IMPLEMENTATION OF SMART GRID ENVIRONMENT IN GREEN CAMPUS PROJECT

Henri MAKKONEN
LUT Energy – Finland
henri.makkonen@lut.fi

Ville TIKKA
LUT Energy – Finland
ville.tikka@lut.fi

Tero KAIPIA
LUT Energy - Finland
tero.kaipia@lut.fi

Jukka LASSILA
LUT Energy – Finland
jukka.lassila@lut.fi

Jarmo PARTANEN
LUT Energy – Finland
jarmo.partanen@lut.fi

Pertti SILVENTOINEN
LUT Energy - Finland
pertti.silventoinen@lut.fi

ABSTRACT

The Aim of this paper is to introduce the implementation of Smart Grid environment in the Green Campus project. Green Campus project is a combination of existing low voltage customer network with smart grid elements. The goal of this project is to have an actual field implementation of smart grid with load control, distributed generation and energy storages. The Smart Grid recognizes the units connected to the system, enabling data gathering from these units via the communication line. Demonstration grid is capable of controlling loads and energy storages to limit consumption spikes as well as reduce energy costs by optimising the energy management system? with the optimisation of an energy management system.

INTRODUCTION

The smart grid concept is a widely discussed method to decrease the existing and incoming problems and bringing new possibilities for the energy production and distribution network in the future [1-3]. Growing electricity consumption can be partly compensated with the DG-units (Distributed Generation) and load control in smart grids [4-6]. This lowers a need of new investments to reinforce the distribution grid.

However, the energy production of the renewable energy sources is less predictable and controllable compared to traditional power plants. Therefore, smart grids can also be used for power balancing using energy storages and load control, decreasing investments for the balancing power plants [2, 7]. In addition, smart grid can be used to form a micro grid (operating as an island), by disconnecting the grid from the distribution network [5]. If the micro grid has enough energy resources to maintain the power balance, the micro grid system is immune to the faults of outside distribution network [2, 5].

The Green Campus Smart Grid (GCSG) project implements a smart grid concept into an existing low voltage customer network in Lappeenranta University of Technology. The Smart Grid consists of DG-units, energy storages, controllable loads and system controller. Most of the work with the Smart Grid environment has been done with the static energy storage, PHEV (Plug-in Hybrid Electric Vehicle) and wind turbine. The furthest of these units concerning smart grid system connection is the control of the PHEV. The Smart Grid environment is the follow-on of the INCA (INteractive Customer gAteway) project in LVDC (Low Voltage Direct Current) laboratory pilot made in the university [8, 9].

SMART GRID ELEMENTS

The Green Campus Smart Grid environment consists of four basic smart grid elements: load control, distributed generator units, energy storages and energy management system. Each of these Smart Grid units has a common gateway interface which can be accessed via ethernet connection. The EMS can gather required information from the SG units by utilising the Ethernet connection, and also control the units.

The EMS operation is based on a database which contains all necessary data from DG-units, energy storages, controllable loads, load demands, load forecasts and electricity prices. Thus, The EMS is capable to optimise the usage of GCSG units. The case concept of the smart grid environment in Green Campus project is illustrated in Fig. 1.

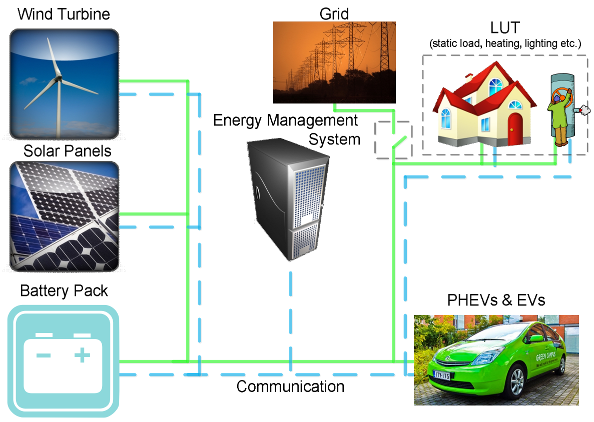

Fig. 1. Smart Grid concept in Green Campus project.

Energy Management System

The Green Campus Smart Grid is capable to interact with smart grid units which has compatible interfaces allowing for example intelligent charging or V2G-option (Vehicle to Grid) for EVs (Electric Vehicle). Having a fully knowledge about resources connected to the Smart Grid, the Smart Grid system is able to operate in island mode in a case of distribution network fault.

