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Energy Management in Smart Buildings with Intelligent Control Systems

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Abstract— Commercial buildings have increased energy demand with lot of energy wastage. Energy efficiency of such buildings can be increased by properly managing the energy. For the same, an Intelligent Energy Management System (EMS) introduced in a commercial building aims to improve environment within the building to ensure customers' comfort. The control system for such a building minimizes the power consumption without compromising the customers' comfort. An intelligent multi-agent control system for energy and comfort management in the smart building serves this purpose. Increased challenges faced by the modern power systems include increased energy demand, environmental concerns etc. The utility along cannot meet all these challenges. Microgrid, which uses renewable energy sources, is a solution for the same. The energy management system, its control and the simulation results show the effectiveness of the energy management system.

Index Terms— Energy management system (EMS), wind generation, solar energy, battery energy storage system, microgrid, intelligent control system, fuzzy controller, energy-efficient building, genetic algorithm.

1 INTRODUCTION

The productivity and quality of life of the people within a commercial building depends on comfort level within it. The comfort factors which influence the above mentioned factors include visual and thermal comforts. These are provided by lighting and air conditioning systems. More comfort is satisfied by more energy consumption. Due to energy scarcity these days, a balance between the energy consumption and the customer's comfort is required.

Increased energy demands can be fulfilled by properly managing energy, giving more preference to the critical loads, managing the noncritical loads. This minimizes total energy consumption. The saved energy can be utilized for later usage of critical loads. This ensures reliability of critical loads when necessary. The intelligent energy management system, introduced under this topic, can serve this purpose.

The intelligent energy management system reduces the total energy consumption. This ensures effective and efficient use of energy, ensuring supply to the critical loads, thus ensuring customers' comfort and minimizes energy wastage. This makes the commercial building an energy-efficient building.

The remainder of the paper is organized as follows: Section 2 describes the overall system layout. Section 3 describes the wind generation. In Section 4, the photovoltaic arrays using solar energy are described. In Section 5, the battery energy storage system and its modelling are described. The design of the intelligent control system is detailed in Section 6. In Section 7, the fuzzy logic controllers are explained. Section 8 gives an idea about the energy management done in the smart building. In Section 9, simulation results are presented. Finally, conclusion is given in Section 10.

2 OVERALL SYSTEM LAYOUT

Increased energy demand is a requirement for the development of any nation. The increasing challenges faced by modern power systems such as environmental concerns, high requirements of reliability, growing social and industrial demands etc. cannot be satisfied by the utility grid alone. Microgrid is an alternative solution for the same.

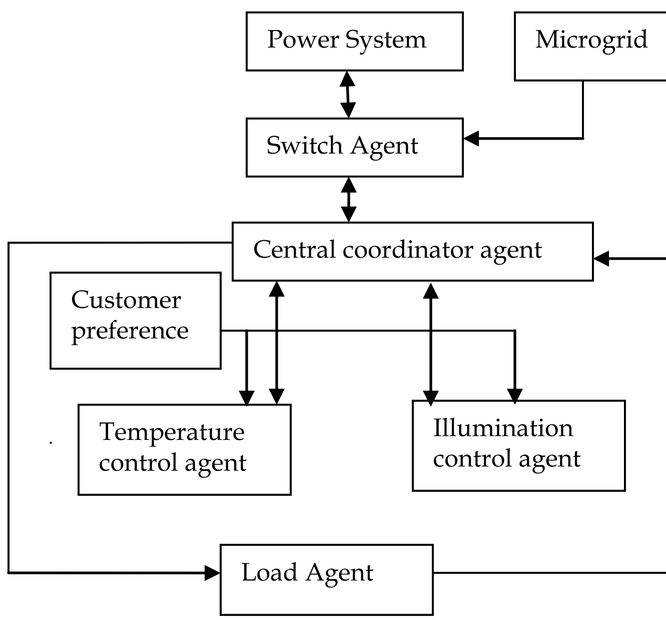

Fig.1.Overall system layout with intelligent control and energy management

Microgrid is used to supply energy to the commercial building under consideration in this work. Microgird uses renewable energy sources such as PV Arrays and wind turbine, which are eco-friendly and avoids environment pollution. Power generated during off-peak hours is stored using battery energy storage system (BESS). The stored energy can be utilized later when required. Microgrid is located close to the controllable loads, which improves reliability and reduces transmission losses. Microgrid system can be connected to and disconnected from the upstream utility grid when required. Therefore, energy exchange between the grid and microgrid is possible. Moreover, when there is utility failure, the microgrid can work as an autonomous grid by supplying the loads connected to that microgrid.

