept under constant review and adjusted in light of the experience gained.

RCM can be used to create a cost-effective maintenance strategy to address dominant causes of equipment failure. It is a systematic approach to defining a routine maintenance program composed of cost-effective tasks that preserve important functions.

2.5.2 Weibull model

In hazard analysis, the deterioration of element is subjected to follow a stochastic process [10]. For binary state system, two condition level $0, 1$ are often used. When receiving a PI or CI, the CS from 1 must be changed into 0. In reliability study, this process is often regarded as renewal process. The renewal is carried out at alternative time t_k $(k = 0, 1, 2, ...)$. In this way, the next renewal time is denoted as $t = t_0 + \tau$, where τ indicating the elapsed time. The life span of an asset is expressed by a random variable ζ. The probability distribution and probability density function of the failure occurrence are $F(\zeta)$ and $f(\zeta)$ respectively. The domain of the random variable ζ is $[0, \infty]$. The living probability (hereafter named as survival probability) expressed by survival function $\tilde{F}(\tau)$ can be defined according to the value of failure probability $F(\tau)$ in the following equation:

$$\tilde{F}(\tau) = 1 - F(\tau). \tag{2.7}$$

The probability, at which the asset performs in good shape until time τ and break down for the first time during an interval of $\tau + \Delta\tau$ can be regarded as hazard rate and expressed in the following equation:

$$\lambda_i(\tau)\Delta\tau = \frac{f(\tau)\Delta\tau}{\tilde{F}(\tau)}, \tag{2.8}$$

where $\lambda(\tau)$ is the hazard function of the asset. In reality, the breakdown probability depends largely on the elapsed time of the asset since its beginning of operation. Thus, the hazard function should take into account the working duration of the asset (time-dependent). In another word, the memory of the system should be inherited. Weibull hazard function is satisfied in addressing the deterioration process [2, 9]:

$$\lambda(\tau) = \alpha m \tau^{m-1}, \tag{2.9}$$

where α is the parameter expressing the arrival density of the asset, and m is the acceleration or shape parameter. The probability density function $f(\tau)$ and survival function $\tilde{F}(\tau)$ in the form of Weibull hazard function can be further expressed in equation (2.10) and (2.11):

$$f(\tau) = \alpha m \tau^{m-1} \exp(-\alpha\tau^m), \tag{2.10}$$
$$\tilde{F}(\tau) = \exp(-\alpha\tau^m). \tag{2.11}$$

Estimation for Weibull's parameter is often with Maximum Likelihood Estimation (MLE) approach on historical data. Thus, the model's parameter is sensitive to how data behaves. We recommend to use this model only when there is sufficient data to be used.

An example of source code for education purpose is given in Github site of Nam Le [1]. The complete program is a copyright of Nam Le.

[1] https://github.com/namkyodai/Models

2.5.3 Markov model

The transition process among the condition states of an infrastructure component is uncertain. Therefore, future condition states cannot be forecasted deterministically. In this situation, Markov transition probability is employed to represent the uncertain transition pattern of the condition states during two time points. Markov transition probabilities can be defined for arbitrary time intervals.

For simplification, Markov transition probabilities can be defined and used to forecast the deterioration of a infrastructure component based on the information from periodical inspection scheme shown in Figure 2.4. The observed condition state of the component at time τ_A is expressed by using the state variable $h(\tau_A)$. If the condition state observed at time τ_A is i, then the state variable $h(\tau_A) = i$. A Markov transition probability, given a condition state $h(\tau_A) = i$ observed at time τ_A, defines the probability that the condition state at a future time (τ_B for example) will change to $h(\tau_B) = j$:

$$\mathrm{Prob}[h(\tau_B) = j | h(\tau_A) = i] = \pi_{ij}. \tag{2.12}$$

The Markov transition probability matrix can be defined and rearranged by using the transition probabilities between each pair of condition states (i, j) as

$$\mathbf{\Pi} = \begin{pmatrix} \pi_{11} & \cdots & \pi_{1J} \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \pi_{JJ} \end{pmatrix}. \tag{2.13}$$

The Markov transition probability (2.12) shows the transition probability between the condition states at two given times τ_A and τ_B, therefore, it is straightforward that the values of a transition probability will differ for different time intervals. Since deterioration continues as long as no repair is carried out $\pi_{ij} = 0$ $(i > j)$. From the definition of transition probability $\sum_{j=1}^{J} \pi_{ij} = 1$. Following conditions must be satisfied:

$$\left.\begin{array}{l} \pi_{ij} \geq 0 \\ \pi_{ij} = 0 \ \ (\text{when } i > j) \\ \sum_{j=1}^{J} \pi_{ij} = 1 \end{array}\right\}. \tag{2.14}$$

The worse level of deterioration is expressed by the condition state J, which remains as an absorbing state in the Markov chain as long as no repair is carried out. In this case $\pi_{JJ} = 1$.

Markov transition probabilities are defined independently from the deterioration history. As shown in Figure 2.4, the condition state at the inspection time τ_A is i, however, the time, at which, condition state changed from $i - 1$ to i is unobservable. In a Markov chain model, it is assumed that the transition probability between the inspection times τ_A and τ_B is only dependent on the condition state at time τ_A.

The Markov chain model is operative and widely applied in management of infrastructure system. Particularly, at management of network level, Markov chain model is used to define the average transition probability of the entire system, or a group of infrastructure components given two periodical inspection data.

Estimation for the Markov transition probability can be done by the MLE approach [10, 11] or Bayesian Estimation approach [6, 8] based on historical data. One advance of using the Markov model is that one time monitoring data can be used. A generic formula to estimate the transition probability is given in following Equations:

$$\pi_{ii} = \exp(-\theta_i Z), \tag{2.15-a}$$

$$\pi_{ii+1} = \frac{\theta_i}{\theta_i - \theta_{i+1}}\{-\exp(-\theta_i Z) + \exp(-\theta_{i+1} Z)\}, \tag{2.15-b}$$

$$\pi_{ij} = \sum_{k=i}^{j} \prod_{m=i}^{k-1} \frac{\theta_m}{\theta_m - \theta_k} \prod_{m=k}^{j-1} \frac{\theta_m}{\theta_{m+1} - \theta_k} \exp(-\theta_k Z), \tag{2.15-c}$$

$$\pi_{iJ} = 1 - \sum_{j=i}^{J-1} \pi_{ij}, \tag{2.15-d}$$

$$(i = 1, \cdots, J-1) \qquad (j = i, \cdots, J).$$

An example of source code for education purpose is given in Github site of Nam Le [2]. The complete program is a copyright of Nam Le.

2.6 Intervention Strategy (IS)

Intervention Strategy (IS) is at asset level (level 7). It is a collection of intervention type for component level (level 8). A collection of ISs will form an Intervention Program for (IP) the station. A collection of IPs will form a Work Program (WP) for network level intervention (e.g. a bid awarded for a designer/contractor can be a WP that consists of intervention program for one or more than one pump stations). Following generic IS is defined to guide the selection of IPs that will be details in the later part of the report.

Table 2.3: Generic intervention strategy (IS).

IS	Definition	Remarks
1	Do Nothing	
2	Minor repair	Require minimal effort and can be done only for certain asset type
3	Major repair	Require extensive efforts to return the asset to likely new condition
4	Replacement/Renewal	Replacing assets or components of asset with identical one or with new model

For each type of asset, IS will be selected based on reliability study and consideration of cost. Further more, Employers inputs and requirements are also taken into account.

2.7 Determination of optimal intervention strategy

Following subsections briefly describe the model that can be used to determine optimal intervention strategy.

2.7.1 Block Replacement Model

It is assumed that a PI is executed after a pre-defined time $n \cdot T$ ($n = 0, 1, 2, \cdots, N$). Once the PI is executed, the functionality and serviceability of the asset could be the same or different from that of the asset before the intervention. In between the time Δt ($[0 \leq \Delta t \leq T]$), hazards could occur and cause the asset in worse CSs (hereafter denoted as i ($i = 1, \cdots, I$)), in which the asset is no longer providing an adequate level of services (LOS). In both cases, when the PI or CI is executed, there are impacts incurred by stakeholders s (e.g. the owner, the users, the public).

Following notations are used to describe the formulation of the model.

[2] https://github.com/namkyodai/Models

$\theta(\Delta t\|t)$	Conditional failure rate i ($i = 1, \cdots, I$) when the asset has been in service in an interval t after the PI
$\Psi(\cdot\|t)$	Any conditional function Ψ given that a PI is executed by a unit of age t, where t is a random variable
$F(t)$	Cumulative distribution function (cdf) of age t of a unit for a PI at execution time
$w_p^s(t)$	Impacts incurred by stakeholder s due to the execution of PI
$w_c^s(t)$	Impacts incurred by stakeholder s due to the execution of CI
$w_o^s(\Delta t\|t)$	Conditional impacts incurred by stakeholder s when the structure is remains in normal operation (*i.e.* providing an adequate LOS) during time interval Δt after a PI has been carried out and the asset has not entered failure state
ρ	discount factor
$p_l^k(t)$	probability of failure at time t of the affecting other assets k
$C_c^{s,k}$	Impacts incurred by stakeholder s due to the execution of an CI on other assets k
T	interval between the PIs
$T^\star$	Optimal interval time between PIs, which is the variable of the model
$\Omega_p(T,t)$	minimum expected total discounted impact for an infinite time span when the asset has been in service during an interval t after the execution of the PI and the asset has not entered failure state
$\Omega_c(T,t)$	minimum expected total discounted impact for an infinite time span when a CI has been executed, of the asset that has been in service during a time interval t after the execution of the PI and the asset has entered failure state

In the model, it is assumed that at each damage level i, there exists a corresponding well defined CI. Within an increment of time Δt, after the asset has been under the PI after time t, the total expected impacts due to the execution of CIs are:

$$v_c(\Delta t|t) = \sum_{s=1}^{S}\left[w_c^s(\Delta t) + \sum_{k=1}^{K} p_l^k \cdot C_c^{s,k}\right] \cdot \theta(\Delta t|t). \tag{2.16}$$

The total impacts due to the execution of PIs and the total impacts incurred by stakeholders during the service time of the asset are defined in Eq. (2.17) and Eq. (2.18), respectively.

$$v_p(t) = \sum_{s=1}^{S} w_p^s(t). \tag{2.17}$$

$$v_o(t) = \sum_{s=1}^{S} w_o^s(t). \tag{2.18}$$

According to the principle of optimality, which is described in [1, p. 15], the minimum expected total discounted impact $\Omega_c(T,t)$ for infinite time is formulated in following equation.

$$\Omega_c(T,t) = \int_0^\infty \left[v_c(\Delta t|t) + \Omega_p(T,\Delta t|t)\right] dF(t). \tag{2.19}$$

The minimum expected total discounted impact $\Omega_p(T,\Delta t|t)$, which appears inside Eq. (2.16), is obtained as follows

$$\Omega_p(T,\Delta t) = min\Gamma(\Delta t). \tag{2.20}$$

where $\Gamma(\Delta t)$ is defined as

$$\begin{aligned}\Gamma(\Delta t) = \int_0^\infty \Bigg[v_o \int_0^{dt} exp(-\rho\tau)d\tau + \{1-\theta(\Delta t|t)dt\} \cdot \Omega_p(T,\Delta t + dt|t)exp(-\rho dt) \\ +\theta(\Delta t|t)dt \cdot \Omega_c(T,\Delta t+dt|t)exp(-\rho dt)\Bigg] dF(t).\end{aligned} \tag{2.21}$$

According to [7], Eq. (2.21) is rewritten in following form

$$\begin{aligned}\Gamma(\Delta t) = \Omega_p(T,\Delta t) + \left[-\rho\Omega_p(T,\Delta t) + d\Omega_p(T,\Delta t)/dt\right] dt \\ + \int_0^\infty \left[v_o + v_c(\Delta t|t)\right] dF(t)dt.\end{aligned} \tag{2.22}$$

Thus, from $\Omega_p(T, \Delta t) = \Gamma(\Delta t)$ (Eq. (2.20)), the following equation can be derived:

$$\Omega_p(T, \Delta t) = exp(\rho \Delta t) \left[\Omega_p(T, 0) - \int_0^{\infty} \int_0^{t} exp(-\rho\tau) \left\{ v_o + v_c(\tau|t) \right\} \right] d\tau dF(t). \quad (2.23)$$

where,

$$\Omega_p(T, 0) = \left\{ 1 - exp(-\rho T) \right\}^{-1} \int_0^{\infty} \left[exp(-\rho T) \left\{ v_p(T, t) \right\} + \int_0^{T} exp(-\rho \Delta t) \left\{ v_o(\Delta t|t) + v_c(\Delta t|t) \right\} dt \right] dF(t). \quad (2.24)$$

when T tends to infinity $T \to \infty$, Eq. (2.24) becomes

$$\Omega_p(\infty, 0) = \int_0^{\infty} \int_0^{\infty} exp(-\rho t) \left[v_o + v_c(\Delta t|t) \right] dt dF(t). \quad (2.25)$$

Eqs. (2.24) and (2.25) are the explicit forms of the expected total discounted impact in infinite time horizon. This is the classical optimization problem. By differentiating the expected total discounted impact $\Omega_p(T, 0)$ and $\Omega_p(\infty, 0)$ and setting it equal to zero, the optimal time $T^\star$ can be obtained. The optimal time $T^\star$ for PI is the solution of the following system of equations:

$$\begin{cases} T^\star = \arg \min\limits_{T^\star \in [0, T]} \Theta_p(T, 0) \\ T^\star = \arg \min\limits_{T^\star \in [0, \infty]} \Theta_p(\infty, 0) \end{cases} \quad (2.26)$$

in which the differentiates of $\Theta_p(T, 0)$ and $\Theta_p(\infty, 0)$ are respectively:

$$\begin{aligned} \Theta_p(T, 0) &= \frac{\delta(\Omega_p(T, 0))}{\delta T} \\ &= \left[1 - exp(-\rho T) \right] \int_0^{\infty} \left[-\rho v_p(T, t) \right. \\ &\quad \left. + d(v_p(T, t))/dT + v_o(T, t) + v_p(T, t) \right] dF(t) \\ &\quad - \rho \int_0^{\infty} \left[exp(-\rho T) \left\{ v_p(T, t) \right\} \right. \\ &\quad \left. + \int_0^{T} exp(-\rho \Delta t) \left\{ v_o(\Delta t|t) + v_c(\Delta t|t) \right\} dt \right] dF(t). \end{aligned} \quad (2.27)$$

and

$$\begin{aligned} \Theta_p(\infty, 0) &= \frac{\delta(\Omega_p(\infty, 0))}{\delta T} \\ &= \int_0^{\infty} \left[-\rho \left\{ v_p(\infty|t) + \int_0^{\infty} exp(-\rho t) \left\{ v_o(\Delta t|t) + v_p(\Delta t|t) \right\} \right\} \right. \\ &\quad \left. + \lim_{T \to \infty} d(v_p(T, t))/dT + v_o(\infty|t) + v_p(\infty|t) \right] dF(t) \end{aligned} \quad (2.28)$$

2.7.2 Time-dependent replacement model

Time-dependent replacement model (or Age replacement model) are the ones where the following conditions apply:

- the asset starts operating at $t = 0$, i.e. it is newly built or newly restored to a like new condition following an intervention;
- the probability of failure is described with $f(t)$ and $F(t)$, i.e. the lifetime density and the lifetime;
- if the asset fails on the interval $(0, T]$ a CI is executed;

- if the object does not fail on the interval $(0, T]$ the object is replaced at T, i.e. the PI replacement is executed, regardless if the object has failed and been restored in the time interval $(0, T]$;
- the execution of a PI restores the object to a like new condition;
- the execution of a CI restores the object to a like new condition.

2.7.2.1 Minimize impact

If an age replacement IS is followed the time to the first intervention, Z, is the minimum amount of the time to failure of the length of the renewal period:

$$Z = min(\tau, T) \tag{2.29}$$

The expected, or mean, time to the first intervention is then determined by

$$E[Z = \int_0^T (1 - F(x))dx] \tag{2.30}$$

The mean impact in one renewal period then equals the probability of failure on T multiplied by the impacts associated with the CI plus the probability that no failure occurs on T multiplied by the impacts associated with the PI:

$$F(T) \times I^{CI} + (1 - F(T)) \times I^{PI} \tag{2.31}$$

The mean impacts per unit time, therefore, equal the mean cost in one renewal period divided by the length of the renewal period, i.e. the time to the first intervention.

$$\eta_{AC} = \frac{F(T) \times I^{CI} + (1 - F(T)) \times I^{PI}}{\int_0^T (1 - F(x))dx]} \tag{2.32}$$

2.7.2.2 Maximize availability

If it is desired to determine the age replacement IS that maximizes availability the following is often assumed, additionally that:

- the PI replacement takes t^{PI};
- the PI takes t^{CI};

If the asset fails before T then the length of the renewal period will, therefore, be $X = t + t^{CI}$, which has the probability $f(t)dt$ of occurring, and if the object does not fail before T then the length of the renewal period will be $X = t + t^{PI}$, which has the probability $1 - F(T)$ of occurring.

In this case, the expected, or mean, renewal period length is:

$$E[X] = \int_0^T (1 - F(x))dx + t^{CI}F(T) + t^{PI}(1 - F(T)) \tag{2.33}$$

As the asset is operational on average $\int_0^T (1 - F(x))dx$ then the availability is given by:

$$\eta_{AA} = \frac{\int_0^T (1 - F(x))dx}{\int_0^T (1 - F(x))dx + t^{CI}F(T) + t^{PI}(1 - F(T))} \tag{2.34}$$

Chapter 3

Data and Analysis

3.1 Fire protection and safety (FDAS) audit

3.1.1 Fire alarm and detection system

No fire alarm detection system was installed in this PS.

3.1.2 Lighting protection system

There is a lightning protection system installed for this in line booster. The strike counter has not registered a single strike. The bare copper wire connecting the lightning arrester to the ground is already dark and corroded.

a - Lightning arrester rod   b - Sticke counter   c - Bare copper wire

Figure 3.1: Protective devices.

3.1.3 Ground-Fault circuit interrupter (GFCI) or electric leakage circuit breaker (ELCB) or Residual circuit devices (RCD)

3.1.3.1 Data and analysis

No ground fault circuit interrupter (GFCI) or earth leakage Circuit breaker (ELCB) protection was installed in the panel this PS.

3.1.3.2 Recommendations

Refer to the conceptual design in Chapter 4

3.1.4 Electrical safety and protective devices

The pump room is only manned by one person. The old pump room was not maintained and not organized. Staying inside the pump room poses danger to the operator because of the open wiring and exposed live parts. There is only entrance and exit.

3.1.4.1 Data and analysis

Facts obtained from inspection are presented in Table 3.1 with indicative figures for each devices presented in Figure 3.2.

Table 3.1: Protective devices.

Item	Visual Check	Status	Remarks
1	Evacuation Plan	0	
2	Fire Extinguishers	0	Pump Station is not equipped with all of the standard safety features and equipment
3	Fire Exits	0	
4	Fire Hose Cabinet	0	
5	Fire Sprinkler System	0	
6	Emergency Exit Signages	0	
7	Emergency Lights	0	
8	PPE Cabinet	0	

3.2 Visual inspection on electrical assets

Results of the visual inspection are reflected in the database that describes also the Asset Registry. Highlights of the outcome for this station are shown in Table 3.3 with visual images shown in Figure 3.3.

3.3 Short circuit calculations and evaluation

3.3.1 Short circuit calculation

Short circuit calculation (SCC) has been done using the software ETAP version 16.2 under following considerations:

- **Available MVA Short Circuit**: Utility supplying normal power to the PS via a 34.5 KV line is MERALCO. The maximum projected fault is to be requested by the owner from the utility. In the calculation, 500MVA available short circuit was used;
- **Transformer**: The SCC was based on a 3 x 50kVA transformer feeding the transfer switch going to the motors. Transformer impedance used in the calculation is per standard impedance in the absence of data;
- **GENSET**:
  - Emergency power will be supplied by 1 Genset, rated at 110 kVA feeding the transfer switch;
  - The result of the short circuit value of the generator sets is slightly lower than the short circuit fault value produced on the bus during normal power mode. Subtransient value of the generator should be provided for a more accurate calculation.
- **Length of wires and cables**: Actual measured length of wires and cables.

Table 3.2: Protective devices.

Item	Description	Status	Findings During Inspection	Remarks
1	Rusty Hinge On Door	0	-Broken Hinge Of The Door	-Unsafe -Door Will Not Be Aligned And Hard To Close - Small Animals May Get Inside
2	Unmaintained Door	0	-Rusty Door Opening - Room Not Secure -Evidence Of Not Observing Cleanliness	-Unsafe -Operator Is Staying Inside The Room -Unclean Environment
3	Ladder	0	- Unprotected Ladder Going To Reservoir -Tree Leaves Blocking The Ladder	-Unsafe -People Climbing Should Be Protected By Cage When Climbing -Leaves Can Retain Water Adding To Slippage
4	Outdoor Stairs	0	- No Hand Rail	-Unsafe -Possible Slipping Of Operator When Going Up The Steps Specially After Rain Pour Or When There Is Drizzle
5	Water Inside Struture	0	- Water Ponding Inside The Structure	-Unsafe -Water Can Be Breeding For Mosquitos If Not Drained
6	Defective Lighting Fixture	0	-Lighting Fixture Is Without Bulb (Not Functioning)	-Unsafe - Can Be A Source Of Fire When Ignited And Not Stored Properly. -Room Where The Operator Stays Is Not Well Lit During The Night
7	Old Structure	0	- Room Was Disorganized With A Lot Of Materials And Devices Stored Inside The Room Where The Operator Stays.	-Unsafe - Can Be A Source Of Fire When Ignited And Not Sored Properly.
8	Hanging Wires	0	- Wires From The Room Were Not Harnessed Or Inside Conduit	-Unsafe - Exposed Wires Still With Power And Can Be A Source Of Fire Hazard.
9	Hanging Wires	0	- Wires From The Room Were Not Harnessed Or Inside Conduit. -Visible Deterioration Of Wires	-Unsafe - Exposed Wires Are Still With Power And Can Be A Source Of Fire Hazard.
10	Hanging Wires	0	- Wires From The Room Were Not Harnessed Or Inside Conduit -Visible Deterioration Of Wire Insulation	-Unsafe - Still With Power And Can Be A Source Electrocution And Of Fire Hazard.

Calculation has been done for both One Phase and Three Phase of short circuit current. Results of the calculations are summarized in Table 3.4. Figure 3.4 and Figure 3.5 represent the graphical representation of Nodes and Links as well as associated values.

The values of SCC shown in the table indicates the followings:

- the values of the FAULT observed to be lower than the values of the protective devices. This infers that the existing protective devices are capable to protect the assets.

3.3.2 Evaluation of protective devices and bus bars

It can be interpreted from the results of the SCC that

- the protective devices and bus bars are still provided adequate level of services and performed per applied standards;

(a - Rusted hinge door)

(b - Broken door)

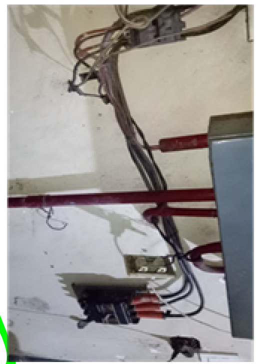
(c- Unprotected ladder)

(d - Stair with handrail)

(e - Water ponding)

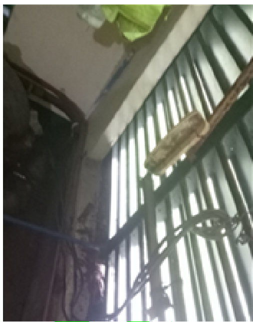
(f - Defective lighting)

(g - Disorganized room)



(h - Hanging wire 01)

(i -Hanging wire 02)



(j -Hanging wire 02)

Figure 3.2: Electrical safety

- there is no undersized electrical components.

3.4 Voltage drop calculation

Voltage drop calculation (VDC) has been conducted in compliance with the code (PEC 2017 ARTICLE 2.15.1.2(A)(1)(b)FPN NO.2) which states the following

- Conductors for feeders, as defined in Article1.1, sized to prevent a voltage drop exceeding 3% at the farthest outlet of power, heating and lighting loads, or combinations of such loads, and where the maximum total voltage drop on both feeders and branch circuits to the farthest outlet does not exceed 5% , will provide reasonable efficiency.

Results of the VDC is presented in Table 3.5

It can be interpreted from the values of the calculation that the VDC is within the limits defined in the applied standard.

Table 3.3: Highlights of visual inspection - Electrical assets

Item	Categories	Asset name	Model	Branch	Status	CS	Remarks
1	Main switch/Switch board				0		
2	Distribution transformer	150 Kva Transformer (Utility Supply))			1	1	
3	Maynilad owned Load Break Switch (LBS)				0		
4	Power cables				1	1	Not visually observed
5	MCC	Moulded Case Circuit Breakers	Bw400Eag, Bw125Jag	Fuji,		1	
	MCC	Uninterruptible Power Supply					
	MCC	Variable Frequency Drive	Vlt Aqua Drive	Danfoss			
	MCC	Miniature Circuit Breakers		Fuji, Schneider			
	MCC	Magnetic Contactors	Sc-N2S				
6	Capacitor bank				0		
7	TVSS	Surge Protection Device		Protec	1	1	
8	Power meter	Kilowatthour Meter	V-62S	Canadian General Elect.	1	1	
9	Filter and Reactors	Harmonic Filter, 70Amps	Vlt	Danfoss	1	1	
10	Instrument Transformer	Current Transformers			1	1	
11	Electrical Protective Relays				1	1	
12	Motors and Switches					1	
13	Transfer Switch	Manual Transfer Switch	Bw400Eag	Fuji	1	1	
14	Uninterruptible power system (UPS) and batteries						
15	Distribution panel boards and associated appurtenances						
16	Ground-fault circuit Interrupter (GFCI) or Electric leakage circuit breaker (ELCB) or Residual Circuit Devices (RCD)						
17	Emergency Generator	Silent Diesel Generator110Kva/88Kw, 220/440V, 60Hz	Hgc-80	Hexagen	1		
18	Building Service and Distribution						
		Lightning Arrester With Counter	Cdr-401	Cirprotec	1		

3.5 Load flow study

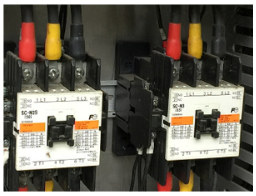
The load flow study (analysis) has been conducted per applied standard. Following Terms are important in the study, thus being extracted from the Philippines Distribution Code for ease of readers.

- **Active Power**: The time average of the instantaneous power over one period of the electrical wave, measured in watts (W) or multiples thereof. For AC circuit or Systems , it is the product of the root-mean –square (RMS) or Effective value of the voltage and the RMS value of the in-phase component of the current. In a three phase system, it is the sum of the Active Power of the individual phases;
- **Apparent Power**: The product of the root-mean –square (RMS) or Effective value of the current and root –mean –square of the voltage. For AC circuit Systems, it is the square root of the sum of the squares of the Active Power and Reactive power, measured in volt-amperes (VA) or multiples thereof;
- **Reactive Power**: The component of the electrical power representing the alternating exchange of stored energy (inductive or capacitive) between sources and loads or between two systems, measured in VAR, or multiples thereof. For AC circuits or systems, it is the product of the RMS voltage and the RMS value of the quadrature component of alternating current. In a three phase system, it is the sum of the Reactive power of the individual

(a - Circuit Breaker)

(b - Loose breaker)

(c- Filters)



(d - Magnetic contactor)

(e - Light arrester)

(f - Current Transformer)

(g - GENSET house)

(h - Mounted transformer)

(i -MTS)

(j -Panel board)

(k -Surge protection devices)

(l -Kilowatt meter)

Figure 3.3: Existing electrical assets

phases;

- **Harmonics (THD)**: Harmonics shall be defined as sinusoidal voltage and currents having frequencies that are integral multiples of the fundamental frequency.

3.5.1 Analysis based on design

The analysis has been conducted under the assumption of the Alerting Setting shown in Table 3.6. Results of the analysis are shown in the diagram (refer to Figure 3.6) with all details summarized in tabular forms (refer to the Appendix)

As can be seen from the figure, parameter values are all acceptable. However, there is an indication in pink color for VFD1, inferring that this asset might have reached the marginal setting, but not critical. It is recommended that this asset shall be closely monitored. The conclusion on this asset will be validated together with the analysis on the Power Quality which is in subsection 3.8.

Summaries on the results are also shown in Table 3.7, Table 3.8, and Table 3.9.

It is concluded from this analysis that all parameter values are within the acceptable ranges.

Table 3.4: Short circuit calculation - results

Item	Description	SCC (kA)	kAIC & CB (kA)	CS	IT	Remarks
A.	Three Phase			1	1	
1	3 X 50 Kva Transformer-Secondary	2.479	-	1	1	Protection Via Fuse Provided By Utility
2	Transfer Switch	2.418	18	1	1	Acceptable
3	Main Mccb 250A 460	2.418	18	1	1	Acceptable
				1	1	
4	Feeder Mccb-1 100A (30HP Motor)	2.391	8	1	1	Acceptable
5	Feeder Mccb-2 100A (30HP Motor) Alternate	2.391	8	1	1	Acceptable
6	Motorized Opening Valve Supply 1	2.391	8	1	1	Acceptable
7	Motorized Opening Valve Supply 2	2.391	8	1	1	Acceptable
8	Motor1 -30Hp	0.143	-	1	1	Protection Via Vfd
9	Motor2-30 Hp	-	-	1	1	Alternate
B	Single Phase					
1	MCCB 30A	2.041	2.5	1	1	Acceptable
2	Dry Type Transformer 2.5 kVA	0.411	-	1	1	Protection Via Upstream Mccb
3	MCB 32A Ups (Lump 3)	0.3964	2.5	1	1	Acceptable
4	MCB 32A Light & Conv Outlet (Lump 4)	0.394	2.5	1	1	Acceptable
5	MCB 32A For Meter (Lump 5)	0.394	2.5	1	1	Acceptable

Table 3.5: Voltage drop calculation - results

Item	From	To	Wire Size mm^2	I Ampe	L m	R Ω/305 m	X Ω/305 m	Vd	%Vd	Remarks
1	Pole Mounted Transformer 50Kva,3 Φ	Ats Panel	250	425	15.52	0.048	0.027	2.06	0.0043	Within Limits
2	MTS Panel	Ecb 250A	250	425	7	0.048	0.027	0.929	0.0019	Within Limits
3	ECB 30A, 2P	Dry Type Transformer 2.5Kva	5.5	40	4.2	1.2	0.063	1.324	0.0055	Within Limits
4	Dry Type Transformer 2.5Kva, 1Φ	UPS Panel	5.5	40	4	1.2	0.063	1.261	0.0053	Within Limits
5	MCCB 100A, 3P	30Hp Motor	30	115	10	0.2	0.057	1.357	0.0028	Within Limits
	Pole mounted to 30 HP motor							3.417	0.71	Within Limits

3.5.2 Analysis based on measured data from the PQA

Analysis has been conducted for the overall system (referherein as MAIN), for Feeder to motor with VFD1 and VDF2, respectively. The detailed reports were obtained from the analytical software (refer to Appendix) with highlights presented in Figure 3.7, Figure 3.8, and Figure 3.9.

Following conclusions can be derived from the reports

- For the overall system, the maximum loading reached about 54 (A) (Figure 3.7), which is lower than the theoretical values (63.8 A)obtained from ETAB software (Figure 3.6). This indicates that actual parameter values are within the acceptance range;
- For the VFD1, the maximum loading reached about 54 (A) (Figure 3.8), which is lower than the theoretical values (33.9 A)obtained from ETAB software (Figure 3.6). This indicates that actual parameter values are not within the acceptance range;
- For the VFD2, the maximum loading reached about 32 (A) (Figure 3.9), which is lower than the theoretical values (33.9 A) obtained from ETAB software (Figure 3.6). This indicates that actual parameter values are within the acceptance range.

From this analysis, it is recommended that continuous monitoring on VFD1 shall be implemented to ensure that the loading is not going to exceed the limit. Furthermore, continuity test on VFD shall be conducted to determine the probable issue.

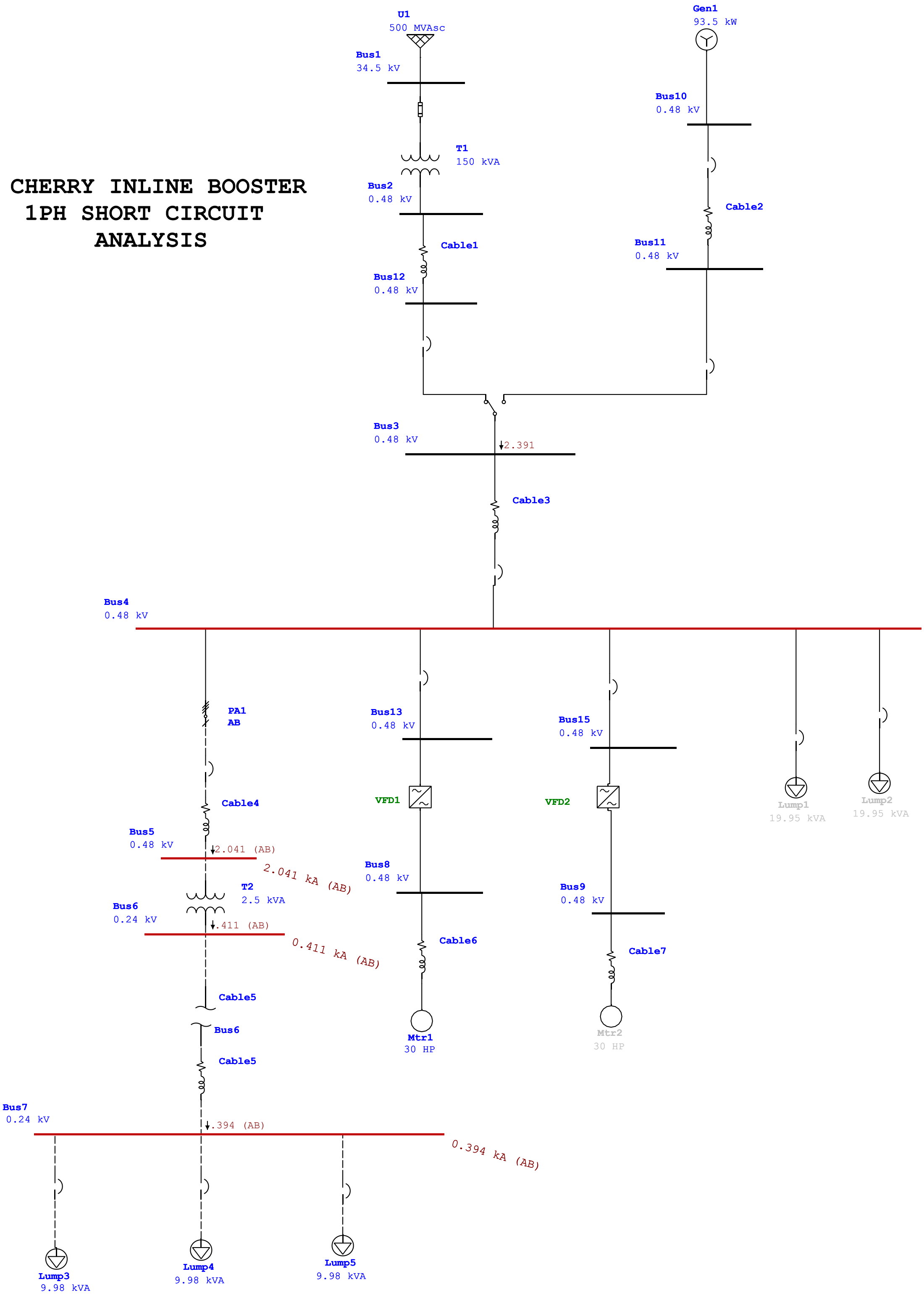


Figure 3.4: One Phase SCC

3.6 Protection coordination study

In protection coordination study, the protective devices nearest to the FAULT shall trip first and the remaining of the protective devices shall not be affected. The results were obtained from the ETAB software and shown in Table 3.10, Table 3.11, and Table 3.12.

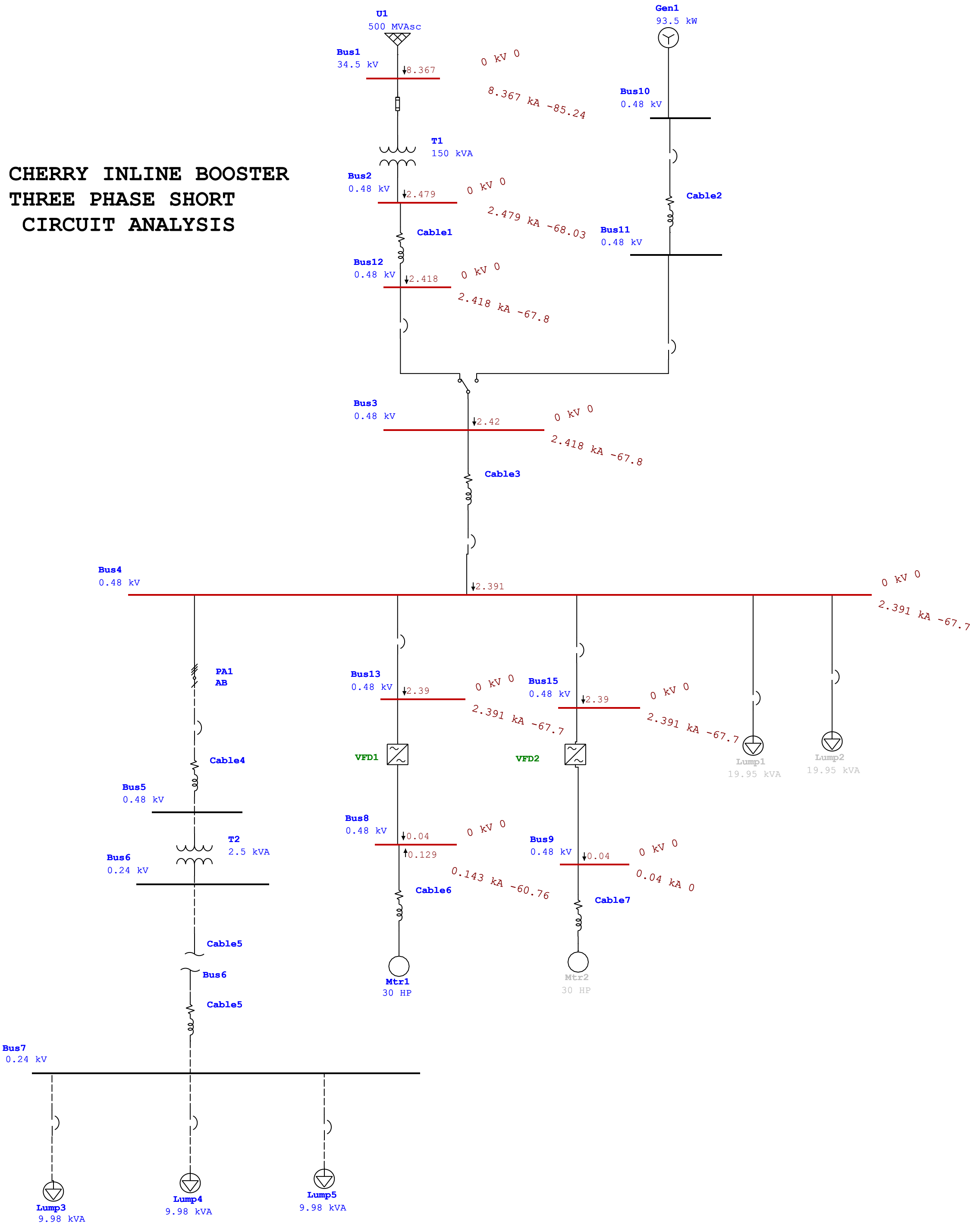


Figure 3.5: Three Phase SCC

Further illustration of the coordination is shown in Figure 3.10.

As can be seen from the tables and the figure, there is a mis-coordination at the instantaneous region. Following conclusions can be realized.

- All trip devices are fixed and can not be adjusted. Hence coordination is deemed to be partial since all branch breaker TCC curves crossed the TCC curve of Main breaker on the instantaneous region.
- No ground fault protection provided due to the type of breaker supplied. However , this is allowed under the Philippine Electrical Code;

Table 3.6: Alert setting

	% Alert Settings	
	Critical	**Marginal**
Loading		
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
Generator Excitation		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

Table 3.7: Summary of total generation, loading, and demand

	MW	Mvar	MVA	% PF
Source (Swing Buses):	0.050	0.030	0.058	86.24 Lagging
Source (Non-Swing Buses):	0.000	0.000	0.000	
Total Demand:	0.050	0.030	0.058	86.24 Lagging
Total Motor Load:	0.030	0.016	0.034	88.48 Lagging
Total Static Load:	0.019	0.012	0.023	85.00 Lagging
Total Constant I Load:	0.000	0.000	0.000	
Total Generic Load:	0.000	0.000	0.000	
Apparent Losses:	0.001	0.002		
System Mismatch:	0.000	0.000		

Number of Iterations: 2

Table 3.8: Bus loading

Bus			Directly Connected Load								Total Bus Load			
			Constant kVA		Constant Z		Constant I		Generic					Percent
ID	kV	Rated Amp	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar	MVA	% PF	Amp	Loading
Bus1	34.500										0.058	86.2	1.0	
Bus2	0.480			0.000							0.057	87.1	70.1	
Bus3	0.480										0.057	87.1	70.1	
Bus4	0.480		0.005	0.003	0.019	0.012					0.057	87.1	70.1	
Bus8	0.480		0.025	0.013							0.028	89.2	34.7	
Bus9	0.480													
Bus12	0.480										0.057	87.1	70.1	

* Indicates operating load of a bus exceeds the bus critical limit (100.0% of the Continuous Ampere rating).
\# Indicates operating load of a bus exceeds the bus marginal limit (95.0% of the Continuous Ampere rating).

Following is recommendation:

- main breaker should be of adjustable and electronic type.

3.7 Harmonic study

Harmonic study has been conducted under the following basics

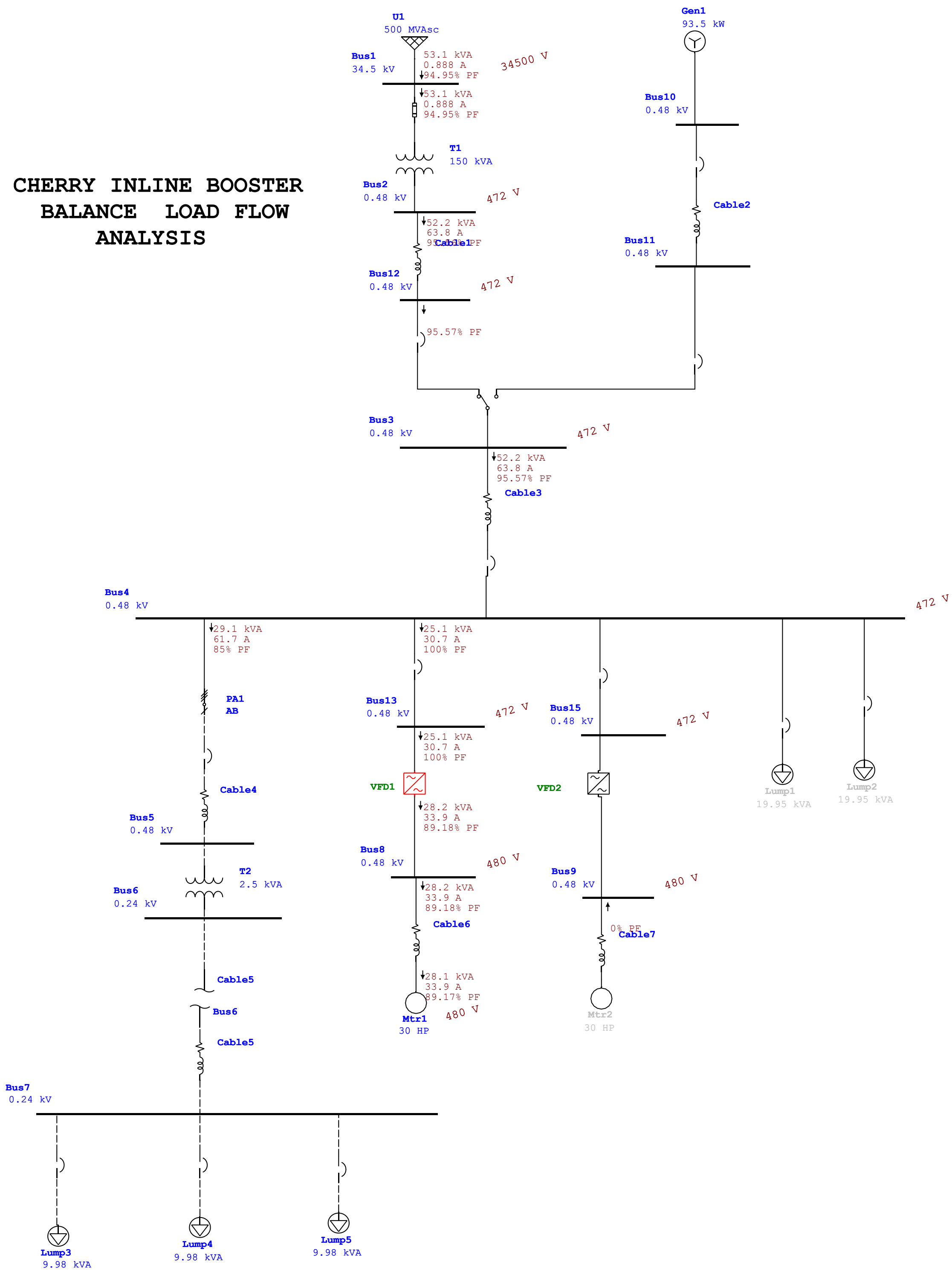


Figure 3.6: Load flow analysis

- Harmonics shall be defined as sinusoidal voltage and currents having frequencies that are integral multiples of the fundamental frequency;
- The total harmonic distortion (THD) shall be defined as the ratio of the RMS value of the harmonic content to the RMS value of the fundamental quantity, expressed in percent;
- PHILIPPINE DISTRIBUTION CODE sets the THD of the voltage at any user system to not exceed 5% during normal operating conditions.

Table 3.9: Branch loading

CKT / Branch		Cable & Reactor			Transformer				
					Capability (MVA)	Loading (input)		Loading (output)	
ID	Type	Ampacity (Amp)	Loading Amp	%		MVA	%	MVA	%
Cable1	Cable	302.68	70.10	23.16					
Cable3	Cable	302.68	70.10	23.16					
T1	Transformer				0.150	0.058	38.9	0.057	38.0

* Indicates a branch with operating load exceeding the branch capability.

