Agent and Multi-Agent Systems

INTELLIGENT CONTROLLER FOR HYBRID RENEWABLE ENERGY SYSTEM BASED ON MULTI-AGENT AND EMBEDDED TECHNOLOGY

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Abstract: *The concept of energy saving management system based on intelligent agent and embedded technology is represented here. This system is designed for management of hybrid renewable energy system (HRES). For testing of suggested approach the prototype grid of energy consumption, production and storage was designed. This grid contains energy consumption block, production block, inner storage block, external supplier block, local data acquisition modules and embedded controller (EC). The design of management system is presented: hardware level with input/output device, embedded controller and super-controller devices. The formalization of intelligent agents for both side is represented next. Internal agents are autonomic agent, local agent seller (LAS) and local agent buyer (LAB). LAS and LAB agents use forecast methods for generation of action. External agents are Agent of Weather Service, Agent Buying Supporter and Agent Selling Supporter.*

Keywords: *renewable energy system; energy saving; energy management system, embedded controller, supercontroller, embedded controller software, intelligent agents, multi-agent theory.*

ACM Classification Keywords: *Smart-grids*

Introduction

For optimal energy usage we need to avoid inefficient use of energy and the loss of energy for instance by the transport. Energy is used to reach a certain level of comfort. The unauthorized and non-optimal energy consumption increase additional costs of resources. The system should be adaptive to the requested energy and the possibilities of the production. Intelligent processes can define what resources can be used based on information from weather forecast, available production, energy consumption forecast and others. It becomes more notable in hybrid energy systems (HES) or HES with renewable energy sources and classic energy suppliers (HRES). Another issue is the scalability in size and distance that need to be managed. Using the embedded technology as a solution could decrease the expenses due to the fact that the controller function can be handled by embedded personal computer with low cost. Another idea is to do management of energy system in automation mode handling information about usage of energy in the past, preferences of the customer and based on the forecast of the behavior as external disturbance (for instance weather changes) and occupancy patterns of the customer in the future as well. This branch of automated system developing is called smart or intelligent adaptive automated systems in the energy saving domain [Cirrincione, 2009].

Background

There are several papers that present approaches to design of energy management systems based on physical aspects, multi-agent system (MAS) and embedded techniques.

Paper [Krichen, 2007] describes modeling and control of a hybrid production unit based on renewable energies comprising two sources: wind/solar and hydrogen storage system. As a previous one approach described at [7] uses set laws and doesn't use intelligent data handling as well. Other authors describe methodologies to model hybrid renewable energy system HRES components, HRES designs and their evaluation [Deshmukh, 2008] based on physical aspects of units. Also they provide criteria for HRES selection based on loss of load probability and cost analysis.

A new approach to the HES based on the technology of the MAS and shifts to intelligent system is proposed in paper [Lagorse, 2009]. Authors use the Fuzzy-Logic-Based approaches and present a architecture of system and simulation model. The multi-agent (MAS) solution to energy management in a distributed hybrid renewable energy generation system based on JADE (Java Agent Development) is described here [Zeng Jun, 2011]. Authors [Kwon, 2008] describes project "Development of Intelligent Distribution Automation System (IDAS)" to do distribution automation system more intelligent. Authors [Dagdougui, 2007] suggest a model of integrated hybrid system based on mix of renewable energy sources and technologies. This model includes an optimization problem for the control of the different ways to store energy. Also MAS approach is considered at papers [Qui, 2008], as distributed multi-agent system (MAS) framework for market-based control in Microgrids. In this paper we suggest other approach to design energy management system based on intelligent agent and embedded technology. In contrast to other approaches, here we consider embedded device General Management Agent Control as a core for EMS and intelligent agent approaches for strategies of buying and selling electricity. This concept could be used in intelligent system of free trade in electricity

