Management of Energy and Comfort Facilities in Modern Buildings using Fuzzy Logic

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Abstract

The electricity supplied by the utility grid is insufficient to meet all the load requirements due the rising trend of power utilization. For this purpose de-centralized energy generation or Micro-grid technology is used in parallel with the utility grid. Energy Management Systems (EMS) in smart buildings and homes are used to control Heating, Ventilation and Air-conditioning (HVAC) systems. Moreover, this system efficiently manage and control the usage of electricity, reduce unnecessary wastage of electrical power and at the same time provide comfort to the occupants of the building up to their desirable level. In this study, various control methods such as PID controllers, fuzzy logic controllers and multi-agent control systems are discussed for optimization of electrical energy and comfort features in modern near-zero energy buildings. In addition fuzzy logic and PID controllers for temperature regulation of airconditioning system is also presented.

***Index Terms**:*

Micro-grid, energy management system, PID controller, fuzzy logic controller, multi-agent control system, genetic algorithm, near-zero energy buildings.

I. Introduction

The demand of energy is increasing rapidly all over the world. Advancements and modernization in the power sector is the foremost important to cope with the deficit of electricity. Not only we need to generate surplus electricity but we also need to control the unnecessary wastage of energy in our everyday life. All the electricity demand cannot be fulfilled by the centralized electrical grid or macro-grid alone. We need to rely on other energy sources too, like renewable energy sources. Distributed or de-centralized energy production also known as micro-grid is a good alternative of utility grid to meet all the energy needs [1][3].

In recent decade, the residential and commercial sector is the most energy consuming sector. It is a need of the hour to optimize this energy utilization in buildings and homes besides not hampering the level of comfort of the users/occupants residing there. The factors like productivity, quality of life, health etc. of the human beings residing in a building is mainly dependent on the level of comfort that is being provided to them. The main factors or conditions of comfort of a person are related to temperature, humidity, lighting, air flow and rate of work [2]. In a broad sense, we can categorize comfort into two main classes: visual comfort and thermal comfort [3]. Thermal comfort is provided by HVAC system in buildings while lighting system is responsible for visual comfort. As the level of comfort increases, the demand of energy consumption also rises. Nowadays, when the world is facing with shortage of electricity especially in developing countries, there is a need to create a balance between utilization of electrical power and the comfort level of customers. This trade-off between energy consumption and comfort level is achieved through various intelligent control systems. These control systems include PID, fuzzy logic, multiagent etc.

According to recent policies, it is of utmost priority that all newly constructed buildings shall be energy efficient and are required to be Near Zero Energy Buildings (NZEB) [2]. This means that they shall have energy saving mechanisms in them which will prevent unwanted expenditure of electricity. Moreover, greater consumption of energy also increases the Operation and Maintenance (O&M) cost of a building. Total energy consumption of a building can be minimized by saving the surplus energy in battery storage banks. This can be achieved through proper management of electric power while at the same time ensuring the guaranteed operation of the critical loads. The energy stored by the battery storage system can be utilized later on by the essential loads [4]-[5].

This paper is organized as follows: Section II is about the literature review. Intelligent systems in building is presented in section III. Analysis and results of a fuzzy based method to control temperature of HAVC system is discussed in section IV. Discussion and future recommendation is mentioned in section V and section VI simultaneously. Section VII concludes the paper.

II. Literature Review

The major load contributors in a building are normally associated with lighting and HVAC systems. The solar irradiation has also an indirect effect on the electricity consumption of a building. In modern buildings, dynamic shading control systems are employed to optimize the use of electricity and manage the adverse effects of sunlight, caused in terms of excess heat, in order to attain a suitable trade-off between comfort level and power consumption [6]. Change in different parameters of the room such as window size, glass transmittance, and wall reflectance can result into different configurations of the room. These different variations of the room can cause an impact on the fuzzy logic control system to achieve an optimal balance between the thermal and comfort levels in the building.

