# Stabilization of grids with significant deal of renewable energy sources

**František Zezulka, Petr Marcoň, Ondřej Sajdl, Ivo Veselý, Zdeněk Bradáč**
**Center for Research and Utilization of Renewable Energy, Brno University of Technology**
**Technická 3082/12, Brno 61600, Czech Republic**
**zezulka@feec.vutbr.cz, macron@feec.vutbr.cz, sajdl@feec.vutbr.cz, veselyi@feec.vutbr.cz, bradac@feec.vutbr.cz**

***Abstract***

Contribution deals with modelling of smart grid with significant ratio of renewable energy sources. The physical model of an integrated smart grid – smart metering system (SEM) enables modelling of different control strategies. Due to the Energy Efficiency Directive of EU Commission, Article 15.8, authors have applied the Demand response principle for demonstration of advantages of the dynamic rates for not only financial profit for individual small energy consumers, but as well as for the stability of smart grids with significant ratio of renewable energy sources.

In the contribution there is specified technical solution of the smart grid part of the SEM, a simulated smart metering subsystem, a principal of modelling of remote energy sources, a principal of utilization of information from weather forecast for smart grid control and a way how to integrate the demand response idea into the grid control strategy.

## 1 Introduction

Recent development in renewable energy sources is a reality. Therefore it is needed so that the society accepts this development and will be able to adapt its energy policy to these sources that don't exhausts non - renewable natural energy sources. It requires a greater adaptability and willingness to change existing style of thinking from the side of official authorities, professional associations as well as from the side of specialists from the energy branch. An example of the small and non - sufficient adaptability of specialists from the energy production and distribution branch is an approach to the Energy Efficiency Directive of EU Commission, Article 15.8. This directive of the EU Commission deals with the issue Demand side Response of energy consumption, shortly Demand Response principal [1].

Authors are convinced, that a great part of colleagues from the energy branch and a great part of the public had not red that directive and are not familiar with it at all. But according information from the USA each small energy consumer could financial profited if the Demand Response system would be realized in his country. The aim of this contribution is therefore to present a model, which demonstrates this principle and shows possibilities how to use the principle and what is needed to its realization and which profit for individual consumers as well as for the national energy could be achieved.

In the contribution there is presented a system Smart Energo Model (SEM), what is in principle a physical simulator of a smart grid, supplemented by a model of a smart metering subsystem. In the upper control layer there is implemented the Demand Response principle. Shortly the Demand Response principle is the distributed control system of energy consumption that uses for the energy control commands from a central supervisor station as well as from energy consumers. Authors show [2], that such a system could contribute not only to financial profit of small energy consumers, but as well as to a higher stability of grids with significant ratio of renewable energy sources in case, that a dynamic rates for energy will be implemented. System Demand response legalizes only this idea and specifies the dynamic rates as the main motivation tool for cooperation of energy producers and distributors on one side and energy consumers on the other side.

In the contribution there is described firstly the physical model of the smart grid with significant ratio of renewable energy sources and its HW solution. In the part of control algorithms there is applied the demand response principle. The function of the SEM enables to demonstrate the influence of demand respond principle on the stability of SEM.

## 2 Demand side response of the energy consumption

### *2.1 Definition of Demand Response (DR) [1]*

Demand side response [1] are programs and activities designed to encourage consumers to check their Electricity Usage Patterns including timing and level of electricity demand, covering all load shape and customer objectives. Demand Response includes time of use and dynamic rates or pricing, reliability programs such as direct load control of device and instantaneous interruptible load, and other market options for demand changes, such as demand side bidding's resources. This enables customers to consume more electricity then the large amounts of wind generation are available for example, and whole sale prices are low.

Demand Response (DR) includes loads, storages, as well as distributed (behind the meter) generation; the latter includes emergency (back - up) generation and/or cogeneration (CHPs). It normally enables a reduction in load, but in fact, can act as a flexible resource either decreasing or increasing consumption, as may be needed for certain balancing services or for the deployment of intermittent resources. This enables customers to consume more electricity when large amounts of wind generation are available for example, and wholesale prices are low.