The EMS handles the optimisation based on the data from the Smart Grid units. The power balance in the micro grid can be maintained with the optimisation algorithm, and thus the most important systems continue operation without interruptions. The optimisation algorithm can also be modified for different schemes. Optimisation can be based on price signal to decrease power consumption during high price hours in order to achieve more economic electricity use, or system can be set to optimise resources and loads based on energy efficiency and losses of the distribution grid.

The database of the Green Campus Smart Grid system is implemented with the SQL (Structured Query Language). The EMS processes the data from the Smart Grid units such that it is able to optimise Smart Grid operation. However, data itself is inserted in the database by the Smart Grid units' interfaces. The interface gathers needed data from the unit and updates the current data in the EMS database, which also contains data from a longer period of time. The previous data from the units assists the EMS to forecast the behaviour of the Smart Grid units. The adaptive system is important because of the difference of the units.

The content of data is determinate by the type of the Smart Grid unit. The communication protocol between the Smart Grid unit's interfaces and the EMS will be based on the database information transfer. The IEC standards for the smart grids can be implemented partly when the standards will be completed. However, most of the planned communication protocols will be kept intact because of the gathered data and the need of control the SG units.

Distributed Generator Units

The DG-units in the Green Campus Smart Grid consist of a wind turbine and a solar panel system. These DG-units are will be connected to the Smart Grid with three phase AC connections. Because the Smart Grid is implemented on the existing low voltage customer network, the DC-bus of these DG-units is not being utilised for other Smart Grid units.

Wind Turbine

The rated power of the wind turbine is 20 kVA and it is connected to the customer low voltage network by a three phase AC connection. The protocol of the wind turbine control is based on Profibus, and therefore an interface between EMS and wind turbine is required. The interface communicates with the Profibus protocol enabling data gathering and also remote control of the wind turbine. The interface is able to shutdown or start up the wind turbine as well as work as a link to a remote client to control the wind turbine. This remote client can bypass the original rotation speed control of the wind turbine and give torque instructions instead. The wind turbine data includes state, current, voltage, power, rotation speed of the wind turbine as well as speed and direction of the wind and outside temperature.

Solar Panels

The rated power of the solar panel system is also 20 kVA. The panels are connected to the customer side low voltage network by a three phase AC connection. The solar panel system feeds maximum available power into the customer grid, but the system can be turned off with the Smart Grid interface. The solar panel system data includes state, current, voltage and power of the solar panels. In addition solar intensity data is collected from few spots in order to increase short-term forecast accuracy of solar power production.

Energy Storages

The Green Campus Smart Grid contains two kinds of energy storages: mobile and static. The mobile energy storages are EVs with different size of batteries with total capacity of 37 kWh and the static energy storage is a 36 kWh static battery pack.

Battery Pack (static energy storage)

The battery pack includes 27 modules, and it has a total nominal voltage of 756 V and total energy of 36 kWh. The battery pack is lithium nano-titanate, which gives better performance and longer cycle count compared to traditional lithium batteries. Maximum rated power for continuous charge or discharge for the battery is about 220 kW (6C), but the power electronics which connects the battery pack to the customer low voltage network must be used to restrict the power because of the limitations of the customer grid.

The control of the battery pack is established with a bidirectional converter. The Smart Grid interface connects to this converter enabling the EMS to control the battery pack's charging or discharging. The battery pack is a key energy resource element in the Smart Grid environment because it is responsible for fine tuning the power balance in island situation. The battery pack interface transfers the necessary data to the EMS via ethernet. The battery pack data includes voltage, current, power and the SOC (State Of Charge) of the battery pack and voltage, current, power and frequency of the bidirectional converter on the customer network side.

Electric Vehicles

Electric vehicles it selves can be easily charged from a charging pole or socket-outlet. Management of the charging can be done by controlling the power flow to the socket or pole; this makes the charging somewhat intelligent based on the control method. However, if the electric car is used as a small scale generator unit (discharging the battery to the grid) it requires most likely modifications to the vehicle. Most of the commercial EVs has unidirectional on-board charger for the one-phase AC connection, which means it is unable to discharge the batteries to the grid without any modifications.

In our Smart Grid environment, the charging poles are

interfaces for the EMS. The EVs have a separate interface inside of them, enabling communication between charging pole and the EV. The communication line is carried out with a PLC (Power Line Communication) modem; thereby the communication uses ethernet protocol via neutral and phase conductor. The communication protocol is based on database information transfer but the protocol between EV and charging pole will be changed to follow the international standards ISO/IEC 15 118 and IEC 61851-23/24 after the standards will be completed. However, the data gathering from the EVs will be kept intact.
Communication enables that the EMS can identify and acknowledge the EV, which makes the vehicle part of the Smart Grid system. Communication allows the EMS to acquire necessary data from the EV as well as can give instructions to the EV to charge, discharge or to be in idle mode. Fig. 2 describes the steps and functions of smart charging for EV.

