Intelligent Control System for Efficient Energy Management in Commercial Buildings

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Abstract—*Increase in energy demand in almost all areas necessitates careful and properly managed use of energy. Conventional energy sources alone cannot meet all the energy requirements and the requirements of the power system. Renewable energy sources are solution to this problem. Increased energy demand in commercial buildings is associated with a lot of energy wastage. Energy efficiency of such buildings can be increased by properly managing the energy. An intelligent Energy Management System (EMS) can serve the purpose. It can improve the environment within the building and thus can ensure customers' comfort. The intelligent Energy Management control system for such a building minimizes the power consumption without compromising the customers' comfort. This is a multi-agent control system for energy and comfort management in the smart buildings. The energy management system, its control and the simulation results are presented in this paper*.

***Keywords—Microgrid, energy management system, fuzzy controller, energy-efficient building, genetic algorithm*.**

I. INTRODUCTION

Day by day the energy demand is increasing. This is required to meet the advancement in all areas of any nation. Also, modern power systems face certain challenges such as environmental concerns, high requirements of reliability, growing social and industrial demands etc. All these requirements cannot be satisfied by the utility grid alone. Microgrid is an important promising technology to meet all these requirements.

In a commercial building, the productivity and quality of life of the people depends on the comfort level within it. Visual and thermal comforts are the main comfort factors [1]. These are provided by lighting and air conditioning systems. The more the comfort level provided, the more is the energy consumption [2]. Energy scarcity, these days, necessitates a balance between the energy consumption and the customers' comfort.

Energy can be saved to a great extent by properly managing the energy while ensuring reliability of the critical loads. This also minimizes the total energy consumption [3]. The saved energy can be utilized later by the critical loads. The intelligent energy management system used in commercial buildings can serve multiple purposes, like reducing the total energy consumption, ensuring effective and efficient use of energy, ensuring supply to the critical loads, and minimizing the energy wastage [1] [4].

The remainder of the paper is organized as follows: Section II describes the overall system layout. Section III describes the microgrid including the renewable energy sources such as photovoltaic (PV) arrays and wind generation and the battery energy storage system for storing surplus energy. The design of the intelligent control system is detailed in Section IV. In Section V, the fuzzy logic controllers are explained with the fuzzy rules. Section VI gives an idea about the intelligent energy management done in a smart building. In Section VII, the control scheme is explained in detail. In Section VIII, the model used for simulation and the results are presented. Finally, conclusion is given in Section IX.

II. SYSTEM LAYOUT

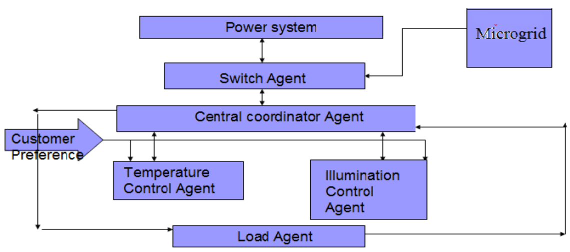

Fig. 1. System Layout with Intelligent Control for Energy Management

The increasing challenges faced by modern power systems cannot be satisfied by the utility grid alone. Microgrid is an alternative solution for the same [5].

The commercial building, under consideration in this work, is supplied with the microgrid, which uses renewable energy sources. This makes the building self-reliant. Here, the renewable energy sources used are the PV Arrays and wind turbine [6], which are eco-friendly and avoid environment pollution. Power generated during off-peak hours is stored using battery energy storage system (BESS) [7]. The stored energy can be utilized later when required. Microgrid is located close to the controllable loads, which improves reliability and reduces the transmission losses. Microgrid can

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be connected to and disconnected from the utility grid when required. Therefore, energy exchange between the grid and microgrid is possible whenever required. Moreover, when there is utility failure, the microgrid can work as an autonomous grid by supplying the loads connected to it [8].

The control system for the smart building utilizes the intelligent multi-agent system technology [4]. This consists of multi-layered agents for the control. The comfort factors under consideration include visual and thermal comforts [1]. Therefore, the critical loads are the lighting and air-conditioning systems, which provide visual comfort [9] and thermal comfort respectively in the commercial building. Through the action of these multilayered agents, the control system minimizes the energy consumption ensuring the customers' comfort [1].

