CSEISMIC 1.0 User Guide



April 2016

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CSEISMIC 1.0 USER GUIDE

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ABBREVIATED TERMS

AC alternating current

CSEISMIC Complete System-Level Efficient and Interoperable Solution   
for Microgrid Integrated Controls

DC direct current

EMS energy management system

GUI graphical user interface

IED intelligent electronic device

IP Internet protocol

ORNL Oak Ridge National Laboratory

PV photovoltaic

RAM random access memory

SCADA supervisory control and data acquisition system

UID unique identifier

VIPM VI Package Manager

# INTRODUCTION

This document is intended as a resource for users of the Complete System-level Efficient and Interoperable Solution for Microgrid Integrated Controls (CSEISMIC). It lists the required hardware and software, and provides examples that will help the user to populate the code with system-specific information

# BACKGROUND

The need for electricity worldwide has grown significantly since the dawn of its discovery. Initially a luxury, it has now transformed into an absolute necessity for many around the world. Still, in many developing countries, access to electricity is either not available or not reliably available. This is a challenge that limits economic growth and development in these countries and reduces quality of life.

In the United States, the electric grid has numerous layers with transmission and distribution networks that have been developed over a hundred years. Most of the electric delivery comes from large generation plants located hundreds of miles from load centers. Large interconnected transmission networks deliver power to substations that distribute it to various residential, commercial, and industrial loads. This ensures that electricity is delivered with high reliability and at a low cost.

There are cases where electric customers do not have access to highly reliable, low-cost electrical energy. Electric customers located in bottlenecked or remote locations or that have experienced a natural disaster that has crippled the existing electric network are prime examples. This can result in a lower quality of life and economic issues.

A microgrid is a small, networked electric grid with additional capabilities. It utilizes local generation and energy storage to supply local needs. For example, individual generators can disconnect from a main delivery system if one exists (islanding), and can interact with other interconnected electric systems where present. Microgrids have been a developing area of research for decades and are becoming a more important discussion topic with distributed generation. Historically supporting increased reliability has been the only focus for the business case of a microgrid. This is often a difficult proposition as the economic value for the enhancement may not make business sense. However, distributed generation assets such as solar can provide additional value. In the past, these local generation assets typically were not competitive in overall cost of electricity compared to the main grid. Only recently has the cost of distributed generation reached a stage where this is changing. As a result, there has been significant growth in deployment of these systems.

Today microgrids exist in a number of locations worldwide. They often provide backup power when the primary electric grid fails or are used to increase the power quality. In most cases, these systems comprise an electric generator that is driven by an engine fueled by natural gas or diesel. These systems provide a very dynamic and flexible resource and serve as a synchronized reference upon which all of the other generation resources follow. However, solar and other resources (e.g., wind power) do not have the same flexibility. They are often direct current (DC) resources driven by environmental factors and have a power electronics conversion system. While the power electronics systems can provide more flexibility, the controls also complicate the overall microgrid architecture. Currently, the primary controls for these resources are based on a grid-connected synchronize-and-follow scheme. Hence, at a minimum, one combustion-based resource with a directly connected prime mover is required. Recent advancements in fully electronic controls for power generation systems may make it feasible to operate microgrids without the aid of synchronous machines. That type of system would provide an opportunity for microgrids to be designed solely around photovoltaics (PVs), wind power, and energy storage. This is important in locations where fuel is not readily available.

Research into microgrids has been ongoing for years, but the deployment of microgrids has been limited to special conditions. An evolution in their deployment is needed, as two recent storms, Katrina and Sandy, have demonstrated. However, the products for microgrid deployment that are available in the market are still fairly new and differ in design. They vary in functionality and response and in their ability to interoperate with equipment from different vendors. Working groups under the umbrella of the Institute of Electrical and Electronics Engineers (IEEE) have started to define the requirements for microgrids and their interconnections to utilities (e.g., standards P2030 and IEEE1547). The standards are still in a drafting state.

# ORNL MISSION

Oak Ridge National Laboratory (ORNL) is undertaking multiple tasks in its mission to expedite the deployment of microgrid systems:

* define a list of microgrid functions,
* provide an open source microgrid solution,
* provide industry with guidance for rapid prototyping options,
* demonstrate the various functions in a microgrid setting,
* develop new control strategies and features beyond those of current microgrids, and
* support standards to move the industry forward.