The European Commission has demonstrated strong support for Demand Response. This is reflected in The Third Energy Package, which requires network operators to take the potential of Demand Response and energy efficiency into account when planning system upgrades. Article 3.2 in [1] also states “In relation to security of supply, energy efficiency/demand side management and for the fulfilment of environmental goals and goals for energy from renewable sources, Member states may introduce the implementation of long term planning, taking into account the possibility of third parties seeking access to the system. This language has now been strengthened further within the Energy Efficiency Directive (EED).

### *2.2 Regulatory requirements for Enabling Demand Response*

The organization SEDC of a lot of EU firms and organizations worked out 10 guidelines for enabling Demand Response participation, in the wholesale, balancing and other system services markets [1]. These have been categorized into four criteria:

1) Enabling consumer participation in Demand Response.
2) Create products.
3) Develop measurement and verification requirements.
4) Ensure fair payment.

### *2.3 Specification of 10 guidelines for enabling Demand Response*

The 10 guidelines correspond to the fourth criteria as following roles:

**Criteria one: Enabling consumer participation in Demand Response**

Rule 1: The participation of aggregated load should be legal, encouraged and enabled in any electricity market where generation participates.

Rule 2: Consumers should have the right to contract with any demand response service provider of their choosing, without interference.

Rule 3: National regulators and system operators should oversee the creation of streamlined, simple contractual and payment arrangements between retailers, BRPs and aggregators. These should reflect the respective costs and risks of all participants.

Rule 4: The aggregated pool of load must be treated as a single unit and the aggregator be allowed to stand in the place of the consumer.

**Criteria two: Create Products**

Rule 5: Create standard products that allow a range of resources to participate, including demand side resources.

**Criteria three: Measurement and Verification**

Rule 6: Establish appropriate and fair measurement and communication protocols

Rule 7: Ensure Demand Response services are compensated at the full market value of the service provided

Rule 8: Create market structures which reward and maximize flexibility and capacity in a manner that provides investment stability

**Criteria four: Payment and risk**

Rule 9: Penalties for noncompliance should be fair and should not favor one resource over the other

Rule 10: Create and enforce requirements for market transparency within the wholesale and balancing market

## 3 Technical specification of the smart energo model

Smart Energo Model (SEM) is a HW integration of a laboratory smart grid, a simulated smart metering system and a physical simulator of energy consumption. The system SEM is depicted in the Fig. 1.

Small power plants utilizing renewable energy sources are connected to a grid. Some of these power plants are placed within the Laboratory of Automation, where the SEM is located [3]. Firstly, there is a PV panels, which are situated on a roof of the building.

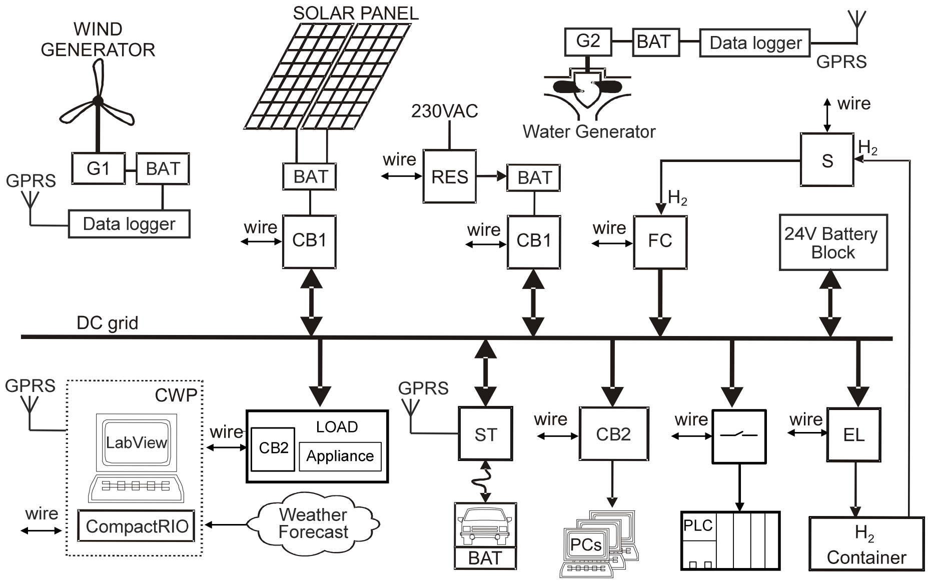


*Fig. 1: Diagram of the SEM*

Other plants must be placed in other locations from practical reasons [4]. Electrical energy (power) of these remote energy sources is produced and measured far from the Laboratory of Automation and the measured data of the power and this information are translated via wireless datalogger to the central control station of the SEM.

