Appendix I
Models Used to Assess the Performance of Solar PV Systems

The photovoltaic industry is poised to experience a period of fast development due to numerous factors, including but not bounded to the following: an increasing hope by public to cut down their carbon emissions, formation of state renewable portfolio standards (RPS), use of third-party power purchase agreements (PPAs), new federal tax incentives for constructing and installing, new PV cell, inverter and storage technologies, and a decrease in the cost of PV system components. When additional PV systems are installed, there will be an increase in need for software package that can be applied for plan, analysis and troubleshooting. A basic example outlining the importance of PV performance monitoring is that new regulatory devices are being put into place that make the amount of tax credit returned from an installation conditional on the amount of electricity generated by a PV system. An incomplete judgment of a PV system's capacities can underestimate system payback and affect potential funding. Once new PV technologies are deployed, anticipated and actual functioning data will be included in databases, and additional presumptions may postulate significant changes to the present empirical and analytical techniques. The utilization of batteries for both small and large-scale energy storage and power conditioning will also be important as PV grid penetration increases. A comprehensive perceptive of available models, capabilities, tradeoffs and shortcomings will be required to maintain with changes in technology and differing needs by end-users both at present and in the future. This new phase of PV deployment will be successful if the photovoltaic, hybrid simulation and battery modeling tools can handle these new challenges.

AI.1 PV Performance Models

Photovoltaic performance models are used to estimate the power output of a photovoltaic system, which typically includes PV panels, inverters, charge controllers and other "balance of system" (BOS) components. These models create a

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generation profile based on a specific geographic location which helps determine how much solar irradiance is available for harvesting. The meteorological inputs for any given location vary by latitude, season and changing weather patterns; being able to accurately determine the generation profile due to these changing variables results in better matching of system load with expected generation. Some models make general assumptions about system components and ratings while other more complex models take into account manufacturer parameters, derived parameters and empirically derived data. These models can also be used to evaluate system performance over time by providing a baseline to compare with if performance suddenly decreases and troubleshooting is necessary. Financial considerations are also important when considering PV; some models are considered "system" models due to the inclusion of capital and operating costs as well as expected benefits in terms of payback period, avoided costs, internal rate of return, levelized cost-of-energy (LCOE), cash flow and depreciable basis, just to name a few. System derate factors are also important as equipment degrades over time resulting in a power output decrease.

Following are some of the commonly used PV software models:

PVSS

The Photovoltaic System Simulation Program (PVSS) is a simple component model built in FORTRAN to simulate PV system performance by allowing the user to choose a variety of different system configurations for both on and off-grid PV systems. A plane of array (POA) radiation model was not used in this model. Array performance is based on a one-diode equivalent circuit equation for determining the current–voltage (I-V) curve. Temperature effects on irradiance are based on equation that is a function of the band-gap, a silicon specific constant, Boltzmann's constant and the cell temperature.

SOLCEL

SOLCEL is a system-level model used for both grid-tied and off-grid (battery storage) PV systems. It is implemented in FORTRAN and can run simulations down to an hourly time-step. A simple equivalent circuit model as described in PVSS is used to model array performance. Temperature effects on array performance are determined using a temperature-corrected efficiency model based on PVSS and modified based on different passive and active cooling configurations. The program can model both flat-plate and concentrating PV (CPV) incorporated onto trackers or fixed arrays. Weather and solar insolation data for the model is obtained using the SOLMET Typical Meteorological Year (TMY) database. SOLCEL is set up to look at different scenarios to determine the best system design for a desired range of costs including, but not limited to PV energy cost, total system cost, life-cycle cost, and rate of return. The two economic-evaluation techniques the program implements are the life-cycle costing methodology and the Department of Energy (DOE)/Electric Power Research Institute (EPRI) required revenue methodology. SOLCEL can also find the optimal configuration with the lowest life-cycle cost

Evans and Facinelli Model

A photovoltaic performance model for PV systems was developed by Arizona State University under contract with Sandia National Laboratories. In the model, system performance is analyzed when using a battery or converted energy from the array for maximum power point tracking (MPPT). The assumption in this model is that the PV arrays only generate power at the maximum power point on the I-V curve. The model runs on a monthly time-step and is implemented in the TRNSYS environment. For POA irradiance, a tilt correction factor is used and the arrays are either tracking or moved monthly to optimize energy production. For array performance, a power temperature coefficient model considers the efficiency, temperature and tilt correction factor. Technologies modeled include cSi and CPV with weather and insolation data taken from the SOLMET TMY database.

PVForm

PVForm by Menicucci was one of the first "system" models for PV applications that can analyze and compare system performance in one or many locations with the benefit of incorporating system costs. The model has the ability to look at both grid-tied and stand-alone systems (with battery storage) and can allow a user to model system degradation, and the effects of load and component changes.

PVForm was also built to both simplify and improve the SOLCEL model. PVForm appears to only model flat plate cSi. For weather and solar insolation, the TMY dataset is utilized. For financial information, PVForm gives users the ability to understand important metrics such as LCOE for comparing the cost of other electricity generating technologies with PV.

PVSIM

PVSIM was developed better understand the electrical behavior between each module in an array. Specifically, it was built to take a look at module mismatch and shading loss. This analysis is done using a two-diode equivalent circuit model with empirically derived parameters from dark I-V measurements at a low (25 °C) and high (50 °C) cell temperatures. The software program allows for users to enter their parameters to create cell I-V curves determined through testing. From there, users can see how an array would perform at a variety of different operating temperatures.

Sandia Photovoltaic Array Performance Model

The Sandia PV Array Performance Model utilizes a database of empirically derived PV module parameters developed by testing modules from a variety of manufacturers. The data can be used to evaluate the performance of PV systems in three ways:

1. Design a PV system to properly match desired generation with load information on timescales that vary from 1 h to 1 year;
2. Calculate the system power rating from module-specific empirically derived formulas developed at SNL, and
3. Provide long term analysis capabilities that are useful for measuring array performance and troubleshooting support.

Where other algorithms attempt to determine array performance in conditions that are not optimal (most of the time), using theoretical and semi-empirical methods, the Sandia PV Array Performance Model is a departure from many of the earlier equations used to derive power from a PV system as it is based on empirical measurements made for modules in conditions other than the manufacturer provided standard test conditions (STC). This model calculates the Isc, Imp, Vmp, Voc, and two other current values at intermediate points. This is accomplished with a curve-fitting process using coefficients derived from module testing. Empirical coefficients are also developed to calculate parameters that are temperature dependent (including a module specific thermal model), effects of air mass and angle of incidence on the short-circuit current, and type of mounting (whether rack mounted or BiPV). This model also allows for the determination of an "effective irradiance", which is the amount of irradiance that actually reaches the cells after other losses are taken into consideration.

Sandia Inverter Performance Model

The Sandia Inverter Performance Model for grid-tied systems characterizes efficiencies in the conversion process from dc-power to ac-power using an empirical method through the testing of operating inverters. Inverter performance is characterized as a function of input power and voltage, and coefficients are derived that can be used in the model. The results of the testing include an inverter parameter database with equations that can be utilized with the Sandia PV Array Performance Model.

PVDesignPro

PVDesignPro software is a commercially available software model developed by the Maui Solar Energy Software Corporation (MSESC) and SNL for photovoltaic systems modeling. The software incorporates algorithms from both of SNL's PV array and inverter performance models as well as SNL's database of PV module and inverter parameters. NIST uses a custom version of PVDesignPro for comparing different PV technologies and predicting PV module performance for BIPV applications. The program uses an hourly time-step for modeling system performance. If financial analysis is desired, the software will take system cost inputs to determine cash flow, payback period, internal rate of return, and utility

Solar Advisor Model

The Solar Advisor Model or SAM, as it is commonly referred to, is a stand-alone software program created in 2006 by a partnership with the National Renewable Energy Laboratory (NREL) and SNL through the DOE Solar Energy Technologies Program. The model is being continuously updated and improved and has an active user community that can be accessed at: http://groups.google.com/group/sam-user-group.

5-Parameter Array Performance Model

The 5-Parameter array performance model was developed from research conducted at the Wisconsin Solar Energy Laboratory (SEL). This model utilizes the well known one-diode array performance model for evaluating PV array performance.

PVWatts

PVWatts is a grid-connected photovoltaic modeling tool developed by NREL that is based on the PVForm algorithms developed at SNL. This includes the POA radiation model and the modified power temperature coefficient model for array performance. A hierarchy of programs that descended from PVForm and from its predecessor,

PVSYST

PVSYST is a photovoltaic system analysis software program developed by the Energy Group at the University of Geneva in Switzerland and can be used at any location that has meteorological and solar insolation data. It is widely used due to the many parameters available for the user to modify. The complexity of the input parameters makes it suitable for expert users.

Other interesting features include a 3-D shading tool that allows a user to draw a structure with PV arrays and see potential shading impacts from simulated obstructions. There is an option to analyze array mismatch to determine more specific Isc and Voc parameters, as well as look at cell/module shading and other voltage losses due to wiring, and soiling. Other useful features include an incident angle modifier and an air mass spectral correction for thin-film modules, as well as the ability for the user to input known parameters and coefficients if measured data is available for both PV modules and inverters.

PV F-Chart

PV F-Chart is a PV array performance modeling software developed at the University of Wisconsin SEL and licensed through F-Chart software. For POA radiation, it uses a simple isotropic sky model. Array performance of cSi modules is calculated as a function of cell temperature, efficiency, and incident angle. For weather and solar insolation, TMY2 data is utilized. Economic analysis results including life-cycle and equipment costs are also included in the analysis.

RETScreen Photovoltaic Project Model

RETScreen is a program developed by Natural Resources Canada for evaluating both financial and environmental costs and benefits for many different renewable energy technologies. RETScreen has a specific Photovoltaic Project Model that can model PV array performance for many locations around the world.

PVSol

PVSol is a photovoltaic systems analysis software program developed by Valentin Energy Software in Germany with an English language version distributed by the Solar Design Company based in the UK. The first version of PVSol was released in 1998. The Expert edition has the most features, including a 3-D shading program.

INSEL

The Integrated Simulation Environment Language (INSEL) solar electricity toolbox from Doppelintegral GmbH in Germany is a photovoltaic systems analysis program. It appears the software was initially developed in 1991. INSEL is modular in the sense that it can be linked to other programs and can be customized by an advanced user.

SolarPro

SolarPro software is a PV system simulation program from Laplace System based in Kyoto, Japan. The first version of the software appears to have been released in 1997. The user must first define the system in terms of mounting, array layout and orientation, then develop a 3-D layout that can have shading objects built-in. Interesting features include detailed analysis of module-specific shading within an array by looking at module I-V curves.

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PVOptimize

PVOptimize is a software tool developed for the California market by KGA Associates and is geared towards installers for generating system quotes and design. The program uses PVWatts for solar resource data and array performance modeling. Modules available for analysis include cSi, CdTe, aSi, CPV and Ribbon. For weather and insolation, the program uses PVWatts (TMY2) data. There are many forms and inputs specific to the incentives and rebates offered by the State of California. Therefore the model may have limited utility to locations outside of California.

OnGrid

OnGrid is a software tool developed for use in the U.S. by Andy Black of OnGrid Solar in California and is focused on what installers need for system quotes and design. The program uses PVWatts for the array performance calculations. Module technologies available for analysis include cSi, aSi, CdTe and Ribbon. This software consists of a macro-enabled Excel spreadsheet that can be customized for any incentive program available in the U.S. Incentives for the State of California are included by default. The spreadsheet can look at system cost, incentives, depreciation, cash flow, O&M costs, and internal rate of return.

CPF Tools

CPF Tools is a software program developed in 2007 by Energy Matters LLC for Clean Power Finance. The software is aimed towards system installers for system design, economics and financing. CPF tools also leverages the technology in RoofRay, which is an on-line interactive tool that allows a user to easily draw an outline of a potential PV array to explore the potential costs and benefits. RoofRay is similar to the IMBY tool developed by NREL for an interactive analysis of potential PV system size. CPF Tools was previously known as Solar Pro Tools

Solar Estimate

Solar Estimate is a web-based tool developed by Energy Matters LLC for both residential and commercial solar resource estimation. The user enters in a zip code and chooses the utility that they purchase power from. Assumptions include a total energy delivered of 78 %, which includes derates for panel, inverter, wiring and panel soiling. For POA radiation and array performance, PVWatts is used. The model does not specify a PV technology, although it is likely based on flat plate cSi modules. Because the model uses PVWatts for determining solar energy, it probably uses TMY2 data for weather and insolation measurements.

AI.2 Hybrid System Models

Hybrid system models are used to simulate the performance of “hybrid” or “distributed energy resource” systems that typically include one or more renewable sources of electricity combined with a traditional fossil based fuel source. These models were built initially to look at the use of PV or wind as a backup source for small and remote off-grid applications. Battery storage and lifetime (primarily from lead-acid) is simulated due to the need for a continuous source of power. More recent models can incorporate sources such as biomass, hydro, and other energy storage devices such as non lead-acid batteries, fuel cells, capacitors, flywheels and compressed air. These models discussed below can also look at grid-tied systems and attempt to capture interactions at the utility scale.

SOLSTOR

SOLSTOR is a model developed at SNL for looking at the overall economics and optimization strategies of different hybrid system configurations. Components include PV arrays, wind turbines and generators. Storage is in the form of batteries and flywheels. Power conditioning options are also available. The model can be run with a utility connection or stand-alone with a backup generator.

The program incorporates some of the PV array performance algorithms as described in SOLCEL. PV technologies that can be modeled include cSi and CPV. SOLSTOR uses the SOLMET database for weather and insolation data. Economic output includes capital costs, O&M costs, energy purchase costs, depreciation, investment tax credits, salvage value and financing.

HybSim

HybSim is a hybrid energy simulator developed and copyrighted at SNL for looking at the costs and benefits of adding renewable energy to a fossil fueled electrical generation system in a remote location. The model requires knowledge of the existing load profile, weather, battery characteristics and a few economic details. At the moment, solar PV is the only renewable energy source available for comparison however wind power will be another choice in a future versions of the model. Current license holders include the University of Michigan and a few corporate customers.

The system is designed to model cSi modules. For weather and insolation, HybSim can use data measured at 15-min intervals. Lifecycle costs are analyzed for system components including PV modules, generators and batteries. Capabilities include comparing cost and performance differences with a diesel only system with one using a combination of diesel, PV, wind and battery storage.

Hysim

Hysim is a hybrid energy simulation model developed at SNL for analyzing the combination of PV, diesel generators and battery storage for stand-alone systems in remote locations. The purpose of this model was to look at increasing overall system reliability by adding the PV and battery storage, as well as the economics associated with PV and batteries compared to existing generator only systems. Hysim uses a modified version of the battery model in SOLCEL. For POA radiation and PV array performance, Hysim uses PVForm. The only PV technology modeled in Hysim is cSi. For weather and insolation data, Hysim uses TMY2. Financial analysis includes LCOE, lifecycle, fuel and O&M costs, as well as cost comparisons between different configurations.

HOMER

HOMER is a hybrid system model developed at NREL in 1993 for both on-grid and off-grid systems. A unique capability that HOMER offers is the ability to find the optimal configuration based on price estimates as well as perform sensitivity analysis to help understand tradeoffs between different technologies and economic considerations. The software has the ability to compare multiple system configurations as well as different battery types. The model can incorporate the following components: PV, wind, hydro, fossil fuel generator, battery, AC/DC converter, electrolyzer, hydrogen tank and reformer. Temperature effects are not considered in the performance calculation, however they can be accounted for as a part of the total system derate. HOMER uses a generic module type for analysis. For weather and insolation, HOMER can use TMY2 formatted data or custom user inputs.

Hybrid2

Hybrid2 is described as a probabilistic time series computer model for evaluating the performance and economics of hybrid electricity generating systems. It was developed by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts Amherst with support from NREL. This program is an engineering design model for hybrid systems consisting of PV, wind, generators and battery storage for both on-grid and off-grid systems.

UW-Hybrid (TRNSYS)

The UW-Hybrid simulation model is described as a quasi-steady performance simulation tool for looking at hybrid systems consisting of solar, wind, diesel generators and battery storage. This hybrid simulator is part of the TRNSYS software program but can be run alone under a demonstration editor version called TRNSED.

RETScreen

RETScreen is a program developed by Natural Resources Canada for evaluating both financial and environmental costs and benefits for many different renewable energy technologies for any location in the world. The Photovoltaic Project Analysis module was covered in Sect. 2.4.1. Electricity generation options include solar, wind, fuel cells, gas or diesel generators, gas turbines, geothermal, tidal power, wave power, hydro turbine, and ocean current power. For combustible fuels, fossil, biomass, waste and hydrogen are listed in terms of inputs for modeling. Energy storage options include batteries.

PVToolbox

PVToolbox is a hybrid system model developed for the Natural Resources Canada CANMET Energy Technology Centre – Varennes (CETC-Varennes). The program is written for use within Matlab Simulink and has been validated using bench tests which describe the model vs. measured performance under different load scenarios. The model looks specifically at PV, diesel generator and battery systems designed for Canadian latitudes and weather conditions.

RAPSIM

The Remote Area Power SIMulator (RAPSIM) is a hybrid system model developed in Australia at the Murdoch University Energy Research Institute (MUERI). This program simulates systems comprising of PV arrays, wind turbines and diesel generators with battery storage. The organization that currently houses the work at the university is called the Research Institute for Sustainable Energy (RISE).

SOMES

SOMES is also known as the Simulation and Optimization Model for Renewable Energy Systems. It was created at the Utrecht University in The Netherlands. The simulation program can look at hybrid systems that utilize PV arrays, wind turbines and generators for generating electricity and batteries for storage. Both technical and economic parameters can be modeled as well as an optimization model to help figure out the best configuration at a specific cost.

IPSYS

IPSYS is a hybrid simulation modeling tool for remote systems. The program has a component type library and can model electricity generation through PV arrays, wind turbines, diesel generators, fuel cells as well as natural gas. Energy storage can be modeled using batteries, hydro reservoirs and hydrogen. The model is written in C++ and there is no current graphical user interface, however there are scripts that can be used to analyze model output within graphs.

HySys

The Hybrid Power System Balance Analyser, or HySys is a hybrid simulation tool developed at the Centro de Investigaciones Energeticas, Medioambientales y Technologicas (CIEMAT) institute in Spain by their wind technology group. The software is primarily for isolated systems and includes electricity from PV arrays, wind turbines and diesel generators. According to the IEA 2008 report as shown in the reference below, the software appears to be under development to operate primarily within Matlab.

Dymola/Modelica

The Fraunhofer Institute for Solar Energy (ISE) in Germany uses the Modelica/ Dymola object oriented programming language for modeling PV-hybrid systems. The electricity sources include PV, wind turbines, generators and fuel cells along with storage in the form of batteries.

Battery Performance Models

Photovoltaic systems provide varying amounts of power throughout the day due to the intermittent nature of sunlight reaching PV panels. Cloudy days, varying temperatures, system latitude, module configuration and shading effects directly affect the amount and timing of photovoltaic energy that can be produced.

SIZEPV

The purpose of SIZEPV was to determine the optimal configuration of a PV system with battery storage using a loss-of-load probability model. The results of this model were by comparing with loss-of-load probabilities calculated with PVForm. The advantage of using SIZEPV for PV systems with battery storage is the ability to run multiple iterations much quicker than if set up using PVForm. The model is limited to lead-acid batteries. Required input data includes battery capacity, minimum allowable state-of-charge (SOC), equalization SOC, backup capacity, equalization schedule, beginning SOC, maximum charge efficiency and maximum discharge efficiency.

KiBaM

The Kinetic Battery Model (KiBaM) is a lead-acid battery modeling application developed by Manwell and McGowan (1993) at the University of Massachusetts RERL. KiBaM is considered a phenomenological model where many of the battery parameters are derived from extensive testing, and uses a modified amp-hour (Ah) cycle counting method to model battery performance and lifetime. The original version was built for wind/diesel systems with PV added in later versions. HOMER, as discussed above, uses a simplified version of the KiBaM model.

Appendix II
Research Projects

A brief description of research projects from various IEEE journals, Research centers and Universities are given in this appendix.

AII.1 A New Converter Topology for Hybrid Wind/ Photovoltaic Energy System

Renewable energy technologies offers clean, abundant energy gathered from self-renewing resources such as the sun, wind etc. As the power demand increases, power failure also increases. So, renewable energy sources can be used to provide constant loads. A new converter topology for hybrid wind/photovoltaic energy system can be proposed. Hybridizing solar and wind power sources provide a realistic form of power generation. The topology uses a fusion of Cuk and SEPIC converters. This configuration allows the two sources to supply the load separately or simultaneously depending on the availability of the energy sources. Renewable energy sources also called non-conventional type of energy are continuously replenished by natural processes. Hybrid systems are the right solution for a clean energy production. Hybridizing solar and wind power sources provide a realistic form of power generation. A hybrid wind and solar energy system with a converter topology can be proposed which makes use of Cuk and SEPIC converters in the design. This converter design overcomes the drawbacks of the earlier proposed converters. This topology allows the two sources to supply the load separately or simultaneously depending on the availability of the energy sources. The output voltage obtained from the hybrid system will be the sum of the inputs of the Cuk and SEPIC converters. This system has lower operating cost and finds applications in remote area power generation, constant speed and variable speed energy conversion systems and rural electrification. MATLAB/ SIMULINK software can be used to model the PV panel, wind turbine, DC-DC converters and the proposed hybrid system.

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AII.2 Energy Conversion Efficiency of a Novel Hybrid Solar System for Photovoltaic, Thermoelectric, and Heat Utilization

A novel hybrid solar system can be designed to utilize photovoltaic (PV) cells, thermoelectric (TE) modules, and hot water (HW) through a multilayered building envelope. Water pipelines are cast within a functionally graded material layer to serve as a heat sink, allowing heat to be easily transferred into flowing water through an aluminum-rich surface, while remaining insulated by a polymer rich bottom. The theoretical energy conversion efficiency limit of the system can be investigated for documenting the potential of this hybrid solar panel design. Given the material properties of each layer, the actual energy conversion efficiency depends on the solar irradiation, ambient temperature, and water flow temperature. Compared to the traditional solar panel, this design can achieve better overall efficiencies with higher electrical power output and thermal energy utilization. Based on theoretical conversion efficiency limits, the PV/TE/HW system is superior to PV/HW and traditional PV systems with 30 % higher output electrical power. However, the advantages of the PV/TE/HW system are not significant from experimental data due to the low efficiency of the bulk TE material. Thus, QW/QD TE materials are highly recommended to enhance the overall efficiency of the PV/TE/HW design. This design is general and open to new PV and TE materials with emerging nanotechnology for higher efficiencies. Hybrid solar panels integrated with Si solar cells, TE materials, and FGM water tube systems can be demonstrated. The FGM water tube systems have good cooling function, which can recover the PV cell efficiency by 30–50 % and 25–40 % for the PV/HW and PV/TE/HW system, respectively, by controlling the temperature and also enhance the TE output power by three times. Incorporation of bulk TE modules in the solar panel shows comparable performance as those of PV/FGM design. High-efficiency QW/QD TE materials could potentially contribute higher electric power and enhance the overall efficiency for PV/TE/HW design.

AII.3 Design and Implementation of Power Converters for Hybrid Wind-Solar Energy Conversion System with an Implementation of MPPT

The power converter can not only transfer the power from a wind generator, but also improve the stability and safety of the system. The proposed system consists of a Permanent magnet synchronous generator (PMSG); a DC/DC boosts converter, a bi-directional DC/DC converter and a full-bridge DC/AC inverter. The wind generator is the main power source of the system, and the battery can be used for energy storage and power compensation to recover the natural irregularity of the wind power. A new system configuration of the front-end rectifier stage for a hybrid wind or photo voltaic energy system can be proposed. The configuration allows the two sources to supply the load separately or simultaneously, depending on the availability of energy sources. The inherent nature of this cuk-sepic fused converter, additional input filters are not necessary to filter out high frequency harmonic content is determinant for the generator life span, heating issue and efficiency. The fused multi-input rectifier stage also allows maximum power from the wind and sun. When it is available an adaptive MPPT algorithm will be used for photo voltaic (PV) system. Operational analysis of the proposed system can be simulated to highlight the merit of the proposed circuit. In this a new multi-input Cuk-SEPIC rectifier stage for hybrid wind/solar energy systems can be presented. The features of this circuit can be: (1) additional input filters are not necessary to filter out high frequency harmonics; (2) both renewable sources can be stepped up/down (supports wide ranges of PV and wind input); (3) MPPT can be realized for each source; (4) individual and simultaneous operation can be supported. By implementing this technique we can increase the power transfer efficiency. We can extract maximum power without any interruption. There is no need to depend upon non renewable energy sources and this could be eco friendly.

AII.4 Unit Sizing and Control of Hybrid Wind-Solar Power Systems

The aim is to provide the core of a CAD/CAA tool that can help designers determine the optimal design of a hybrid wind-solar power system for either autonomous or grid-link application. The analysis employs linear programming techniques to minimize average production cost of electricity while meeting the load requirements in a reliable manner, and takes environmental factors into consideration both in the design and operation phases. While in autonomous systems, the environmental credit gained as compared to diesel alternatives can be obtained through direct optimization, in grid-linked system emission is an another variable to be minimized such that the use of renewable energy can be justified. A controller that monitors the operation of the autonomous or grid-linked systems design can be used. Such a controller determines the energy available from each of the system components and the environmental credit of the systems. It gives details related to cost, unmet and spilled energies, and battery charge and discharge losses. It uses linear programming principle to reduce the cost of electricity. The use of renewable energy offers substantial environmental credit when compared to grid/diesel alternatives. This analysis will allow the user to study the interaction among economic, operational and environmental factors. It offers an useful tool for the design and analysis of hybrid wind-solar power systems.

AII.5 Application of Integrated Wind Energy Conversion System (WECS) and Photovoltaic (PV) Solar Farm as STATCOM to Regulate Grid Voltage During Night Time

The integration of wind energy conversion system (WECS) with photovoltaic (PV) solar farm (SF) can be proposed which could act as a flexible a.c transmission system controller-static synchronous compensator during night time, to regulate the point of common coupling voltage and to rectify faults when SF is not producing any active power. A novel concept of optimal utilization of a PV SF as a STATCOM can be proposed and validated through MATLAB/SIMULINK simulation. The proposed control will enable increased connections of WECS. The proposed strategy of PV SF control will facilitate integration of more wind plants in the system without needing additional voltage-regulating devices. PV Solar farm virtually inactive during night time in terms of active power generation can be used to regulate the distribution voltage at PCC within utility specified limits even during wide variations in WF output and rectifies the fault. This novel strategy implies operating PV solar plant as a generator during the day [providing megawatts (MW)] and ancillary services provider at night [providing mega volt amperes (MVARs)]. This may pose interesting questions on ownership/partnership/lease options, license to operate, etc., and possible code changes by the regulator.

AII.6 Application of Fuzzy Wavelet Transform to Smooth WindPV Hybrid Power System Output with Battery Energy Storage System

The battery energy storage system (BESS) is the current typical means of smoothing intermittent wind or solar power generation. The proposed system could present the results of a wind/PV/BESS hybrid power system simulation analysis undertaken to improve the smoothing performance of wind and Photo Voltaic (PV) power generation. A power smoothing control method can be proposed based on fuzzy logic and wavelet transform for reducing output power fluctuations of wind/PV/BESS hybrid power generation systems. Wind and PV power generation systems have the disadvantage of an unstable power output, which can impact negatively on utility- and micro-grid operations. One means of solving this problem is to integrate WPGS and PVGS with a battery energy storage system. For such hybrid generation systems, control strategies need to be developed to efficiently dispatch power. Therefore, a fuzzy-logic-based wavelet filtering control method can be proposed for smoothing the output fluctuation of the WPGS and PVGS hybrid power generation system. Simulation results demonstrate that the proposed control strategy can manage battery SOC within a specified target region while smoothing WPGS and PVGS output power.

AII.7 Night Time Application of PV Solar Farm as STATCOM to Regulate Grid Voltage

The concept of utilizing photovoltaic (PV) solar farm (SF) as flexible a.c transmission system controller-static synchronous compensator, to regulate the point of common coupling voltage during night time when the SF is not producing any active power can be proposed. The control will enable increased connections of Wind Energy Conversion System (WECS) to the grid on average wind energy which is the best at night when the atmosphere is stable. By combining the wind and solar PV on a utility scale the uncertainty of generation is greatly reduced and more reliable energy source can be created. Times of no energy production from either wind or solar dropped by 50 % or more for each time. Given one megawatt wind turbine and one mega watt of solar panels placed immediately south of the turbine they can both utilize the same pad mount transformer and electrical collection system reducing the initialized cost. MATLAB/simulink based simulation results can be presented for validation of the system. Thus by combining wind and solar power plants the whole is greater than the sum of its parts and the intermittency of renewable energy is significantly reduced by paring the two individual one-megawatt systems which have nearly opposite production phase gross capacity factor of 0.608 was attained when not curtailing either wind or solar.

AII.8 Micro Perspectives for Decentralized Energy Supply

To evaluate the electricity costs, of the PV-battery system, the progression of the power demand and electricity production can be evaluated and compared with cost and revenue of the resulting energy flow based on the electricity purchase prices and the EEG bonus for the feed in of renewable solar energy. But the high purchase price of the storage reduces the financial gain of the photovoltaic system. From the examined case it is revealed that the redox flow batteries are the most promising technology and lead acid batteries are more lucrative than lithium ion batteries due to their lower initial costs. The calculation can predict the cost effectiveness of a solar system with energy storage and therefore help to find the best battery size for a certain household. The high interest in storage systems is not surprising when considering the current, and the debate about rising electricity fees. Due to the high asset costs of storage systems, the cost effectiveness of a solar system is clearly reduced and one is risking a negative return if the application is not configured properly. Therefore, an individual technical and economical optimization is highly recommended, especially concerning the storage size. Redox flow batteries have a high financial potential and outrank the other two studied battery technologies. But it remains to be seen whether redox flow systems will be available for this application and whether the cost prediction is applicable. Despite poor efficiency, low operating life and high capacity loss, lead acid battery systems are surprisingly more profitable than lithium ion systems. Also the market incentive program for storages of the German government improves the financial results clearly. But even with this support, the return of an installation without storage is about twice as large.

AII.9 Application of Photovoltaic (PV) Solar Farm in STATCOM to Regulate the Grid Voltage

A method of integrating the connections between photovoltaic (SF) and wind farm in the nearest surrounding place can be proposed. The energy distribution of both depends upon the storage batteries, which are one of the main advantageous of the distribution system. This method using point to common coupling to regulate voltage on the late night, when the solar farm is not generating any useful Power. The proposed method of Photovoltaic (SF) as elastic AC Transmission system controller-static synchronous compensator and wind farm as Flexible DC transmission must be enable improved connections of wind energy conversion system (WECS) to the grid. The entire system achieved to the reversible direction of grid voltage regulation using the Photovoltaic (SF) and storage energy to the batteries. A combination of Photovoltaic solar farm and wind energy conversion system (WECS) based on distribution of the production of energy system can be stored in to a battery. The two direction inverter acts as a switch of PV solar farm is using a battery charger especially during the late-night to charge the batteries and energy would be storage. The proposed method introduced concept of indirect feeder link paths to regulate the voltage control can be presented in which the voltage level increase, automatically the extensive amount of reverse power flow from WF is controlled by utilizing the solar farm inverter to charge the batteries and storage the power. The proposed system can be simulated using Simulink blocks in MATLAB. Simulation results could verify the achievement and efficiency of the proposed approach to regulate the feeder voltage by exchanging real active power through the storage batteries. In future work, the proposed approach will be expanded for a medium voltage large scale PV Solar- wind farm power based distribution system. This strategy implies operating PV solar plant and wind farm as a distributed generator [providing megawatts (MW)] and ancillary services provider at day time.

AII.10 Solar PV-Wind Hybrid Power Generation System

Renewable energy sources i.e. energy generated from solar, wind, biomass, hydro power, geothermal and ocean resources are considered as a technological option for generating clean energy. But the energy generated from solar and wind is much less than the production by fossil fuels, however, electricity generation by utilizing PV cells and wind turbine increased rapidly in recent years. The Solar-Wind hybrid Power system that control the renewable energy in Sun and Wind to generate electricity relies mainly on micro controller which ensures the optimum utilization of resources and hence improves the efficiency as compared with their individual mode of generation. Also it increases the reliability and reduces the dependence on one single source. A portion of the energy required for a private house, farm house, a small company, an educational institution or an apartment depending on the need at the site where used has been supplied with the electricity generated from the wind and solar power. It reduces the dependence on one single source and has increased the reliability. Hence we could improve the efficiency of the system as compared with their individual mode of generation. This hybrid solar-wind power generating system suits for industries and domestic purposes also.

AII.11 Reliability Well-Being Assessment of PV-Wind Hybrid System Using Monte Carlo Simulation

The utilization of renewable energy has gained momentum nowadays due to the rapid decrease in fossil fuel resources and increased environmental concerns. But the amount of power available from these natural resources will vary continuously from place to place and time to time depending on its geographical locations, terrains, altitude, climatic conditions. So the energy supplied from these sources will be fluctuating in nature. Hybrid energy systems are excellent options for supplying small isolated power systems (SIPS) and remote villages where conventional grid cannot reach due to technical and economical reasons. It will discuss various components of hybrid energy systems involving photo voltaic (PV) and wind energy conversion systems (WECS) and their modeling for reliability studies. The reliability of supply can be the major concern in the hybrid energy systems. Several methods for reliability evaluation have been reported. The traditional methods for evaluating reliability evaluation like deterministic and probabilistic techniques have their own disadvantages. An improved method known as system well-being analysis which is the combination of deterministic and probabilistic techniques has been applied for evaluation of reliability of the system applying Monte Carlo simulation technique. Finally the renewable energy can be converted into useful electrical energy by making use of photovoltaic (PV) and wind energy conversion systems and all the designing are done according to Indian conditions and the cost is also reliable.

