GREEN CAMPUS – SMART GRID

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ASBTRACT

The aim of this paper is to introduce implementation of smart grid technologies in Green Campus Smart Grid (GCSG) project in Lappeenranta University of Technology. The main objectives of the GCSG project are to realise a fully functional smart grid environment, to demonstrate the operation of different smart grid functionalities and to provide platform for further research and development of smart grid systems.

The GCSG consists of DG-units (Distributed Generation), energy storages, demand control system and energy storage control system. Furthermore, the system comprises a communication based intelligent protection system for safe island operation. All the components of the GCSG system interact with each other, end-users and external systems through common interfaces, allowing for instance intelligent charging and V2G-operation (Vehicle to Grid) of compatible electric vehicles. The core of the system control is an Energy Management System (EMS). Therefore, the Green Campus project offers an open research platform for several key functionalities of the smart grid environment.

1. INTRODUCTION

The smart grid concept is widely discussed issue to solve problems with growing energy consumption, distributed generation installation, energy efficiency, power supply reliability and power quality [1]. Publications about smart grid concepts and pilots, distribution generation in smart grid and electric vehicles in smart grids have been presented for example in [2-6]. However, smart grid also produces new challenges, especially in the area of power balancing and protection [7]. Power balance in a small islanding household is more challenging to achieve than in large scale micro grids. The smaller the micro grid, the higher is the significance of unpredictable random load variation inflicted by the occupants. With low base load level, the impact of load variation is more significant and can cause the micro grid to fall. When the size of the micro grid grows to hundreds or even thousands of electricity end-users, the effect of the random load variation diminishes and the behaviour of the base load starts to dominate. Furthermore, the internal damping in the system increases along with the system size. In this case, the operation of the micro grid power system starts to resemble the operation of the conventional large scale power systems. In small micro grids large changes in the state of the system are more probable than in the large systems and internal damping is very low or does not exist at all. Thus, the time constants of the micro grid control system, already from the random load variation perspective, have to be significantly shorter than in large power systems.

Moreover, renewable energy sources as the main power supply does not ease-up the situation. Creation of local micro grids truly calls for intelligent “smart grid”, enabled by such technologies as central energy management systems, communication between the electric devices or independent intelligence integrated in the electric devices, and of course support given by energy storages. The energy management system and communication makes possible the prioritisation of the loads, fast power balance corrections and optimisation of the use of energy storages.

The implementation of the Green Campus Smart Grid utilises the experience from the installations and technical solutions made for a LVDC (Low Voltage Direct Current) laboratory pilot in Lappeenranta University of Technology [8, 9]. The goal of the implementation phase is to integrate smart grid elements in an existing customer-end low voltage network. The implementation work is divided into three main parts; interconnection of wind and solar generation (1), introduction of electric vehicles (EVs) and static battery energy storages as well as demand response (2), implementation of intelligent system control optimising the use of energy sources based on market situation, technical constraints and end-user needs. The GCSG system can optimise its internal consumption, interact with electric vehicles, accept versatile distributed generation units and operate in island when necessary. The basic concept and the units of the Green Campus Smart Grid are presented in former publication [10].

In this paper, the Green Campus Smart Grid environment and control methods are presented. The main target of the paper is to introduce the communication structure of the GCSG. The control of the Smart Grid units is based on the TCP/IP protocol and the information from the Smart Grid units is stored to a database. In addition, basic control objectives and interfaces of the SG-units are represented.

The structure of the paper is following. Section 2 of the paper covers the basic structure of the Green Campus Smart Grid, followed by the presentation of the basic control objectives and interfaces of the SG-units. Section 4 introduces the communication and control structure of the GCSG. Finally, section 5 concludes the paper.