Several studies regarding various intelligent control schemes and algorithms for optimization of energy and comfort management in buildings has been conducted by different researchers. These control systems include both classical/traditional and adaptive/optimal controllers. The various types of traditional controllers are Integral (I) Controller, Proportional Integral (PI) Controller and Proportional Integral Derivative (PID) Controllers. Whereas the adaptive controllers are used where supervisory control and data acquisition system is being implemented. The optimization function of predictive controller is dependent on the value of future reference point [7][8]. Adaptive fuzzy controllers are able to change their behavior according to the external temperature, humidity and illuminance conditions and self-regulate them according to the user demand in the various buildings. The most popular adaptive controller is fuzzy adaptive controller.

Fuzzy method used to control lighting systems and it has been found to be an easy solution when optimization of lighting, thermal and comfort aspects are dealt with. It is mainly concerned about efficient improvements in energy consumptions in a room using fuzzy logic control.

An intelligent multi-agent control system for effective management of energy in commercial offices and buildings is presented in [3]. An autonomous micro-grid technology consisting of renewable wind and photo voltaic systems is used in conjunction with the conventional power supply. Airconditioning and Lighting systems being the essential entities of a building are referred to as "critical loads" while all other loads are called "non-critical loads". The control system based on multi-layered agent topology consists of four agents: switch agent, central controller agent, local controller agents and load agent. Fuzzy logic controllers are used to control the critical loads. Fuzzy controllers tune the temperature and illumination intensities according the preferences fixed by the user. That is how energy optimization is achieved through fuzzy controllers while at the same time ensuring user's overall comfort level [9]. Furthermore, genetic algorithms are used for further energy optimization within the building, thus making it more efficient in terms of power utilization.

III. Intelligent Systems In Buildings

There are several different variations and applications of intelligent controllers in smart buildings including fuzzy logic based controllers, neuro-fuzzy logic controllers, adaptive fuzzy PD and adaptive fuzzy based PID logic controllers [10]. The block diagram of fuzzy logic controller is shown in Figure-1.

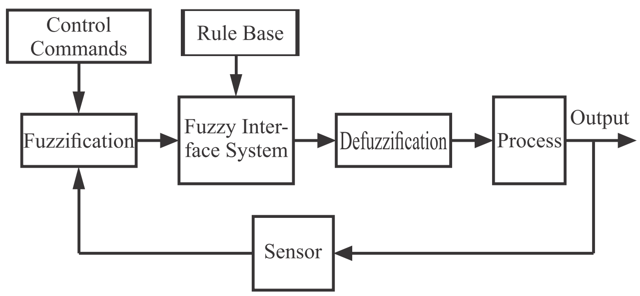

Fig. 1 Block diagram of fuzzy logic controller

A. Fuzzy Logic Based Controllers

Fuzzy control logic is actually an algorithm based on mathematical modeling. It is used to deal with uncertain conditions [1]. In fuzzy logic, the values of variables range between 0 and 1 in comparison with the crisp digital logic. Control systems based on fuzzy logic are efficient in governing complex systems, which cannot be represented in a systematic way. They are capable of taking input from the user or human operators and convert them into a linguistic, rule-based engine: the operation and control philosophy is generally governed by a set of "if-then" rules [11]-[12]. These rules allow programming of fuzzy control process based upon past knowledge and understanding, without having know-how of the involved phenomena.

B. Neuro-Fuzzy Logic Controllers

These hybrid systems arise when neural systems are used in fuzzy logic control methods. Such systems find great applications in optimization of energy in modern buildings [13].

Moreover, genetic algorithm is an optimization technique that is based on human biological genetic system and natural selection. This technique is utilized to further optimize the energy consumption is buildings, hence reducing the total energy consumed by the critical loads in a building. This is achieved by choosing the optimized desired values of temperature and illumination instead of the values defined by the customers or building users [3]. The user's set values are adjusted for the minimum power utilization with the available power as the constraint.