The physical equivalent of the energy produced in remote power plants is physically simulated by the controlled power box RES, which is situated in the laboratory of Automation (Fig. 1) and connected into the SEM by means of the boxes CB1 (Fig. 2). The RES box is controlled by a Compact RIO control system according the information from wireless datalogger which is situated near the remote energy source to measure its power Pi.

The thick lines in the Fig. 1 represent material and energy flows, dashed lines represent wireless communication links. Each power control device (CB1, CB2, RES) communicates with the Central control station (CCS) physically through input / output circuits via wired connections in the laboratory. These non-power control connections are not indicated in Fig. 1 for better clarity of the Fig. 1.

The Compact RIO controls flows of energy from different energy sources and control the energy consumption as well. This CCS system can determine the power from different resources simulated power plants. The SEM has to work according the "energy law"

$$\sum P_i = 0, i = 1, 2, \ldots, n \qquad (1)$$

Where $P_i$ is a power delivered by a power source or consumed by appliance.

The remote resources supplying energy to SEM (simulated by the RES) are wind and water turbine, the really physical power plants connected physically to the grid are the fuel cell and solar panels. Each of resource supplies the SEM with approximately 200 - 300 W peak. Given the simplicity of physical realization, safety experiments and low cost, the SEM works with 24 V DC of the energy excesses are stored in electric car batteries. The designed SEM has at its disposal number of batteries for an each individual power source instead of large centralized battery storages. Although the storage of electrical energy into hydrogen seems to be a less promising, a hydrogen fuel cell (FC) (one metal-hydride container as a hydrogen storage) will be integrated into the SEM. in order to realize a. peak energy source [5].

The energy consumption from the grid is controlled by the Compact RIO control system and by the CB2 box.

The described smart grid part of the SEM is connected with the smart metering one [6]. The smart metering and consumption control represents a typical small energy consumer who will participate in the smart energo system utilizing demand response principals. Depending on the cost of energy the individual consumer in cooperation with the central control station will switch on or switch off big electrical appliances in the household or in general “control” their consumption.

### 3.1 Communication and Control devices and instrumentation of the Smart Energo Model (SEM)

The data transfer from the remote energy sources is realized with a GSM data logger. Power meters of these sources are located near the water and wind power plant and instant power data is transmitted wirelessly (GPRS) to the central control station (CSS) with Compact RIO. The laboratory uses wired connection - RS 232 (RS 485) or Ethernet – among each controlled power controller (CB1) and control appliance blocks (CB2).

Physical model of all remote renewable energy sources (RES) is simulated with the QPX 1200 SP 1200W DC Power Supply which represents a common physical source (with the exception of PV source and the fuel cell). The battery of the RES has to be connected with the grid via developed control block CB1 which is directly physically connected to the SEM.

Control block CB1 [2] is a controlled bidirectional power switcher. It enables pump a power from and to the grid because of the equation. (1).

Control block CB1 consists of a controlled DC / DC converter for voltage adjustment (upward) and the power from local 12V batteries (which can be 8 to 14 V DC according a current recharge level). Based on information from the meter (IS) the Compact RIO in the CCS control system regulates a voltage and controls the CB1 power supplied into the SEM. This power corresponds with power of the remote energy source or from the PV panels.

For a case when the energy supplied to the SEM is greater than a total consumption of the SEM, an each current regulator (CB1) is equipped with a controlled battery charger SE. According to the chosen algorithm, the SEM is charging batteries with controlled power until a selected recharge level is reached.

Another physical SEM source is a fuel cell (FC). The fuel cell (FC) is connected via its own voltage regulator and a power regulator to the SEM.