The smart building is supplied by the microgrid system, which makes the building self-reliant, which is a requirement these days. The intelligent multi-agent system technology is applied to the control system for the smart building, which provides flexibility in control. Multi-layered agents are provided for the control. The comfort factors under consideration include visual and thermal comforts. Therefore, the critical loads are the lighting and air-conditioning systems, which provides visual and thermal comforts respectively in the commercial building. Through the cooperation of these multi-layered agents, the control system minimizes the energy consumption ensuring the customer comfort.

3 WIND GENERATION

As demonstrated in this document, the numbering for sections upper case Arabic numerals, then upper case Arabic numerals, separated by periods. Initial paragraphs after the section title are not indented. Only the initial, introductory paragraph has a drop cap.

Wind power is extracted from wind turbines, which is an important renewable energy.

The power extracted from the wind turbine [26] is given by:

$$P_m = C_p(½ \varrho A u^3) = C_p P_w \quad (1)$$

where:

C_P is the coefficient of performance of wind turbine, A is the cross-sectional area of the packet of air in m^2, ϱ is the air density in kg/m^3 and u is the wind speed in m/s.

4 SOLAR ENERGY

The commercial building is supplied with microgrid, which uses renewable energy resources. Distributed renewable energy resources are used as the primary energy supply to the commercial building and the utility grid is to supply the back-up. The loads in the building consume renewable energy first and then the extra requirement is taken from the utility grid. Among the renewable energy sources, the energy through photovoltaic (PV) effect can be considered as the effective and sustainable resource, which is in abundance and cheapest form of energy. It can generate direct current electricity without environmental impact and contamination. The PV system is static, quiet, and free of moving parts, and these make it have little operation and maintenance costs. The voltage and current available at the terminals of a PV device may directly feed small loads. More sophisticated applications, solar generation typically consists of: the PV array, a control unit to track the phase of the utility voltage, a DC/AC inverter stage, an isolation transformer to ensure the DC is not injected into the network, an output filter to restrict the harmonic currents into the network. The Phase Locked Loop (PLL) technique has been used so far as a common way for generating the current reference synchronized with the utility voltage in the PV power conversion system.

The characteristic equations [12] of PV arrays are used for modeling the same.

5 BATTERY ENERGY STORGAE SYSTEM

Increasing automation and computerization is required for the growth of the economy of any country. The same requires increased energy. The surplus energy from renewable sources can be stored for further usage by storage devices like batteries during off-peak hours. During off-peak periods, the battery is charged from the microgrid via a converter. The converter converts the alternating current into dc. During discharge, the direct current generated in the battery is transformed by the converter to alternating current, which is delivered for meeting energy demands during peak hours.

Thevenin's equivalent model [19] is obtained for modeling of Battery Energy Storage System (BESS). This made the easy modeling of storage system possible.

6 INTELLIGENT CONTROL SYSTEM

Modern control technologies provide more robustness, efficiency and flexibility to the power system which makes the Smart Grid concept. Smart Grid concept is an emerging technology these days, which enables the participation by customers. This provides power quality and reliability. Increased energy demand necessitated more decentralized generation due to changing market operation and more complex distribution systems. Therefore, it is difficult to manage the network from central control system. The intelligent control system technology provides a solution for creating such distributed control systems with secure and reliable network operations with changing operational scenario. The smart Building Energy Management System (BEMS) is an application of the same. The Energy Management System (EMS) in a commercial building aims to improve environment within the building.

The intelligent control system, here, is a multi-agent layered control system made up of multiple agents including four agents. The agent can be a software or physical entity. Here, the agent-based intelligent control system is designed for energy management in a smart commercial building.

