Energy Efficiency Improvement on Demand Side Management for Active Distribution System by using Fuzzy Inference System

[1] Zin Wai Wai Lwi, [2] Okka, [3] Zarchi Linn
[1, 2, 3] Department of Electrical Power Engineering, Yangon Technological University, Insein Township, Yangon, Myanmar.
[1] zinwaiwailwin1989@gmail.com, [2] okkamon@gmail.com, [3] zclinn@gmail.com

Abstract: *Since electrical energy is the form of energy that cannot be effectively stored, it must be generated, distributed and consumed immediately. The power plants are designed to meet the maximum demand as load on power plant is variable. If there is a large difference between peak demand and average demand, it results in high generation cost per unit. One of the technical challenges of active networks is to maintain an acceptable voltage level. This problem has initiated many researchers to control network voltage profile. Several approaches to mitigate the voltage issues include the use of coordinated or centralized and decentralized methods. Demand Side Management (DSM) is one of the most important aspects in active distribution network towards energy efficiency. This paper provides that Demand Side Management (DSM) of typical home is implemented for load control scheme to be smooth demand load curve for improving voltage profile.*

Keywords: *Demand Side Management; Energy Efficiency; Load Control Scheme.*

1. INTRODUCTION:

Electricity is the most versatile and widely used form of energy, as such, global demand is growing continuously. However, electricity generation is currently the largest single source of greenhouse gas emissions, making a significant contribution to climate change. There are approaches within the developed world to reduce reliance on fossil fuels and move to a low-carbon economy to guarantee energy security and mitigate the impact of energy use on the environment. To mitigate the consequences of climate change, the current electrical system needs to undergo adjustments. The solution to these problems is not only in generating electricity more cleanly, but also in optimizing the use of the available generating capacity. To achieve such optimization, the smart grid comes into play [1] [2].

Evolution from typical electromechanical meters to modern smart meters will enable a reliable communication link all over the grid system making it easy to monitor and control. Smart meters will be capable of handling real time information to improve the efficiency of power delivery and usage. A smart meter can set the temperature value below the reference value at off-peak demands for home appliances such as refrigerators or air conditioners. Smart meters will support demand side management. Demand side management will enable customers to make decisions when they will use electricity and how much [4].

Demand for electricity should be made more adaptive to supply conditions, avoiding peaks of demand, resulting in a more efficient grid with lower prices for consumers. As a result, the new electrical grid intends to get an economic balance and increase the efficiency of the current the electrical supply. Energy efficient technologies such as intelligent controls systems that adjust the heating temperature, lighting can help with the management of consumption in buildings and houses. This intelligent control system which introduce the concept of smart home can give consumers control over the amount of electricity they use [3] [5] [6].

This paper is focused on Demand Side Management (DSM) that are designed to encourage low consumption by the consumer during peak hour to shape the utility load curve. By scheduling the appliances, heavy loads are shifted from peak hour to off peak hour according to their energy consumption profile to be smooth demand load curve for typical home system. The rest of the paper is discussed about active distribution network, demand side management, load control scheme and results in selected case study and then is concluded.

2. DEMAND SIDE MANAGEMENT IN ACTIVE DISTRIBUTION NETWORK:

The main function of electric distribution networks is to transfer power between the bulk power system and end customers as well as to carry out the required voltage transformations. This section of the power system plays the largest role in the power quality perceived by the consumers. The main components of an active distribution network are distribution substations, primary distribution feeder distribution transformers, distribution cabling, metering and control equipment, and distributed generators The operation of active distribution network is realized by centralized systems such as Distribution Management System (DMS) which is monitoring and controlling devices at primary substations and medium voltage feeders to enhance medium voltage network reliability [8] [10].

Distribution Network Automation could be in the form of a communication system that controls the customer load and reduces peak load generation by automatic load management. It may also be a more extensive system where an unattended distribution substation can be transformed to an attended one by installing an onsite microprocessor which monitors the substation continuously, make operating decisions, issue commands or reports changes in the system to the load dispatch center, store data for future use depending on the requirements of the utility. The functions of distribution network automation are load management, operational management and remote meter reading [7].