C. Adaptive Fuzzy PD and Adaptive Fuzzy Based PID Logic Controllers

Such systems have replaced the conventional PD and PID controllers. Adaptive fuzzy based PD controller uses a 2nd degree equation as a reference model to determine the gains values of the controller [14]. The output of a precisely designed adaptive fuzzy PD controller is much closer to behavior of the desired model of the building. By using adaptive fuzzy PID controllers, the controller gains are selected much more accurately; so optimization results are achieved closer to the desired results.

IV. Analysis And Results of a Fuzzy Based Method to Control Temperature of HVAC System

The Figure 2 presents the PID and fuzzy logic control model for a typical building temperature control of HVAC system. The input to fuzzy controller is the error signal and the rate of variation in error or its derivation function. The output of fuzzy controllers is given as inputs to the HVAC system. The output of the HVAC system is given as a negative feedback to the controllers to make a closed-loop system. The fuzzy logic controller for temperature is given in Figure 3.

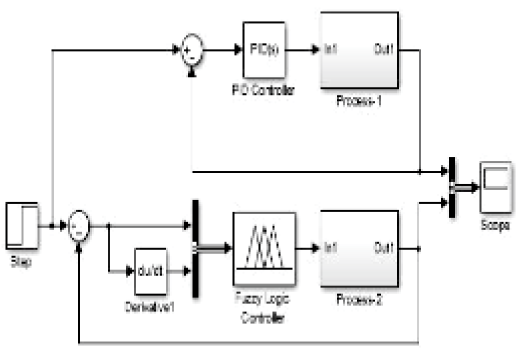

Fig. 2. MATLAB SIMULINK Model to Control Temperature of HVAC System using PID and Fuzzy Control System

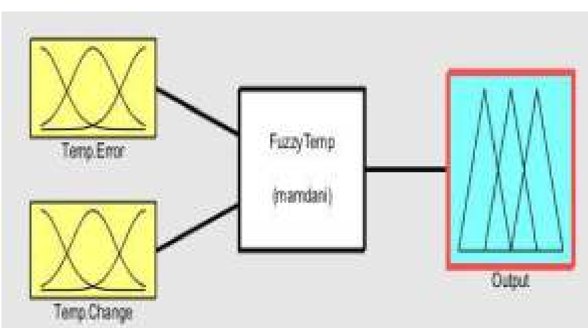

Fig. 3. Fuzzy Logic Controller for Temperature System

The input variables (temperature) in this control system are mapped into triangular membership function. The input and output variables are distributed into seven different ranges: Negative Large (NL), Negative Medium (NM), Negative Small (NS), Zero (ZO), Positive Small (PS), Positive Medium (PM) and Positive Large (PL).

The triangular input membership functions for input and output are depicted in Figures 4 and Figure 5 respectively.