III. MICROGRID

Distributed renewable energy sources are used as the primary energy supply to the commercial building and the utility grid is to supply the backup [10]. The loads in the building consume renewable energy first and then the extra requirement is taken from the utility grid. The microgrid used here consists of distributed generators (DGs) including photovoltaic (PV) arrays and wind generation and battery energy storage system.

A. Wind Generation

Wind power is extracted from wind turbines, which is an important renewable energy. The power extracted from the wind turbine [11] is given by:

$$P_m=C_p(\tfrac{1}{2}\rho A u^3)=C_p P_w \qquad (1)$$

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.

B. Solar Energy

The energy through photovoltaic (PV) effect can be considered as an effective and sustainable resource, which is in abundance. It can generate direct current electricity without environmental impact or contamination. The PV system is static, quiet, and free of moving parts, and so there are less operation and maintenance costs. For supplying to the ac loads [12], solar generation module consists of the PV arrays for generation and a control unit to track the phase of the utility voltage, a DC/AC inverter stage, an isolation transformer to ensure that DC is not injected into the network, an output filter to restrict the harmonic currents into the network etc. The Phase Locked Loop (PLL) technique is used for synchronization with the utility grid. The characteristic equations [13] of PV arrays are used for modeling the same.

C. Battery Energy Storage System

For storing the surplus energy from the renewable sources, battery energy storage system is used, which is charged during off-peak hours via a converter to convert ac into dc. During discharge, the dc is transformed by the converter to ac, which is delivered for meeting energy demands during peak hours. Thevenin's equivalent model [14] is obtained for modeling of Battery Energy Storage System (BESS).

IV. INTELLIGENT CONTROL SYSTEM

Modern control technologies provide more robustness, efficiency and flexibility to the power system which realizes the Smart Grid concept. Smart Grid concept is an emerging technology these days, which enables the participation by the customers. This provides power quality and reliability. Increased energy demand necessitates more decentralized generation due to changing market operations and more complex distribution systems. Therefore, it is difficult to manage the network from a central system. The intelligent control system technology provides secure and reliable operations of the system. The smart Building Energy Management System (BEMS) is an application of the same. The Energy Management System (EMS) [15] in a commercial building aims to improve the environment within the building and minimizes the energy consumption.

The intelligent control system, described in this paper, is a multi-layered agent-based control system [1] made up of multiple agents including four agents. An 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. The agents are switch agent, central controller agent, local controller agents and load agent.

A. Switch Agent

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

B. Central Controller Agent

*T*he central controller agent coordinates grid, microgrid, and all the critical and noncritical loads and ensures the customers' comfort. All the control action is performed by the central controller agent. The overall comfort within the building is defined by the comfort factor, which is given by the expression:

$$\text{Comfort factor}=m_1\,[1-(e_T/T)^2]+m_2[1-(e_L/L)^2] \qquad (2)$$

where:

m_1 and m_2 are the weighting factors of temperature and illumination respectively, e_T is the error between the set and the final values of temperature, e_L is the error between the set and the final values of illumination, T is the set value of temperature and L is the set value of illumination.

The value of comfort factor lies between 0 and 1. The customers' comfort is ensured when it is greater than 0.9.

C. Local Controller Agents

The local controller agents are fuzzy controllers for controlling comfort factors like thermal and visual comforts.

D. Load Agent

The load agent controls all the noncritical loads. This disconnects the noncritical loads based on their priority. The energy that is saved from the controlled disconnection of the noncritical loads can be utilized later by the critical loads for providing necessary comfort.

V. FUZZY LOGIC CONTROLLERS

Fuzzy control [16] 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 between 0 and 1.

A. Fuzzy Controller for Temperature Control

A fuzzy controller is developed [17] for maintaining the indoor thermal comfort in the commercial building. The inputs to this fuzzy controller are the error in temperature and the change of errors and the output is the required power.

The fuzzy rules for the temperature controller are shown in table I.

TABLE I. FUZZY CONTROL RULES FOR TEMPERATURE CONTROL

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

B. Fuzzy Controller for 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 [18] is used for providing a comfortable illumination.

The fuzzy rules for the illumination controller are shown in table II.

TABLE II. FUZZY CONTROL RULES FOR ILLUMINATION CONTROL

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

VI. ENERGY MANAGEMENT USING INTELLIGENT CONTROL SYSTEM

The aim of the control system design for energy management in smart commercial buildings is to minimize the energy consumption and to ensure the customers' comfort. For the same, an intelligent control system is used here, which is mentioned below.