AII.12 Design of Off-Grid Home with Solar-Wind-Biomass Energy

Due to the limited reserves of fossil fuels and global environmental concerns for the production of electrical power generation and utilization, it is very necessary to use renewable energy sources. By use of hybrid systems we can implement renewable energy sources which are very economical for remote villages, homes etc. In particular, rapid advances in wind-turbine generator, biomass generator and photovoltaic technologies have brought opportunities for the utilization of wind and solar resources for electric power generation world-wide. So by the use of hybrid systems consisting of Biomass, PV and also wind for production of electrical energy in these remote areas can be more economical. If the development of a computer-based approach for evaluating, the general performance of standalone hybrid PV- Biomass-wind generating systems are analyzed, then these results can be useful for developing and installing hybrid systems in remote areas. It focuses on the economical consideration and simulation approach for a standalone hybrid systems having PV, wind and Biomass for electrical production in remote areas. The average solar radiation, quantity of biomass, average wind speed for the remote area for prediction of general performance of the generating system have been taken into account. Simulation studies were carried out using HOMER software. Simulation results will be given for performance evaluation of a stand-alone hybrid wind-PV generating unit for a residential house which is to be located in a remote area. The system is a off grid one. Finally, the results obtained and methods can be suggested to enhance the performance of the proposed model.

AII.13 Modeling and Control of Hybrid Photovoltaic Wind Energy Conversion System

A hybrid energy conversion system combining photovoltaic and wind turbine can be as a small-scale alternative source of electrical energy where conventional generation is not practical. The hybrid system consists of photovoltaic panels, wind turbines and storage batteries. The wind and PV are used as main energy sources, while the battery can be used as back-up energy source. Two individual DC-DC boost converters can be used to control the power flow to the load. A simple and cost effective control with DC-DC converter is used for maximum power point tracking (MPPT) and hence maximum power is extracted from the turbine and the photo voltaic array. The modeling of hybrid system can be developed using MATLAB- SIMULINK. The proposed model takes sunlight irradiance and cell temperature as input parameters and outputs the I-V and P-V characteristics under various conditions. The masked icon makes the block model more user-friendly and a dialog box lets the users easily configure the PV model. It describes renewable energy hybrid Wind-PV with battery energy storage system. In Hybrid Wind-PV System, PV system acts as a main source. A simple and cost effective maximum power point tracking technique can be proposed for the photovoltaic and wind turbine without measuring the environmental conditions. This is based on controlling the photovoltaic terminal voltage or current according to the open circuit voltage or short circuit current and the control relationship between the turbine speed and the dc-link voltage can be obtained using simple calculations. A complete description of the hybrid system can be presented along with its detailed simulation results which ascertain its feasibility.

AII.14 Multi-Objective Optimization for Sizing of Solar-Wind Based Hybrid Power System

The concept of integrating photovoltaic (PV) and wind energy conversion system can be proposed. This hybrid technology could act as a flexible ac transmission system controller-static synchronous compensator, to regulate the point of common coupling voltage during night time when the Solar farm is not producing any active power. PV Solar farm (SF) is used to regulate the distribution voltage at point of common coupling (PCC) within utility specified limits even during wide variations in WF output and rectifies the fault. This implies operating PV solar plant as a generator during the day[providing megawatts (MW)] and ancillary services provider at night [providing mega volt amperes (MVARs)]. The capacitor banks can be used in parallel with other sources in order to reduce DC bus variation. A Fuel Cell-electrolyzer combination can be used as a backup and a long-term storage system. A simulation model for the hybrid energy system can be developed using MATLAB/Simulink. The system performance under different scenarios can be verified by carrying out simulation studies using a practical load demand profile and real weather data. This is based on controlling the photovoltaic terminal voltage or current according to the open circuit voltage or short circuit current and the control relationship between the turbine speed and the dc-link voltage can be obtained using simple calculations. For simulation, the data solar irradiance, temperature and wind speed can be used. The power fluctuation of the hybrid system is less dependent on the environmental conditions as compared to the power generated of individual PV and Wind energy generation systems.

AII.15 Design and Comparative Evaluation of a Hybrid Wind-Solar Power System

In today's world the rising rate of consumption and the price of fossil fuels and the environmental problems caused by the conventional power generation draw worldwide attention to renewable energy technologies. In fact, renewable energy systems are pollution free, takes low cost and less gestation period, user and social friendly. However, renewable power unit based on single source (wind or solar source) may not be effective in terms of cost, efficiency and reliability. A viable alternative solution is by combining these different renewable energy sources to form a hybrid energy system. An efficient hybrid model can be developed and compared with hybrid model which is using battery as its storage system instead of fuel cells. A complete hybrid power system of this nature may be too expensive and too labor intensive for many Industrial Technology Departments. In this hybrid system with using fuel cell is more efficiency, long life and cheapest compare to hybrid system with using battery. The enhancements to instruction, especially in making electrical power measurements more physical, intuitive, and real-world are substantial and the costs and labor involved in some adaptation to a smaller scale setup are reasonable. The use of solar/wind & FC hybrid power generation is an especially vivid and relevant choice for as these are power sources of technological, political, and economic importance in their state. In other places, other power sources could be used. For example hybrid combinations of wind power, solar power, geothermal power, hydroelectric power, tidal power, biomass generated power, power from incineration of solid wastes, and many other technologies could be considered depending on local interests and resources.

AII.16 Analysis and Design of a Domestic Solar-Wind Hybrid Energy System for Low Wind Speeds

An application based system is designed on the basis of the solar and wind data for areas in Northern India. The power generated by the system can be intended for domestic use. The most common source of unconventional power in homes is battery based UPS (Uninterrupted Power Supply) inverter. The UPS inverter charges the battery with conventional grid power. This system will charge the battery of the UPS inverter by using only wind and solar power, which will make the system cost effective and more reliable. The reason for using both solar and wind is that the recent studies have proven that combined system can be more productive and consistent and the other thing is that neither of them can be used for continuous power generation. In the system illustrated, the solar-wind system provides power periodically which is controlled by electronic methods and a microcontroller is used to monitor the power from both the inputs. The switching action is provided from the microcontroller to the battery charging based on the power received from solar photovoltaic panel and wind generators. An efficient system has been proposed comprising of solar panel, wind generator, charge controller and charge storage unit(battery). Solar panel is selected as the main input and the wind resource will be used only in the absence of the solar photovoltaic (PV) output. Based on the above mentioned analysis the solar-wind hybrid systems can be used by any domestic user at a place where wind speeds are not that good. It will charge the battery even when there is no grid power. There is lots of space for improvement in this system like Maximum Power Point Tracking (MPPT) or other power enhancement methods. This improvement can be incorporated without any big increase in the system costing because there is only a little addition to the electronic components to the charge controller circuitry. This can prove a vital system in the field of renewable energy resources.

AII.17 Probabilistic Performance Assessment of Autonomous Solar-Wind Energy Conversion Systems

The development of a general probabilistic model of an autonomous solar-wind energy conversion system (SWECS) is composed of several wind turbines (wind farm), several photovoltaic (PV) modules (solar park), and a battery storage feeding a load. The model takes into consideration outages due to the primary energy fluctuations and hardware failure. It allows the simulation of wind farms and solar parks containing either identical or different types of wind turbines and PV modules with the load being fed from either the renewable sources, or the battery storage, or both. A methodology can also be presented to determine an upper limit on the size of the battery storage required to satisfy a given load profile taking into consideration the charging/discharging of the batteries. The proposed strategy of PV SF control will facilitate integration of more wind plants in the system without needing additional voltage-regulating devices. PV Solar farm virtually inactive during night time in terms of active power generation can be used to regulate the distribution voltage at PCC within utility specified limits even during wide variations in WF output and rectifies the fault.

AII.18 Application of Off Grid Solar PV System for Power Processing Unit

A novel multi-functional power processing unit capable of extracting maximum power from solar photovoltaic panels can be described. It employs a combination of a voltage controlled voltage source inverter (VCVSI) and a current controlled voltage source inverter (CCVSI), connected in series on the DC side and in parallel on the AC side. The Power Processing Unit is able to provide an uninterruptible power supply feature, load voltage stabilization, unity power factor operation, maximum power point tracking, and higher efficiency for charging the battery from renewable energy sources and more reactive power support. The experimental results from the proto typed system confirm validity of the proposed topology. The fundamental concept and experimental results of a novel power conditioner for extracting maximum available energy of different renewable energy sources can be described. The proposed power conditioner employs two voltage source inverters connected in series on the DC side and in parallel on the AC side. The power conditioner provides unity power factor and maximum power point tracking as well as more reactive power support in all modes of operation through control of the instantaneous output parameter of inverters. It can be demonstrated that the proposed Power Processing Unit is an innovative solution to power conditioning for a weak grid, and suitable for application such as in hybrid power Systems.

AII.19 Application of APC Technique in a Unique Standalone Solar and Wind Hybrid Generation System

In India, more than 200 million people live in rural areas without access to grid-connected power. A convenient and cost-effective solution would be hybrid power systems which can reduce dependency on grid supply, improve reliability. An unique standalone hybrid power generation system can be, applying advanced power control techniques(APC), fed by four power sources: wind power, solar power, storage battery, and fuel cell, and which is not connected to a commercial power system. One of the primary needs for socio-economic development in any nation in the world is the provision of reliable electricity supply systems. This work is a development of an indigenous technology hybrid Solar–Wind and fuel cell Power system that harnesses the renewable energies in Solar- Wind and fuel cell to generate electricity. Here, electric DC energies produced from photovoltaic and wind turbine systems are transported to a DC disconnect energy Mix controller. The controller is bidirectional connected to a DC-AC float charging-inverter system that provides charging current to a heavy duty storage bank of Battery and at the same time produces inverted AC power to AC loads. Under current acute power shortage scenario with increasing cost of natural gas, coal and turbine fuel and due to their impact on environment, there is a very urgent and great need of finding alternate source of energy to generate electricity. There are several ways by which electricity can be generated using renewable sources such as solar, wind, biogas, etc. Individual generation of solar and wind energy is costlier. Solar and wind energy integrated technologies have great potential to benefit our nation. They can diversify our energy supply, reduce our dependence on imported fuels, improve the quality of the air we breathe, offset greenhouse gas emissions, and stimulate our economy by creating jobs in the manufacturing and installation of solar and wind energy systems. By using solar and wind integrated system we can electrify remote area also it is applicable for metro cities in future to avoid unwanted load shedding.

AII.20 Hybrid Solar and Wind Power: An Essential for Information Communication Technology Infrastructure and People in Rural Communities

One of the primary needs for socio-economic development in any nation in the world is the provision of reliable electricity supply systems. This work is a development of an indigenous technology hybrid Solar -Wind Power system that harnesses the renewable energies in Sun and Wind to generate electricity. Here, electric DC energies produced from photovoltaic and wind turbine systems are transported to a DC disconnect energy Mix controller. The controller is bidirectional connected to a DC-AC float charging-inverter system that provides charging current to a heavy duty storage bank of Battery and at the same time produces inverted AC power to AC loads. The 2002–2009, 8 years wind velocity data for Abeokuta and its environs were collected. The two parameters distribution was used to simulate power in W/m^2 densities for the 8-years period. The step by step design of 1,000 W solar power supply system's was done as a sample case. Load estimates of a typical rural community and for rural ICT infrastructures were estimated. Simulation of wind power capacity in W/m^2 in Abeokuta, Ogun State Nigerian was done based on the obtained wind data. The results can predict that the average exploitable wind power density between 4 and 14.97 W/m^2 is realizable and that development of hybrid wind-solar system for off- grid communities will go a long way to improve socio-economy lives of people. There is the need for the provision of an alternative sustainable electric power supply system to provide electricity to rural and the unreached communities. The importances of Information Communication Technology for e-service to rural communities are inevitable in order to achieve the MDGs objective. Also there is the need for rural banking and hospitals if the social and economic lives of rural citizens in Nigeria are to be improved. The provision of hybrid solar -wind energy system to power ICT infrastructures, banking and hospitals in rural and the unreached communities that are not connected to National Grid Power supply system is very important so as to maintain a continuous electricity supply. When considering the cost and overall efficiency, it is advisable for all the stakeholders who have concern for the rural community development to embrace solar and wind power.

AII.21 Renewable Hybrids Grid-Connection Using Converter Interferences

Use of Renewable Energy power sources is the best possible solution today to reduce increasingly risk of global warming and the most important type of renewable is Wind and Solar energies which are the most efficient. The green power generation resources are used power generators in Distributed Generation (DGs) sources that are in direct relation with the use of micro capacity power generating units of power system that are installed in distribution level of power systems or all segments that loads and energy consumers are located. Hybrid systems vary in models. The best hybrid model available today is combination of grid connected wind turbines and solar PV cells that can compensate each other in the grid connected state. In addition, solar cells provide electricity required in day-time while wind turbines compensate the power needed in the night period. Solar cells are consisted of a series of assembly of different cells together to form a flat photovoltaic system to absorb the photons and generate electricity by electrons energized in the circuit. On the other hand, Systems for conversion of energy of wind use PM Synchronous Generators. Recently, wind turbines are even enhanced to use VSD drives to provide the machine the ability of generation in cases that rotational speed varies with changes in speed of wind. The simplified version of the solar-wind hybrid system is provided and Simulations are done to confirm expectation outcomes of this connection. The connection considerations of wind and Solar hybrid systems that are connected to grid are discussed and working is done in ETAP. Wind turbines can be presented as changeable source by time and solar systems are simulated as DC systems connected to grid using DC-AC Inverters in ETAP. In Hybrid systems of Solar and wind, the capacity is compensated by each other in different cases.

AII.22 Hybrid (Solar and Wind) Energy Systems for Rural Electrification

Hybrid power system can be used to reduce energy storage requirements. The influence of the Deficiency of Power Supply Probability (DPSP), Relative Excess Power Generated (REPG), Energy to Load Ratio (ELR), fraction of PV and wind energy, and coverage of PV and wind energy against the system size and performance can be analyzed. The technical feasibility of PV-wind hybrid system in given range of load demand can be evaluated. The methodology of Life Cycle Cost (LCC) for economic evaluation of stand-alone photovoltaic system, stand-alone wind system and PV-wind hybrid system can be developed and simulated using the model. The optimum combination of solar PV-wind hybrid system lies between 0.70 and 0.75 of solar energy to load ratio and the corresponding LCC is minimum. The PV-wind hybrid system returns the lowest unit cost values to maintain the same level of DPSP as compared to standalone solar and wind systems. For all load demands the levelized energy cost for PV-wind hybrid system is always lower than that of standalone solar PV or wind system. The PV-wind hybrid option is techno-economically viable for rural electrification. There is the need for the provision of an alternative sustainable electric power supply system to provide electricity to rural and the unreached communities. The importances of Information Communication Technology for e-service to rural communities are inevitable in order to achieve the MDGs objective. Also there is the need for rural banking and hospitals if the social and economic lives of rural citizens in Nigeria are to be improved. The provision of hybrid solar -wind energy system to power ICT infrastructures, banking and hospitals in rural and the unreached communities that are not connected to National Grid Power supply system is very important so as to maintain a continuous electricity supply. When considering the cost and overall efficiency, it is advisable for all the stakeholders who have concern for the rural community development to embrace solar and wind power.

AII.23 Standalone Wind Energy

A procedure for the probabilistic treatment of solar irradiance and wind speed data is reported as a method of evaluating, at a given site, the electric energy generated by both a photovoltaic system and a wind system. It describes the development of a general probabilistic model of an autonomous solar-wind energy conversion system (SWECS) composed of several wind turbines (wind farm), several photovoltaic (PV) modules (solar park), and a battery storage feeding a load. The model takes into consideration outages due to the primary energy fluctuations and hardware failure. It allows the simulation of wind farms and solar parks containing either identical or different types of wind turbines and PV modules with the load being fed from either the renewable sources, or the battery storage, or both. A methodology can also be presented to determine an upper limit on the size of the battery storage required to satisfy a given load profile taking into consideration the charging/discharging of the batteries. The combined utilization of renewables such as solar and wind energy is becoming increasingly attractive. Proper methods need to be employed that consider the inherent variability of these two technologies while determining the performance of a wind-solar hybrid energy conversion system (ECS). A stochastic approach has been utilized to develop the megawatt resource assessment model (MWRAM) of a wind-solar hybrid ECS at any selected location. The parameters required to define the probabilistic models can be computed from site-specific data using the maximum likelihood estimation method. The wind portion consists of several interconnected wind turbines while the solar component is a parabolic trough solar thermal electric generating system. Different applications of the model to assess resource benefits including capacity factors and reserve requirements from effective utilization of both wind and solar energy have been explored at different levels with varying wind-solar proportions. The integration of wind energy conversion system (WECS) with photovoltaic (PV) solar farm (SF) which acts as flexible a.c transmission system controller-static synchronous compensator during night time, to regulate the point of common coupling voltage and to rectify faults when SF is not producing any active power. The proposed control will enable increased connections of WECS. MATLAB/Simulink based simulation results can be presented for validation of the system.

AII.24 To Design Solar (Photovoltaic): Wind Hybrid Power Generation System

In recent year's generation of electricity using the different types of renewable sources are specifically evaluated in the economical performance of the overall equipment. Solar power & wind power has received considerable attention worldwide. The proposed methodology can be applied to evaluate the potential of Solar (photovoltaic) –wind hybrid system to produce electricity for a community and other state. Through this hybrid system we can reduce pollution and decrease the global warming. In this we can analyze the data of wind and solar energy and evaluate the average energy by using hybrid system we have fulfills the energy demand into the future. In future by using of better quality sensor can increase the potential. Because maintained cost becomes low using the better quality data logger is can increase the energy production. In future we have to install large solar and wind plant which are cheaper as compared to small plants. The Modeling and simulation of the Solar (photovoltaic) –wind hybrid system can be carried out using MATLAB/SIMULINK. The capitalization of renewable resources potential confers real premises to achieve some strategic aims, but also the durable development of energy sector and the protection of the environment. In order to exploit the economic potential of renewable resources in competitive conditions on the energy market, it is necessary to adopt and implement some energy policies and specific resources. The promotion of energy production from renewable resources represents an imperative objective in present times justified by environment protection, the increase of energetic independence by supplying sources diversity and, of course, economic and social cohesion reasons.

AII.25 Increasing Efficiency of Solar PV and Windenergy Conversion Systems Using Pyroelectric Effect

To harvest solar micro-energy using the pyroelectric effect and low wind flow can be proposed. The basic concept can be presented and validated by laboratory experiments with controlled airflow. The measured temperature variation, subject to the intensity of radiation and wind speed in the environment was demonstrated to reach 16 °C. The time variation of temperature was 0.53 $°Cs^{-1}$ with the speed of airflow at 2 ms^{-1}. The power density with PZT as the pyroelectric material was 4.2 Wcm^{-3} in laboratory conditions. Both the thermodynamic model and electric model of the pyroelectric generator were established, and a numerical procedure was developed to predict the system performance which was proven to be reliable. The characteristics of such an energy harvesting system can be analyzed in detail by simulation. In this study, a new method of harvesting solar thermal energy was proposed. The time variation of temperature reached 0.23 $°Cs^{-1}$ with radiation of 1,000 Wm^{-2} and 0.53 $°Cs^{-1}$ with speed of airflow at 2 ms^{-1}. The corresponding average power density with PZT as the pyroelectric material was 4.2 Wcm^{-3}. The predicted Carnot efficiency of the PYEG reached 13.3 % with the proposed method. The measured time variation of temperature possible with wind flow under natural conditions could be higher than that achieved under laboratory conditions, and the equivalent power density under natural conditions was in the same order of magnitude as that measured under laboratory conditions. The detailed analysis on the PYEG was achieved by modeling the method. Both the thermodynamic and electric models were considered in an energy harvesting process aiming at driving low-power electronics. A numerical procedure was developed to predict the system performance. The characteristics of the proposed energy harvesting process could be estimated with the simulation. This proposal outlined the basic rules for the thermo dynamic design of the proposed PYEG. Although the power density of the proposed PYEG was much lower than that which a thermoelectric generator developed before (1.3 $mWcm^{-3}$), the inherent, simple structure of such a PYEG could be essential in some typical applications. The major cost of the PYEG included only the active material, and the cost-effectiveness is currently estimated as 15 W/euro (or 11 W/dollar) with PZT. Further work on this newly proposed energy harvesting method could inspect the thermal response of the PYEG to the complicated weather condition (sunny, windy, rainy, cloudy, snowy, etc.).

AII.26 Integrating Variable Energy Resources in Control Centers for Reliable Grid Operation

Wind power capacity has experienced tremendous growth in the past decade, thanks to wind benefits. A review of the interconnection issues of distributed resources including wind power with electric power systems, and reports the developments of interconnection standards in Canada and IEEE is accomplished. It describes the recent R&D programs in wind energy power's environmental benefits, technological advance, and government incentives. It presents the recent developments in wind energy conversion systems, and their social and environmental conversion system. A functional structure of a wind energy conversion system can be introduced, before making a comparison between the two typical wind turbine operating schemes in operation, namely constant-speed wind turbine and variable-speed wind turbine. In addition, the modeling and dynamic behavior of a variable speed wind turbine with pitch control capability is explained in detail and the turbine performance curves can be simulated in the MATLAB/Simulink.

AII.27 A Multifunctional Power Processing Unit for an Off-Grid PV Diesel Hybrid Power System

A novel multi-functional power processing unit capable of extracting maximum power from solar photovoltaic panels can be described. It employs a combination of a voltage controlled voltage source inverter (VCVSI) and a current controlled voltage source inverter (CCVSI), connected in series on the DC side and in parallel on the AC side. This Power Processing Unit can be able to provide an uninterruptible power supply feature, load voltage stabilization, unity power factor operation, maximum power point tracking, and higher efficiency for charging the battery from renewable energy sources and more reactive power support. The experimental results from the proto typed system confirm validity of the proposed topology. The fundamental concept and experimental results of a novel power conditioner for extracting maximum available energy of different renewable energy sources can be described. The proposed power conditioner employs two voltage source inverters connected in series on the DC side and in parallel on the AC side. The power conditioner provides unity power factor and maximum power point tracking as well as more reactive power support in all modes of operation through control of the instantaneous output parameter of inverters. It has demonstrated that the proposed Power Processing Unit is an innovative solution to power conditioning for a weak grid, and suitable for application such as in hybrid power Systems.

AII.28 Analysis, Design and Control of a Standalone Hybrid Renewable Energy Conversion System

This paper deals with the analysis, design and control of a proposed standalone hybrid renewable energy conversion system based on solar and wind energy sources employing a full bridge dc-dc converter and a Permanent Magnet Brush-Less DC (PMBLDC) generator. The proposed MPPT (Maximum Power Point Tracking) controllers of solar-PV (Photo-Voltaic) array and WECS (Wind Energy Conversion System) are operating on P&O (Perturb and Observation) based on FLC (Fuzzy Logic Control) method. It requires the sensing of the dc voltage and current output of solar-PV and the rectified output voltage of PMBLDC generator driven by a wind turbine. The power quality is maintained at the load end by using an output voltage controller of the VSI (Voltage Source Inverter) and the load leveling is implemented through the battery. The model of the system can be developed in Matlab and capability of designed MPPT control is investigated during varying solar insulation and wind speeds. Renewable energy sources also called non-conventional type of energy are continuously replenished by natural processes. Hybrid systems are the right solution for a clean energy proposed which makes use of Cuk and SEPIC converters in the design. This converter design overcomes the drawbacks of the earlier proposed converters. This topology allows the two sources to supply the load separately or simultaneously depending on the availability of the energy sources. The output voltage obtained from the hybrid system is the sum of the inputs of the Cuk and SEPIC converters. This system has lower operating cost and finds applications in remote area power generation, constant speed and variable speed energy conversion systems and rural electrification. MATLAB/ SIMULINK software can be used to model the PV panel, wind turbine, DC-DC converters and the proposed hybrid system.

AII.29 Modelling and Control of a Hybrid Renewable Energy System to Supply Demand of a Green-Building

Renewable energy sources are an “indigenous” environmental option, economically competitive with conventional power generation where good wind and solar resources are available. Hybrid plants can help in improving the economic and environmental sustainability of renewable energy systems to fulfil the energy demand. The aim is to present the architecture of a Decision Support System (DSS) that can be used for the optimal energy management at a local scale through the integration of different renewable energy sources. The integrated model representing a hybrid energy generation system connected to the grid can be developed. It consists of PV and solar thermal modules, wind turbine and biomass plant. Moreover, a framework can be presented for the optimization of the different ways to ensure the electrical and thermal energy demand of the micro grid as well as the water demand, with specific reference to two main cases for the real time energy optimal control: the presence/absence of a storage system. Finally, the optimization model can be applied to a case study. A DSS for real time energy management can be proposed to define the optimal energy flows in a building characterized by a mix of renewable resources (solar plate collector, PV, biomass, wind and battery storage) to satisfy different energy demands. The model is applied to the case of Capo Vado (Liguria Region) and optimal results to satisfy all the energy demands are found for a testing day in the month of November.

AII.30 Renewable Energy Resources (Fuel Cell Technologies)

The recent severe energy crisis has forced the world to develop new and alternative methods of power generation, which could not be adopted so far due to various reasons. The magneto-hydro-dynamic (MHD) power generation is one of the examples of a new unique method of power generation. The other non-conventional methods of power generation may be such as solar cells, fuel cells, thermo-electric generator, thermionic converter, solar power generation, wind power generation, geothermal energy generation, tidal power generation etc. It elucidates about Different Energy sources, why we are going for non-conventional energy sources, Different non-conventional energy sources & comparison between them, about fuel cells and their applications. Starting with the current state of technology, the detailed R&D needs can be presented for the cell, stack, system, fuel and fuel processing for the proton exchange membrane. The PEMFC is being developed for automotive propulsion, portable power and distributed power applications. Toyota Prius (commercialized suv vehicle using PEMFC) is the first step in vehicles segment released in commercial market utilizing the fuel cell technology. At present, these fuel cells have gone through demonstration projects for performance levels and anticipated improvements. The major issues are the cost/kW, durability and reliability. Extensive efforts are being devoted to improve the performance with less costly materials, lower material content, more simplified systems/components, less number of parts, addressing transient and steady state performance issues, reducing the losses, etc.

AII.31 Modeling and Control for Smart Grid Integration with MPPT of Solar/Wind Energy Conversion System

Performance optimization, system reliability and operational efficiency are key characteristics of smart grid systems. A novel model of smart grid-connected PV/WT hybrid system can be developed. It comprises photovoltaic array, wind turbine, asynchronous (induction) generator, controller and converters. The model can be implemented using MATLAB/SIMULINK software package. Perturb and observe (P&O) algorithm is used for maximizing the generated power based on maximum power point tracker (MPPT) implementation. The dynamic behavior of the proposed model is examined under different operating conditions. Solar irradiance, temperature and wind speed data is gathered from a grid connected, 28.8 kW solar power system located in central Manchester. Real-time measured parameters are used as inputs for the developed system. The proposed model and its control strategy offer a proper tool for smart grid performance optimization. A novel PV/WT hybrid power system is designed and modeled for smart grid applications. The developed algorithm comprises system components and an appropriate power flow controller. The model can be implemented using the MATLAB/SIMULINK software package, and designed with a dialog box like those used in the SIMULINK block libraries. The available power from the PV system is highly dependent on solar radiation. To overcome this deficiency of the PV system, the PV module was integrated with the wind turbine system. The dynamic behavior of the proposed model is examined under different operating conditions. Solar irradiance, temperature and wind speed data is gathered from a 28.8 kW grid connected solar power system located in central Manchester. The developed system and its control strategy exhibit excellent performance for the simulation of a complete day. The proposed model offers a proper tool for smart grid performance optimization.

AII.32 Augmented Horizontal Axis Wind Energy Systems

Solar PV cells are the devices which convert photons directly into electrical energy. Photovoltaic cells are made of special materials called semiconductors such as silicon. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material and hence free electrons are created. It then needs to herd these stray electrons to electric current by creating an electrical imbalance. Creating the imbalance is achieved by adding small quantities of other elements. This creates two different type of silicon-n-type, which has spare electrons and p-type which has holes in the place of missing electrons. When these two materials are side by side, the n-type silicon's spare electrons rush to fill the gaps in the p-type silicon. This means the n-type silicon becomes positively charged and p-type silicon becomes negatively charged. This creates a potential difference causing the flow of electrons. Differential heating of the surface of the earth creates the movement of large masses of air on the surface of the earth i.e. the wind. The wind energy conversion system converts the kinetic energy of the wind to electricity or other forms of energy. The major components of wind energy convertors are wind turbine, generators, interconnection apparatus and control systems. Installing solar cells involves more initial cost. Apart from that, it also involves the cost of inverters and charge storage elements. The efficiency of solar pv cells is about just 14–15 %. The efficiency depends on the purity of the silicon wafer. The cost of getting pure silicon is much higher. Although the solar pv cells have more constrains it is the best alternative for non-renewable resources and is more eco friendly. Advanced researches to implement hybrid, plastic and flexible solar PV cells should be carried. This also involves the role of the government to encourage the installment of solar pv cells. The efficiency of wind energy conversion is up to about 40–60 %. The cost of wind energy conversion has decreased due to extensive researches over the years. This should also be accompanied by giving incentives to encourage research.

AII.33 Hybrid (Solar and Wind) Energy Systems for Rural Electrification

Performance optimization, system reliability and operational efficiency are key characteristics of smart grid systems. Hybrid power system can be used to reduce energy storage requirements. The influence of the Deficiency of Power Supply Probability (DPSP), Relative Excess Power Generated (REPG), Energy to Load Ratio (ELR), fraction of PV and wind energy, and coverage of PV and wind energy against the system size and performance can be analyzed. The technical feasibility of PV-wind hybrid system in given range of load demand can be evaluated. The methodology of Life Cycle Cost (LCC) for economic evaluation of stand-alone photovoltaic system, stand-alone wind system and PV-wind hybrid system can be developed and simulated using the model. The optimum combination of solar PV-wind hybrid system lies between 0.70 and 0.75 of solar energy to load ratio and the corresponding LCC is minimum. The PV-wind hybrid system returns the lowest unit cost values to maintain the same level of DPSP as compared to standalone solar and wind systems. For all load demands the levelised energy cost for PV-wind hybrid system is always lower than that of standalone solar PV or wind system. The PV-wind hybrid option is techno-economically viable for rural electrification. In the present scenario standalone solar photovoltaic and wind systems have been promoted around the globe on a comparatively larger scale. These independent systems cannot provide continuous source of energy, as they are seasonal. The solar and wind energies are complement in nature. By integrating and optimizing the solar photovoltaic and wind systems, the reliability of the systems can be improved and the unit cost of power can be minimized. A PV wind hybrid systems is designed for rural electrification for the required load at specified Deficiency of Power Supply Probability (DPSP). A new methodology can be developed to determine the size of the PV wind hybrid system using site parameters, types of wind systems, types of solar photovoltaic system, number of days of autonomy of battery and life period of the system.

AII.34 Simulation and Harmonics Reduction of Wind-PV Hybrid System

A hybrid energy conversion system combining photo voltaic and wind turbine as a small-scale alternative source of electrical energy can be proposed. The set-up consists of a photo-voltaic solar-cell array, a mast mounted wind generator, lead-acid storage batteries, a PWM inverter unit to convert DC power to AC power, IGBT and three-phase loads, as the wind and sun shine is not available all the time, solar and wind power alone are poor power sources. Thus Hybridizing solar and wind power sources together with storage batteries is better option. Photo-Voltaic or solar cells, convert the energy from sunlight into DC electricity. PVs holds advantage over other renewable energy sources in that they give off no noise, and practically require no maintenance. Wind- turbines and PV cells provide DC power. A semiconductor-based device known as a power inverter is used to convert the DC power to AC power. The hybrid unit contains two complete generating plants, a PV solar cell plant and a wind-turbine system. These sources are connected in parallel to a 12 V DC line. The power is next connected to a DC to AC inverter and is then supplied from the inverter's output to a three phase load. A generalized PV model which is representative of the all PV cell, module, and array can be developed with Matlab/Simulink and verified with a PV cell and a commercial module. The proposed model takes sunlight irradiance and cell temperature as input parameters and outputs the I-V and P-V characteristics under various conditions. Such a generalized PV model is easy to be used for the implementation on Matlab/Simulink modeling and simulation platform. Especially, in the context of the Sim Power System tool, there is now a generalized PV model which can be used for the model and analysis in the field of solar PV power conversion system. The future work includes that dc output when converted to ac by inverter contains harmonics; these harmonics can be reduced by various technologies.

AII.35 Dead Band Method for Solar Irradiance and Power Ramp Detection Algorithms

Integration of solar photovoltaic (PV) power plants onto the electric utility grid can pose some challenges from the perspective of operating the power system (balancing load and demand) and in interconnecting a PV power plant (controlling distribution system voltage variations and thus power quality). An issue of particular importance is the rate at which the solar irradiance changes, and the consequent rate at which the power output changes, i.e. the ramp rates. Pertinent information describing the ramps is the frequency, duration, and magnitude of the ramps. It compares different methods of computing ramp rates in both irradiance and power. The "dead band" method, a historical data compression technique, is demonstrated for identifying fluctuations in the one second to several second timeframe. Ramp calculation methods are presented along with the results describing ramp events for two case studies. A dead band technique was proposed to identify irradiance and power ramp rates. Two case studies were included; one for detecting irradiance ramps and one for detecting power ramps from a solar PV plant. This technique was found to sufficient in resolving rapid variations in power that can occur at a PV power plant. Ramp rates and ramp durations can be tabulated in histograms, tables, heat maps, envelope plots, and contour plots to characterize the ramping behavior of the solar resource or of a power plant. The dead band method is expected to be computationally similar to the swinging door method, and both are able to capture ramps at a variety of timescales. The dead band method (not unlike the swinging door method) requires pre-calibrating the algorithm to determine the sensitivity to ramp detection. This calibration requires judgment by the user in determining what type of ramp events are of interest for a particular application, making it tunable to the user's needs.