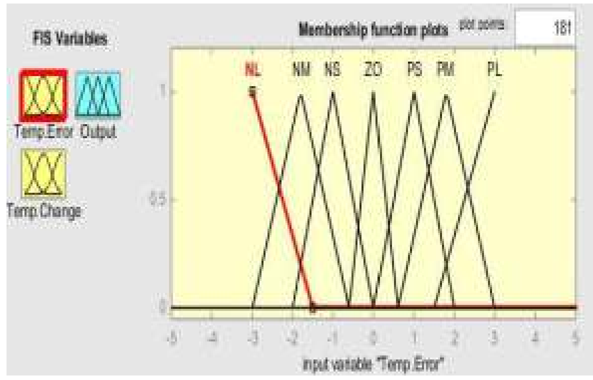

Fig. 4 Membership Function of Input

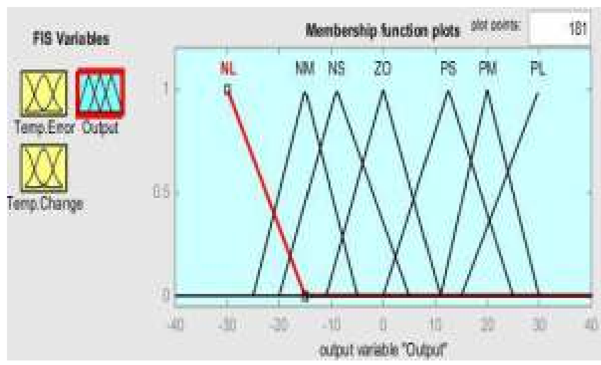

Fig. 5 Membership Function of Output

Rule development is shown in Table 1 which forms the basis of 49 fuzzy logic rules for this control system in the form of "If-Then" statements. The output of this fuzzy control system is the logical AND operation of the membership functions of two different inputs.
If the temperature error is NL and the rate of variation of error is also NL, then the output signal should be PL. According to Table 1, the rule viewer of the fuzzy logic control system is shown in Figure 6.

TABLE I. Fuzzy Logic Rules For Temperature System

Fuzzy Rules		**Error In Temperature System**						
		NL	**NM**	**NS**	**ZO**	**PS**	**PM**	**PL**
	NL	PL	PL	PM	PM	PS	PS	NS
	NM	PL	PL	PM	PS	PS	NS	NS
AE	**ZO**	PM	PM	PS	ZO	NS	NM	NM
	PS	PM	PS	PS	NS	NS	NM	NM
	PM	PS	PS	NS	NS	NM	NL	NL
	PL	PS	NS	NS	NM	NM	NL	NL

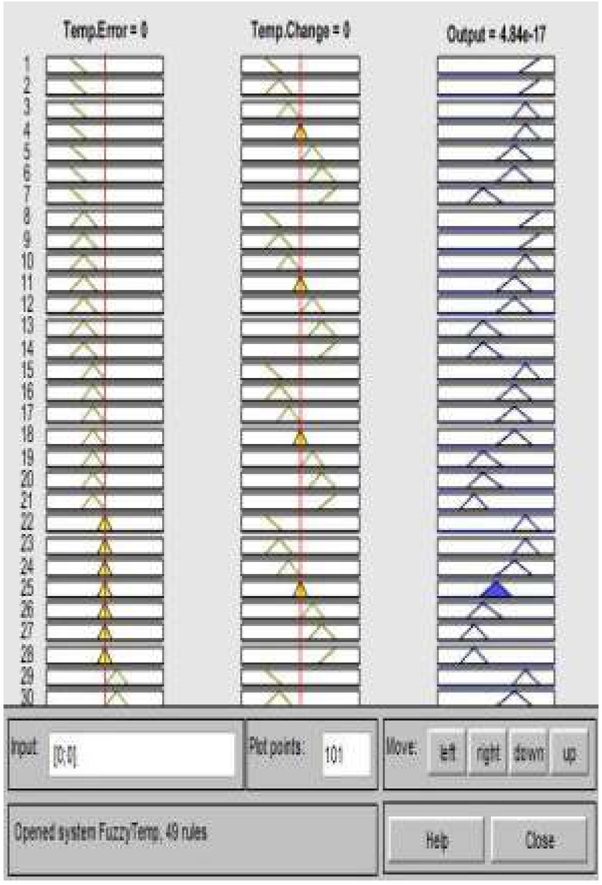

Fig. 6. Rule Viewer for Fuzzy Logic

The control surface of this fuzzy based control system is presented in Figure 7.