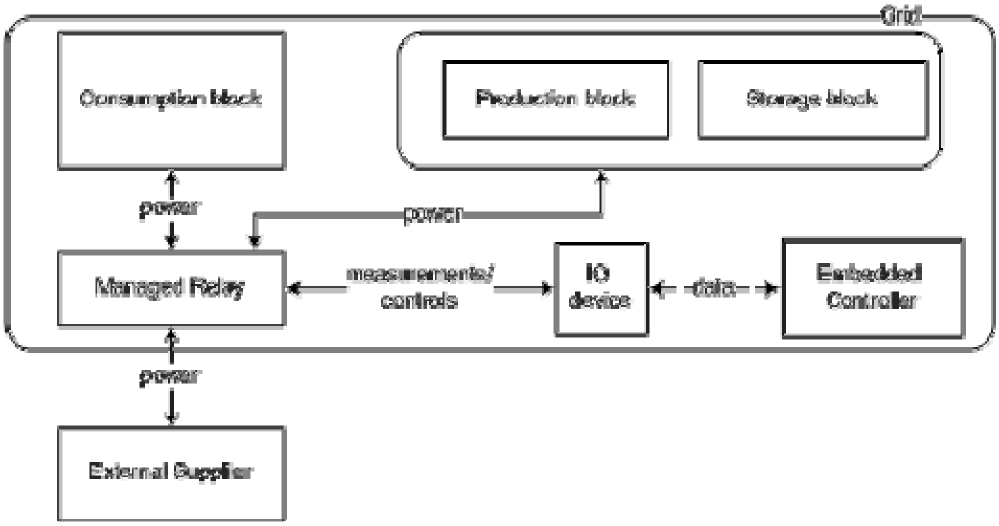

Fig. 1 - Grid architecture

It is designed to control the balance of consumption and production of electricity "zero villages" and to allow owners of private homes to buy and sell electricity according to the user's occupancy patterns.

Grid prototype overview

Standard grid contains the following units: energy consumption block with load E_c, production block with production parameters E_p, inner storage block with capacity E_s , external supplier block with permanent electricity sources E_{ext} and local data acquisition modules and embedded controller (see fig. III-A). For prototyping of presented system we use DC electricity circuit with voltage 12V. This grid could be included into zero energy balance villages where each grid (house) could be represented as small energy plant/production/storage unit. House owners will consume energy from their batteries first and if needed they get energy for closest buildings to buy additional energy. Electricity will be bought from power plant if the building needs more electricity than available in all buildings of the zero energy balance village.

A. Energy consumption block. Consumption block (CB) includes energy consumers (such as equipment, lightning and so on). The load depends on occupancy patterns of grid owner. The power of CB is defined P_{CB} Wh.

B. Energy production block. Production block here contains photovoltaic panel (PV) with power P_{PB}. Energy production depends on input energy to PV system. Hourly power output from PV system defines according to [Dagdouguia, 2010] as.

$$PP_{pb} = I_{Tj\mu} A_{pv} \quad (1)$$

where μ is system efficiency, I_{Tj} - input energy, A_{pv} – area of PV system .

Table 1- switches of the relay

Case	Input/Output 1	Input/Output 2
1	'Autonomy'	Consumption block Production/Storage Block
2	'Buying'	Consumption block External Suppliers
3	'Selling'	Production/Storage Block External Suppliers
4	'Buying'	External Block Production/Storage Block

C. Energy storage blocks

For storing the energy inside of grid the battery storage is used with required battery capacity (in ampere hour B_{rc}). It could be connected with PV through the charge controller. In this production block combines with energy storage blocks.

D. Relay

The relay is used for switching different resources depends on voltage and current in the system. The sensors are embedded into the relay and provide information output for Input/output device. The combinations of relays switches are represented in the table I. The case 1 presents production of electricity is enough for internal consumption. The case 2 occurs then need to use external supplier for inner demands. The case 3 is grid sells the electricity then consumption less than production. And last case 4 then grid buys energy and keeps in internal batteries.

E. Data acquisition

Data acquisition modules measures energy generated by solar panels, energy consumed in the building and energy accumulated in the storage.

F. External suppliers

External suppliers are represented as or batteries storage or AC/DC inventors. We assume that external suppliers are permanent source of energy. Also grid is able to get electricity from External suppliers and keep in internal storage (buying) or put electricity to external network (selling).