Demand Side Management

Demand side management (DSM) commonly refers to programs implemented by utility companies to control the energy consumption at the customer side of the meter. These programs are employed to use the available energy more efficiently without installing new generation and transmission infrastructure. DSM programs include conservation and energy efficiency programs, fuel substitution programs, demand response programs, and residential or commercial load management programs. Residential load management programs usually aim at one or both of the following design objectives: reducing consumption and shifting consumption. The reducing consumption program can be achieved among users by encouraging energy aware consumption patterns and by constructing more energy efficient buildings. However, there is also a need for practical solutions to shift the high power household appliances to off peak hours to reduce the peak-to-average ratio (PAR) in load demand. Appropriate load shifting is foreseen to become even more crucial as plug in hybrid electric vehicles [11].

Demand side management (DSM) is used to describe the actions of a utility, with the objective of altering the end use of electricity, whether it be to increase demand, decrease it, shift it between high and low peak periods, or manage it when there are intermittent load demands. In other words DSM is the implementation of measures that can help the customers to use electricity more efficiency. Existing approaches to reduce demand have been limited to either directly controlling the devices used by the consumers or to providing customers with tariffs that deter peak time use of electricity. With the deployment of smart meters, it is possible to make real time measurements of consumption, providing every home and every commercial and industrial consumer with the ability to automatically reduce load in response to signals from the grid. Demand-side management is designing automation technologies when faced with uncertainty in predictions of future demand and supply [6].

The six main types of load shape objective in Demand Side Management (DSM) are shown in fig 1.

Fig.1 The six main types of load shape objective in Demand Side Management (DSM).

DSM includes all measures, programs, equipment and activities that are directed towards improving efficiency and cost effectiveness of energy usage on the customer side of the meter. Primary reasons for implementing DSM are shortage of supply, and distribution network overload during peak loads.

Implementation of DSM has proved to be advantageous to both consumers and the utilities.

For the consumer:

- Delay in the next price rise for electricity.
- Efficient operation of equipment and hence reduced overall energy bills.
- Chance to participate in the planning stages of a new DSM scheme of a network management programme.

For the utility companies:

- Improved load factor (difference between the peak and valley loads on the load curve)
- Building of new generation units and setting up associated transmission, distribution networks or reconfiguring the existing infrastructure is delayed. This is an economic option and also reduces the pollution levels.
- The utility can design load curves such that loads perform efficiently and also the network is not overloaded at peak demand intervals. Hence preventing deterioration of network infrastructure and frequent maintenance.

3. CASE STUDY OF DSM FOR TYPICAL HOME IN STAR CITY COMPOUND, THANLYIN TOWNSHIP:

This paper is focused on Star City Compound which is located along the shore of Bago, river, it is 135 acres residential development located in Thanlyin Township, Yangon Division, Myanmar. It will comprise approximately 10,000 apartments, hospital, school, restaurant and shopping center. The Star City compound is composed of four types of residential building which are Building A, Building B, Building C, and Galaxy Tower. Currently, the maximum power demand is 650.7kW which is the only for Building A, and Building B as the rest of the building are in no used due to under construction. There are one bed room model (82m^2), two bed room model (85m^2) and three bed room model (115m^2) and four bed room model (139m^2). In this paper, two bed room model is sampled for typical home to implement Demand Side Management (DSM). The single line diagram for the Star City compound is shown in fig 2. The 33/11 kV substation in which 20 MVA transformer with 16 feeders supplies to all the building of star city compound.