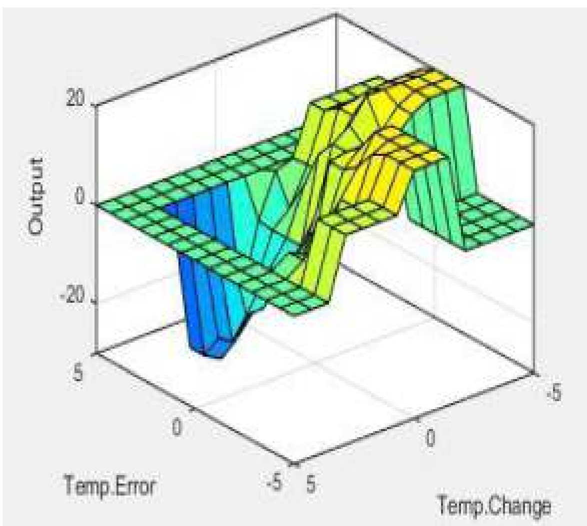

Fig. 7. Control Surface of this Fuzzy Logic Control System

Comparison of PID controller and fuzzy logic controller is shown in Figure 8. Here it can be seen that PID controller is giving more overshoot and settling time as compared to the fuzzy logic controller.

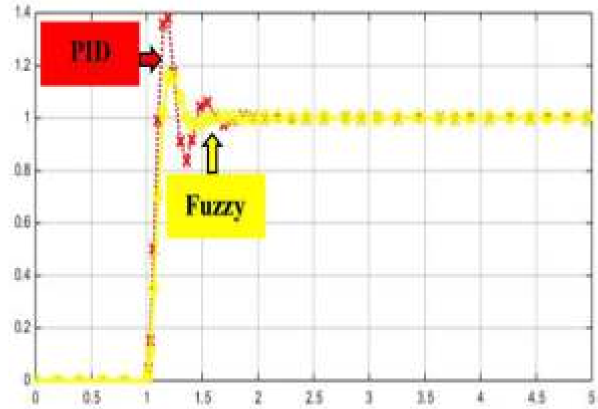

Fig. 8. Comparison of PID vs Fuzzy Logic Control System

V. Discussion

Different control methods or schemes that can be deployed for building energy and comfort management systems are discussed in this study.

Now-a-days, the controllers commonly used in buildings are based on fuzzy logic approach instead of the traditional controllers. The fuzzy controllers are based on logical reasoning which forms the basis of a rule table. Such controllers give optimal performance when the values of input and output gains are selected appropriately and the rules are defined properly. The controllers used in modern buildings are used to cut-down the increasing usage of electricity while at the same time they ensure that suitable comfort level is provided to the building occupants.

The dependence on the national grid can also be reduced by using the concept of distributed energy sources, also termed as micro-grid. Micro-grid uses renewable energy sources such as wind power or solar energy. The integration or dis-connection of micro-grid with national grid is also carried out with the help of fuzzy controllers.

Agent based control systems use more than one fuzzy logic controllers that serve different purposes. In this type of system, one is the main controller which performs the overall control actions of the whole system. The other controllers are used for controlling or switching the loads, coordinating the integration of utility grid with the micro-grid and controlling various process variables.

VI. Directions For Further Work

The work presented in this report can further be extended by the establishment of a more comprehensive and precise identification of input statistics and more precise selection of fuzzy logic rules. The system could also be tested under other climatic conditions and different orientations of lighting and shading effects to reduce emissions of carbon dioxide, increase the indoor air quality and decrease the consumption of electricity in the buildings.

Although the fuzzy controller is robust, it may not be optimal for all operating conditions when membership functions or fuzzy rules are not properly selected. Thus, a self-tuning mechanism needs to be incorporated in the fuzzy control method in order to ensure its operability at its most optimal configuration. Self-learning or tuning can be achieved by the integration of fuzzy logic control system with the neural networks. Hence, more research in this area needs to be carried out.

VII. Conclusion

Fuzzy logic control system is a useful method to efficiently manage and control the energy consumption in a building while at the same time providing suitable comfort level to the building users. Its performance is far better as compared to the conventional PID controllers. Such a controller achieves the transient response at a faster rate and it has less overshoot, thus making its steady-state response more stable in contrast to PID controller. It design is also independent of a specific operating quiescent point as it does not require to be modeled mathematically. Such systems are based on logical decisions and artificial intelligence.

It is also worth mentioning from this study that the use of distributed energy sources can lower the dependence on the utility grid. The control and integration of the micro-grid with the main grid and overall system control is made possible through the use of intelligent fuzzy controllers.

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