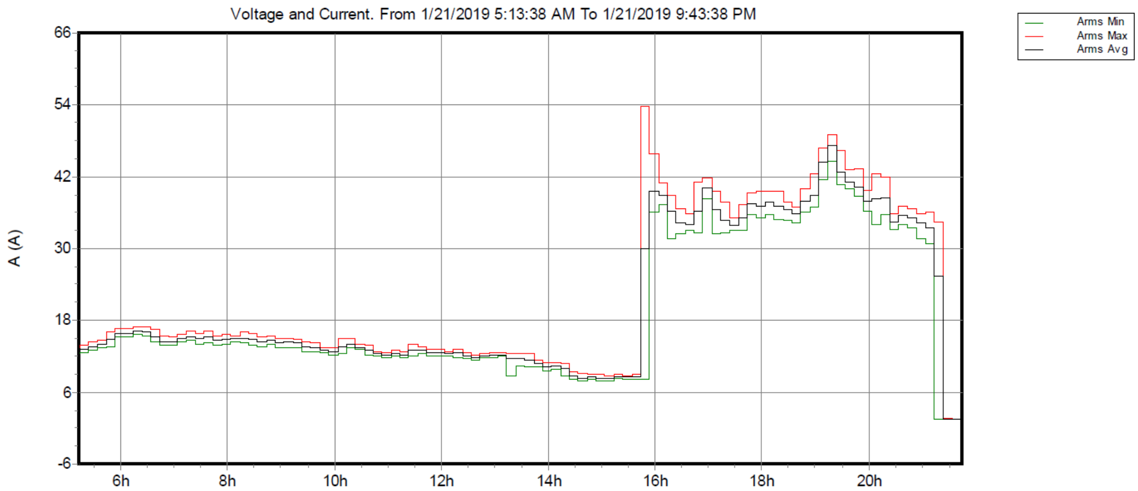


Figure 3.7: Main: 250 Amperes

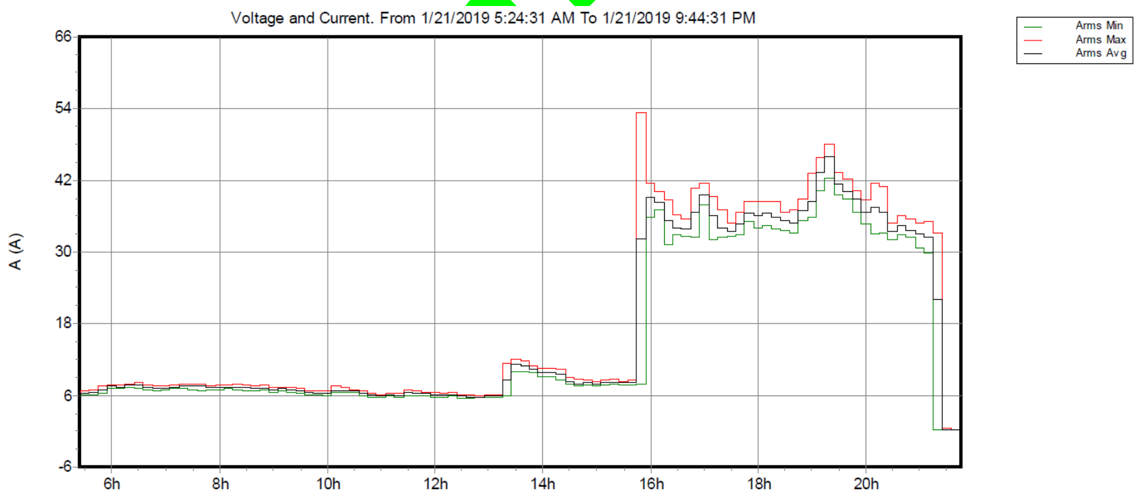


Figure 3.8: Feeder: VFD-1 for 30 HP motor

3.7.1 As per design

Results of the study as per design are shown in Figure 3.11, Figure 3.12, and Figure 3.13

It can be seen from the figures that there are a number of distortions, which are connected to bus 4. It is notable to observe that the percentage of the THD is 4.96%, which is very close to the margin of 5%.

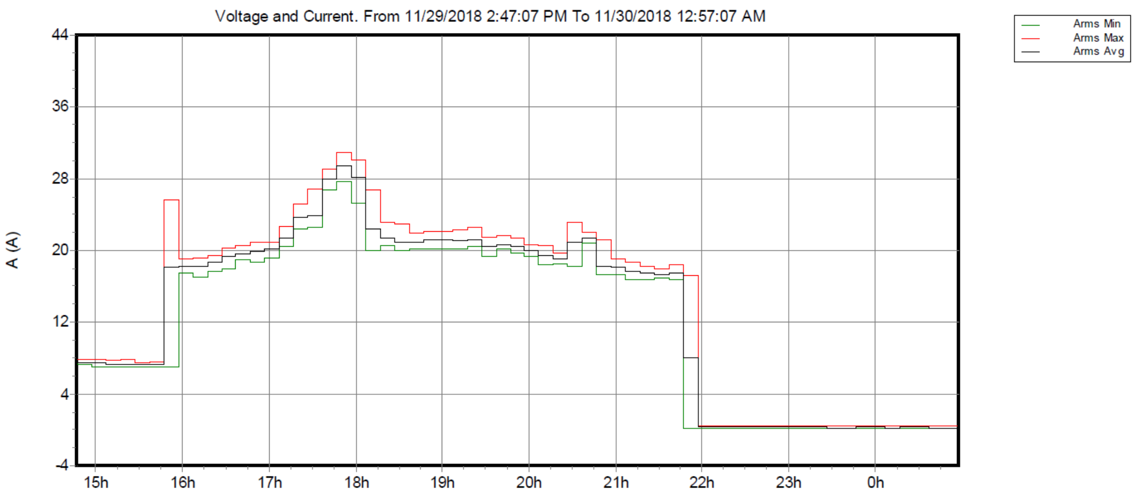


Figure 3.9: Feeder: VFD-2 for 30 HP motor

Table 3.10: Protective Device Settings - Low Voltage Circuit Breaker with Thermal-Magnetic Trip Device

LVCB ID	Manufacturer	Breaker		Thermal		Magnetic (Inst.)	
		Model	Size	Setting	Trip (Amps)	Setting	Trip (Amps)
CB4	Fuji Electric	BW400EAG	250	Fixed	250	Fixed	8 xIn
CB9	Fuji Electric	BW125JAG	100	Fixed	100	Fixed	8 xIn
CB10	Fuji Electric	BW125JAG	100	Fixed	100	Fixed	8 xIn
CB11	Fuji Electric	BW32SAG	32	Fixed	32	Fixed	8 xIn
CB12	Fuji Electric	BW32SAG	32	Fixed	32	Fixed	8 xIn
CB1	Fuji Electric	BW400EAG	250	Fixed	250	Fixed	8 xIn

Table 3.11: Cable-circuit breaker coordination

Items	Protective Device			Cable Protection				Max Fault 3Ph-Amps	Reference kV
	Location	ID	Type	Pickup Limit	Ampacity	Damage Curve	Condition		
Cable1	Load	CB1	TM-Magnetic	-	-	Pass	Trip curve protects the damage curve	2418	0.48
			TM-Thermal	Pass	Pass	Pass	Therm. Trip 250 A is within 302.7 A = Ampacity Therm. Trip 250 A is within max. limit of 302.7 A = Ampacity x 100% Trip curve protects the damage curve		
Cable3	Load	CB4	TM-Magnetic	-	-	Pass	Trip curve protects the damage curve	2391	0.48
			TM-Thermal	Pass	Pass	Pass	Therm. Trip 250 A is within 302.7 A = Ampacity Therm. Trip 250 A is within max. limit of 302.7 A = Ampacity x 100% Trip curve protects the damage curve		

3.7.2 Per actual

Results of the study based on the PQA are presented in Figures 3.14, 3.15, 3.16, 3.17, 3.18, and 3.19

Table 3.13 shows also the summary of the study, in which the min, average, and max values are presented along with the limit of 5%.

It can be interpreted from the table that values Main and VFD1 infer that there might be a

Table 3.12: MCCB coordination

Zone		Stream		Max Fault		Ref.	Coord.	Amp Range		Condition
ID	type	up PD	down PD	type	Amp	kV	status	From	To	
Bus4	Bus	CB4	CB9	3Ph	2391	0.48	Alert	2000	2000	Miscoordination, the time gap is smaller than 0.001 sec margin at I=2000 A, Plot Ref. kV=0.48
				L-G			Warning			L-G fault coordination is not possible.
			CB11	3Ph	2391	0.48	Alert	2000	2000	Miscoordination, the time gap is smaller than 0.001 sec margin at I=2000 A, Plot Ref. kV=0.48
				L-G			Warning			L-G fault coordination is not possible.
			CB12	3Ph	2391	0.48	Alert	2000	2000	Miscoordination, the time gap is smaller than 0.001 sec margin at I=2000 A, Plot Ref. kV=0.48
				L-G			Warning			L-G fault coordination is not possible.
			CB10	3Ph	2391	0.48	Alert	2000	2000	Miscoordination, the time gap is smaller than 0.001 sec margin at I=2000 A, Plot Ref. kV=0.48
				L-G			Warning			L-G fault coordination is not possible.

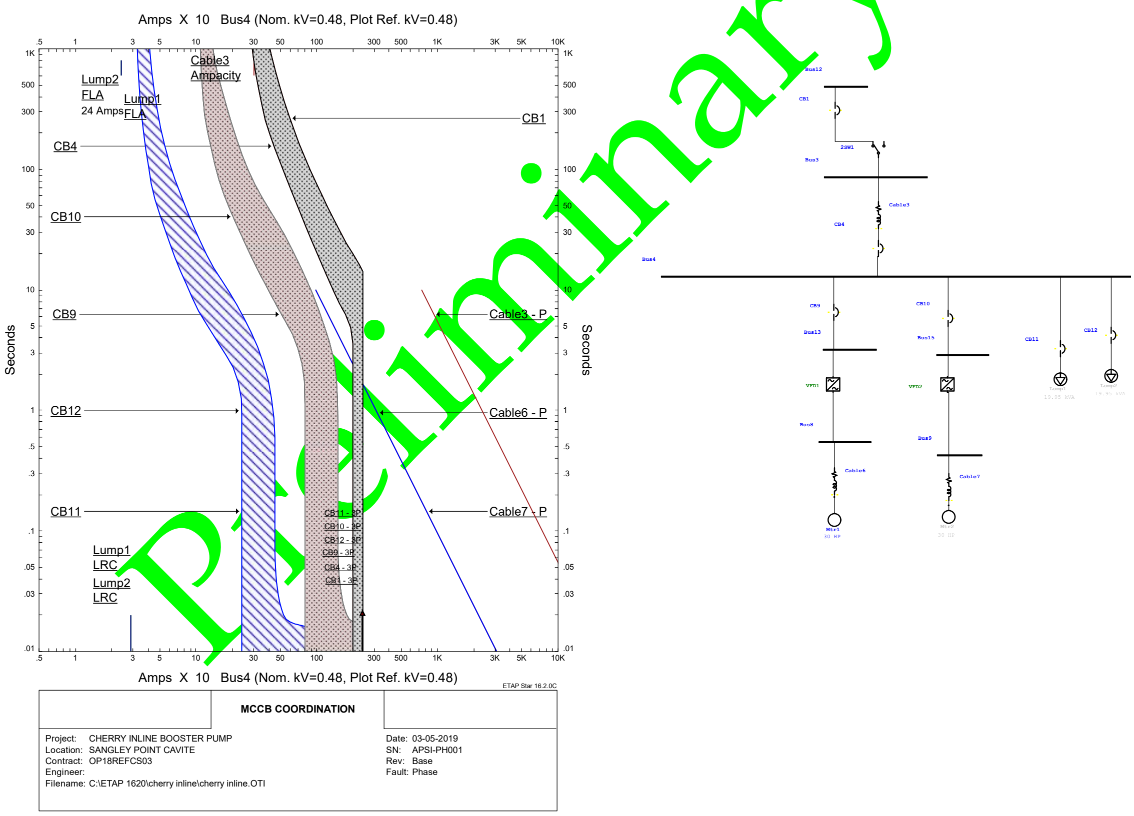


Figure 3.10: Coordination plot

concern, particularly for the harmonic orders of 3rd, 5th, and 7th being dominant registers. This might cause heating on the equipment.

Recommendation shall be realized together with the recommendation from the study of Power Quality Analysis (refer to subsection 3.8)

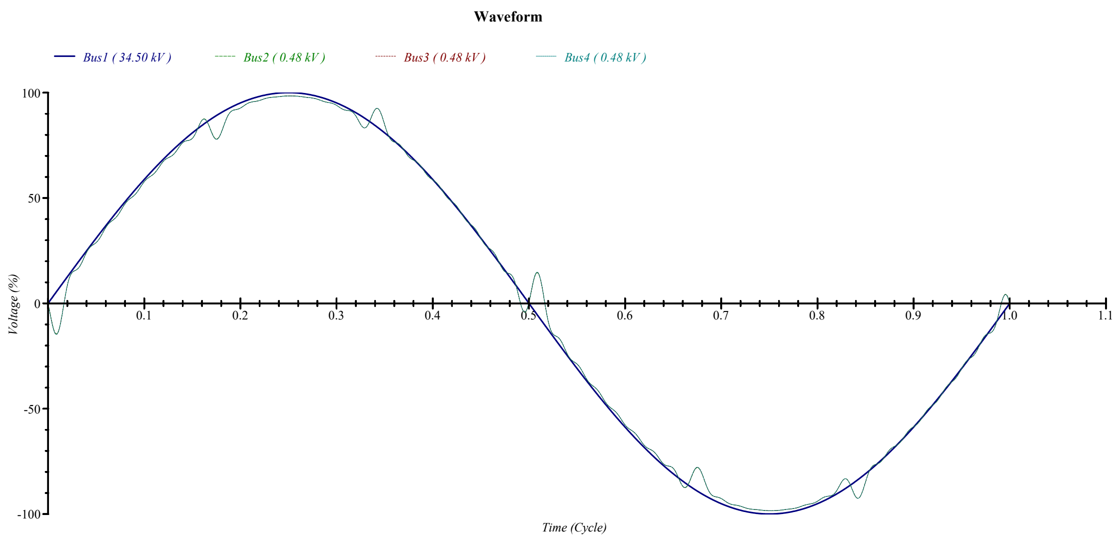


Figure 3.11: Bus wave form

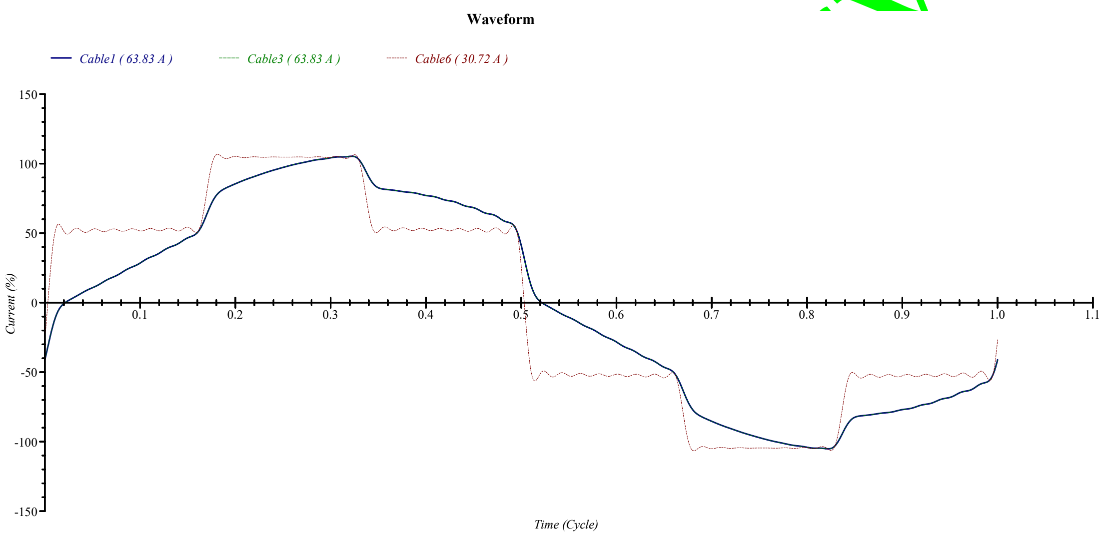


Figure 3.12: Cable waveform

Table 3.13: Harmonic study

Total Harmonic Distortion (%)	Phase	Minimum	Average	Maximum	Limits (5%)	Remarks
Main 250A (Load side)	AB	1.44	3.36	3.90		
	BC	1.27	2.56	2.86	5	Within Limits
	CA	1.53	3.36	3.90		
VFD-1	AB	3.22	3.36	3.90		
	BC	2.89	3.01	3.37	5	Within Limits
	CA	3.22	3.36	3.90		
VFD-2	AB	2.11	2.20	2.68		
	BC	1.63	1.68	1.97	5	Within Limits
	CA	2.11	2.20	2.68		

3.8 Power quality analysis

The Power Quality Analysis (TQA) has been conducted on the Main system, VFD1, and VFD2 of this PS. The Power Quality Analyzer used is FLUKE 430-II. Figure 3.20 shows the analyzer

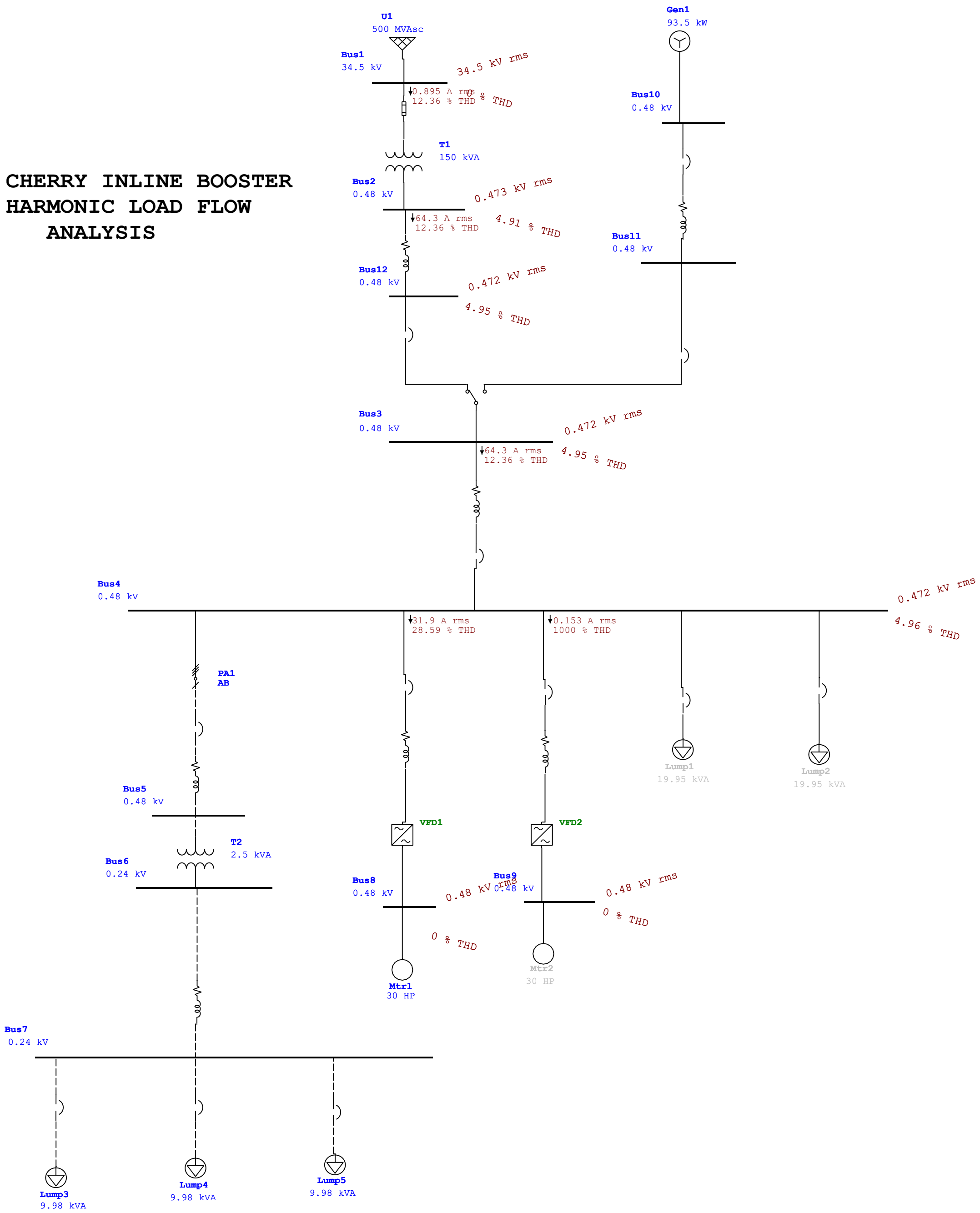


Figure 3.13: Load flow

during the course of measurement for the station.

3.8.1 Objectives and expected outcomes

The preliminary objectives and expected outcomes from this analysis are

- Record the voltage and current profile on the load side of Circuit Breaker with the recording interval set every five (10) minutes;
- Record power profile (KW, KVA, KVAR) on the load side of Circuit Breaker with the recording interval set every ten (10) minutes.
- Record Total Harmonic Distortion (THD);

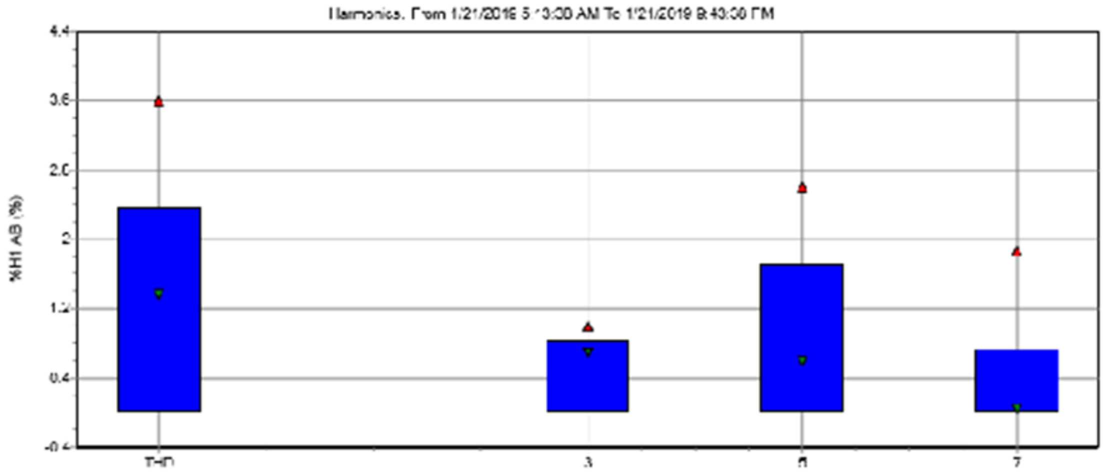


Figure 3.14: Voltage harmonic - AB

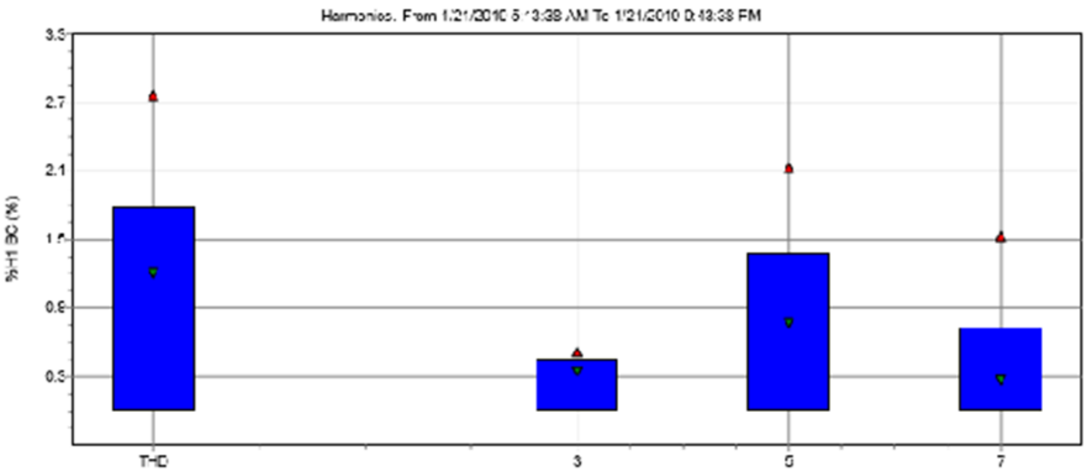


Figure 3.15: Voltage harmonic - BC

- Record Values of Short Duration Voltage Variation that will exceed the limit set by Philippine Distribution code;
- Record values of Long Duration Voltage Variation that will exceed the limit set by the Philippine Distribution Code;
- Record values of Frequency Variation that will exceed the limit set by Philippine Distribution code;
- Record Transient voltage Surge defined by PDC and using Computer Business Equipment Manufacturer's Association(CBEMA) and Information Technology Industry Council (ITIC) Curve International Standard;
- Compute for Voltage Unbalance and compare it on the Voltage unbalance limit set by PDC;
- Recommendations.

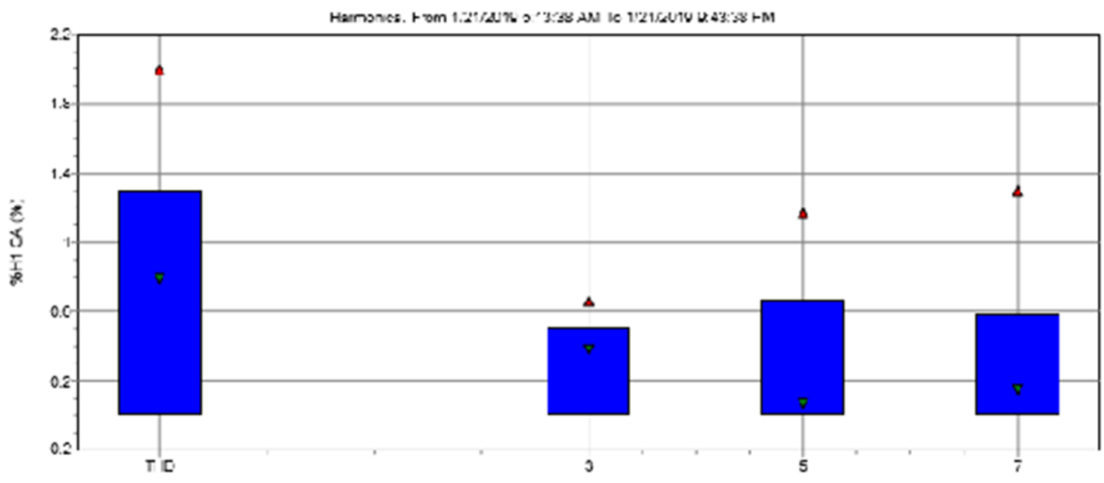


Figure 3.16: Voltage harmonic - CA

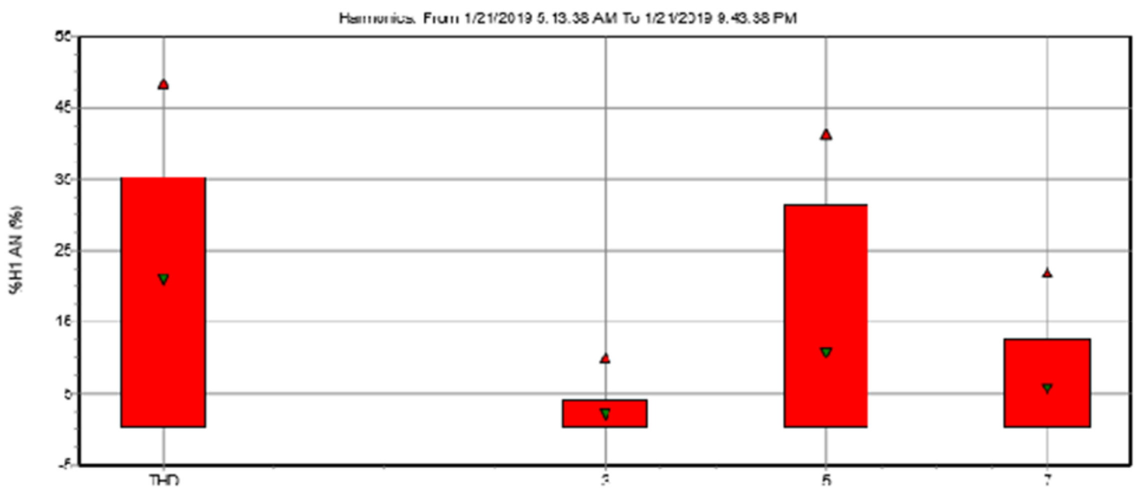


Figure 3.17: Current harmonic -AB

3.8.2 Basic

The assessments made in this report are in accordance to IEEE Standard 1159-1995 "IEEE Recommended Practice for Monitoring Electric Power Quality".

The Philippine Distribution Code was used as the local reference for power quality standards. According to the Philippine Distribution Code, a power quality problem exists when at least one of the categories in the tables of following sections is present during the normal operation of the electrical system

3.8.3 Results

Any values outside these limits are noted in the report. Values within the limits are considered to be within safe operating range.

3.8.3.1 RMS Voltage compliance

The steady-state rms voltage must remain within the range of 90.00% to 110.00%.

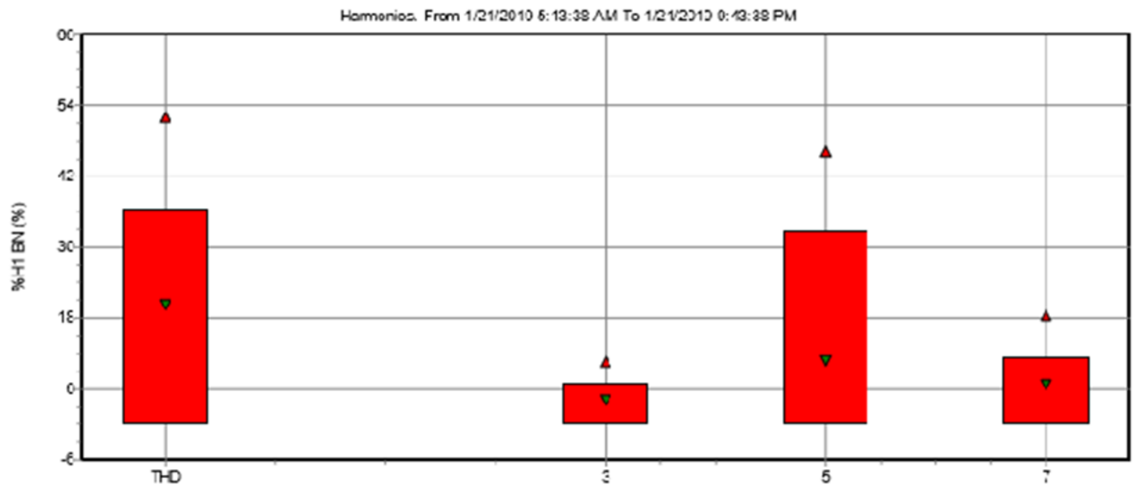


Figure 3.18: Current harmonic -BC

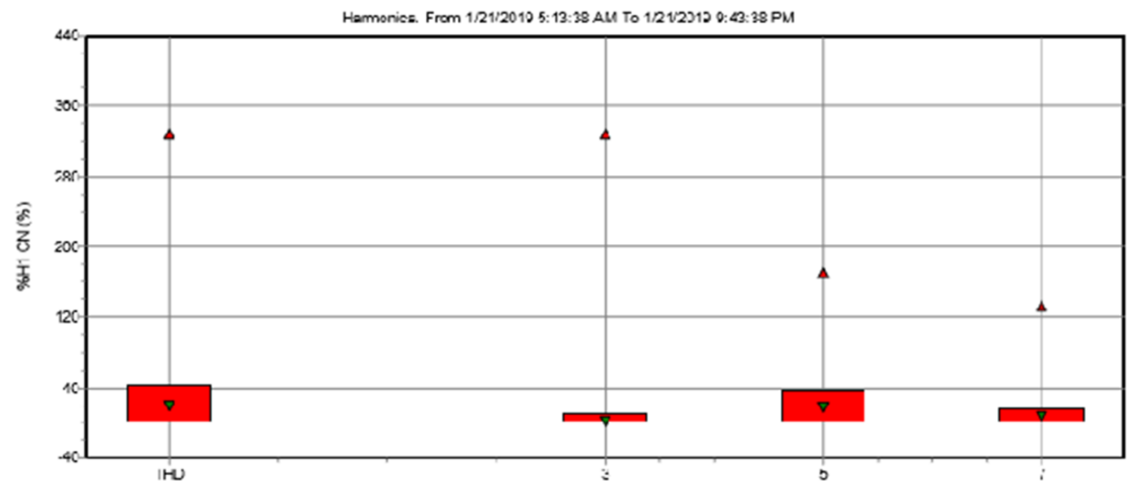


Figure 3.19: Current harmonic -CA

- Over Voltage – if the RMS value of the voltage is greater than or equal to 110% of the nominal value
- Under Voltage – if the RMS value of the voltage is less than or equal to 90% of the nominal voltage

Results are shown in Table 3.14.

3.8.3.2 Voltage unbalance compliance

Voltage Unbalance shall be defined as the maximum deviation from the average of the three phase voltages divided by the average of the three phase voltages expressed in percent. The maximum voltage unbalance at the connection point of any user, excluding the voltage unbalance passed on from the grid shall not exceed 2.5% during normal operating conditions.

Results are shown in Table 3.15.

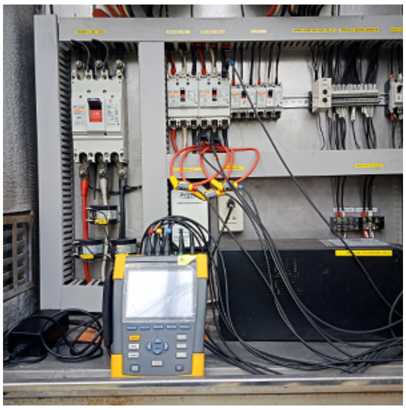


Figure 3.20: Power quality analyzer plugging during measurement

Table 3.14: Power quality - RMS Voltage compliance

RMS VOLTAGE (460 VOLTS)	Phase	Minimum	Average	Maximum	Limits	Remarks
Main 250A (Load side)	AB	449.94	465.3	474.84		
	BC	457.72	471.4	477.32	±10% (414-506V)	Within Limits
	CA	449.94	465.3	474.84		
VFD-1	AB	449.68	460.18	474.76		
	BC	387.66*	408.04	468.34	±10% (414-506V)	Outside Limits
	CA	449.68	460.18	474.76		
VFD-2	AB	455.48	466.18	474.70		
	BC	463.28	470.61	477.76	±10% (414-506V)	Within Limits
	CA	455.48	466.18	474.70		

* Should be cause for concern. Value reached voltage limitation. The incident was recorded on 1/21/2019, 8:214:31PM

Table 3.15: Power quality -Voltage unbalance

Voltage unbalance	Phase	Minimum	Average	Maximum	Limits (%)	Remarks
Main 250A (Load side)		1.15	0.87	0.35	2.5	Within Limits
VFD-1		9.64	7.85	0.91	2.5	Outside limits
VFD-2		1.14	0.63	0.43	2.5	Within Limits

3.8.3.3 Current unbalance compliance

Results are shown in Table 3.16 with note that the current unbalance should not exceed 10%.

Table 3.16: Power quality -Current unbalance

Current unbalance	Phase	Minimum	Average	Maximum	Limits (%)	Remarks
Main 250A (Load side)	AB	0.30	0.70	2.30		
	BC	0.40	0.70	0.80	$\leq$ 10%	Within Limits
	CA	0.10	0.50	1.50		
	Overall	1.15	1.20	2.68		
VFD-1	AB	1.33	1.60	2.57		
	BC	-0.27	-0.70	-0.73	$\leq$ 10%	Outside Limits
	CA	-1.07	-0.90	-1.83		
	Overall	3.40	3.88	4.60		
VFD-2	AB	0.50	-0.23	0.90		
	BC	-0.20	-0.23	-0.30	$\leq$ 10%	Within Limits
	CA	-0.30	-0.33	-0.60		
	Overall	2.18	1.36	2.83		

3.8.3.4 Harmonic - THD compliance

Results are shown in Table 3.17 with the following notes:

- Harmonics shall be defined as sinusoidal voltage and currents having frequencies that are integral multiples of the fundamental frequency;
- The total harmonic distortion (THD) shall be defined as the ratio of the RMS value of the harmonic content to the RMS value of the fundamental quantity, expressed in percent;
- PHILIPPINE DISTRIBUTION CODE sets the THD of the voltage at any user system to not exceed five percent (5%) during normal operating conditions.

Table 3.17: Power quality -Harmonic THD compliance

THD compliance	Phase	Minimum	Average	Maximum	Limits (%)	Remarks
Main 250A (Load side)	AB	1.44	3.36	3.90		
	BC	1.27	2.56	2.86	$\leq$ 5%	Within Limits
	CA	1.53	3.36	3.90		*
VFD-1	AB	3.22	3.36	3.90		
	BC	2.89	3.01	3.37	$\leq$ 5%	Within Limits
	CA	3.22	3.36	3.90		*
VFD-2	AB	2.11	2.20	2.68		
	BC	1.63	1.68	1.97	$\leq$ 5%	Within Limits
	CA	2.11	2.20	2.68		*

* Probable problem as the harmonic at 3rd, 5th, and 7th orders were register dominent.
This might cause heating on equipment

3.8.3.5 Harmonic - TDD compliance

Results are shown in Table 3.18 with the following notes:

- The Total Demand Distortion (TDD) shall be defined as the ratio of the RMS value of the harmonic content to the RMS value of the rated or maximum fundamental quantity, expressed in percent;
- PHILIPPINE DISTRIBUTION CODE sets the TDD of the current at any user of the system to not exceed five percent (5%) during normal operating conditions.

It is important to note that the values obtained for the THD (refer to previous sections) might declare the parameter values within the limits. However, the overall conclusion shall be derived together with the TDD compliance as the values of the TDD coming from the asset while the THD values coming normally from the sources.

Table 3.18: Power quality -Harmonic TDD compliance

TDD compliance	Phase	Minimum	Average	Maximum	Limits (%)	Remarks
Main 250A (Load side)	AB	4.98	15.38	39.19		
	BC	5.24	15.77	41.65	$\leq$ 5%	Outside limits
	CA	4.94	15.38	194.09		
VFD-1	AB	2.42	15.14	45.33		
	BC	2.51	15.65	46.45	$\leq$ 5%	Outside limits
	CA	2.30	15.12	193.54		
VFD-2	AB	17.88	19.76	46.72		
	BC	18.62	20.69	45.28	$\leq$ 5%	Outside limits
	CA	18.36	20.59	73.81		

In this situation, results of TDD are significant higher than the limit of 5%, indicating a certain degree of probability that there is an existing issue.

3.8.3.6 100% Power frequency (HZ) compliance

Results are shown in Table 3.19 with the following notes:

- A nominal fundamental frequency of 60HZ, PHILIPPINE DISTRIBUTION COCE set an acceptable limit of 59.7 HZ. for low frequency and 60.3 hz for high frequency.

Table 3.19: Power quality -Harmonic TDD compliance

Frequency	Phase	Minimum HZ	Average HZ	Maximum HZ	Limits HZ	Remarks
Main 250A (Load side)		59.71	60.07	60.30	59.7-60.3	Within Limits
VFD-1		59.71	60.10	60.30	59.7-60.3	Within Limits
VFD-2		59.68	60.06	60.30	59.7-60.3	Within Limits

3.8.3.7 Power factor

Results are shown in Table 3.20 with the following notes:

- The ideal situation is a cos phi or DPF equal or close to 1. Utilities may charge additional cost (penalty when var readings are high because they need to provide apparent power (VA, kVA) that does not include both var and W).

Table 3.20: Power quality -powerfactor

Power factor	Phase	Minimum	Average	Maximum	Limits	Remarks
Main 250A (Load side)		0.86	0.92	0.93	>0.85	Within Limits
VFD-1		0.75	0.89	0.90	>0.85	Outside limits
VFD-2		0.21	0.92	0.92	>0.85	Outside limits

3.8.3.8 Flicker

Results are shown in Table 3.21 with the following notes:

- A measuring period of 2 hours (Plt) is useful when there may be more than one interference source with irregular working cycles and for equipment such as welding machines. Plt $\leq$ 1.0 is the limit used in standards like EN15160;
- The 10 min (Pst) uses a longer measuring period to eliminate the influence of random voltage variations.

Table 3.21: Power quality -powerfactor

Flicker	Parameter	Minimum	Average	Maximum	Limits	Remarks
Main 250A (Load side)	Plt	0.194	0.192	0.183	<=0.80	Within Limits
	Pst	0.262	0.261	0.237	<=1.0	Within Limits
VFD-1	Plt	0.257	0.711	1.829	<=0.80	Outside limits
	Pst	0.365	1.62	4.186	<=1.0	Outside limits
VFD-2	Plt	0.202	0.185	0.195	<=0.80	Within Limits
	Pst	0.239	0.234	0.325	<=1.0	Within Limits

3.8.4 Conclusion and Recommendations

- In general the most efficient way to troubleshoot electrical systems, is to begin at the load and work towards the building's service entrance. Measurements are taken along the way to isolate faulty components or loads;
- Monitoring up to a period of one week is recommended to perform a quality check That allows you to obtain a good impression of power quality;

- According to IEEE 519. "Most motor loads are relatively tolerant of harmonics". However, IEEE 519-1992 states further that, "Even in the case of the least susceptible equipment, harmonics can be harmful. Harmonics, can cause dielectric thermal or voltage stress, which causes premature aging of electrical insulation. A major effect of harmonic voltages and currents in rotating machinery (induction and synchronous) is increased heating due to iron and copper losses at the harmonic frequencies. The harmonic components thus affect the machine efficiency, and can also affect the torque developed";
- In the case of this station, the total demand distortion is outside the limits set in the Philippine Distribution Code. From the application perspective, we're most concerned with the maximum harmonic current levels, and the impact they have on the distribution system. This makes TDD a much more useful metric for power inverter distortion;
- Voltage unbalance causes high unbalanced currents in stator windings resulting in overheating and reduced motor life. As in the case of VFD1, voltage deviation which is outside limit were recorded. Check cause of voltage unbalance which is often caused by current unbalance;
- Crest Factor – A high crest factor value for current was recorded to signify a distorted current waveform. A CF of 1.8 or higher means high waveform distortion. This can be attributed on the current drawn by the rectifier;

Main	VOLTAGE		CURRENT	
Phase	MIN	MAX	MIN	MAX
A	1.41	1.44	1.42	3.27
B	1.41	1.43	1.39	2.87
C	1.41	1.43	1.4	7.22

- Since a filter is already in place (73A VLT, Advance Harmonic Filter AHF005) when the measurements were taken and current harmonics is still high, consider a one week monitoring to validate the values. A second filter may be considered to properly address the 3rd, 5th and 7th harmonics. An active filter (cancellation of all harmonics) can be considered altogether.

3.9 Grounding system study

The study has been conducted in accordance with the ITP. Some of representative pictures during measurement are shown in Figure 3.21.

Results of the study are shown in Table 3.22 with the following note:

- The resistance between the main grounding electrode and ground should be no greater than five ohms for large commercial or industrial systems and 1.0 ohm or less for generating or transmission station grounds unless otherwise specified by the owner. (Reference ANSI/IEEE Standard 142)

3.10 Electrical system design and analysis

3.10.1 Basics

In accordance with Article 1.3 Electrical Plans and specifications of the Philippine Electrical Code 2017 Edition, Electrical design analysis shall be included and submitted separately together with the electrical plans. These includes the followings:

1. Branch circuits, sub-feeders, feeders, busways, and service entrance;
2. Types, ratings, and trip settings of overload protective device;
3. Calculation of voltage drops;

(a - Voltage -LA post)

(b - Bare copper wire)

(c - Ground resistance measure)

(d - Voltage measure - MTS)

(e - Ground pod connection)

(f - Voltage on BCW)

(g - Voltage on rod)

Figure 3.21: Grounding system measurement

4. Calculation of short circuit current for determining the interrupting capacity of overcurrent protective device for residential, commercial and industrial establishment;
5. Protection coordination of overcurrent protective devices;
6. ARC-flash Hazard Analysis to determine the required personal protective equipment (PPE).

ARC flash Hazard Analysis is required and is intended for concerned parties to be informed and made aware of the importance of personal protective equipment (PPE) and its type for the

Table 3.22: Ground system measurement results

Locations	Asset/Room	Resistance	Findings	Recommendations	Effects	Risks
Lightning Arrester Post	Test Point 1 Bare Copper Wire	1.24 Ω	Within The 5 Ω Limit As Per Nfpa And Ieee Standards	(1)Check Tightness Of Connection Of Bcw To Ground Rod (2) Grounding System Electrical And Mechanical Connections Should Be Free Of Corrosion. (3) Replace Bcw For Better Conductivity.	None	None
Mts Equipment Ground	Test Point 2 Bare Copper Wire	7.2 V	Measured Voltage In The Bare Copper Wire	Check And Trace Where The Voltage Is Coming From And Correct The Connection	Danger To Personnel And Damage To Equipment If Not Immediately Corrected	Health And Safety Risks For Facilities And Personnel And Damage To Equipment Or Accessories
Mts Equipment Ground	Test Point 2 Ground Rod	8.2 V	Same As Mts Equipment	Same As Mts Equipment	Same As Mts Equipment	Same As Mts Equipment
Genset	Test Point 3 Bare Copper Wire	NA	Connected To Grounding Busbar Of Mts	Same As Mts Equipment	(1) Unwanted Voltage Maybe Present On Non-Current Carrying Metal Objects (2) Equipment Might Be Damaged During A Fault Condition	(1) Incorrect Operation Of Overcurrent Device With Ground Fault Protection (2) Health And Safety Risks For Facilities And Personnel

flash hazard risk category determined by the analysis (refer to Table 3.23).

Table 3.23: ARC flash hazard risk categories and PPE ratings (Appendix H, PEC 2017)

Risk CAT.	Range of calculated incident energy [cal/cm^2]	Minimum Ppe Rating [Cal/Cm^2]	Clothing Required
0	0 < E ≤1.2	N/A	4.5-14.0 Oz/Yd2Untreated Cotton
1	1.2 < E ≤ 4	4	Flame Retardant (Fr) Shirt And Pants
2	4 < E ≤ 8	8	Cotton Underclothing Plus Fr Shirt And Pants
3	8 < E ≤ 25	25	Cotton Underclothing Plus Fr Shirt, Pants, Overalls Or Equivalent
4	25 < E ≤40	40	Cotton Underclothing Plus Fr Shirt, Pants, Plus Double Layer Switching Coat And Pants Or Equivalent
5	40 < E ≤ 100	100	Cotton Underclothing Plus Fr Shirt, Pants, Plus Multi-Layer Switching Suit Or Equivalent

3.10.2 Results

Results are briefly presented in the following subsections. Details reports generated by the software are enclosed as part of the Appendix of this report (can also be an electronic files)

3.10.2.1 Branch circuits, sub-feeders, feeders and service entrance

Figure 3.22 shows the SLD with values associated with each nodes and links.

3.10.2.2 Types, ratings, and trip settings of overload protective device

Types, ratings, and trip settings of overload protective devices are shown in Table 3.24

3.10.2.3 Calculation of voltage drops

3.10.2.4 Calculation of short circuit current 3-PHASE & 1-PHASE

Table 3.26 and Table 3.27 show summaries of results on short circuit and monentary duty, respectively.