6.1 Switch Agent

The switch agent serves the purpose of connecting and/or disconnecting the microgrid to and/or from the utility grid.

6.2 Central Coordinator Agent

*T*he central coordinator-agent coordinates grid and microgrid, all the critical and noncritical loads and ensures the customer comfort. All the control action is performed by the central coordinator agent. The overall comfort in the building is defined by the comfort factor given by:

$$Comfort=\mu_1 [1-(e_T/T_{set})^2]+\mu_2[1-(e_L/L_{set})^2] \quad (2)$$

where:

μ_1 and μ_2 are the weighting factors,
e_T is the error in temperature,
e_L is the error in illumination,
T_{set} is the set value of temperature
L_{set} is the set value of illumination.

The value of comfort lies in the range [0,1]. Customer comfort is ensured when it is greater than 0.9.

6.3 Local Coordinator Agent

The local controller-agents are used to control thermal comfort and visual comfort. The local controller agents are fuzzy controllers for controlling the different comfort factors like thermal and visual comforts.

6.4 Load Agent

The load agent controls all the noncritical loads. This disconnects the noncritical loads based on their priority so that energy can be saved for further usage by the critical loads for providing necessary comfort.

7 FUZZY LOGIC CONTROLLERS

Fuzzy control provides a formal methodology for representing, manipulating, and implementing a human's knowledge about how to control a system; i.e. fuzzy logic can be used to control nonlinear systems that are difficult to model mathematically. In contrast with "crisp logic", where binary sets have two-valued logic, fuzzy logic variables may have a truth value that ranges in degree between 0 and 1.

7.1 Temperature Control

A fuzzy controller is developed for maintaining the indoor thermal comfort in a commercial building. The inputs of this fuzzy controller are the error in temperature and the change of errors and the output is the required power.

The membership functions of the inputs and output of the fuzzy controller are shown in Figs. 2, 3, and 4.

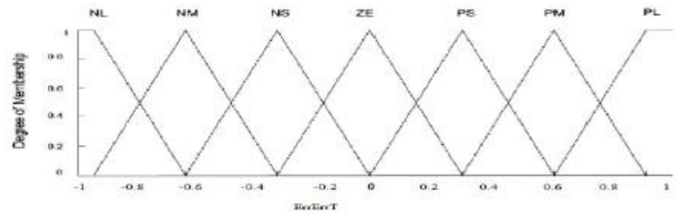

Fig.2. Membership functions of change in error

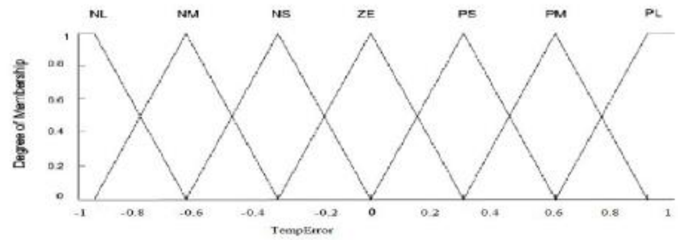

Fig.3. Membership functions of temperature error

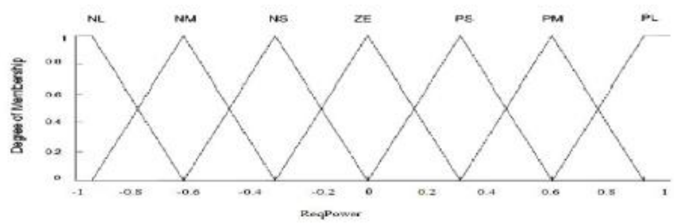

Fig.4. Membership functions of the output, required power

TABLE I
FUZZY CONTROL RULES FOR LOCAL TEMPERATURE CONTROLLER

Required Power	TempError							
		NL	NM	NS	ZE	PS	PM	PL
ErrErrT	NL	PL	PL	PM	PM	PS	PS	NS
	NM	PS	PS	PM	PL	PS	PS	NS
	NS	PM	PS	PS	PS	NS	NS	NM
	ZE	PM	PM	PS	ZE	NS	NM	NM
	PS	PM	PS	PS	PS	PS	NM	NM
	PM	PS	PS	NS	NS	NM	NL	NL
	PL	NS	NS	PL	NM	NM	NL	NL

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7.2 Illumination Control

Improper lighting can cause adverse health effects. Therefore, the building indoor environment should be properly illuminated to provide visual comfort. Artificial lighting, therefore, is a requirement to ensure visual comfort in the smart commercial building. For ensuring proper visual comfort, fuzzy control system is used for providing comfortable illumination.