Design of management system

A. Hardware design

1) Input - output device: Through common user interface input - output device transfers information from sensors about voltage V, current I and/or energy consumption P to embedded device and pass control signal from ED to relay.

2) Embedded controller: Embedded controller or General Measurement Agent Control (GMAC) tracks the status of production, consumption and storage in each building and controls it and acquire to switch the relay (buy or sell) energy due the status of sensors in system or ordered by super-controller. The embedded controller is collecting data, setting control commands and transfer information to Supercontroller

3) Super-controller: The super-controller receives and analyses energy data from all grids in a village to estimate how much electricity must be bought and sold for each grid. Therefore the Super-controller predicts energy consumption and energy production analyzing weather forecast, current weather conditions, and historical values and building parameters. Each grid (house) with energy production units will become an energy dealer and will be able not only to save energy but also get some profit out of it. To buy or sell electricity the Super-controller identifies the optimal dealer/consumer which is a grid in the neighborhood or any of power plants connected in the region.

B. Intelligent agents

1) General formalization: Based on MAS theory and theory of active systems [Weiss, 1999] each agent is formalized as

$$Ag = < G, S, A, \theta, \varphi > \quad (2)$$

where G - goal of agent, $S = \{s_1, s_2, \ldots s_n\}$- set of environment states, $A = \{a_1, a_2, \ldots a_n\}$ - set of action, knowledge base θ and operator $\varphi: G \times \theta \times S \rightarrow A$. We define 2 subsets of agent: subset of inner agents AgI for each j grid and subset of external agents Ag_E for supercontroller. In this system represents as

$$S = (\{Ag_I\}_j, \{Ag_E\}) \quad (3)$$

where j - index of grid and j = j=1,…,N and N – number of grids.

2) Internal agents:

Subset of inner agents: Subset includes

$$Ag_i = (Ag_{au}, A_{sl}, Ag_{by}) \quad (4)$$

where Ag_{au} - autonomic agent, Ag_{sl}- local agent seller, Ag_{by} - local agent buyer.

Autonomic Agent: This agent has a goal to keep consumption block working. The local production for local needs is considered in high priority.

Action is to set relay's switch at 1st 'Autonomy' position A1 and 2nd position 'buying A2. The environmental subset is $S_{V,CB}$– voltage in CB, $S_{I,CB}$ - current in CB, $S_{V,PB\&SB}$ - voltage in PB and SB, $S_{I,PB\&SB}$ - current in PB and SB. It generates actions according to the rules

$$A1: S_{V,CB} * S_{I,CB} < S_{V,PB\&SB} * S_{I,PB\&SB} \quad (5)$$

$$A1: S_{V,CB} * S_{I,CB} > S_{V,PB\&SB} * S_{I,PB\&SB} \quad (6)$$

Local Agent Seller: This agent's aim is to sell energy to external net and get maximum profit during set selling period Ts. It has the following environment states: $S_{DM,j}$ - demand of other j grids from N - 1 in Wh, S_{PDM} - set of prices in local net, S_{EC} - set of energy consumption profiles in the past, S_{WC} - set of weather condition in Ts. Action is set of A_{LAS} at times t, $t = 1 \ldots T_s$ with elements $A_{LAS}(t)$. Each element has one from two values at current time: $a3 = \{A3, A1\}$, e.g. switch #3 'Selling' when local grid sells electricity and switch #1 'Autonomy' when local grid does not sell. Operator $\varphi_{LAS}(C_{LAS})$ adjusted based on forecast procedure of local grid's demand during T_s [Kamaev, 2010]. Parameters C_{LAS} are being discovered during optimization procedure. Also Ag_{LAS} provides his action to super-controller agent in advance.

Local Agent Buyer: The aim of agent is buying energy from external net to cover internal grid's demand and with minimum price during set buying period T_b. It has the following environment states: $SS_{SP\backslash j}$ - supply of other j grids from N - 1 in Wh, S_{sps} - set of prices in local net, S_{ec} - set of energy consumption profiles in the past, S_{WC} – set of weather condition in Tb. Information has been transferred into super-controller agents as well.