2. GREEN CAMPUS SMART GRID

The Green Campus Smart Grid consists of DG-units, energy storages, demand control system and Energy Management System. Every SG-unit has its own Smart Grid interface, which enables common protocol between the EMS and the SG-units. The EMS gathers required information from the SG-units via Ethernet connection. The information is collected into a database of the EMS, enabling optimisation of the SG-units. The Green Campus Smart Grid is implemented in an existing low voltage customer network in Lappeenranta University of Technology. The case concept of Green Campus Smart Grid is presented in Fig. 1.

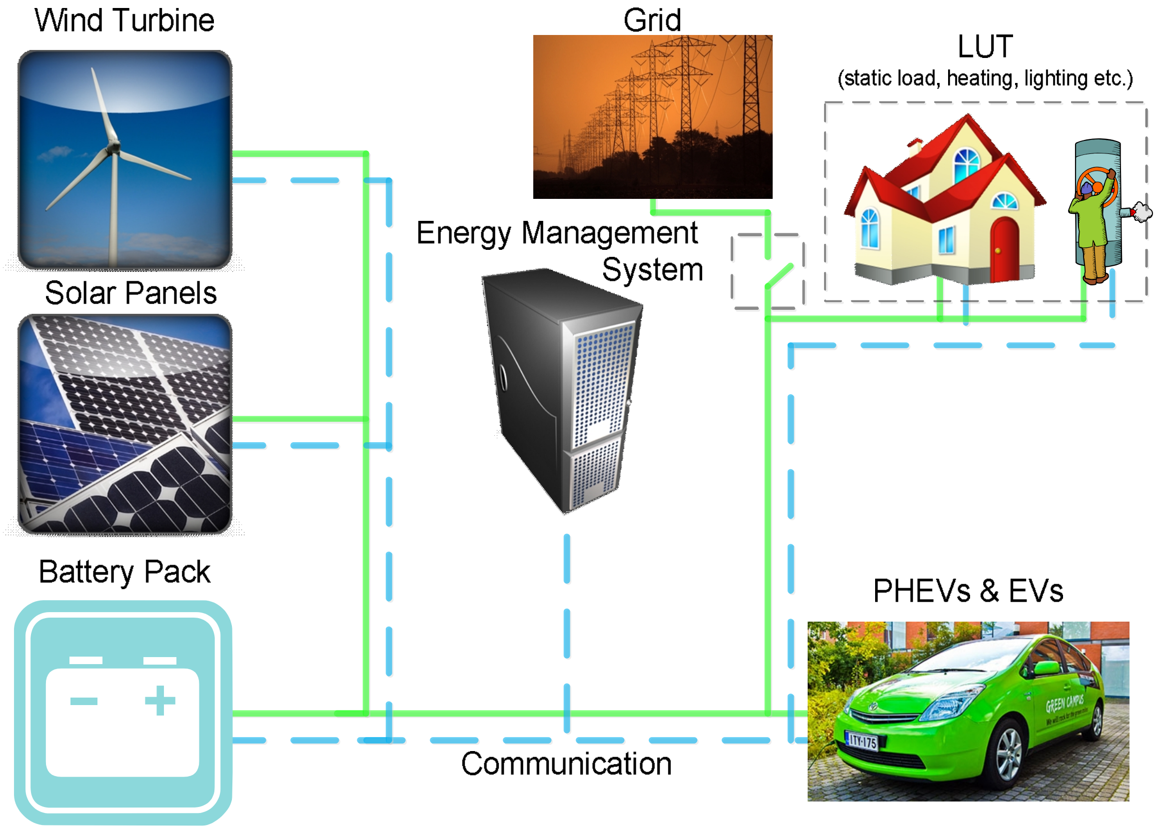

Fig. 1. The case concept of Green Campus Smart Grid environment.

The communication is implemented via Ethernet connection. The most important SG units, such as the generators, EVs and energy storages (battery management systems – BMS) and most important controllable loads are connected to the EMS as directly as possible through optical fibre network. Furthermore, the optical fibre network is used for realising system protection especially in the case of island operation (differential line protection, locking of anti-islanding protection when islanding is allowed, etc.). Hence, the faults in the distribution grid do not affect the communication of the GCSG. Furthermore there is also backup connection from protection purposes realised with copper cables. The existing LAN of the university building complex is also used for controlling loads outside the island operatable demonstration grid, expanding the micro grid to include the whole low voltage network of the university. The LAN is also used for presenting information of the operation of the GCSG on info-screens to be installed on main halls.