The energy demand in all areas is increasing day by day. But the generation by the conventional methods cannot meet all these demands. Therefore renewable energy sources find relevance to meet the increased energy demand. Insufficient energy to meet the entire increased energy requirement may adversely affect the performance of critical loads like those in hospitals, commercial buildings etc., since such loads always require continuous power supply.

As generation is scarce for the increased energy requirement, proper energy management is required. This work aims at developing an intelligent control system for proper and required usage of energy within a smart commercial building. The main purpose of energy management is not just to minimize the energy consumption but also to ensure customers' comfort. The intelligent energy management system implemented here employs fuzzy controllers [17] for the critical loads. For the continuous power supply, distributed generation using renewable energy sources is essential which can supply power locally as per the need. This makes the building self reliant. Here, photovoltaic arrays and wind turbines [6] are used as the renewable energy resources.

The critical loads in the commercial building include lighting and air conditioning systems, providing visual and thermal comforts within the building environment. Overall comfort is ensured within the building for improving the quality of life and productivity within the building. The noncritical loads within the building are swimming pool pump, fountain pump and decoration lamps. The energy management system, introduced here, reduces the total energy consumption within the building and the saved energy can be utilized for further usage by the critical loads when required. This ensures visual and thermal comforts. This is the basis of the control system design. The energy management system designed here manages the noncritical loads for minimizing the total energy consumption within the building. It gives more preference to the critical loads by giving continuous supply to the critical loads and properly managing the noncritical loads with required connection and disconnection of the same using the load agent. Thus the total energy consumption within the building is reduced.

VII. CONTROL SCHEME

The control scheme is explained as below:

Here, the renewable energy sources [6] are used to supply energy to the loads within building, which makes the building self-reliant. For optimum usage of energy by the critical loads (lighting and air-conditioning systems), fuzzy controllers [16] are implemented in the critical loads. They properly select the illumination and temperature levels according to the set values. The set values are the customers' preferences. The fuzzy logic controllers select the required illumination and temperature values considering the set values given by the customers. This minimizes the energy consumption of the critical loads and also ensures the customers' overall comfort within the building. If the energy requirement of the critical loads cannot be met by the microgrid, then noncritical loads like swimming pool pump, fountain pump and decoration lamps are properly managed so that the saved energy from them can be utilized by the critical loads [10]. Proper control of noncritical loads is accomplished by generating proper control signals for the circuit breakers connecting the noncritical loads. At each step, each noncritical load is intelligently controlled for minimizing the total energy consumption within the building. If energy requirement by the critical loads is not met by the microgrid even after the proper management of noncritical loads, the same is met by the utility grid to ensure the overall comfort. The energy management is done with the help of the central controller agent, which is a MATLAB control program.

Genetic algorithm (GA) is an optimization technique which is based on natural genetics and natural selection. Optimization using Genetic Algorithm is done for further minimizing the power consumption [2]. This is done by selecting the optimized set values of illumination and temperature. The set values are optimized for the minimum power consumption with the available power as the constraint. The optimized set values can further reduce the energy consumption and thereby the total energy consumption within the building is reduced. The control scheme, in this case, is the same as mentioned above with the set values as the customers' preferences. The difference is that, in the second case, instead of the set values of illumination and temperature given by the customers, optimized set values of illumination and temperature are used. At each level of control, the total energy consumption is less when the set values of illumination and temperature are optimized when compared to the same when the set values are the customers' preferences. For ensuring the customers' comfort, the comfort factor is obtained using equation (2). If it is greater than 0.9, overall comfort is ensured within the building. A comparison is also carried out for the total energy consumption and the customers' comfort with the customers' preferences and the optimized set values.

VIII. SIMULATION AND RESULTS

This paper introduces an intelligent control system used for the intelligent management of energy in a smart commercial building. MATLAB is used to simulate the intelligent control system for energy management in the commercial building.