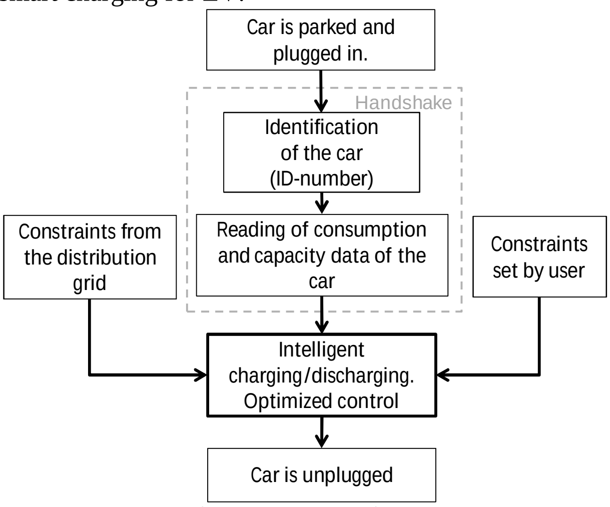

Fig. 2. Block diagram for smart charging of EV.

The mode of the vehicle is determined by the EMS and the constraints made by the EV user. The EMS mode control includes also constraints from the distribution grid and electricity price. However, the constraints set by the user overdrive the EMS control, which means that the EV is in service at anytime, and it allows also the charging of the EV start immediately. The user constraints include the time when the vehicle should be fully charged and the minimum level of SOC, assuring the vehicle is partially usable in any time, even if it has been discharging.
The handshake identifies the car for the Smart Grid opening a communication line for the data transfer and control. The handshake contains the ID of the car, battery SOC, maximum capacity, maximum charge and discharge power and user constraints. The EMS is capable to form a charging profile for the EV by utilising the collected information, load curves and price signals. Fig. 3 illustrates the communication structure of the Smart Grid system for a modified PHEV.

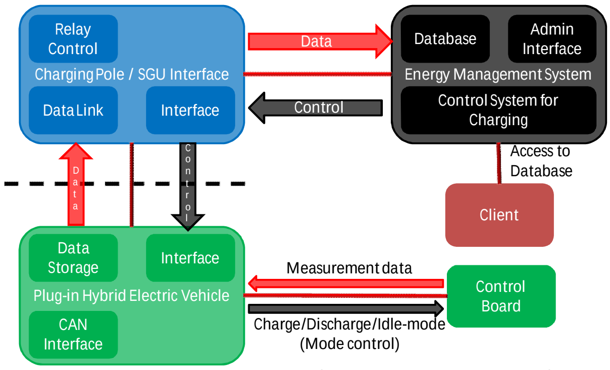

Fig. 3. Communication structure of the Smart Grid system for the modified Plug-in Hybrid Electric Vehicle.

When the PHEV is plugged in, the interface uploads all the data of the last driving cycle to the EMS database. During the time which PHEV is plugged in, it updates the EMS database frequently every second with the current data. The EMS can optimise the usage of the PHEV based on the acquired data.

Load Control

Load controlling is essential part of the Smart Grid, especially when operating in the island mode. The Smart grid can form a micro grid even with limited energy resources if the load prioritisation is allowed. This also enables a longer time period as an island. Load controlling is also important for the optimisation of load curve and price signal.
The Smart Grid can also control heating. Unlike other loads, heat controlling does not directly affect to consumption of electricity, because the heating system is district heating. Nevertheless, including the heating in Smart Grid system is important factor, because the heating is one of the most significant energy consumption units in the Finnish households. Therefore, the possibility to control the heating system with the EMS offers more accurate comparison between the Smart Grid environment and the Finnish households.
Most of the controllable loads are lighting but also the energy storages can be considered as loads. The most significant priority loads are ICT devices, which enable the communication between Smart Grid units.

SMART GRID CONTROL PRINCIPLES

The Smart Grid has three basic control methods: load curve optimisation, price signal optimisation and island mode optimisation. The load curve and price signal optimisation can work together, but island mode optimisation overdrives these two first optimisations; the aim of this is the optimisation of the energy resources.

Load curve optimisation

The load curve optimisation has several different viewpoints. The optimisation can be based on i.e. minimising load transitions, minimising the consumption peaks and prioritise EV charging. The Smart Grid can be modified to prioritise different objectives. The main data for this optimisation is load curve forecast, total power consumption of Smart Grid and measured or estimated power consumption or production for the Smart Grid units.