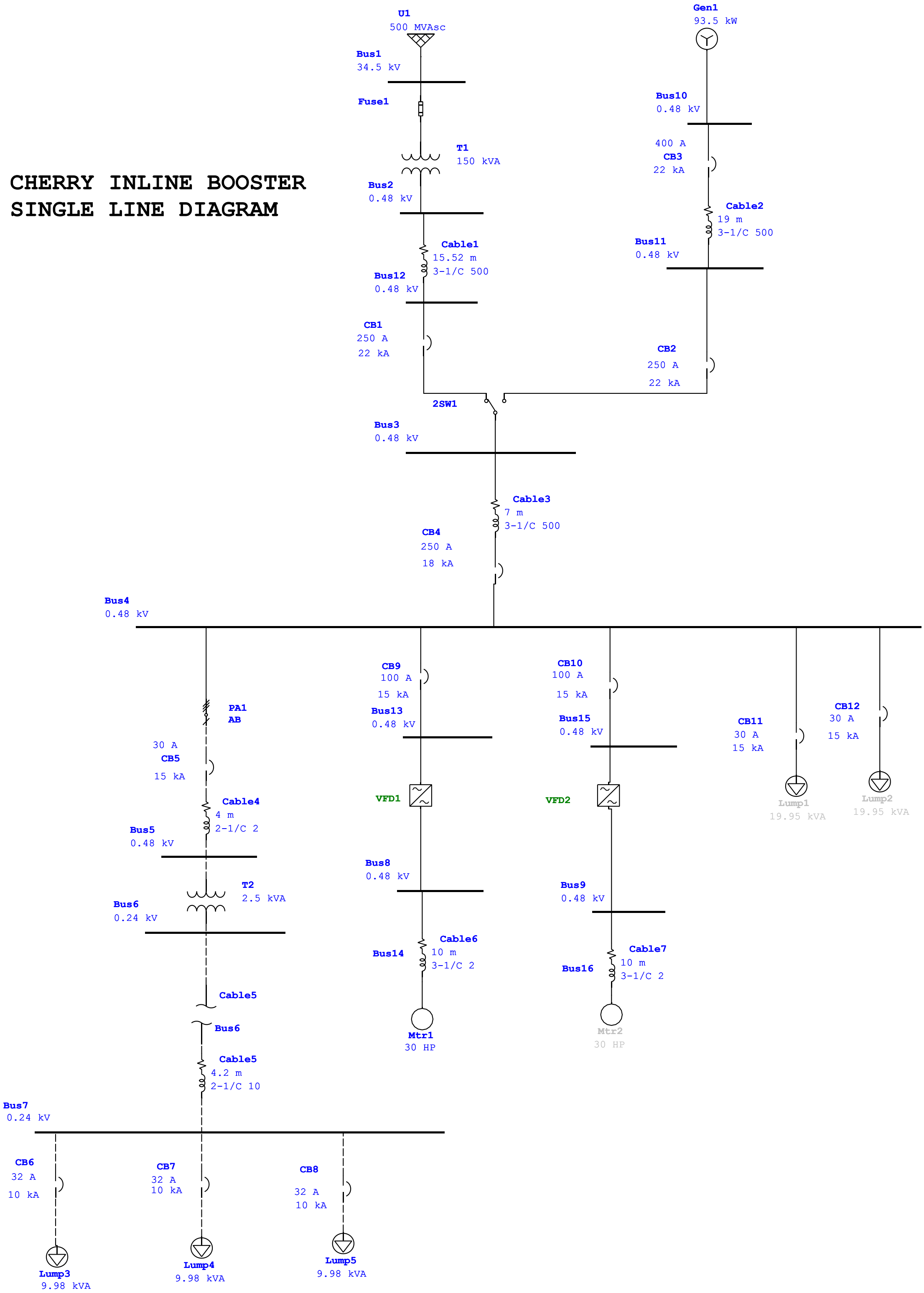


Figure 3.22: Single line diagram

3.10.2.5 Protection coordination of overcurrent protective devices

Results of study on protection coordination are presented in subsection 3.6. With reference to the coordination plot shown in Figure 3.10, it is remarked that partial coordination only for the main and feeder breakers. TCC of feeders crosses the TCC of enclosed circuit breaker upstream of the feeders.

Table 3.24: Protective Device Settings - Low Voltage Circuit Breaker with Thermal-Magnetic Trip Device

LVCB ID	Manufacturer	Breaker		Thermal		Magnetic (Inst.)	
		Model	Size	Setting	Trip (Amps)	Setting	Trip (Amps)
CB4	Fuji Electric	BW400EAG	250	Fixed	250	Fixed	8 xIn
CB9	Fuji Electric	BW125JAG	100	Fixed	100	Fixed	8 xIn
CB10	Fuji Electric	BW125JAG	100	Fixed	100	Fixed	8 xIn
CB11	Fuji Electric	BW32SAG	32	Fixed	32	Fixed	8 xIn
CB12	Fuji Electric	BW32SAG	32	Fixed	32	Fixed	8 xIn
CB1	Fuji Electric	BW400EAG	250	Fixed	250	Fixed	8 xIn

Table 3.25: Voltage drop summary

Item	From	To	Wire Size, Mm^2	I	Length Meters	R Ω/305M	X Ω/ 305M	Vd	%Vd	Remarks
1	Pole Mounted Transformer 50Kva,3Φ	Ats Panel	250	425	15.52	0.048	0.027	2.06	0.43	Within Limts
2	Mts Panel	Ecb 250A	250	425	7	0.048	0.027	0.929	0.19	Within Limts
3	Ecb 30A, 2P	Dry Type Transformer 2.5Kva	5.5	40	4.2	1.2	0.063	1.324	0.55	Within Limts
4	Dry Type Transformer 2.5Kva, 1Φ	Ups Panel	5.5	40	4	1.2	0.063	1.261	0.53	Within Limts
5	Mccb 100A, 3P	30Hp Motor	30	115	10	0.2	0.057	1.357	0.28	Within Limts
	Pole Mounted To 30 Hp Motor							3.417	0.71	Within Limits

Table 3.26: Momentary duty Summary

1/2 Cycle - 3-Phase, LG, LL, & LLG Fault Currents

Prefault Voltage = 100 % of the Bus Nominal Voltage

Bus		3-Phase Fault			Line-to-Ground Fault			Line-to-Line Fault			*Line-to-Line-to-Ground		
ID	kV	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.
Bus1	34.500	0.695	-8.338	8.367	0.695	-8.338	8.367	7.221	0.602	7.246	6.874	4.771	8.367
Bus2	0.480	0.927	-2.299	2.479	0.000	0.000	0.000	1.991	0.803	2.147	1.991	0.803	2.147
Bus3	0.480	0.913	-2.239	2.418	0.000	0.000	0.000	1.939	0.791	2.094	1.939	0.791	2.094
Bus4	0.480	0.907	-2.212	2.391	0.000	0.000	0.000	1.916	0.786	2.071	1.916	0.786	2.071
Bus8	0.480	0.070	-0.125	0.143	0.083	-0.032	0.089	0.108	0.061	0.124	-0.136	-0.057	0.148
Bus9	0.480	0.040	0.000	0.040	0.040	0.000	0.040	0.000	0.035	0.035	-0.020	-0.035	0.040
Bus12	0.480	0.913	-2.239	2.418	0.000	0.000	0.000	1.939	0.791	2.094	1.939	0.791	2.094
Bus13	0.480	0.907	-2.212	2.391	0.000	0.000	0.000	1.916	0.786	2.071	1.916	0.786	2.071
Bus15	0.480	0.907	-2.212	2.391	0.000	0.000	0.000	1.916	0.786	2.071	1.916	0.786	2.071

All fault currents are symmetrical (1/2 Cycle network) values in rms kA.
* LLG fault current is the larger of the two faulted line currents.

3.10.2.6 Arc-flash Hazard Analysis

3.10.3 Recommendations

According to the results of the Arc Flash Analysis, Cotton underclothing plus FR shirt, pants, plus multi-layer switching suit or equivalent should be worn when opening the cover of the MCC. Arc flash Boundary (AFB) is about 30.6 feet (9.33 meters). Contributors to the arc flash are the motor loads and the VFD's.

An Arc flash label (refer to Figure 3.24) should be placed on the MCC as per requirement of the Philippine Electrical code.

Table 3.27: Momentary duty Summary

3-Phase & 1-Phase Fault Currents: (Prefault Voltage = 100 % of the Bus Nominal Voltage)

Bus		Device			Momentary Duty					Device Capability		
ID	kV	ID	Ckt #	Type	Symm. kA rms	X/R Ratio	M.F.	Asymm. kA rms	Asymm. kA Peak	Symm. kA rms	Asymm. kA rms	Asymm. kA Peak
Bus4	0.480	Bus4		Bus	2.391	2.4	1.073	2.567	4.314			
Bus5	0.480	Bus5		Bus	2.041	2.3	1.064	2.172	3.630			
Bus6	0.240	Bus6		Bus	0.411	1.0	1.001	0.412	0.604			
Bus7	0.240	Bus7		Bus	0.394	0.9	1.001	0.394	0.574			

Method:→IEEE - X/R is calculated from separate R & X networks.

Protective device duty is calculated based on total fault current

For 1-Phase 3-Wire systems (fed from center-tap transformers), the calculated momentary duty for panel's main and feeder protective devices are based on max. of 1-pole and 2-pole faults.

* Indicates a device with momentary duty exceeding the device capability.

Table 3.28: Incident Energy Summary

Bus			Total Fault Current (kA)		Arc-Flash Analysis Results			
ID	Nom. kV	Type	Bolted	Arcing	FCT (cycles)	Incident E (cal/cm²)	AFB (ft)	Energy Level
# Bus1	34.500	Open Air	8.367	8.367	6.000	17.683	11.54	Level D
Bus2	0.480	Open Air	2.479	1.711	6.000	0.426	0.89	Level A
Bus3	0.480	MCC	2.418	1.950	6.000	0.736	1.11	Level A
Bus4	0.480	MCC	2.391	1.642	1662.737	169.313	30.61	>Max.
# Bus8	0.480	MCC	0.143	0.143	6.000	0.017	0.18	Level A
# Bus9	0.480	MCC	0.040	0.040	6.000	0.005	0.09	Level A
Bus12	0.480	Switchboard	2.418	1.930	6.000	0.462	1.05	Level A
Bus13	0.480	MCC	2.391	1.932	6.000	0.728	1.11	Level A
# Bus14	0.480	Other	0.144	0.144				
Bus15	0.480	MCC	2.391	1.932	6.000	0.728	1.11	Level A
# Bus16	0.480	Other	0.040	0.040				

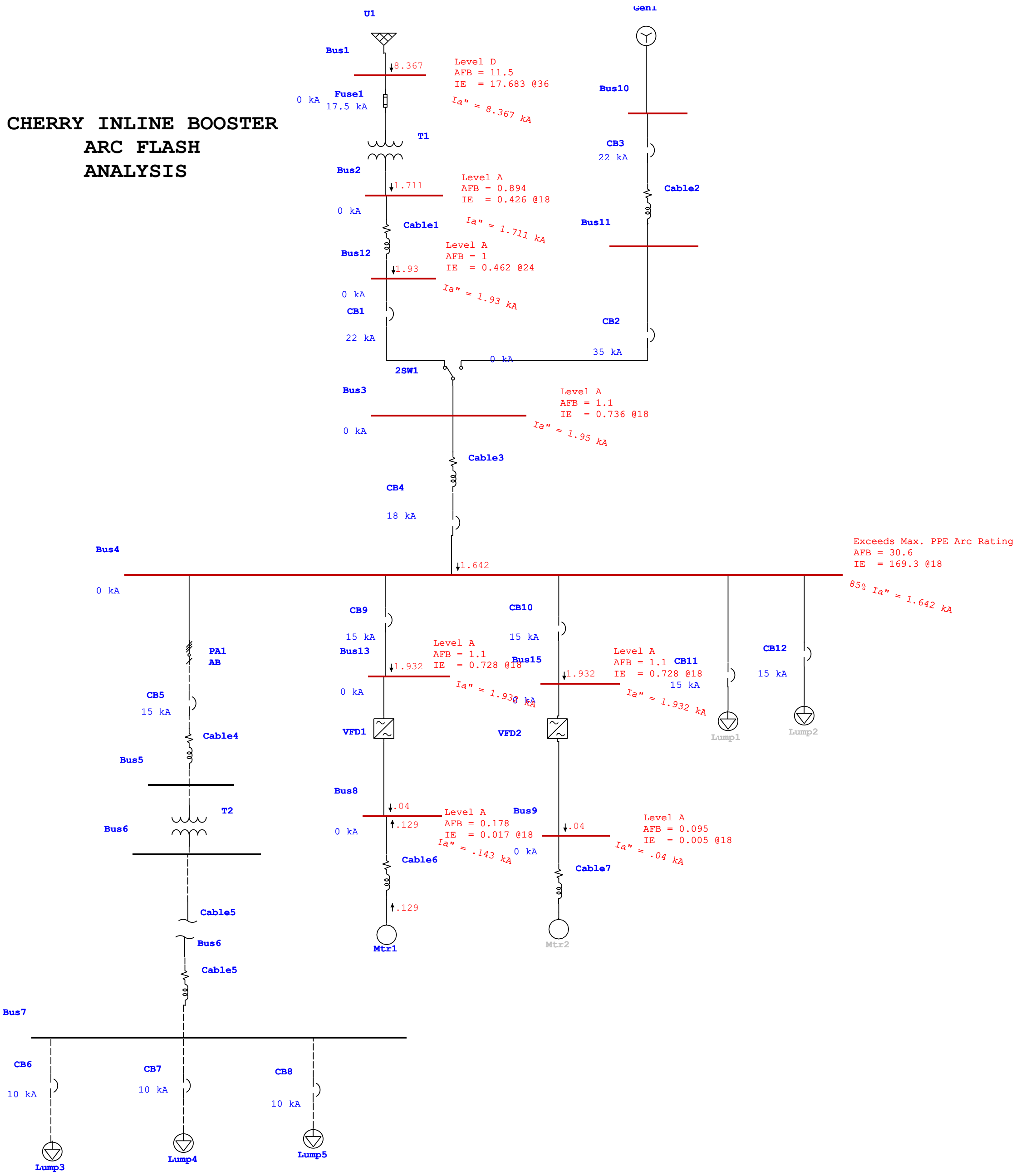


Figure 3.23: ARC flash analysis

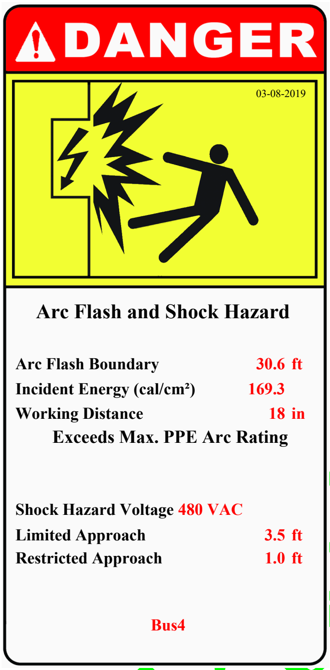


Figure 3.24: Cable waveform

Chapter 4

Conceptual Design and Reliability Study

4.1 Basis of Design

4.1.1 As-built drawings

A collection of as-built drawings are given in A3 print out with electronic files saved both in PDF and CAD formats.

4.1.2 Conceptual design

The conceptual design is provided in the Appendix.

Bibliography

[1] R.E. Bellman and S.E. Dreyfus. *Applied Dynamic Programing*. New Jersey: Princeton University Press, 1962.

[2] Bryan Dodson. *The Weibull Analysis Handbook*. Quality Press, American Society for Quality, 2006.

[3] GHD and Maynilad. *Minutes - Project Progress Meeting and Technical Presentation on Report Structure and Asset Registry*. Minutes OP18REFCS03-MOM-1000-G005B. GHD and Maynilad, 2018.

[4] GHD, RBSanchez, and APSI. *Inspection Testing Plan for Cherry inline PS*. Tech. rep. OP18REFCS03-ITP-CHE-G001A. GHD, Dec. 2018.

[5] Paresh Girdhar and Octo Moniz. *Practical Centrifugal Pumps - Design Operation and Maintenance*. Elsevier, 2005.

[6] G. Jeff. *Bayesian Methods: A Social and Behavioral Sciences Approach*. 2nd ed. Chapman, Hall/CRC Taylor, and Francis Group, 2006.

[7] Naoko Kaio and Shunji Osaki. "Extended Block Replacement Models". In: *Operations Research* 18.1 (1984), pp. 59–70.

[8] Kiyoshi Kobayashi, Kiyoyuki Kaito, and Nam Lethanh. "A Bayesian Estimation Method to Improve Deterioration Prediction for Infrastructure System with Markov Chain Model". In: *International Journal of Architecture, Engineering and Construction* 1.1 (2012), pp. 1–13.

[9] Kiyoshi Kobayashi, Kiyoyuki Kaito, and Nam Lethanh. "Deterioration Forecasting Model with Multistage Weibull Hazard Functions". In: *Journal of Infrastructure Systems* 16.4 (2010), pp. 282–291. DOI: `10.1061/(ASCE)IS.1943-555X.0000033`. URL: `http://link.aip.org/link/?QIS/16/282/1`.

[10] T. Lancaster. *The econometric analysis of transition data*. Cambridge University Press, 1990.

[11] Nam Lethanh. "Stochastic Optimization Methods for Infrastructure Management with Incomplete Monitoring Data". PhD thesis. Graduate School of Engineering, Kyoto University, 2009. URL: `http://hdl.handle.net/2433/85384`.

Appendix A

Load Flow Analysis

Instrument Information

Model Number	435-II
Serial Number	41183106
Firmware Revision	V05.04

Software Information

Power Log Version	5.4
FLUKE 430-II DLL Version	1.2.0.13

General Information

Recording location	MAIN 250AMPS BREAKER
Client	MAYNILAD CHERRY IN LINE
Notes	Naval Base, Heracleo Alano Sangley Point Cavite City

Measurement Summary

Measurement topology	3-element delta mode
Application mode	Logger
First recording	1/21/2019 5:13:38 AM 688msec
Last recording	1/21/2019 9:43:38 PM 688msec
Recording interval	0h 10m 0s 0msec
Nominal Voltage	460 V
Nominal Current	250 A
Nominal Frequency	60 Hz
File start time	1/21/2019 5:03:38 AM 688msec
File end time	1/21/2019 9:43:38 PM 688msec
Duration	0d 16h 40m 0s 0msec
Number of events	Normal: 0 Detailed: 0
Events downloaded	No
Number of screens	1
Screens downloaded	Yes
Power measurement method	Unified
Cable type	Copper
Harmonic scale	%H1
THD mode	THD 40
CosPhi / DPF mode	DPF

Scaling

Phase:	
Current Clamp type	i430Flex
Clamp range	N/A
Nominal range	250 A
Sensitivity	x10 AC only
Current ratio	1:1
Voltage ratio	1:1
Neutral:	
Current Clamp type	i430Flex
Clamp range	N/A
Nominal range	250 A
Sensitivity	x10 AC only
Current ratio	1:1
Voltage ratio	1:1

Recording Summary

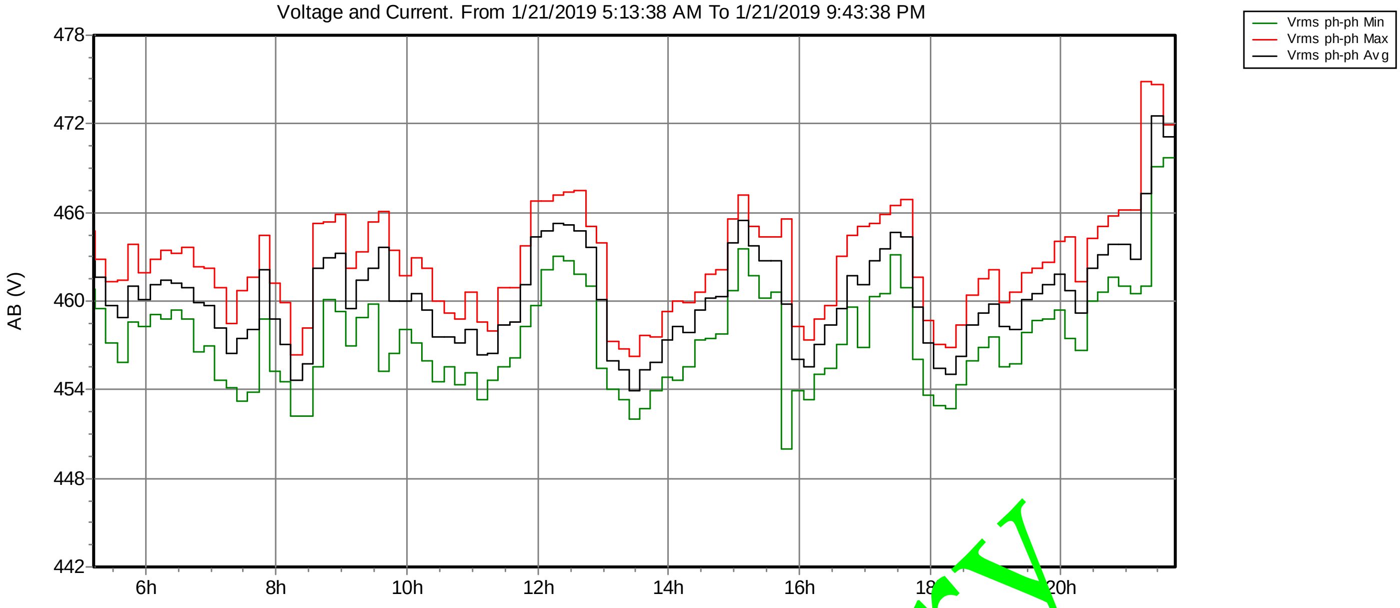
RMS recordings	100
DC recordings	0
Frequency recordings	100
Unbalance recordings	100
Harmonic recordings	100
Power harmonic recordings	100
Power recordings	100
Power unbalance recordings	0
Energy recordings	100
Energy losses recordings	0
Flicker recordings	100
Mains signaling recordings	100

Events Summary

Dips	0
Swells	0
Transients	0
Interruptions	0
Voltage profiles	0
Rapid voltage changes	0
Screens	1
Waveforms	0
Intervals without measurements	0
Inrush current graphics	0
Wave events	0
RMS events	0

apsi

Voltage and Current. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM



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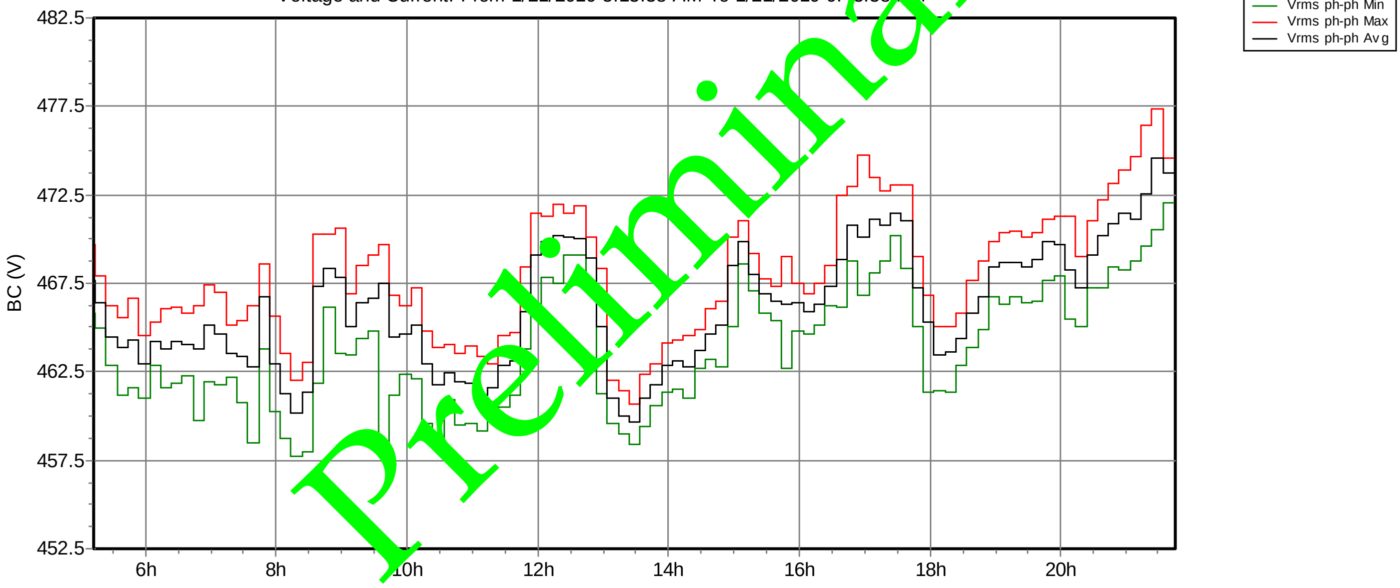

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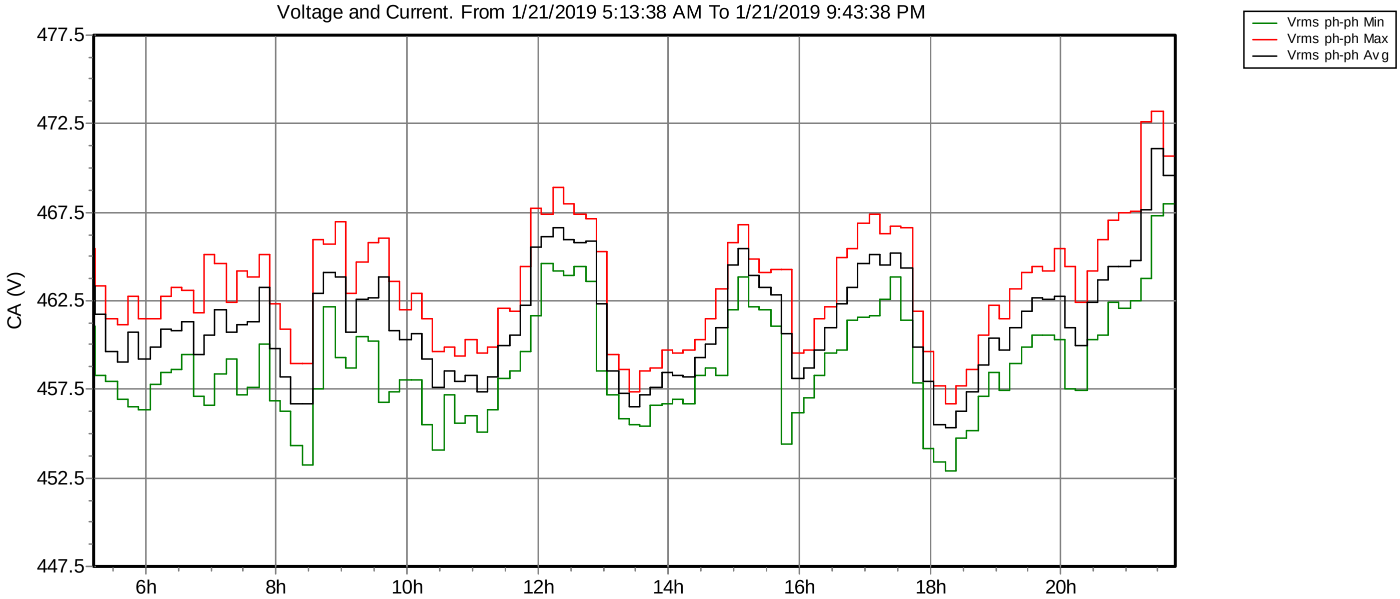

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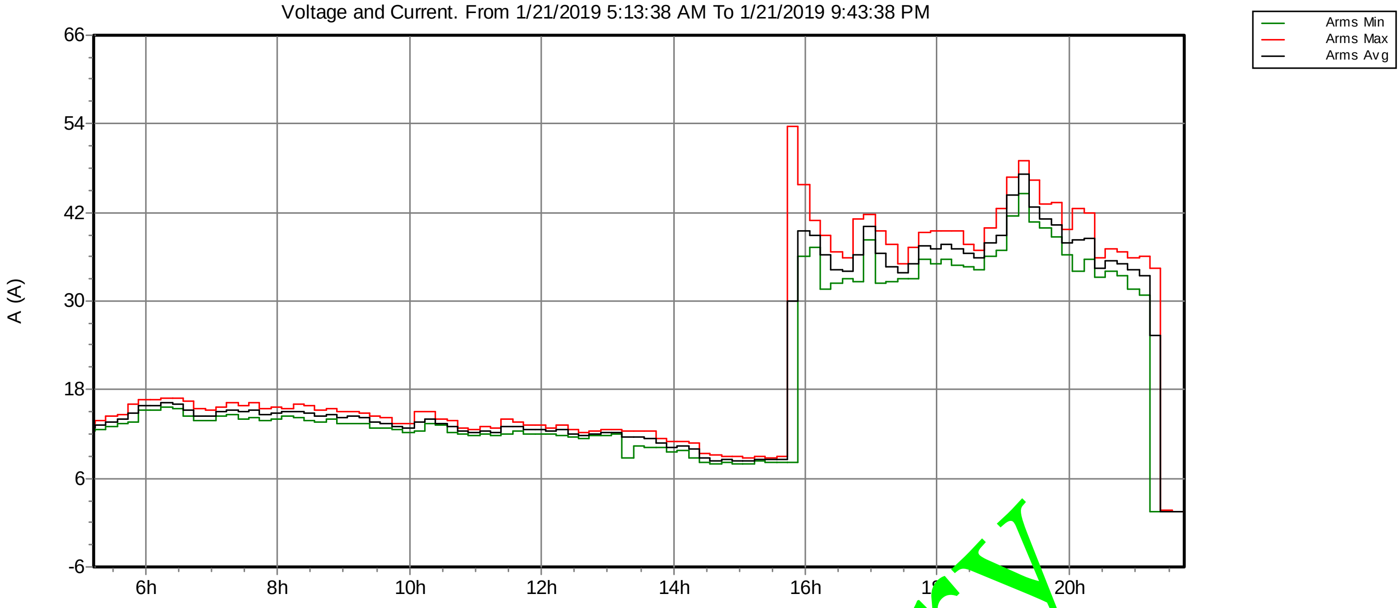

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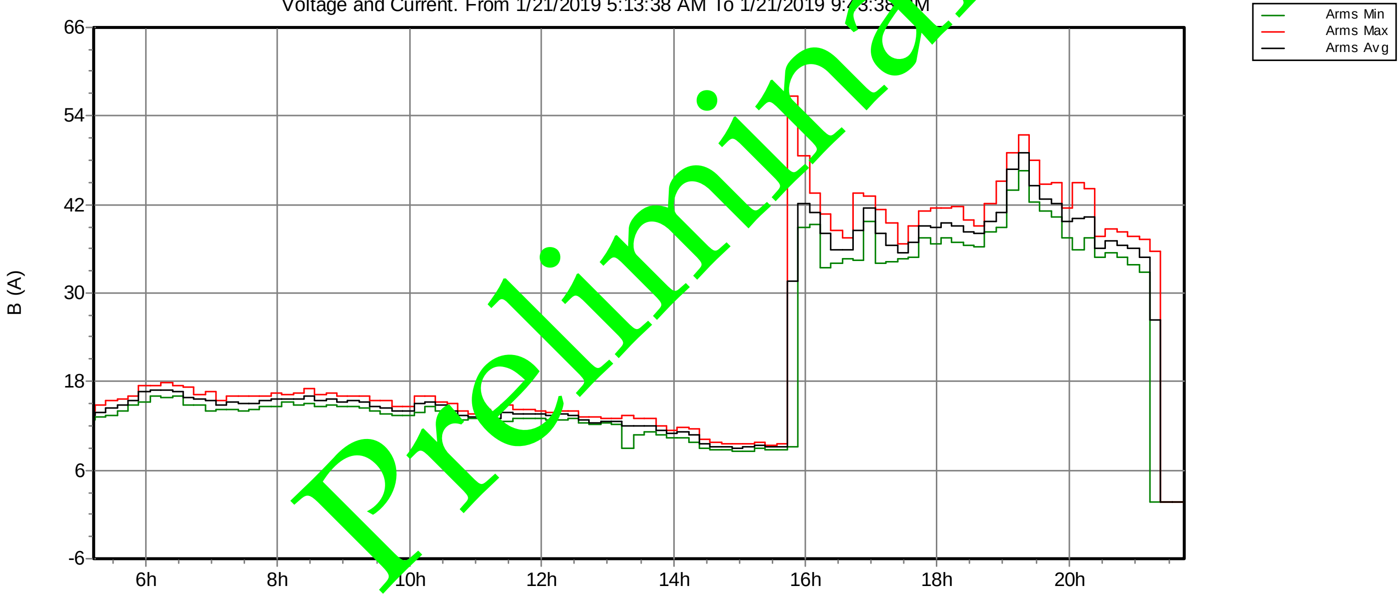

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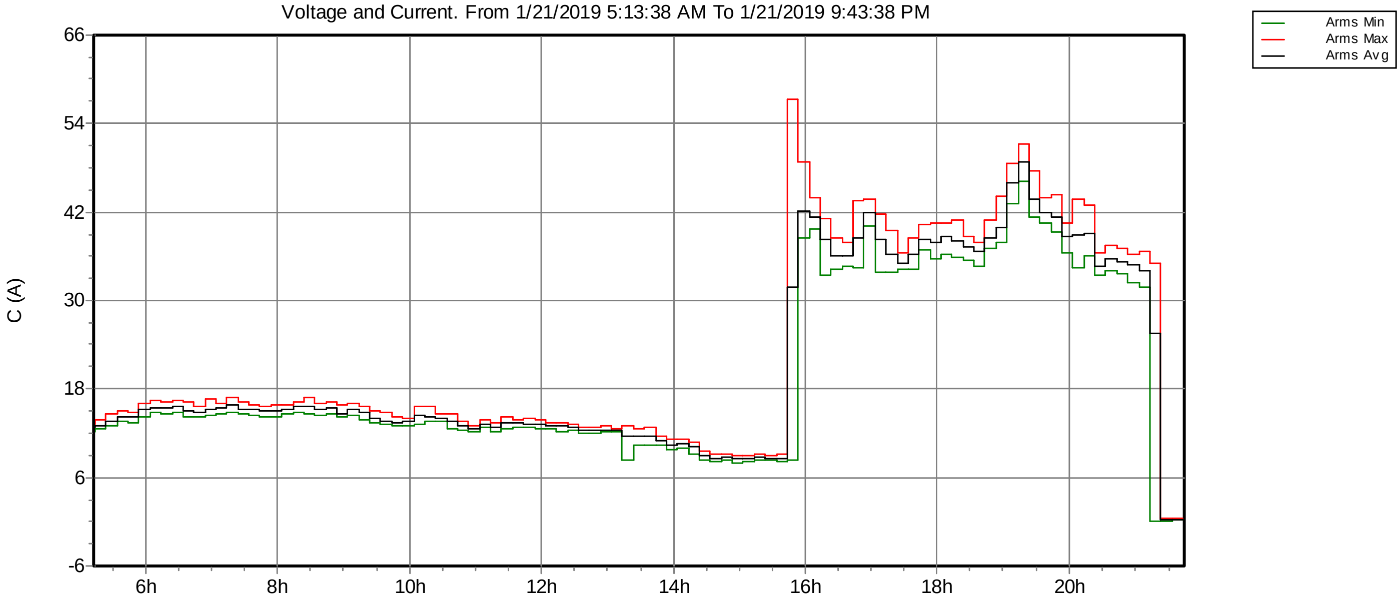

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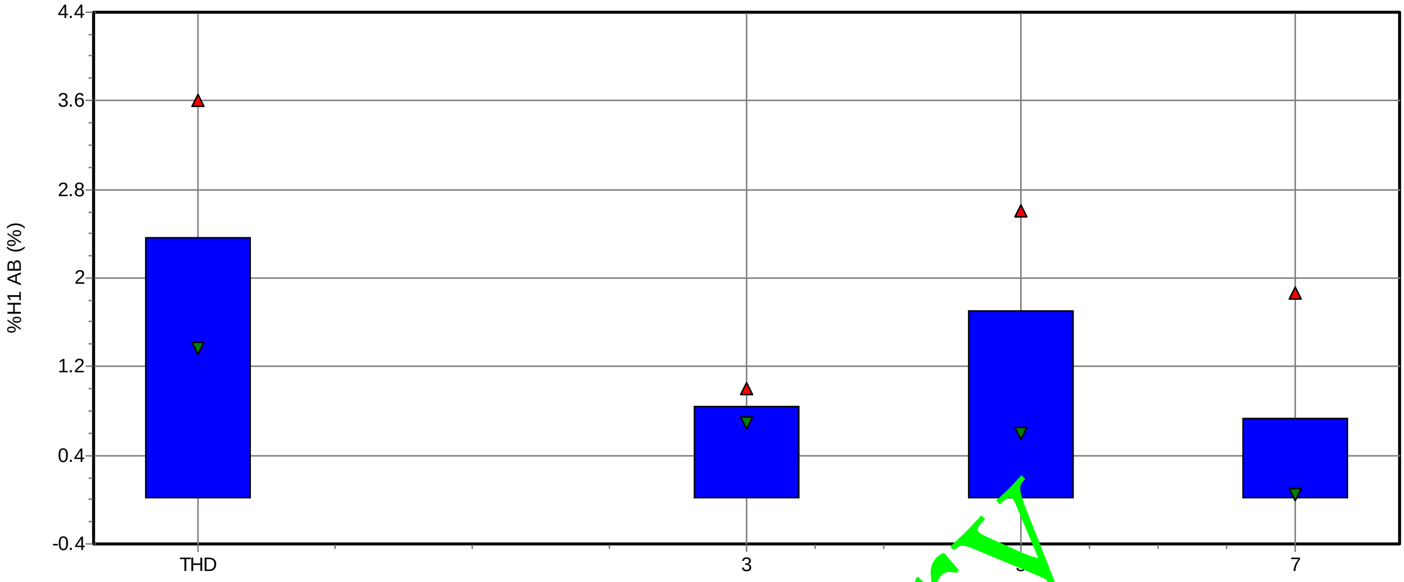

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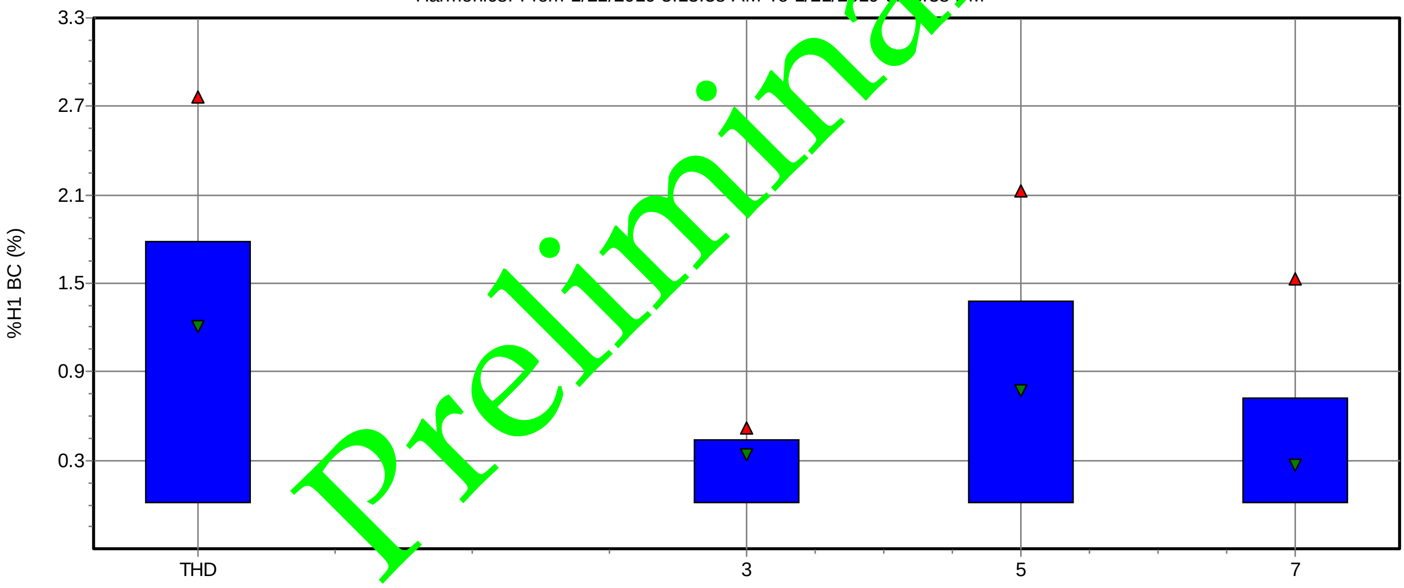

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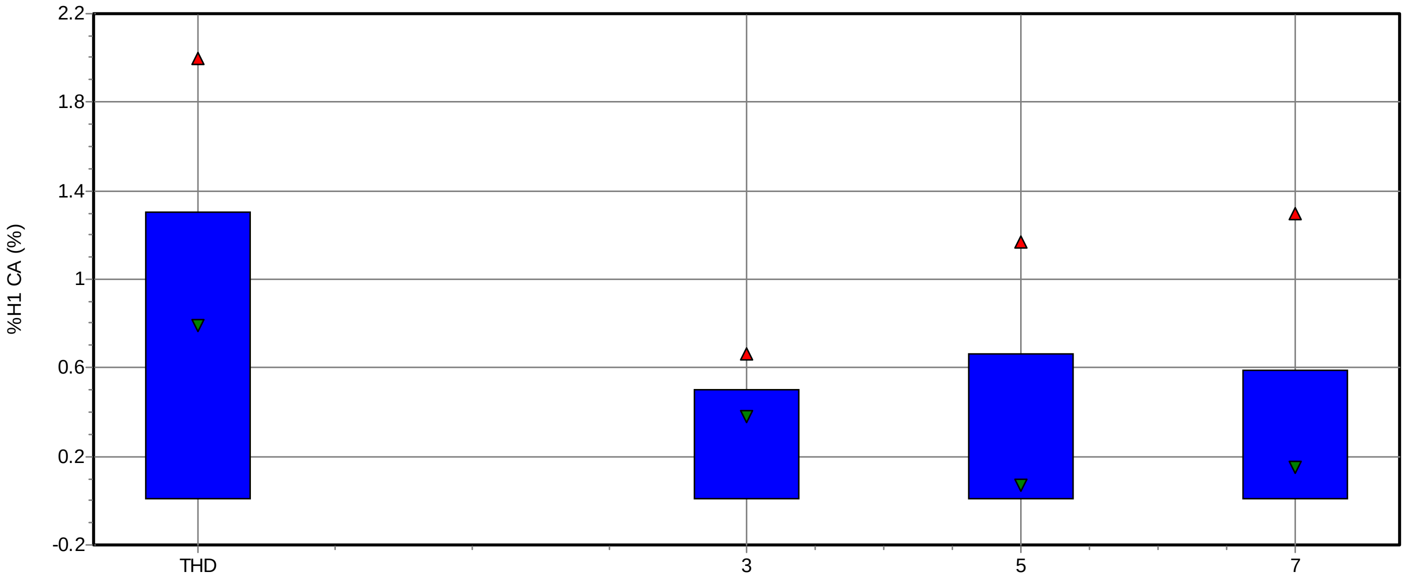
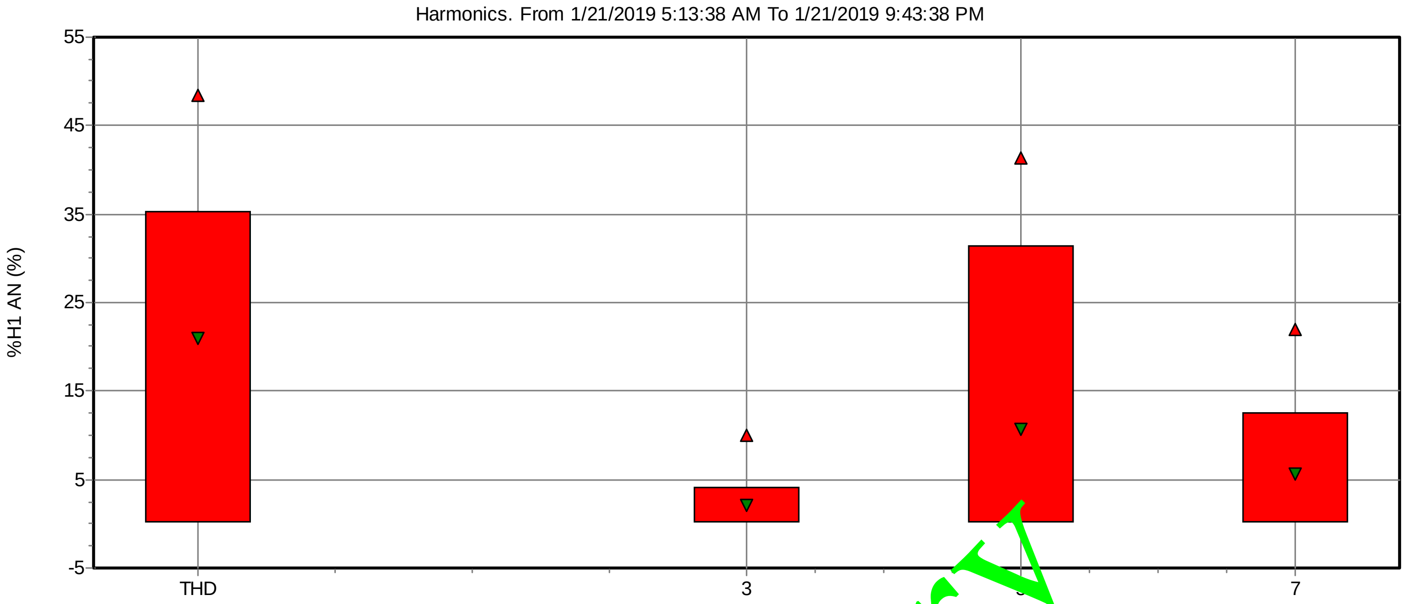
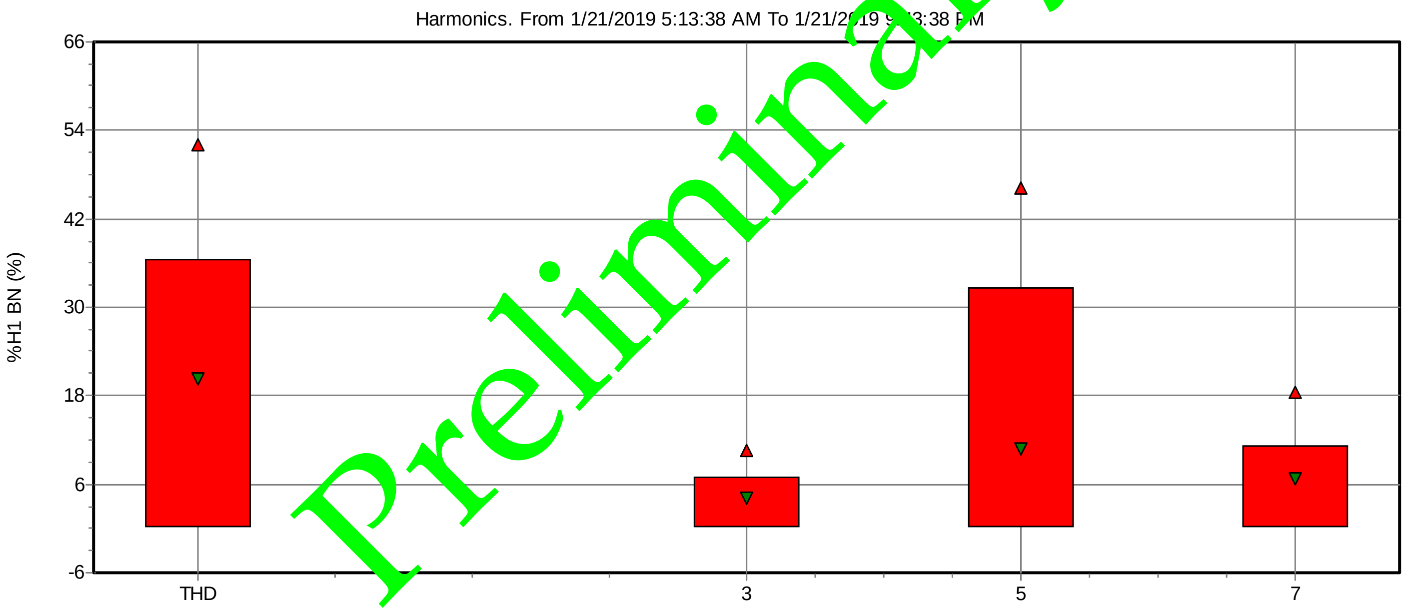