# BASICS

The main design of Complete System-Level Efficient and Interoperable Solution for Microgrid Integrated Controls CSEISMIC is similar to that of a typical grid configuration:

* An energy management system (EMS) that dispatches operational optimization commands to the generation, energy storage, and load resources. This system considers circuit topology for voltage profile considerations, uncertainty associated with renewable (e.g., wind and solar) and load forecasting through stochastic processes, and load shedding and reserves for emergency off-grid conditions. The EMS also acts as the single-point interface to an operator or operations center. The CSEISMIC EMS has been dubbed “MicroEMS.”
* A supervisory control and data acquisition (SCADA) system that in real-time implements the EMS commands to control the generation, energy storage, and load resources, microgrid switch, system protection, and other assets as shown in Figure 1. This system also activates the different control modes to ensure stable operation of the intelligent electronic devices (IEDs) within the microgrid when connected and disconnected from a main grid. The CSEISMIC SCADA system has been dubbed “MicroSCADA.”
* A communications system that provides an interoperable framework for the various components (e.g., generator types, energy storage systems) and parameters (e.g., load, forecasting). The communications system must be able to communicate with vendor-specific equipment using multiple open protocols such as Modbus and BACnet.
* Device controller systems that convert the target requests from the MicroSCADA into actionable events and that relay information back to the MicroSCADA. Systems include power electronics controllers and devices that convert DC output generated by PVs and wind-powered generators to alternating current (AC) for standard tie-in and load-side management.
* System protection that can rapidly interrupt and isolate a fault. This is not trivial; the overcurrent protection schemes applied to standard distribution systems do not necessarily work on microgrids due to the addition of generation assets creating reverse current flow conditions.

Hardware and LabVIEW software from National Instruments, MathWorks-based analytical tools, and hardware components from other vendors were used in the development of CSEISMIC. Higher-level learning algorithms and adaptive controls are being investigated.

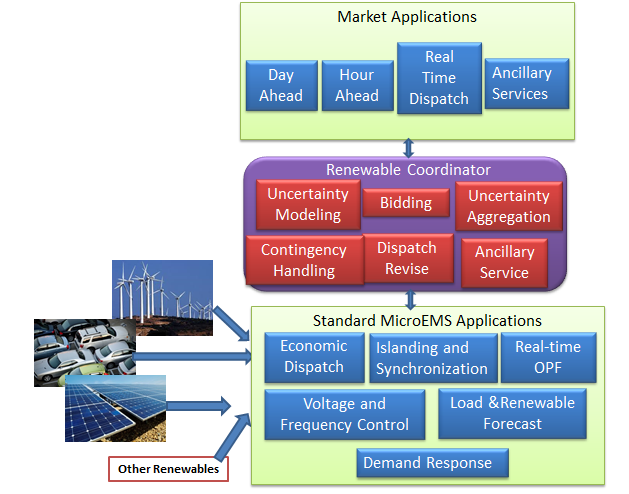


Figure 1. Example depiction of CSEISMIC.

## MASTER CONTROLLER (MicroEMS AND MicroSCADA)

The master controller performs the EMS and SCADA functions and has a number of components. MicroEMS, used in the current CSEISMIC framework, was developed utilizing optimization toolsets in MathWorks MATLAB software and ORNL-developed objective functions. MicroSCADA is hosted on the same computer and directly communicates to end devices [intelligent electronic devices (IEDS)]. A protocol has been developed to exchange information between MicroSCADA and MicroEMS (see CSEISMIC Technical Specifications document).

The current EMS functions include the following:

* The ability to perform various market-based transactions with a utility operator. The transactions are utilized in establishing day-ahead and hourly market prices and to dispatch generation and energy storage resources while grid connected for highest value.
* Provide ancillary services as a provision to attract higher value to the microgrid and to support the larger transmission system.
* Perform renewable and load forecasting and capture the expected and uncertainty in errors.
* Economic dispatch, unit commitment, and real-time optimal power flow to ensure that the system is optimally dispatched within constraints.

The SCADA functions are

* to ensure that consistent communications are up and running (i.e., that dispatch commands are sent and that measurement data are pulled from devices);
* to watches for islanding as a result of a microgrid switch opening and sending a transition command to a main source controller; and
* to perform grid synchronization by issuing a command to the main controller and to the microgrid switch controller.