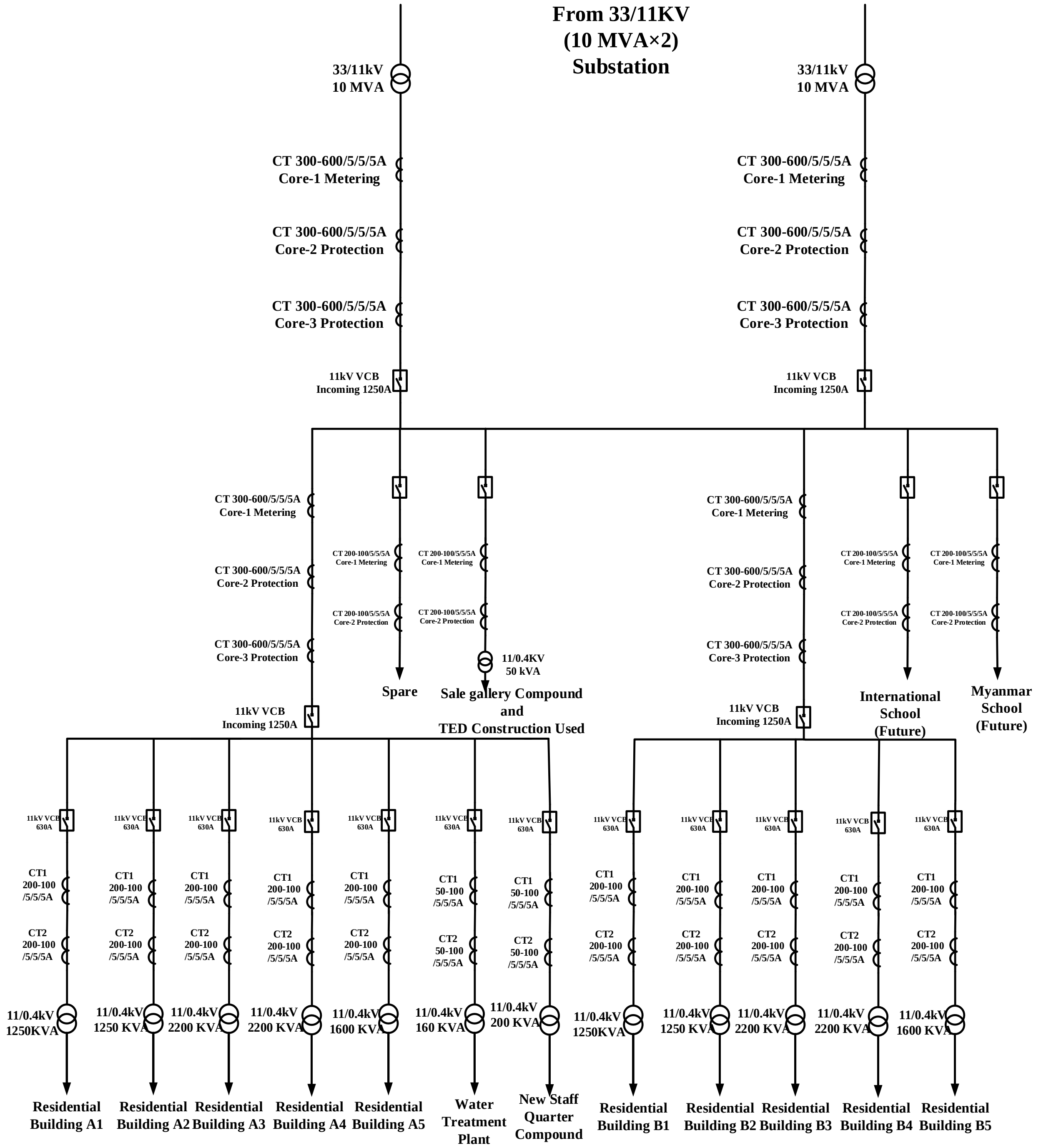

Fig.2 Single Line Diagram for Star City Compound

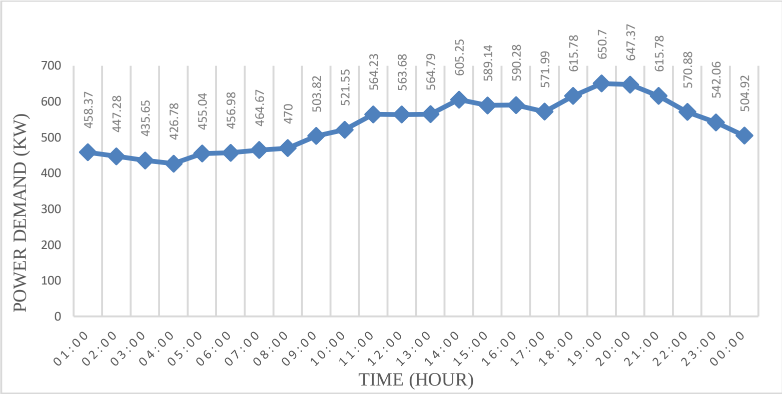

Fig.3 The power demand curve of star city compound for a day.

From the fig 3, the peak demand is 650.7kW at 7:00 pm and the valley demand is 426.78kW at 4:00 am. The average demand is 537.875kW for a day. If DSM objectives such as peak clipping and valley filling is applied, this daily load curve will be flatter load curve. The flatter load profile means that load factor is improved to this distribution network. The flatter load profile can lower whole sale price and defer grid investment costs. DSM can decrease the overall electricity wholesale price by reducing peaks so that the more expensive peaking plants are called on less.

Table 1. Appliances used in the load control scheme

Appliance	Power (W)	Quantity	Hours per day	Cycles per Day	Day Shift	Category
Air-con for Living and Dining Room	1300	1	6 hrs	12	After -noon	Temperature Controller
Air con for Master Bed Room	1100	1	6 hrs	12	Night	Temperature Controller
Air con for Second Bed Room	700	1	6 hrs	12	Night	Temperature Controller
Water heater	1200	2	2 hrs	4	Morning	Temperature Controller
Washing Machine	3000	1	1 hr	2	Any	Wet
Fridge	150	1	24 hrs	48	All	Cold
Coffee Maker	500	1	30 mins	0.5	Morning	Cooking
Microwave	1400	1	1 hr	2	Morning	Cooking
Kitchen	1000	1	2 hrs	4	Morning	Cooking
LED Round Down Light (L3)	24	5	12 hrs	24	Night	Lighting (Dinning)
LED Round Down Light (L4)	12	8	12 hrs	24	Any	Lighting (Living)
LED Round Down Light (L4 A)	12	2	12 hrs	24	Night	Lighting (Bed Room)
Compact Fluorescent(TCD) Bulk Head Light	18	1	12 hrs	24	Morning Night	Lighting (Kitchen)
Television System	500	2	12 hrs	24	Any	Entertainment
Laptop	200	2	12 hrs	24	Any	Periodic Load
Hair Dryer	1000	1	30 mins	1	Any	Personal Care
Clothes Iron	1000	1	2 hrs	4	Any	Miscellaneous