Harmonics. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM
%H1 AN (%)
55
45
35
25
15
5
-5
THD
3
7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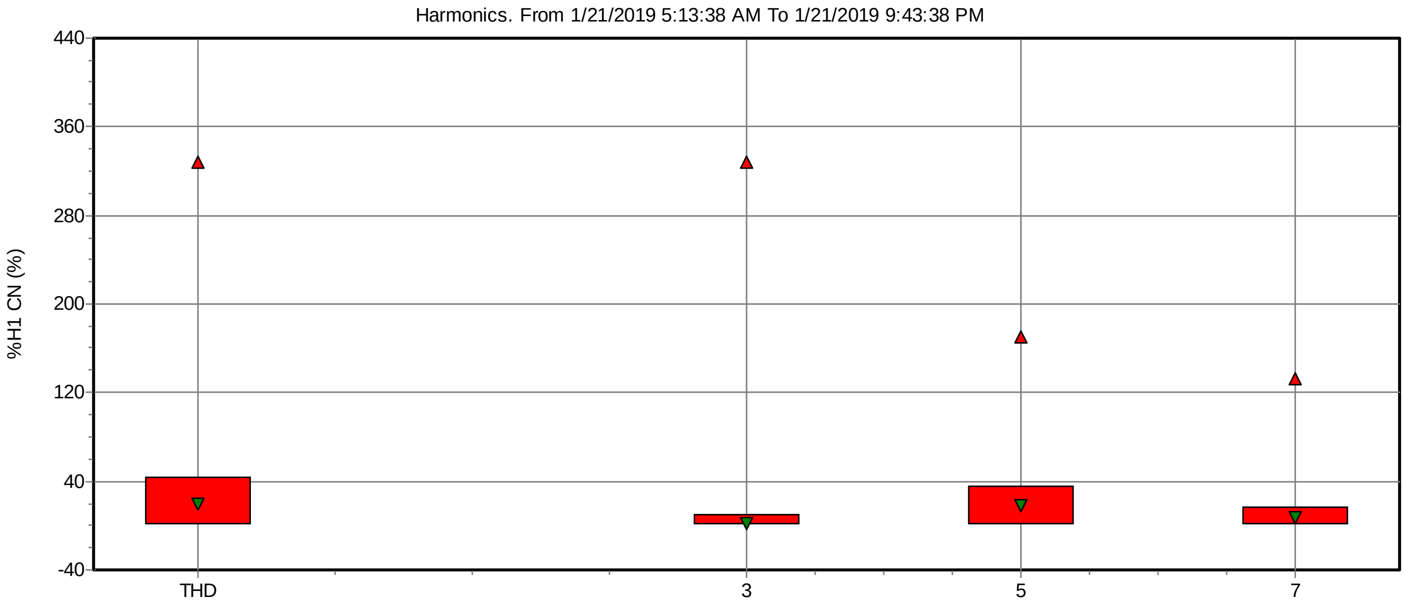
18
6
-6
THD
3
5
7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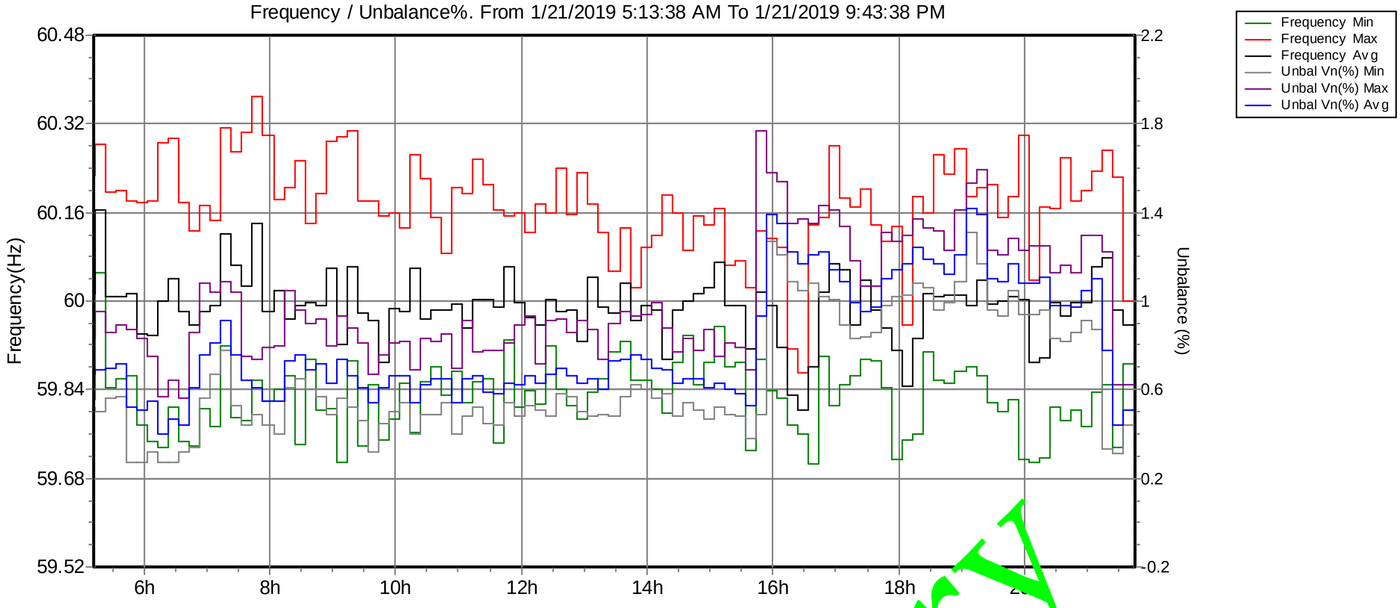
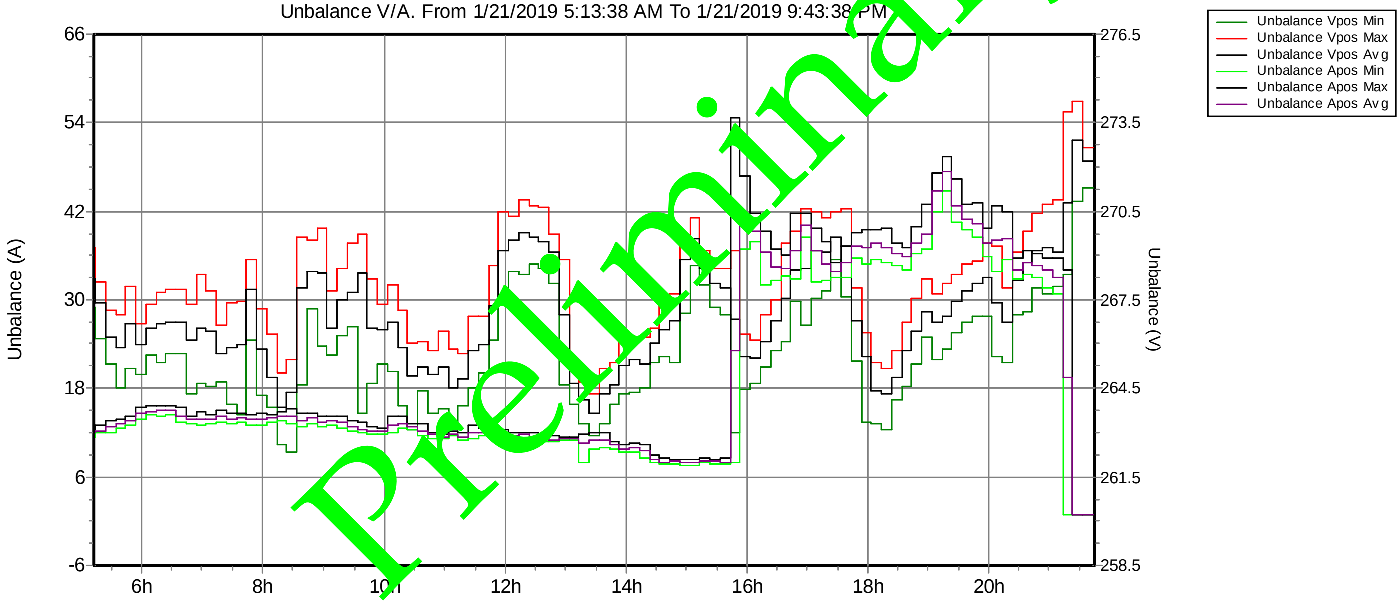
%H1 CN (%)
440
360
280
200
120
40
-40
THD
3
5
7

Frequency / Unbalance%. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM



Unbalance V/A. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM



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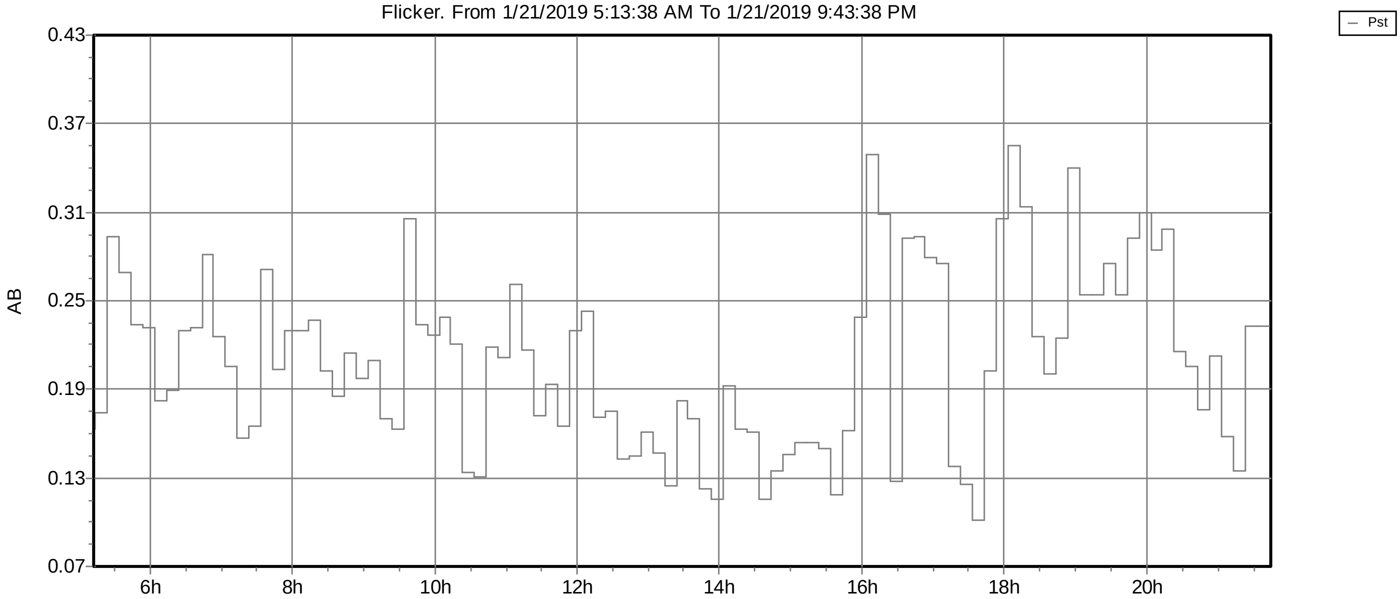

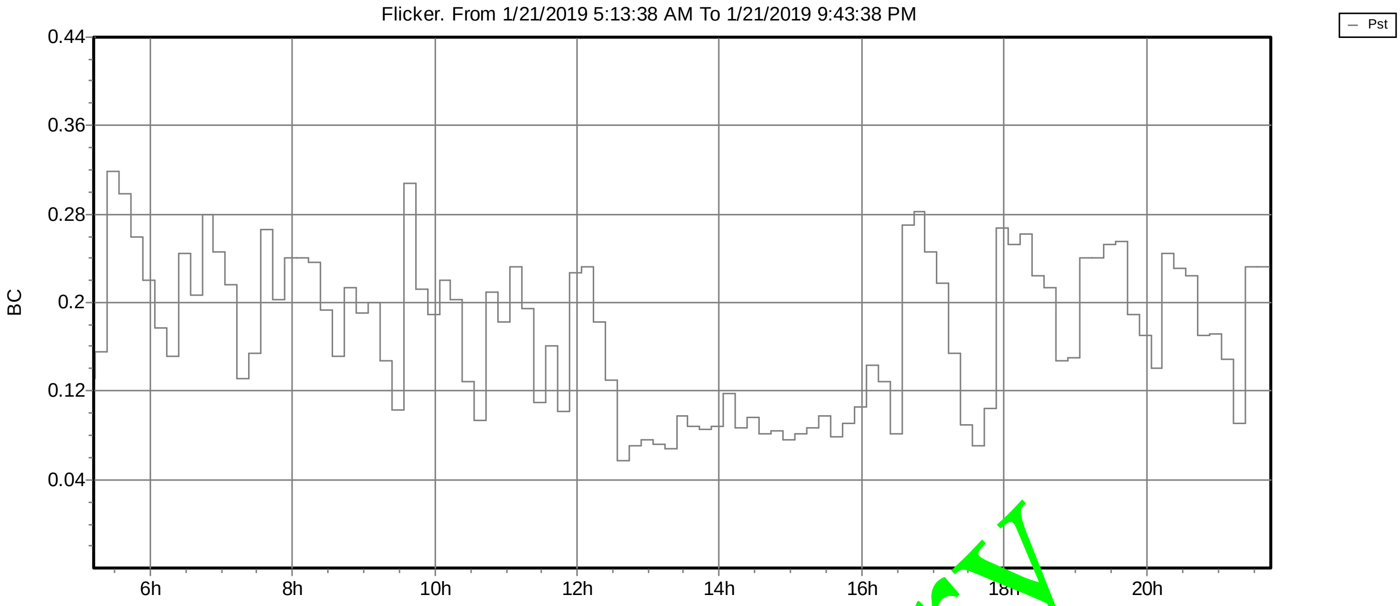
Flicker. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM
Pst
BC
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0.36
0.28
0.2
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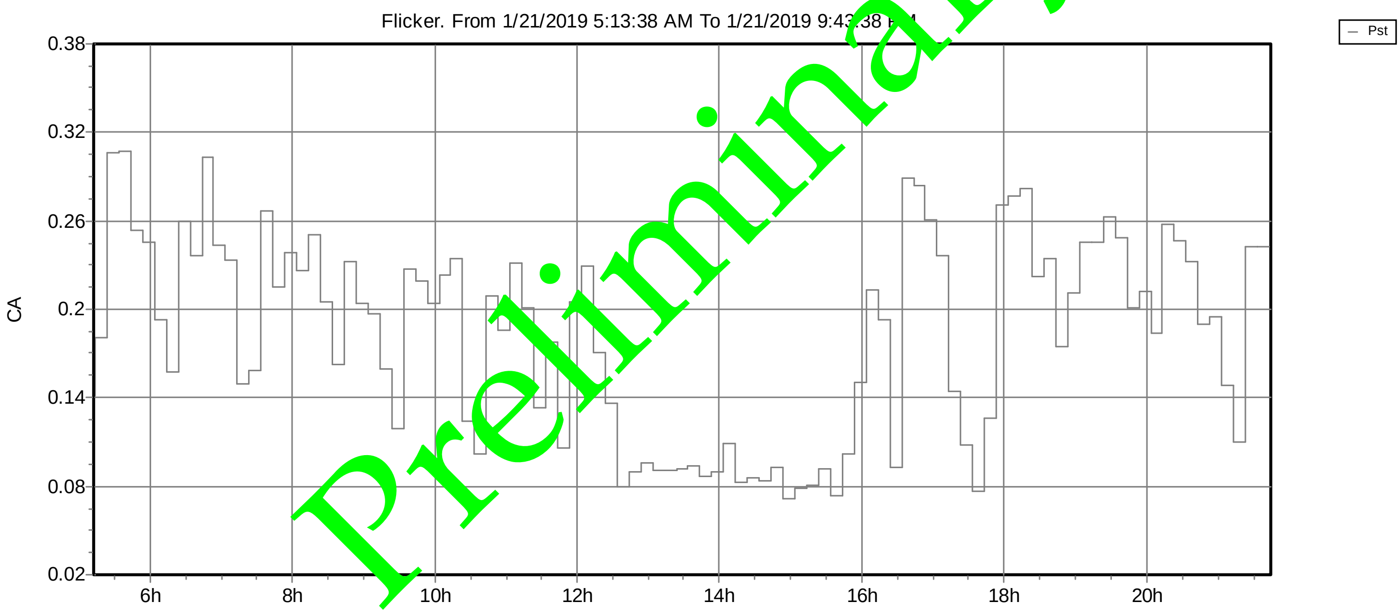
6h
8h
10h
12h
14h
16h
18h
20h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Pst
CA
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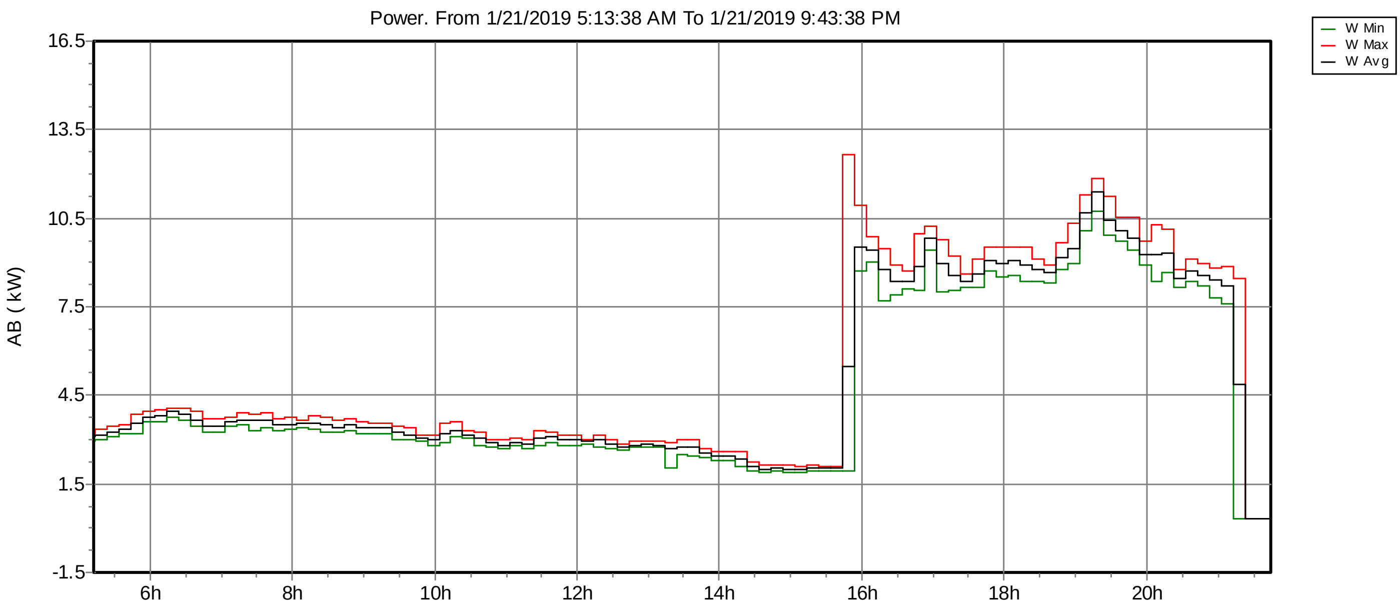
14h
16h
18h
20h


Power. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM
W Min
W Max
W Avg
AB (kW)
16.5
13.5
10.5
7.5
4.5
1.5
-1.5
6h
8h
10h
12h
14h
16h
18h
20h

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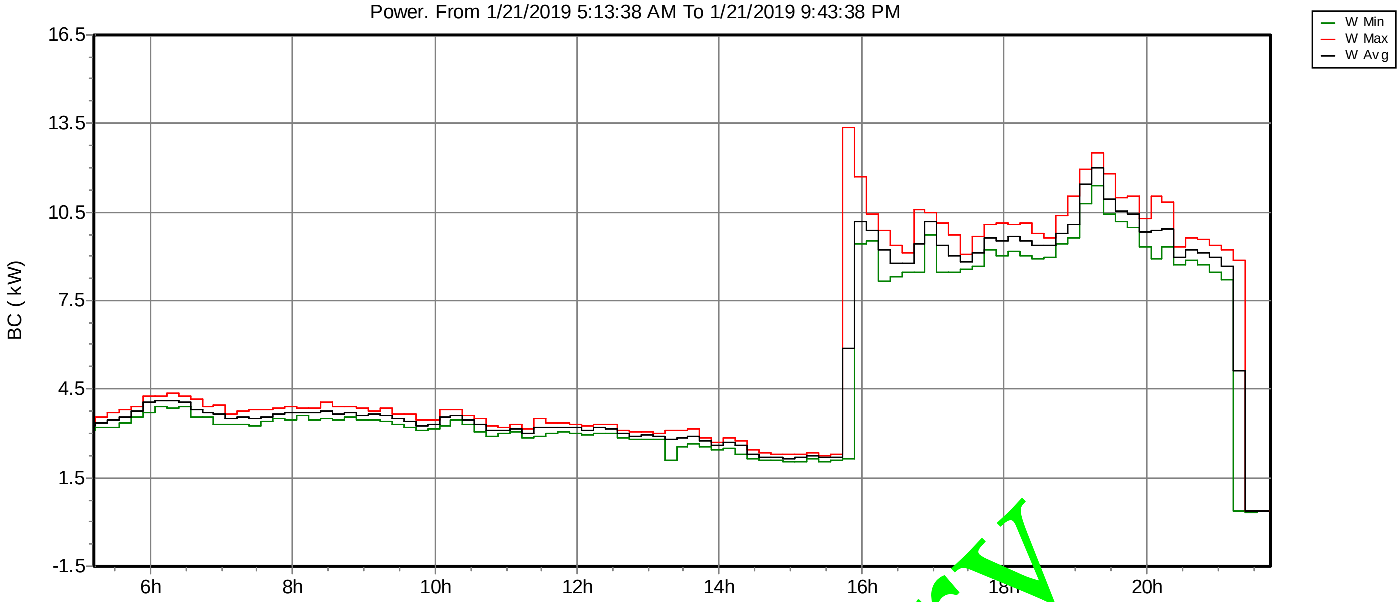
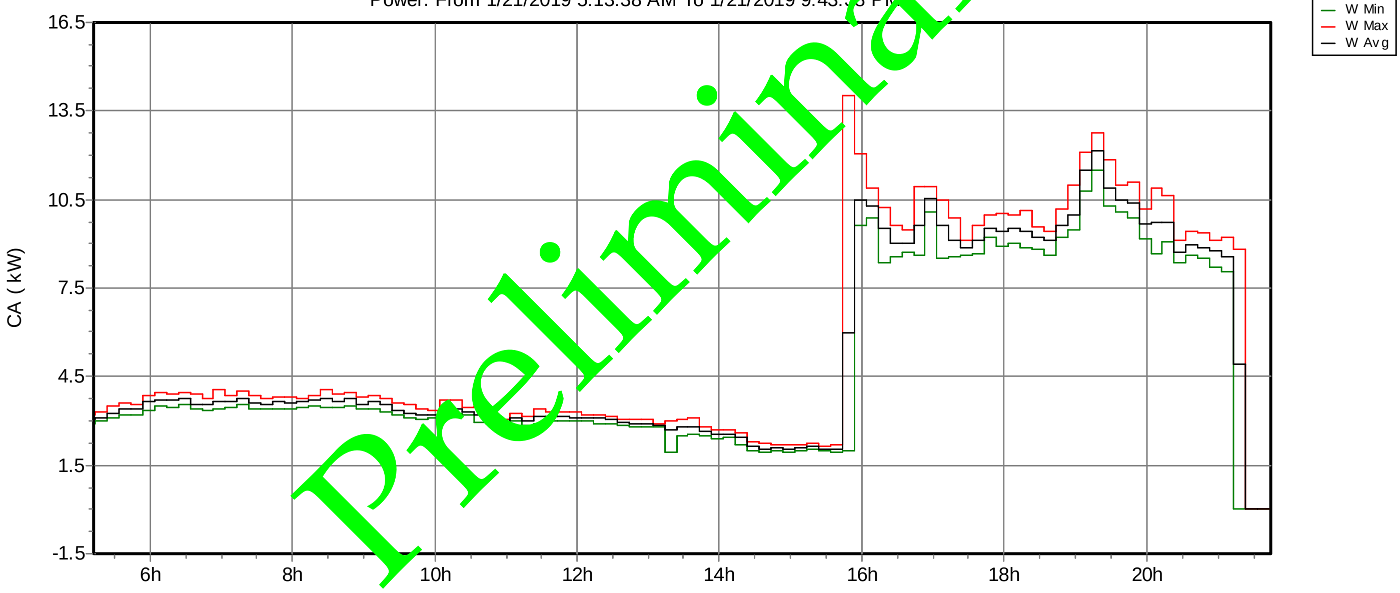


Power. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM



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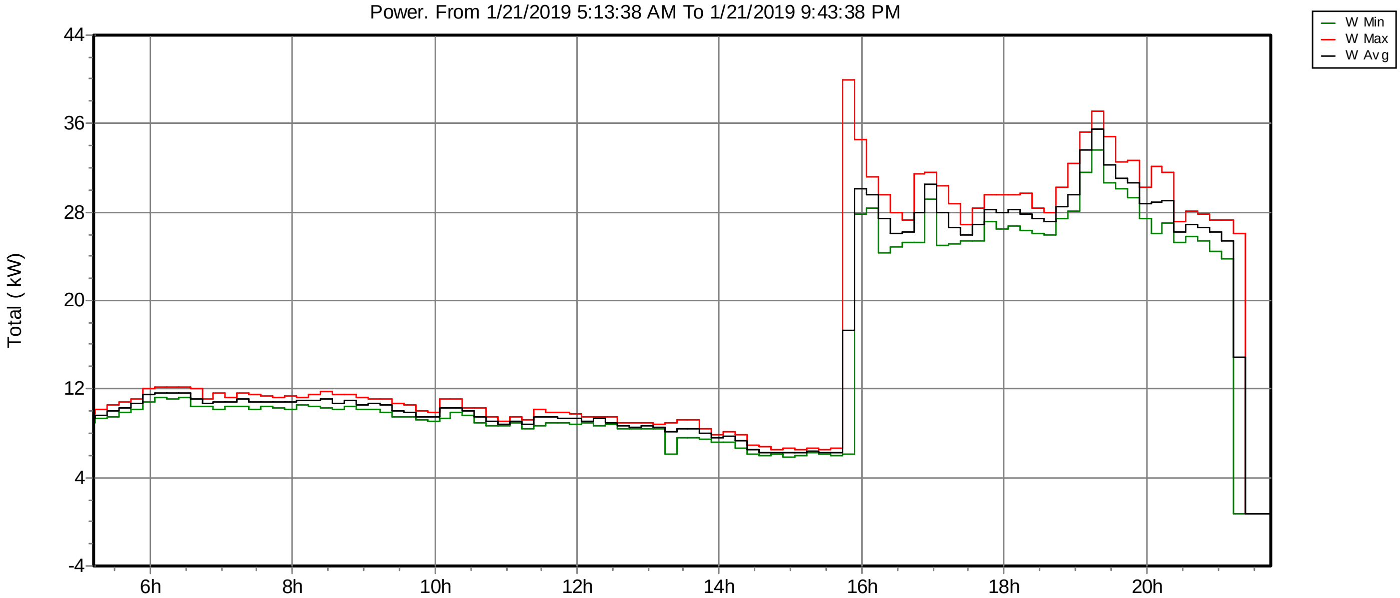
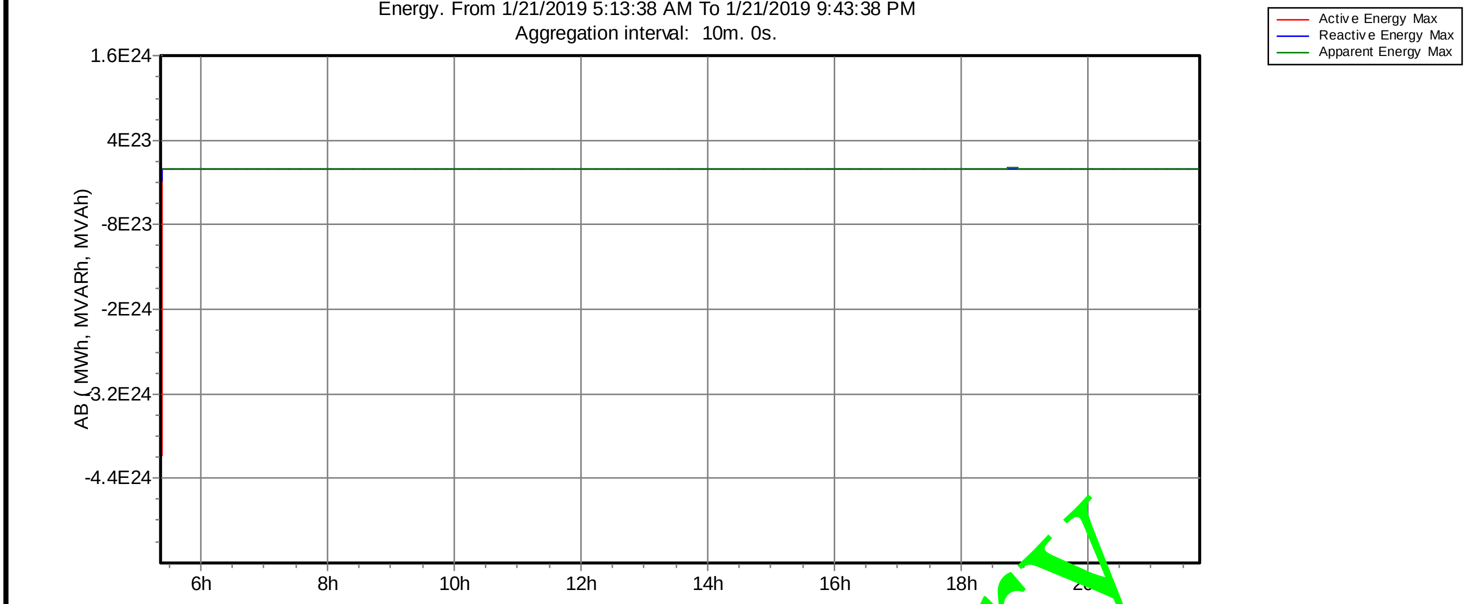


Energy. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM
Aggregation interval: 10m. 0s.



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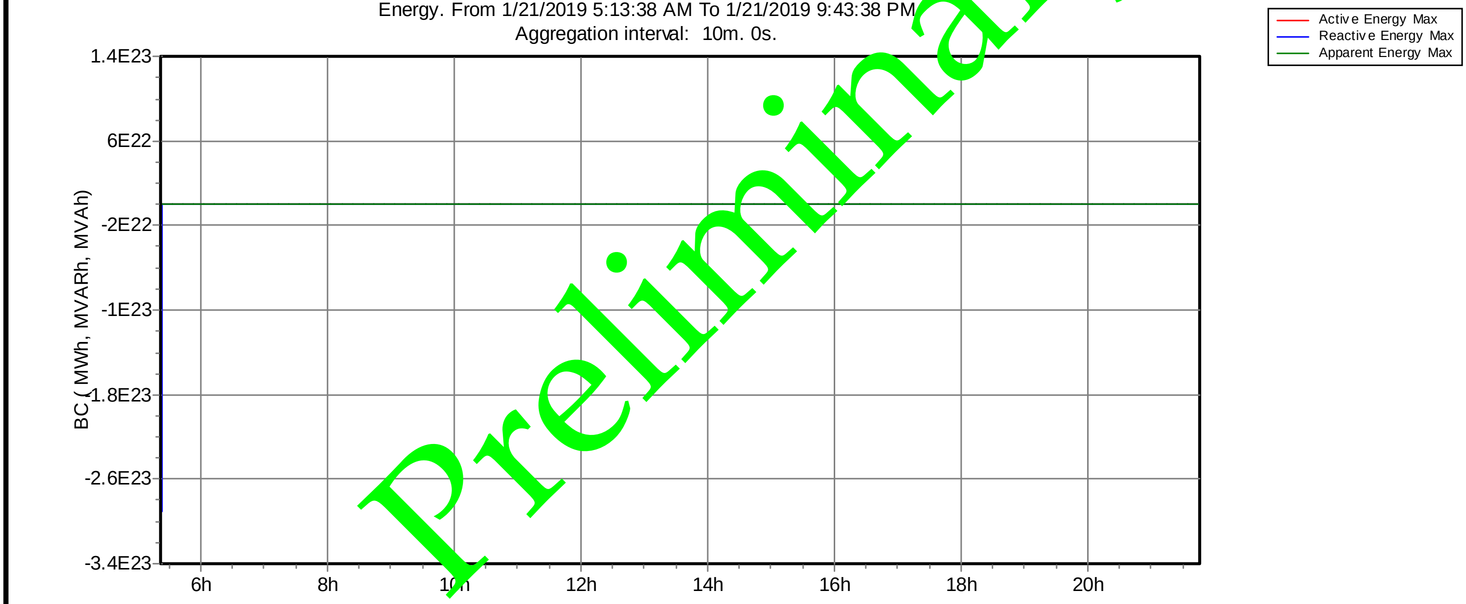

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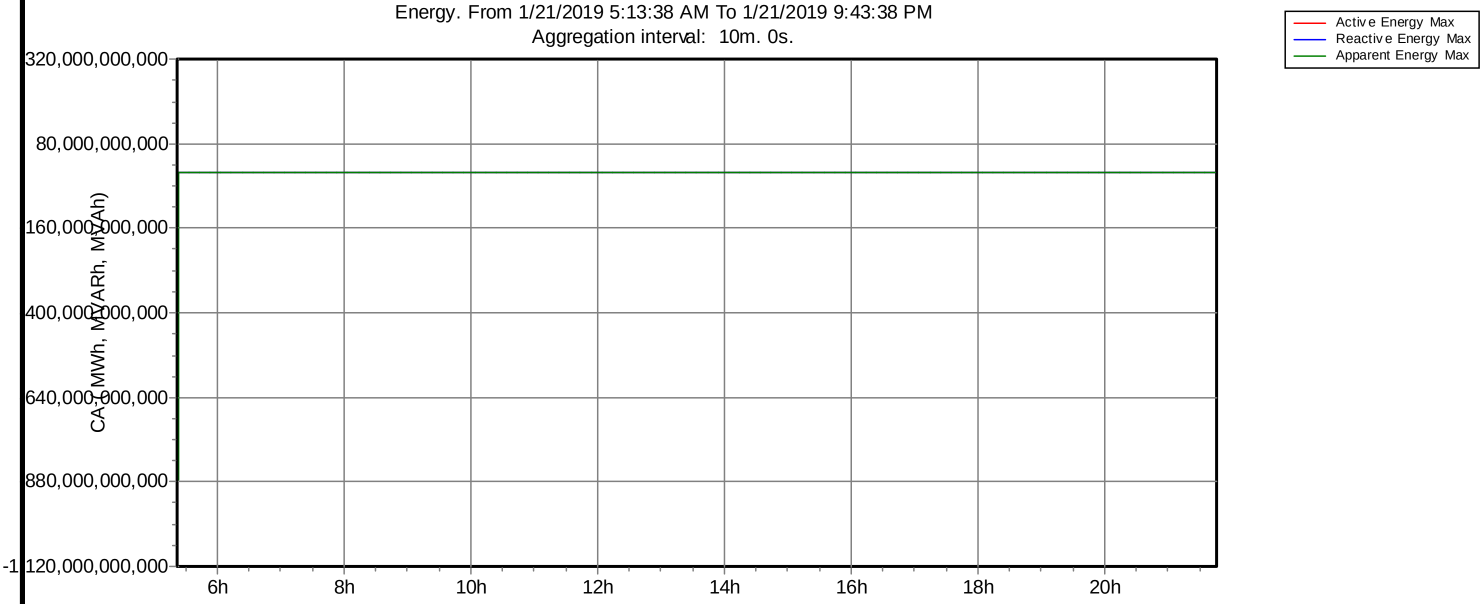
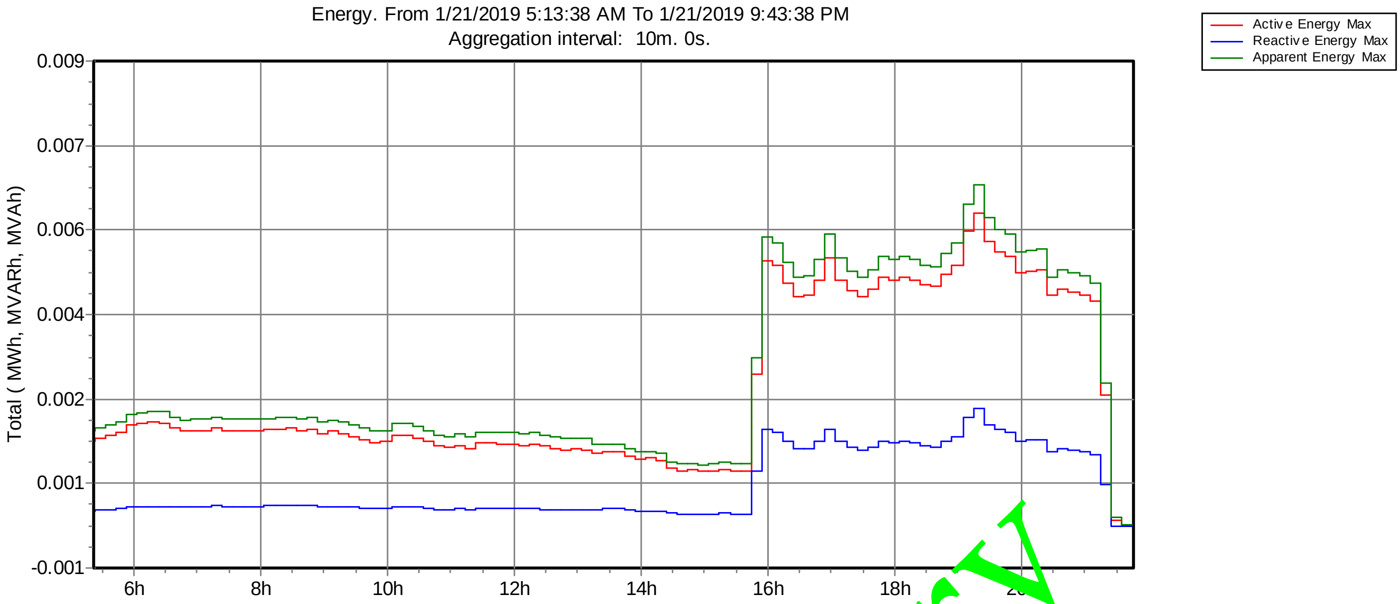
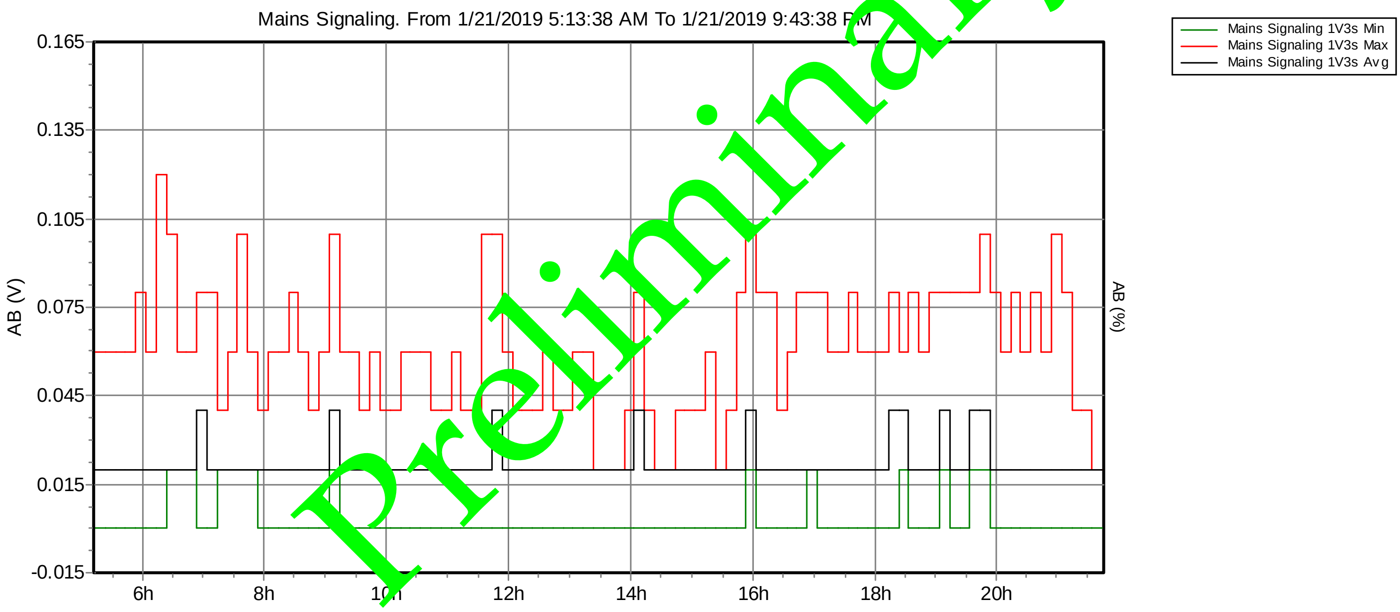
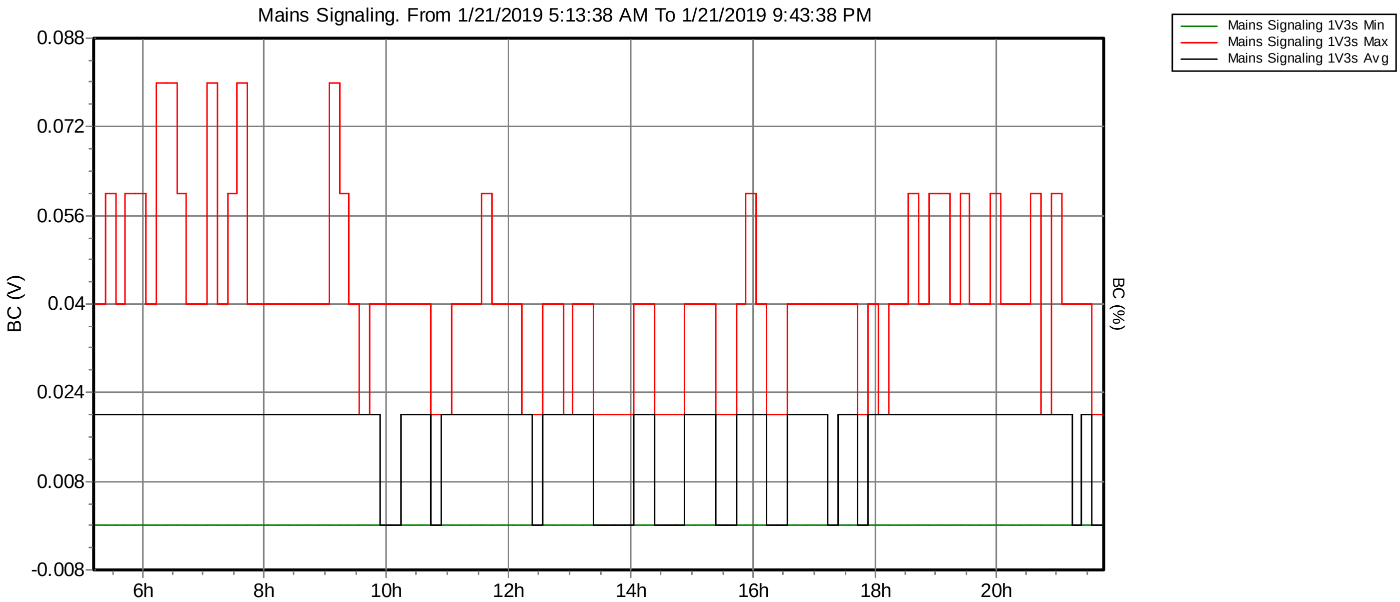
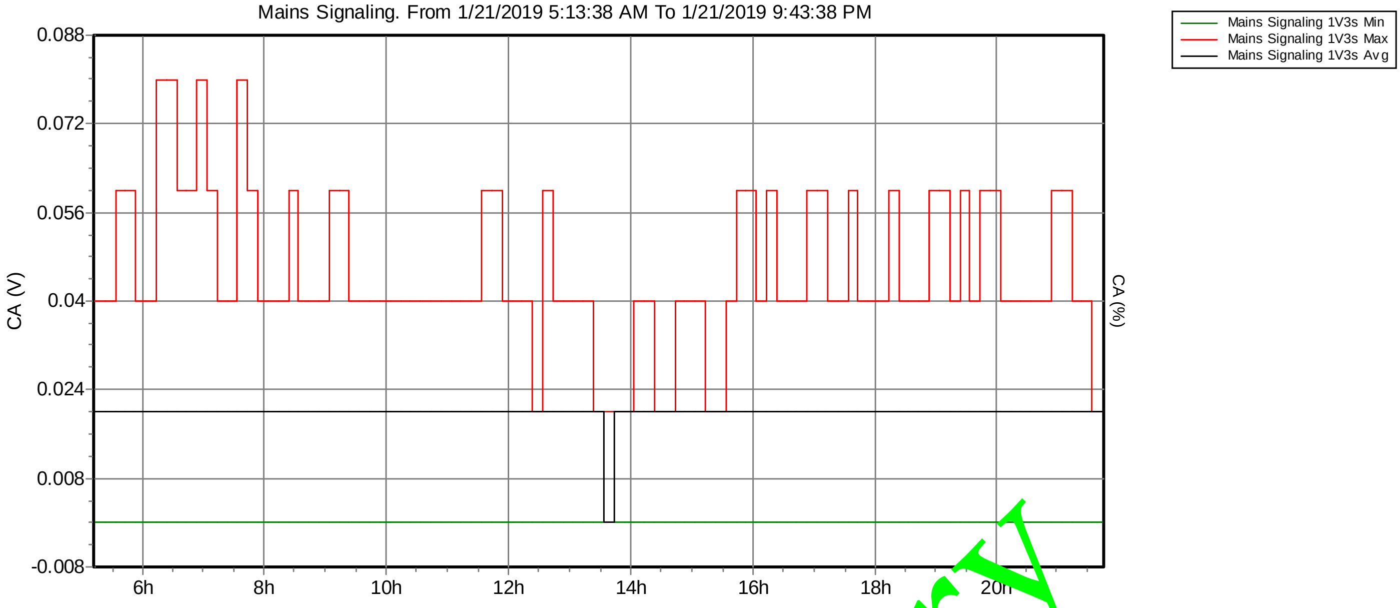



Energy. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM
Aggregation interval: 10m. 0s.
Total (MWh, MVARh, MVAh)
Active Energy Max
Reactive Energy Max
Apparent Energy Max
0.009
0.007
0.006
0.004
0.002
0.001
-0.001
6h
8h
10h
12h
14h
16h
18h

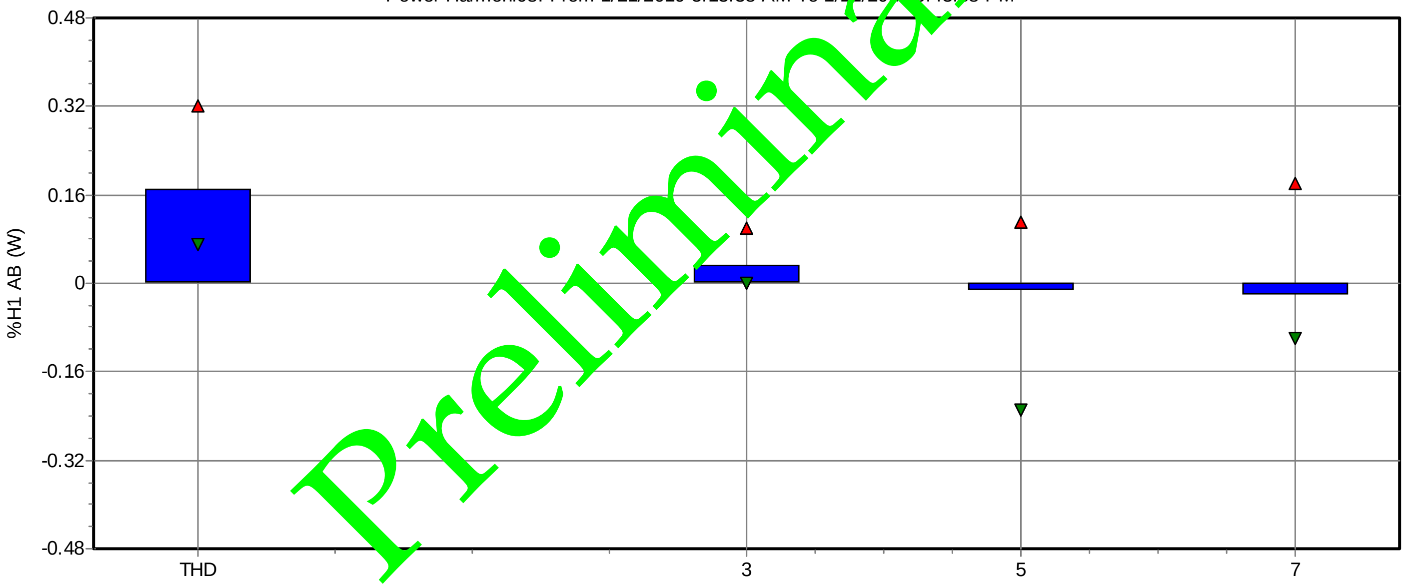

Mains Signaling. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM
Mains Signaling 1V3s Min
Mains Signaling 1V3s Max
Mains Signaling 1V3s Avg
AB (V)
AB (%)
0.165
0.135
0.105
0.075
0.045
0.015
-0.015
6h
8h
12h
14h
16h
18h
20h