## DEVICE CONTROLLERS

In the ORNL framework, National Instruments hardware and software are utilized as the main interface to all of the device systems. They provide the interoperable communication framework. An additional feature due to the size of the processors is the ability to control other systems. At ORNL, the controls for various generation assets and energy storage devices have been developed on the National Instruments platforms:

* activation of devices from an inactive state,
* switching control for DC-to-AC converter voltage/frequency control mode and real and reactive power control mode,
* islanding monitoring and control of the microgrid switch,
* synchronization and control of the microgrid switch, and
* opening and closing breakers.

# HARDWARE REQUIREMENTS

The system used in the development and testing of CSEISMIC has the following specifications. It is recommended to use a system with equivalent or better specifications.

* Intel® Xeon® CPU E5-2630 v3 @ 2.4 GHz
* 32.0 GB RAM
* 500 GB hard drive

# SOFTWARE REQUIREMENTS

The system used in the development and testing of CSEISMIC has the following software. It is recommended to use a system with equivalent software.

* Microsoft Windows 7 Enterprise Version 6.1 (Build 7601: Service Pack 1)
* Java 1.7.0\_11-b21 with Oracle Corporation Java HotSpot™ 64-Bit Server VM mixed mode
* MathWorks MATLAB Version: 8.3.0.532 (R2014a)
* Curve Fitting Toolbox Version 3.4.1 (R2014a)
* Data Acquisition Toolbox Version 3.5 (R2014a)
* Global Optimization Toolbox Version 3.2.5 (R2014a)
* Instrument Control Toolbox Version 3.5 (R2014a)
* Optimization Toolbox Version 7.0 (R2014a)
* Signal Processing Toolbox Version 6.21 (R2014a)
* Statistics Toolbox Version 9.0 (R2014a)
* National Instruments LabVIEW 2015 Professional Development System 32-bit
* Datalogging and Supervisory Control Module 15.0.0 or  
  LabVIEW Real-Time 15.0.0
* NI Keyed Array Library 2.0.0.11
* NI String Tools Library 2.0.0.5
* OpenG String Library 4.1.0.12

# INSTALLATION

## MATLAB (MATHWORKS)

The user should seek support from MathWorks for MATLAB installation. (See Mathworks.com for detailed instructions on how to install MATLAB.)

## LABVIEW (NATIONAL INSTRUMENTS)

LabVIEW should be installed from the LabVIEW 2015 Platform DVD. Installation must include the LabVIEW Professional Development System and the Datalogging and Supervisory Control Module or Real-Time Module.

Installation of additional libraries needs to be performed using VI Package Manager (VIPM), which is installed with LabVIEW. Information on connecting to LabVIEW and installing packages can be found in the help file installed with VIPM.

# CONFIGURATION

In this section, the needed files for operating the microgrid controller and file structures are discussed.

## SYSTEM CONFIGURATION

To run the CSEISMIC system, it is recommended that the Windows Firewall be disabled.

## EMS CONFIGURATION

### Energy Storage Configuration Files

The energy storage unit configuration for the optimization is located in the following directory:   
<CSEISMIC>\EMS\System Architecture Data\Network Model\Battery.   
The file **Battery Parameter.csv** contains the configuration of each of the energy storage units in the system. An example energy storage configuration file is provided in the directory. The following information is required:

* **Battery #** is the unique identifier (UID).
* **Bus #** is the bus number in the system configuration upon which the energy storage unit is interconnected.
* **Voltage (V)** is the rated voltage of the energy storage system.
* **Power Rating (kVA)** is the rated capacity of the energy storage system.
* **Energy Rating (kWh)** is the rated energy-stored capacity of the energy storage system.
* **Ramp Rate (kW/s)** is the rate at which the energy storage system can transition from one set point to another.
* **Max Power Factor (leading)** is the maximum power factor that the energy storage system is able to produce (largest positive reactive power output in relation to real power).
* **Max Power factor (lagging)** is the maximum power factor that the energy storage system is able to produce (largest negative reactive power output in relation to real power).
* **Min SOC (%)** is the minimum operational state of charge of the energy storage unit. The user should not specify numbers below 0. There should not be any restrictions on the use of full rated power throughout this range.
* **Max SOC (%)** is the maximum operational state of charge of the energy storage unit. The user should not specify numbers greater than 100. There should not be any restrictions on the use of full rated power throughout this range.
* **Charging Efficiency** is the efficiency of the energy storage system during charging. This efficiency accounts for losses of the inverters and other supporting systems.
* **Discharging Efficiency** is the efficiency of the energy storage system during discharging. This efficiency accounts for losses of the inverters and other supporting systems.
* **Start SOC (%)** is the current state of charge (SOC). This is modified during microgrid operations to reflect current readings.
* **End SOC (%)** is the final target optimization for the next 24 h.