The smart meter has the responsibility of releasing load for each appliance, monitoring the set of appliances, control the peak of demand per cycle and control the limit of load per day, and prioritizing the order that the appliances demand power, If the appliances that need operate during all day should demand power first, after that coming the morning appliances, afternoon appliances, night appliances, and just after those appliances the "Any" appliances can demand load. The appliances have to monitor their operating window, request the necessary load from the smart meter at the start of an operating window and in each cycle, negotiate with the smart meter if can operate or should wait until next cycle. If an appliance demand 100W and there is 90W remaining, the smart meter will not release any load. In this scenario the smart meter just controls if the limit of load per cycle and limit of load per day is not violated, the first appliance that demand will be served.

4. LOAD CONTROL SCHEME USING FUZZY INFERENCE SYSTEM (FIS):

In the load control scheme, the load is classified into temperature controller, wet appliances, cold appliances, and life style appliances such as lighting, cooking appliances, entertainment, periodic load and miscellaneous appliances upon their categories. All devices is considered in this model have only two possible states, ON and OFF, and change between these states via their internal schedule or an external command. For this model, typical domestic profile is considered with fixed time intervals consisting of single days divided in period of half hour. Each time slot t ϵ T where T=1, 2, 3…48. The working hour per day and cycles per day of each appliances is shown in Table 1.1. As shown in Table 1, all appliances have their priority on day shift. If an appliance has the value "Any" in its day shift, it means there is no priority to this appliance, it can operate in any cycles and it is needed to control upon customer comfort index, peak reduction index and suitable index with fuzzy inference system.