The membership functions of the input and output of the local illumination controller are shown in Figs. 5 and 6.

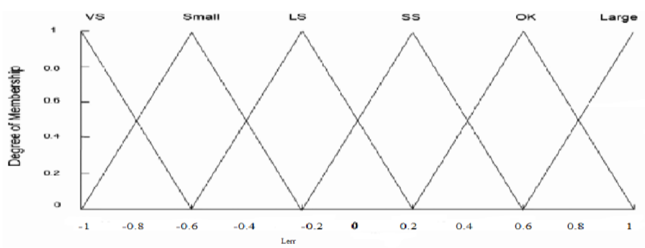

Fig.5. Membership functions of the input, illumination error.

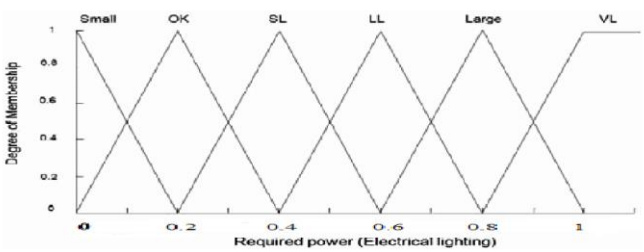

Fig.6. Membership functions of the output, required power.

TABLE II

FUZZY CONTROL RULES FOR LOCAL ILLUMINATION CONTROLLER

Lerr	VS	SMALL	LS	SS	OK	LARGE
Preq	LARGE	LARGE	LL	LL	OK	OK

8 ENERGY MANAGEMENT USING INTELLIGENT CONTROL SYTEM

Scarce generation may adversely affects the performance of critical loads like those in hospitals, commercial buildings etc. But, such loads always require continuous power supply. Since generation is scarce, proper energy management is required for proper and required usage of energy within the smart commercial building to ensure customers' comfort minimizing energy consumption even by the critical loads. For the continuous power supply, distributed generation using renewable energy sources, was essential which could supply power locally as per the need. This makes the building eco-friendly. Here photovoltaic arrays and wind turbines are used. With proper energy management, lot of energy can be saved and at the same time, lot of energy wastage can be minimized. This saved energy can also be utilized for further usage by the critical loads ensuring the reliability of the same.

The aim of the control system design for energy management in smart commercial buildings is to minimize the power consumption ensuring customers' comfort. For the same, an intelligent control system is used in this study, which is mentioned above.

The critical loads in the commercial building considered are lighting and air conditioning systems, providing visual and thermal comforts within the building environment for improving the quality of life and productivity within the building. The noncritical loads considered are swimming pool pump, fountain pump and decoration lamps. The energy management system could reduce the energy consumption and the saved energy could be utilized for further usage by the critical loads when required for providing visual and thermal comforts. This was the basis of the control system design.

Optimization using Genetic Algorithm (GA), which is based on natural genetics and natural selection, was provided for further minimizing the power consumption and the corresponding set values of illumination and temperature were taken. These optimized set values could reduce further power consumption and thereby energy consumption.

9 SIMULATION RESULTS

Matlab/Simulink is used to simulate the multi-agent control system.

The multi-agent control system was used for the intelligent control of the smart commercial building. The critical loads, under consideration, here, are the lighting and air conditioning systems and the noncritical loads are swimming pool pump, fountain pump and decoration lamps. At each step, each load is intelligently controlled for minimizing energy consumption within the building. Microgrid was used to supply energy to the building. The extra energy required is taken from the storage system. For the same, control signals are generated for the control of the circuit breaker of battery storage. For minimizing critical load minimization fuzzy logic controllers are used for the lighting and air conditioning systems. Then, further minimization was accomplished with proper control of noncritical loads like swimming pool pump, fountain pump and decoration lamps. This control was implemented by generating proper control signals for the circuit breakers connecting noncritical loads. At each level of control of energy is minimized and comfort is maintained.