2.1 Smart Grid units

The GCSG environment contains four basic SG-units: DG-units, loads, energy storages and an energy management system. In the GCSG, these units technically are loads, controllable loads, wind turbine, solar panels, electric vehicles, energy storages and energy management system. However, EV can be also listed as a DG-unit or as an energy storage if it has V2G-option (Vehicle to Grid). The SG-units are controllable by a common gateway interface, which excludes some of the loads. The excluded loads are basically manually controlled loads.

Controllable loads:

- Heating of laboratory hall (can also be used as additional artificial load during island operation if needed in summer time)
- Corridor lights
- Outdoor lights
- EV charging points (cars + bicycles etc.)
- Air conditioning and exchange (need air quality monitoring)
- Hot water (not implemented now, but plans exist)
- Car engine heater poles (possible implementation)

2.1.1 Energy Management System

The Energy Management System (EMS) handles the control of the SG-units based on the information about the SG-units in the EMS database. With a common interface, the EMS can use the same command protocol for all of the SG-units. The EMS includes an optimising algorithm, exploiting database containing information supported by the SG units (Smart Grid). The database contains necessary data from DG-units, energy storages, controllable loads and load demand for optimising the usage of the smart grid units. Hence, the GCSG system is able to control consumption and cut consumption peaks by controlling loads and energy storages. With the real time data from the SG units, a part of the system – so called demonstration grid – can also operate in an island mode, maintaining the power balance with the energy storages, demand response and generator control. However, the optimisation algorithm can be modified for different schemes with a different coefficient for the optimisation methods.

The data of the SG-units needed for the optimisation differs accordingly to the type of the SG-unit and also different brands and models have different kinds of data available. This produces problems with the specifications of the database, making it harder to form correct database section for the SG-units. Therefore, the database is maintained by the EMS but the data is uploaded to the database directly by the SG-unit interface. This enables the SG-unit interface to form correct database section for the specific unit. Even though it requires more functions from the SG-unit interface, the interface has been modified to operate with the certain SG-unit, already containing information of the available data from the SG-unit. The communication structure concept in Green Campus Smart Grid is illustrated in Fig. 2.