1. Customer Comfort Index

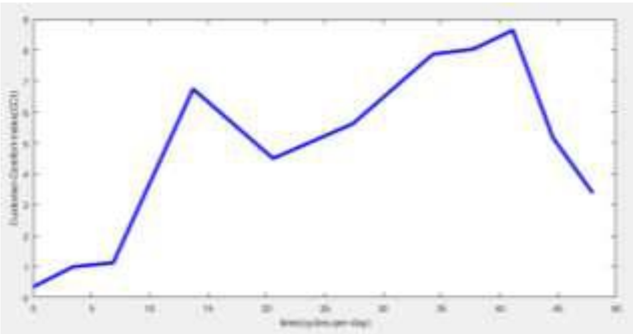

Fig.4 The customer comfort index of washing machine for cycles per day

In this case, the input variable is time (cycles per day) which ranges from 0 to 48 as well as the output variable is customer comfort index (CCI) from 0 to 9. It has 8 rules for Fuzzy Inference System (FIS) which is applied for all "Any" day shift loads although the rule priority changes according to the customer desired. The customer desired rules for each controllable load is different. The valley period for washing machine with customer comfort index is in 0 cycle whereas the peak period is in 41cycles as shown in fig 4.

2. Peak Reduction Index

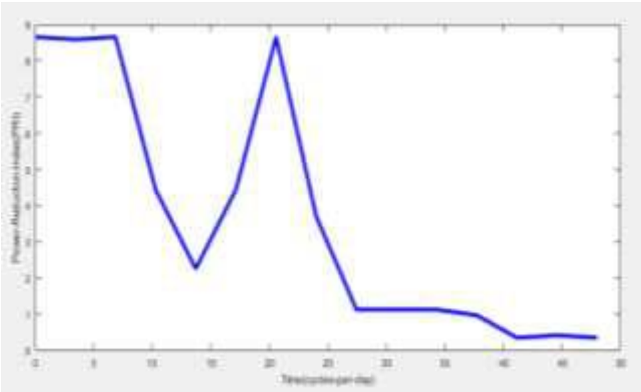

Fig. 5 The peak reduction index of washing machine for cycles per day

In the evaluation of peak reduction index, the input variable is time which range is same as the customer comfort index and output variable is peak reduction index (PRI). It has also 8 rules for Fuzzy Inference System (FIS) which is applied for all "Any" day shift loads. These rules do not differ on varying the types of loads because peak reduction index depends on the daily load profile. Its peak and valley period is opposite to the customer comfort index curve. The above figure shows the peak reduction index for washing machine.

3. Suitable Index Based on Customer Comfort Index and Peak Reduction Index

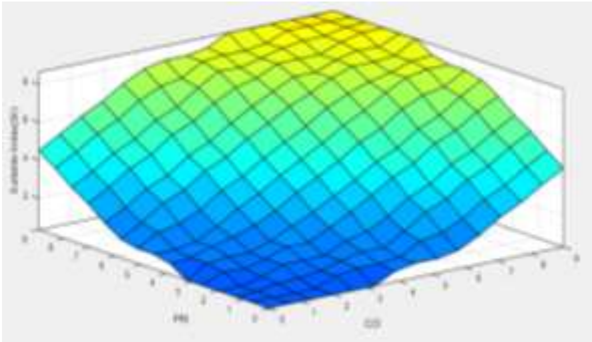

Fig. 6 Suitable Index between Customer Comfort Index and Peak Reduction Index for washing machine

The suitable index with 81 rules is the optimize solution between customer comfort and peak reduction. The FIS input variable is customer comfort index and peak reduction index and output variable is suitable index. The maximum suitable index is the condition both PRI and CCI is the maximum whereas the minimum suitable index is both of which is zero which is shown in fig 6. According to the suitable index, the "Any" day shift loads is implemented into the Demand Side Management Program (DSM) to give the optimization load profile.