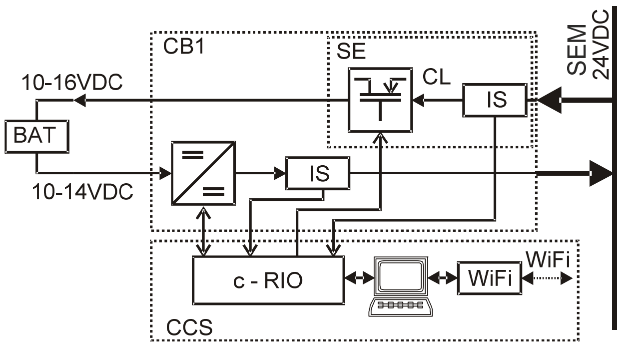


*Fig. 2: Diagram of controlled power controller CB1.*

### 3.2 Controlled system of consumption

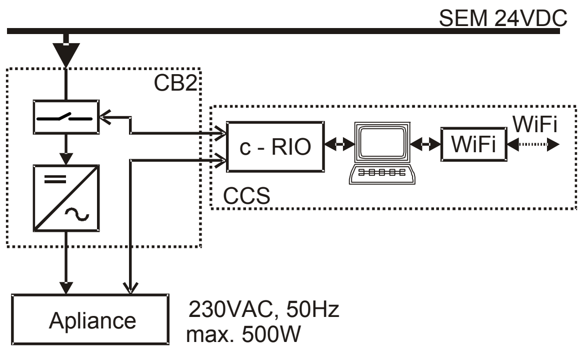


*Fig. 3: Control unit CB2 of appliance.*

In the Fig. 1 there is shown what can be involved in the controlled system consumption. Firstly it is the instrumentation of the laboratory - programmable Logical Controllers (PLCs), with the 24V DC supply, therefore, they are connected via CB1 (DC/DC converter. After that it is lot of PCs, which are connected via non-controlled DC/AC converter and in the future we plan to design, realize and connect a model of an e-car supply station ST. The last one will be equipped by a controlled double current direction ST to have a possibility not only to charge e-cars batteries, but also to take energy from e- car batteries in case of energy deficiency in the grid.

For purposes of the promised main aim of the contribution – the Demand response idea demonstration - the Controlled system of consumption is equipped by a control load device the STARTRON Electronic Load Type 3229 (LOAD), which enables more then 50A load on the 24V. The Electronic Load is controlled by the CCS according a smart control algorithms and enables physical simulation of the all energy consumption of simulated typical small energy consumer(s).

## 4 Control strategy of the CCS

CSS has several functions. Firstly it is establishment, assessment and saving of the wireless communication with dataloggers of remote energy sources (water and wind turbines), next the communication among devices connected physically with the grid (CB1, CB2, EL and all the hydrogenous network and the RES simulator). The other function of the CCS is a control of the grid according eq. (1) in real time. Next function is receiving and assessment of data from internet servers of weather forecast, assessment data in a predictive module of the control program and generation of appropriate action of CB1, CB2, LOAD. Next function of the CCS is data acquisition from the smart metering subsystem in order to correct the table of the expected and planned energy consumption and use the information about the dynamic tariff. Due to it, that in SEM we can free apply a dynamic tariff, the logical algorithm for the dynamic tariff is applied: the more energy is in the grid, the lower tariff. And it is a real application of the demand response principal, while it has sense for consumers to move energy consumption of bigger appliances into the time of lower tariff.

The predictive algorithm and on –line data processing of the actual as well as future amount of energy in the grid utilize information from weather forecast and enables a smart strategy of small consumers as well as center of producers and distributors.