Appendix III
SIMULINK Block Sets

The MATLAB/SIMULINK blocks used in relation with solar PV, wind energy conversion systems and fuel cell are described in this section. The description of the block with block parameters and their setting is discussed below:

AIII.1 Series RLC Load

Implement linear series RLC load

Library

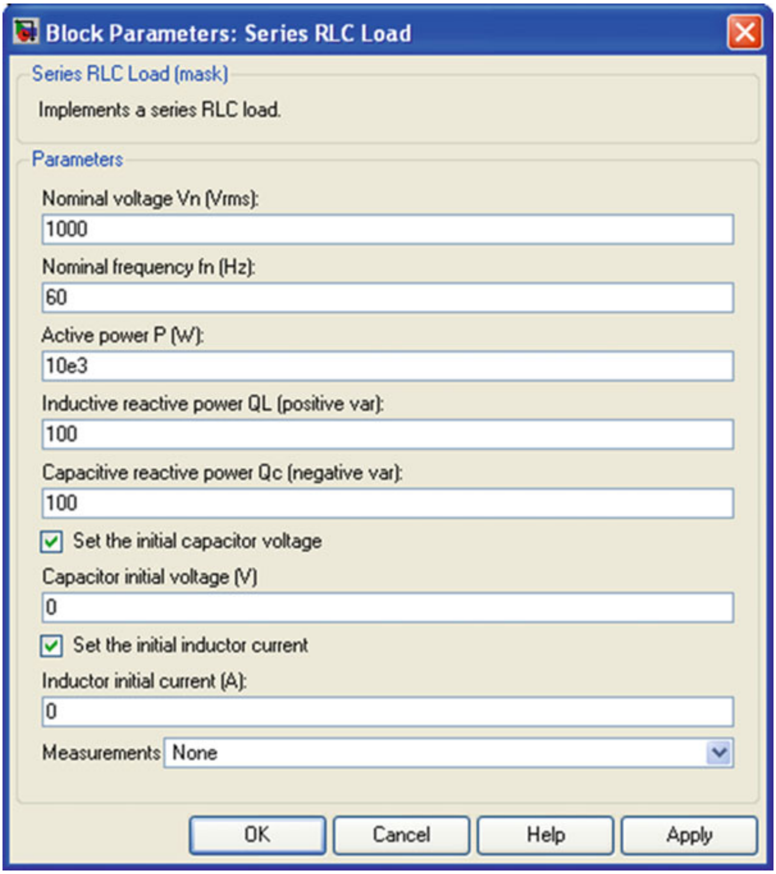
Elements

Description

The Series RLC Load block implements a linear load as a series combination of R L C elements. At the specified frequency, the load exhibits a constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage. Only elements associated with nonzero powers are displayed in the block icon.

S. Sumathi et al., *Solar PV and Wind Energy Conversion Systems*,
Green Energy and Technology, DOI 10.1007/978-3-319-14941-7

Dialog Box and Parameters



Nominal Voltage Vn

The nominal voltage of the load, in volts RMS.

Nominal Frequency fn

The nominal frequency, in hertz.

Active Power P

The active power of the load, in watts.

Inductive Reactive Power QL

The inductive reactive power QL, in vars. Specify a positive value, or 0.

Capacitive Reactive Power QC

The capacitive reactive power QC, in vars. Specify a positive value, or 0.

Set the Initial Capacitor Voltage

If selected, the initial capacitor voltage is defined by the **Capacitor initial voltage** parameter. If not selected, the software calculates the initial capacitor voltage in order to start the simulation in steady-state.

The **Set the initial capacitor voltage** parameter have no effect on the block if the capacitive reactive power is equal to zero.

Capacitor Initial Voltage (V)

The initial capacitor voltage used at the start of the simulation. The **Capacitor initial voltage** parameter have no effect on the block if the capacitive reactive power is equal to zero and if the **Set the initial capacitor voltage** parameter is not selected.

Set the Initial Inductor Current

If selected, the initial inductor current is defined by the **Inductor initial current** parameter. If not selected, the software calculates the initial inductor current in order to start the simulation steady-state.

The **Set the initial inductor current** parameter have no effect on the block if the inductive reactive power is equal to zero.

Inductor Initial Current (A)

The initial inductor current used at the start of the simulation. The **Inductor initial current** parameter have no effect on the block if the inductive reactive power is equal to zero and if the **Set the initial inductor current** parameter is not selected.

AIII.2 Parallel RLC Load

Implement linear parallel RLC load

Library

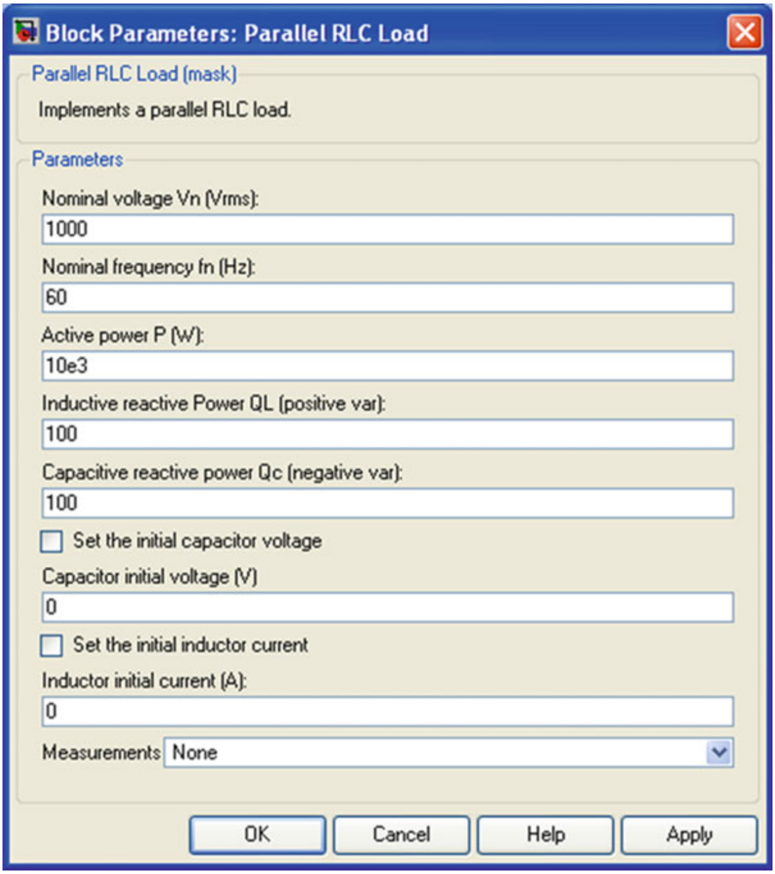
Elements

Description

The Parallel RLC Load block implements a linear load as a parallel combination of RLC elements. At the specified frequency, the load exhibits a constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage.

Only elements associated with nonzero powers are displayed in the block icon.

Dialog Box and Parameters



Nominal Voltage Vn

The nominal voltage of the load, in volts RMS (Vrms).

Nominal Frequency fn

The nominal frequency, in hertz (Hz).

Active Power P

The active power of the load, in watts.

Inductive Reactive Power QL

The inductive reactive power QL, in vars. Specify a positive value, or 0.

Capacitive Reactive Power QC

The capacitive reactive power QC, in vars. Specify a positive value, or 0.

Set the Initial Capacitor Voltage

If selected, the initial capacitor voltage is defined by the **Capacitor initial voltage** parameter. If not selected, the software calculates the initial capacitor voltage in order to start the simulation in steady-state.

The **Set the initial capacitor voltage** parameter have no effect on the block if the capacitive reactive power is equal to zero.

Capacitor Initial Voltage (V)

The initial capacitor voltage used at the start of the simulation. The **Capacitor initial voltage** parameter have no effect on the block if the capacitive reactive power is equal to zero and if the **Set the initial capacitor voltage** parameter is not selected.

Set the Initial Inductor Current

If selected, the initial inductor current is defined by the **Inductor initial current** parameter. If not selected, the software calculates the initial inductor current in order to start the simulation steady-state.

The **Set the initial inductor current** parameter have no effect on the block if the inductive reactive power is equal to zero.

Inductor Initial Current (A)

The initial inductor current used at the start of the simulation. The **Inductor initial current** parameter have no effect on the block if the inductive reactive power is equal to zero and if the **Set the initial inductor current** parameter is not selected.

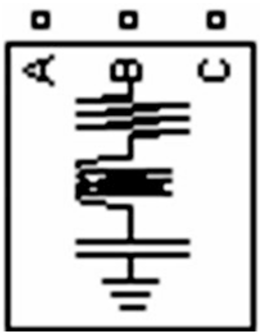
AIII.3 Three-Phase Series RLC Load

Implement three-phase series RLC load with selectable connection

Library

Elements

Description

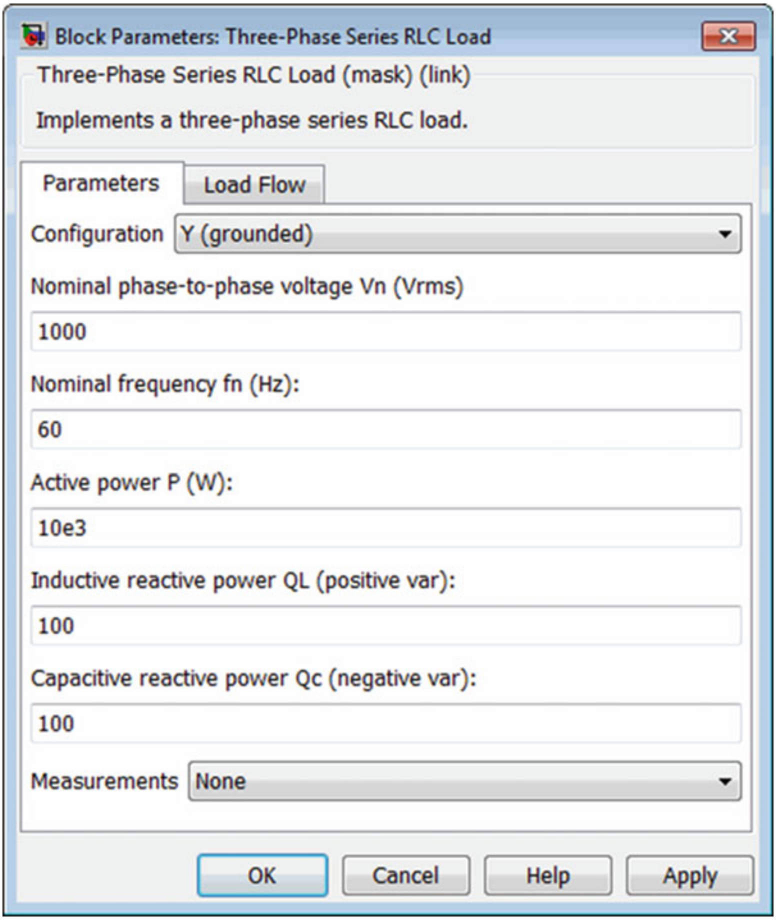


The Three-Phase Series RLC Load block implements a three-phase balanced load as a series combination of RLC elements. At the specified frequency, the load exhibits a constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage.

Only elements associated with nonzero powers are displayed in the block icon.

Dialog Box and Parameters

Parameters Tab



Configuration

The connection of the three phases. Select one of the following four connections:

`Y(grounded)`	Neutral is grounded
`Y(floating)`	Neutral is not accessible
`Y(neutral)`	Neutral is made accessible through a fourth connector
`Delta`	Three phases connected in delta

The block icon is updated according to the load connection.

Nominal Phase-to-Phase Voltage Vn

The nominal phase-to-phase voltage of the load, in volts RMS (Vrms).

Nominal Frequency fn

The nominal frequency, in hertz (Hz).

Active Power P

The three-phase active power of the load, in watts (W).

Inductive Reactive Power QL

The three-phase inductive reactive power QL, in vars. Specify a positive value, or 0.

Capacitive Reactive Power Qc

The three-phase capacitive reactive power QC, in vars. Specify a positive value, or 0.

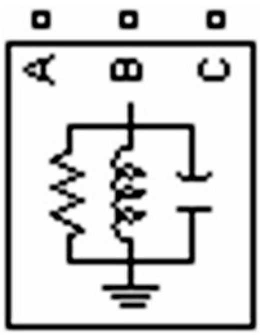
AIII.4 Three-Phase Parallel RLC Load

Implement three-phase parallel RLC load with selectable connection

Library

Elements

Description

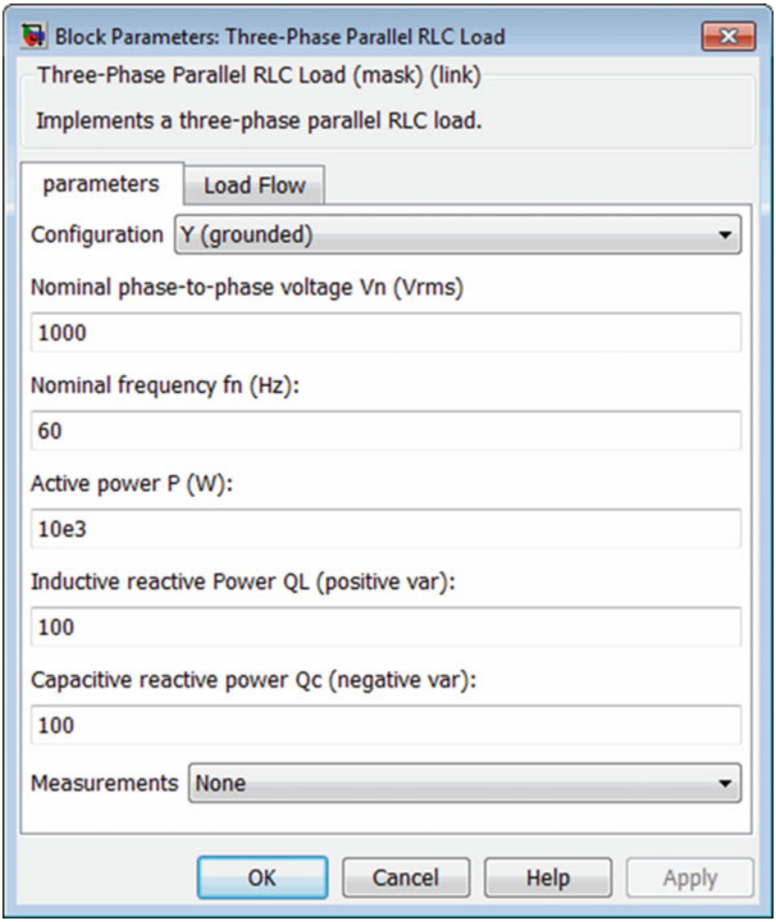


The Three-Phase Parallel RLC Load block implements a three-phase balanced load as a parallel combination of RLC elements. At the specified frequency, the load exhibits a constant impedance. The active and reactive powers absorbed by the load are proportional to the square of the applied voltage.

Only elements associated with nonzero powers are displayed in the block icon.

Dialog Box and Parameters

Parameters Tab



Configuration

The connection of the three phases. Select one of the following four connections:

`Y(grounded)`	Neutral is grounded
`Y(floating)`	Neutral is not accessible
`Y(neutral)`	Neutral is made accessible through a fourth connector
`Delta`	Three phases connected in delta

The block icon is updated according to the load connection.

Nominal Phase-to-Phase Voltage Vn

The nominal phase-to-phase voltage of the load, in volts RMS (Vrms).

Nominal Frequency fn

The nominal frequency, in hertz (Hz).

Active Power P

The three-phase active power of the load, in watts (W).

Inductive Reactive Power QL

The three-phase inductive reactive power QL, in vars. Specify a positive value, or 0.

Capacitive Reactive Power QC

The three-phase capacitive reactive power QC, in vars. Specify a positive value, or 0.

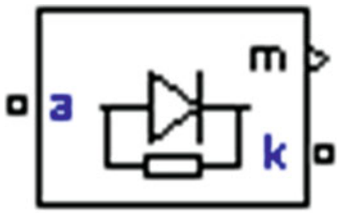
AIII.5 Diode

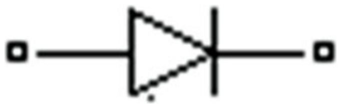
Implement diode model

Library

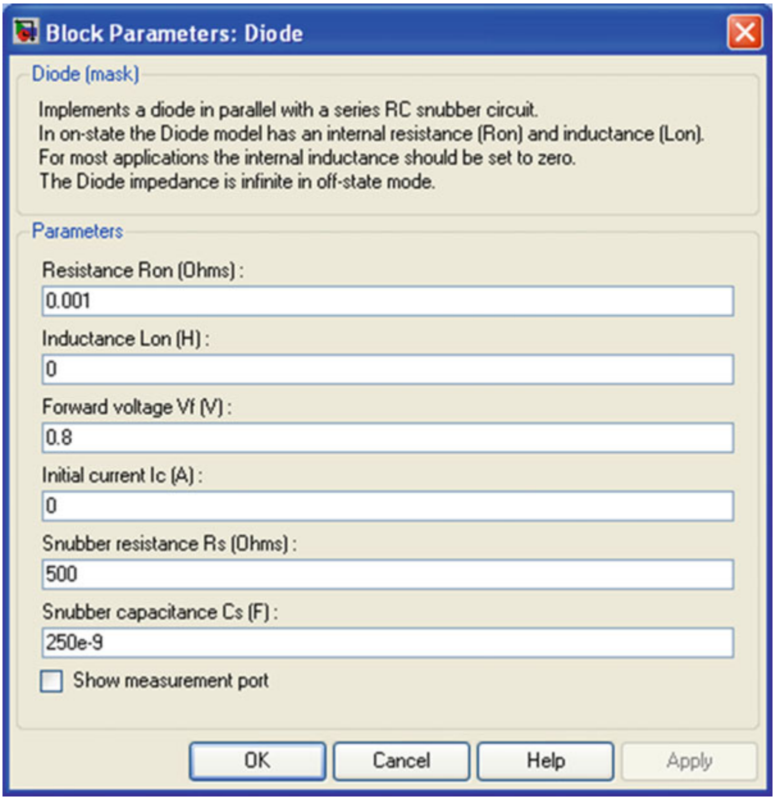
Power Electronics

Description





Dialog Box and Parameters



Resistance Ron

The diode internal resistance Ron, in ohms (Ω). The **Resistance Ron** parameter cannot be set to 0 when the **Inductance Lon** parameter is set to 0.

Inductance Lon

The diode internal inductance Lon, in henries (H). The **Inductance Lon** parameter cannot be set to 0 when the **Resistance Ron** parameter is set to 0.

Forward Voltage Vf

The forward voltage of the diode device, in volts (V).

Initial Current Ic

Specifies an initial current flowing in the diode device. It is usually set to 0 in order to start the simulation with the diode device blocked. If the **Initial Current IC** parameter is set to a value greater than 0, the steady-state calculation considers the initial status of the diode as closed.

Initializing all states of a power electronic converter is a complex task. Therefore, this option is useful only with simple circuits.

Snubber Resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to inf to eliminate the snubber from the model.

Snubber Capacitance Cs

The snubber capacitance in farads (F). Set the **Snubber capacitance Cs** parameter to 0 to eliminate the snubber, or to inf to get a resistive snubber.

Show Measurement Port

If selected, adds a Simulink® output to the block returning the diode current and voltage.

AIII.6 Ideal Switch

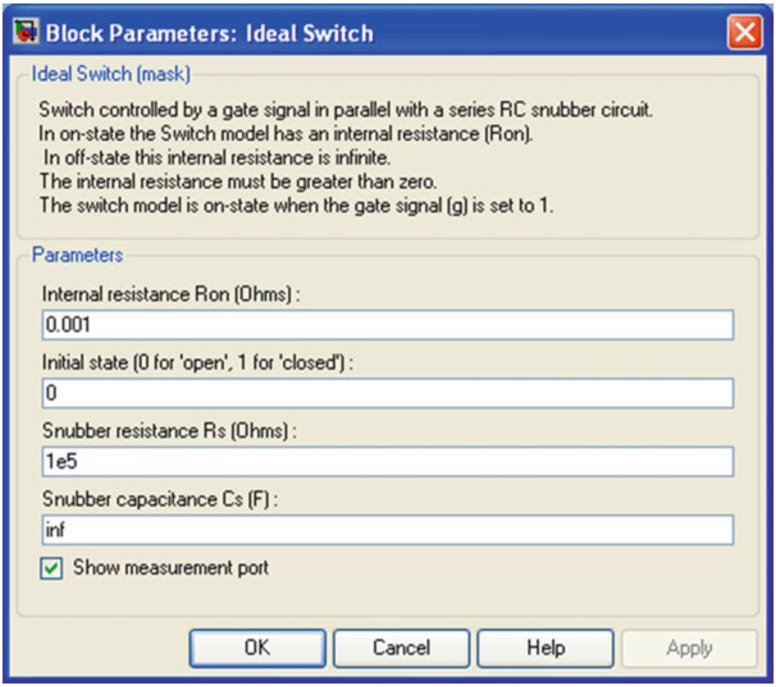
Implement ideal switch device

Library

Power Electronics

Description

Dialog Box and Parameters



Internal Resistance Ron

The internal resistance of the switch device, in ohms (Ω). The **Internal resistance Ron** parameter cannot be set to 0.

Initial State

The initial state of the Ideal Switch block. The initial status of the Ideal Switch block is taken into account in the steady-state calculation.

Snubber Resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to inf to eliminate the snubber from the model.

Snubber Capacitance Cs

The snubber capacitance in farads (F). Set the **Snubber capacitance Cs** parameter to 0 to eliminate the snubber, or to inf to get a resistive snubber.

Show Measurement Port

If selected, add a Simulink® output to the block returning the ideal switch current and voltage.

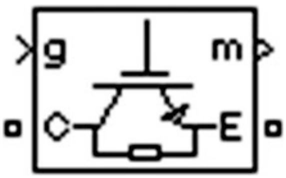
AIII.7 IGBT

Implement insulated gate bipolar transistor (IGBT)

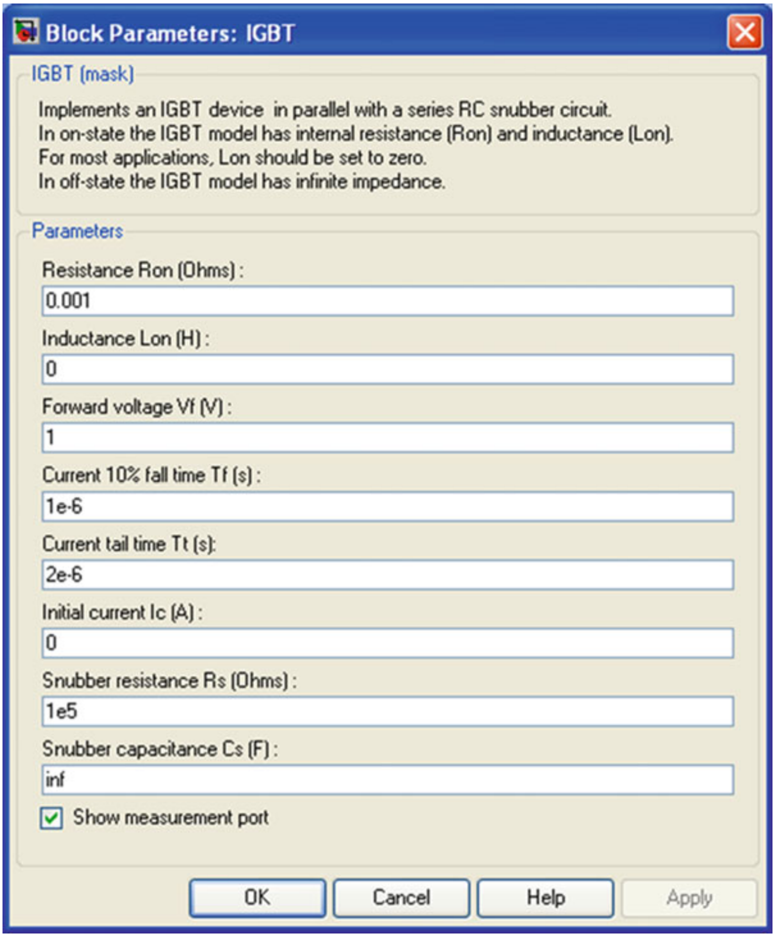
Library

Power Electronics

Description



Dialog Box and Parameters



Resistance Ron

The internal resistance Ron, in ohms (Ω). The **Resistance Ron** parameter cannot be set to 0 when the **Inductance Lon** parameter is set to 0.

Inductance Lon

The internal inductance Lon, in henries (H). The **Inductance Lon** parameter is normally set to 0 except when the **Resistance Ron** parameter is set to 0.

Forward Voltage Vf

The forward voltage of the IGBT device, in volts (V).

Current 10 % Fall Time

The current fall time Tf, in seconds (s). This parameter is not modeled when the **Enable use of ideal switching devices** parameter of the Powergui block is selected.

Current Tail Time

The current tail time Tt, in seconds (s). This parameter is not modeled when the **Enable use of ideal switching devices** parameter of the Powergui block is selected.

Initial Current Ic

You can specify an initial current flowing in the IGBT. It is usually set to 0 in order to start the simulation with the device blocked.

If the **Initial Current IC** parameter is set to a value greater than 0, the steady-state calculation considers the initial status of the IGBT as closed. Initializing all states of a power electronic converter is a complex task. Therefore, this option is useful only with simple circuits.

Snubber Resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to inf to eliminate the snubber from the model.

Snubber Capacitance Cs

The snubber capacitance in farads (F). Set the **Snubber capacitance Cs** parameter to 0 to eliminate the snubber, or to inf to get a resistive snubber.

Show Measurement Port

If selected, add a Simulink® output to the block returning the diode IGBT current and voltage.

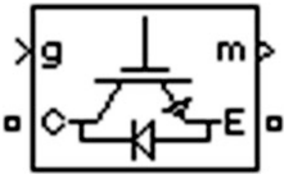
AIII.8 IGBT/DIODE

Implements ideal IGBT, GTO, or MOSFET and antiparallel diode

Library

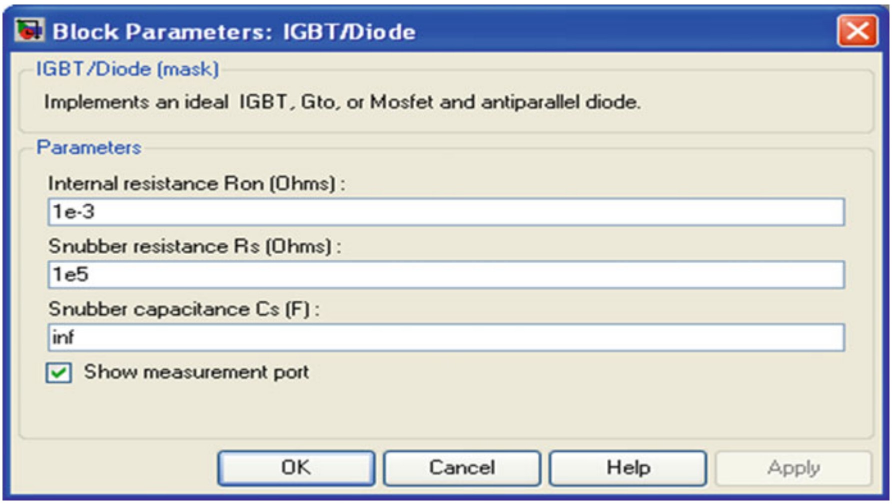
Power Electronics

Description



The IGBT/Diode block is a simplified mode of an IGBT (or GTO or MOSFET)/ Diode pair where the forward voltages of the forced-commutated device and diode are ignored.

Dialog Box and Parameters



Internal Resistance Ron

The internal resistance Ron of the IGBT device, in ohms (Ω).

Snubber Resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to inf to eliminate the snubber from the model.

Snubber Capacitance Cs

The snubber capacitance in farads (F). Set the **Snubber capacitance Cs** parameter to 0 to eliminate the snubber, or to inf to get a resistive snubber.

Show Measurement Port

If selected, add a Simulink® output to the block returning the diode IGBT current and voltage.

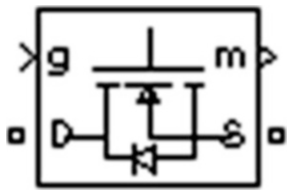
AIII.9 MOSFET

Implement MOSFET model

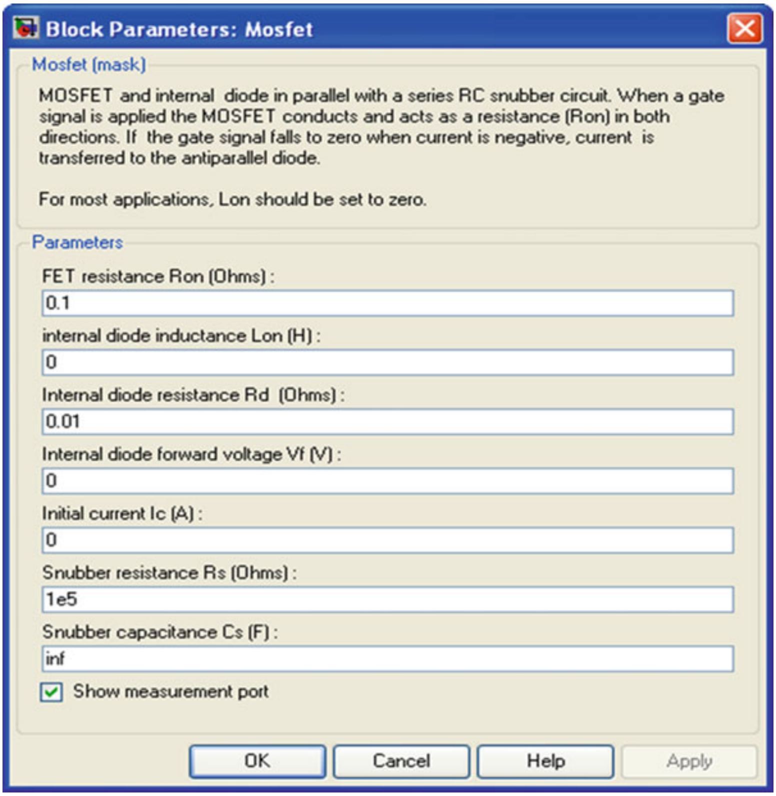
Library

Power Electronics

Description



Dialog Box and Parameters



FET Resistance Ron

The internal resistance Ron, in ohms (Ω). The **Resistance Ron** parameter cannot be set to 0 when the **Inductance Lon** parameter is set to 0.

Internal Diode Inductance Lon

The internal inductance Lon, in henries (H). The **Inductance Lon** parameter is normally set to 0 except when the **Resistance Ron** parameter is set to 0.

Internal Diode Resistance Rd

The internal resistance of the internal diode, in ohms (Ω).

Internal Diode Forward Voltage Vf

The forward voltage of the internal diode, in volts (V).

Initial Current Ic

You can specify an initial current flowing in the MOSFET device. It is usually set to 0 in order to start the simulation with the device blocked.

If the **Initial current IC** parameter is set to a value greater than 0, the steady-state calculation considers the initial status of the MOSFET as closed. Initializing all states of a power electronic converter is a complex task. Therefore, this option is useful only with simple circuits.

Snubber Resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubber from the model.

Snubber Capacitance Cs

The snubber capacitance, in farads (F). Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubber, or to `inf` to get a resistive snubber.

Show Measurement Port

If selected, add a Simulink® output to the block returning the MOSFET current and voltage.

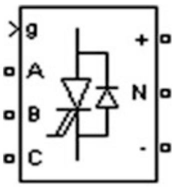
AIII.10 Three-Level Bridge

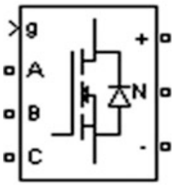
Implement three-level neutral point clamped (NPC) power converter with selectable topologies and power switching devices

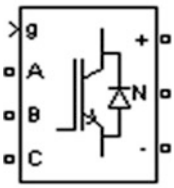
Library

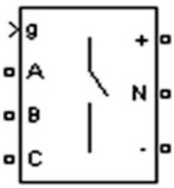
Power Electronics

Description

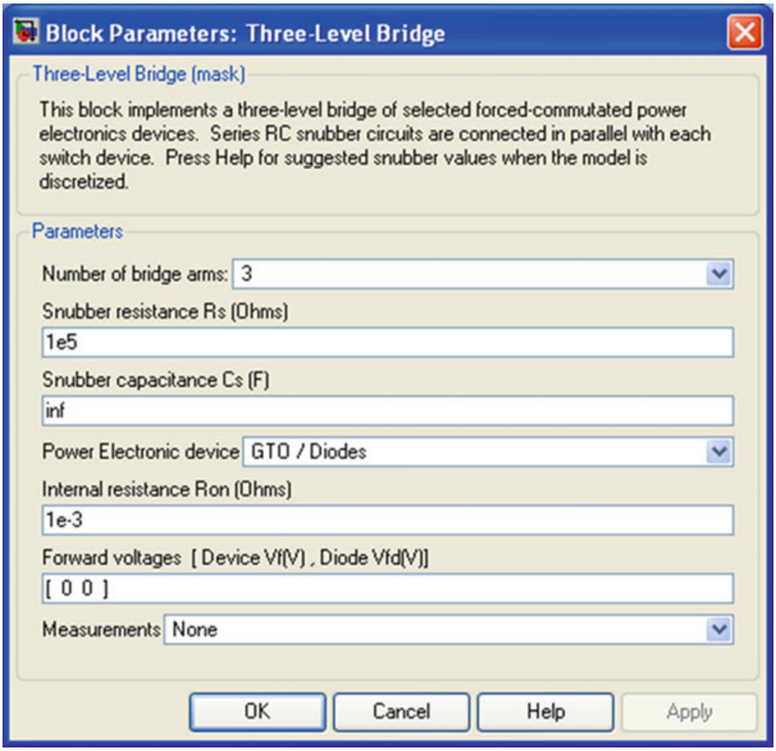








Dialog Box and Parameters



Number of Bridge Arms

Determine the bridge topology: one, two, or three arms.

Snubber Resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubbers from the model.

Snubber Capacitance Cs

The snubber capacitance, in farads (F). Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubbers, or to `inf` to get a resistive snubber.

For forced-commutated devices (GTO, IGBT, or MOSFET) the Three-Level Bridge block operates satisfactorily with resistive snubbers as long as the firing pulses are sent to the switching devices.