For optimizing the set values, Genetic Algorithm was used. This minimized the energy consumption further. At each level of control, the total energy consumption was less when set values of illumination and temperature were optimized when compared to the same when the set values set as customer's preference. This was evident by the table given below:

TABLE III
COMPARISON OF ENERGY CONSUMTPION AT EACH LEVEL OF CONTROL OF NONCRITICAL LOADS

	Storage Control	Storage Control & Swimming Pool Pump Control	Storage, Swimming Pool Pump & Fountain Pump Control	Storage, Swimming Pool Pump, Fountain Pump & Decoration Lamp Control	Storage, Swimming Pool Pump, Fountain Pump, Decoration Lamp & Grid Control
Set values-Customer's preference	292884 Wh	232904 Wh	246248 Wh	244044 Wh	253980 Wh
Set values-Optimized	291510 Wh	273270 Wh	243410 Wh	242950 Wh	243460 Wh

Comfort factors obtained are above 0.9 at each level of control, which ensured customers' comfort within the building.

10 CONCLUDING REMARKS

In the explained energy management system, environmental friendliness is ensured due to the use of microgrid technology. The microgrid, here, used PV arrays and wind turbines. The multi-agent control system performed its function. The energy consumption within the building is minimized with proper control of storage, noncritical loads and grid. The customers' comfort is also ensured, which was evident from the values obtained which are greater than 0.9. Optimization done with Genetic Algorithm (GA) further reduced the energy consumption within the building, which made the building more energy efficient.

REFERENCES

[1] Lingfeng Wang, Zhu Wang, Rui Yang, "Intelligent Multi-agent Control System for energy and comfort management in smart and sustainable buildings", *IEEE Trans. Smart Grid*, pp. 1-13, Feb 2012.

[2] Stefania CONTI, Salvatore RAITI, Giuseppe TINA, "Modelling of LV Photovoltaic Grid-connected Distributed Generation", *8th International Conference on Electricity Distribution*, pp. 6-9, June 2005

[3] I. H. Altas1,* and A.M. Sharaf, "A Photovoltaic Array Simulation Model for Matlab-Simulink GUI Environment," *IEEE Transactions on Energy Conversion*, Vol. 11, No.4, December 2007, pp. 341-345.

[4] Zhu Wang, Rui Yang and Lingfeng Wang, "Multi-agent Control System with Intelligent Optimization for smart and energy-efficient buildings", *IEEE Trans. Smart Grid*, 2010, pp. 1144-1149.

[5] Zhu Wang, Rui Yang and Lingfeng Wang, "Intelligent Multi-agent Control for Integrated building and Micro-grid Systems", *IEEE Trans. Smart Grid*, 2011, pp. 1-7.

[6] Zhu Wang, Rui Yang and Lingfeng Wang, "Multi-agent Intelligent Controller Design for Smart and Sustainable building", *IEEE Trans. Smart Grid*, 2010, pp. 1-6.

[7] Murali Krishna Kouluri, Pandey R.K., "Intelligent Agent Based Micro-grid Control", *IEEE-IAMA* 2011, pp. 62-66.

[8] M.H.Ghaemi, "Modelling and Control of Dynamic Systems", *Laboratory, Gdansk University of Technology, Faculty of Ocean Engineering and Ship Technology*, pp. 57-63.

[9] Jan Jantzen, Design Of Fuzzy Controllers, *"Technical University of Denmark, Department of Automation, Bldg 326, DK-2800 Lyngby, DENMARK.* Tech. report no 98-E 864 (design), 19 Aug 1998, pp.1-27.

[10] M. Pipattanasomporn, H. Feroze, *Student,* S. Rahman," Multi-Agent Systems in a Distributed Smart Grid: Design and Implementation," *Proc. IEEE PES 2009 Power Systems Conference and Exposition (PSCE'09)*, pp.1-8, Mar 2009.

[11] John Twidell, Tony Weir, "Renewable Energy Resources", Second Indian Reprint 2008, Taylor & Francis, ISBN: 10:0-419-25330-3.