The hierarchical structure of the control SW is in the Fig. 4

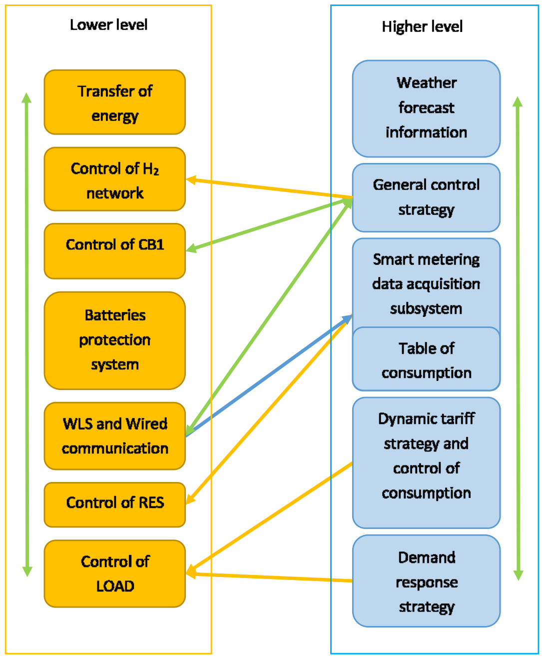


*Fig. 4: Structure of the SEM control and data acquisition.*

For modeling purposes of the demand response principle was defined a table of energy consumption of a typical household Tab 1, where are values of expected (requested) consumption during one typical day. According to the Tab.1 the control algorithm of the CCS gives into the eq. (1) values of the immediate consumption and of the amount of energy which will be requested in longer period. The algorithm also defines the tariff (from the immediate as well as predictive lack or access of energy in the grid) and switch on or switch off the appliances. Instead of the smart metering subsystem which is not realized in the SEM, the Tab.1 is used.

*Table 1: Energy consumption of appliances per day.*

| Applience | Power[kW] | Hour in day | | | | | | Runetime [min.] | Frequency per day |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | | 21 | 22 | 23 | | |
| Washing mashine | 3 | 0 | 0 | | 0 | 0 | 0 | 150 | 1 |
| Dishwasher | 1,5 | 0 | 0 | | 0 | 0 | 0 | 72 | 0 |
| Fridge | 0,5 | 1 | 1 | | 1 | 1 | 1 | 10,2 | 24 |
| Freezer | 0,5 | 1 | 0 | | 0 | 1 | 0 | 7,5 | 12 |
| Oven | 2,5 | 0 | 0 | | 0 | 0 | 0 | 120 | 0 |
| Iron | 0,7 | 0 | 0 | | 0 | 0 | 0 | 120 | 0 |
| TV1 | 0,2 | 0 | 0 | ... | 1 | 1 | 1 | 60 | 4 |
| TV2 | 0,15 | 0 | 0 | | 0 | 0 | 0 | 60 | 5 |
| Radio | 0,02 | 0 | 0 | | 0 | 0 | 0 | 90 | 2 |
| PC | 0,25 | 0 | 0 | | 1 | 1 | 1 | 60 | 14 |
| Notebook | 0,07 | 0 | 0 | | 1 | 1 | 0 | 60 | 4 |
| Light 1 | 0,04 | 0 | 0 | | 1 | 2 | 1 | 5 | 7 |
| Light 2 | 0,06 | 0 | 0 | | 1 | 1 | 0 | 60 | 3 |
| ⋮ | ⋮ | ⋮ | ⋮ | | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |

In the next period of the SEM development the smart metering model will be realized including distributed smart electrical sockets and a central smart meter. This system will enable correction of the Tab.1 by actual as well as historical data about the consumption or a total replacement of the Tab.1 by real – time information from the smart metering subsystem.

## 5 Conclusion

Paper shows physical realization of the smart grid model (SEM). The SEM is a model of smart grid with significant deal of renewable energy sources combined with intelligent control due to information from a smart metering subsystem. There are connected the simulator RES of remote energy sources (water and wind turbines), PV panels, the fuel cell, the electrolyzer in the SEM. The SEM enables modelling of different strategies of the grid control and application and demonstration of the demand response principle. The energy consumption is physically simulated by a controlled load (LOAD). The control system of the SEM has two levels and is realized by the Compact RIO control system. The control SW is programmed in LabView. The low level control system provides firstly protection of batteries, control of grid devices (CB1, CB2, RES) and control of the energy flow from local to the central batteries and vice versa. The higher control level utilizes information from internet server, due to the demand response principle defines the dynamic rates and according the energy score in the grid and requested consumption data from the Tab.1 (applied instead of a physical smart metering model) controls the energy consumption. Authors plan to realize a physical model of a full smart metering subsystem in a near future.

## 6 Acknowledgement

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## 7 Literature


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