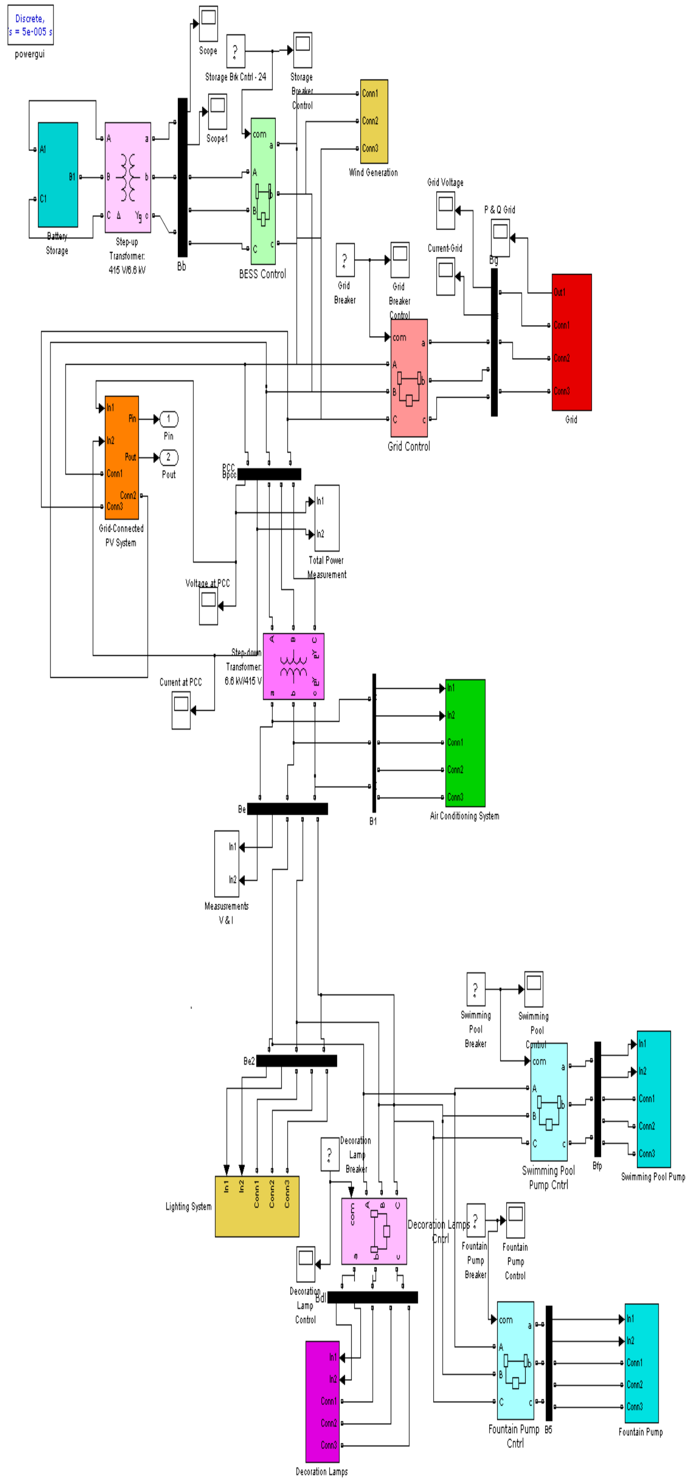

Fig. 2. MATLAB/Simulink model used for buiding energy management system

The MATLAB/Simulink model used for simulation is given in figure 2. The use of fuzzy controllers minimizes the energy consumption of the lighting and air conditioning systems by proper selection of illumination and temperature according to the customers' preferences. Proper energy management is accomplished with the control system described in this paper. Genetic Algorithm (GA) optimizes the set values of temperature and illumination. This minimizes the total energy consumption further. This is evident from the results, which are given below.

The comfort factors obtained are above 0.9 at each level of control, which means the customers' comfort is ensured within the building. With optimized set values, the comfort ensured is more when compared to the other case where the set values are the customers' preferences.

TABLE III. COMPARISON OF TOTAL ENERGY CONSUMPTION AT EACH LEVEL OF CONTROL OF STORAGE, NONCRITICAL LOADS AND GRID

	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-Customers' preferences	292884 Wh	292824 Wh	246248 Wh	244044 Wh	253980 Wh
Set values-Optimized	291510 Wh	273270 Wh	243410 Wh	242950 Wh	243460 Wh

TABLE IV. COMPARISON OF POWER CONSUMPTION WITH STORAGE, NONCRITICAL LOADS AND GRID

Time Period (Hr)	0	4.0000	8.0000	12.0000	16.0000	20.0000	24.0000
Power without Optimization (W)	1.0e+004 * 0	0.6154	1.1882	1.0825	1.1913	1.0902	1.1821
Power with Optimization (W)	1.0e+004 * 0	0.5899	1.1390	1.0376	1.1420	1.0451	1.1332