Price signal optimisation

The price signal optimisation is mostly based on the price signal from the electricity markets. Nevertheless, this optimisation has some constraints, especially energy storages minimum SOC level and other user-defined constraints for the EVs. However, the price signal optimisation correlates well with load curve optimisation while minimising load transitions, because the night-time hours are mostly less expensive and has less power consumption than daytime hours. The ideal effect of the load curve optimising by minimising load transitions and price signal optimising is presented in Fig. 4.

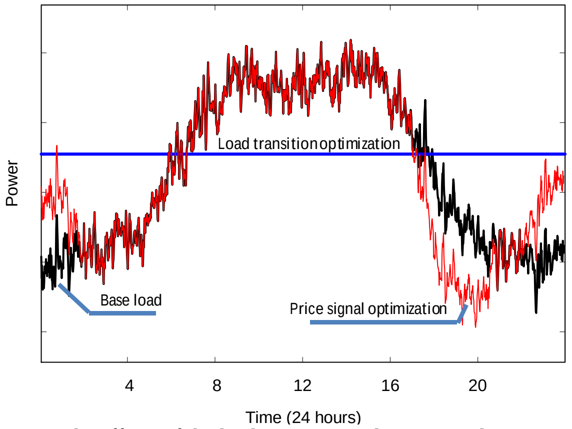

Fig. 4. The effects of the load transition and price signal optimisation to the base load curve.

Island mode

Firstly, entering the island mode fluently in larger scale is a challenging goal. Setting up the micro grid immediately after the fault has been detected in the distribution grid needs fast acting power sources and controllable loads. However, our first target in Smart Grid system is to be able to transit into island mode by using a softer start for the micro grid even if it takes a longer time span. That is, before the grid is disconnected from the distribution grid, the EMS balances consumption and production. After disconnection, the battery pack takes responsibility from the fine tuning of the quality and the stability of the micro grid. The disconnection from the distribution network will be done with a remote controlled switch.

Because the energy consumption can be higher than the energy produced by the distributed generators, the system must be able to bring down the micro grid softly after the energy storages are low. That is how the risk of damaging the electric devices during the shutdown can be minimised. In addition, the communication gateway for the Smart Grid gets cut off after the shutdown. Therefore, the micro grid system must be able to simultaneous shutdown all the energy sources.

Island mode optimisation

The main target in the transition to the micro grid is to keep primary loads online. This means that the load curve and price signal optimisations alter to the load minimising optimisation. However, if the micro grid has enough distributed generation, the EMS can optimise between energy storage usage and load control. The duration of the operation in island mode is usually unknown and thus the default method is to minimise the discharging of the energy storages.

DISCUSSION

The aim of the Green Campus Smart Grid project is to have an open smart grid environment for research purposes. The uniform interface for all the Smart Grid units allows easy implementation of additional units to the Green Campus Smart Grid environment. An open interface for the optimisation and modifications gives great opportunity for different researches.

REFERENCES

[1] M. Hashmi, 2011, “Survey of smart grid concepts, architectures, and technological demonstrations worldwide”, *IEEE PES Conference on Innovative Smart Grid Technologies*, 1 - 7

[2] P. Hallberg and et al, 2009, "Smart Grid and Networks of the Future - EURELECTRIC Views", *EURELECTRIC*, Ref. 2009-030-0440

[3] P. Stangierski, 2011, “Smart grid ready concept”, *8th International Conference on the European Energy Market (EEM)*, 40 – 44

[4] T. Lyon, 2012, “Is “smart charging” policy for electric vehicles worthwhile?”, *Energy Policy*, volume 41, 2012, 259-268

[5] T.L. Vandoorn, 2011, “Active Load Control in Islanded Microgrids Based on the Grid Voltage”, *IEEE Transactions on Smart Grid*, 2011, 127 – 139

[6] J.M. Guerrero, 2010, “Distributed Generation: Toward a New Energy Paradigm”, *Industrial Electronics Magazine*, IEEE, 52-64

[7] J. Lassila, 2009, “Electric Cars – Challenge or Opportunity for the Electricity Distribution Infrastructure?”, *European conference Smart Grids and E-Mobility 2009*

[8] P. Nuutinen, 2011, “Implementing a laboratory development platform for an LVDC distribution system”, *IEEE International Conference on Smart Grid Communications (SmartGridComm)*, 84 - 89

[9] H. Makkonen, 2010, “Battery charging and discharging in automotive applications – Laboratory pilot”, *2nd European Conference Smart Grids and E-Mobility 2010*