If the firing pulses to forced-commutated devices are blocked, the bridge operates as a diode rectifier. In this condition, you must use appropriate values of

Rs and Cs. If the model is discretized, you can use the following formulas to compute approximate values of Rs and Cs:

$$Rs > 2\frac{Ts}{Cs}$$

$$Cs < \frac{Pn}{1000(2\pi f)Vn^2},$$

where

Pn = nominal power of single- or three-phase converter (VA)
Vn = nominal line-to-line AC voltage (Vrms)
f = fundamental frequency (Hz)
Ts = sample time (s)

These Rs and Cs values are derived from the following two criteria:

- The snubber leakage current at fundamental frequency is less than 0.1 % of nominal current when power electronic devices are not conducting.
- The RC time constant of snubbers is higher than two times the sample time Ts.

Note that the Rs and Cs values that guarantee numerical stability of the discretized bridge can be different from actual values used in the physical circuit.

Power Electronic Device

Select the type of power electronic device to use in the bridge.

Internal Resistance Ron

Internal resistance of the selected devices and diodes, in ohms (Ω).

Forward Voltages [Device Vf, Diode Vfd]

The forward voltage of the selected devices (for GTO or IGBT only) and of the antiparallel and clamping diodes, in volts.

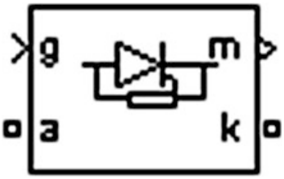
AIII.11 Thyristor

Implement thyristor model

Library

Power Electronics

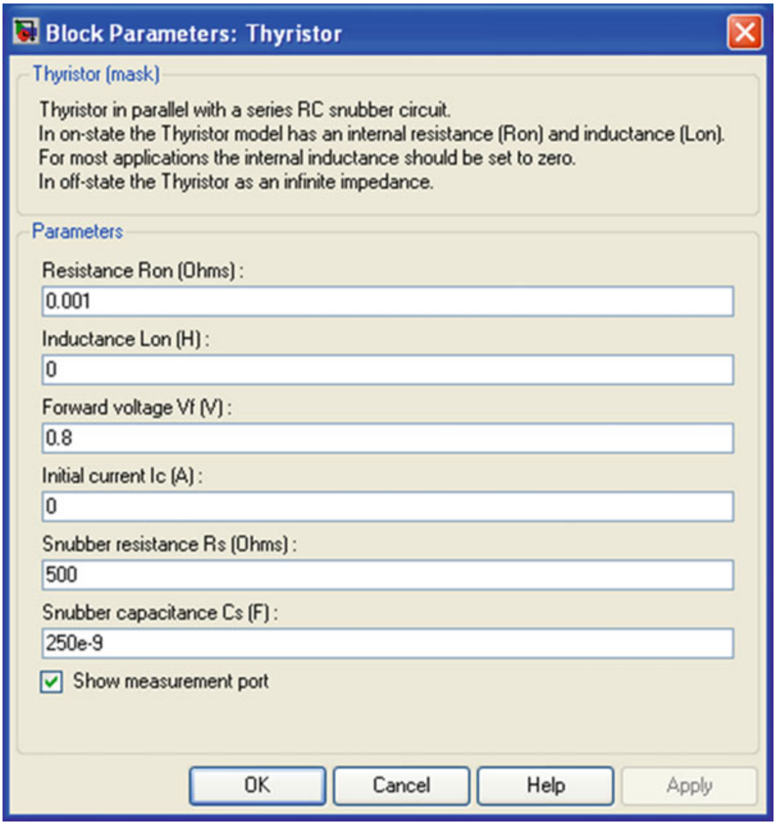
Description



Dialog Box and Parameters

Thyristor Model and Detailed Thyristor Model

In order to optimize simulation speed, two models of thyristors are available: the thyristor model and the detailed thyristor model. For the thyristor model, the latching current *Il* and recovery time *Tq* are assumed to be 0.



Resistance Ron

The thyristor internal resistance Ron, in ohms (Ω). The **Resistance Ron** parameter cannot be set to `0` when the **Inductance Lon** parameter is set to `0`.

Inductance Lon

The thyristor internal inductance Lon, in henries (H). The **Inductance Lon** parameter is normally set to 0 except when the **Resistance Ron** parameter is set to `0`.

Forward Voltage Vf

The forward voltage of the thyristor, in volts (V).

Initial Current Ic

When the **Inductance Lon** parameter is greater than 0, you can specify an initial current flowing in the thyristor. It is usually set to 0 in order to start the simulation with the thyristor blocked.

You can specify an **Initial current Ic** value corresponding to a particular state of the circuit. In such a case all states of the linear circuit must be set accordingly. Initializing all states of a power electronic converter is a complex task. Therefore, this option is useful only with simple circuits.

Snubber Resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubber from the model.

Snubber Capacitance Cs

The snubber capacitance in farads (F). Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubber, or to `inf` to get a resistive snubber.

Show Measurement Port

If selected, add a Simulink® output to the block returning the thyristor current and voltage.

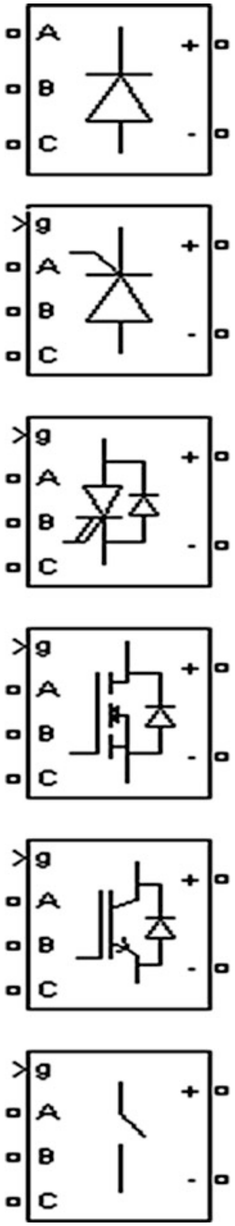
AIII.12 Universal Bridge

Implement universal power converter with selectable topologies and power electronic devices

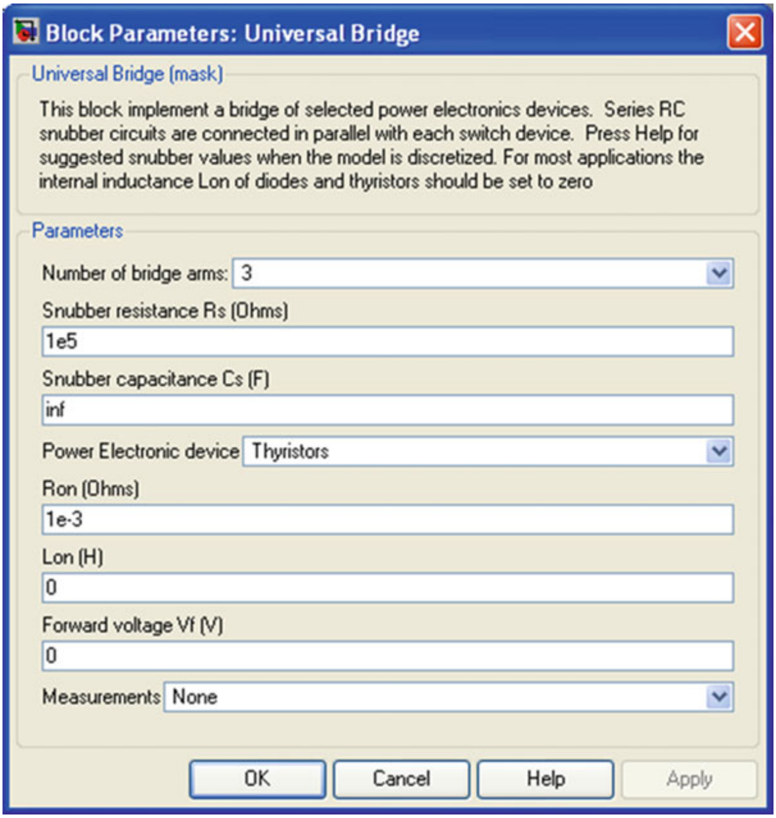
Library

Power Electronics

Description



Dialog Box and Parameters



Number of Bridge Arms

Set to `1` or `2` to get a single-phase converter (two or four switching devices). Set to `3` to get a three-phase converter connected in Graetz bridge configuration (six switching devices).

Snubber Resistance Rs

The snubber resistance, in ohms (Ω). Set the **Snubber resistance Rs** parameter to `inf` to eliminate the snubbers from the model.

Snubber Capacitance Cs

The snubber capacitance, in farads (F). Set the **Snubber capacitance Cs** parameter to `0` to eliminate the snubbers, or to `inf` to get a resistive snubber.

In order to avoid numerical oscillations when your system is discretized, you need to specify Rs and Cs snubber values for diode and thyristor bridges. For forced-commutated devices (GTO, IGBT, or MOSFET), the bridge operates satisfactorily with purely resistive snubbers as long as firing pulses are sent to switching devices.

If firing pulses to forced-commutated devices are blocked, only antiparallel diodes operate, and the bridge operates as a diode rectifier. In this condition appropriate values of Rs and Cs must also be used.

When the system is discretized, use the following formulas to compute approximate values of Rs and Cs:

$$Rs > 2\frac{T_s}{Cs}$$
$$Cs < \frac{P_n}{1000(2\pi f)V_n^2},$$

where

P_n = nominal power of single or three phase converter (VA)
V_n = nominal line-to-line AC voltage (V_{rms})
f = fundamental frequency (Hz)
T_s = sample time (s)

These Rs and Cs values are derived from the following two criteria:

- The snubber leakage current at fundamental frequency is less than 0.1 % of nominal current when power electronic devices are not conducting.
- The RC time constant of snubbers is higher than two times the sample time Ts.

These Rs and Cs values that guarantee numerical stability of the discretized bridge can be different from actual values used in a physical circuit.

Power Electronic Device

Select the type of power electronic device to use in the bridge.

When you select `Switching-function based VSC`, a switching-function voltage source converter type equivalent model is used, where switches are replaced by two voltage sources on the AC side and a current source on the DC side. This model uses the same firing pulses as for other power electronic devices and it correctly represents harmonics normally generated by the bridge.

When you select `Average-model based VSC`, an average-model type of voltage source converter is used to represent the power-electronic switches. Unlike the other power electronic devices, this model uses the reference signals (uref) representing the average voltages generated at the ABC terminals of the bridge. This model does not represent harmonics. It can be used with larger sample times while preserving the average voltage dynamics.

See `power_sfavg` for an example comparing these two models to an Universal Bridge block using IGBT/Diode device.

Ron

Internal resistance of the selected device, in ohms (Ω).

Lon

Internal inductance, in henries (H), for the diode or the thyristor device. When the bridge is discretized, the Lon parameter must be set to zero.

Forward Voltage Vf

This parameter is available only when the selected **Power electronic device** is `Diodes` or `Thyristors`.

Forward voltage, in volts (V), across the device when it is conducting.

Forward Voltages [Device Vf, Diode Vfd]

This parameter is available when the selected **Power electronic device** is `GTO/Diodes` or `IGBT/Diodes`.

Forward voltages, in volts (V), of the forced-commutated devices (GTO, MOSFET, or IGBT) and of the antiparallel diodes.

[Tf (s) Tt (s)]

Fall time Tf and tail time Tt, in seconds (s), for the GTO or the IGBT devices.

Measurements

Select `Device voltages` to measure the voltages across the six power electronic device terminals.

Select `Device currents` to measure the currents flowing through the six power electronic devices. If antiparallel diodes are used, the measured current is the total current in the forced-commutated device (GTO, MOSFET, or IGBT) and in the antiparallel diode. A positive current therefore indicates a current flowing in the forced-commutated device and a negative current indicates a current flowing in the diode. If snubber devices are defined, the measured currents are the ones flowing through the power electronic devices only.

Select `UAB UBC UCA UDC voltages` to measure the terminal voltages (AC and DC) of the Universal Bridge block.

Select `All voltages and currents` to measure all voltages and currents defined for the Universal Bridge block.

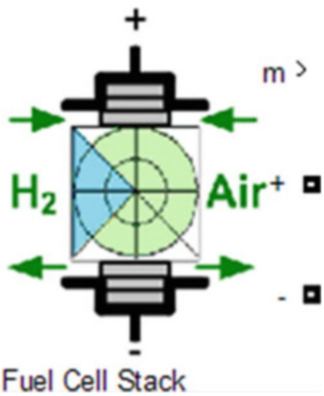
AIII.13 Fuel Cell Stack

Implement generic hydrogen fuel cell stack model

Library

Electric Drives/Extra Sources

Description

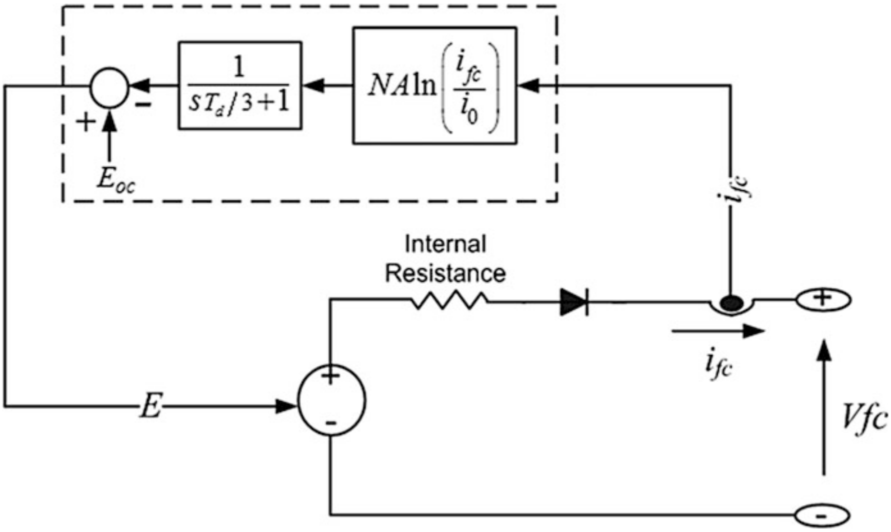


The Fuel Cell Stack block implements a generic model parameterized to represent most popular types of fuel cell stacks fed with hydrogen and air.

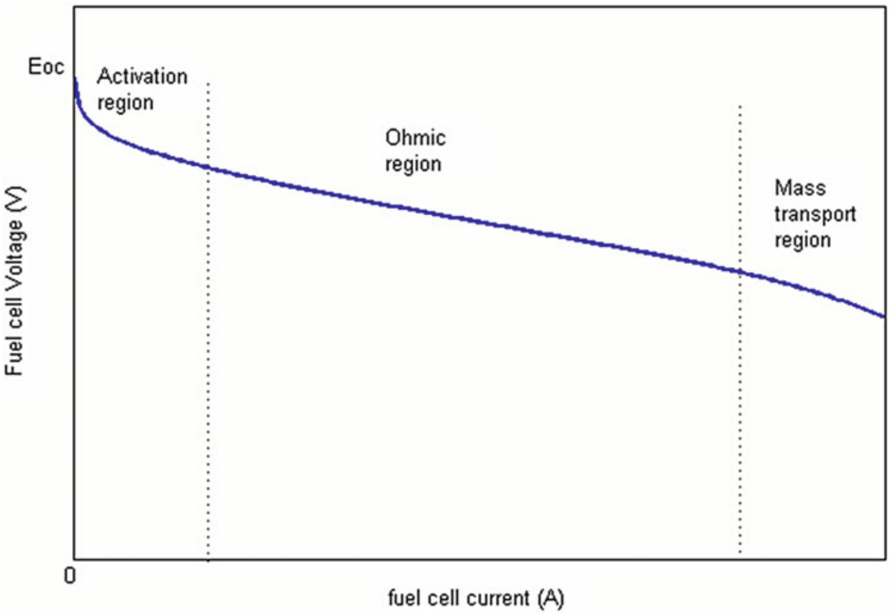
The block represents two versions of the stack model: a simplified model and a detailed model. You can switch between the two models by selecting the level in the mask under **Model detail level** in the block dialog box.

Simplified Model

This model is based on the equivalent circuit of a fuel cell stack shown below:



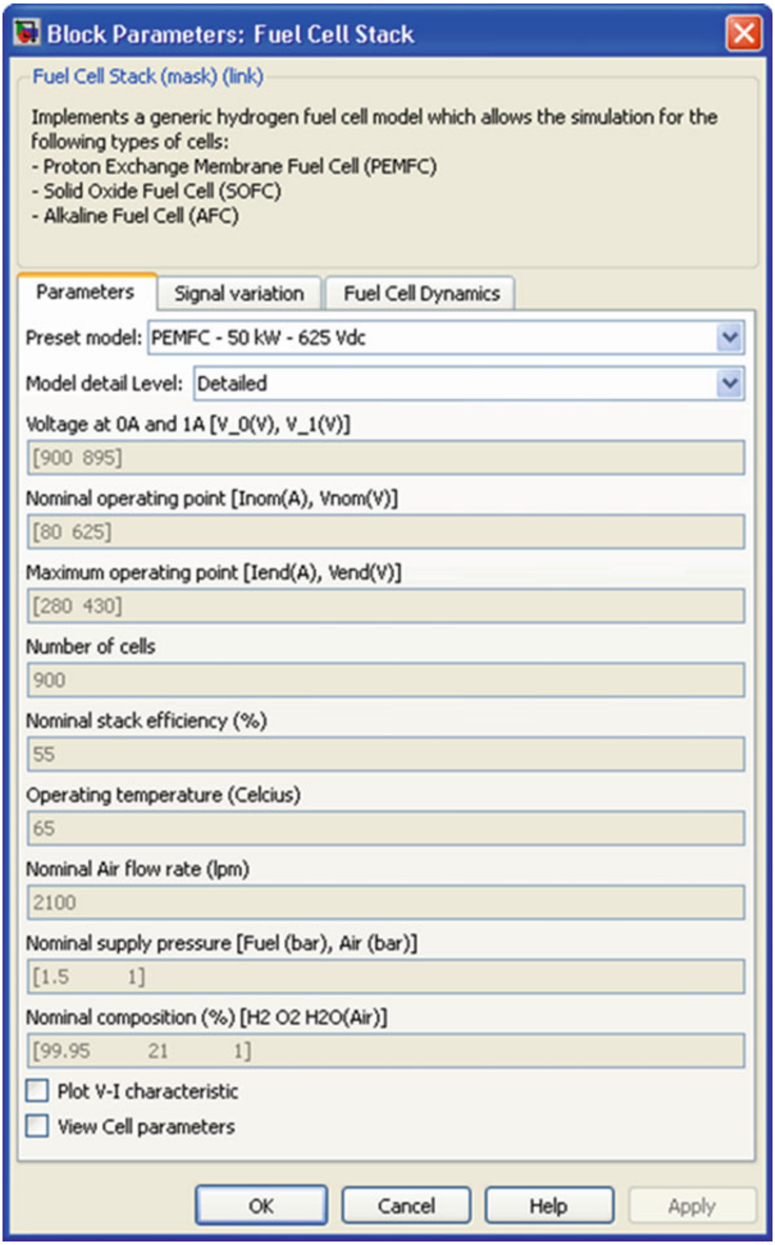
The simplified model represents a particular fuel cell stack operating at nominal conditions of temperature and pressure. The parameters of the equivalent circuit can be modified based on the polarization curve obtained from the manufacturer datasheet. You just have to input in the mask the value of the voltage at 0 and 1 A, the nominal and the maximum operating points, for the parameters to be calculated. A diode is used to prevent the flow of negative current into the stack. A typical polarization curve consists of three regions:



The first region represents the activation voltage drop due to the slowness of the chemical reactions taking place at electrode surfaces. Depending on the temperature and operating pressure, type of electrode, and catalyst used, this region is more or less wide. The second region represents the resistive losses due the internal resistance of the fuel cell stack. Finally, the third region represents the mass transport losses resulting from the change in concentration of reactants as the fuel is used.

Dialog Box and Parameters

Parameters Tab



Preset Model

Provides a set of predetermined polarization curves and parameters for particular fuel cell stacks found on the market:

- No (User-Defined).
- PEMFC – 1.26 kW – 24 Vdc.
- PEMFC – 6 kW – 45 Vdc.
- PEMFC – 50 kW – 625 Vdc.
- AFC – 2.4 kW – 48 Vdc.

Select one of these preset models to load the corresponding parameters in the entries of the dialog box. SelectNo (User-Defined) if you do not want to use a preset model.

Model Detail Level

Provide access to the two versions of the model:

- Simplified.
- Detailed.

When a simplified model is used, there is no variable under the **signal variation** pane

Voltage at 0 A and 1 A

The voltage at 0 A and 1 A of the stack (Volts). Assuming nominal and constant gases utilizations.

Nominal Operating Point

The rated current (Ampere) and rated voltage (Volts) of the stack. Assuming nominal and constant gases utilizations.

Maximum Operating Point

The current (Ampere) and voltage (Volts) of the stack at maximum power. Assuming nominal and constant gases utilizations.

Number of Cells

The number of cells in series in the stack. This parameter is available only for a detailed model.

Nominal Stack Efficiency

The rated efficiency of the stack relative to the low heating value (LHV) of water. This parameter is available only for a detailed model.

Operating Temperature

The nominal temperature of operation in degrees Celsius. This parameter is available only for a detailed model.

Nominal Air Flow Rate

The rated air flow rate (l/min). This parameter is available only for a detailed model.

Nominal Supply Pressure

Rated supply pressure (absolute) of fuel and air in bars. This parameter is available only for a detailed model.

Nominal Composition

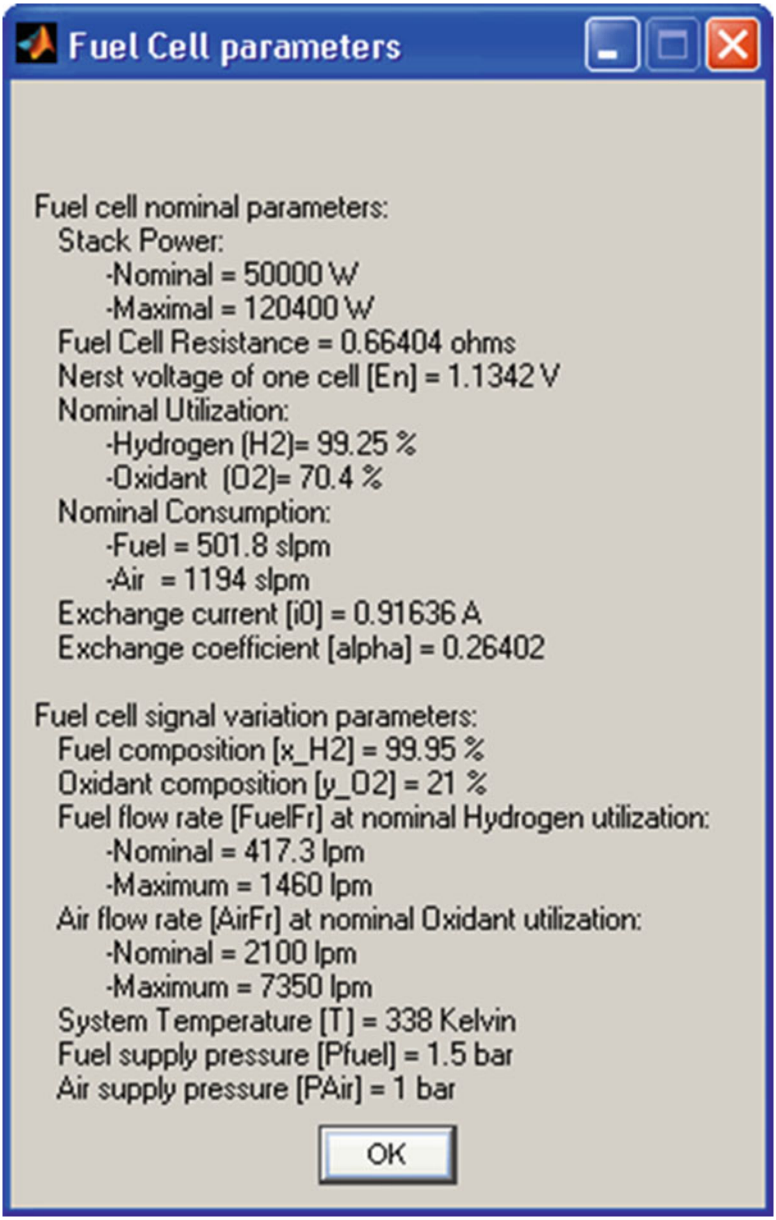
The rated percentage of hydrogen (x) in the fuel, oxygen (y) and water (w) in the oxidant. This parameter is available only for a detailed model.

Plot V-I Characteristic

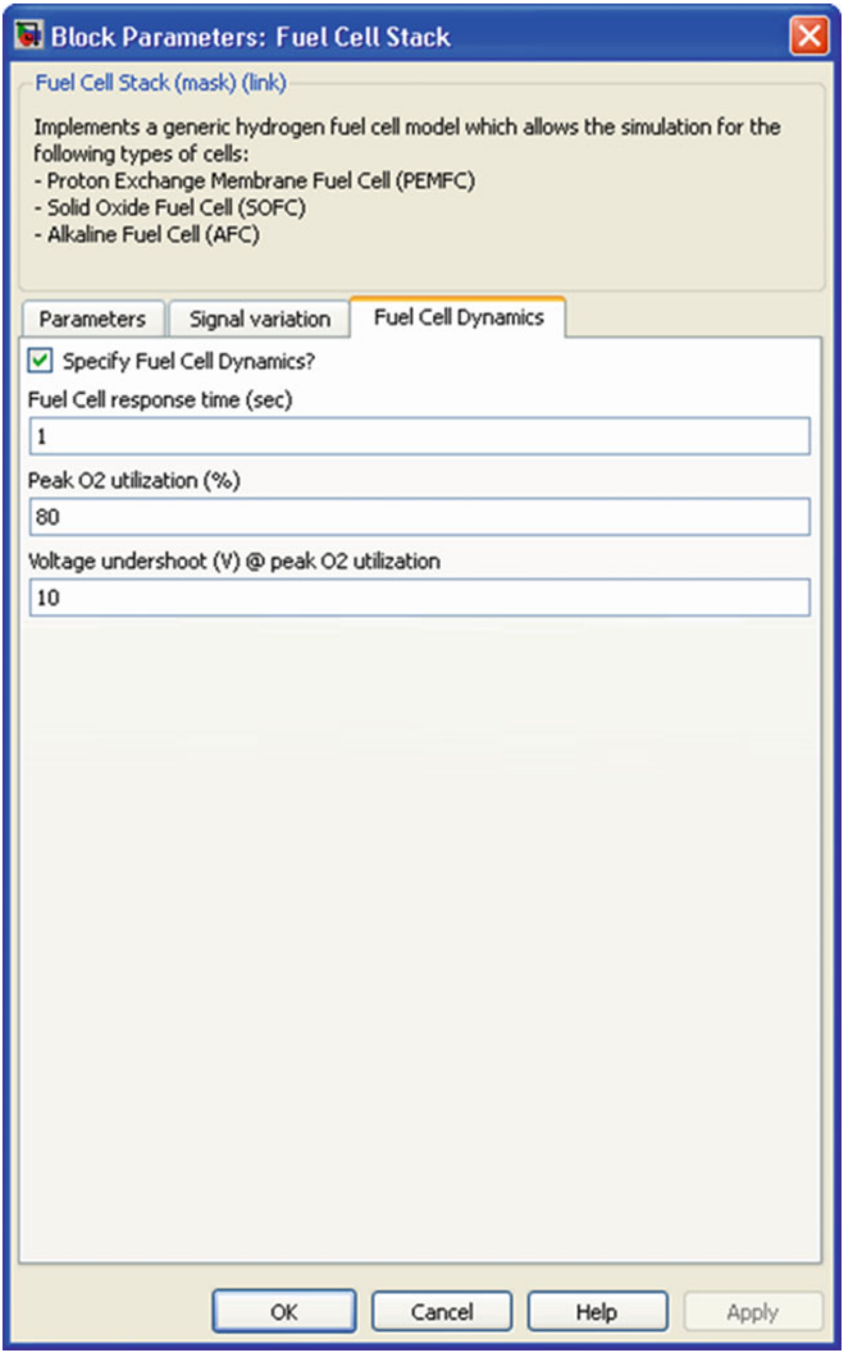
Plots a figure containing two graphs. The first graph represents the stack voltage (Volts) vs. current (A) and the second graph represents the stack power (kW) vs. current (A). To plot the graphs, select the checkbox. This checkbox is available only for a detailed model.

View Cell Parameters

Presents the overall parameters of the stack. This checkbox is available only for a detailed model. Select the checkbox to view the parameters. The dialog box is shown below.



Fuel Cell Dynamics Tab



Specify Fuel Cell Dynamics?

Asks whether you want to specify the fuel cell dynamics. Select the checkbox to enter the fuel cell response time in seconds.

Fuel Cell Response Time (Sec)

Enter the response time of the cell (at 95 % of the final value). This parameter becomes visible only when the **Specify Fuel Cell Dynamics?** checkbox is selected.

Peak O_2 Utilization (%)

Enter the peak oxygen utilization at nominal condition of operation. This parameter becomes visible only when the **Specify Fuel Cell Dynamics?** checkbox is selected and the **Air flow rate** checkbox is selected under the **Signal variation** pane.

Voltage Undershoot (V) @ Peak O_2 Utilization

Enter the voltage undershoot (Volts) at peak oxygen utilization at nominal condition of operation. This parameter becomes visible only when the **Specify Fuel Cell Dynamics?** checkbox is selected and the **Air flow rate** checkbox is selected under the **Signal variation** pane.

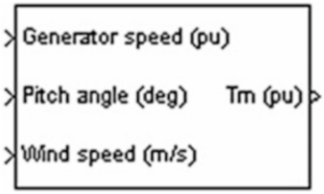
AIII.14 Wind Turbine

Implement model of variable pitch wind turbine

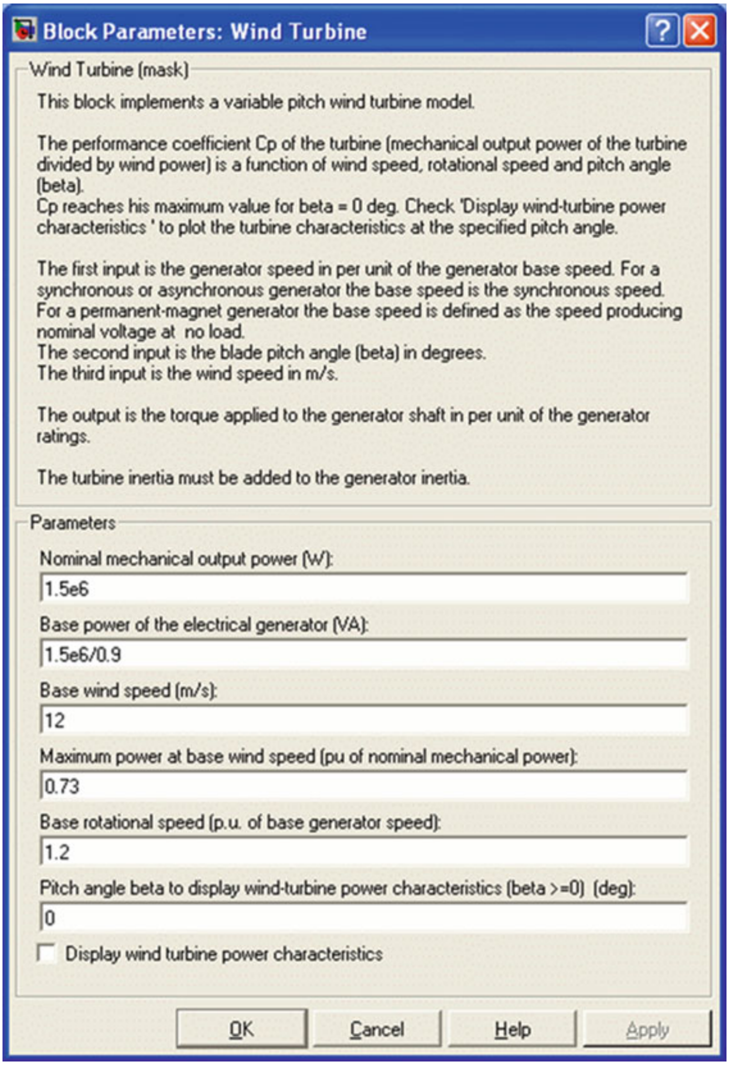
Library

Renewable Energy/Wind Generation

Description



Dialog Box and Parameters



Nominal Mechanical Output Power

The nominal output power in watts (W).

Base Power of the Electrical Generator

The nominal power of the electrical generator coupled to the wind turbine, in VA. This parameter is used to compute the output torque in pu of the nominal torque of the generator.

Base Wind Speed

The base value of the wind speed, in m/s, used in the per unit system. The base wind speed is the mean value of the expected wind speed. This base wind speed produces a mechanical power which is usually lower than the turbine nominal power.

Maximum Power at Base Wind Speed

The maximum power at base wind speed in pu of the nominal mechanical power. This parameter is the power gain k_{p} already defined.

Base Rotational Speed

The rotational speed at maximum power for the base wind speed. The base rotational speed is in pu of the base generator speed. For a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load.

Pitch Angle Beta to Display Wind Turbine Power Characteristics

The pitch angle beta, in degrees, used to display the power characteristics. Beta must be greater than or equal to zero.

Display Wind Turbine Power Characteristics

If this parameter is checked, the turbine power characteristics are displayed for different wind speeds and for the specified pitch angle beta.