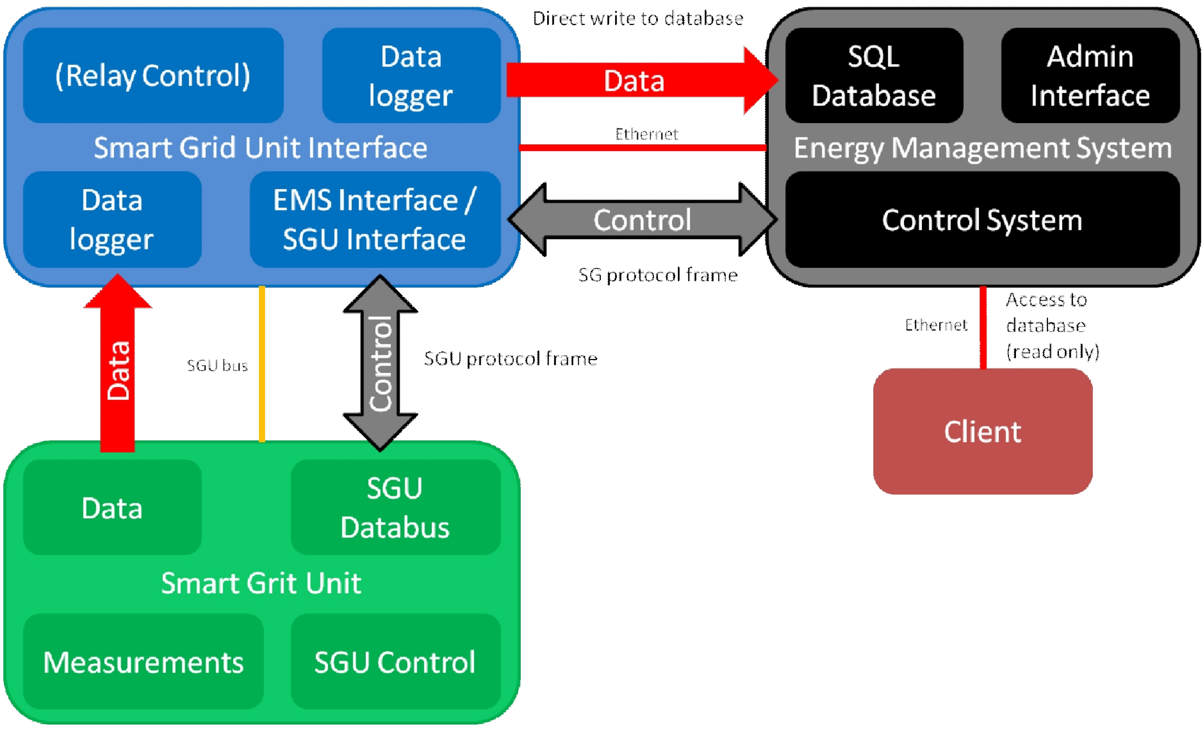

Fig. 2. Concept of the communication structure between the EMS and the SG-units.

The database of the EMS is implemented with SQL (Structured Query Language). The database is updated periodically by the SG-units and the EMS processes the uploaded data in and optimises the GCSG operation based on that. The database also contains information about load curves forecasts, previously realised load curves, electricity price and also forecasts for the wind turbine and solar panel system. The database can also be accessed for reading by a separate client, which allows reviewing the operation of the GCSG remotely.

2.1.2 Distributed Generation

The main DG-units in the GCSG are wind turbine and solar panel system. An EV with the V2G-option as well as energy storage can be also classified as a DG-unit, but the EMS in the GCSG environment handles them as their own classes. The DG-units has important part of the GCSG concerning island operation. The EMS can maintain the island with the real time data from the SG-units, and energy production in this operation mode is especially important. Even though the DG-units are not responsible for the power balancing in the GCSG, stable energy production in island operation is desirable.

The static battery pack (total capacity of 36 kWh) is responsible for the fast and fine power balancing of the Smart Grid. The maximum consumption of the Smart Grid environment will be 50-80 kW and the battery pack is capable of producing temporary power of 200 kW. Hence, the static battery pack can provide enough power for whole Smart Grid for a short period of time. The rated power of the wind turbine is 20 kVA and solar panel system 20 kVA, making it possible to sustain island operation in the GCSG longer period of time in ideal conditions. With the help of load controlling and load prioritising, the duration can be further increased.

The PHEVs and EVs can have also possibility to discharge their batteries to the grid. The combined energy of the EVs currently available for the GCSG is 30 kWh. However, the main purpose of the EVs is to use it to travel between places, making it possible that the EV is unavailable for the GCSG. Also user definitions about the charging time or minimum SOC (State Of Charge) in discharge can restrict the usage of the EV as a distributed generator unit. However, the EV in the GCSG has integrated interface for user to define the time when charging should be ready. This allows the EMS to optimise the usage of the EVs as energy storages.

2.1.3 Load management

The Green Campus Smart Grid environment has three kinds of load classes: load, controllable loads and energy storages. The normal loads cannot be controlled but the rated powers of the static loads are predefined in the EMS database. Controllable loads have simple interfaces for the connection to the GCSG, allowing the EMS control the loads through the common interface. Energy storages can be also considered as loads as well as distributed generation units. EVs operate more likely as a load than as a distributed generator unit, whereas static energy storage operates the same time as a load as a DG-unit.