Mains Signaling. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM
Mains Signaling 1V3s Min
Mains Signaling 1V3s Max
Mains Signaling 1V3s Avg
BC (V)
BC (%)
0.088
0.072
0.056
0.04
0.024
0.008
-0.008
6h
8h
10h
12h
14h
16h
18h
20h

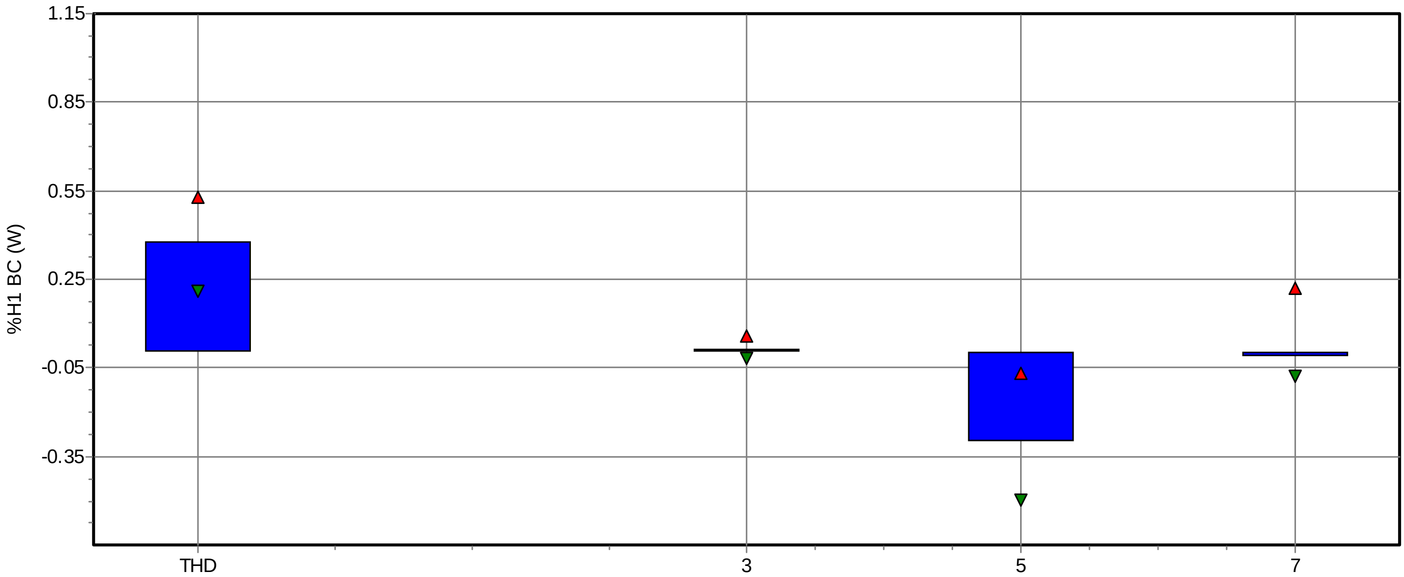
Mains Signaling. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM

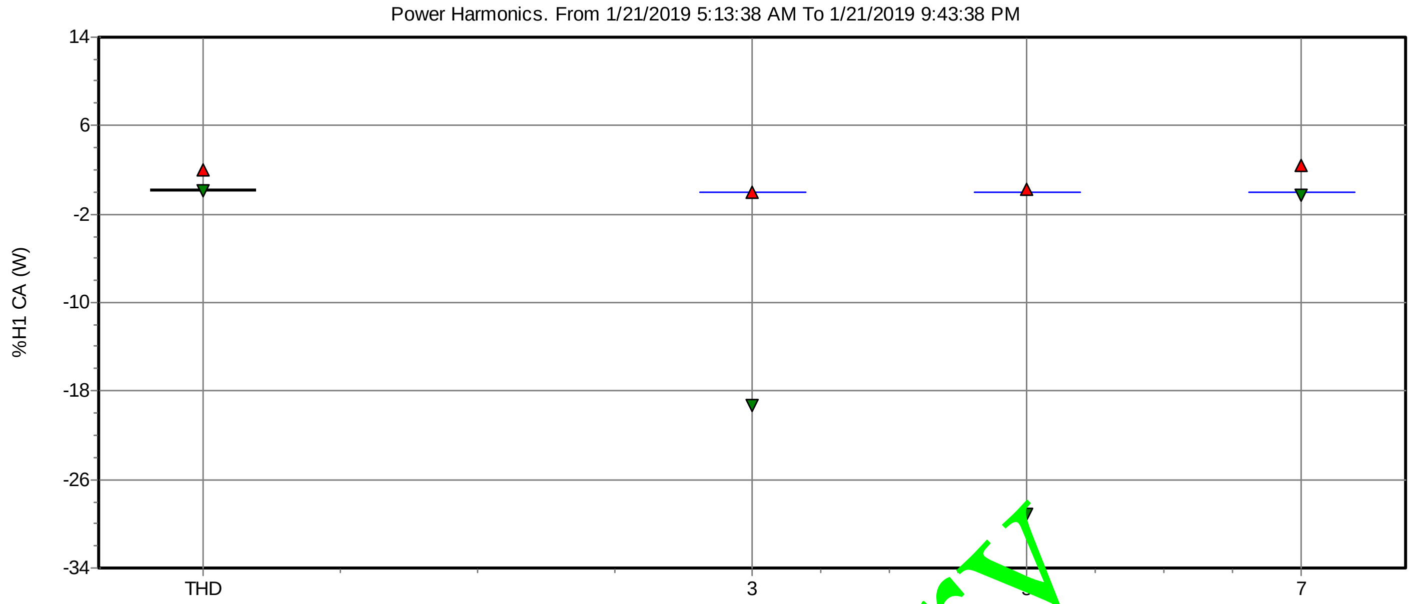


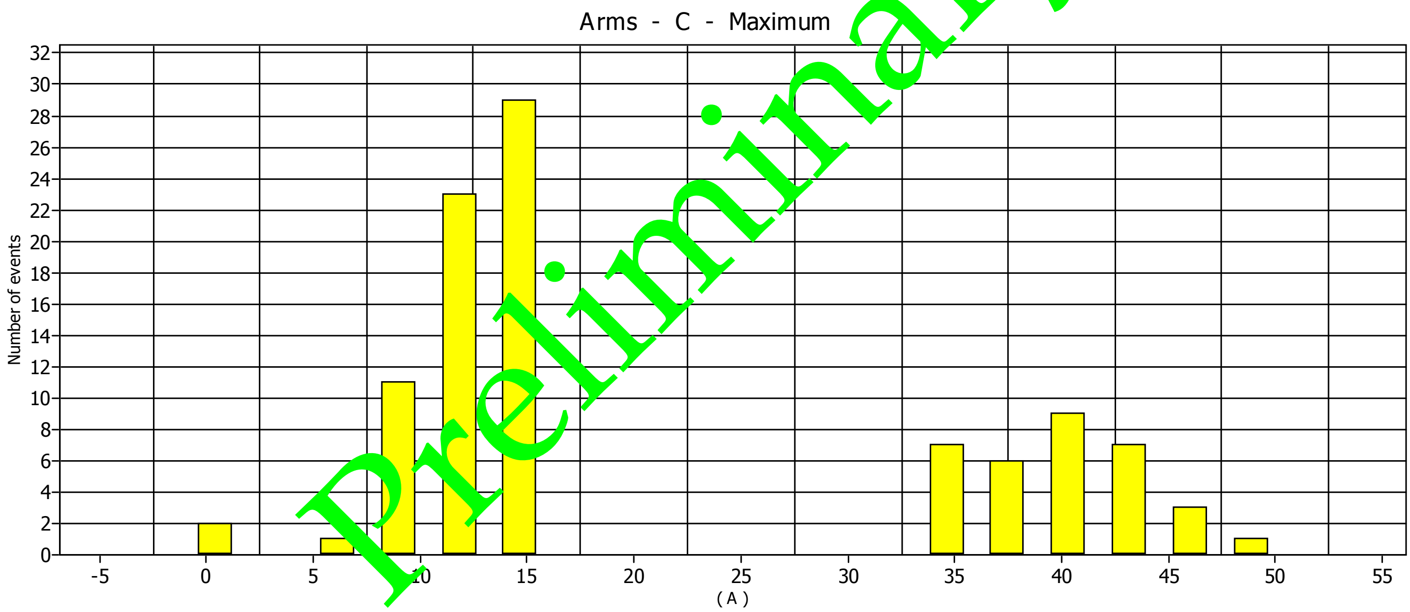
Power Harmonics. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM



Power Harmonics. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM




Power Harmonics. From 1/21/2019 5:13:38 AM To 1/21/2019 9:43:38 PM
14
6
-2
-10
-18
-26
-34
%H1 CA (W)
THD
3
7


Arms - C - Maximum
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Number of events
-5
0
5
10
15
20
25
30
35
40
45
50
55
(A)

Instrument Information

Model Number	435-II
Serial Number	34843110
Firmware Revision	V05.04

Software Information

Power Log Version	5.4
FLUKE 430-II DLL Version	1.2.0.13

General Information

Recording location	FEEDER VFD-1
Client	MAYNILAD CHERRY IN LINE PUMP STATION
Notes	Naval BAse, Heracleo Alano Sangley Point Cavite City

Measurement Summary

Measurement topology	3-element delta mode
Application mode	Logger
First recording	1/21/2019 5:24:31 AM 13msec
Last recording	1/21/2019 9:44:31 PM 13msec
Recording interval	0h 10m 0s 0msec
Nominal Voltage	460 V
Nominal Current	100 A
Nominal Frequency	60 Hz
File start time	1/21/2019 5:14:31 AM 13msec
File end time	1/21/2019 9:44:31 PM 13msec
Duration	0d 16h 30m 0s 0msec
Number of events	Normal: 1 Detailed: 2
Events downloaded	No
Number of screens	1
Screens downloaded	Yes
Power measurement method	Unified
Cable type	Copper
Harmonic scale	%H1
THD mode	THD 40
CosPhi / DPF mode	DPF

Scaling

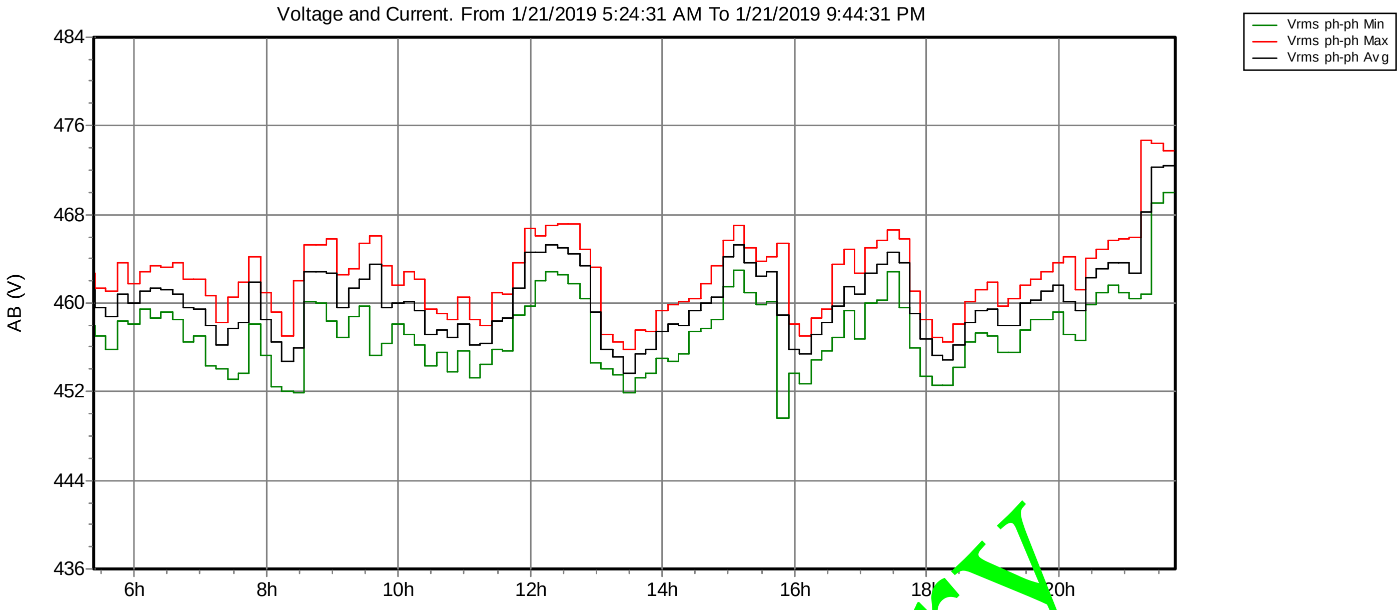
Phase:	
Current Clamp type	i430Flex
Clamp range	N/A
Nominal range	100 A
Sensitivity	x10 AC only
Current ratio	1:1
Voltage ratio	1:1
Neutral:	
Current Clamp type	i430Flex
Clamp range	N/A
Nominal range	100 A
Sensitivity	x10 AC only
Current ratio	1:1
Voltage ratio	1:1

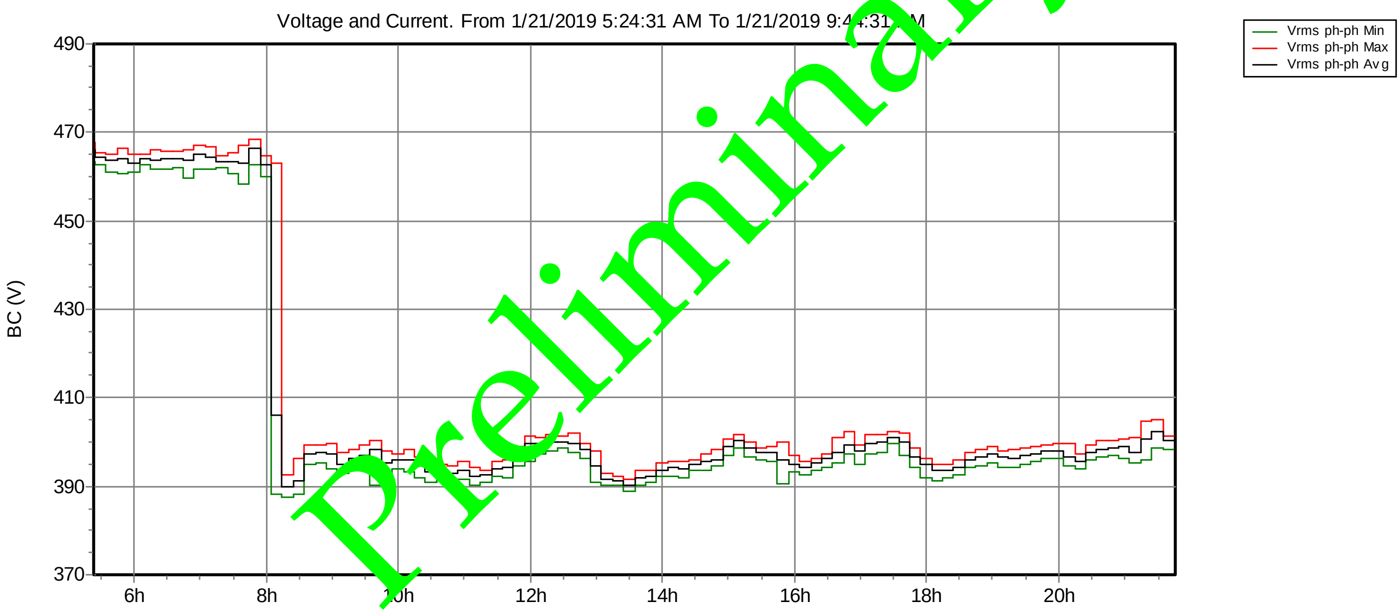
Recording Summary

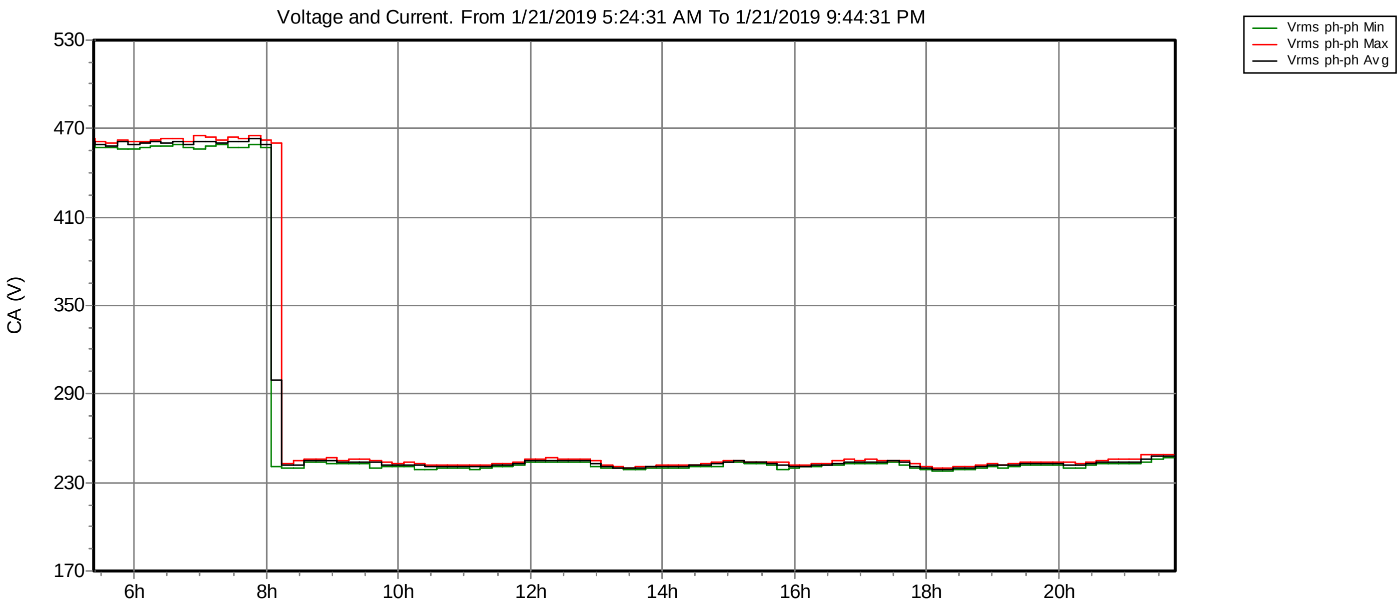
RMS recordings	99
DC recordings	0
Frequency recordings	99
Unbalance recordings	99
Harmonic recordings	99
Power harmonic recordings	99
Power recordings	99
Power unbalance recordings	0
Energy recordings	99
Energy losses recordings	0
Flicker recordings	99
Mains signaling recordings	99

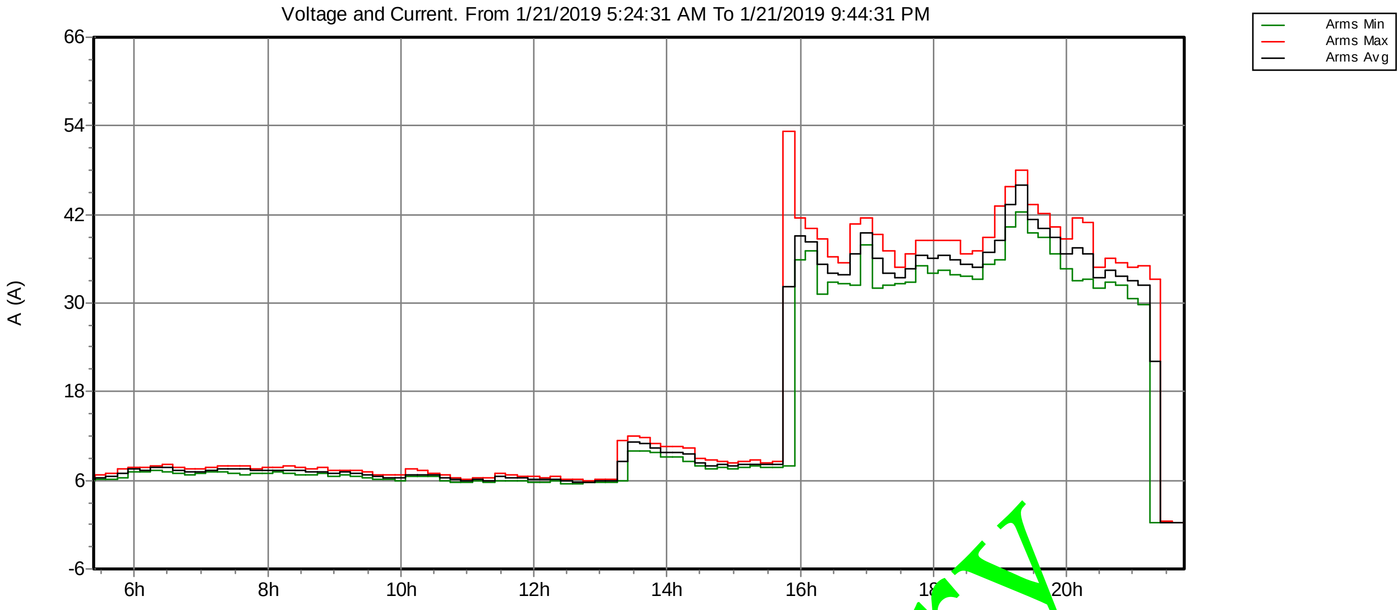
Events Summary

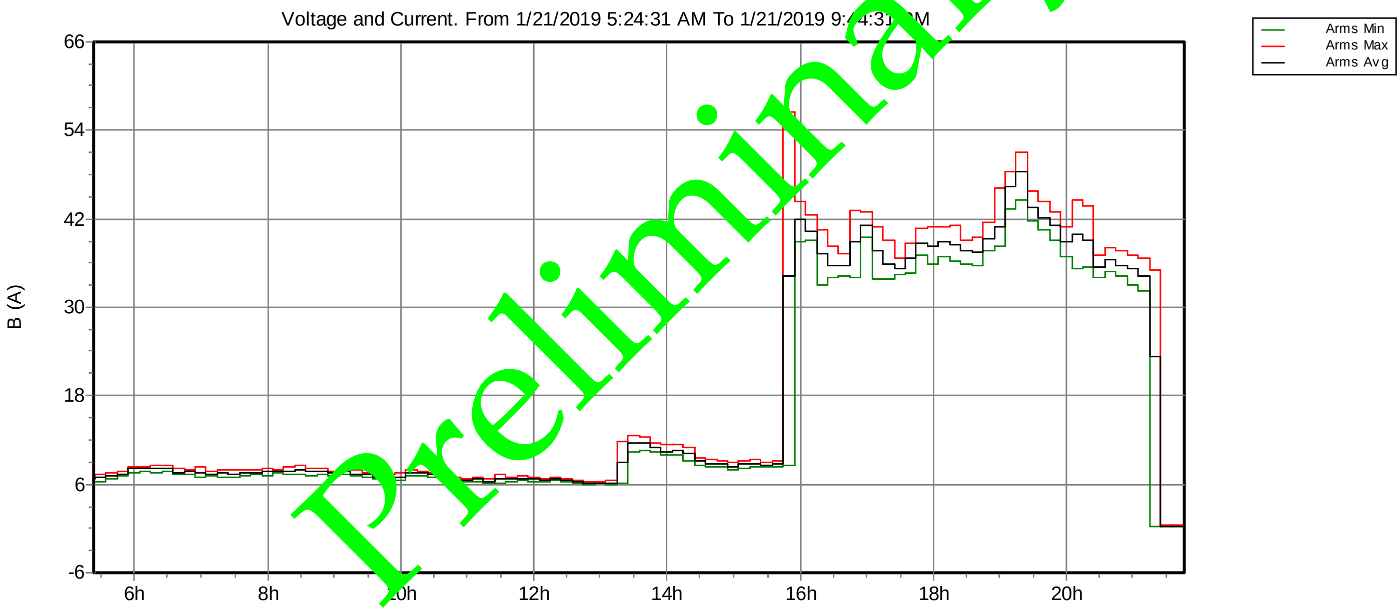
Dips	0
Swells	0
Transients	0
Interruptions	0
Voltage profiles	0
Rapid voltage changes	0
Screens	1
Waveforms	0
Intervals without measurements	0
Inrush current graphics	0
Wave events	0
RMS events	0

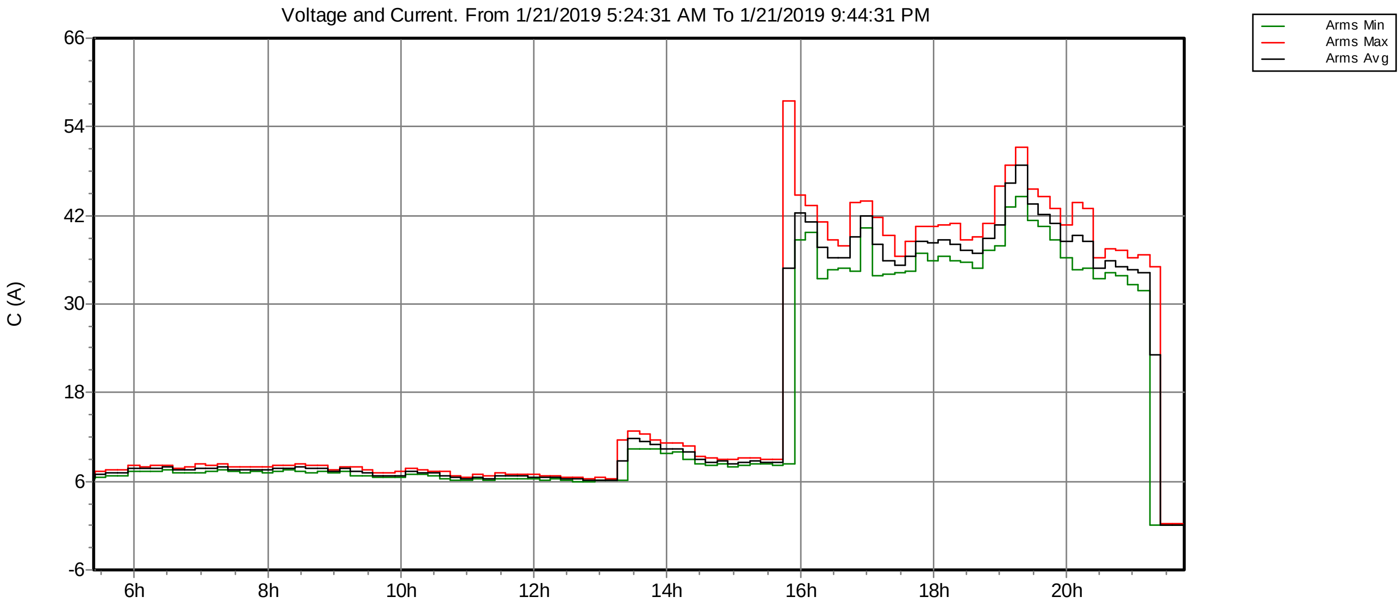

Voltage and Current. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
484
476
468
460
452
444
436
AB (V)
6h
8h
10h
12h
14h
16h
18h
20h
Vrms ph-ph Min
Vrms ph-ph Max
Vrms ph-ph Avg

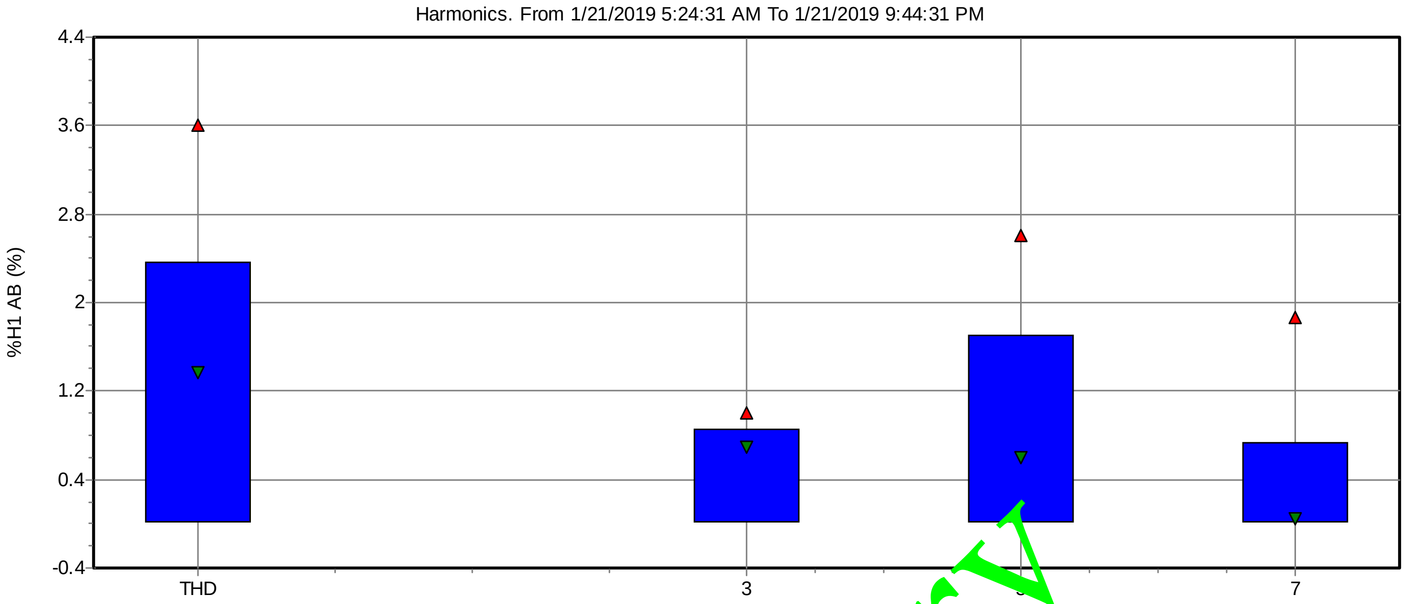

Voltage and Current. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
490
470
450
430
410
390
370
BC (V)
6h
8h
10h
12h
14h
16h
18h
20h
Vrms ph-ph Min
Vrms ph-ph Max
Vrms ph-ph Avg

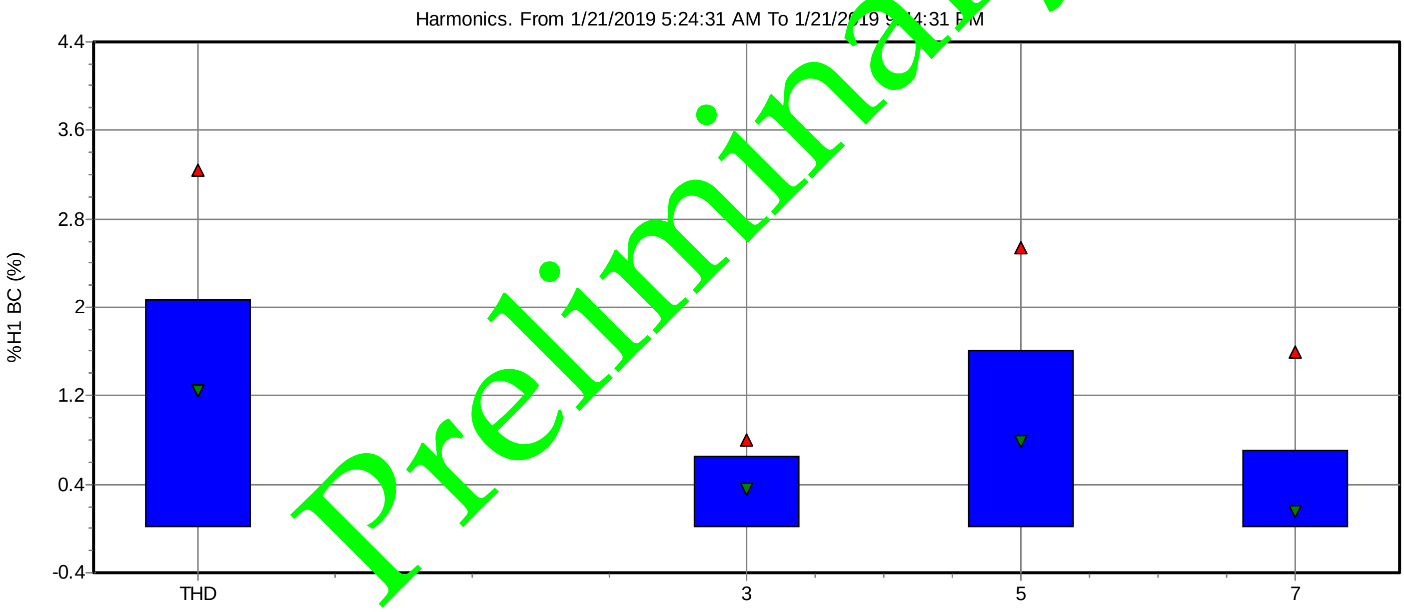

Voltage and Current. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
530
470
410
350
290
230
170
CA (V)
6h
8h
10h
12h
14h
16h
18h
20h
Vrms ph-ph Min
Vrms ph-ph Max
Vrms ph-ph Avg

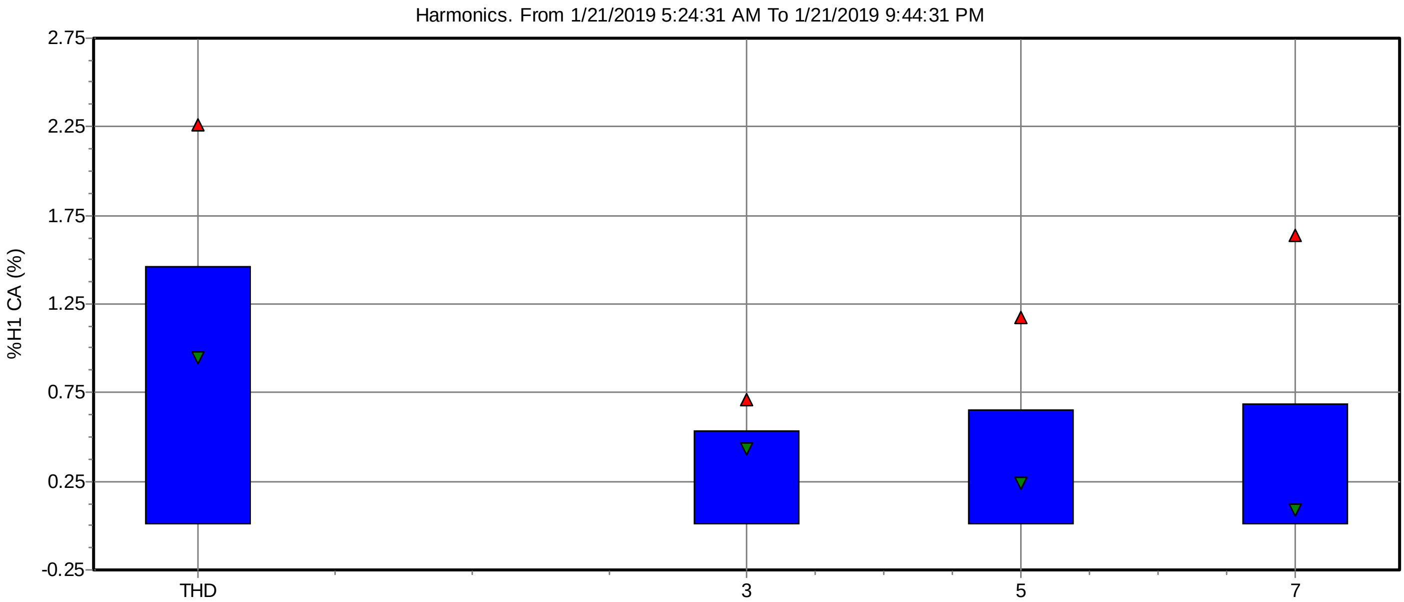

Voltage and Current. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
A (A)
66
54
42
30
18
6
-6
6h
8h
10h
12h
14h
16h
18h
20h
Arms Min
Arms Max
Arms Avg

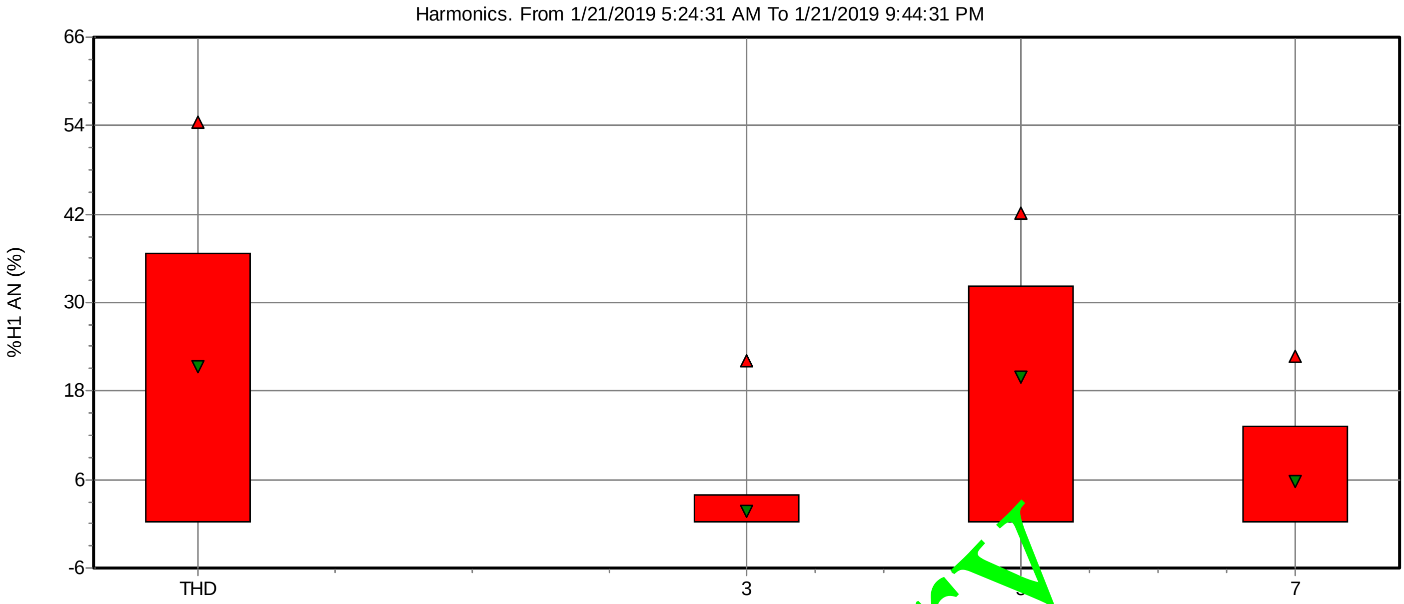

Voltage and Current. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
B (A)
66
54
42
30
18
6
-6
6h
8h
10h
12h
14h
16h
18h
20h
Arms Min
Arms Max
Arms Avg

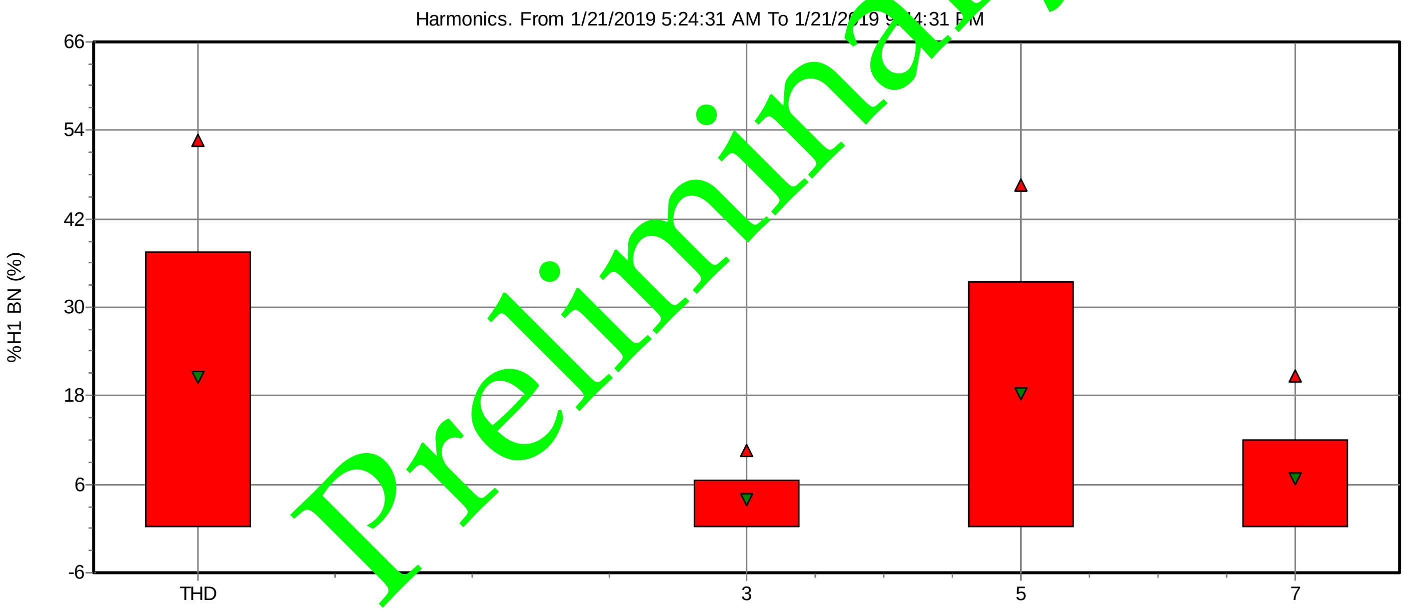

Voltage and Current. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
C (A)
66
54
42
30
18
6
-6
6h
8h
10h
12h
14h
16h
18h
20h
Arms Min
Arms Max
Arms Avg

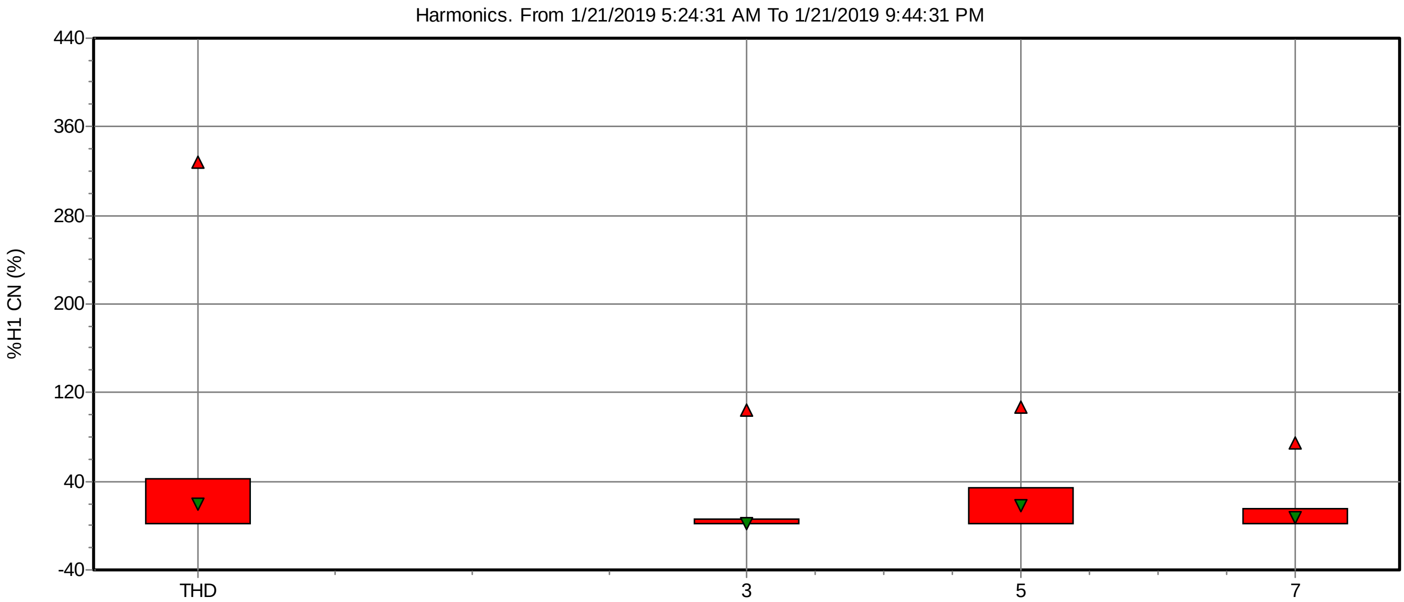

Harmonics. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
%H1 AB (%)
4.4
3.6
2.8
2
1.2
0.4
-0.4
THD
3
5
7


Harmonics. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
%H1 BC (%)
4.4
3.6
2.8
2
1.2
0.4
-0.4
THD
3
5
7

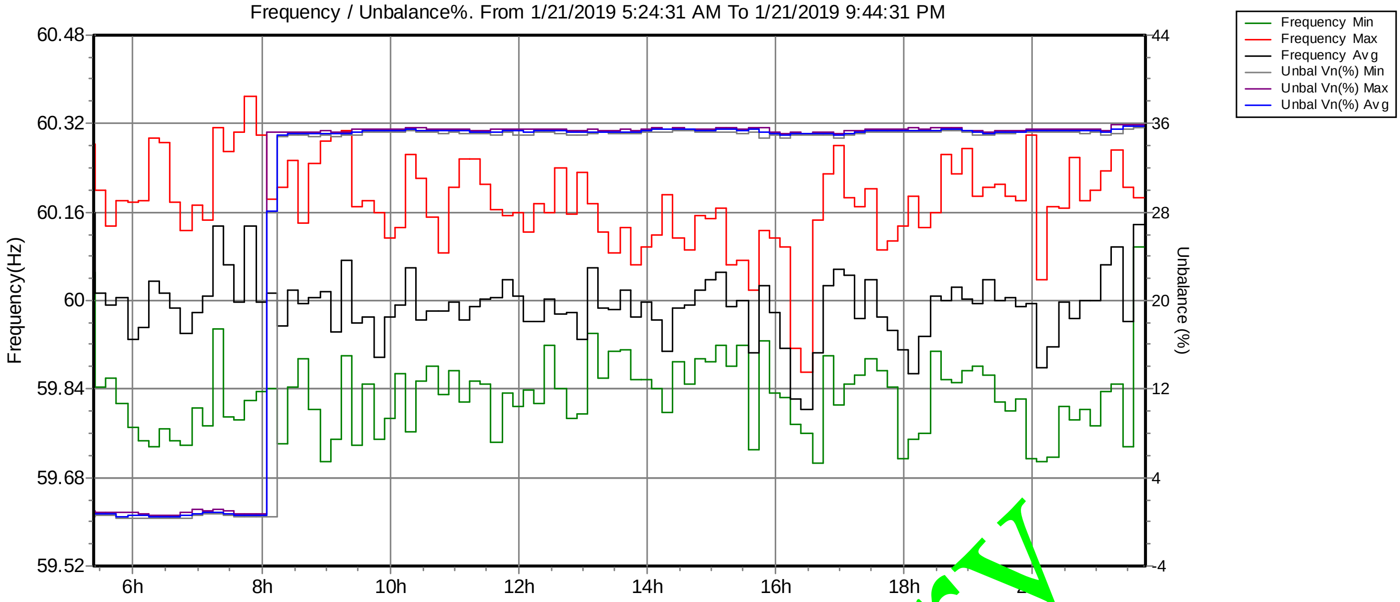

Harmonics. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
%H1 CA (%)
2.75
2.25
1.75
1.25
0.75
0.25
-0.25
THD
3
5
7