[12] Basim Alsayid and Jafar Jallad, "Modelling and Simulation of Photovoltaic Cells/Modules/Arrays", *International Journal of Research and Reviews in Computer Science (IJRRCS)*, Vol. 2, No. 6, December 2011, ISSN: 2079-2557, pp. 1327-1331.

[13] PAVLOV, G. PAPAZOV and M. GERGANSKA, "Battery Energy Storage Systems", *UNESCO Regional Office for Science and Technology for Europe (ROSTE)*, Technical Report No.7, pp. 1-146.

[14] Hao Qian, Jih-Sheng Lai, Chair, Wensong Yu, Kathleen Meehan, Douglas K. Lindner, Douglas J. Nelson, "A High-Efficiency Grid-Tie Battery Energy Storage System", *National Semiconductor Corporation (Santa Clara, CA)*, pp. 1-150.

[15] M. H. Ghaemi, "Modeling and Control of Dynamic Systems, Laboratory", *Gdansk University of Technology, Faculty of Ocean Engineering and Ship Technology*, Exercise 8, pp. 57-63.

[16] I.H. Altas and A.M. Sharaf, "A Generalized Direct Approach for Designing Fuzzy Logic Controllers in Matlab/Simulink GUI Environment", *International Journal of Information Technology and Intelligent Computing*, Int. J. IT&IC no.4 vol.1, 2007, pp. 1-27.

[17] Xiaohong Guan, Fellow, IEEE, Zhanbo Xu, and Qing-Shan Jia, Member, IEEE, "Energy-Efficient Buildings Facilitated by Microgrid", *IEEE Transactions on Smart Grid*, Vol. 1, No. 3, December 2010, pp. 243-252.

[18] Shahram Javadi, Islamic AZAD University, Central Tehran Branch, "Energy Management in Buildings Using MATLAB", *MATLAB – A Ubiquitous Tool for the Practical Engineer*, pp. 165- 176.

[19] Puneet K. Goel, Bhim Singh, *Fellow, IEEE*, S. S. Murthy, *Life Senior*

Member, IEEE, and Navin Kishore, "Isolated Wind–Hydro Hybrid System Using Cage Generators and Battery Storage*", IEEE Transactions On Industrial Electronics*, Vol. 58, No. 4, April 2011, pp. 1141-1153.

[20] Huan-Liang Tsai, Ci-Siang Tu, and Yi-Jie Su, "Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK", *Proceedings of the World Congress on Engineering and Computer Science 2008,* pp. 978-986, June 2008.

[21] F. D. Kanellos, A. I. Tsouchnikas, N. D. Hatziargyriou, Senior Member, IEEE, "Micro-Grid Simulation during Grid-Connected and Islanded Modes of Operation*", International Conference on Power Systems Transients (IPST'05) in Montreal, Canada,* pp. 1-6, June 19-23, 2005.

[22] Timothy J.Rose, "Fuzzy Logic with Engineering Applications"-2nd Edition, Wiley |2007| ISBN: 978-0-470-86076-2.

[23] I.H. Altas and A.M. Sharaf, "A Generalized Direct Approach for Designing Fuzzy Logic Controllers in Matlab/Simulink GUI Environment", *International Journal of Information Technology and Intelligent Computing*, Int. J. IT&IC no.4 vol.1, 2007, pp. 1-27.

[24] Wang Gui-juan, Wang Zuo-xun and Gu Shuai, "The design of fuzzy control system for power-saving lighting on MATLAB", *2009 Sixth International Conference on Fuzzy Systems and Knowledge Discovery*, IEEE 2009, pp. 455-458.

[25] Guozhong Zheng Youyin Jing, Hongxia Huang, Puzhao Ma, "Thermal comfort and Indoor Air Quality of Task Ambient Air Conditioning in Modern Office Buildings", *2009 International Conference on Information Management, Innovation Management and Industrial Engineering*, IEEE 2009, pp. 533-536.

[26] Dr. Gary L. Johnson, "Wind Energy Systems", Chapter-4-Wind Turbine Power, pp.1-54.