### Electrical System Configuration Files

The cable and transformer impedance model files for the optimization are located in the following directory:   
<CSEISMIC>\EMS\System Architecture Data\Network Model\Cable and Transformer.   
The file **Cable\_and\_Transfomer\_Parameters.csv** contains the configuration of each of the system impedances.

An example cable and transformer configuration file is provided in the directory. The following information is required:

* **Cable #** is the UID.
* **From** is the bus number in the system configuration upon which the cable or transform is interconnected.
* **To** is the bus number in the system configuration upon which the cable or transform is interconnected.
* **Conductor Type** is the type of conductor utilized.
* **Voltage Rating (V)** is the rated voltage of the conductor.
* **Conductor AWG is** the gauge of the conductor.
* **Conductor Length (ft.)** is the length of the conductor.
* **Capacity (kVA)** isthe kVA rating of the conductor.
* **R in Ohms** is the equivalent resistance measured in ohms of the conductor.
* **X in Ohms** isthe equivalent ohms for the electrical reactance of the conductor.

### PV Configuration Files

The PV configuration files for the optimization are located in the following directory:   
<CSEISMIC>\EMS\System Architecture Data\Network Model\PV.   
The file **Solar\_config.csv** contains the configuration of each of the PV systems.

An example PV configuration file is provided in the directory. The following information is required:

* **PV #** is the UID.
* **Bus #** is the bus number in the system configuration upon which the PV is interconnected.

### Generator Configuration Files

The generator configuration files for the optimization are located in the following directory:   
<CSEISMIC>\EMS\System Architecture Data\Network Model\Generator.   
The file **Generator model.csv** contains the configuration of each of the generator systems.

An example generator configuration file is provided in the directory. The following information is required:

* **Generator #** is the UID.
* **Bus #** is the bus number in the system configuration upon which the generator unit is interconnected.
* **Voltage (V)** is the rated voltage of the generator system.
* **Power Rating (kVA)** is theis the rated capacity of the energy storage system.
* **Min P** is themaximum power the generator is able to produce.
* **Max P** is the minimum power the generator is able to produce.
* **Max Power Factor (leading)** is the maximum power factor that the generator system is able to produce (largest positive reactive power output in relation to real power).
* **Max Power factor (lagging)** is the maximum power factor that the generator system is able to produce (largest negative reactive power output in relation to real power).
* **4th -order coefficient (the fuel consumption)** is assumed to be a four-order polynomial of power output of generators (i.e., *a* × *P*4 + *b* × *P*3 + *c* × *P*2 + *d* × *P* + *e*); thus, in this equation,
* **4th order coefficient** is “*a*,”
* **3rd order coefficient** is “*b*,”
* **2nd order coefficient** is “*c*,”
* **1st order coefficient** is “*d*,” and
* **0th order coefficient** is “*e*.”
* **Start-up time (s)** is the-time needed for a generator from starting to output minimum power.
* **Start-up cost ($)** is the cost to start up a generator.
* **Fuel cost($/L)** is the price of fuel.
* **Initial Status** is the-on/off status of generator at *t*0 (1 for on and 0 otherwise).

### Load Configuration Files

The location of the load configuration files for the optimization are located in the following directory:

<CSEISMIC>\EMS\System Architecture Data\Network Model\Load.

The file **Load\_config.csv** contains the configuration of each of the loads.

An example **Load\_config.csv** file is provided in the directory. The following information is required:

* **Load #** is the UID.
* **Bus #** is the bus number in the system configuration upon which the load is interconnected.
* **Load Priority** is the definition of the load priority. The user shall choose from “Critical/Priority/Normal.”

### The .ini Files

Configuration files to set up communications between SCADA and devices are in the format found in the .ini files. These files identify information such as Modbus registers, IP address, and parameters. For information on .ini files see examples located in   
<CSEISMIC>\EMS\System Architecture Data\Communications.

### Forecast Data

Forecast data files are used by the EMS to supplement optimization. Both a load forecast and a PV forecast are necessary. If PV is not being used in a microgrid, a forecast data set of all zeros is necessary. See Sect. 8.2.7.2, “PV Forecast Data,” for more information.