Action is set of ALAB at times t, $t = 1 \ldots T_b$ with elements $A_{LAB}(t)$ Each element has one from two values at current time: $a3 = \{A3, A1\}$, e.g. switch #4 'Buying' when local grid buys electricity and switch #1 'Autonomy' when local grid does not buy. Operator $\varphi_{LAS}(C_{LAS})$ adjusted based on forecast procedure of local grid's demand during Ts. Parameters CLAB are being discovered during optimization procedure.

3) External agents:

Subset of external agents: External agents compose the subset

$$Ag_E = \langle Ag_{wh}, Ag_{bs}, Ag_{ss} \rangle \quad (7)$$

where Ag_{wh} - agent of weather service, Ag_{bs} agent buying supporter, Ag_{ss}- agent selling supporter.

Agent of Weather Service: The aim for Ag_{wh}, is collecting and providing information about weather condition during forecast horizon period T_f .

Agent Buying Supporter: Agent's aim is collecting and providing information about supply during forecast horizon period T_f .

Agent Selling Supporter: The aim for Ag_{ss} is collecting and providing information about demand in the net during forecast horizon period T_f .

Case studies

A. Case 1

The result for normal work is represented in Fig. 2. The autonomic agent switches relay to mode 2 (buy) in the beginning of simulation (0:00). At time 9:30 it switches to mode 1 (autonomy). At time 19:30 it switches to ode 2 again.

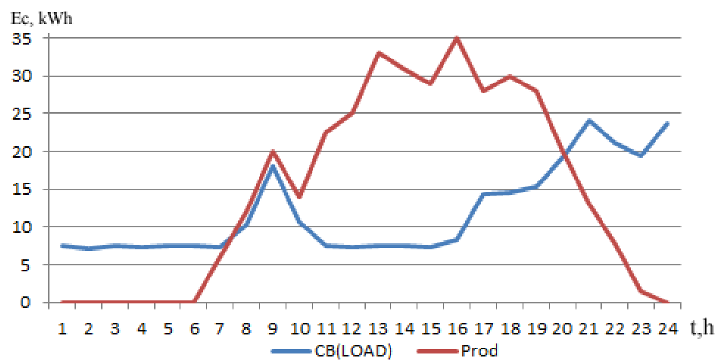

Fig. 2 - Case studies. Case 1

B. Case 2

Another example represented in Fig. 3. At 00:00 autonomic agent switches to mode 1, next at time 11:30 to mode 2, next 18:45 back to mode 1.

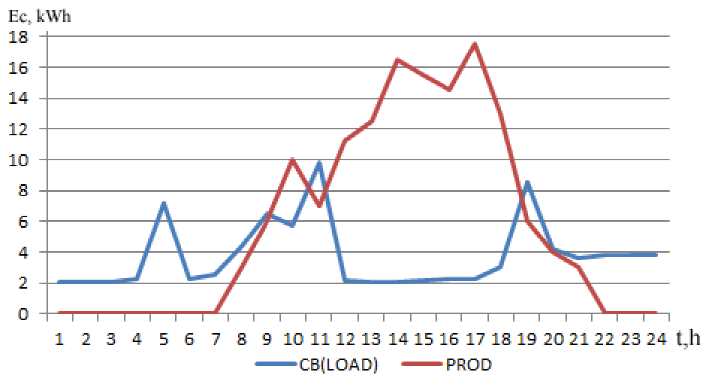

Fig. 3 - Case studies. Case 2

Conclusion

For efficient management of hybrid renewable and classical energy systems the intelligent agent-based (MAS) and embedded solution is presented in this paper. A personal embedded computer as a local controller allows expanding management system to include different devices with a similar interface.

We suggest 2 side architecture with embedded distributed controllers and a super-controller. The software includes multi-agents based on application with 2 types of agents. Internal agents with intelligent algorithms that are deployed at the local embedded device that underline autonomy in decision making process and the cooperation with other grids in the net.

Although we consider the simple grid with consumption, production and storage block in DC mode, this concept could be applied for different HRES.

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