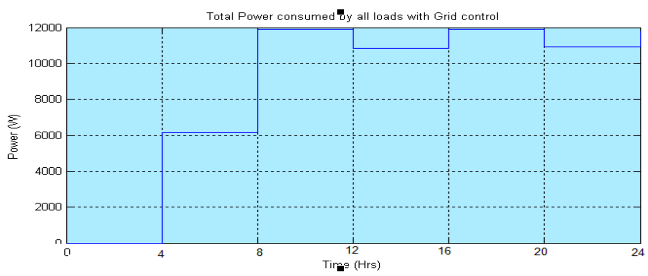

Fig. 3. The power consumed by the loads with storage, noncritical loads and grid controls (without optimization)

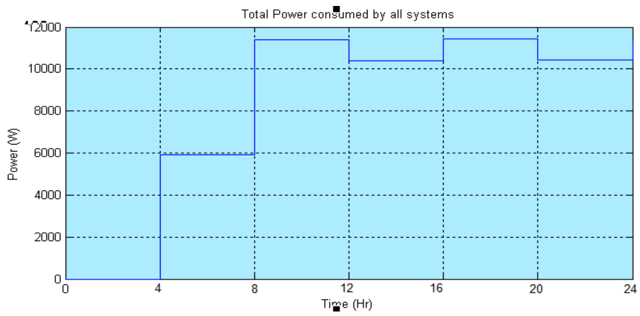

Fig. 4. The power consumed by the loads with storage, noncritical loads and grid controls (with optimization)

TABLE V. COMPARISON OF COMFORT FACTORS WITH STORAGE, NONCRITICAL LOADS AND GRID CONTROLS

Time Period (Hr)	0	4.0000	8.0000	12.0000	16.0000	20.0000	24.0000
Comfort factors without Optimization	-Inf	0.9260	0.9753	0.9991	0.9987	0.9892	0.9781
Comfort factors with Optimization	-Inf	0.8846	0.9992	0.9959	0.9991	0.9878	0.9992

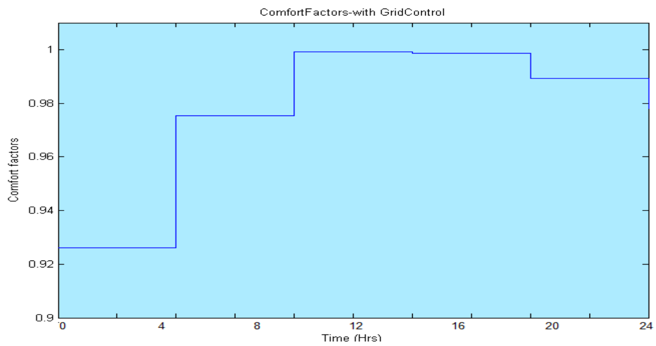

Fig. 5. The comfort factors with storage, noncritical loads and grid controls (without optimization)

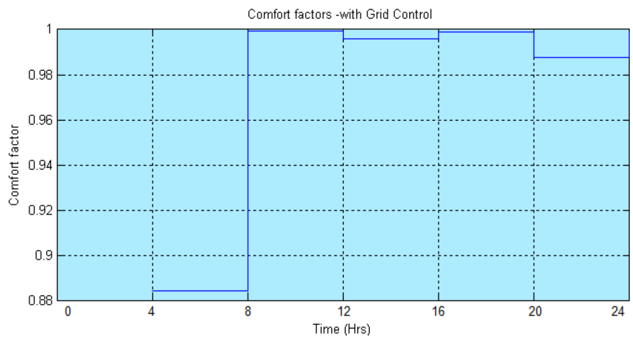

Fig. 6. The comfort factors with storage, noncritical loads and grid controls (with optimization)

IX. CONCLUSION

In the explained intelligent energy management system, in this paper, environmental friendliness is ensured with the use of microgrid technology. The microgrid uses PV arrays and wind turbines. The intelligent control system performs its function, which is evident from the results given here. The energy consumption within the building is minimized with proper control of storage, noncritical loads and grid. The customers' comfort is also ensured, which is evident from the values obtained for comfort factors which are greater than 0.9. Optimization, done with Genetic Algorithm (GA), further reduces the total energy consumption within the building, which makes the building more energy efficient.

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