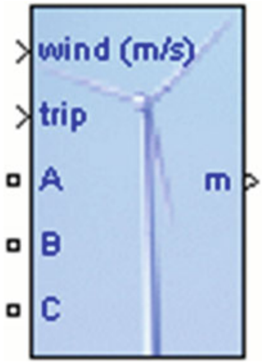
AIII.15 Wind Turbine Doubly-Fed Induction Generator (Phasor Type)

Implement phasor model of variable speed doubly-fed induction generator driven by wind turbine

Library

Renewable Energy/Wind Generation

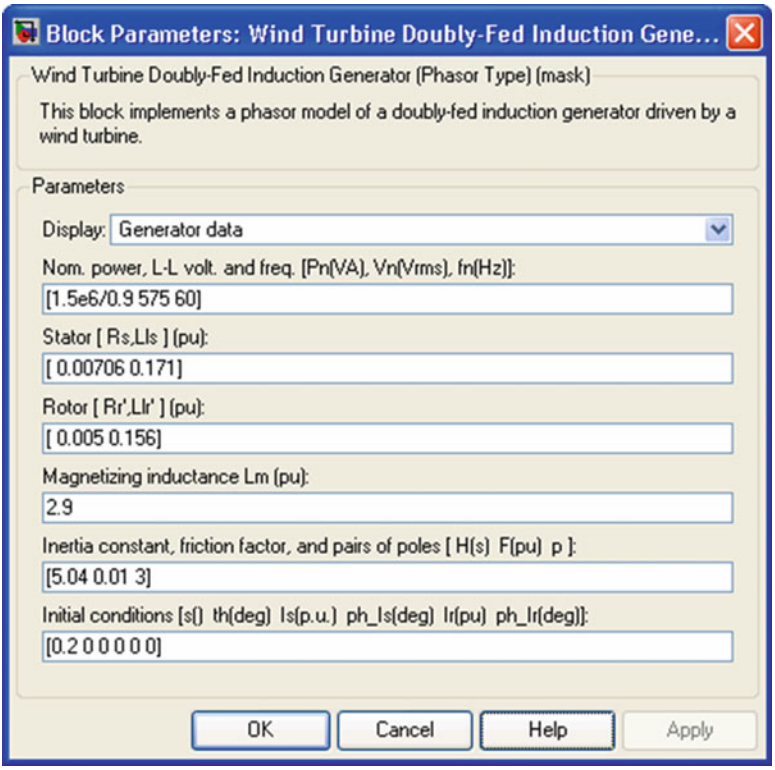
Description



Dialog Box and Parameters

The WTDFIG parameters are grouped in four categories: Generator data, Converters data, Turbine data, and Control parameters. Use the Display listbox to select which group of parameters you want to visualize.

Generator Data Parameters



WTDFIG Modeled Using Positive-Sequence Only

The WTDFIG is modeled by a three-wire system using two current sources. The WTDFIG does not generate any zero-sequence current, but it can generate negative-sequence currents during unbalanced system operation.

Nominal Power, Line-to-Line Voltage and Frequency

The nominal power in VA, the nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Stator [Rs, Lls]

The stator resistance Rs and leakage inductance Lls in pu based on the generator rating.

Rotor [Rr', Llr']

The rotor resistance Rr' and leakage inductance Llr', both referred to the stator, in pu based on the generator rating.

Magnetizing Inductance Lm

The magnetizing inductance Lm in pu based on the generator rating.

Inertia Constant, Friction Factor and Pairs of Poles

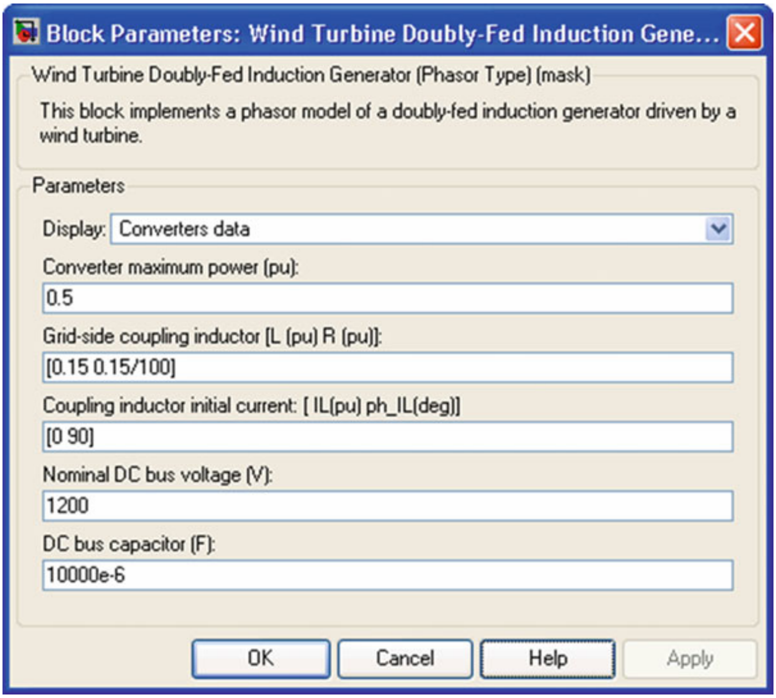
Combined generator and turbine inertia constant H in seconds, combined viscous friction factor F in pu based on the generator rating and number of pole pairs p.

You may need to use your own turbine model, in order for example, to implement different power characteristics or to implement the shaft stiffness. Your model must then output the mechanical torque applied to the generator shaft. If the inertia and the friction factor of the turbine are implemented inside the turbine model you specify only the generator inertia constant H and the generator friction factor F.

Initial Conditions

The initial slip s, electrical angle Θ in degrees, stator phasor current magnitude in pu, stator phasor current phase angle in degrees, rotor phasor current magnitude in pu and rotor phasor current phase angle in degrees.

Converters Data Parameters



Converter Maximum Power

The maximum power of both C_{grid} and C_{rotor} in pu of the nominal power. This parameter is used to compute the maximum current at 1 pu of voltage for C_{grid}. The maximum current for C_{rotor} is 1 pu.

Grid-Side Coupling Inductor [L R]

The coupling inductance L and its resistance R in pu based on the generator rating.

Coupling Inductor Initial Currents

The coupling inductor initial phasor current in positive-sequence. Enter magnitude IL in pu and phase ph_IL in degrees. If you know the initial value of the current corresponding to the WTDFIG operating point you may specify it in order to start simulation in steady state. If you don't know this value, you can leave [0 0]. The system will reach steady-state after a short transient.

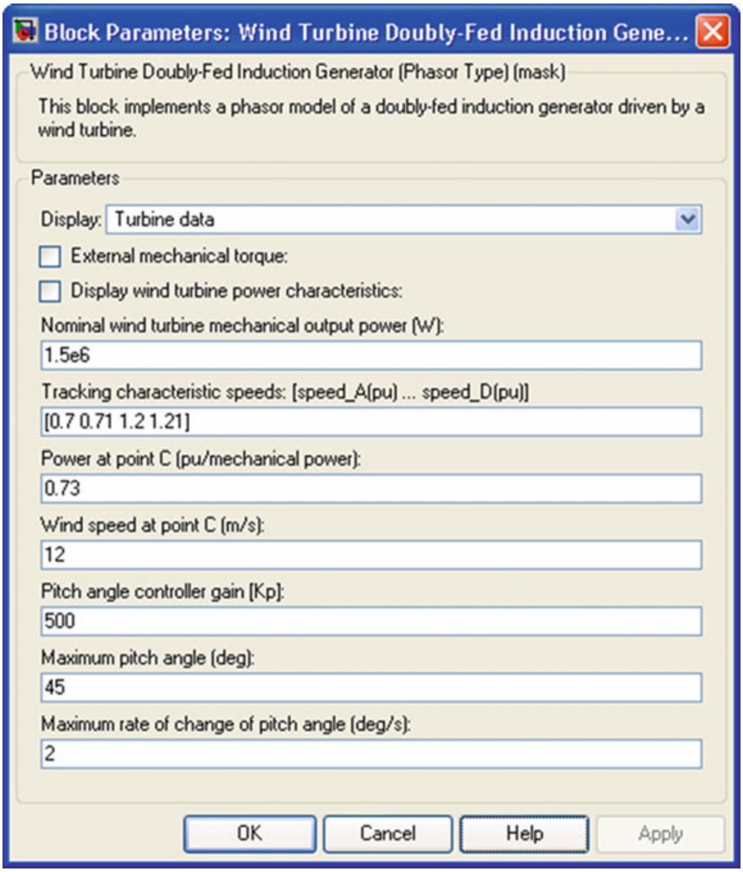
Nominal DC Bus Voltage

The nominal DC bus voltage in volts.

DC Bus Capacitor

The total capacitance of the DC-link in farads. This capacitance value is related to the WTDFIG rating and to the DC-link nominal voltage. The energy stored in the capacitance (in joules) divided by the WTDFIG rating (in VA) is a time duration which is usually a fraction of a cycle at nominal frequency. For example, for the default parameters, (C = 10,000 μF, Vdc = 1,200 V, Pn = 1.67 MVA) this ratio $1/2 \cdot C \cdot V_{dc}^2/P_n$ is 4.3 ms, which represents 0.26 cycle for a 60 Hz frequency. If you change the default values of the nominal power rating and DC voltage, you should change the capacitance value accordingly.

Turbine Data Parameters



External Mechanical Torque

If this parameter is checked, a Simulink® input named Tm appears on the block, allowing to use an external signal for the generator input mechanical torque. This external torque must be in pu based on the nominal electric power and synchronous speed. For example, the external torque may come from a user defined turbine model. Following the convention used in the induction machine, the torque must be negative for power generation.

Electric Power-Speed Characteristic

This parameter is visible only when the **External mechanical torque** parameter is checked. It is used to specify a series of speed-power pairs for the tracking characteristic. The speed is in pu based on synchronous speed and the power is in pu based on nominal generator power.

Display Wind Turbine Power Characteristics

If this parameter is checked, the turbine power characteristics at zero degree of pitch angle are displayed for different wind speeds. The tracking characteristic is also displayed on the same figure.

This parameter is not visible when the **External mechanical torque** parameter is checked.

Nominal Wind Turbine Mechanical Output Power

This parameter is not visible when the **External mechanical torque** parameter is checked.

The nominal turbine mechanical output power in watts.

Tracking Characteristic Speeds

This parameter is not visible when the **External mechanical torque** parameter is checked.

Specify the speeds of point A to point D of the tracking characteristic in pu of the synchronous speed. speed_B must be greater than speed_A and speed_D must be greater than speed_C.

Power at Point C

This parameter is not visible when the **External mechanical torque** parameter is checked.

Specify the power of point C of the tracking characteristic in pu of the **Nominal wind turbine mechanical output power.**

Wind Speed at Point C

This parameter is not visible when the **External mechanical torque** parameter is checked.

Specify wind speed in m/s for point C. The power at point C is the maximum turbine output power for the specified wind speed.

Pitch Angle Controller Gain [Kp]

This parameter is not visible when the **External mechanical torque** parameter is checked.

Proportional gain Kp of the pitch controller. Specify Kp in degrees/(speed deviation pu). The speed deviation is the difference between actual speed and speed of point D in pu of synchronous speed.

Maximum Pitch Angle

This parameter is not visible when the **External mechanical torque** parameter is checked.

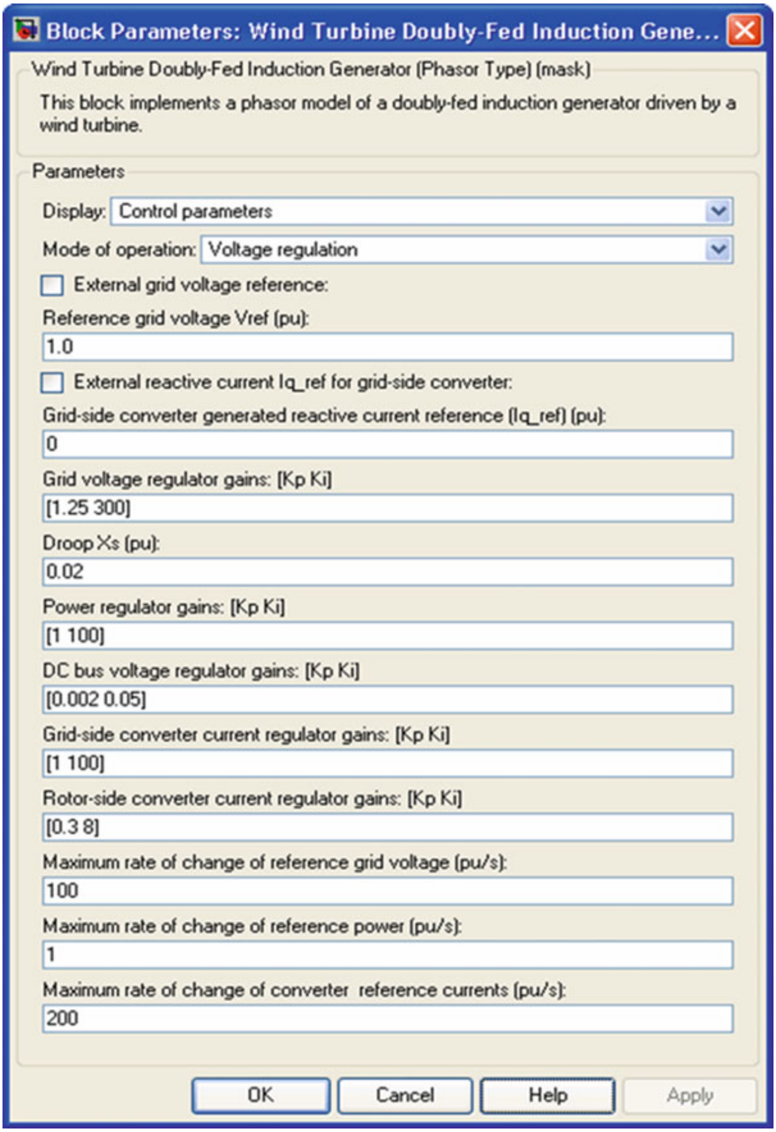
The maximum pitch angle in degrees.

Maximum Rate of Change of Pitch Angle

This parameter is not visible when the **External mechanical torque** parameter is checked.

The maximum rate of change of the pitch angle in degrees/s.

Control Parameters



Mode of Operation

Specifies the **WTDFIG** mode of operation. Select either `Voltage regulation` or `Var regulation`.

External Grid Voltage Reference

This parameter is not visible when the **Mode of operation** parameter is set to `Var regulation.`

If this parameter is checked, a Simulink input named Vref appears on the block, allowing to control the reference voltage from an external signal in pu. Otherwise a fixed reference voltage is used, as specified by the parameter below.

Reference Grid Voltage Vref

This parameter is not visible when the **Mode of operation** parameter is set to `Var regulation` or when the **External grid voltage reference** parameter is checked.

Reference voltage, in pu, used by the voltage regulator.

External Generated Reactive Power Reference

This parameter is not visible when the **Mode of operation** parameter is set to `Voltage regulation.`

If this parameter is checked, a Simulink input named Qref appears on the block, allowing to control the reference reactive power, at grid terminals, from an external signal in pu. Otherwise a fixed reference reactive power is used, as specified by the parameter below.

Generated Reactive Power Qref

This parameter is not visible when the **Mode of operation** parameter is set to `Voltage regulation` or when the **External generated reactive power reference** parameter is checked.

Reference generated reactive power at grid terminals, in pu, used by the var regulator.

External Reactive Current Iq_ref for Grid-Side Converter Reference

If this parameter is checked, a Simulink input named Iq_ref appears on the block, allowing to control the grid-side converter reactive current from an external signal in pu. Specify a positive value for Iq_ref for generated reactive power. Otherwise a fixed reactive current is used, as specified by the parameter below.

Grid-Side Converter Generated Reactive Current Reference (Iq_ref)

This parameter is not visible when the **External reactive current Iq_ref for grid-side converter reference** parameter is checked.

Reference grid-side converter reactive current, in pu, used by the current regulator. Specify a positive value of Iq_ref for generated reactive power.

Grid Voltage Regulator Gains [Kp Ki]

This parameter is not visible when the **Mode of operation** parameter is set to `Var regulation`.

Gains of the AC voltage regulator. Specify proportional gain Kp in (pu of I)/(pu of V), and integral gain Ki, in (pu of I)/(pu of V)/s, where V is the AC voltage error and I is the output of the voltage regulator.

Droop Xs

This parameter is not visible when the **Mode of operation** parameter is set to `Var regulation`.

Droop reactance, in pu/nominal power, defining the slope of the V-I characteristic.

Reactive Power Regulator Gains [Kp Ki]

This parameter is not visible when the **Mode of operation** parameter is set to `Voltage regulation`.

Gains of the var regulator. Specify proportional gain Kp in (pu of I)/(pu of Q), and integral gain Ki, in (pu of I)/(pu of Q)/s, where Q is the reactive power error and I is the output of the var regulator.

Power Regulator Gains [Kp Ki]

Gains of the power regulator. Specify proportional gain Kp in (pu of I)/(pu of P), and integral gain Ki, in (pu of I)/(pu of P)/s, where P is the power error and I is the output of the power regulator.

DC Bus Voltage Regulator Gains [Kp Ki]

Gains of the DC voltage regulator which controls the voltage across the DC bus capacitor. Specify proportional gain Kp in (pu of I)/(Vdc), and integral gain Ki, in (pu of I)/(Vdc)/s, where Vdc is the DC voltage error and I is the output of the voltage regulator.

Grid-Side Converter Current Regulator Gains [Kp Ki]

Gains of the grid-side converter current regulator.

Specify proportional gain Kp in (pu of V)/(pu of I) and integral gain Ki, in (pu of V)/(pu of I)/s, where V is the output Vgc of the current regulator and I is the current error.

Rotor-Side Converter Current Regulator Gains [Kp Ki]

Gains of the rotor-side converter current regulator.

Specify proportional gain Kp in (pu of V)/(pu of I) and integral gain Ki, in (pu of V)/(pu of I)/s, where V is the output Vr of the current regulator and I is the current error.

Maximum Rate of Change of Reference Grid Voltage

This parameter is not visible when the **Mode of operation** parameter is set to `Var regulation`.

Maximum rate of change of the reference voltage, in pu/s, when an external reference voltage is used.

Maximum Rate of Change of Reference Reactive Power

This parameter is not visible when the **Mode of operation** parameter is set to `Voltage regulation`.

Maximum rate of change of the reference reactive power, in pu/s, when an external reference reactive power is used.

Maximum Rate of Change of Reference Power

Maximum rate of change of the reference power in pu/s.

Maximum Rate of Change of Converters Reference Current

Maximum rate of change of the reference current in pu/s for both the rotor-side and the grid-side converters.

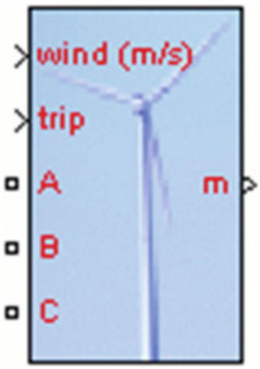
AIII.16 Wind Turbine Induction Generator (Phasor Type)

Implement phasor model of squirrel-cage induction generator driven by variable pitch wind turbine

Library

Renewable Energy/Wind Generation

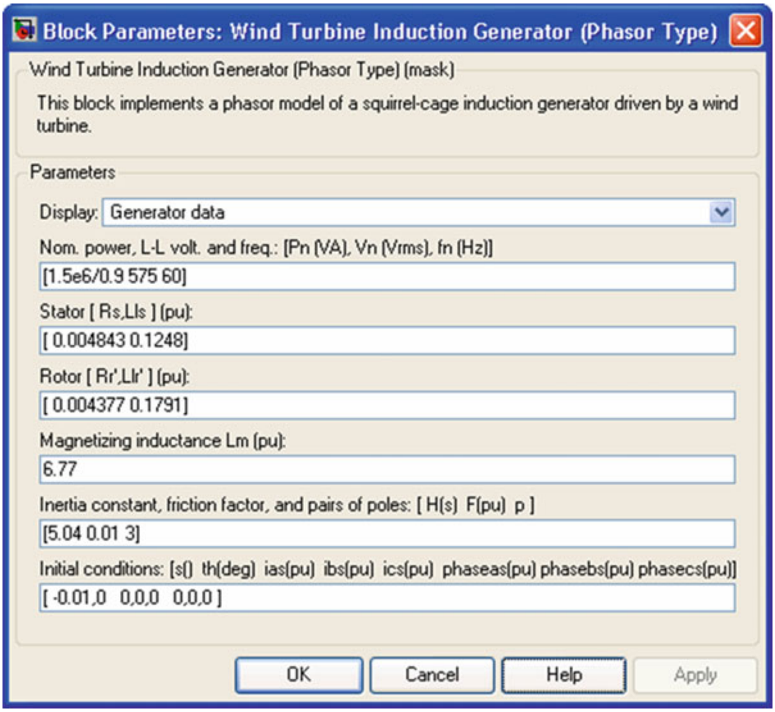
Description



Dialog Box and Parameters

The WTIG parameters are grouped in two categories: Generator `data` and Turbine data». Use the Display listbox to select which group of parameters you want to visualize.

Generator Data Parameters



Nominal Power, Line-to-Line Voltage and Frequency

The nominal power in VA, the nominal line-to-line voltage in Vrms and the nominal system frequency in hertz.

Stator [Rs, Lls]

The stator resistance Rs and leakage inductance Lls in pu based on the generator ratings.

Rotor [Rr’, Llr’]

The rotor resistance Rr’ and leakage inductance Llr’, both referred to the stator, in pu based on the generator ratings.

Magnetizing Inductance Lm

The magnetizing inductance Lm in pu based on the generator ratings.

Inertia Constant, Friction Factor and Pairs of Poles

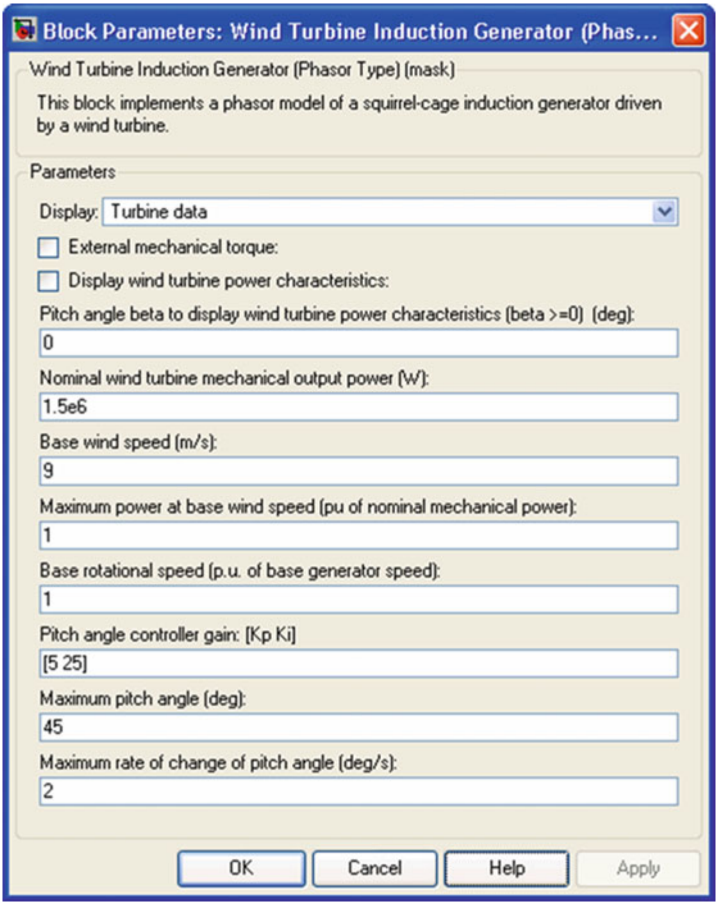
Combined generator and turbine inertia constant H in seconds, combined viscous friction factor F in pu based on the generator ratings and number of pole pairs p.

You may need to use your own turbine model, in order for example, to implement different power characteristics or to implement the shaft stiffness. Your model must then output the mechanical torque applied to the generator shaft. If the inertia and the friction factor of the turbine are implemented inside the turbine model you specify only the generator inertia constant H and the generator friction factor F.

Initial Conditions

The initial slip s, electrical angle Θ in degrees, stator current magnitude in pu and phase angle in degrees.

Turbine Data Parameters



External Mechanical Torque

If this parameter is checked, a Simulink® input named Tm appears on the block, allowing to use an external signal for the generator input mechanical torque. This external torque must be in pu based on the nominal electric power and synchronous speed of the generator. For example, the external torque may come from a user defined turbine model. By convention for the induction machine, the torque must be negative for power generation.

Display Wind Turbine Power Characteristics

If this parameter is checked, the turbine power characteristics at the specified pitch angle are displayed for different wind speeds.

This parameter is not visible when the **External mechanical torque** parameter is checked.

Nominal Wind Turbine Mechanical Output Power

This parameter is not visible when the **External mechanical torque** parameter is checked.

The nominal turbine mechanical output power in watts.

Base Wind Speed

This parameter is not visible when the **External mechanical torque** parameter is checked.

The base value of the wind speed, in m/s, used in the per unit system. The base wind speed is the mean value of the expected wind speed. This base wind speed produces a mechanical power which is usually lower than the turbine nominal power.

Maximum Power at Base Wind Speed

This parameter is not visible when the **External mechanical torque** parameter is checked.

The maximum power at base wind speed in pu of the nominal mechanical power.

Base Rotational Speed

This parameter is not visible when the **External mechanical torque** parameter is checked.

The rotational speed at maximum power for the base wind speed. The base rotational speed is in pu of the base generator speed.

Pitch Angle Controller Gain [Kp Ki]

This parameter is not visible when the **External mechanical torque** parameter is checked.

Proportional and Integral gains Kp and Ki of the pitch controller. Specify Kp in degrees/(power deviation pu) and Ki in degrees/(power deviation pu)/s. The power deviation is the difference between actual electrical output power and the nominal mechanical power in pu of the generator nominal power.

Maximum Pitch Angle (deg)

This parameter is not visible when the **External mechanical torque** parameter is checked.

The maximum pitch angle in degrees.

Maximum Rate of Change of Pitch Angle

This parameter is not visible when the **External mechanical torque** parameter is checked.

The maximum rate of change of the pitch angle in degrees/s.

Appendix IV
Data for Case Study

The Measurement of power quality is done in PSG College of Technology at k-block. Assessment and problem evaluation from the results in case study done has been described briefly in Chap. 8.

Table AIV.1 Solar panel details

Symbol	Parameter	Value
Standard test conditions		
V_{MMP}	**Maximum power point voltage**	30 V
I_{MMP}	**Maximum power point current**	8.33 A
V_{OC}	**Open circuit voltage**	36.8 V
I_{SC}	**Short circuit current**	8.83 A
Series fuse		20 A

Table AIV.2 SMA inverter details

Symbol	Parameter	Value
DC side		
V_{DCmax}	**Maximum DC voltage**	1,000 V
V_{DCMMP}	**Maximum power point DC voltage**	580–800 V
I_{DCmax}	**Maximum DC current**	36 A
AC side		
$V_{AC,r}$	**AC output voltage**	380/400/415 V
$P_{AC,r}$	**Power output at AC side**	20 kW
S_{max}	**Apparent power**	20 kVA
$f_{AC,r}$	**frequency**	50 Hz
I_{DCmax}	**Maximum current at AC side**	29 A
cosφ	**Power factor**	0.8 (Under/Over excited)

S. Sumathi et al., *Solar PV and Wind Energy Conversion Systems*,
Green Energy and Technology, DOI 10.1007/978-3-319-14941-7

AIV.1 Fluke Power Quality Analyzer

Fluke 430 Series II Three-phase power quality and energy analyzers pinpoint power quality problems and monetize energy Loss, The new 430 Series II analyzers offer the best in power quality analysis, and introduce, for the first time ever, the ability to monetarily quantify losses caused by power quality issues.

- Energy loss calculator: Classic active and reactive power measurements, unbalance and harmonic power, are quantified to pinpoint true system energy losses in rupees (other local currencies available).
- Power inverter efficiency: Simultaneously measure AC output power and DC input power for power electronics systems using optional DC clamp.
- Power Wave data capture: 435 and 437 Series II analyzers capture fast RMS data, show half-cycle and waveforms to characterize electrical system dynamics (generator start-ups, UPS switching).
- Waveform capture: 435 and 437 Series II models capture 50/60 cycles (50/60) Hz of each event that is detected in all modes, without set-up.
- Automatic Transient Mode: 435 and 437 Series II analyzers capture 200 kHz waveform data on all phases simultaneously up to 6 kV.
- Fully Class-A compliant: 435 and 437 Series II analyzers conduct tests according to the stringent international IEC 61000-4-30 Class-A standard.
- Mains signaling: 435 and 437 Series II analyzers measure interference from ripple control signals at specific frequencies.
- 400 Hz measurement: 437 Series II analyzer captures power quality measurements for avionic and military power systems.
- Troubleshoot: Analyze the trends using the cursors and zoom tools.
- Highest safety rating in the industry: 600 V CAT IV/1,000 V CAT III rated for use at the service entrance.
- Measure all three phases and neutral: With included four flexible current probes with enhanced thin flex designed to fit into the tightest places.
- Automatic Trending: Every measurement is always automatically recorded, without any set-up.
- System-Monitor: Ten power quality parameters on one screen according to EN50160 power quality standard.
- Logger function: Configure for any test condition with memory for up to 600 parameters at user defined intervals.
- View graphs and generate reports: With included analysis software.
- Battery life: Up to 8 h operating time per charge on Li-ion battery pack (Figs. AIV.1 and AIV.2).

Fig. AIV.1 Fluke 434 series II energy analyzer

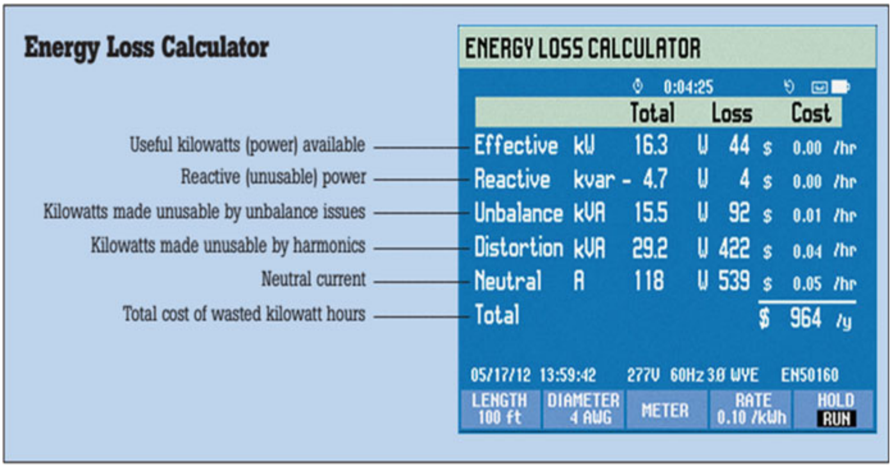


Fig. AIV.2 Special measurement included in FLUKE 434 series II

The meter can be used for:

- Frontline troubleshooting quickly diagnoses problems on-screen to get your operation back online.
- Energy loss management measure and quantify specific causes of energy losses to enable simple return-on-investment calculation of harmonics and unbalance mitigation equipment.
- Power inverter efficiency simultaneously measure AC input power and DC output power for power electronics systems.
- Capture fast Root Mean Square (RMS) data, show half-cycle and waveforms to characterize electrical system dynamics.
- Predictive maintenance detects and prevents power quality issues before they cause downtime.
- Qualities of service compliance validate incoming power quality at the service entrance.
- Long-term analysis Uncover hard-to-find or intermittent issues.
- Load studies Verify electrical system capacity before adding loads.
- Dynamic load testing capture instantaneous values to see the effect of load switch on generators and UPS systems.