#### Load forecast data

The default location of this file is C:\Load\_Forecast\_Data\Load Forecast Data\YYYY\_MM\_DD\, where “YYYY\_MM\_DD” is the current date. For example, July 3, 2016, would be 2016\_07\_03.  
The file containing the load forecast data is designated as **Load\_forecast \_YYYY\_MM\_DD.txt.** The file consists of hourly total load forecast data in watts over 48 hours. The file should contain data starting from 12:00 AM with a total length of 48 values (representing 48 hours of forecast). A new line character separates each data point. Only a single column format is expected. Only a single load is supported in this release of CSEISMIC.

#### PV forecast data

The default location of this file is C:\Load\_Forecast\_Data\PV Forecast Data\YYYY\_MM\_DD\, where “YYYY\_MM\_DD” is the current date. For example, July 3, 2016, would be 2016\_07\_03.

The file containing the PV forecast data is designated as **PV Output\_YYYY\_MM\_DD.txt**. The data structure within this file is composed of forecasted PV output in watts in time intervals of 5 minutes. The file should contain data starting from 12:00 AM with a total length of 2880 values (representing 48 hours of forecast). A new line character separates each data point. This file can be any number of columns (not to exceed 100), but only the first column will be pulled for information in terms of the forecast data. Only a single PV system is supported in this release.

#### Day-ahead price data

The default location of the day-ahead price data file is C:\Load\_Forecast\_Data\Real Time Price Data\. The price data are currently pulled from <http://www.pjm.com/pub/account/Impda/YYYYMMDD-da.csv>. This is a third-party source of data and is subject to change. YYYYMMDD is the current date. For example, July 3, 2016, would be 20160703.

#### Blackstart device sequence

The location of the blackstart device sequence file is located in the following directory:   
<CSEISMIC>\EMS\System Architecture Data\System Configuration\.   
The file **blackstart\_devices.txt** contains a list of devices in the order of activation for blackstart excluding the voltage/frequency controller (ensure that the blackstart device identifier is present in the .ini files).

#### Islanding switch device identification

The location of the microgrid switch identifier file is located in the following directory: <CSEISMIC>\EMS\System Architecture Data\System Configuration\.   
The file **relay\_island\_controller.txt** contains a single device name, which identifies the microgrid switch (ensure that the islanding switch device identifier is present in the .ini files).

#### Main source controller identification

The location of the voltage/frequency device identifier file is located in the following directory:   
<CSEISMIC>\EMS\System Architecture Data\System Configuration\.   
The file **island\_controller.txt** contains a single device name, which identifies the voltage/frequency controller (ensure that the main source controller device identifier is present in the .ini files).

# EXECUTION

## SCADA

1. Open <CSEISMIC>\SCADA\SCADA Application.lvproj.
2. Expand **SCADA Launcher.lvlib**.
3. Open **Launcher.vi**.
4. Click on the **Run** button.

## EMS (BASELINE STARTUP)

1. Ensure that SCADA is up and running.
2. Launch five separate instances of MATLAB.
3. Open following .m files in each of the instances:

* Matlab\_EMS.m
* Emergency\_Monitoring.m
* Optimization\_Results\_Ongrid.m
* Optimization\_Results.m
* Data\_Display\_Prototype.m

1. Run MATLAB scripts.
2. Click on **Start** button on Emergency\_Monitoring graphical user interface (GUI).
3. Click on **Start** button on Optimization\_Results\_Ongrid GUI.
4. Click on **Start** button on Optimization\_Results GUI.
5. Select **Optimization Settings** in Matlab\_EMS GUI.
6. Click on **Start** button on Matlab\_EMS GUI.
7. Once Activation has completed, click on **Start** button on Data\_Display\_Prototype.

# FUTURE EXPECTED UPDATES

## MATLAB

1. MATLAB is currently utilized to support the EMS system. In the next release, the entirety of the microgrid controller will be within LabVIEW environment.

## ENERGY STORAGE

1. Charging and discharging efficiency are fixed numbers. A future release will include efficiency curves instead of single numbers.

## FORECAST DATA

1. Currently, the time resolution for the expected solar forecast data is a 1 min time resolution. In future releases, the data resolution will be modified to accept any number of time frames.
2. Currently, the addition of more than a single PV system is not supported in the EMS. In a future release, the number of PV systems that will be supported will not be limited to a single system.
3. Currently, the time resolution for the expected load forecast data utilized is hourly. In future releases, this will be modified to accept any number of time frames.
4. Currently, the addition of more than a load is not supported in the EMS. In a future release, the number of loads that will be supported will not be limited.

In a future release, the file structures supporting the forecasting will no longer be available. Forecast data will be directly transmitted through messaging.