The static energy storage interface is the most complicated because it is responsible for the power balancing of the GCSG. The static energy storage's interface must be able to handle specific power rate demands from the EMS. The EV interface consists of two separate units. The EV has integrated interface onboard, which acts as a user interface and charge mode management system. The EV interface is connected to the CAN (Control Area Network) gateway of the car and to the BMS (Battery Management System), and handles the control of the charge modes (idle, charge and discharge). Second interface is implemented in the charging pole, enabling communication between the EMS and the EV. The most important function of the charging pole interface is to offer an interface between the EMS and the electric vehicles. Even though the EV interface could be modified to operate directly with the EMS, the interface between the charging pole and the EV can have benefits in the future. The interface can be freely modified to offer upcoming standardised interface for the commercial electric vehicles.

The control of the loads can be based on the load curve optimisation, load prioritising, price signal optimising or island mode optimising. Nevertheless, the EMS controls the loads based on the priority list, predefined in the EMS database. The priority of the SG loads needs to be set manually to correspond to the specific SG-unit identification number (ID), therefore priority specification being only required action for new SG-units from the EMS point of view if the new unit fits in existent SG-unit type.

2.2 Communications

The SG protocol frame between the EMS and SG-unit interface is common between all the SG-units. However, the SGU protocol frame differs accordingly to the type, brand and model of the SG-unit. For example, the PHEV (Plug-in Hybrid Electric Vehicle) has an integrated Smart Grid interface enabling the SGU protocol being defined and modified freely, whereas wind turbine SGU protocol is based on the supplier's Profibus protocol. Customisation of the SG-units' interfaces makes the structure of the interface more complicated but simplifies the EMS interface. Thus, the EMS is able to have a common interface between every SG-unit.

The most important data for the EMS is current power or rated power of the SG-units. The power information can be real time data or in advance specified rated power for the specific SG-unit. The database section of the SG-unit can contain more information of the unit for research or additional control purposes, but the optimising of the GCSG requires only a part of the unit's data. The needed data depends on the type of the SG-unit. Required basic data from the SG-units are presented in Table 1.

Table 1. Required basic data from the different types of SG-units (x = not available, v = available, - = unknown).

ID	TYPE	STATUS	POWER	RATED POWER	SOC	ENERGY	<DATA>
00xxx	Load	x	x	v	x	x	-
10xxx	Controllable load	v	x	v	x	x	-
20xxx	Distributed generation	v	v	v	x	x	-
30xxx	EV	v	v	v	v	v	-
31xxx	EV with V2G	v	v	v	v	v	-
40xxx	Energy storage	v	v	v	v	v	-
50xxx	<Specific unit>	-	-	-	-	-	-
…	…	-	-	-	-	-	-
yyxxx	…	-	-	-	-	-	-

Controlling of the SG-units is determined by the identification number. The two first numbers of the ID specifies the type of the SG-unit. The last three numbers gives unique identifier for the SG-unit. The ID number consists from five hexadecimal numbers, allowing of connecting 4094 (excluding Ids yy000) SG-units of the same type. However, large number of SG-units will cause problems with the database. The control commands are common for certain types of SG-units and the EMS can identify the possible commands for the SG-unit by the ID number. The concept of basic commands based on the ID is presented in Table 2.

Table 2. Basic commands types available for the EMS based on the SG-unit ID (x = not available, v = available, - = unknown).

ID	TYPE	ON/OFF	IDLE	CHARGE	DISCHARGE	<COMMAND>
00xxx	Load	x	x	x	x	-
10xxx	Controllable load	v	x	x	x	-
20xxx	Distributed generation	v	v	x	x	-
30xxx	EV	v	v	v	x	-
31xxx	EV with V2G	v	v	v	v	-
40xxx	Energy storage	v	v	v	v	-
50xxx	<Specific unit>	-	-	-	-	-
…	…	-	-	-	-	-
yyxxx	…	-	-	-	-	-

Table 2 present only basic commands of the SG-units. For example, the energy storage's commands are more complex regarding the charge and discharge commands. The EMS can give specific power rate for the energy storage for charging and discharging, whereas EVs has constant power rates. If the SG-unit has more functions compared to other similar units, it can be inserted to the command table. However, the basic commands are needed only for the EMS to control the power balance and consumption, and the additional commands are more likely to be used with a separate interface. This case is possible i.e. for wind turbine, which can be set to accept remote torque instructions instead of automatic rotation speed control.

The control is based on TCP/IP protocol with a predefined control frame. When the SG-unit is connected into the GCSG, the Ethernet connection is operational and open all the time. At the connection, the SG-unit sends the ID of the unit to the EMS, allowing the EMS to identify and verify the connection. Therefore, if there is any kind of faults in the communication line, the EMS notices the disconnection of the SG-unit and can react to the situation.

The open connection also allows the EMS to have a real time list of the SG-units connected into the Smart Grid. The Ethernet connection is made only by the SG-unit, leaving the unit responsible for restoring the connection when necessary. The SG-unit is set both to form the connection and the database section for itself into the EMS. This aids at adding new SG-units to the system.

2.3 Control of the Smart Grid

The EMS optimisation algorithm is responsible for the control of the SG-units. Optimisation of the control can be approached from several different points of views, but the basic functions are load control and energy storage control. The DG-units are ideally producing maximum amount of available energy and the real need of shutting down the DG-units can be only occur while operating in island mode (overproduction) if faults are excluded.

The GCSG has three basic optimisation principles: load curve optimisation, price signal optimisation and island mode optimisation. Load curve optimisation can be used for reducing consumption peaks, reduce load transitions, shifting consumption or prioritise certain loads. Price signal optimisation responses to electricity price alteration, reducing or increasing the consumption accordingly. Island mode optimisation aims only for sustaining the micro grid in balance.

Entering the island mode fluently from the distribution grid failure is one of the most challenging issues. The micro grid switch must operate automatically if a fault in the distribution grid occurs and disconnect the GCSG from the distribution grid. This requires the ability to sense the possible faults in the distribution grid. At the same time with the distribution grid failure the EMS must adjust the power balance roughly, so that consumption meets production on some level. The accuracy is determined by the amount of "dumb" loads (ID 0yxxx) in the system, because the statuses of these loads are unavailable by the EMS. Hence, the static energy storage is responsible for the stability and fine tuning of the micro grid. The information about the disconnection from the distribution grid is send immediately to the energy storage interface, informing the static energy storage to take responsibility for the stability of the grid.

After the failure in the distribution grid, the GCSG must be able to connect back to the distribution grid. This requires frequency synchronising of the GCSG with the distribution grid. Frequency adjustment can be easily made by the energy storage's inverter, but the challenge is to secure that the frequency information from the Smart Grid and distribution grid are time synchronised.

3 CONCLUSIONS

In this paper, the Green Campus Smart Grid environment is presented. The GCSG is a demonstration grid of smart grid concept in low voltage customer network. The GCSG is used for developing and researching smart grid technologies, enabling smart charging, load controlling, distributed generation, grid optimisation and island operation. The focus of this paper is the communication structure and control objectives of the GCSG environment. The communication is based on the Ethernet connection between the EMS's and SG-units' interfaces. The information of the SG-unit is inserted in the EMS database, and the control of the SG-units is implemented with TCP/IP protocol. The SG-units has unique identifiers, which allow the EMS to identify the type of the SG-unit. The EMS can optimise the usage of the SG-units with the information in the database. In addition, the GCSG can detach from the distribution grid and sustain itself for a period of time.

The aim of the GCSG project is to have fully operational smart grid environment, which can optimise consumption of the Smart Grid, interact with electric vehicles, accept distributed generation units and operate in island when necessary. Moreover, the GCSG allows information for the research purposes from many different SG-unit and open interface for developing and testing.

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