Instrument Information

Model number	FLUKE 430-II
Serial number	24663010
Firmware revision	V04.01

Software Information

Power log version	4.1
FLUKE 345 DLL version	11.20.2006
FLUKE 430 DLL version	1.8.0.0
FLUKE 430-II DLL version	1.0.0.28

Measurement Summary

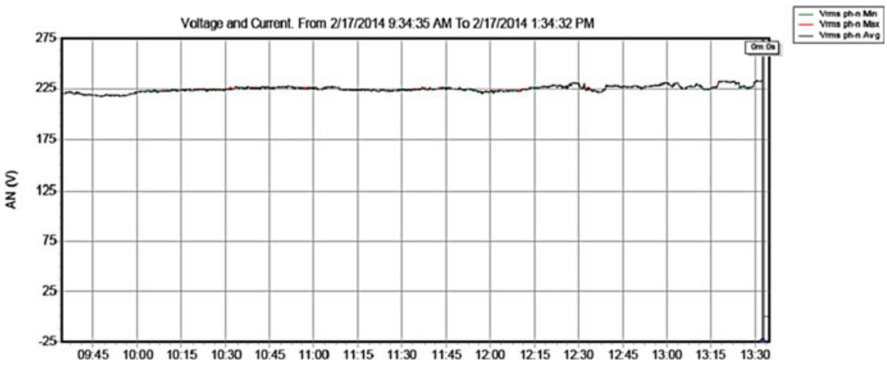
Measurement topology	Wye mode
Application mode	Logger
First recording	2/17/2014 9:34:35 AM
Last recording	2/17/2014 1:34:32 PM
Recording interval	0 h 0 m 3 s 0 m sec
Nominal voltage	230 V
Nominal current	300 A
Nominal frequency	50 Hz
File start time	2/17/2014 9:34:35 AM
File end time	2/17/2014 1:34:32 PM
Duration	0d 3 h 59 m 57 s 0 m sec
Number of events	7
Events downloaded	No
Number of screens	100
Screens downloaded	No
Power measurement method	Unified
Cable type	Copper
Harmonic scale	%H1
THD mode	THD 40
CosPhi/DPF mode	Cos Phi

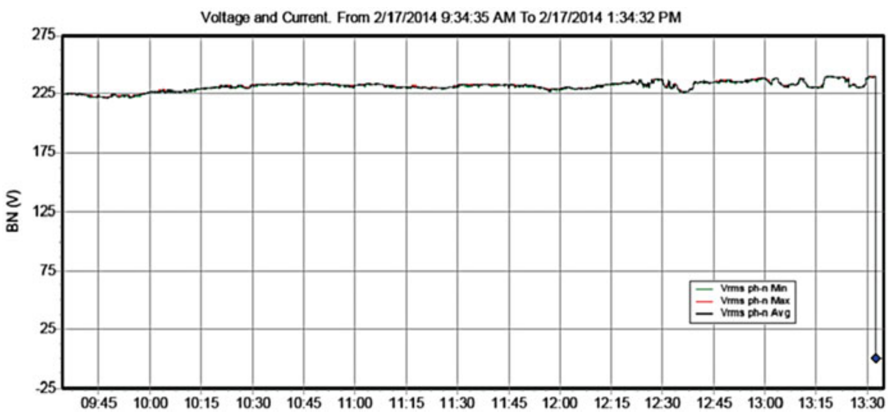
Recording Summary

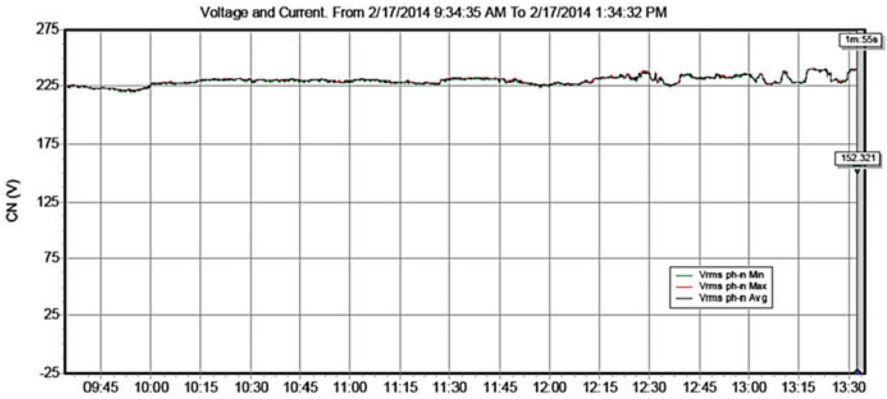
RMS recordings	4,800
DC recordings	0
Frequency recordings	4,800
Unbalance recordings	4,800
Harmonic recordings	4,800
Power harmonic recordings	0
Power recordings	4,800
Power unbalance recordings	0
Energy recordings	4,800
Energy losses recordings	0
Flicker recordings	0
Mains signaling recordings	0

Events Summary

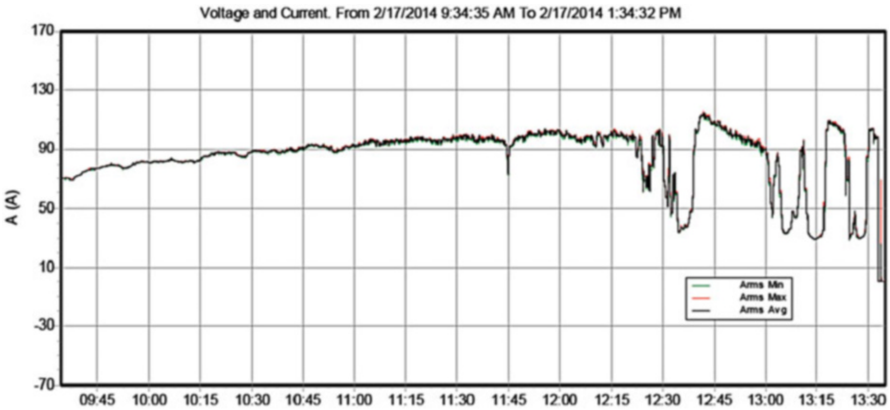
Dips	1
Swells	0
Transients	4
Interruptions	2
Voltage profiles	0
Rapid voltage changes	0
Screens	0
Waveforms	0
Intervals without measurements	0
Inrush current graphics	0
Wave events	0
RMS events	0



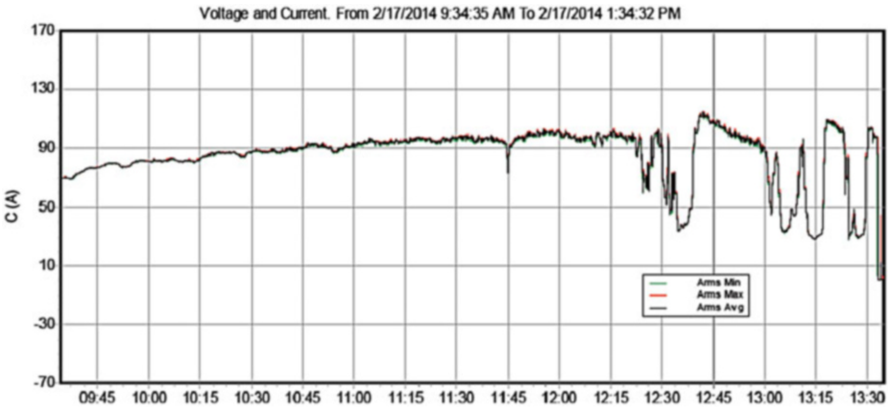


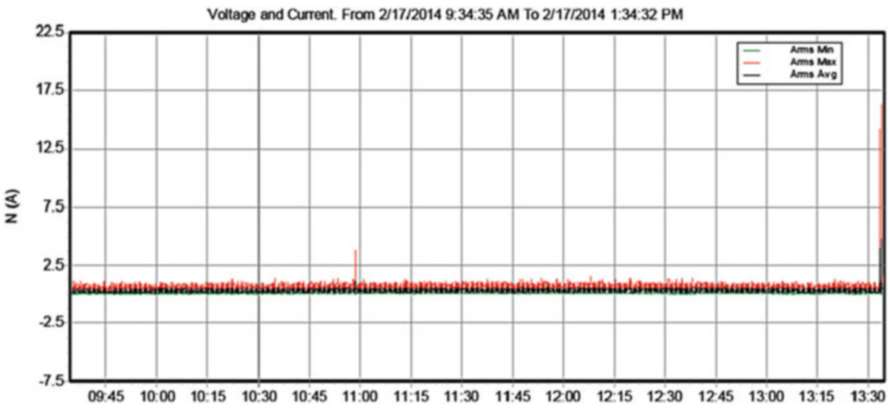

Voltage and Current. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
CN (V)
275
225
175
125
75
25
-25
09:45 10:00 10:15 10:30 10:45 11:00 11:15 11:30 11:45 12:00 12:15 12:30 12:45 13:00 13:15 13:30
1m:55s
152.321
Vrms ph-n Min
Vrms ph-n Max
Vrms ph-n Avg

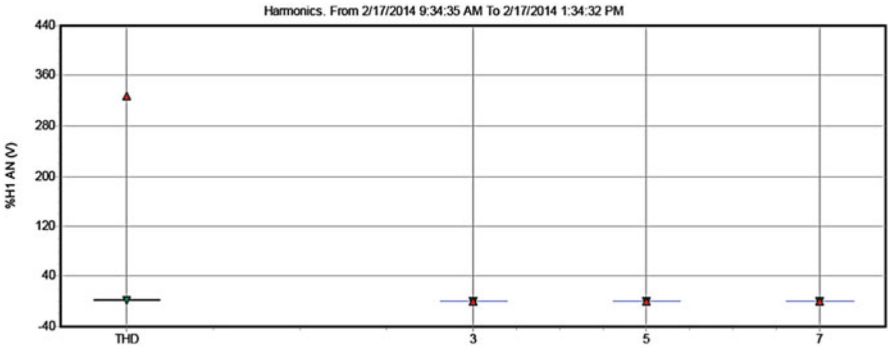

Voltage and Current. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
NG (V)
165
135
105
75
45
15
-15
09:45 10:00 10:15 10:30 10:45 11:00 11:15 11:30 11:45 12:00 12:15 12:30 12:45 13:00 13:15 13:30
Vrms n-gnd Min
Vrms n-gnd Max
Vrms n-gnd Avg

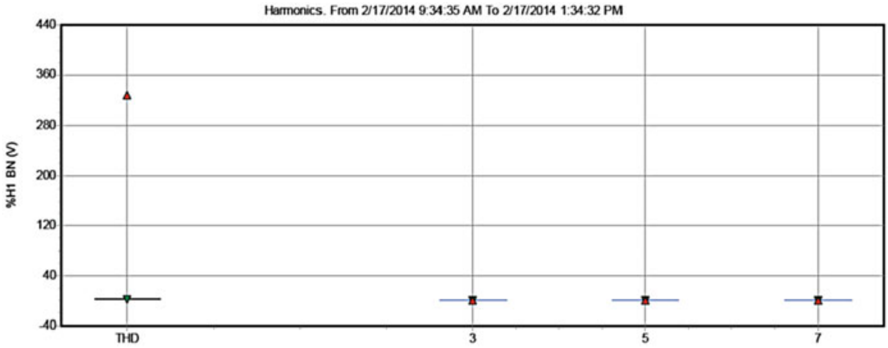

Voltage and Current. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
A (A)
170
130
90
50
10
-30
-70
09:45 10:00 10:15 10:30 10:45 11:00 11:15 11:30 11:45 12:00 12:15 12:30 12:45 13:00 13:15 13:30
Arms Min
Arms Max
Arms Avg

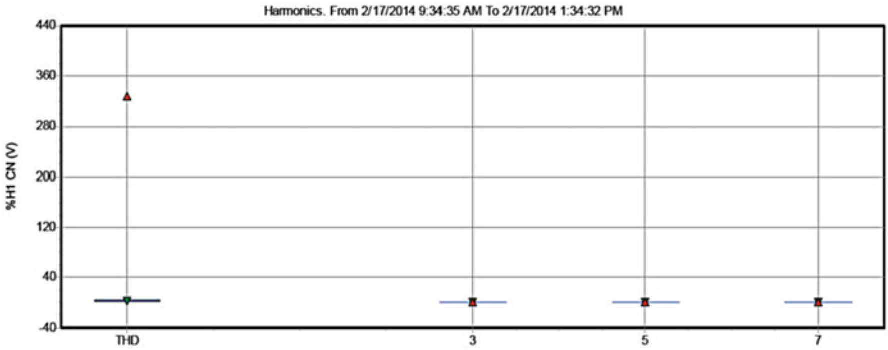

Voltage and Current. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
B (A)
170
130
90
50
10
-30
-70
09:45 10:00 10:15 10:30 10:45 11:00 11:15 11:30 11:45 12:00 12:15 12:30 12:45 13:00 13:15 13:30
Arms Min
Arms Max
Arms Avg

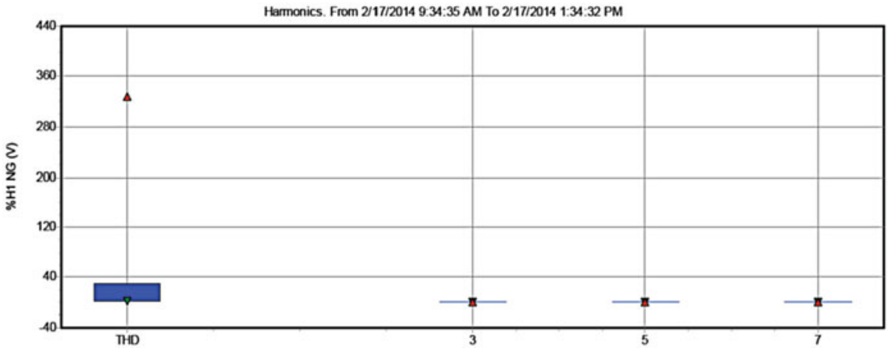

Voltage and Current. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
C (A)
170
130
90
50
10
-30
-70
09:45 10:00 10:15 10:30 10:45 11:00 11:15 11:30 11:45 12:00 12:15 12:30 12:45 13:00 13:15 13:30
Arms Min
Arms Max
Arms Avg

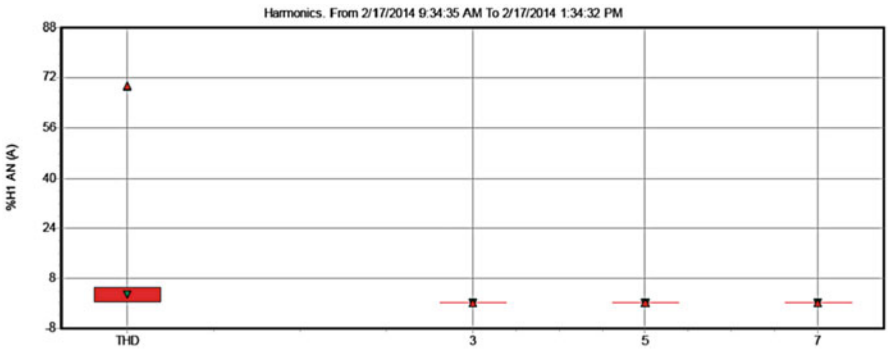

Voltage and Current. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
N (A)
22.5
17.5
12.5
7.5
2.5
-2.5
-7.5
09:45 10:00 10:15 10:30 10:45 11:00 11:15 11:30 11:45 12:00 12:15 12:30 12:45 13:00 13:15 13:30
Arms Min
Arms Max
Arms Avg

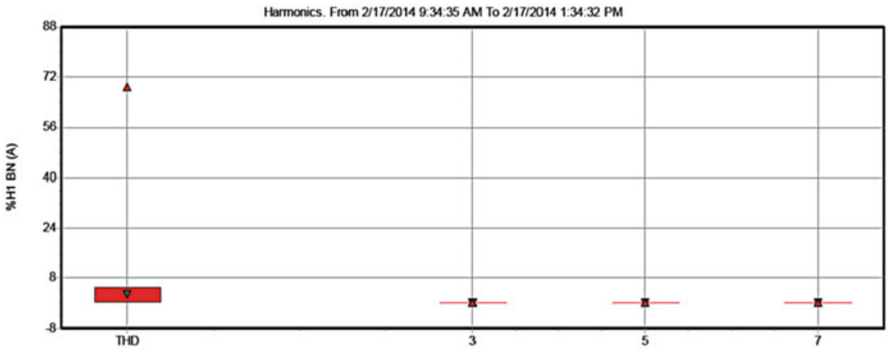

Harmonics. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
%H1 AN (V)
440
360
280
200
120
40
-40
THD
3
5
7

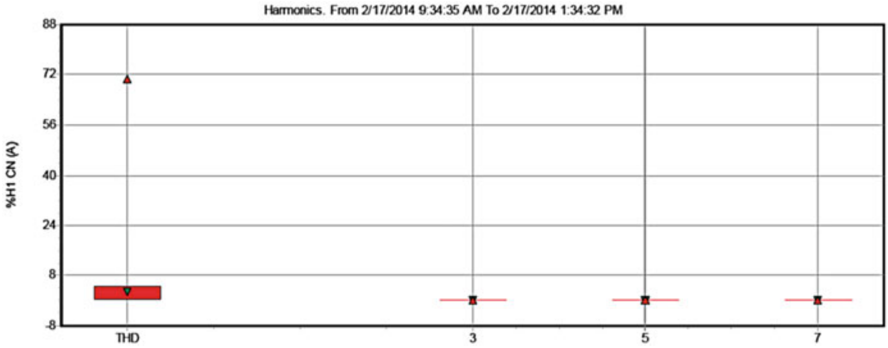

Harmonics. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
%H1 BN (V)
440
360
280
200
120
40
-40
THD
3
5
7

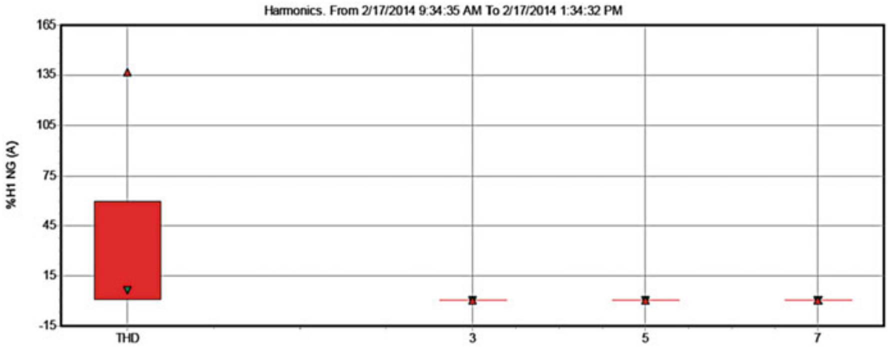

Harmonics. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
%H1 CN (V)
440
360
280
200
120
40
-40
THD
3
5
7

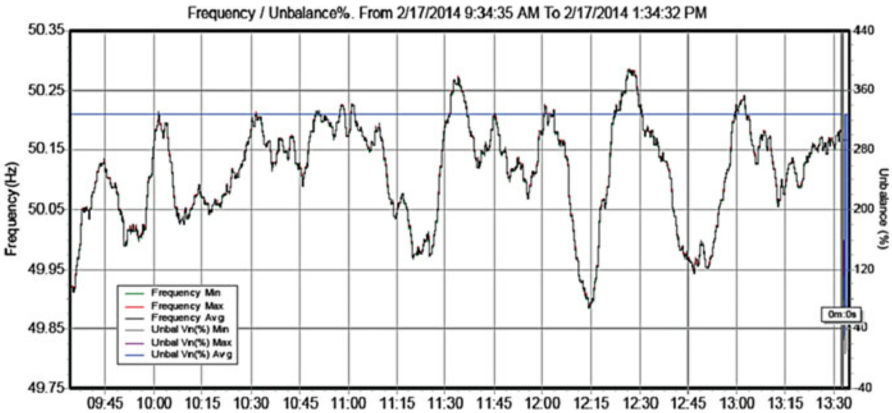

Harmonics. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
%H1 NG (V)
440
360
280
200
120
40
-40
THD
3
5
7

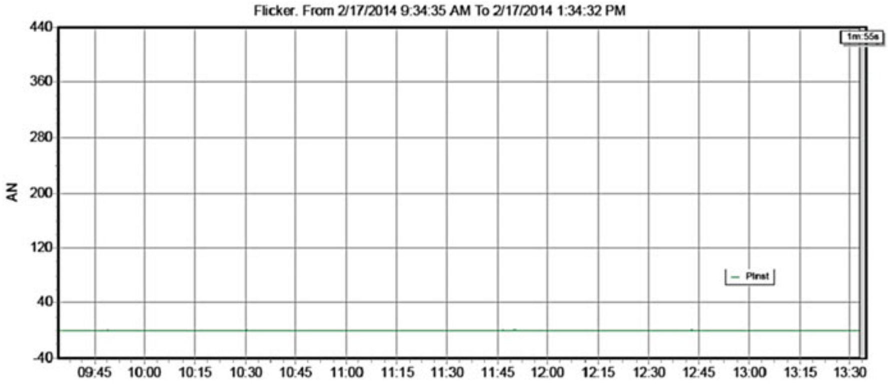

Harmonics. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
%H1 AN (A)
88
72
56
40
24
8
-8
THD
3
5
7

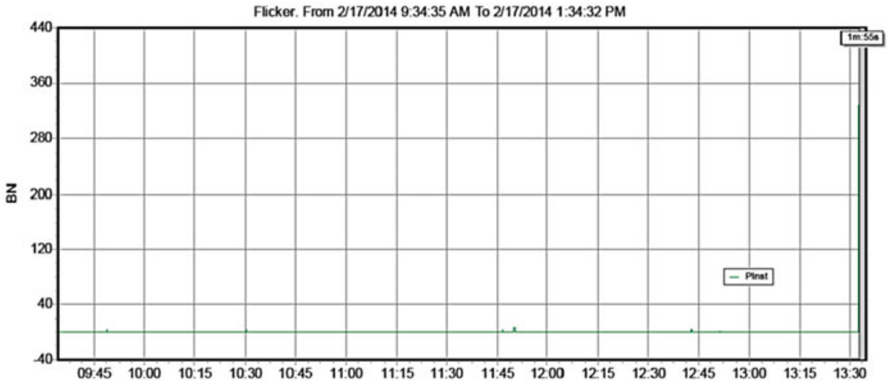

Harmonics. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
%H1 BN (A)
88
72
56
40
24
8
-8
THD
3
5
7

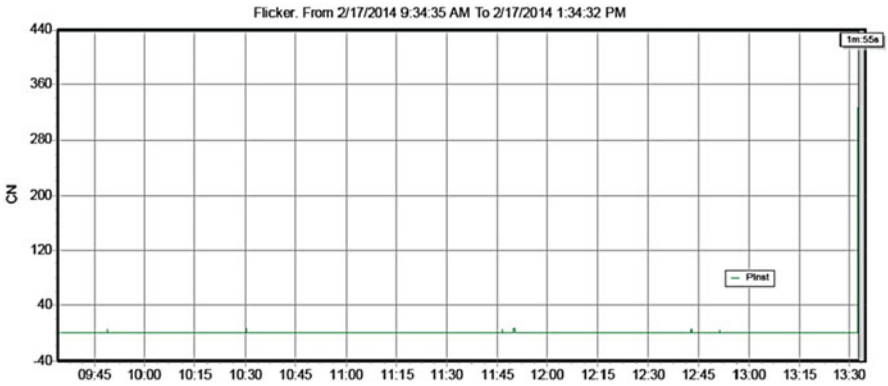

Harmonics. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
%H1 CN (A)
88
72
56
40
24
8
-8
THD
3
5
7

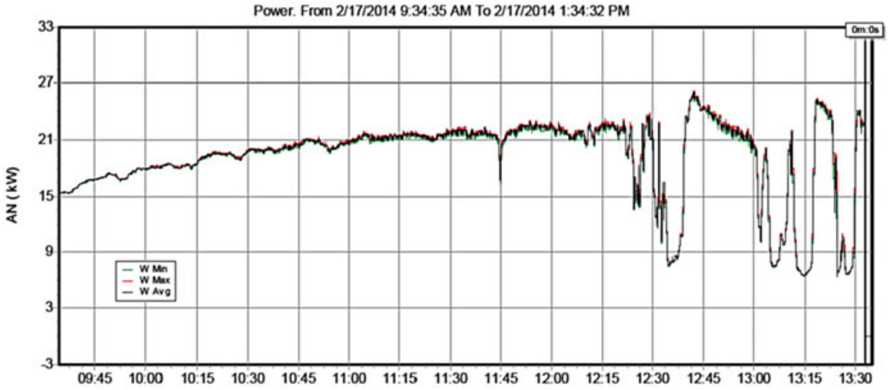

Harmonics. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
%H1 NG (A)
165
135
105
75
45
15
-15
THD
3
5
7

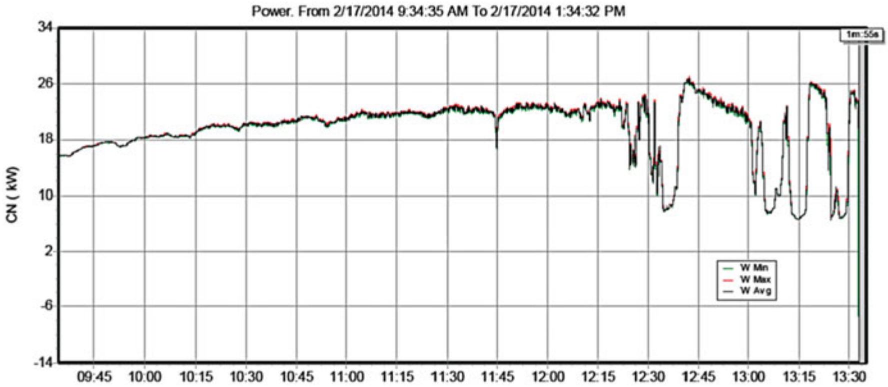

Frequency / Unbalance%. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
Frequency(Hz)
Unbalance (%)
50.35
50.25
50.15
50.05
49.95
49.85
49.75
440
360
280
200
120
40
-40
Frequency Min
Frequency Max
Frequency Avg
Unbal Vn(%) Min
Unbal Vn(%) Max
Unbal Vn(%) Avg
0m:0s
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30

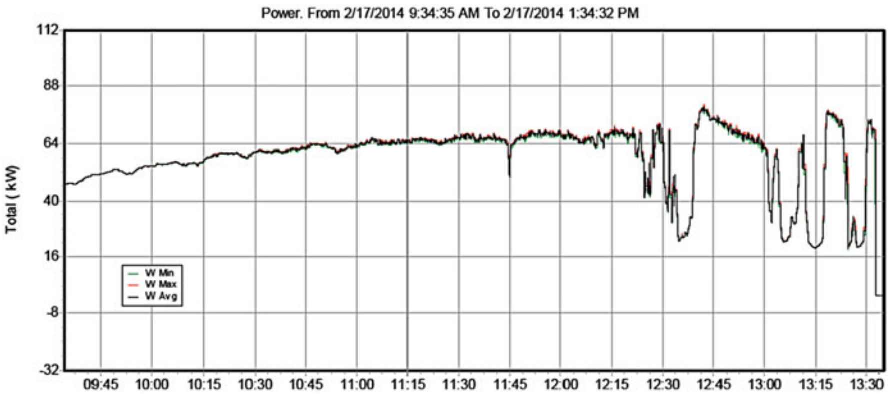

Flicker. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
440
360
280
AN
200
120
40
-40
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
Plnst
1m:55s

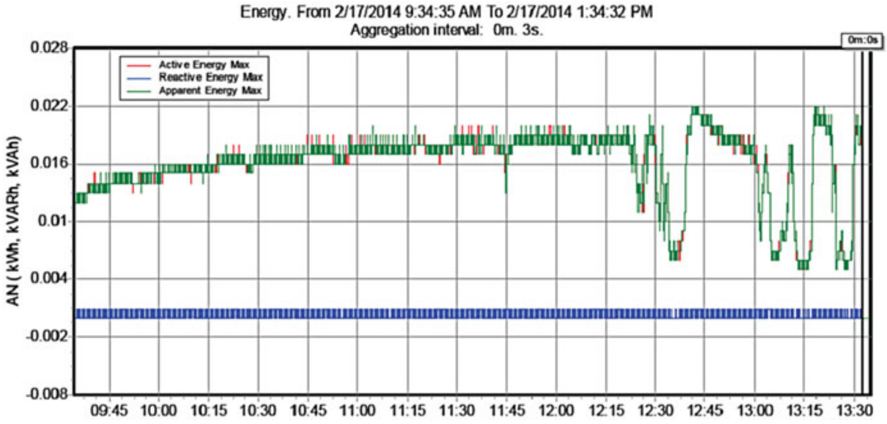

Flicker. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
440
360
280
BN
200
120
40
-40
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
Plnst
1m:55s

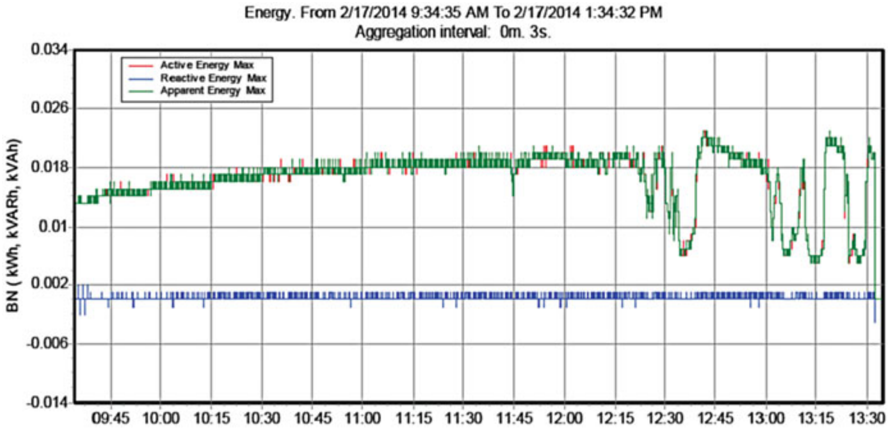

Flicker. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
440
360
280
CN
200
120
40
-40
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
Plnst
1m:55s

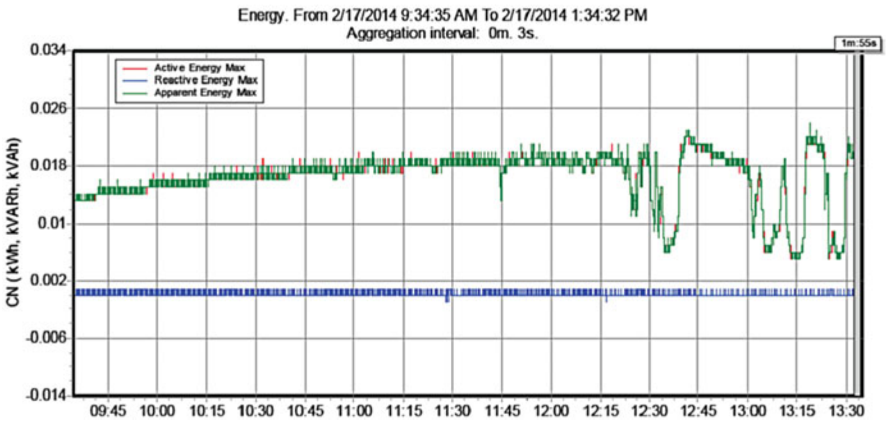

Power. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
AN (kW)
W Min
W Max
W Avg
0m:0s

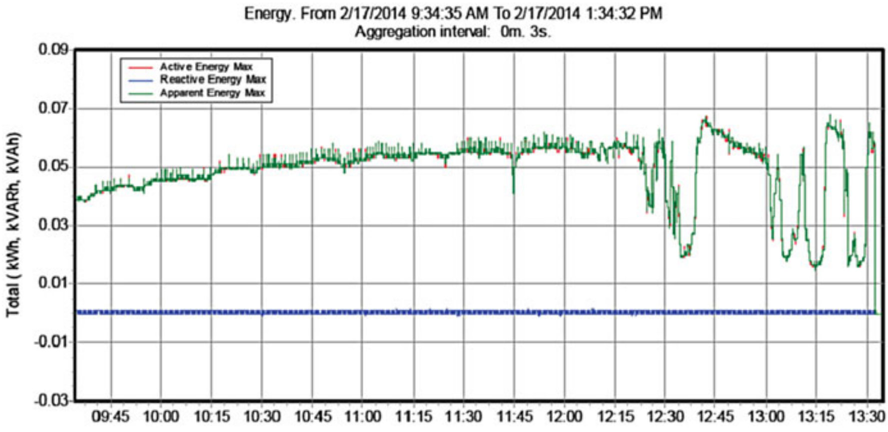

Power. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
CN (kW)
W Min
W Max
W Avg
1m:55s

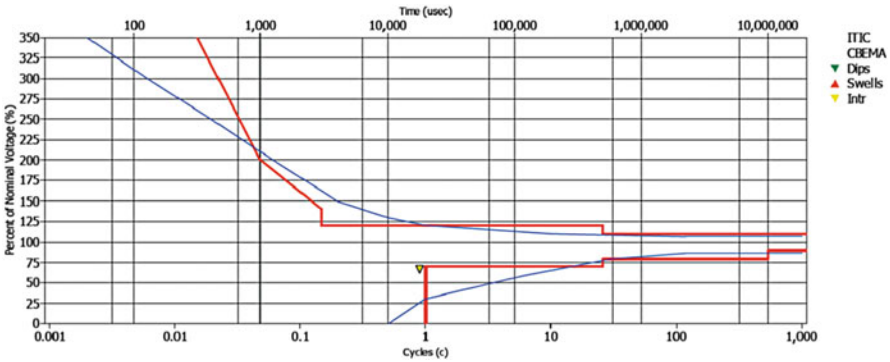

Power. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
Total (kW)
W Min
W Max
W Avg

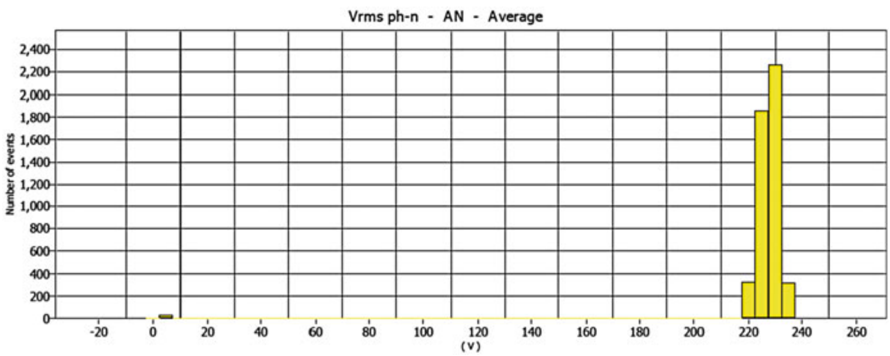

Energy. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
Aggregation interval: 0m. 3s.
0m:0s
Active Energy Max
Reactive Energy Max
Apparent Energy Max
AN (kWh, kVARh, kVAh)
0.028
0.022
0.016
0.01
0.004
-0.002
-0.008
09:45 10:00 10:15 10:30 10:45 11:00 11:15 11:30 11:45 12:00 12:15 12:30 12:45 13:00 13:15 13:30

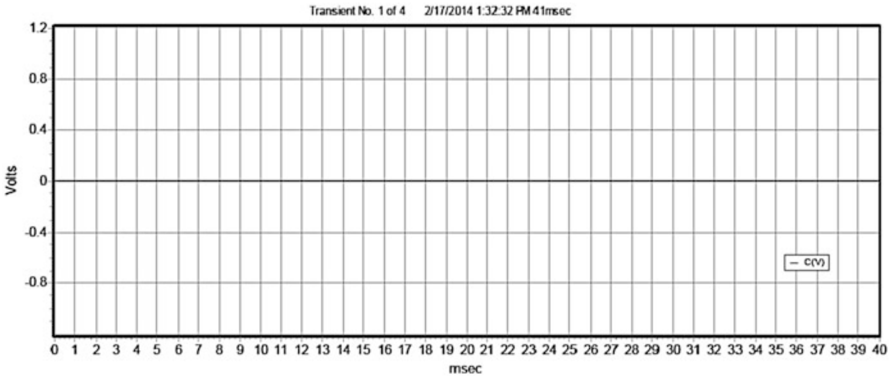

Energy. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
Aggregation interval: 0m. 3s.
Active Energy Max
Reactive Energy Max
Apparent Energy Max
BN (kWh, kVARh, kVAh)
0.034
0.026
0.018
0.01
0.002
-0.006
-0.014
09:45 10:00 10:15 10:30 10:45 11:00 11:15 11:30 11:45 12:00 12:15 12:30 12:45 13:00 13:15 13:30