5. RESULTS:

For the demand side management of a typical home, three load control schemes are implemented based on FIS system. In the load control schemes, the based loads are operated at the specified times (cycles). The loads mentioned as 'Any' in Table 1 will operate according to the selected load control scheme. In CCI scheme, the 'Any' loads will operate at customer leisure times. In PRI scheme, the 'Any' loads will turn on while the load demand is minimum. In case of SI, the 'Any' loads will operate by taking into account the conditions of customer availability and low demand of the system. The operation of each 'Any' load is determined by the corresponding FIS system presented in the previous section. The resulting daily load curve for the typical home with customer index, peak reduction index and suitable index with Fuzzy Inference system are shown in Fig 7.

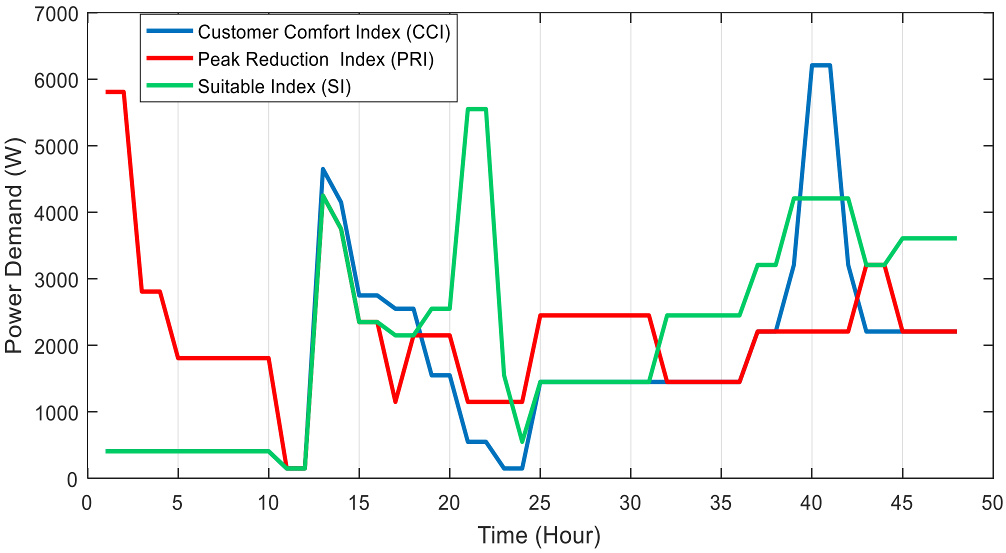

Fig.7 The comparison of power demand in three scenario

The total kWh consumed in these three different scenarios such as CCI, PRI and SI is the same however the value of peak power demand and cycles are different according to each scenario. In the case under study, the energy consumption per day for a typical home is 53.088 kWh. In case of CCI, the peak power demand is 7208W which is occurred at 41 cycles but the peak power demand of PRI is 5808W at 1 cycle. The value of peak power demand for the case of SI is only about 5550W at the 22 cycles. As the reduction of peak power demand, the load factor in the case of SI is increased comparing with the load factor in the case of CCI. The comparison of different load factor in different scenarios is shown in figure. These load factor is calculated by the following equation.

$$\text{Load Factor} = \frac{\text{Total Kilowatt Hour for a day}}{\text{Peak Demand } \times \text{Hour per day}}$$