Harmonics. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
%H1 AN (%)
66
54
42
30
18
6
-6
THD
3
5
7

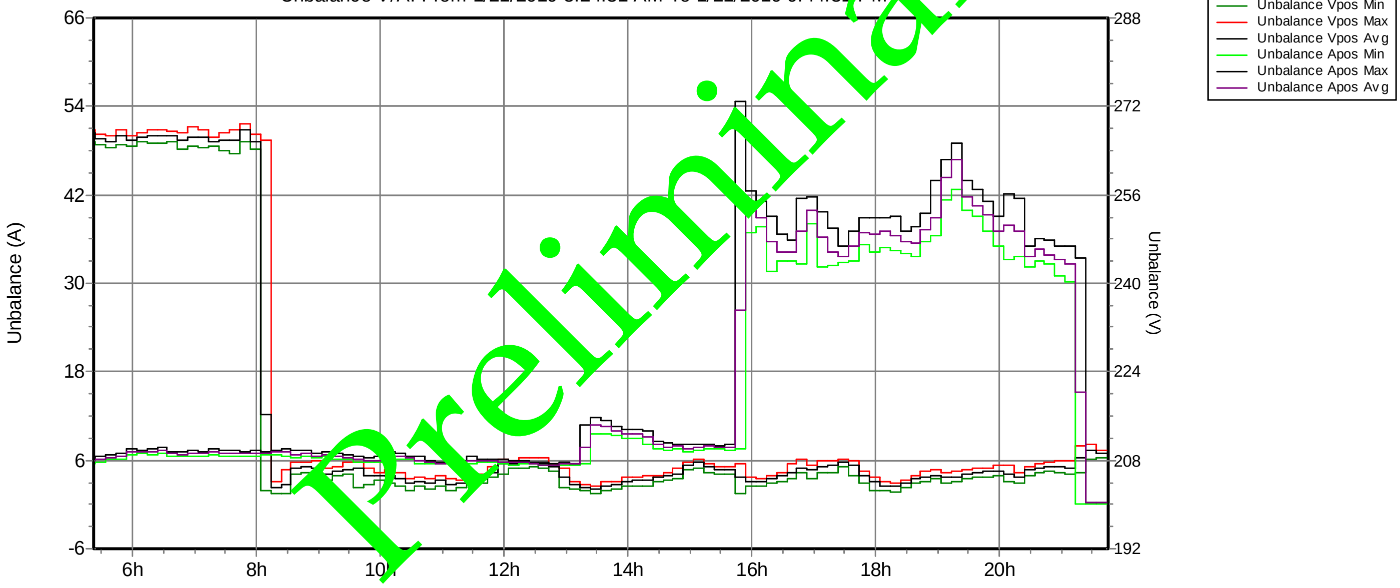

Harmonics. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
%H1 BN (%)
66
54
42
30
18
6
-6
THD
3
5
7
Preliminary


Harmonics. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
%H1 CN (%)
440
360
280
200
120
40
-40
THD
3
5
7

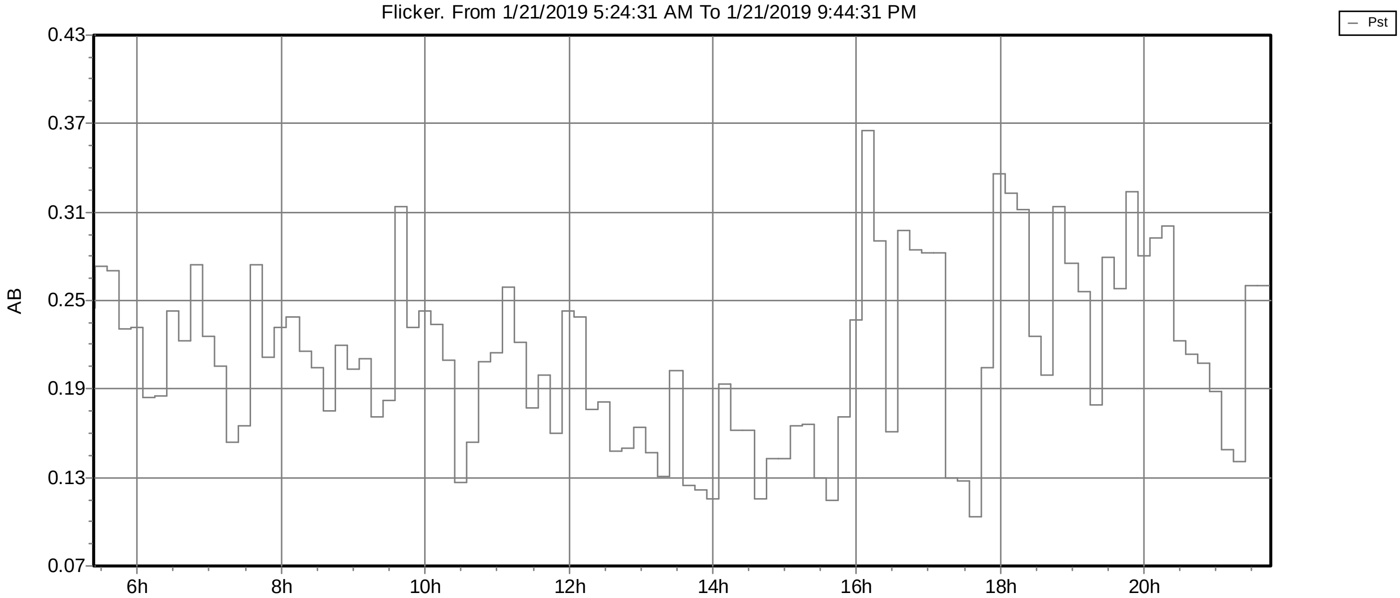
Frequency / Unbalance%. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM

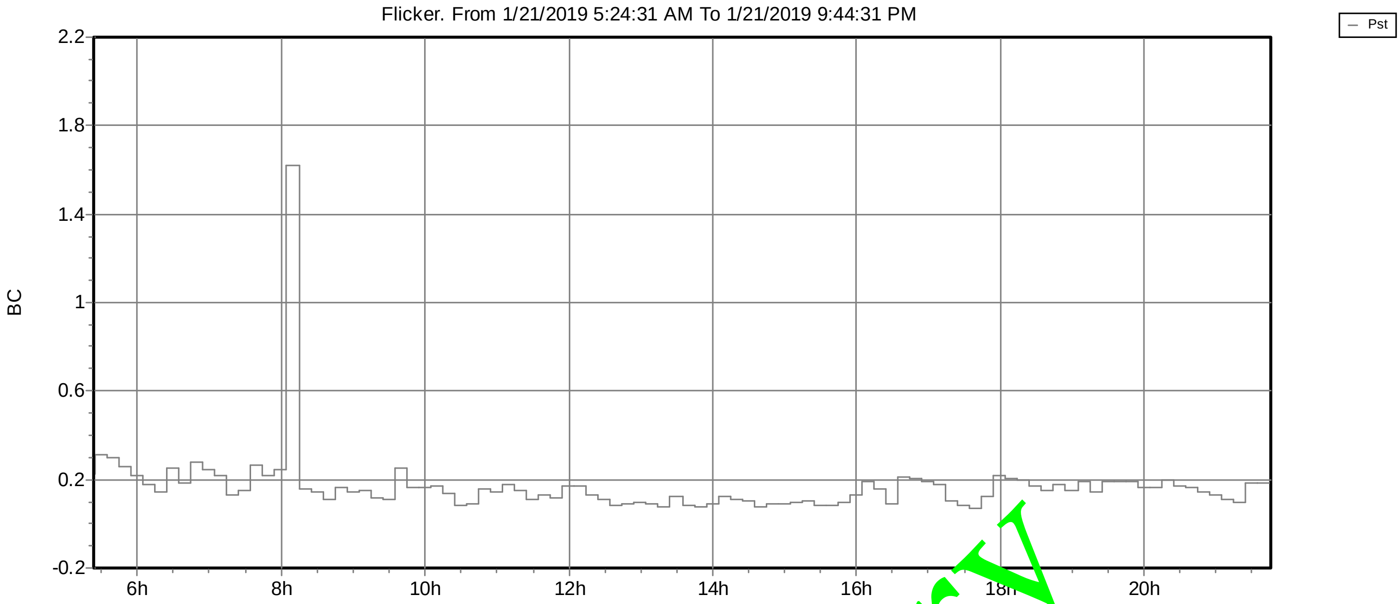


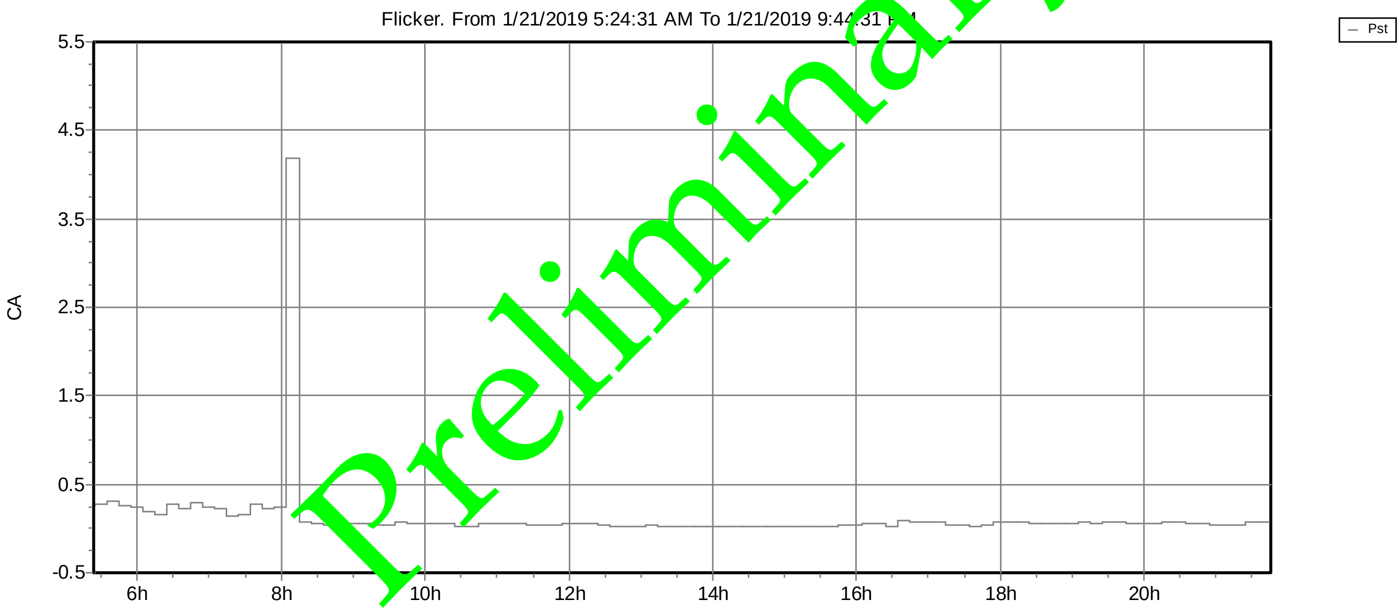
Unbalance V/A. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM

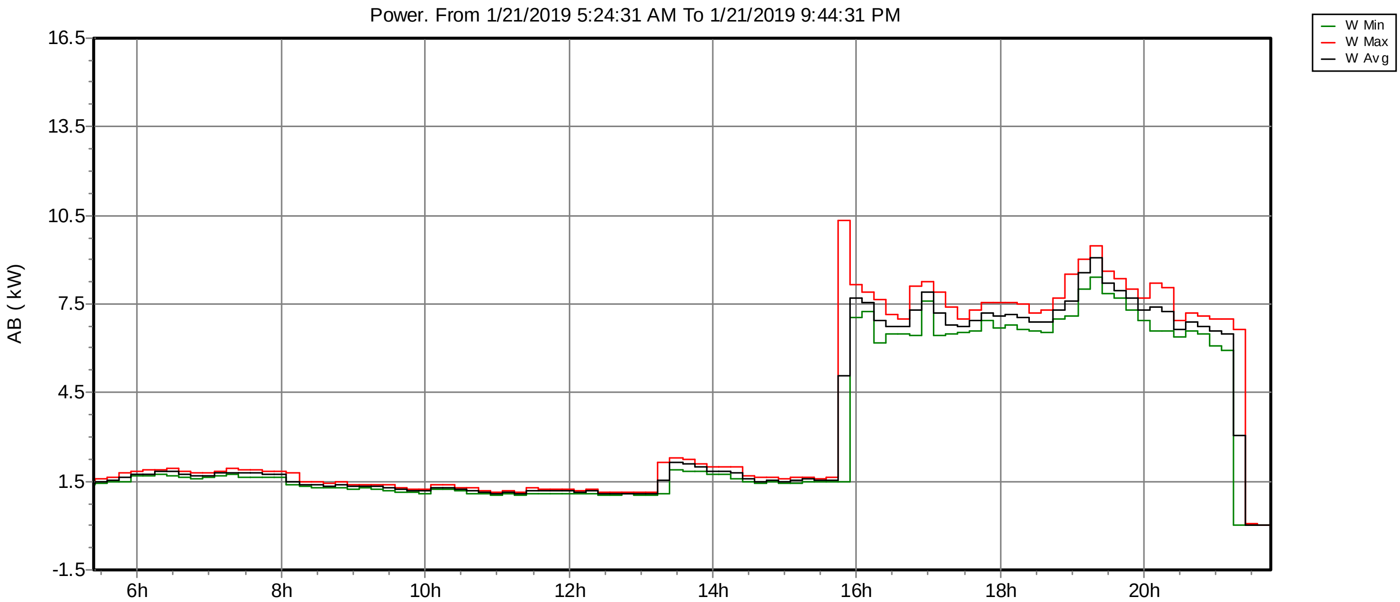


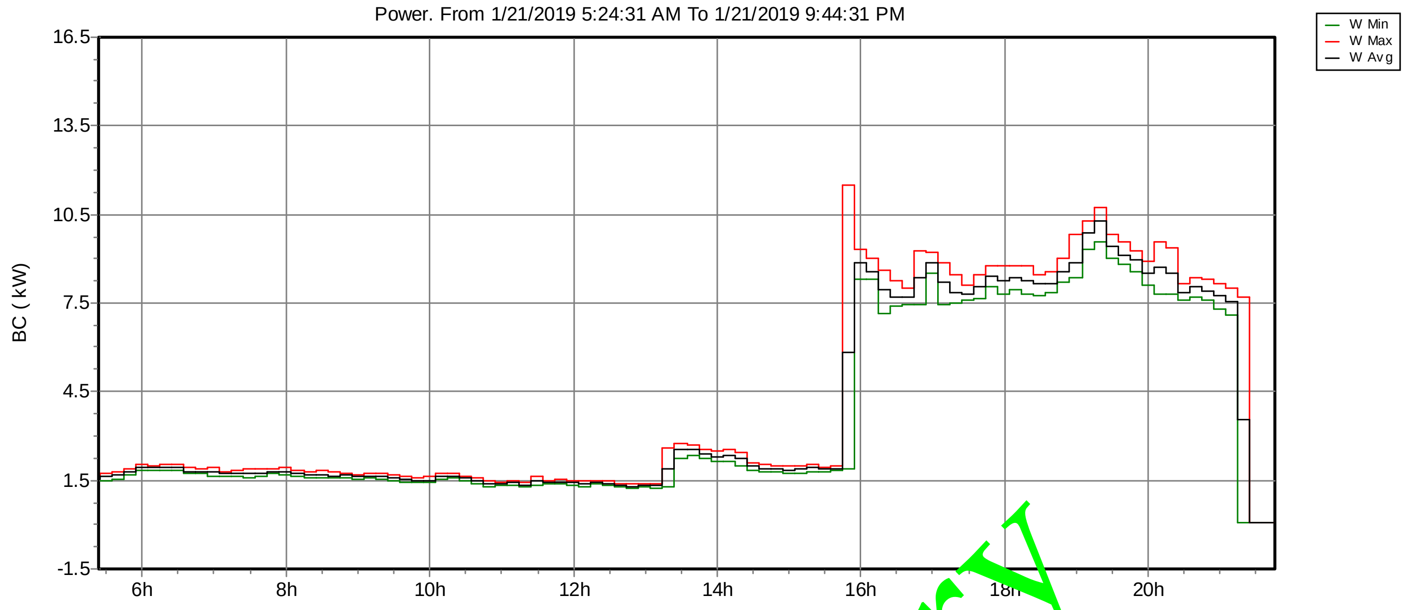
Flicker. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM

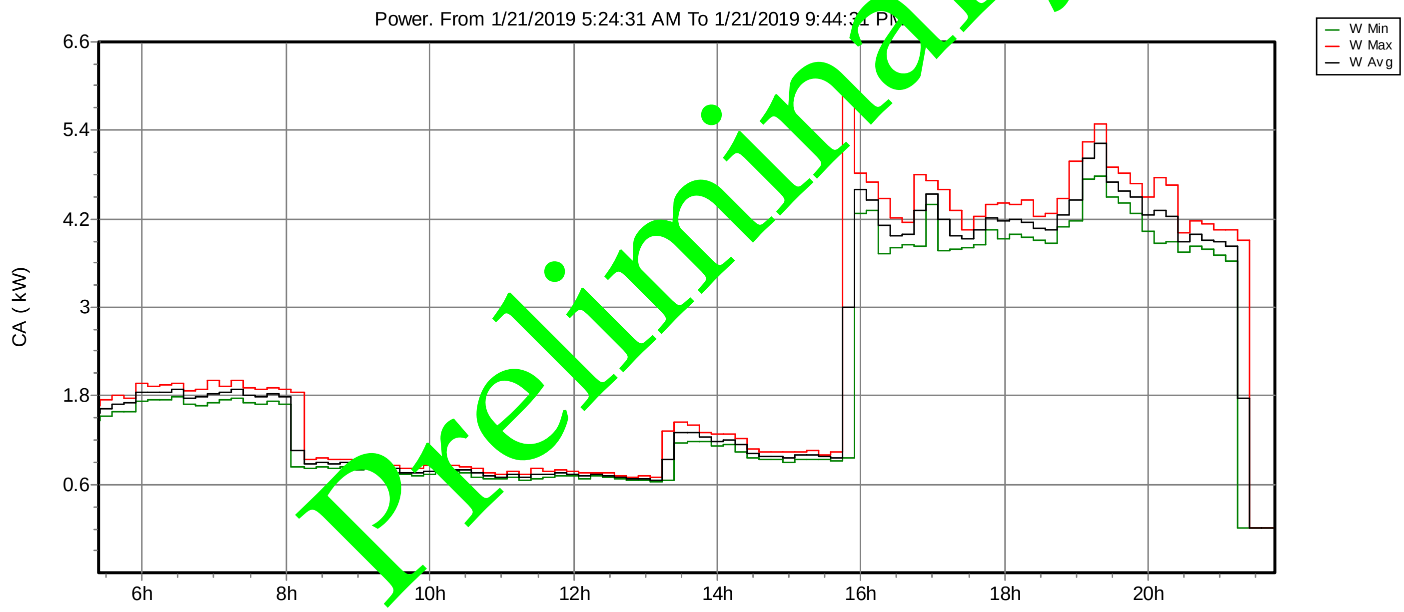


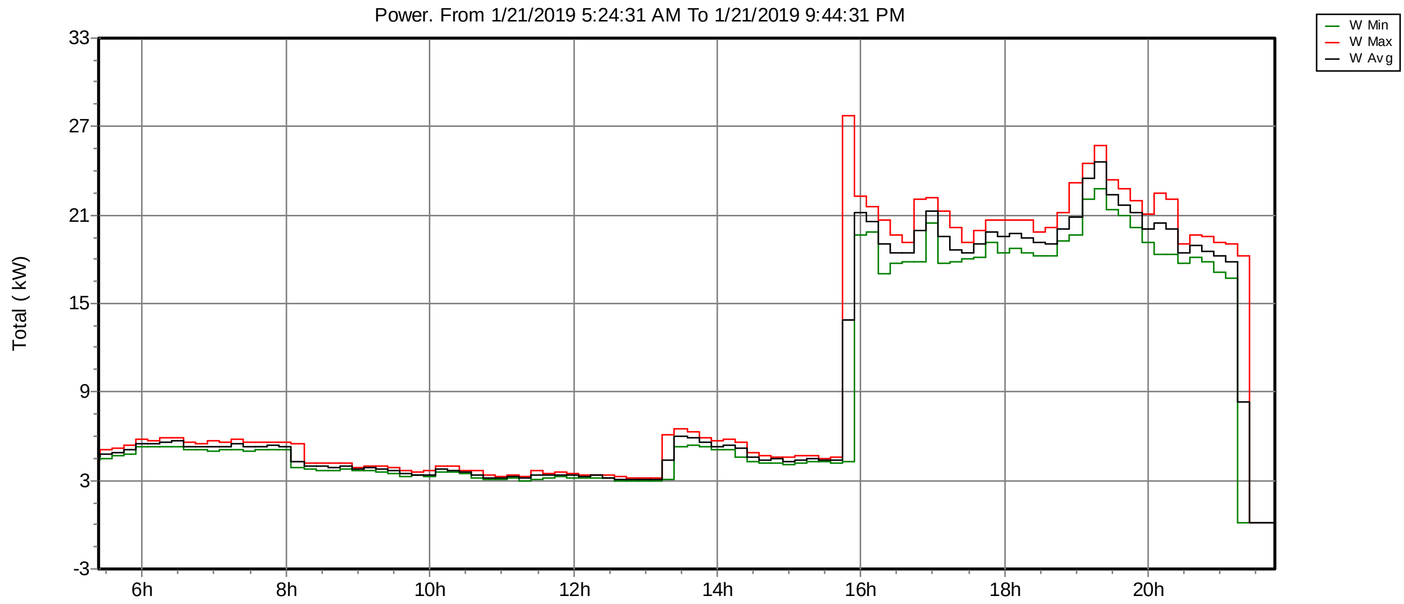

Flicker. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
Pst
BC
2.2
1.8
1.4
1
0.6
0.2
-0.2
6h
8h
10h
12h
14h
16h
18h
20h


Flicker. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
Pst
CA
5.5
4.5
3.5
2.5
1.5
0.5
-0.5
6h
8h
10h
12h
14h
16h
18h
20h

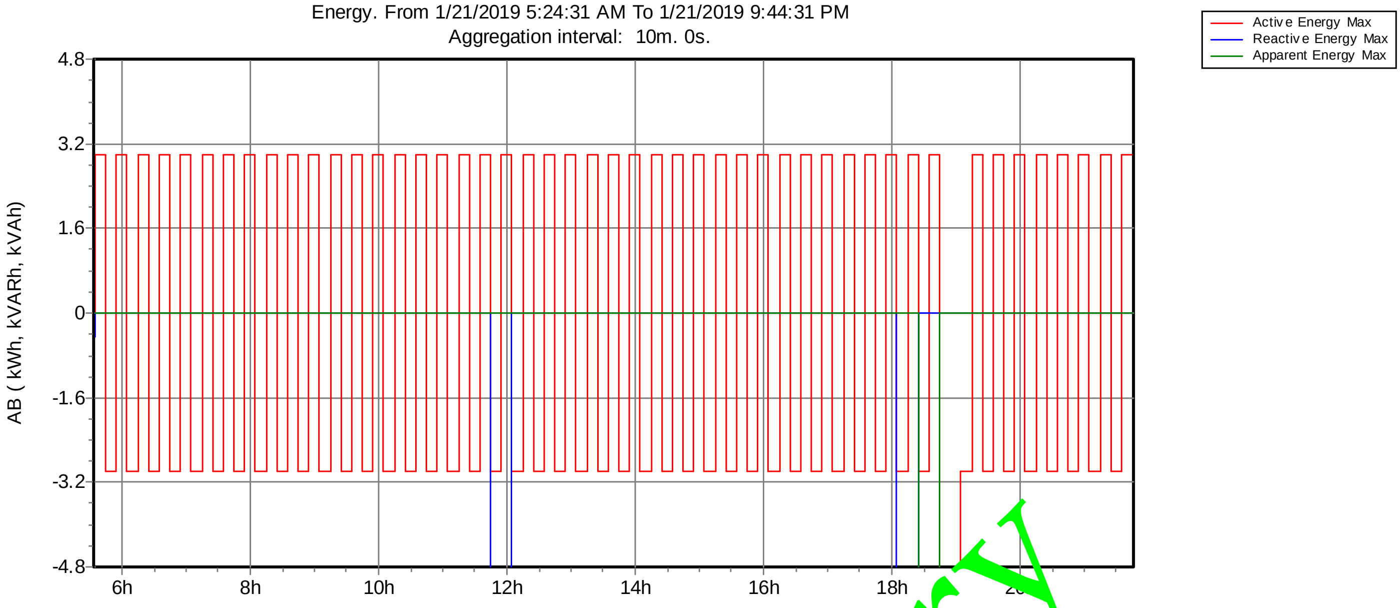

Power. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
W Min
W Max
W Avg
AB (kW)
16.5
13.5
10.5
7.5
4.5
1.5
-1.5
6h
8h
10h
12h
14h
16h
18h
20h


Power. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
BC (kW)
16.5
13.5
10.5
7.5
4.5
1.5
-1.5
6h
8h
10h
12h
14h
16h
18h
20h
W Min
W Max
W Avg

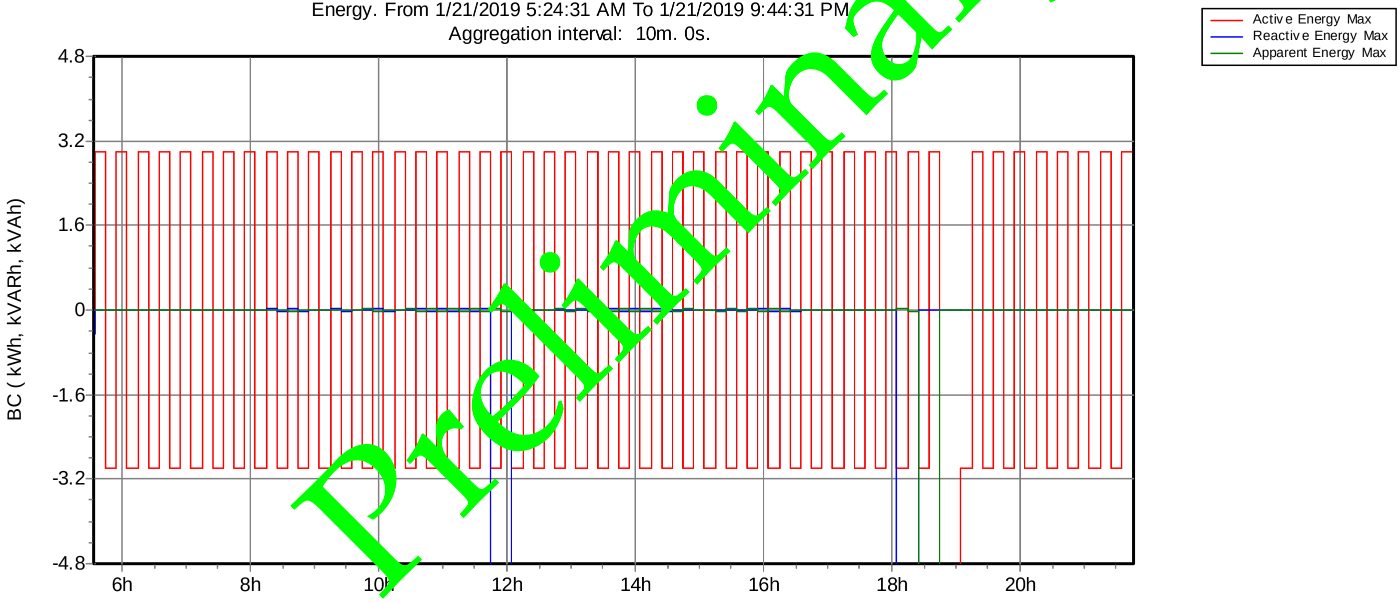

Power. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
CA (kW)
6.6
5.4
4.2
3
1.8
0.6
6h
8h
10h
12h
14h
16h
18h
20h
W Min
W Max
W Avg


Power. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
Total (kW)
33
27
21
15
9
3
-3
6h
8h
10h
12h
14h
16h
18h
20h
W Min
W Max
W Avg

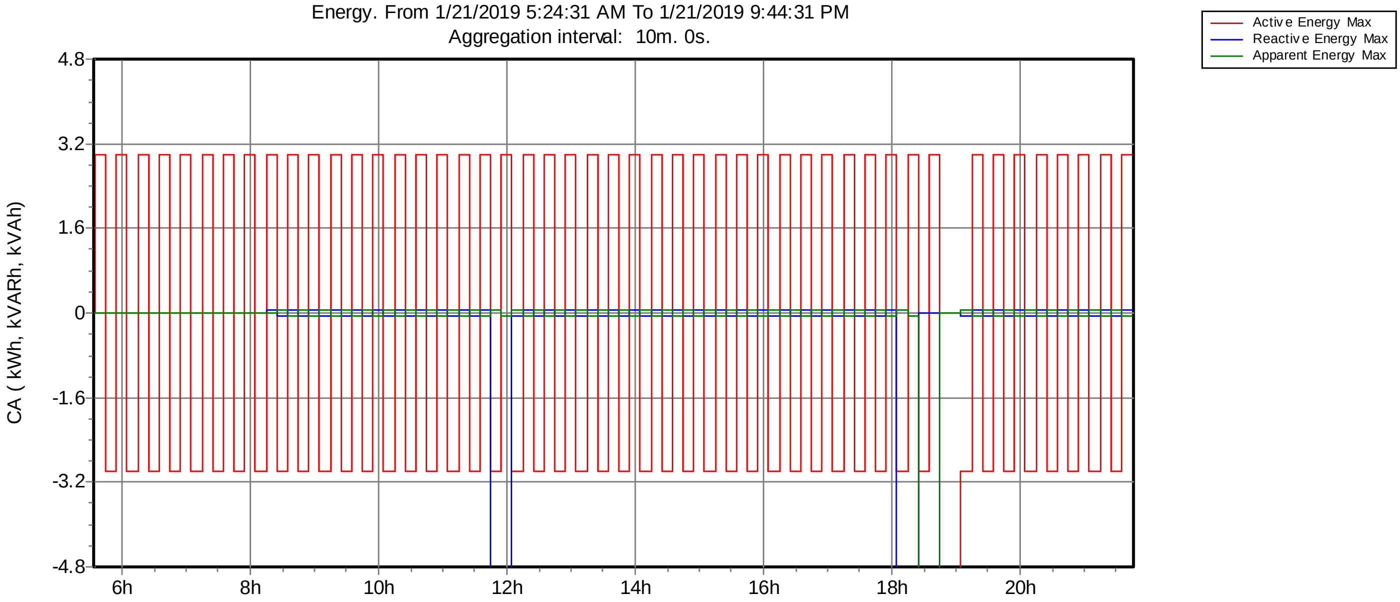
Energy. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
Aggregation interval: 10m. 0s.

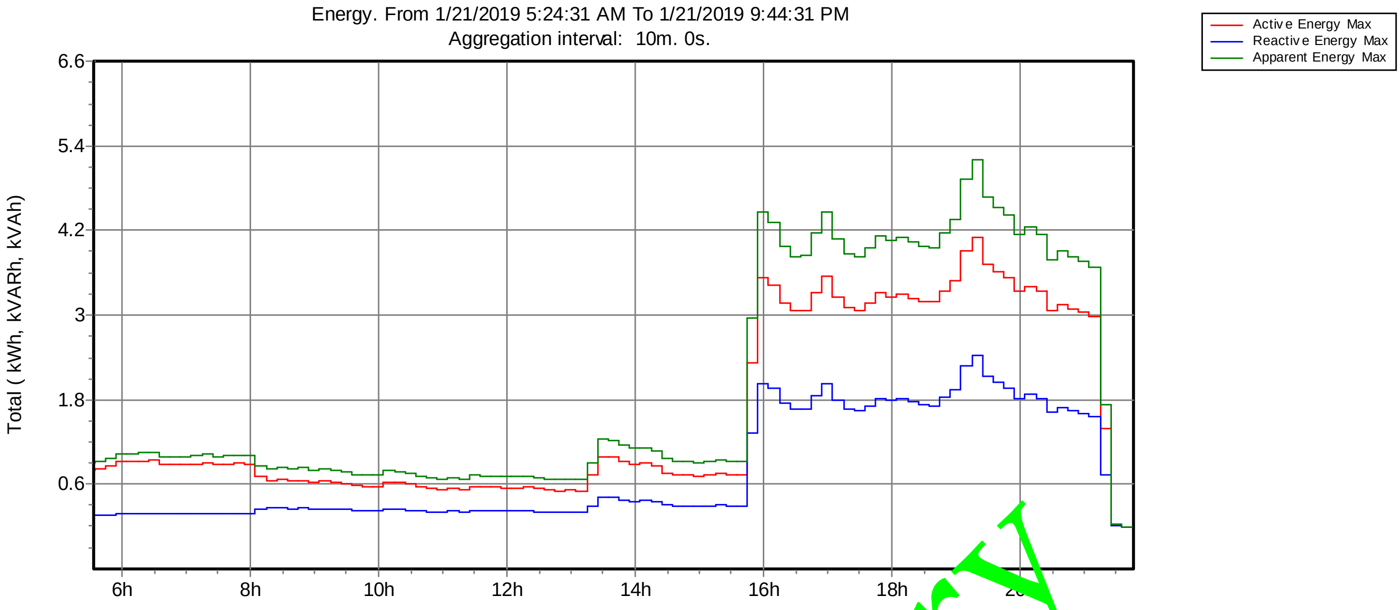


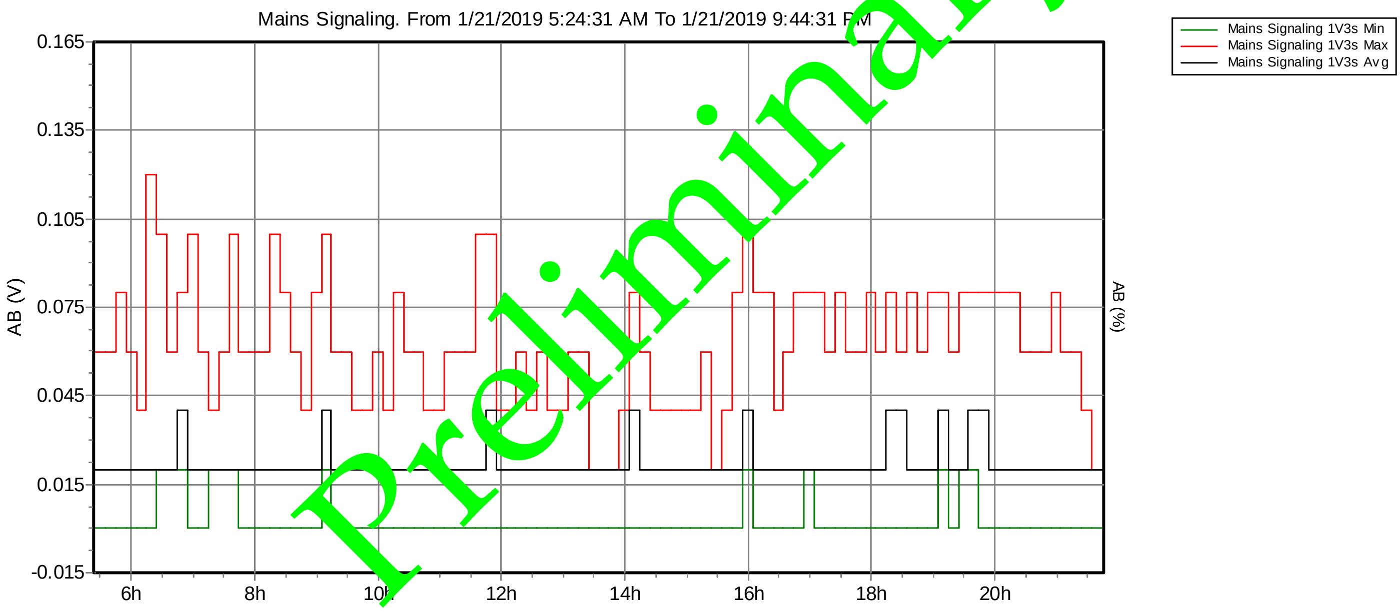
Energy. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
Aggregation interval: 10m. 0s.

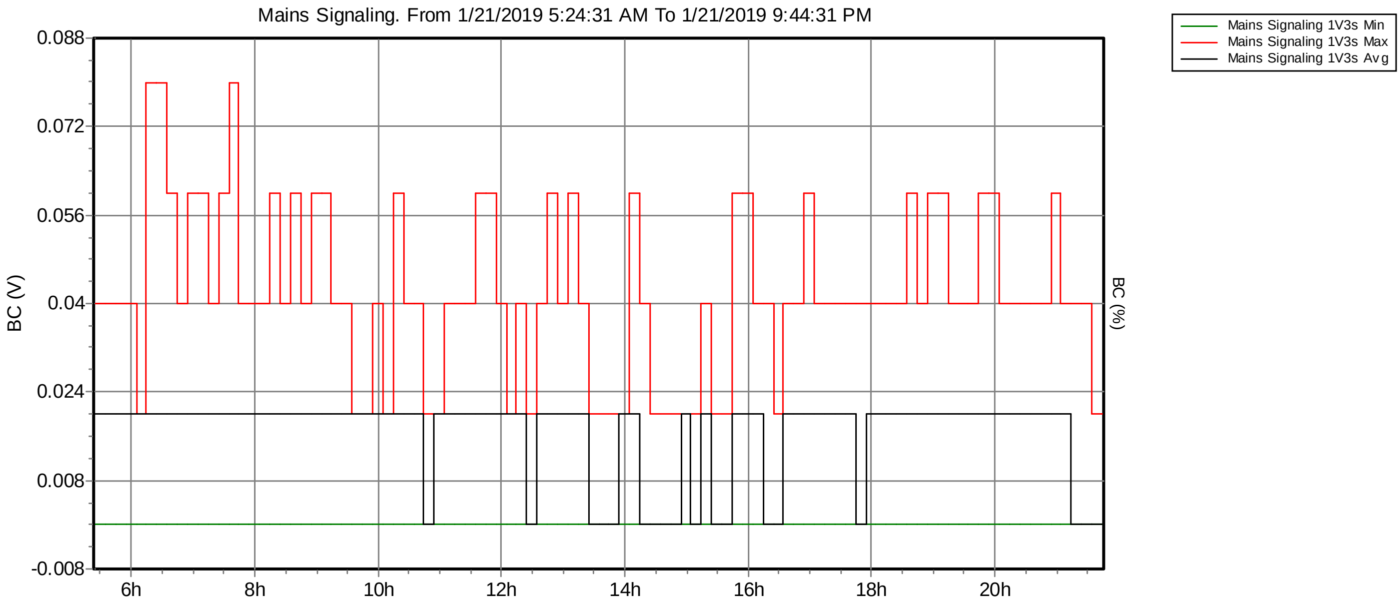


Energy. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
Aggregation interval: 10m. 0s.

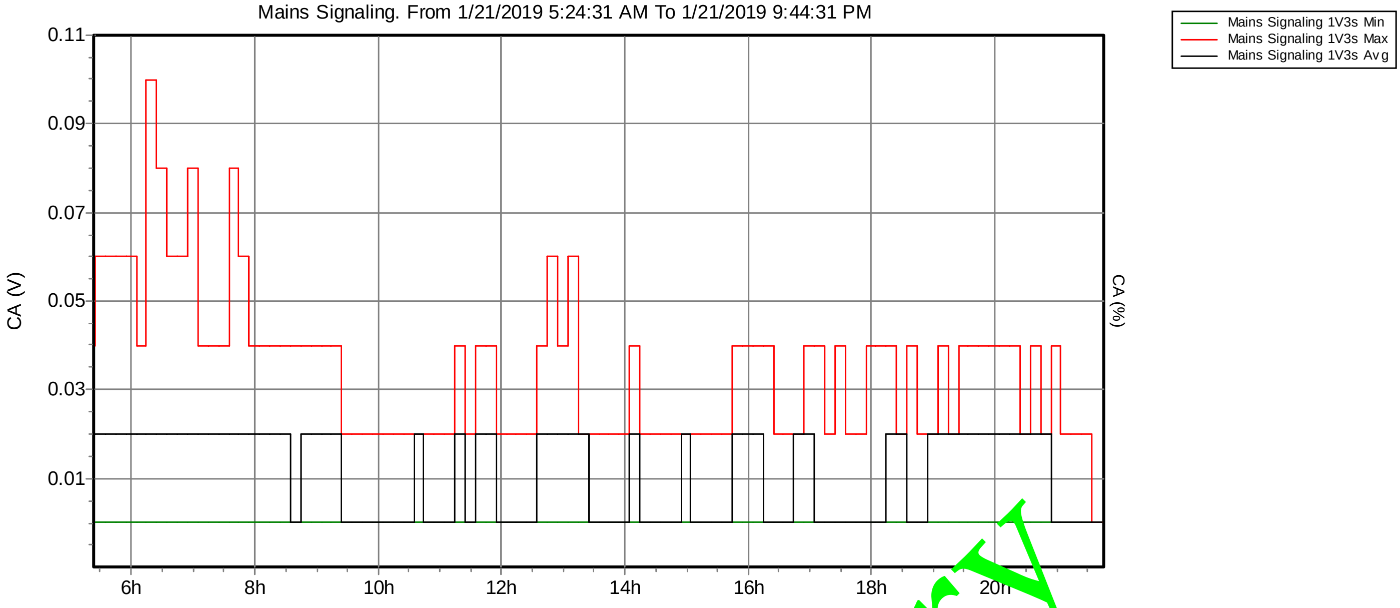



Energy. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
Aggregation interval: 10m. 0s.
Total (kWh, kVARh, kVAh)
6.6
5.4
4.2
3
1.8
0.6
6h
8h
10h
12h
14h
16h
18h
20h
Active Energy Max
Reactive Energy Max
Apparent Energy Max

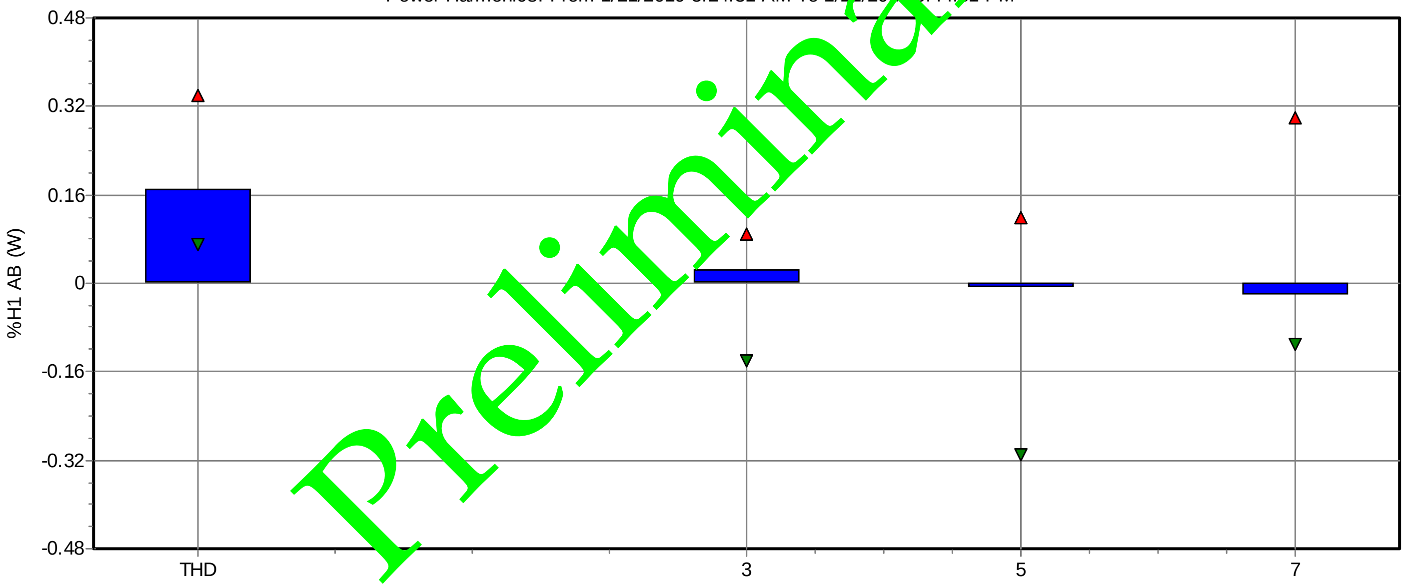

Mains Signaling. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
AB (V)
AB (%)
0.165
0.135
0.105
0.075
0.045
0.015
-0.015
6h
8h
10h
12h
14h
16h
18h
20h
Mains Signaling 1V3s Min
Mains Signaling 1V3s Max
Mains Signaling 1V3s Avg
Preliminary


Mains Signaling. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
BC (V)
BC (%)
0.088
0.072
0.056
0.04
0.024
0.008
-0.008
6h
8h
10h
12h
14h
16h
18h
20h
Mains Signaling 1V3s Min
Mains Signaling 1V3s Max
Mains Signaling 1V3s Avg

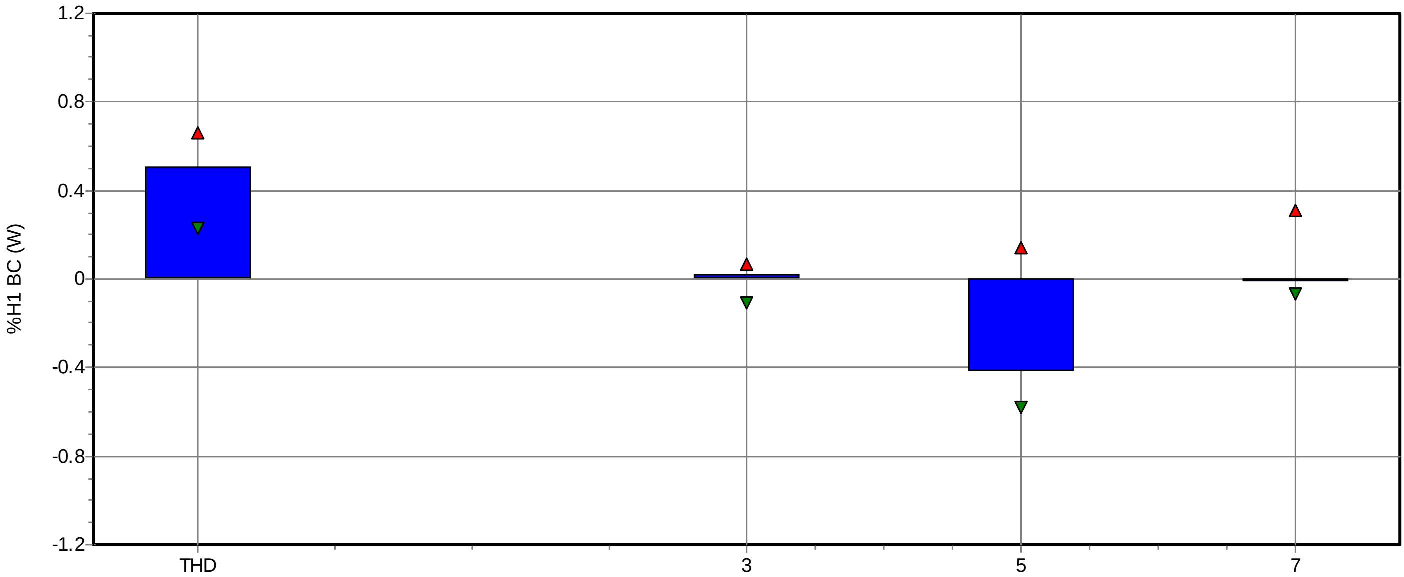
Mains Signaling. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM

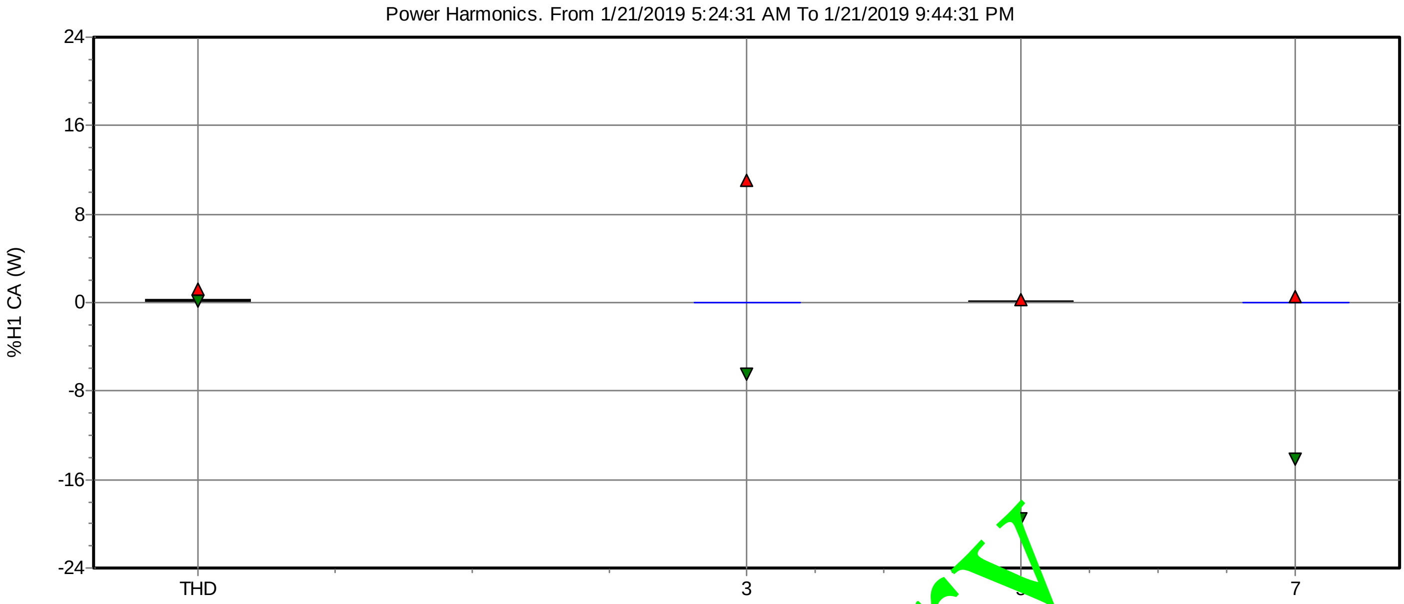


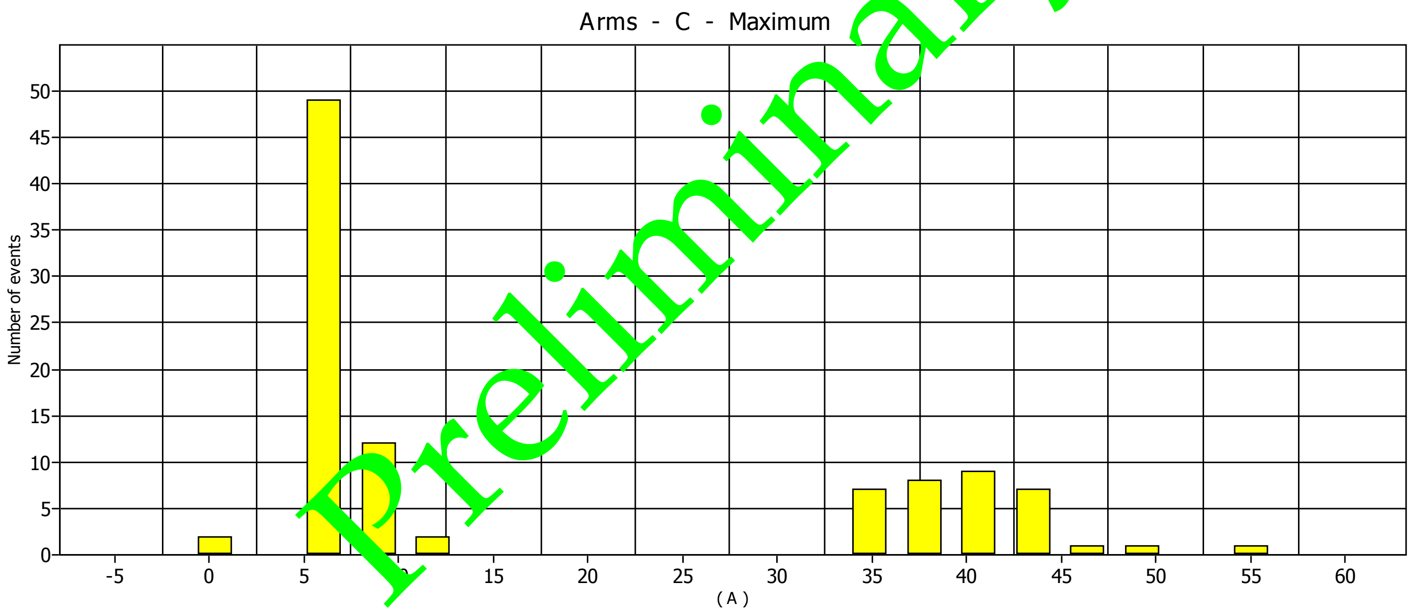
Power Harmonics. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM



Power Harmonics. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM




Power Harmonics. From 1/21/2019 5:24:31 AM To 1/21/2019 9:44:31 PM
%H1 CA (W)
24
16
8
0
-8
-16
-24
THD
3
7


Arms - C - Maximum
Number of events
50
45
40
35
30
25
20
15
10
5
0
-5
0
5
15
20
25
30
35
40
45
50
55
60
(A)

Instrument Information

Model Number	435-II
Serial Number	41183106
Firmware Revision	V05.04

Software Information

Power Log Version	5.4
FLUKE 430-II DLL Version	1.2.0.13

General Information

Recording location	FEEDER VFD-2
Client	MAYNILAD CHERRY IN LINE PUMP STATION
Notes	Naval Base Heracleo Alano Sangley Point Cavite City

Measurement Summary

Measurement topology	3-element delta mode
Application mode	Logger
First recording	11/29/2018 2:47:07 PM 168msec
Last recording	11/30/2018 12:57:07 AM 168msec
Recording interval	0h 10m 0s 0msec
Nominal Voltage	460 V
Nominal Current	100 A
Nominal Frequency	60 Hz
File start time	11/29/2018 2:37:07 PM 168msec
File end time	11/30/2018 12:57:07 AM 168msec
Duration	0d 10h 20m 0s 0msec
Number of events	Normal: 0 Detailed: 0
Events downloaded	No
Number of screens	1
Screens downloaded	Yes
Power measurement method	Unified
Cable type	Copper
Harmonic scale	%H1
THD mode	THD 40
CosPhi / DPF mode	DPF

Scaling

Phase:	
Current Clamp type	i430TF
Clamp range	N/A
Nominal range	100 A
Sensitivity	x10 AC only
Current ratio	1:1
Voltage ratio	1:1
Neutral:	
Current Clamp type	i430Flex
Clamp range	N/A
Nominal range	100 A
Sensitivity	x10 AC only
Current ratio	1:1
Voltage ratio	1:1

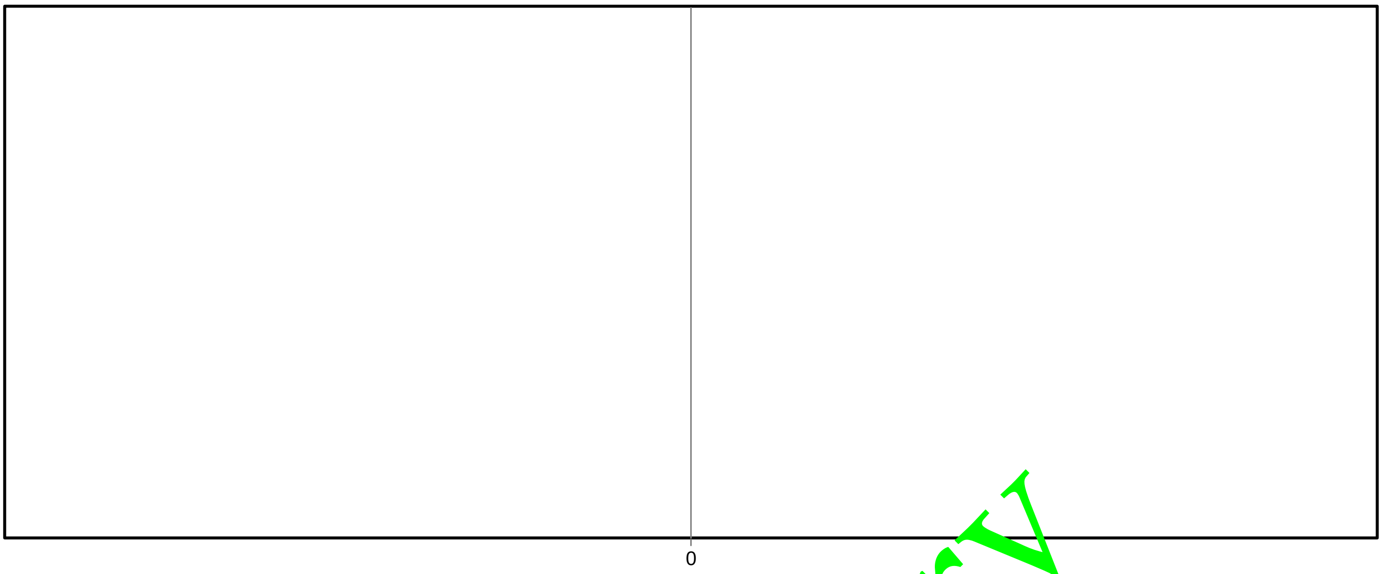
Recording Summary

RMS recordings	62
DC recordings	0
Frequency recordings	62
Unbalance recordings	62
Harmonic recordings	62
Power harmonic recordings	62
Power recordings	62
Power unbalance recordings	0
Energy recordings	62
Energy losses recordings	0
Flicker recordings	62
Mains signaling recordings	62

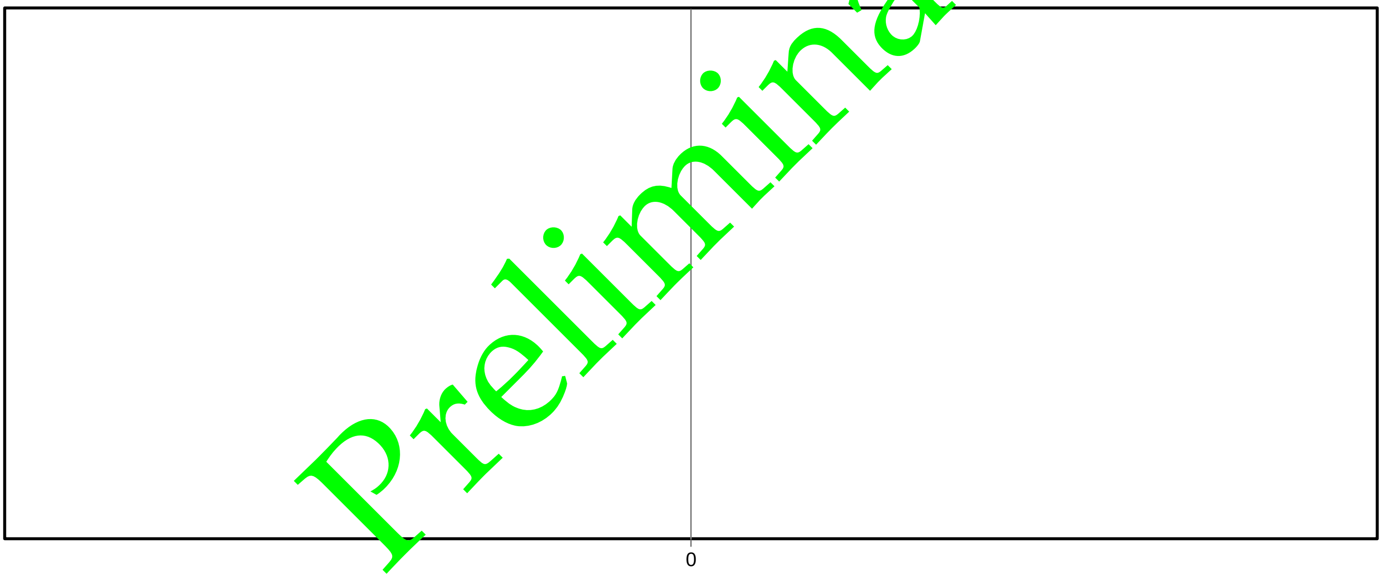
Events Summary

Dips	0
Swells	0
Transients	0
Interruptions	0
Voltage profiles	0
Rapid voltage changes	0
Screens	1
Waveforms	0
Intervals without measurements	0
Inrush current graphics	0
Wave events	0
RMS events	0

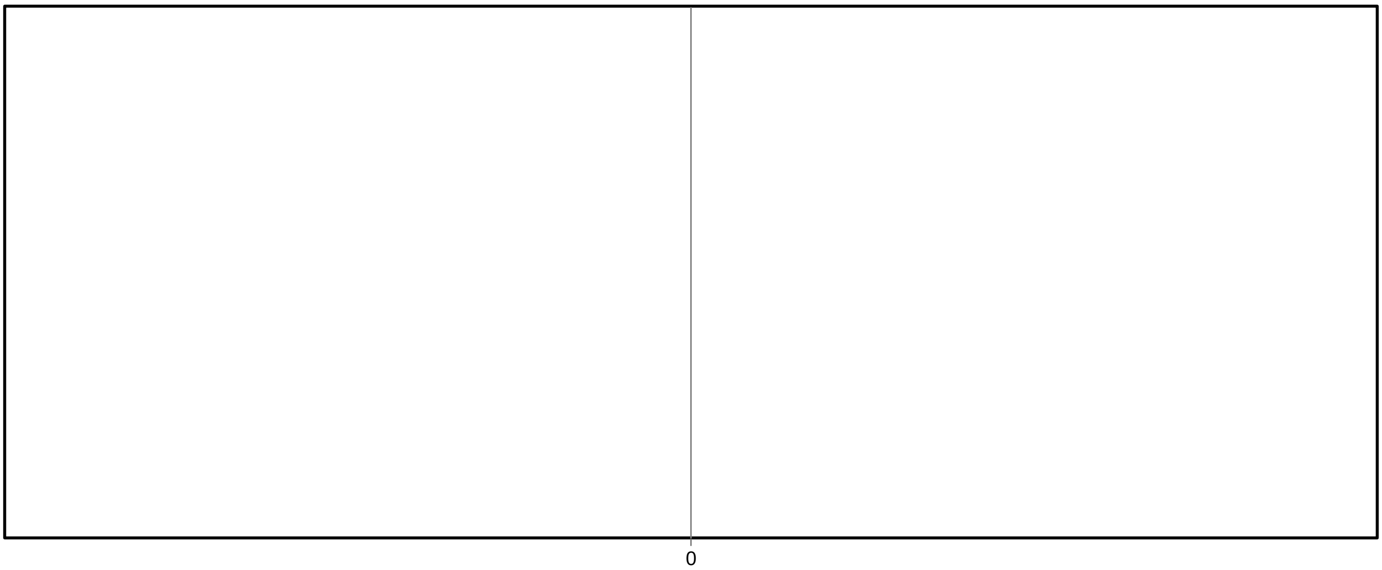
Voltage and Current. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



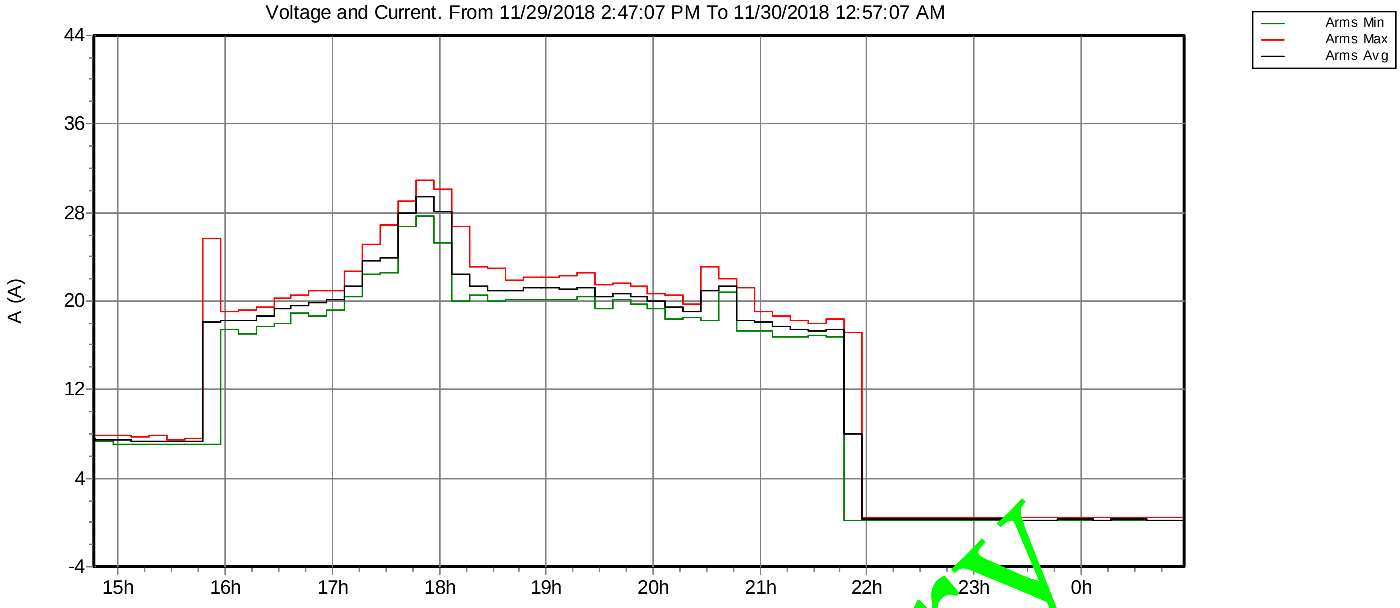
Voltage and Current. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



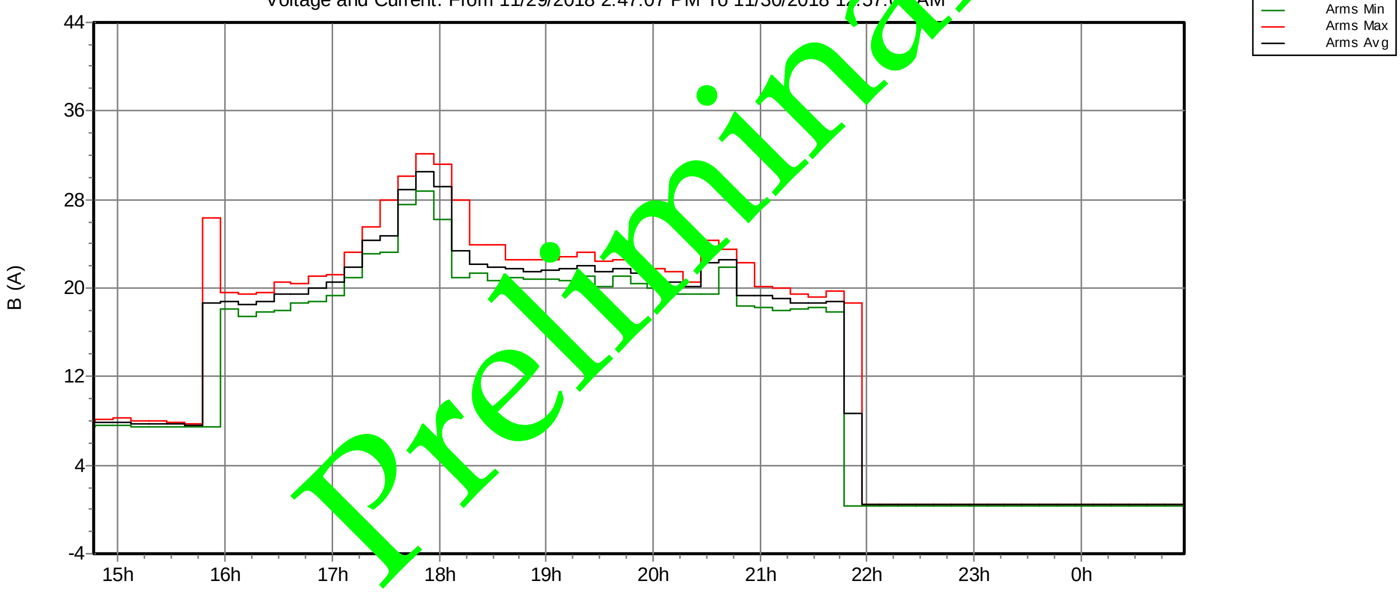
Voltage and Current. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



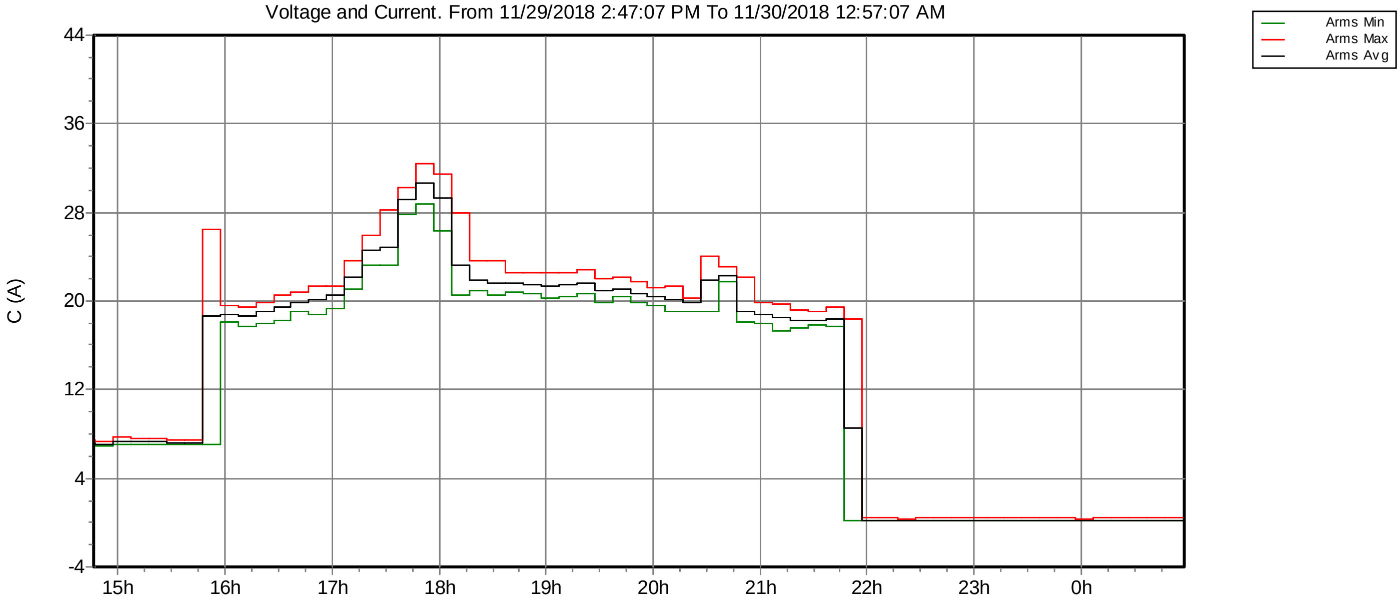
Voltage and Current. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM

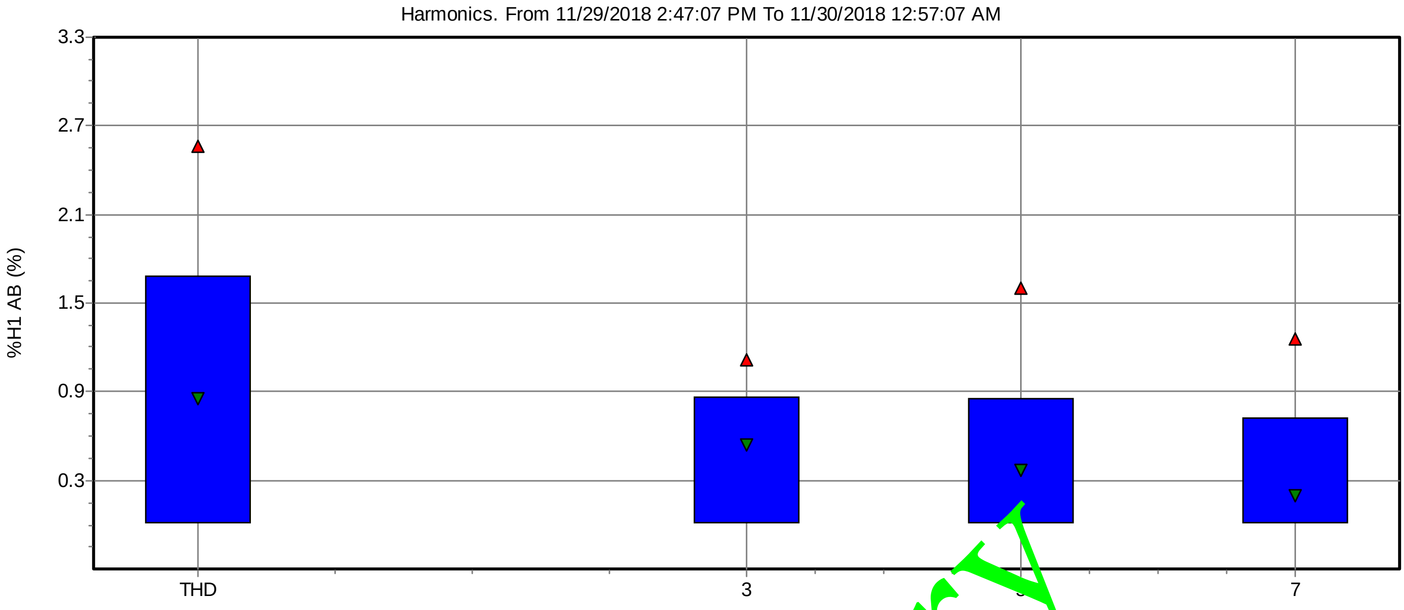


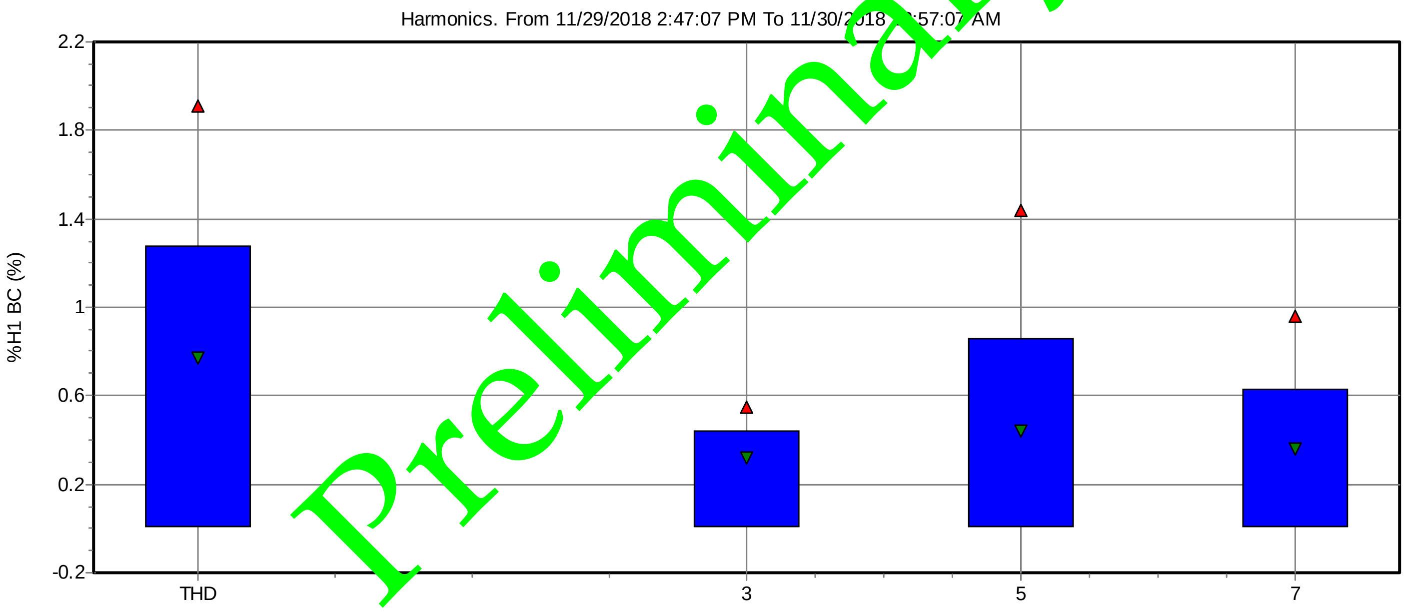
Voltage and Current. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM

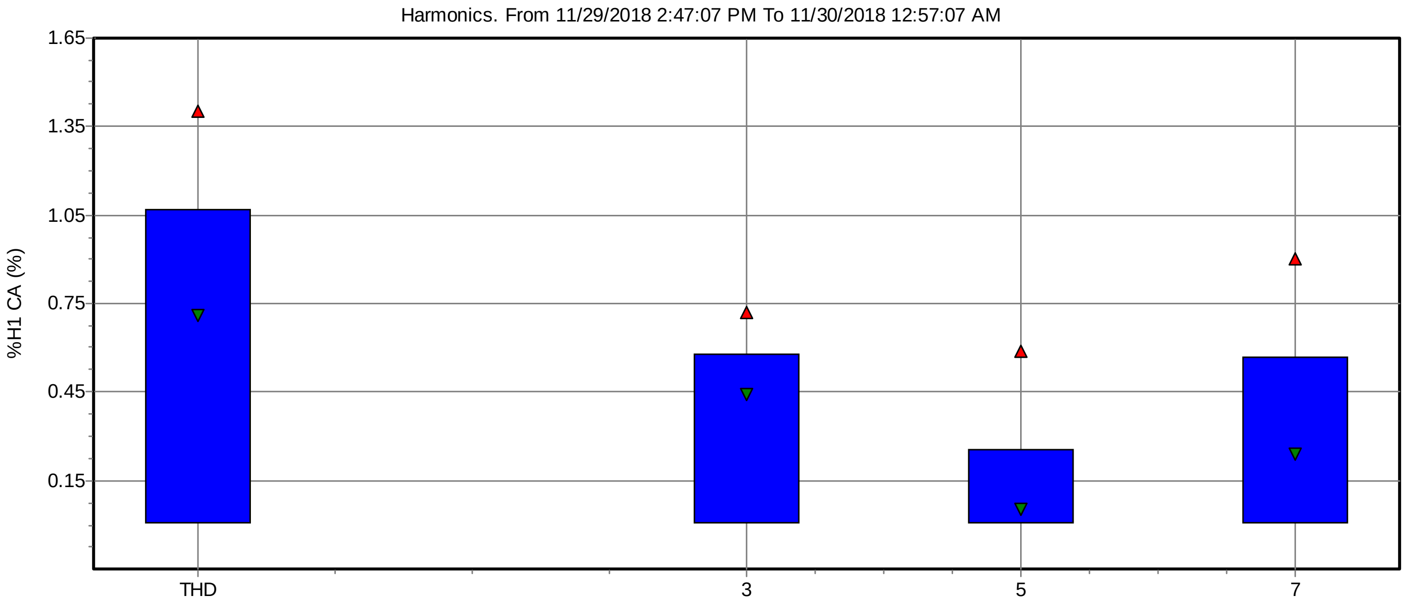


Voltage and Current. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM

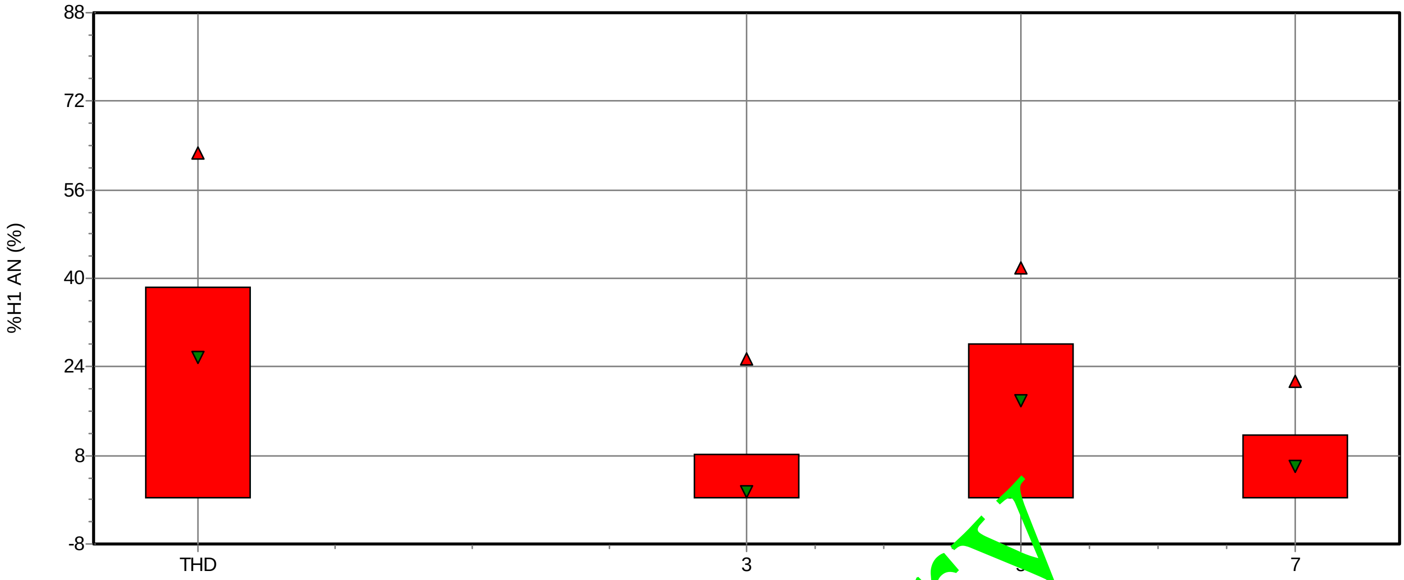



Harmonics. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
%H1 AB (%)
3.3
2.7
2.1
1.5
0.9
0.3
THD
3
7

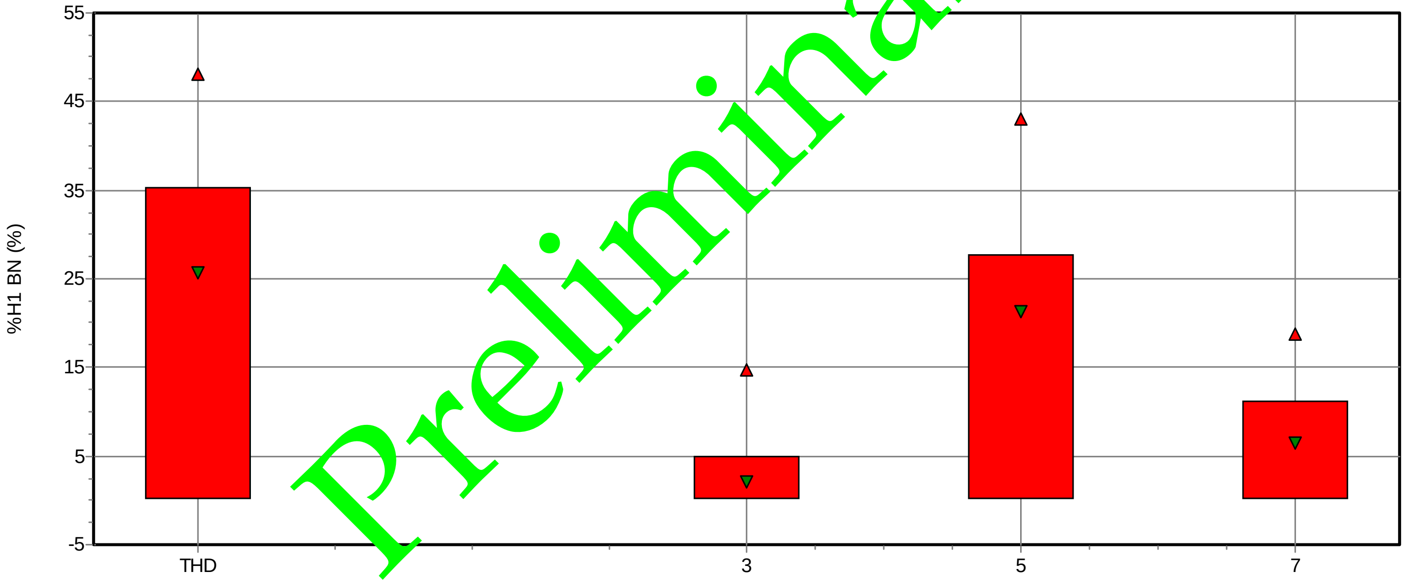

Harmonics. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
%H1 BC (%)
2.2
1.8
1.4
1
0.6
0.2
-0.2
THD
3
5
7


Harmonics. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
%H1 CA (%)
1.65
1.35
1.05
0.75
0.45
0.15
THD
3
5
7

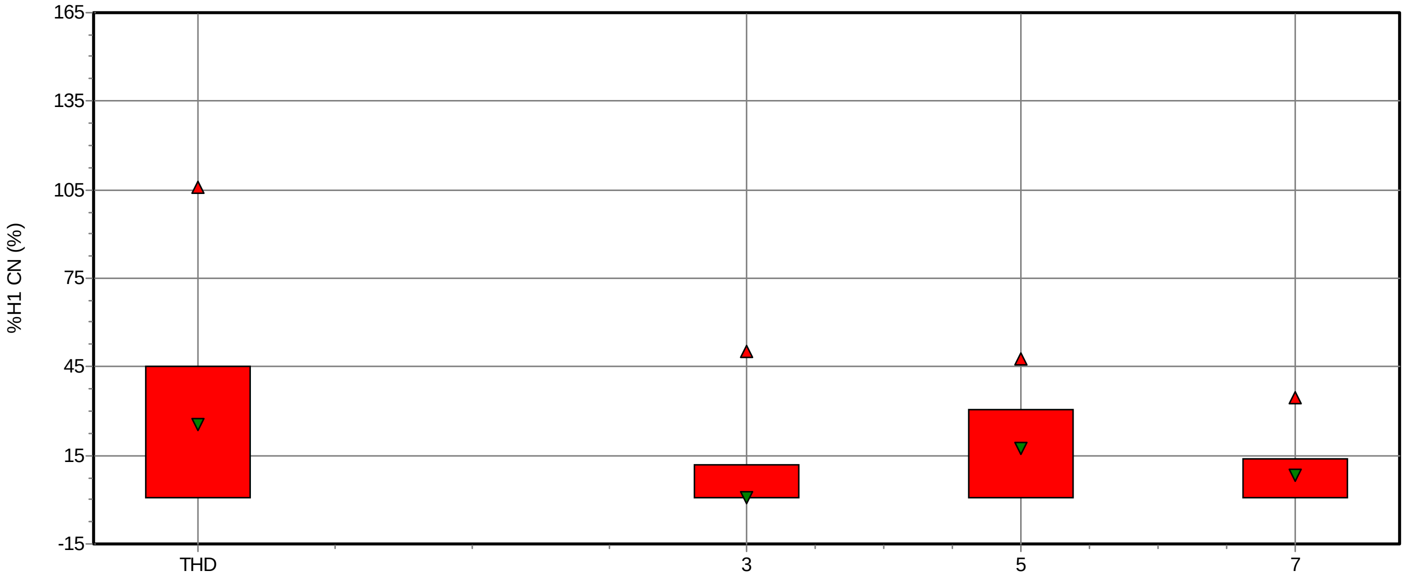
Harmonics. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



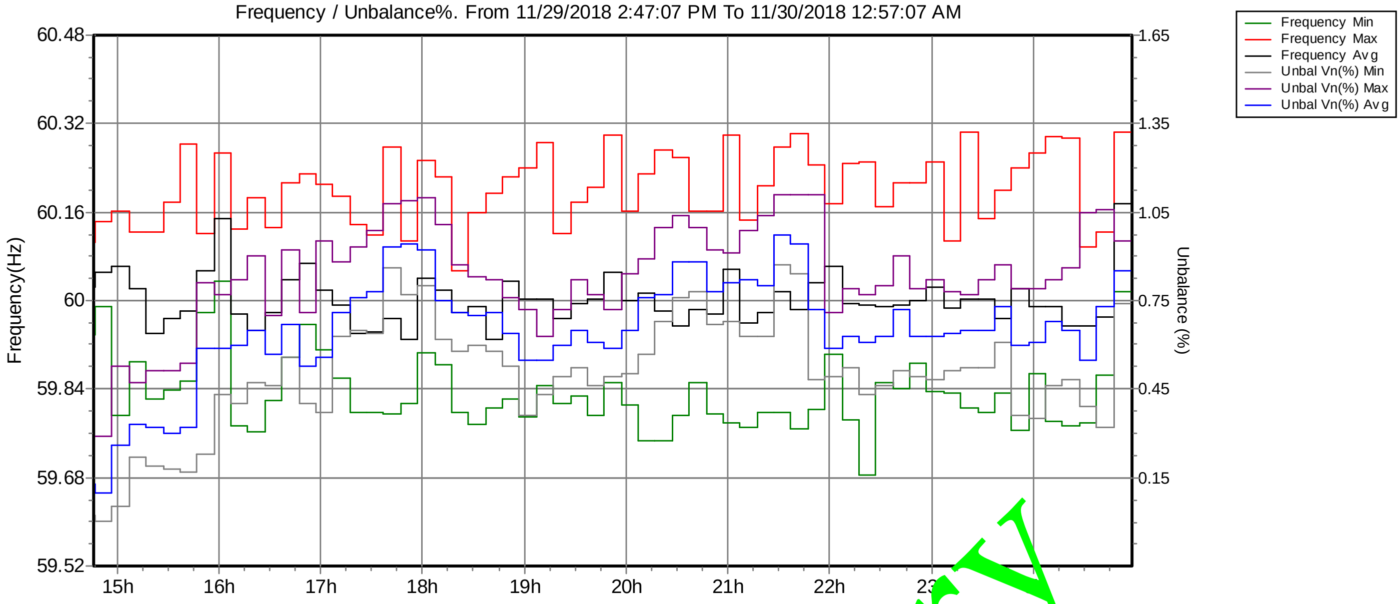
Harmonics. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



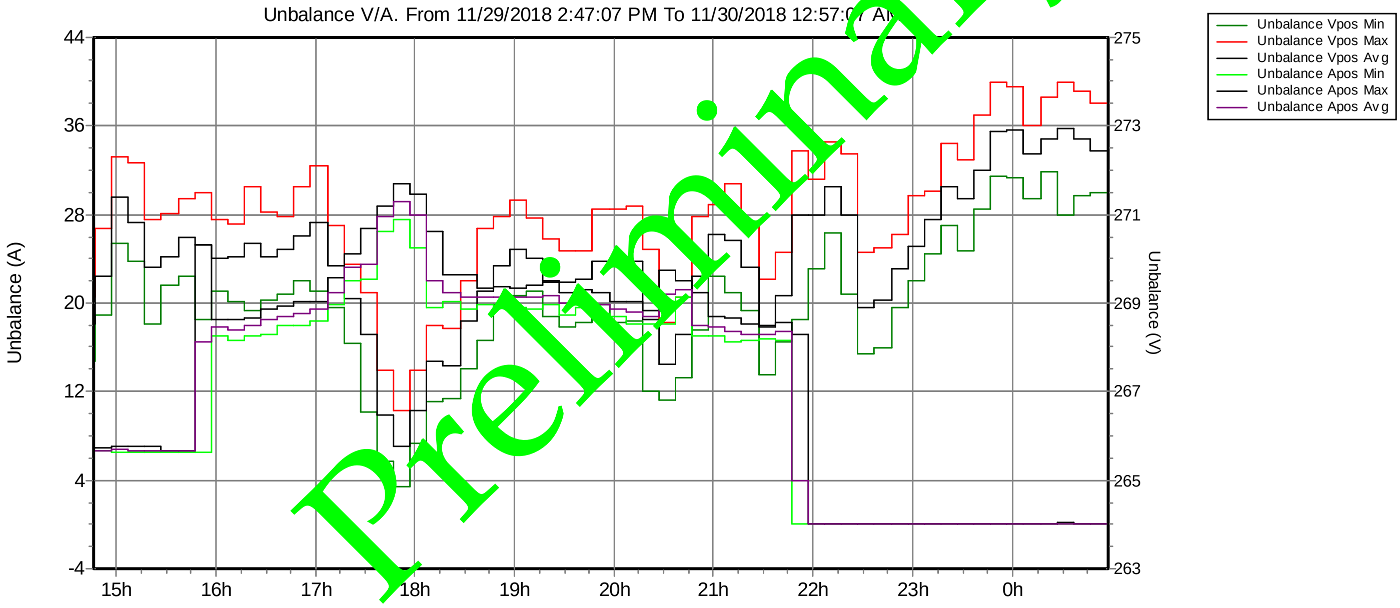
Harmonics. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



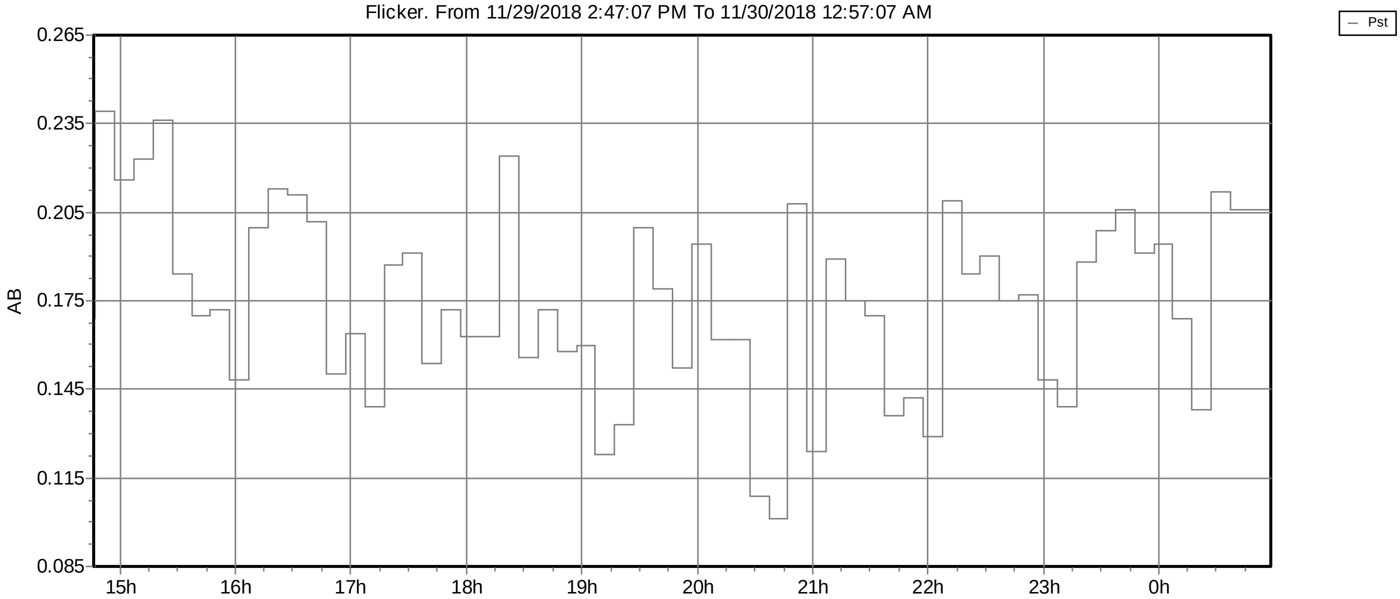
Frequency / Unbalance%. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