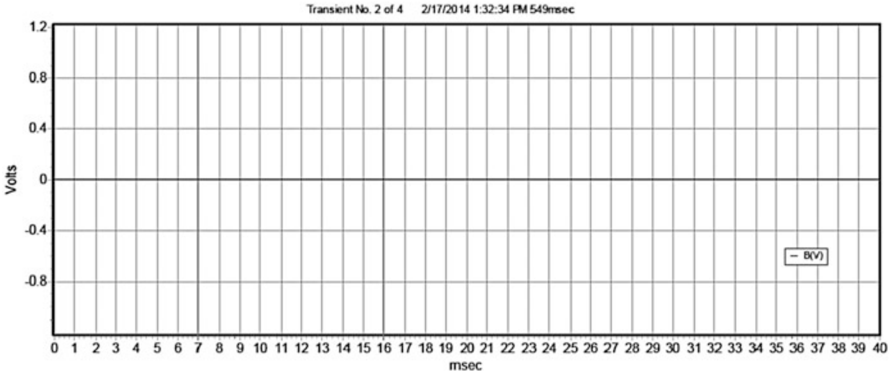

Energy. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
Aggregation interval: 0m. 3s.
1m:55s
Active Energy Max
Reactive Energy Max
Apparent Energy Max
CN (kWh, kVARh, kVAh)
0.034
0.026
0.018
0.01
0.002
-0.006
-0.014
09:45 10:00 10:15 10:30 10:45 11:00 11:15 11:30 11:45 12:00 12:15 12:30 12:45 13:00 13:15 13:30

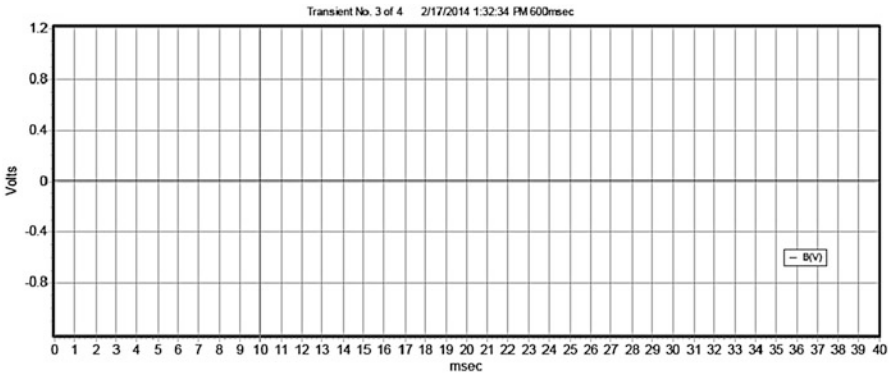

Energy. From 2/17/2014 9:34:35 AM To 2/17/2014 1:34:32 PM
Aggregation interval: 0m. 3s.
Active Energy Max
Reactive Energy Max
Apparent Energy Max
Total (kWh, kVARh, kVAh)
0.09
0.07
0.05
0.03
0.01
-0.01
-0.03
09:45 10:00 10:15 10:30 10:45 11:00 11:15 11:30 11:45 12:00 12:15 12:30 12:45 13:00 13:15 13:30

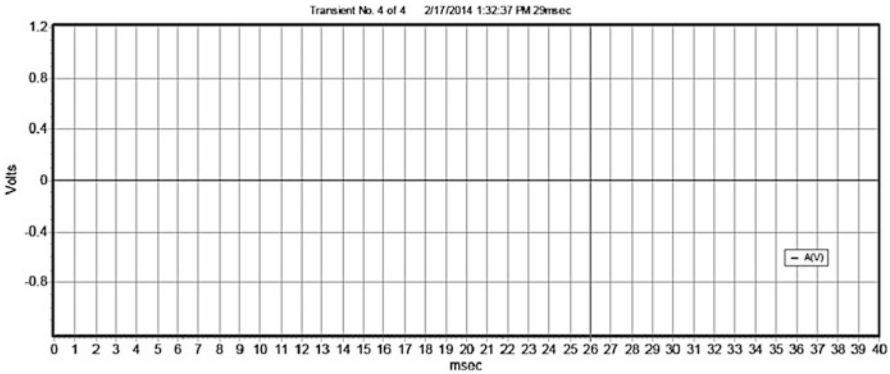

Time (usec)
100 1,000 10,000 100,000 1,000,000 10,000,000
ITIC
CBEMA
Dips
Swells
Intr
Percent of Nominal Voltage (%)
350 325 300 275 250 225 200 175 150 125 100 75 50 25 0
0.001 0.01 0.1 1 10 100 1,000
Cycles (c)


Vrms ph-n - AN - Average
Number of events
2,400 2,200 2,000 1,800 1,600 1,400 1,200 1,000 800 600 400 200 0
-20 0 20 40 60 80 100 120 140 160 180 200 220 240 260
(V)


Transient No. 1 of 4 2/17/2014 1:32:32 PM 41msec
1.2
0.8
0.4
0
-0.4
-0.8
Volts
C(V)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
msec


Transient No. 2 of 4 2/17/2014 1:32:34 PM 549msec
1.2
0.8
0.4
0
-0.4
-0.8
Volts
B(V)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
msec


Transient No. 3 of 4 2/17/2014 1:32:34 PM 600msec
1.2
0.8
0.4
0
-0.4
-0.8
Volts
B(V)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
msec



Instrument Information

Model number	FLUKE 430-II
Serial number	24663010
Firmware revision	V04.00

Software Information

Power log version	4.1
FLUKE 345 DLL version	11.20.2006
FLUKE 430 DLL version	1.8.0.0
FLUKE 430-II DLL version	1.0.0.28

Measurement Summary

Measurement topology	Wye mode
Application mode	Logger
First recording	1/29/2014 10:50:01 PM
Last recording	1/30/2014 1:52:21 AM
Recording interval	0 h 0 m 10s 0 m sec
Nominal voltage	230 V
Nominal current	300 A
Nominal frequency	50 Hz
File start time	1/29/2014 10:50:01 PM
File end time	1/30/2014 1:52:21 AM

(continued)

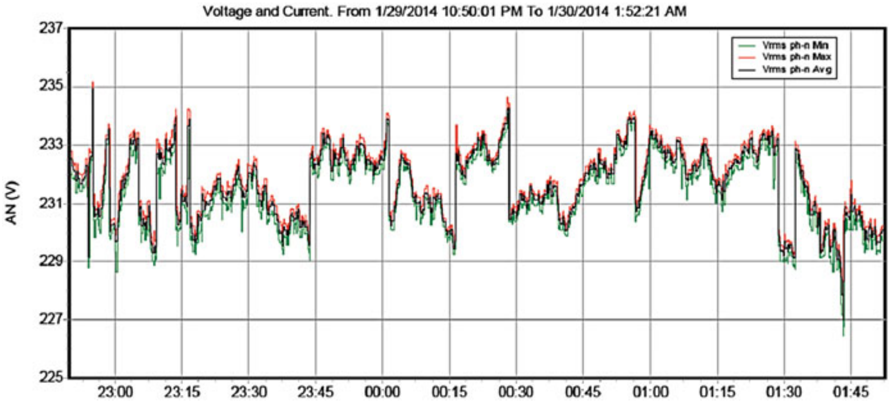
Duration	0 d 3 h 2 m 20 s 0 m sec
Number of events	0
Events downloaded	No
Number of screens	63
Screens downloaded	Yes
Power measurement method	Unified
Cable type	Copper
Harmonic scale	%H1
THD mode	THD 40
CosPhi/DPF mode	Cos Phi

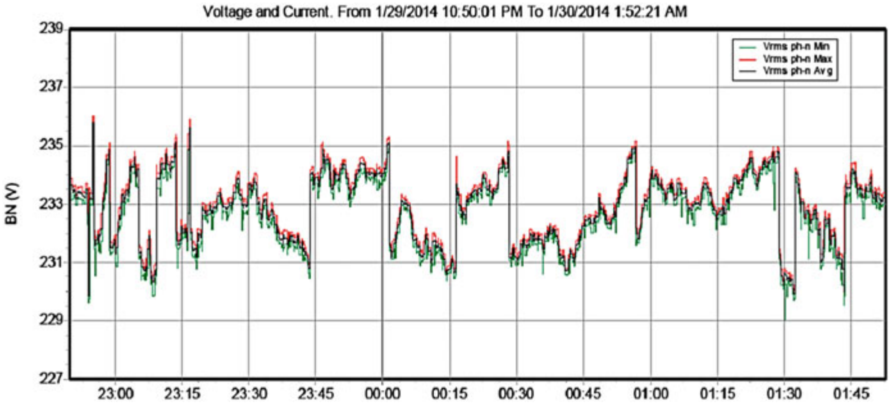
Recording Summary

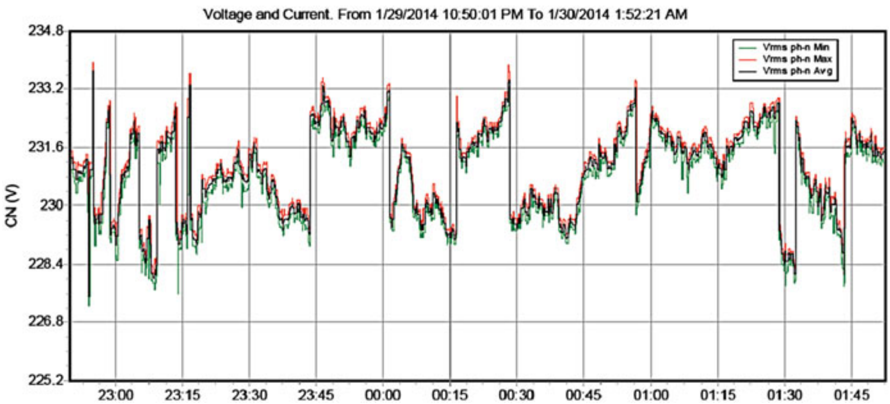
RMS recordings	1,095
DC recordings	0
Frequency recordings	1,095
Unbalance recordings	1,095
Harmonic recordings	0
Power harmonic recordings	0
Power recordings	1,095
Power unbalance recordings	0
Energy recordings	1,095
Energy losses recordings	0
Flicker recordings	0
Mains signaling recordings	0

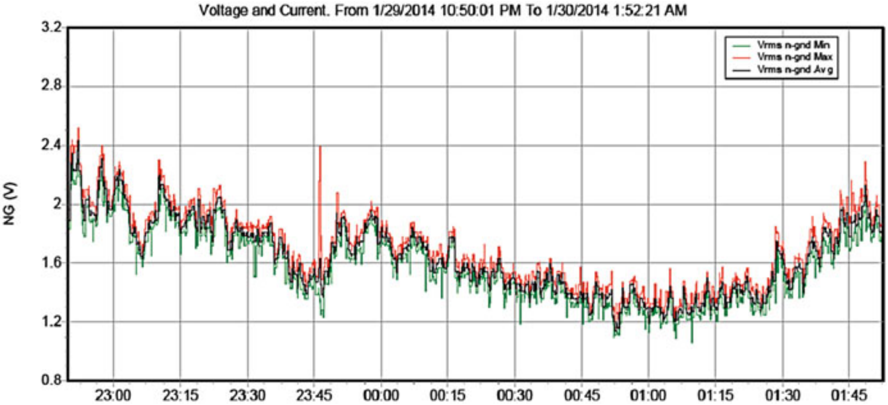
Events Summary

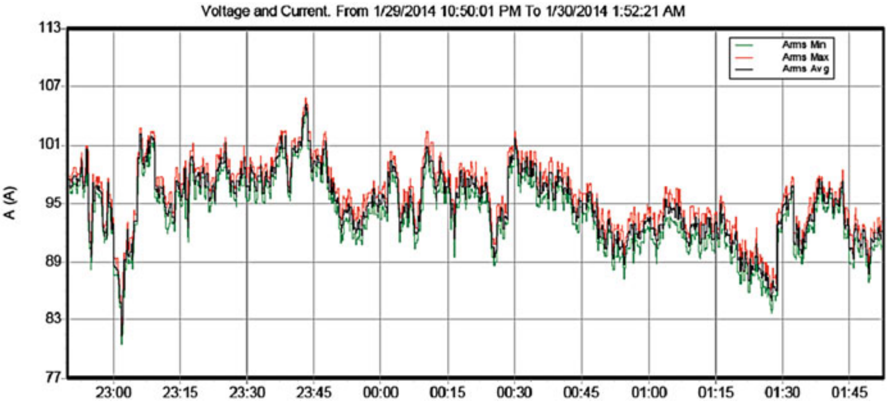
Dips	0
Swells	0
Transients	0
Interruptions	0
Voltage profiles	0
Rapid voltage changes	0
Screens	63
Waveforms	0
Intervals without measurements	0
Inrush current graphics	0
Wave events	0
RMS events	0

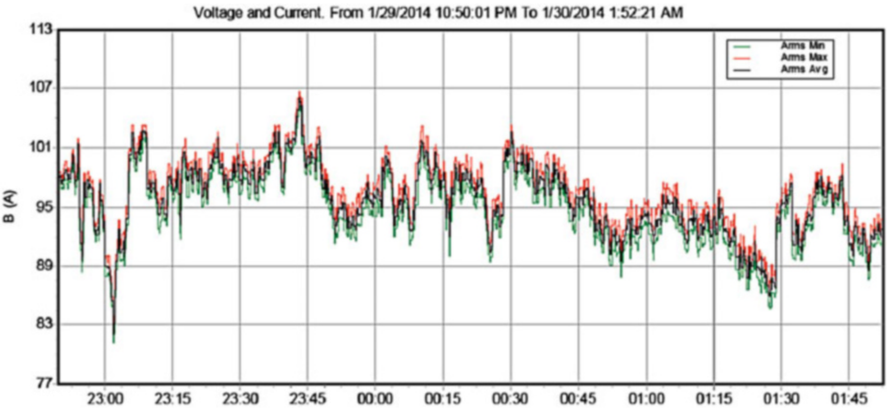

Voltage and Current. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
AN (V)
237
235
233
231
229
227
225
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
Vrms ph-n Min
Vrms ph-n Max
Vrms ph-n Avg

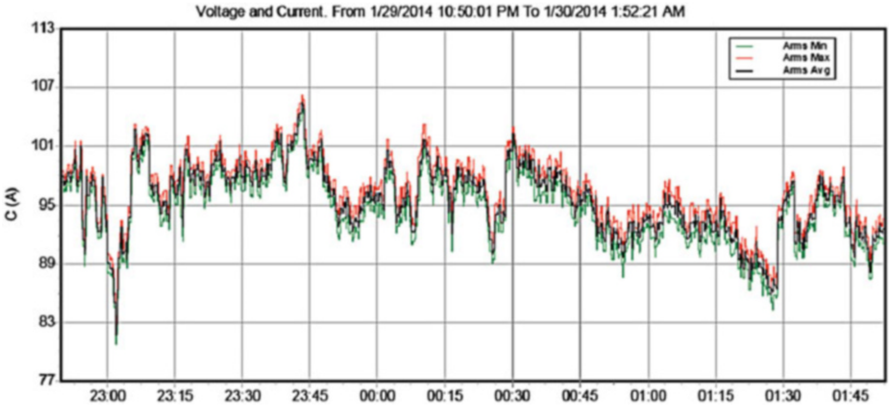

Voltage and Current. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
BN (V)
239
237
235
233
231
229
227
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
Vrms ph-n Min
Vrms ph-n Max
Vrms ph-n Avg

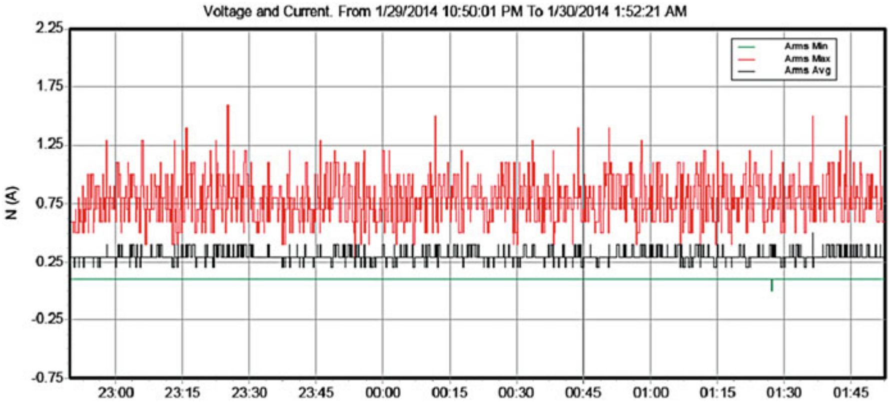

Voltage and Current. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
CN (V)
234.8
233.2
231.6
230
228.4
226.8
225.2
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
Vrms ph-n Min
Vrms ph-n Max
Vrms ph-n Avg

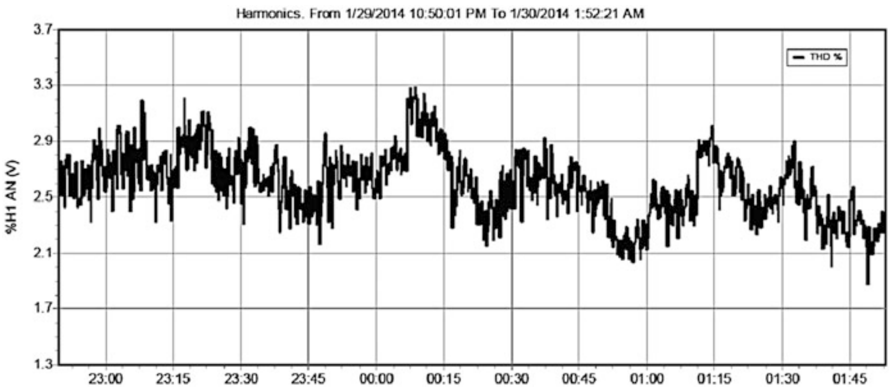

Voltage and Current. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
NG (V)
3.2
2.8
2.4
2
1.6
1.2
0.8
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
Vrms n-gnd Min
Vrms n-gnd Max
Vrms n-gnd Avg

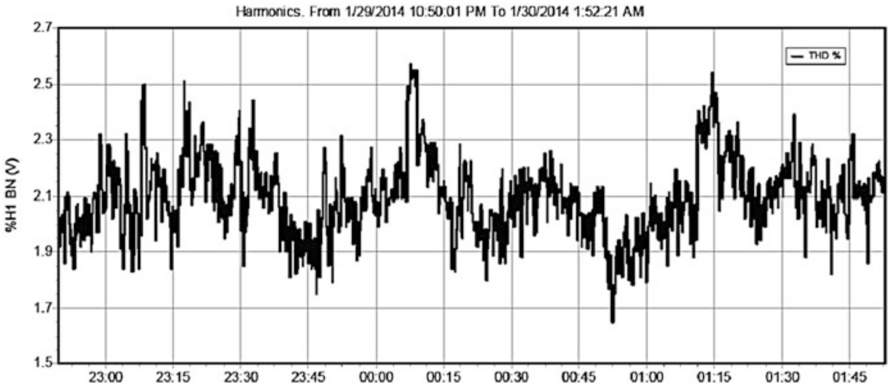

Voltage and Current. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
A (A)
113
107
101
95
89
83
77
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
Arms Min
Arms Max
Arms Avg

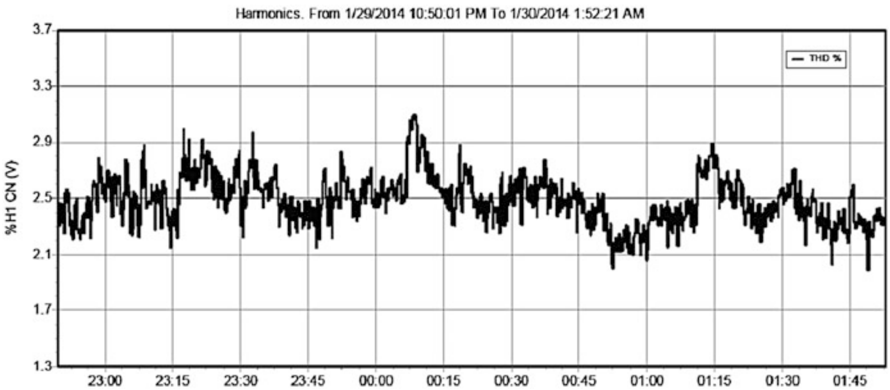

Voltage and Current. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
B (A)
113
107
101
95
89
83
77
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
Arms Min
Arms Max
Arms Avg

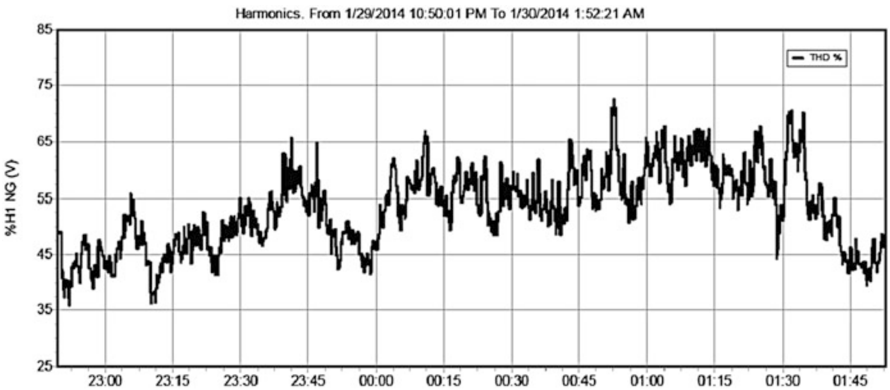

Voltage and Current. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
Arms Min
Arms Max
Arms Avg
C (A)
113
107
101
95
89
83
77
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

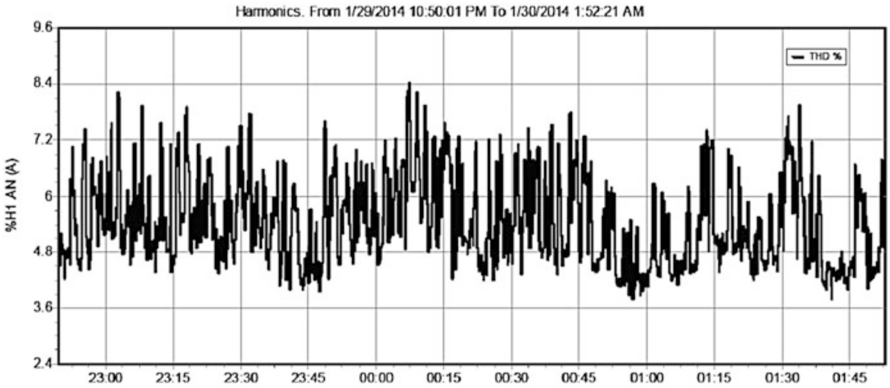

Voltage and Current. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
Arms Min
Arms Max
Arms Avg
N (A)
2.25
1.75
1.25
0.75
0.25
-0.25
-0.75
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

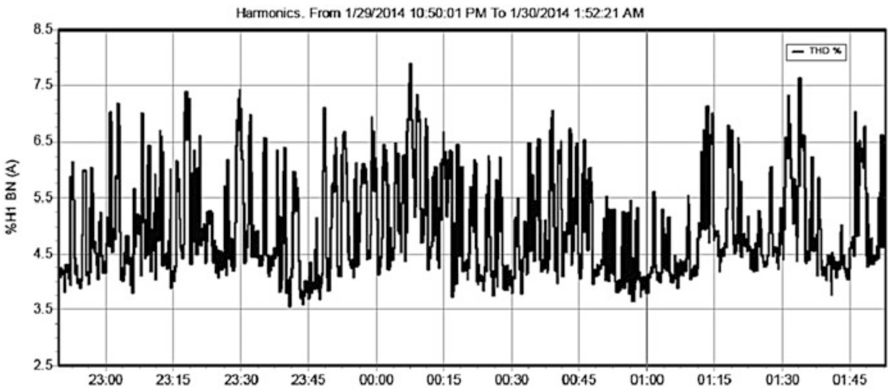

Harmonics. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
THD %
%H1 AN (V)
3.7
3.3
2.9
2.5
2.1
1.7
1.3
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

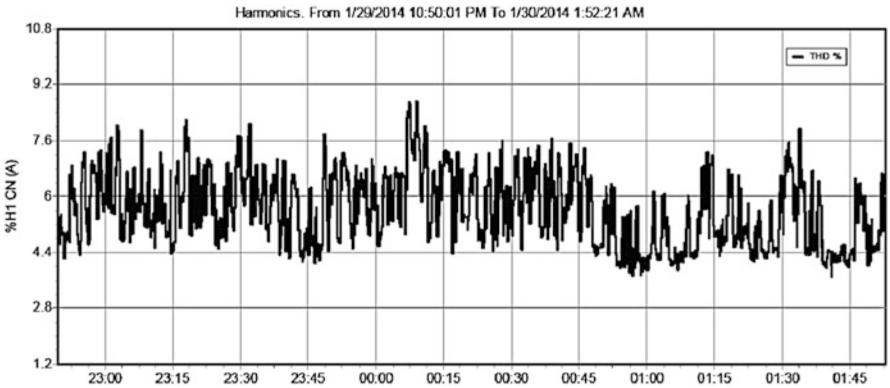

Harmonics. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
%H1 BN (V)
THD %
2.7
2.5
2.3
2.1
1.9
1.7
1.5
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

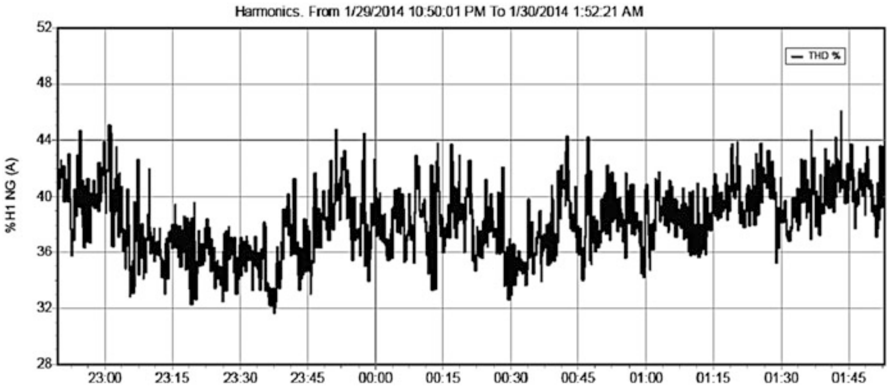

Harmonics. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
%H1 CN (V)
THD %
3.7
3.3
2.9
2.5
2.1
1.7
1.3
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

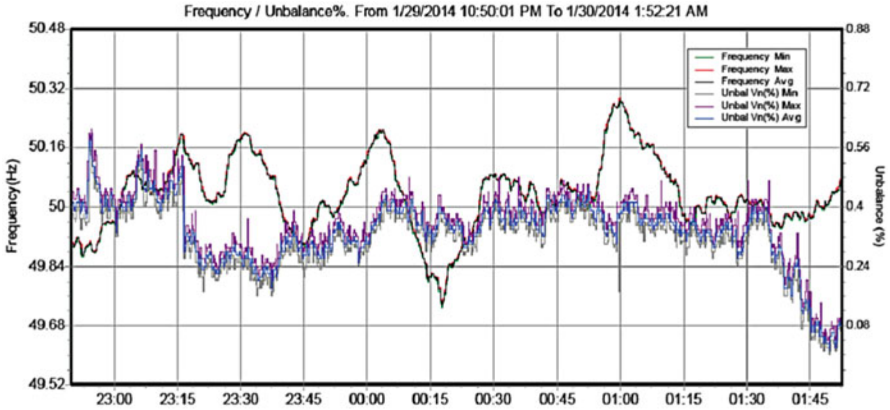

Harmonics. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
%H1 NG (V)
THD %
85
75
65
55
45
35
25
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

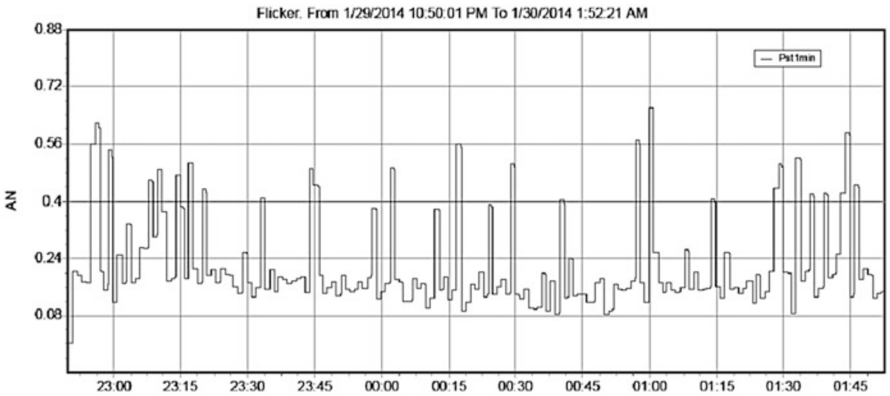

Harmonics. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
%H1 AN (A)
THD %
9.6
8.4
7.2
6
4.8
3.6
2.4
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

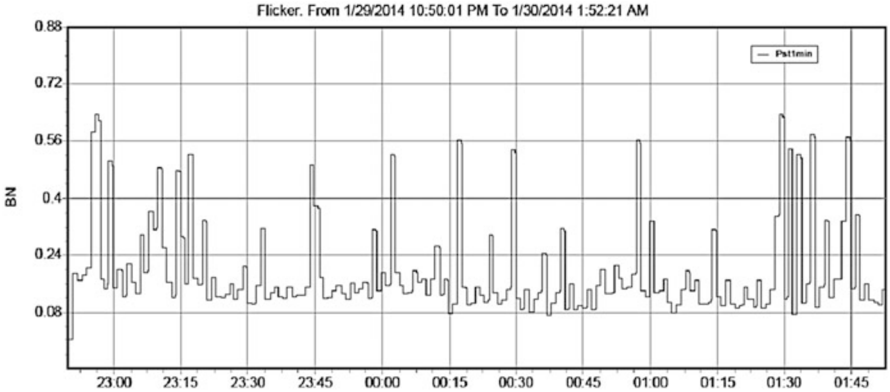

Harmonics. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
%H1 BN (A)
THD %
8.5
7.5
6.5
5.5
4.5
3.5
2.5
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

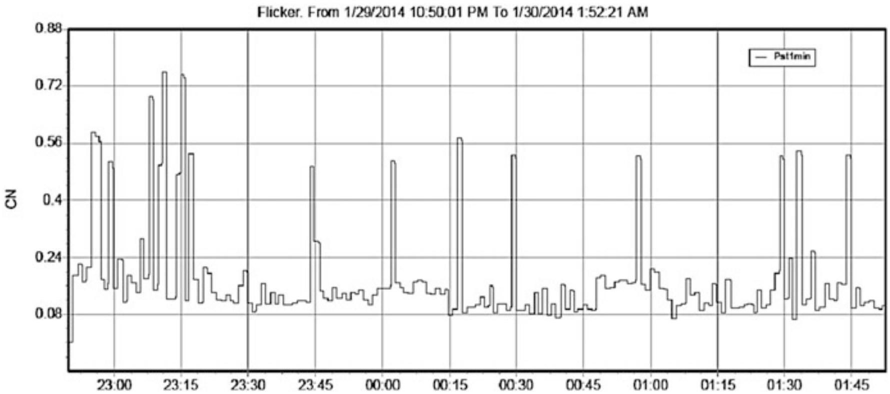

Harmonics. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
%H1 CN (A)
THD %
10.8
9.2
7.6
6
4.4
2.8
1.2
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

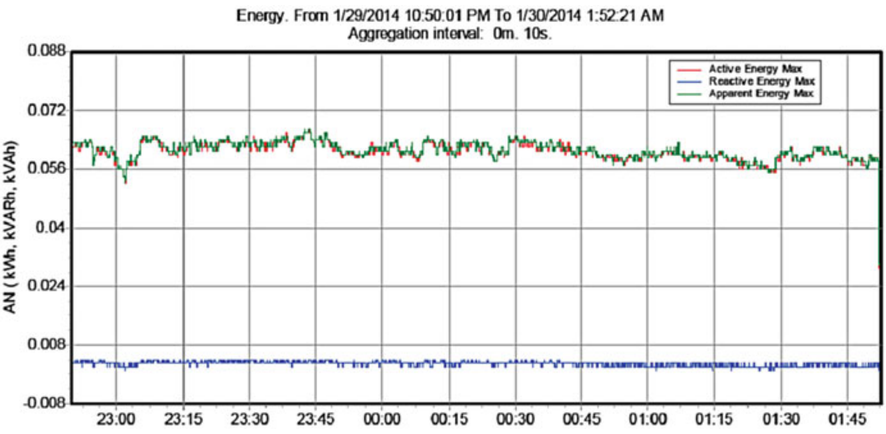

Harmonics. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
THD %
% H1 NG (A)
52
48
44
40
36
32
28
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

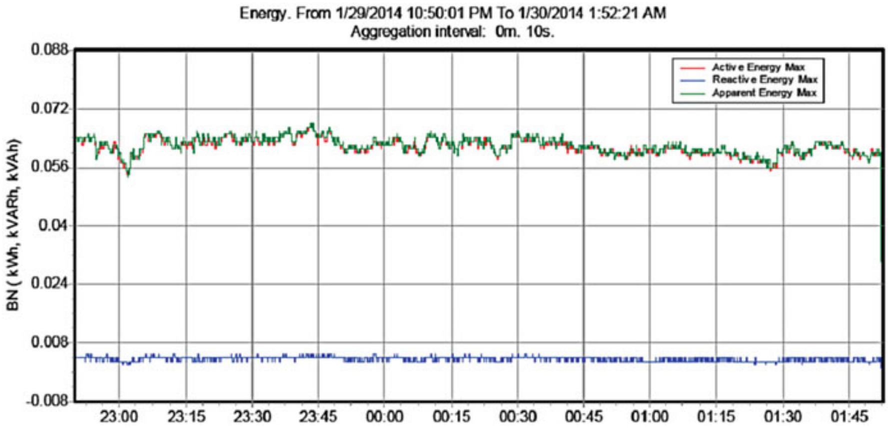

Frequency / Unbalance%. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
Frequency Min
Frequency Max
Frequency Avg
Unbal Vn(%) Min
Unbal Vn(%) Max
Unbal Vn(%) Avg
Frequency(Hz)
Unbalance (%)
50.48
50.32
50.16
50
49.84
49.68
49.52
0.88
0.72
0.56
0.4
0.24
0.08
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