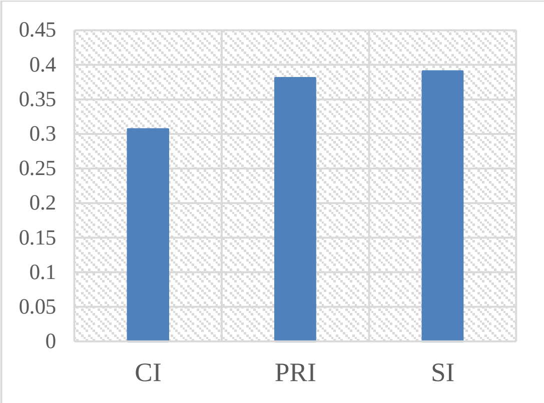

Fig.8 The comparison of load factor for each scenario

As shown in Fig 8, the load factor for SI is maximum with the value of 0.3986. The load factor value for PRI is about 0.3809 and that for CI is 0.3069. According to the results, the load factor can be improved significantly by SI load control scheme with minimum load demand. With the reduction in maximum demand, the current drawn and hence the voltage drop in the system can be reduced. Load factor are a simple, but accepted measure of distribution system efficiency. As load factor, in essence, means energy efficiency, by improving load factor in Demand Side Management (DSM) technique, the energy efficiency is improved in active distribution network.

6. CONCLUSIONS:

Demand Side Management (DSM) has reformed the traditional mode to construct a new power plant in order to meet the demand. DSM optimize the consumption manner and improving the power consumption efficiency. DSM is a strategy to save energy, reduce consumption and environment improvement. DSM programs facilitate users to shift loads from peak hours to off hours to reduce peak load. In this paper, three load control schemes based on FIS system are presented. The 'Any' loads in a typical home are scheduled to operate at a specific cycle determined by corresponding FIS system. By scheduling the appliances, heavy loads are shifted from peak hour to off peak hour according to their energy consumption profile to be smooth demand load curve for typical home system. The flatter load curve gives the improvement of load factor which means that the energy efficiency is improved in active distribution network.

7. ACKNOWLEDGEMENT:

The author expresses her thanks to her supervisor Dr.Okka who is professor and head of Electrical Power Department, and Dr. Zarchi Linn who is associate professor, Department of Electrical Power Engineering, Yangon Technological University, for their advice, good suggestions, directions, guidance, and supports.

REFERENCES:

1. Manisa Pipattanasomporn, Senior Member, IEEE, Murat Kuzlu, Member, IEEE, Saifur Rahman,Fellow, IEEE, and Yonael Teklu, Member, IEEE. "*Load Profiles of Selected Major Household Appliances and Their Demand Response Opportunities*", IEEE 1949-3053, 2013.
2. Subrata Mukhopadhyay, Senior Member, IEEE, and Ashok K. Rajput,"*Demand Side Management and Load Control – An Indian Experience*", IEEE, 978-1-4244-6551-4/10/$26.00 , 2010.
3. Ramiz Alaileh, Member, IEEE, Mohammed Yousif, Ahmed Fadul, Mark Preece. "*Energy Efficiency and Demand Side Management in Abu Dhabi*", IEEE GCC Conference and exhibition, Doha, Qatar, November 17-20, 2013.
4. Mario Šipoš, Mario Primorac, Zvonimir Klaić. "*Demand Side Management inside a Smart House*", Volume 6, Number 2, 2015.
5. Jingshuang Shen, Chuanwen Jiang and Bosong Li. "*Controllable Load Management Approaches in Smart Grids*", Energies, 11187-11202; doi: 10.3390/en81011187, 2015.
6. RodrigoMartins, Felipe Meneguzzi. "*A Smart Home model to Demand Side Management*", Proceedings of the 12th International Conference on Autonomous Agents and Multi-agent Systems (AA-MAS2013),Ito, Jonker, Gini and Shehory (eds.), Saint Paul, Minnesota,US, May,6 -10,2013.
7. Jayanth Krishnappa. "*Active Networks: Demand Side Management and Voltage Control*", Master of Science in Energy Systems and the Environment, September 2008.
8. NetworkSami Repo, Shengye Lu , Timo Pöhö ,Guillermo Ravera and Felipe Alvarez-Cuevas Figuerola "*Active Distribution Network Concept for Distributed Management of Low Voltage*", 4th IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe) Copenhagen, October 6-9, 2013.

9. Swati Singh, Surabhi Chandra. "*Energy Efficiency and Demand Side Management*", International Advanced Research Journal in Science, Engineering and Technology (IARJSET) National Conference on Renewable Energy and Environment (NCREE-2015) IMS Engineering College, