Investigation of best practices in building of smart homes control systems

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***Abstract*—this article presents the methods used in smart home control systems in the integration of renewable energy sources (RES), battery storage, and other electricity sources. The work also investigates the methods for optimization of the hoses consumption in case of integration of heat and cold sources including renewable heat generation (RES). In near future the smart houses will present a significant part of the participants at the energy markets, so the optimization methods investigation having economical parameter is also in the scope of this investigation.**

***Index Terms*—smart house, renewable energy sources, demand respond, optimal control of energy systems**

I. INTRODUCTION

The current European policy in the field of energy is focused on decreasing of the fossil fuels usage and its replacement with alternative fuels like RES (Renewable energy sources), hydrogen, biomass, etc in respect to reduce the greenhouse emissions to zero until 2050[1,2]. This rules will affect the buildings and citizen houses to implement newest technology to be able to respond to the modern world challenges and will define the necessary conditions for the smart houses in the near future [3].

Smart house or Smart home are terms which are related mainly to houses where the energy system is fully automated [4,5].

The present heat and power installations of the houses includes many different loads and generating sources. The participation of renewable energy sources with stochastic behavior depending on weather and other conditions and stochastic behavior of the loads usage leads to rise of new challenges for the houses control systems which optimize the energy consumption and decreasing the householder's bills. From one side these are control systems for local control of the generation sources and from other side this are the possibilities for interoperability with higher levels control systems in DSO and TSO companies and interoperability with the systems of electricity and heat markets.

Concerning [6] the future energy systems will need to increase its flexibility in the part of generation and the demand side flexibility shod be able to ensure that final consumer/prosumer become active member of the energy markets. Some task in research area of the renewable energy implementation in future are related to:

Studies for storage flexibilities in operation of electrical grids (including Microgrids) which is strongly related to smart homes.

Storage and generation sizing depending on their parameters like investments, lifetime, efficiency, interconnection possibilities, etc.

Integration of energy storage systems with conventional power generation including improvement of efficiency of load hours of CHPs (Combined Heat and Power).

Flexible potential from aggregation of heating and cooling systems like power-to-heat technologies, heat pumps and heat boilers to provide balancing services.

Designing of standalone (island) buildings supplied by renewable energy

Optimal utilization of DSR (Demand side response), respecting the demand requirements and required data.

This research presents some of the known technics used in power generation and demand response in respect identify some gapes to be covered in future research work in the field of control systems for optimization of loads and generation facilities in future smart homes.

II. SMART HOMES POWER SYSTEMS

The present electrical and heat energy systems of the houses may consist of many different energy sources and heat and electricity loads. The sources of primary energy could be:

- Electrical grid
- Renewable energy sources
- Local conventional electricity and/or heat generators
- District heating systems

The present technologies for local energy generation are given in Table. I

TABLE I
ENERGY GENERATION UNITS

ENERGY TECHNOLOGY	ENERGY SOURCES
RES	Solar Wind
Combined Heat and Power	Natural gas Hydrogen Hydrogen and gas Other
Local Heating Systems	Coil Natural gas Biomass

One possible schematic of a smart house with utilization of electrical and heat storage and electrical and heat generation from RES and CHP is shown on Fig.1

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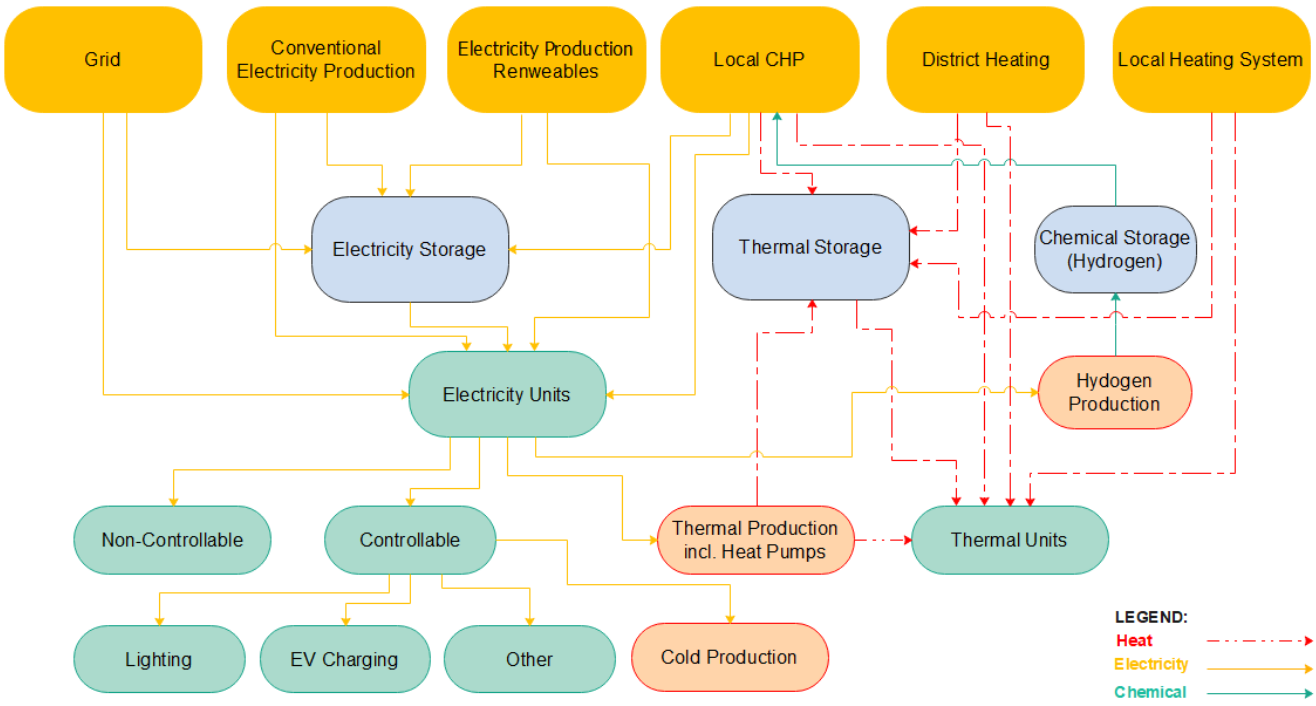

Fig.1. Smart House Energy System Structure

The shown at Fig.1 scheme shows that the future smart house will be very complex system of generating, accumulating and consuming units. To be able to ensure proper utilization of all units and automatic system for control and optimization of energy flows should be used. This automatic system will require an information collected from the generating and consuming units, weather stations, market information, etc. Also this system should be able to collect, analyze and predict data related to the power consumption and usual consumer behavior. The legal and environmental regulations related to such systems and the market conditions should be strictly followed designing and using the systems and this will lead in making the control and optimization systems more complex. All this requirements lead to the following elements of the smart house control system.

1. Monitoring systems
   This system is intended to collect and visual presenting of the data related to:

- Electrical energy consumption of each electricity consumer which has the ability to be controlled.
  The control ability is related to the possibility a certain load to be switched on and off at a certain time or its consumption is possible to be reduced or increased (lighting, electrical units, etc.)
- Consumption and/or production of the power conversion units including heat, cold and chemical energy units
- Efficiency of the power conversion units
- Parameters of the storages (batteries, head/cold accumulators, electrical vehicles, etc.) including the estimation of the stored energy
- Units status related to their health and workability
- Meteorological data which are necessary for some optimization algorithms
- Market data related to the economical optimization of the energy consumption/production
- Estimation of the devices utilization, (OEE (Overall Equipment Efficiency), for generating units and storages utilization).
  The best way to provide data for the SHCS (Smart house control system) is to use Smart metering devices with communication capabilities.

2. System for data storage
   The data storage is necessary to collect data for analyzing the consumer/prosumer energy behavior and providing proper modelling and forecasting. Most commonly used technologies are the relational databases (MS SQL Server, MySQL, Oracle, etc), Cloud based technologies [7,8,9] or Block-Chain Technologies[10,11].
3. Communication system
   The smart house communication system should be able to collect information from the internal generating and consuming devices and should be able to exchange data with third party systems like the systems of DSO and TSO, District heating operators, Market operators, etc. For the local communication system it is possible to use wired or wireless communication (WiFi, 3G, 4G,5G,RFID, Bluetooth, etc.). Standard communication protocols in BMS systems are: ModbusRTU, ModbusTCP, BacNet, KNX, Dali, etc. The communication with third party systems is provided using OPC DA, OPC UA, IoT, etc. technologies. More detailed selection of communication protocols for building automation systems its physical realization is given in [12]. The interoperability of the BMS station and DSO/TSO

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1operators and market systems protocols IEC61850 and IEC60870-104 protocols could be used [13].

4. Building Management System(BMS)
   BMS system consist of several parts to control different building sub-systems:

- Production of head and/or cold
- Buildings heating and cooling
- Lighting control
- Ventilation systems
- Access control systems

In near future the building management systems will integrate and control the systems for electricity and/or chemical energies production.

The central BMS station should be able to implement control on the units for energy production and consumption of different vendors, which lead to the necessity of support of wide range of communication protocols.

The control systems consists of two control levels:

- Local control – to execute control function on the related technology parameters
- Management Control Station – to execute data, analyses, modelling, forecasting and set point optimization depending on different optimization criteria under current environmental and technical conditions

III. SMART HOUSE FLEXIBLE CONTROL

The flexibility of energy production and/or consumption is ensured by solving optimization problems which consist of many variables and constrains. Different authors focus on using different objective function. Some of them are summarized as follows:

- Minimal grid electricity consumption
- Minimal price of the bought energy (electricity or heat). In this case the problem may vary depending on the trading rules.
- Minimal CO2 emissions
- Maximal renewables energy production
- Maximal equipment utilization, etc.

In many cases more than one optimization criteria could be used which transforms the problem into multi-objective one. The constrains of the problem could be divided into three types:

- Technical/Technological (minimal and maximal level of loads/production rise, number or times for switching on/off the loads/production)
- Economical (Prices or quantities for trading purposes, etc.)
- Environmental (Weather conditions)

In the above table are given some methods used in solving different optimization problem related to the smart house energy system optimal control. In TABLE II are summarized the different objective function types applied to house energy consumption:

TABLE II
Objective functions used for energy optimization purposes

Оптимизационен модел	Метод на решаване
Optimal loads control	[14,15,16,17]
Minimal electricity price/Minimal consumed quantity	[20]
Optimal batteries utilization	[18,19]
Minimal electricity price under maximal consumer satisfactory	[20]
Minimal price of stored energy	[20]
Minimal utilization expenses	[22]
Optimal batteries charge/discharge	[24,25,26]
Minimal emissions and utilization expenses	[22,23]
Maximal trading quantities	[26]
Maximal production form RES	[27]
Economic profit maximizing	[28,29]

The advantages and disadvantages of the different methods [14-28] are given in [7] and summarized as follows:

- Linear programming [27]
- Quadratic programming [15]
- Nonlinear programming[17]
- Markov decisions[21]
- Artificial Neural Networks[21,35]
- Genetic algorithms [23]
- Particle swarm algorithms [22]
- Fuzzy [30]
- Model predictive control [28]
- Robust algorithms [29]

The data for making optimization methods usually are provided by measurement systems or are related to some forecasting. Usually the following parameters are in the scope of the forecasting:

- Electricity/Heat demand
- Electricity/Heat production
- Electricity/Heat price forecasting
- Electricity/Heat trading quantities

The forecasting is a key aspect in building management system as it provides the missing information form the metering system. The forecasting period depends on the decision making periods in BMS system and concerning the investigation the following methods are the most commonly used in the recent years:

Modeling and forecasting method	Source
NARX	[33,34]
Regressive Analyses	[34]
Least Square Support Vector Machines	[34]
Exponential smoothing	[35]
Machine Learning Method	[354]

The Decision Making Process for the BMS Station is given at Fig.2

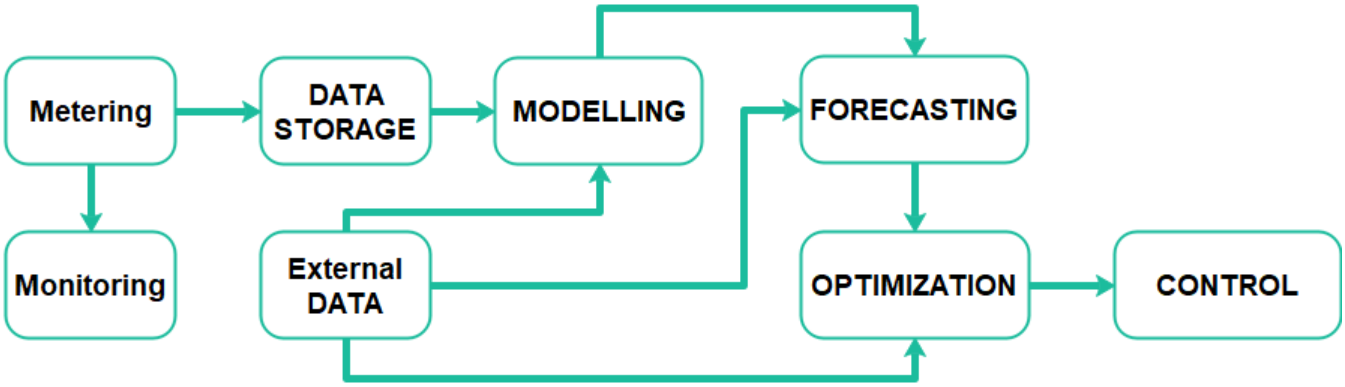

Fig.2 Decision Making Procedure for Smart House Energy System Implementation

IV. Conclusion

Concerning the provided investigation is obvious that the problem of optimal control of the production and consuming facilities is partially solved for special cases. It is visible from many publications including the publication of some EU projects that the problems with integration of large number of small RES units in the energy systems form one hand will led a significant problem with its aggregation and control and from another hand will led to problems related to the consumers/prosumers participation in the electricity systems and their satisfaction. The main future works related to integration of RES in smart hose will be in the following ways:

1. Maximizing the production form RES subject to optimal equipment utilization (including loads and storage units).
2. Prices of energy optimization (including electricity and heat energy)
3. Integration of energy conversion units and heat capacities to improve the impact of RES utilization.

To realize this goals more advanced algorithms should be designed and implemented in the control systems. New testing facilities should be designed and put in use to provide proper way for testing the designed algorithms.

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