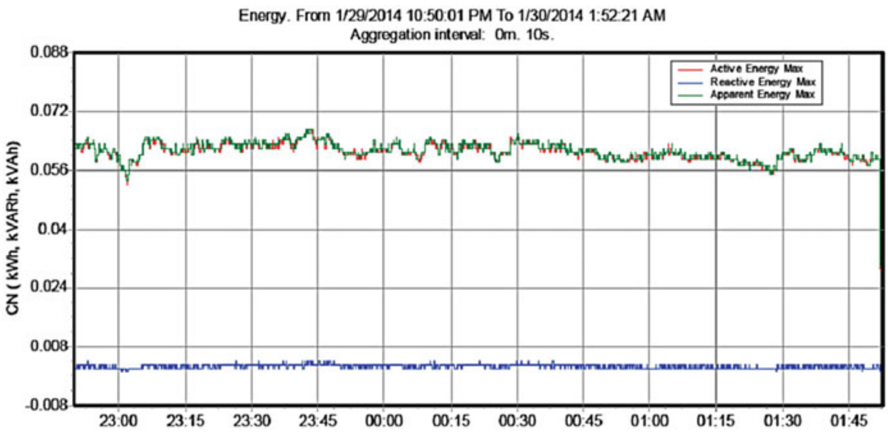

Flicker. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
Pst1min
AN
0.88
0.72
0.56
0.4
0.24
0.08
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

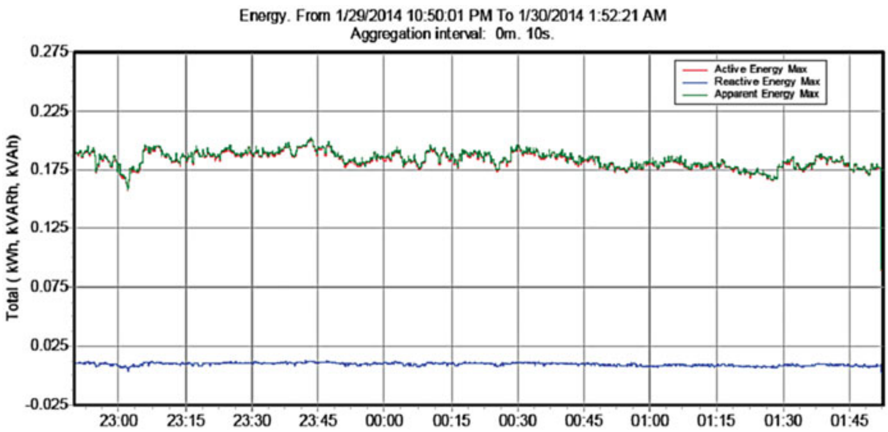

Flicker. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
BN
0.88
0.72
0.56
0.4
0.24
0.08
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
Pst1min

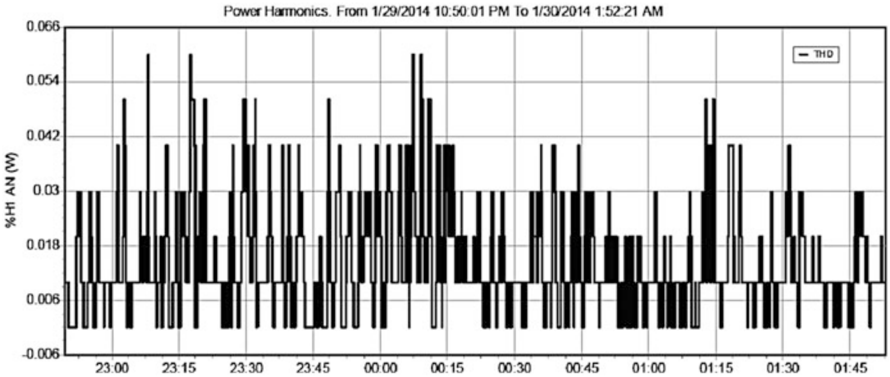

Flicker. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
CN
0.88
0.72
0.56
0.4
0.24
0.08
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
Pst1min

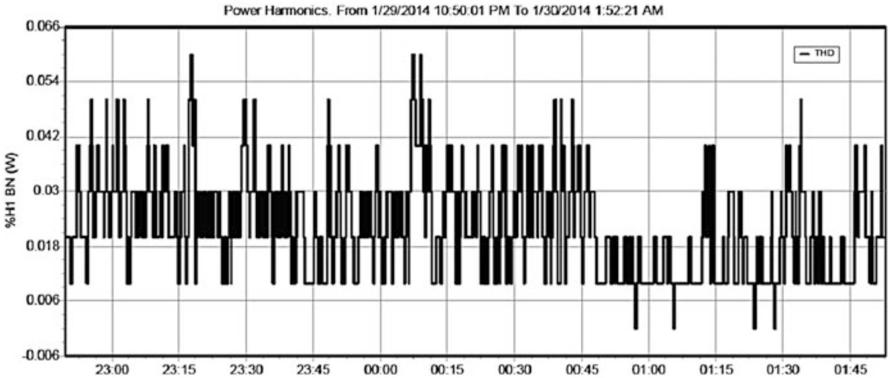

Energy. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
Aggregation interval: 0m. 10s.
AN (kWh, kVARh, kVAh)
0.088
0.072
0.056
0.04
0.024
0.008
-0.008
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
Active Energy Max
Reactive Energy Max
Apparent Energy Max

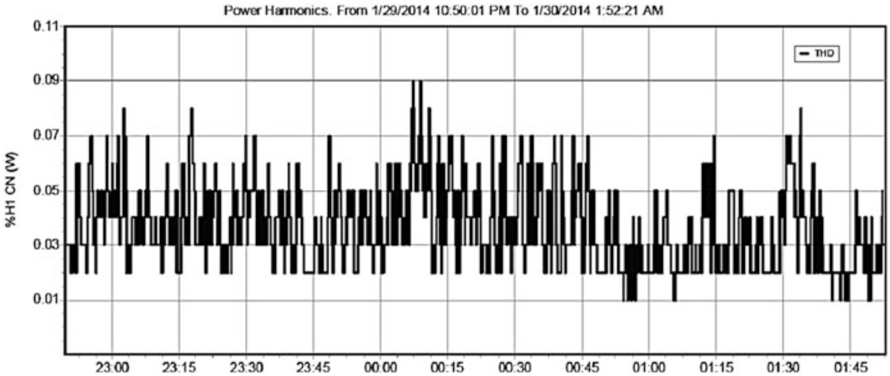

Energy. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
Aggregation interval: 0m. 10s.
Active Energy Max
Reactive Energy Max
Apparent Energy Max
BN (kWh, kVARh, kVAh)
0.088
0.072
0.056
0.04
0.024
0.008
-0.008
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45

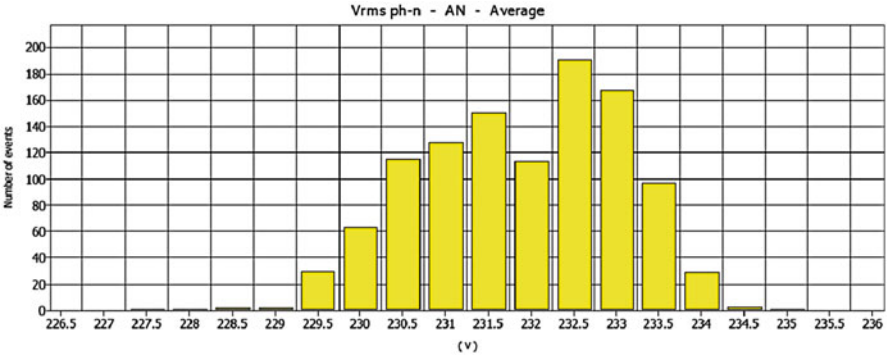

Energy. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
Aggregation interval: 0m. 10s.
Active Energy Max
Reactive Energy Max
Apparent Energy Max
CN (kWh, kVARh, kVAh)
0.088
0.072
0.056
0.04
0.024
0.008
-0.008
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45


Energy. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
Aggregation interval: 0m. 10s.
Active Energy Max
Reactive Energy Max
Apparent Energy Max
Total (kWh, kVARh, kVAh)
0.275
0.225
0.175
0.125
0.075
0.025
-0.025
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45


Power Harmonics. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
%H1 AN (W)
0.066
0.054
0.042
0.03
0.018
0.006
-0.006
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
THD


Power Harmonics. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
%H1 BN (W)
0.066
0.054
0.042
0.03
0.018
0.006
-0.006
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
THD


Power Harmonics. From 1/29/2014 10:50:01 PM To 1/30/2014 1:52:21 AM
%H1 CN (W)
0.11
0.09
0.07
0.05
0.03
0.01
23:00
23:15
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
01:30
01:45
THD



Instrument Information

Model number	FLUKE 430-II
Serial number	24663010
Firmware revision	V04.01

Software Information

Power log version	4.1
FLUKE 345 DLL version	11.20.2006
FLUKE 430 DLL version	1.8.0.0
FLUKE 430-II DLL version	1.0.0.28

Measurement Summary

Measurement topology	Wye mode
Application mode	Logger
First recording	2/5/2014 8:56:32 AM
Last recording	2/5/2014 9:00:52 AM
Recording interval	0 h 0 m 10 s 0 msec
Nominal voltage	230 V
Nominal current	300 A
Nominal frequency	50 Hz
File start time	2/5/2014 8:56:32 AM
File end time	2/5/2014 9:00:52 AM
Duration	0 d 0 h 4 m 20 s 0 msec
Number of events	0

(continued)

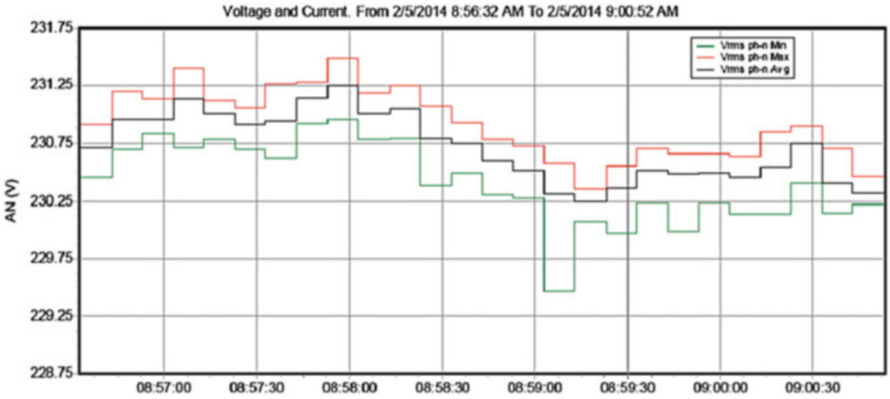
Events downloaded	No
Number of screens	100
Screens downloaded	No
Power measurement method	Unified
Cable type	Copper
Harmonic scale	%H1
THD mode	THD 40
CosPhi/DPF mode	Cos Phi

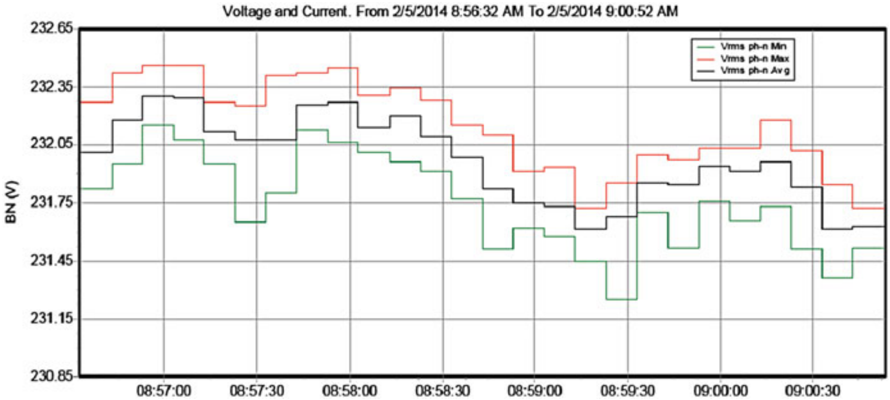
Recording Summary

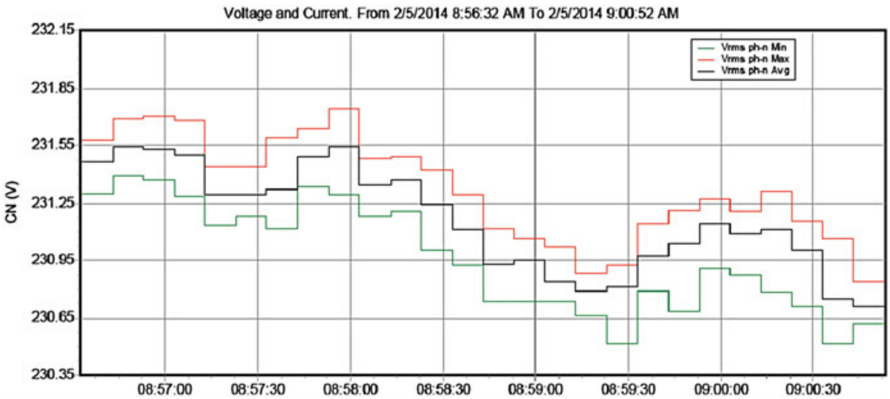
RMS recordings	27
DC recordings	0
Frequency recordings	27
Unbalance recordings	27
Harmonic recordings	0
Power harmonic recordings	0
Power recordings	0
Power unbalance recordings	0
Energy recordings	0
Energy losses recordings	0
Flicker recordings	0
Mains signaling recordings	0

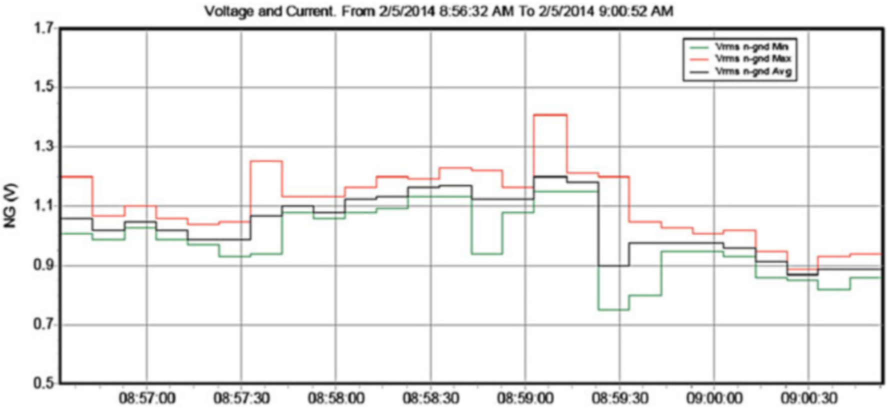
Events Summary

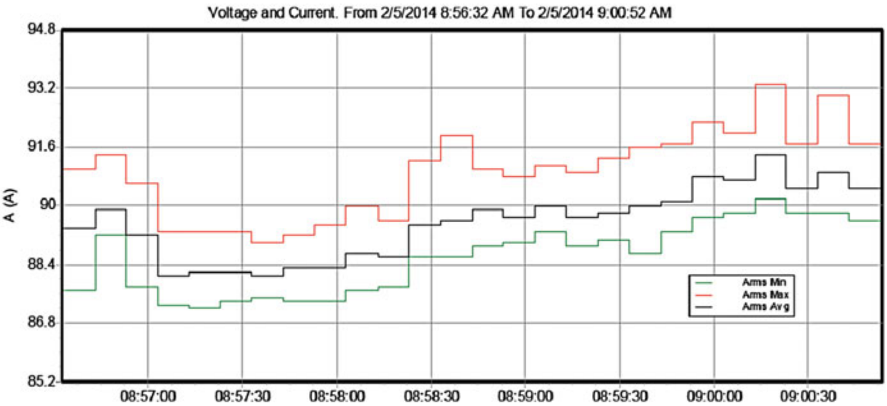
Dips	0
Swells	0
Transients	0
Interruptions	0
Voltage profiles	0
Rapid voltage changes	0
Screens	0
Waveforms	0
Intervals without measurements	0
Inrush current graphics	0
Wave events	0
RMS events	0

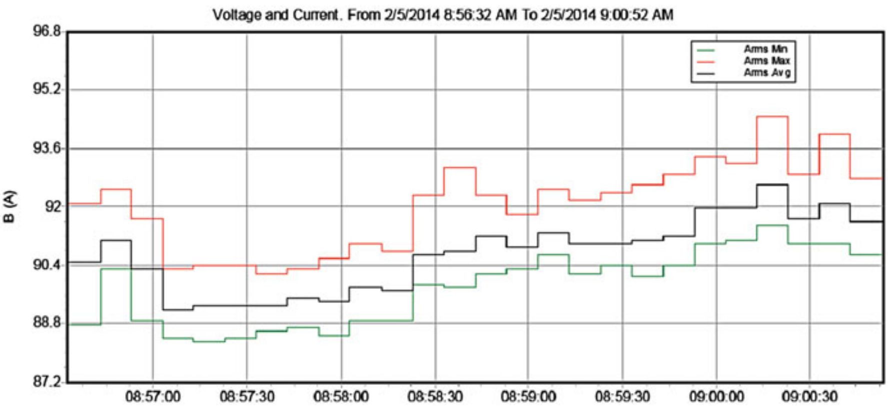

Voltage and Current. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
Vrms ph-n Min
Vrms ph-n Max
Vrms ph-n Avg
AN (V)
231.75
231.25
230.75
230.25
229.75
229.25
228.75
08:57:00
08:57:30
08:58:00
08:58:30
08:59:00
08:59:30
09:00:00
09:00:30

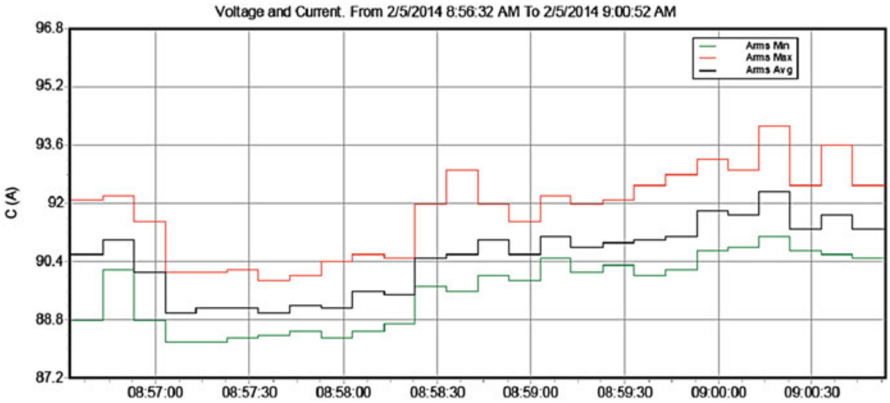

Voltage and Current. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
Vrms ph-n Min
Vrms ph-n Max
Vrms ph-n Avg
BN (V)
232.65
232.35
232.05
231.75
231.45
231.15
230.85
08:57:00
08:57:30
08:58:00
08:58:30
08:59:00
08:59:30
09:00:00
09:00:30

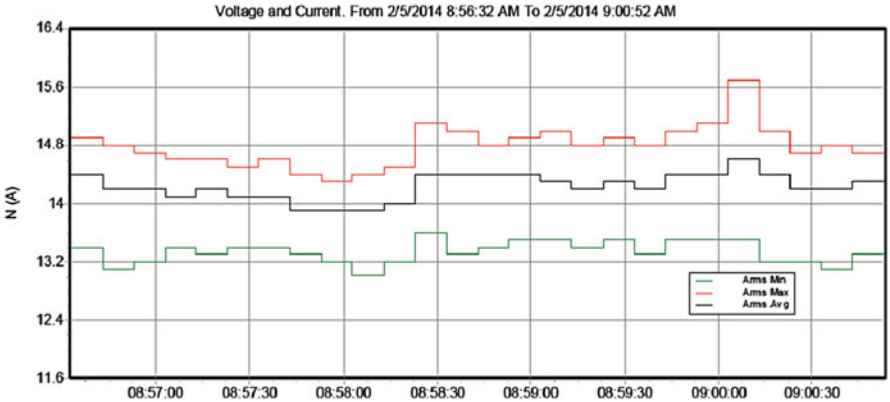

Voltage and Current. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
Vrms ph-n Min
Vrms ph-n Max
Vrms ph-n Avg
CN (V)
232.15
231.85
231.55
231.25
230.95
230.65
230.35
08:57:00
08:57:30
08:58:00
08:58:30
08:59:00
08:59:30
09:00:00
09:00:30

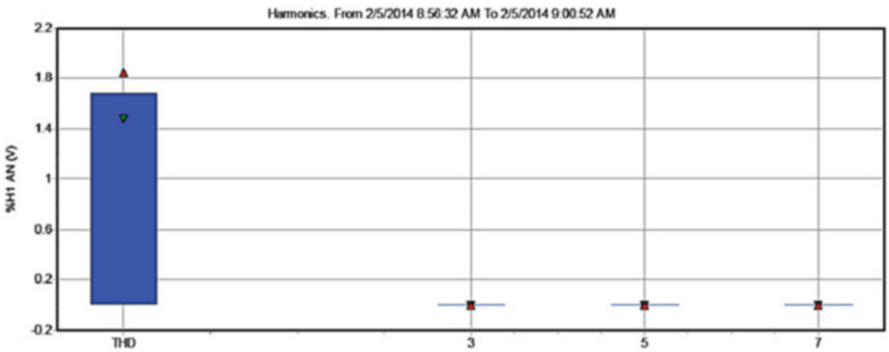

Voltage and Current. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
Vrms n-gnd Min
Vrms n-gnd Max
Vrms n-gnd Avg
NG (V)
1.7
1.5
1.3
1.1
0.9
0.7
0.5
08:57:00
08:57:30
08:58:00
08:58:30
08:59:00
08:59:30
09:00:00
09:00:30

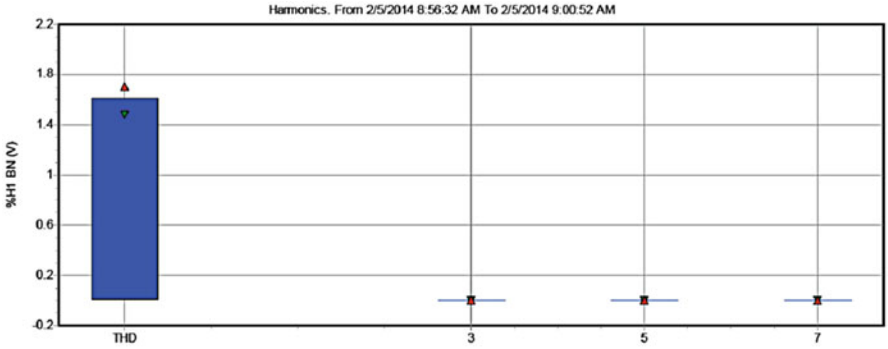

Voltage and Current. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
Arms Min
Arms Max
Arms Avg
A (A)
94.8
93.2
91.6
90
88.4
86.8
85.2
08:57:00
08:57:30
08:58:00
08:58:30
08:59:00
08:59:30
09:00:00
09:00:30

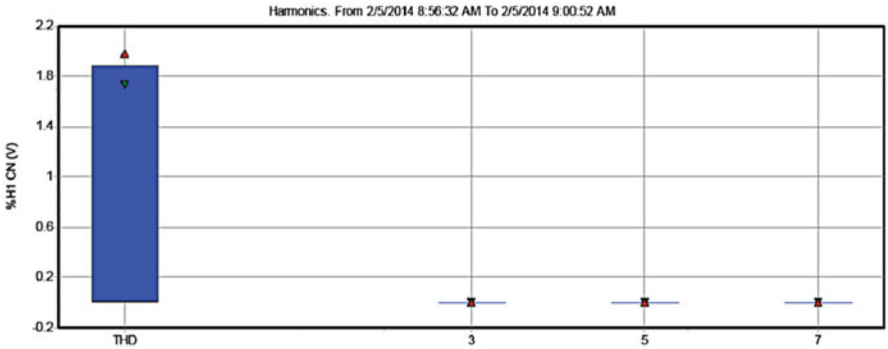

Voltage and Current. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
Arms Min
Arms Max
Arms Avg
B (A)
96.8
95.2
93.6
92
90.4
88.8
87.2
08:57:00
08:57:30
08:58:00
08:58:30
08:59:00
08:59:30
09:00:00
09:00:30

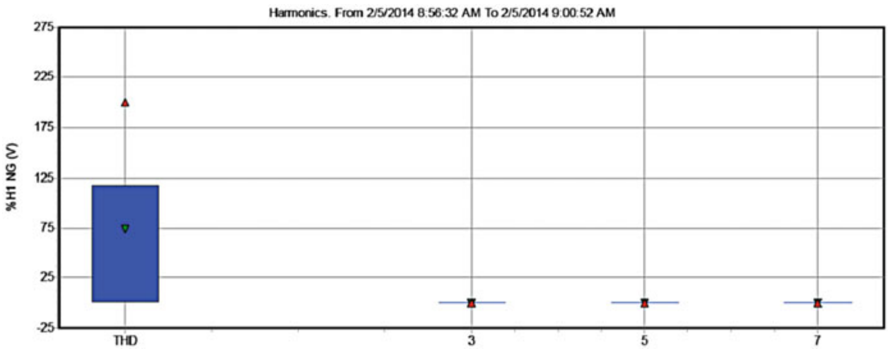

Voltage and Current. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
Arms Min
Arms Max
Arms Avg
C (A)
96.8
95.2
93.6
92
90.4
88.8
87.2
08:57:00
08:57:30
08:58:00
08:58:30
08:59:00
08:59:30
09:00:00
09:00:30

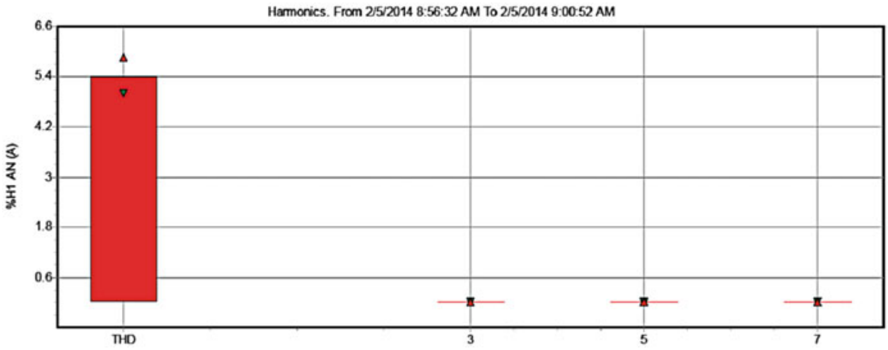

Voltage and Current. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
Arms Min
Arms Max
Arms Avg
N (A)
16.4
15.6
14.8
14
13.2
12.4
11.6
08:57:00
08:57:30
08:58:00
08:58:30
08:59:00
08:59:30
09:00:00
09:00:30

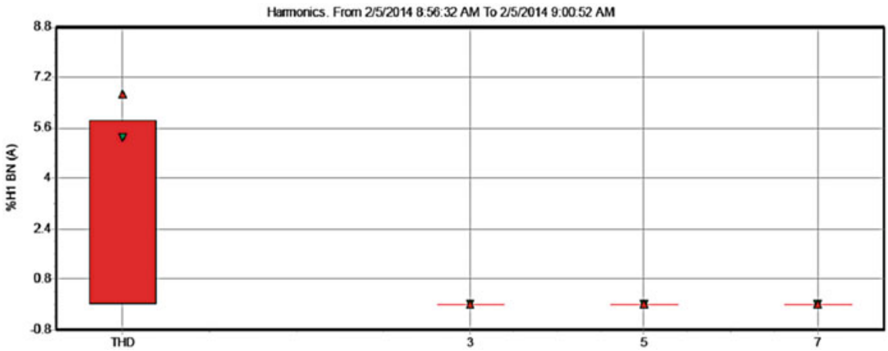

Harmonics. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
%H1 AN (V)
2.2
1.8
1.4
1
0.6
0.2
-0.2
THD
3
5
7

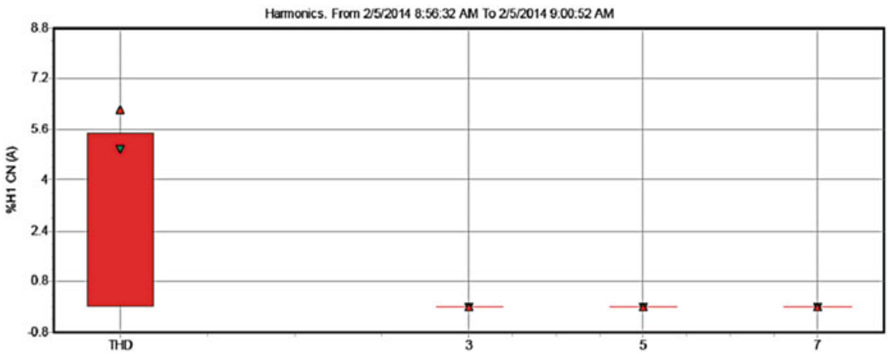

Harmonics. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
%H1 BN (V)
2.2
1.8
1.4
1
0.6
0.2
-0.2
THD
3
5
7

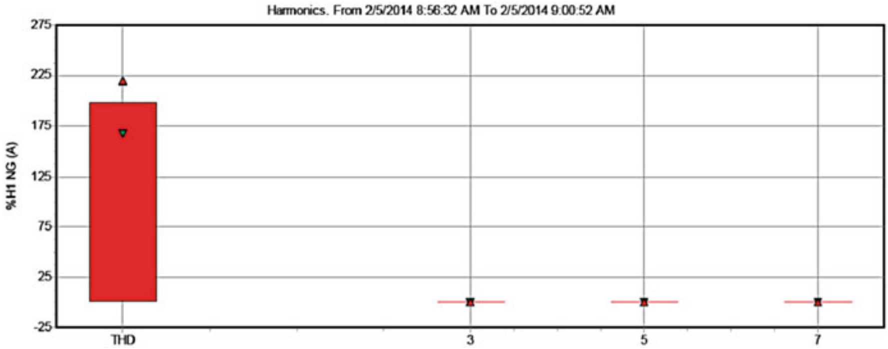

Harmonics. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
%H1 CN (V)
2.2
1.8
1.4
1
0.6
0.2
-0.2
THD
3
5
7

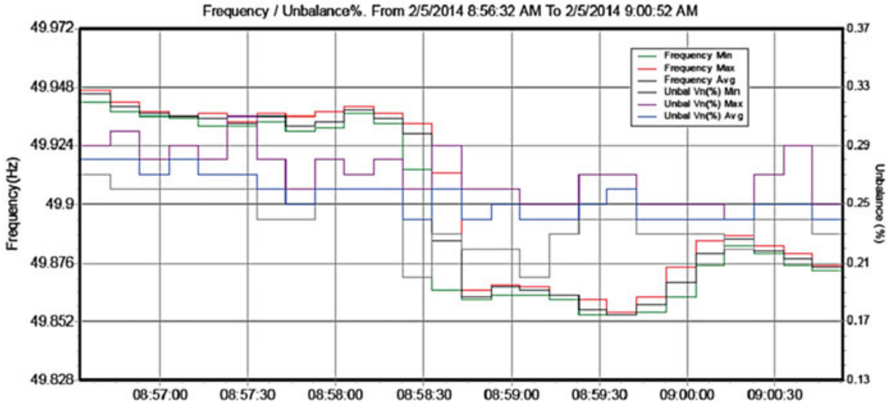

Harmonics. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
%H1 NG (V)
275
225
175
125
75
25
-25
THD
3
5
7

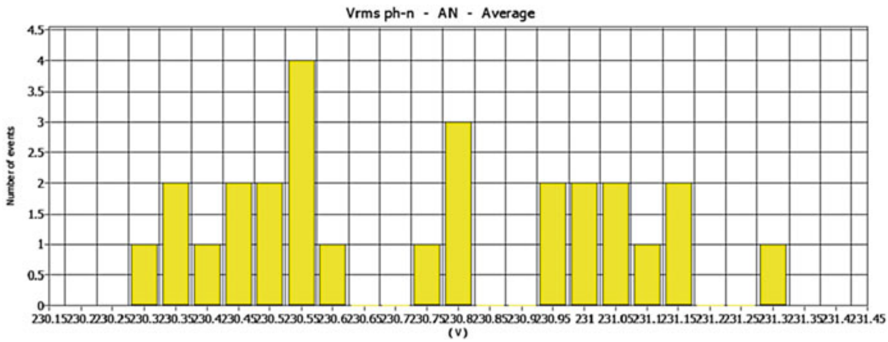

Harmonics. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
%H1 AN (A)
6.6
5.4
4.2
3
1.8
0.6
THD
3
5
7


Harmonics. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
%H1 BN (A)
8.8
7.2
5.6
4
2.4
0.8
-0.8
THD
3
5
7


Harmonics. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
%H1 CN (A)
8.8
7.2
5.6
4
2.4
0.8
-0.8
THD
3
5
7


Harmonics. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
%H1 NG (A)
275
225
175
125
75
25
-25
THD
3
5
7


Frequency / Unbalance%. From 2/5/2014 8:56:32 AM To 2/5/2014 9:00:52 AM
Frequency(Hz)
Unbalance (%)
Frequency Min
Frequency Max
Frequency Avg
Unbal Vn(%) Min
Unbal Vn(%) Max
Unbal Vn(%) Avg
49.972
49.948
49.924
49.9
49.876
49.852
49.828
0.37
0.33
0.29
0.25
0.21
0.17
0.13
08:57:00
08:57:30
08:58:00
08:58:30
08:59:00
08:59:30
09:00:00
09:00:30


Vrms ph-n - AN - Average
Number of events
(V)

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S. Sumathi et al., *Solar PV and Wind Energy Conversion Systems*,
Green Energy and Technology, DOI 10.1007/978-3-319-14941-7