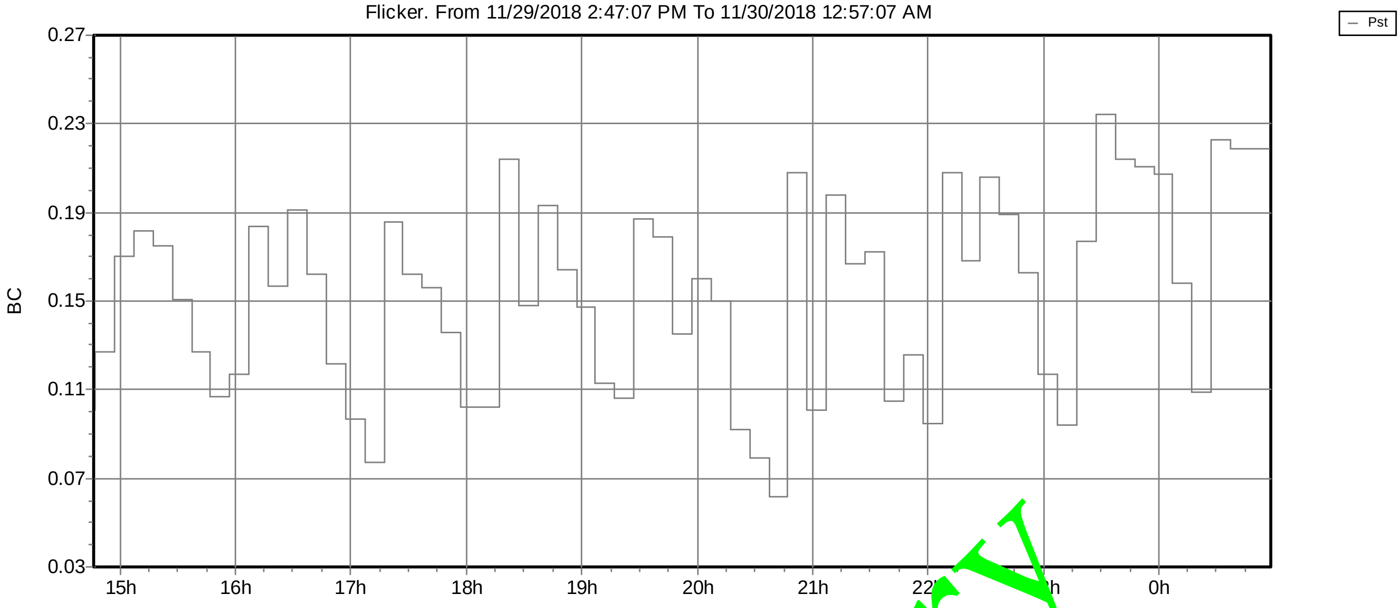
Unbalance V/A. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



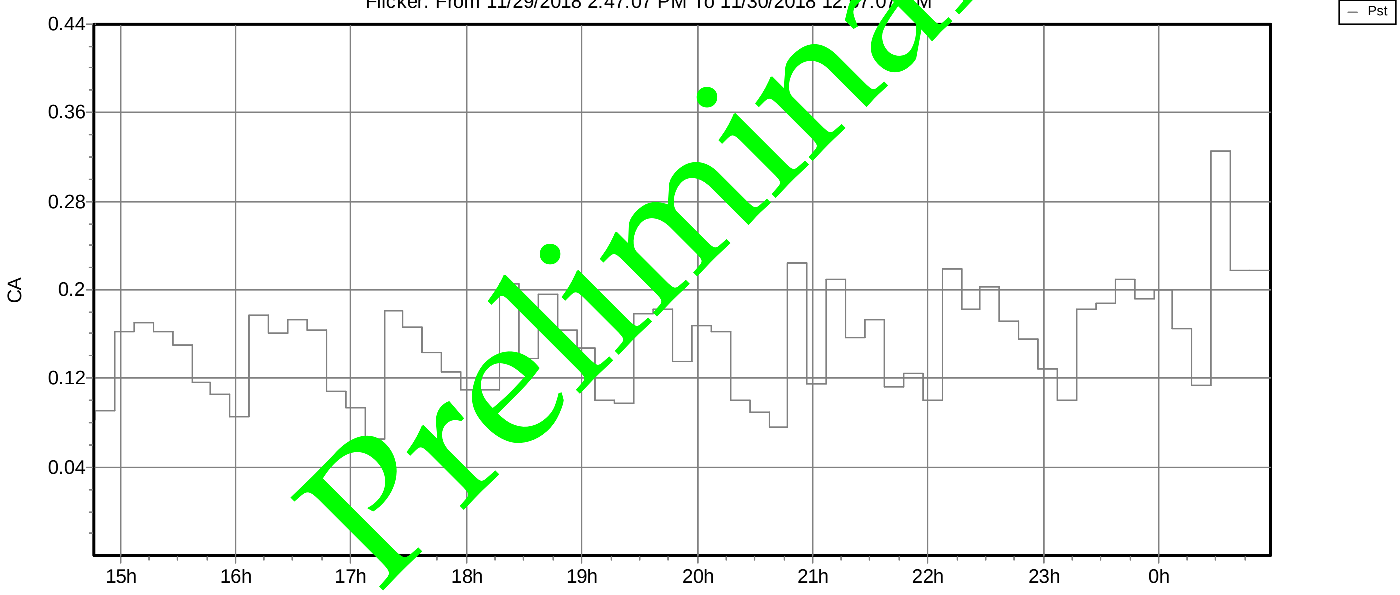
Flicker. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



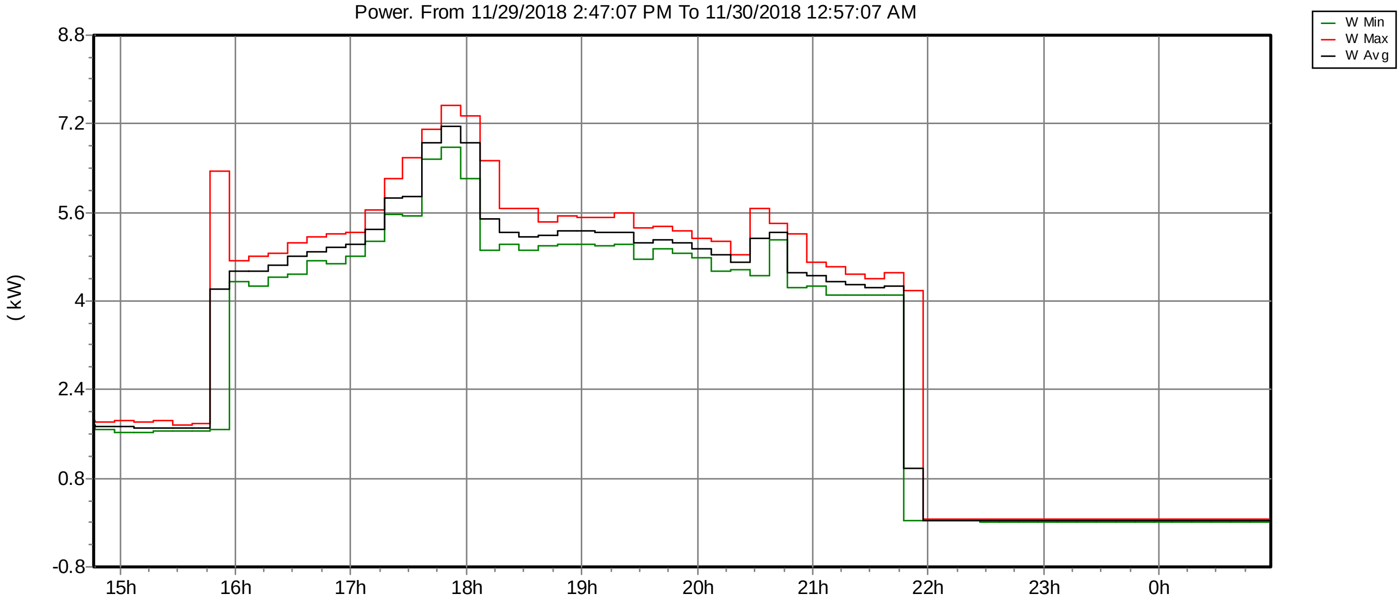
Flicker. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



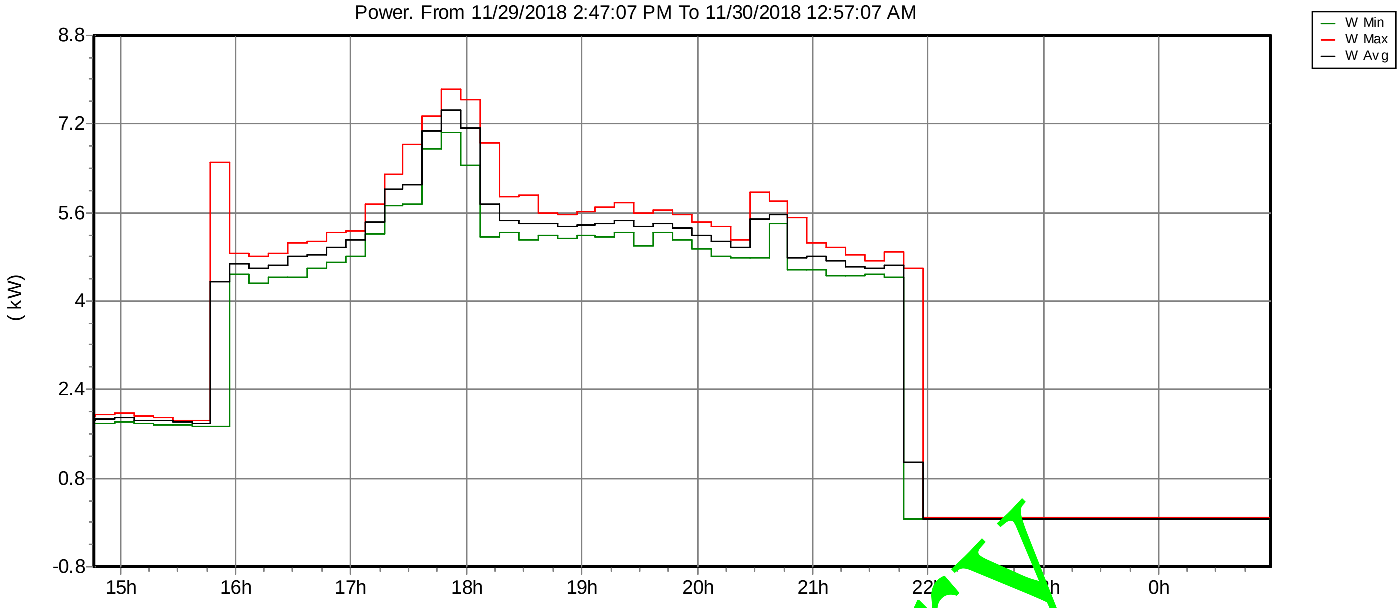
Flicker. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



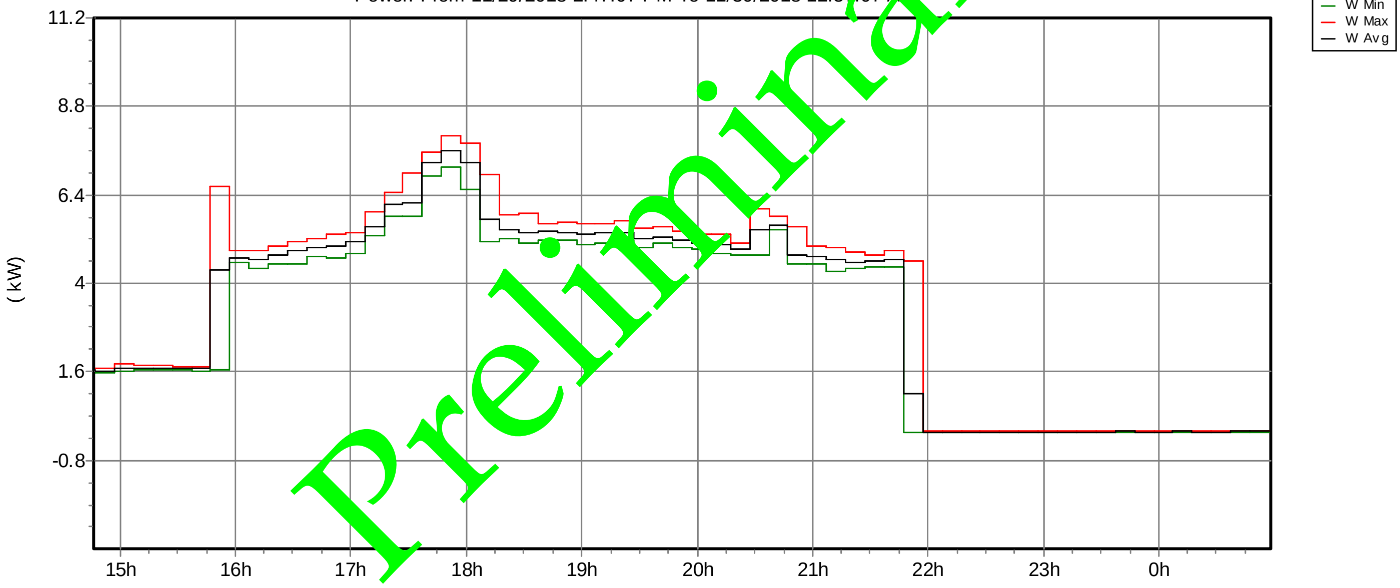
Power. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



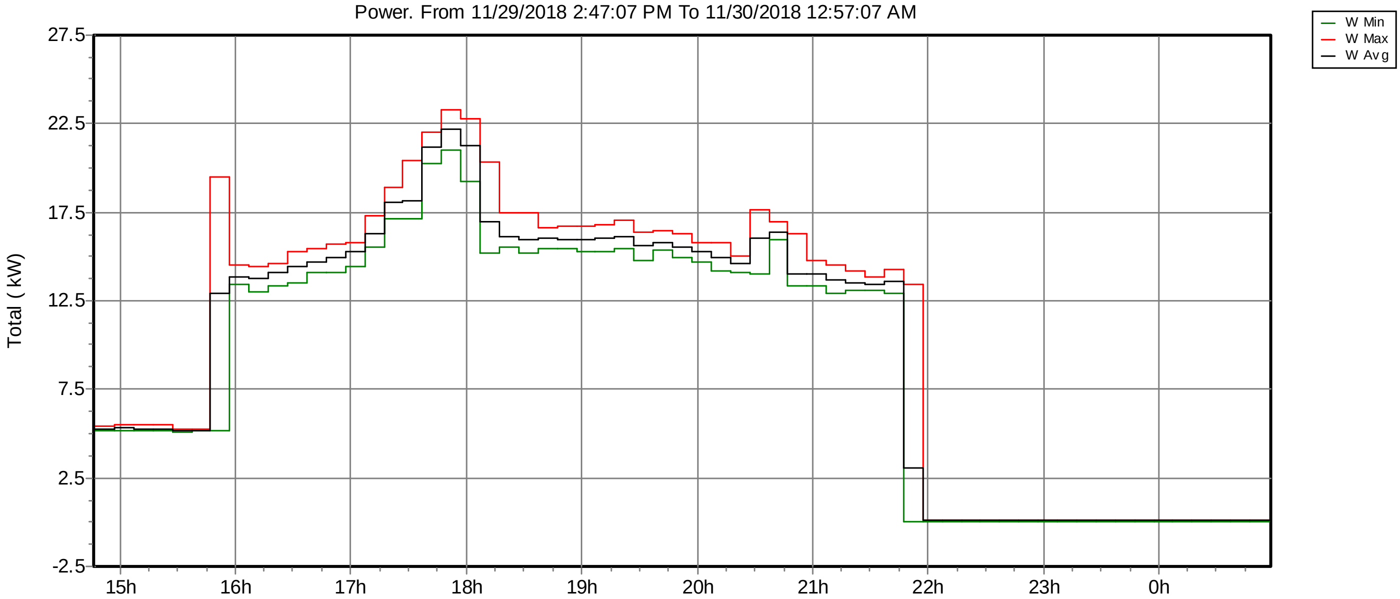
Power. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



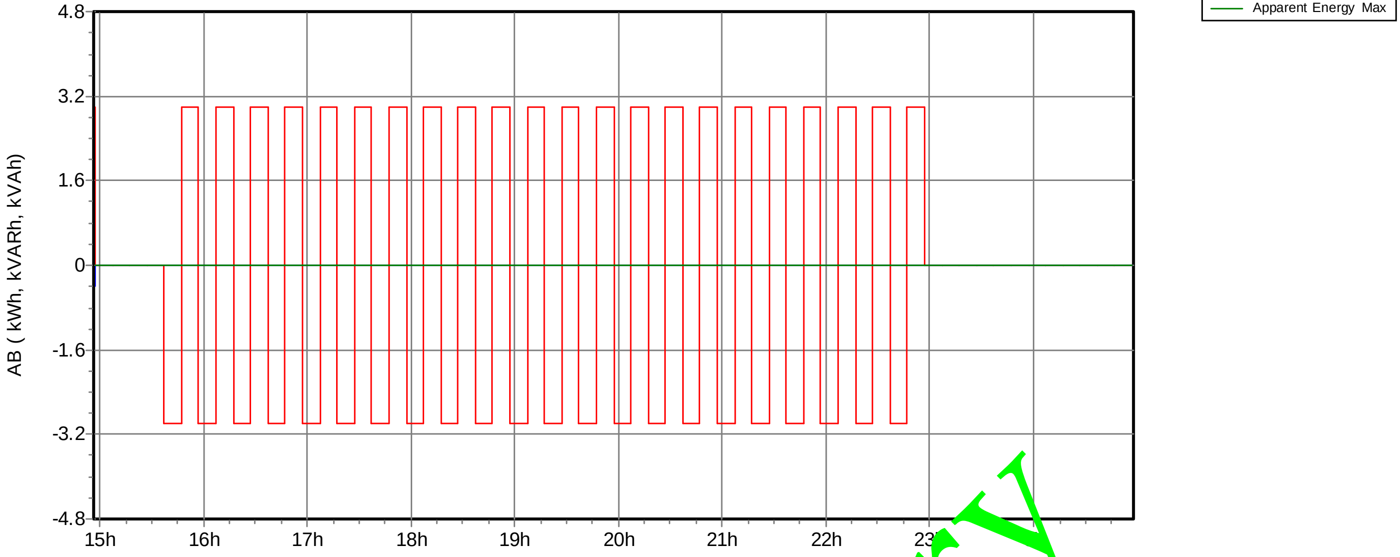
Power. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



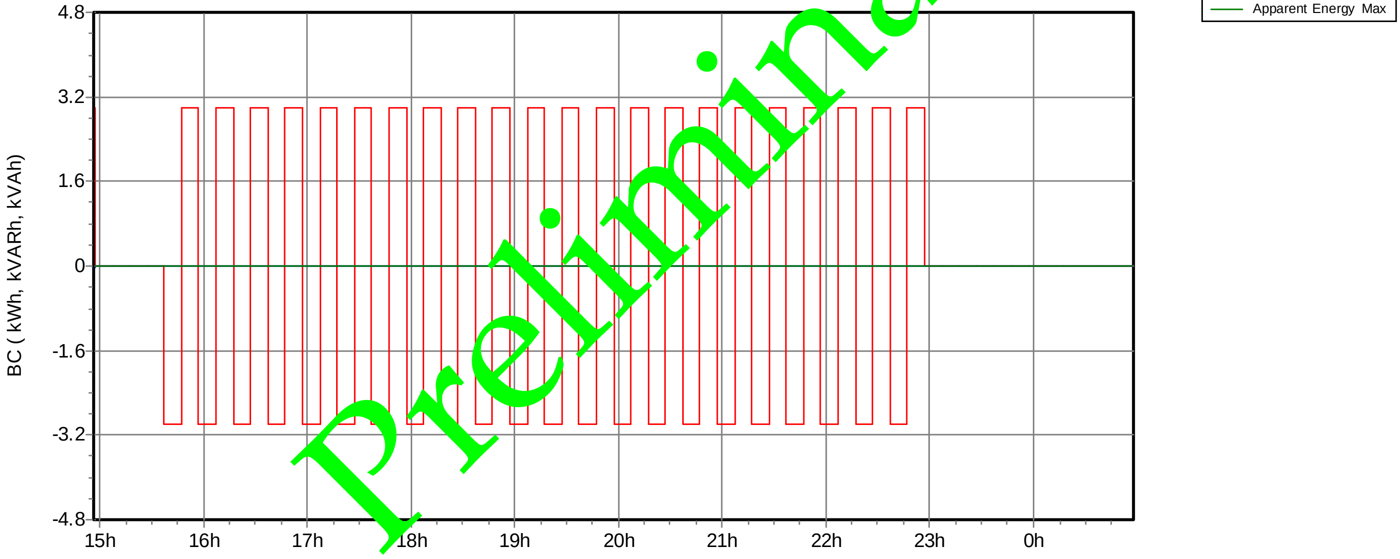
Power. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM



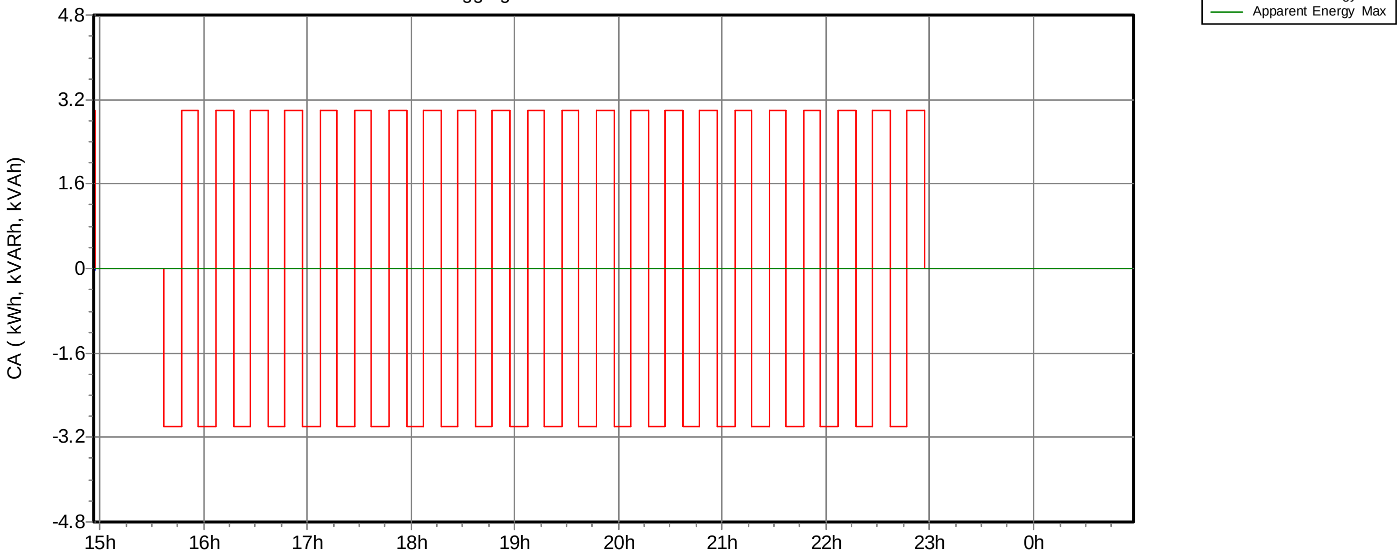
Energy. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
Aggregation interval: 10m. 0s.

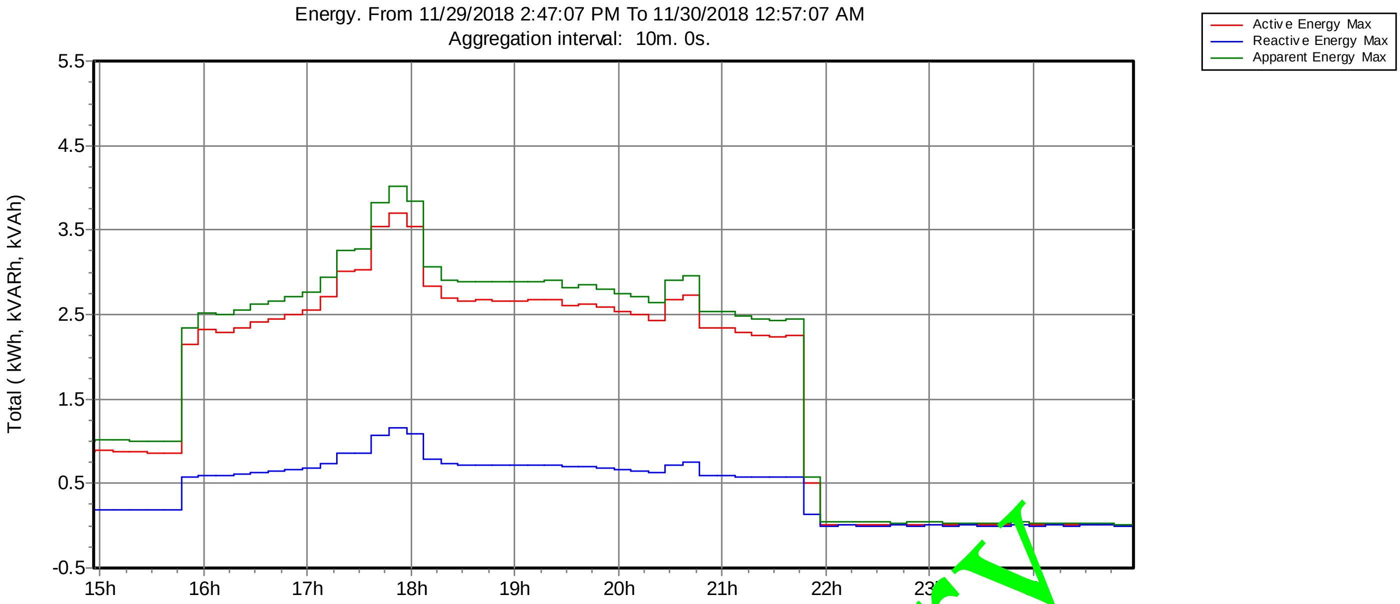


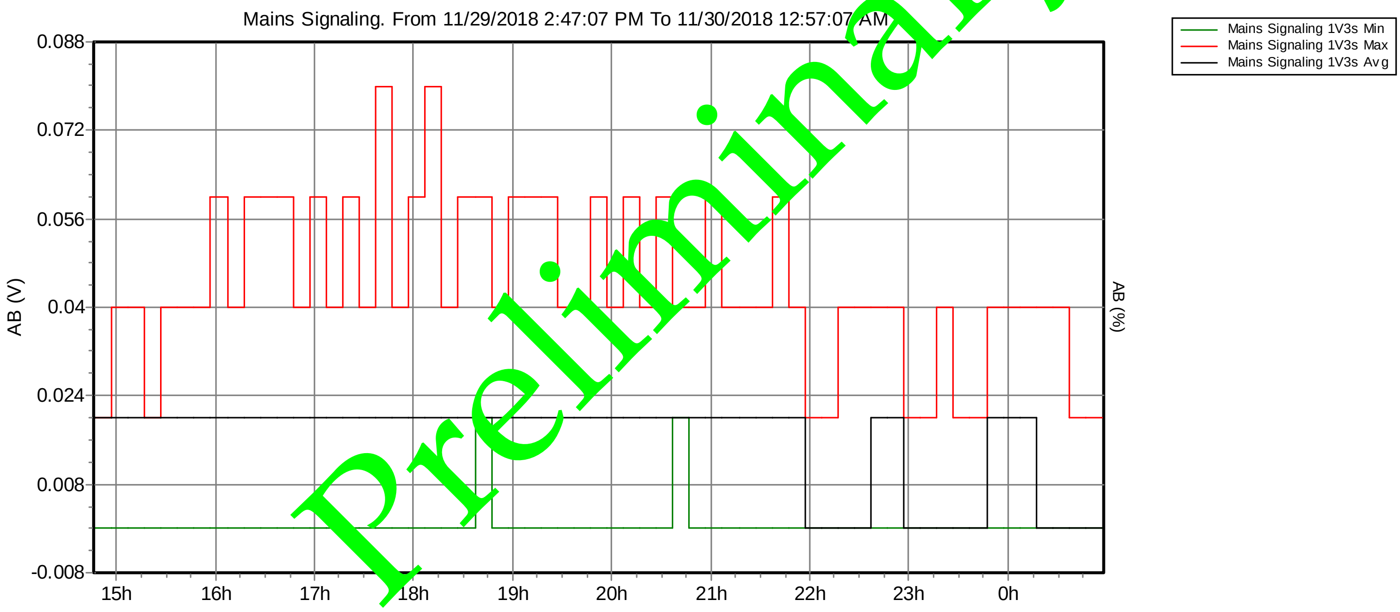
Energy. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
Aggregation interval: 10m. 0s.

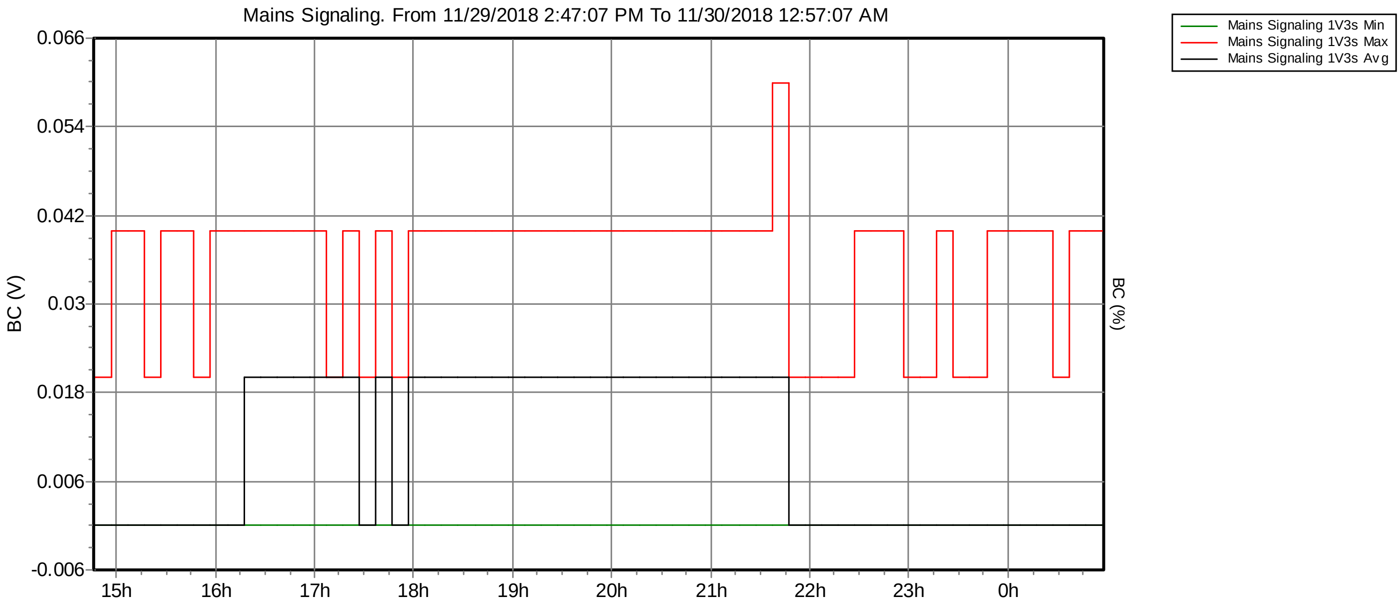


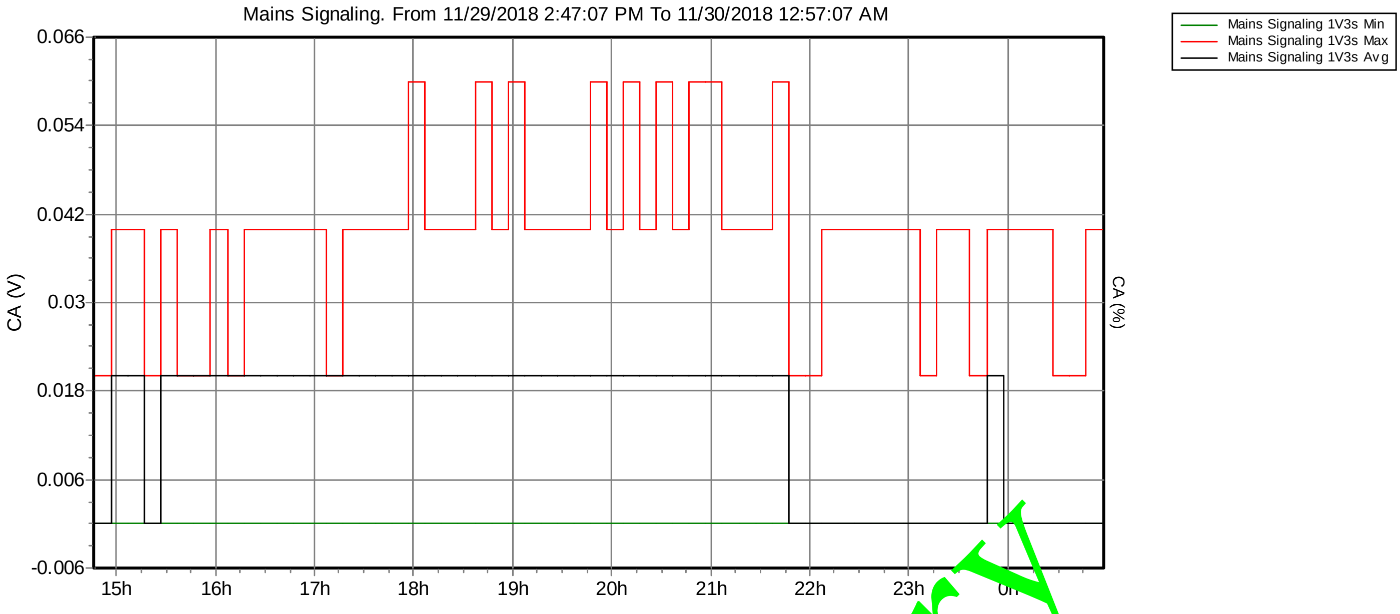
Energy. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
Aggregation interval: 10m. 0s.

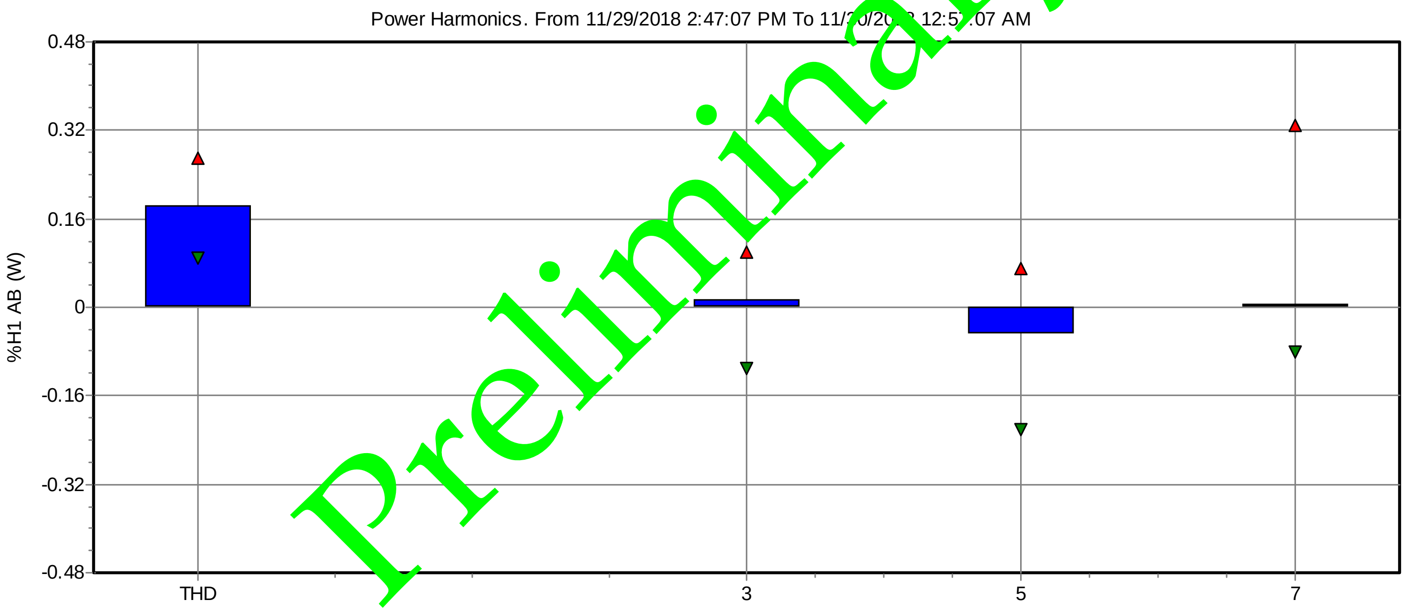


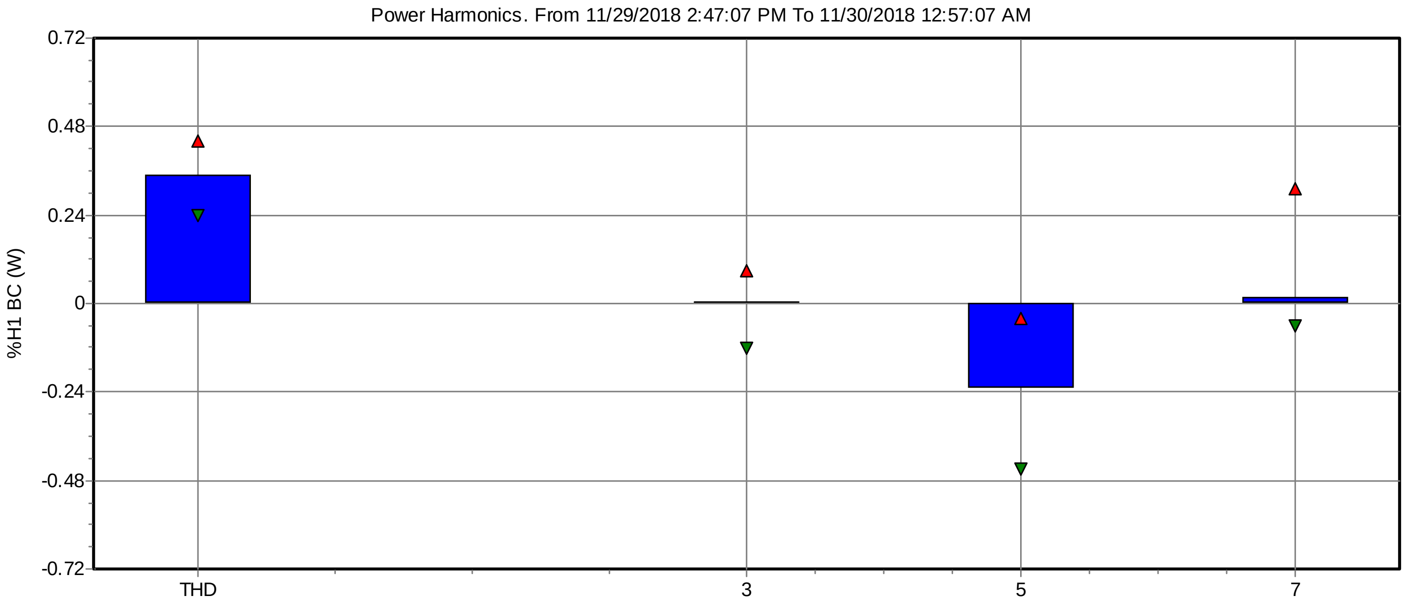

Energy. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
Aggregation interval: 10m. 0s.
Total (kWh, kVARh, kVAh)
Active Energy Max
Reactive Energy Max
Apparent Energy Max
5.5
4.5
3.5
2.5
1.5
0.5
-0.5
15h
16h
17h
18h
19h
20h
21h
22h
23h

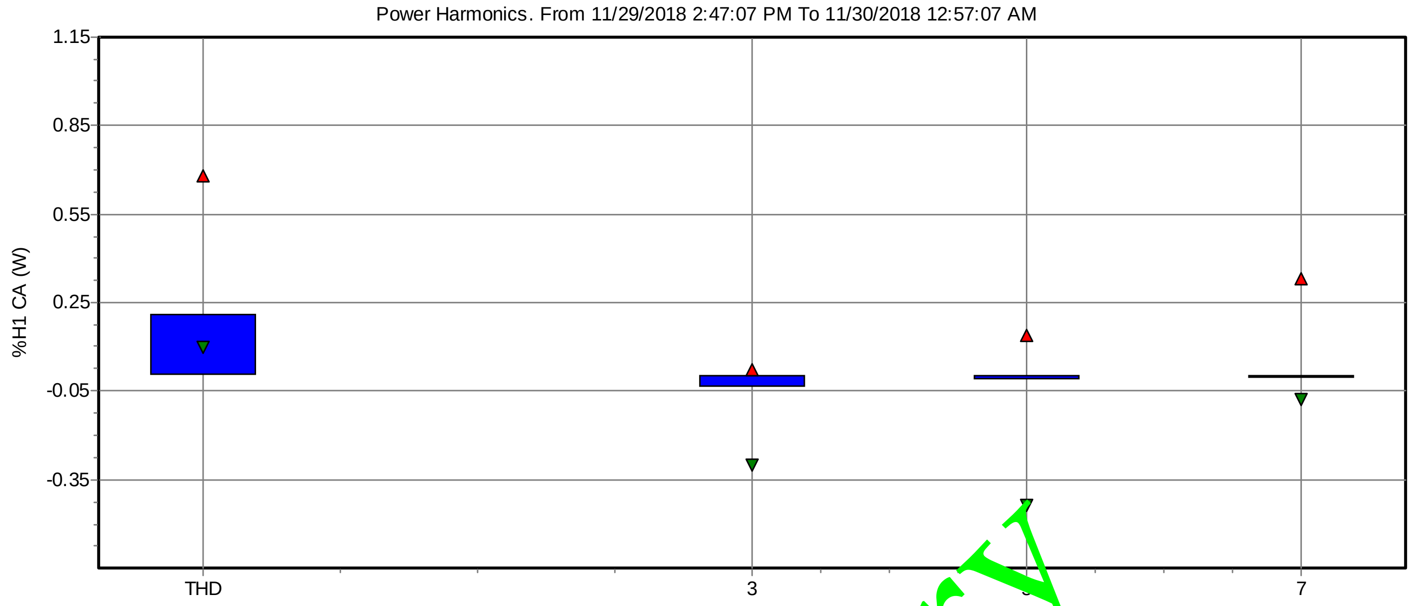

Mains Signaling. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
AB (V)
AB (%)
Mains Signaling 1V3s Min
Mains Signaling 1V3s Max
Mains Signaling 1V3s Avg
0.088
0.072
0.056
0.04
0.024
0.008
-0.008
15h
16h
17h
18h
19h
20h
21h
22h
23h
0h

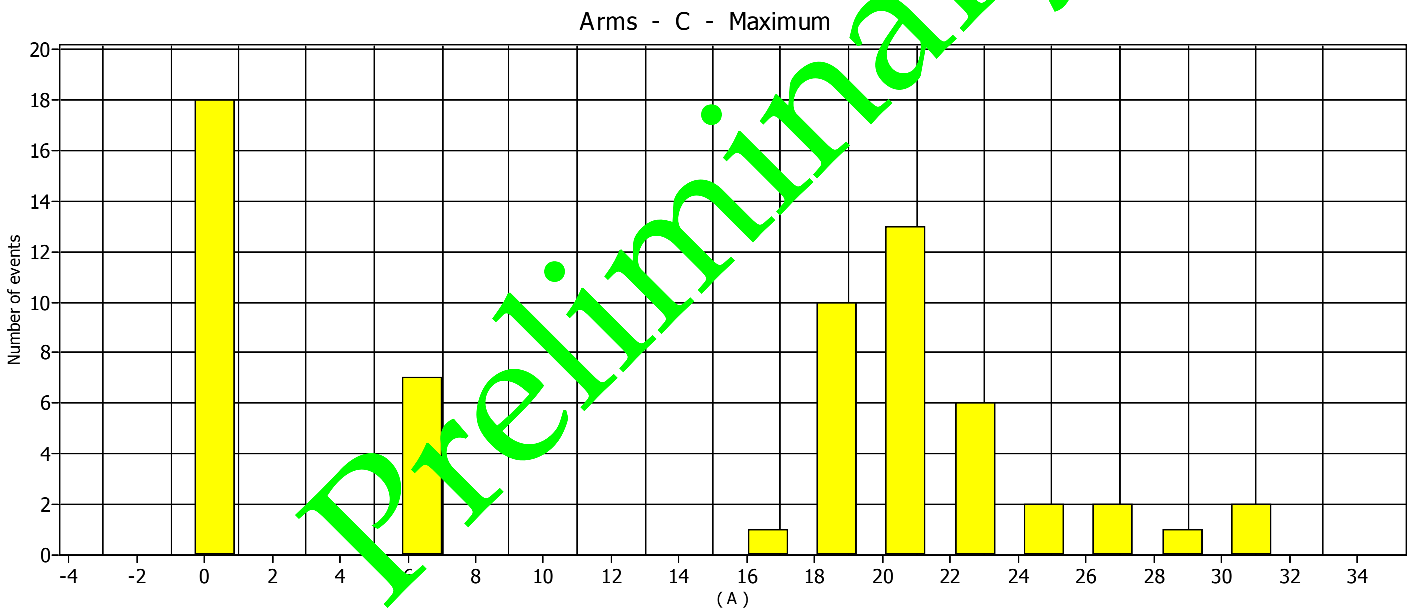

Mains Signaling. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
BC (V)
BC (%)
Mains Signaling 1V3s Min
Mains Signaling 1V3s Max
Mains Signaling 1V3s Avg
0.066
0.054
0.042
0.03
0.018
0.006
-0.006
15h
16h
17h
18h
19h
20h
21h
22h
23h
0h


Mains Signaling. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
Mains Signaling 1V3s Min
Mains Signaling 1V3s Max
Mains Signaling 1V3s Avg
CA (V)
CA (%)
0.066
0.054
0.042
0.03
0.018
0.006
-0.006
15h
16h
17h
18h
19h
20h
21h
22h
23h


Power Harmonics. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
%H1 AB (W)
0.48
0.32
0.16
0
-0.16
-0.32
-0.48
THD
3
5
7
Preliminary


Power Harmonics. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
%H1 BC (W)
0.72
0.48
0.24
0
-0.24
-0.48
-0.72
THD
3
5
7


Power Harmonics. From 11/29/2018 2:47:07 PM To 11/30/2018 12:57:07 AM
%H1 CA (W)
1.15
0.85
0.55
0.25
-0.05
-0.35
THD
3
7


Arms - C - Maximum
Number of events
(A)
20
18
16
14
12
10
8
6
4
2
0
-4
-2
0
2
4
8
10
12
14
16
18
20
22
24
26
28
30
32
34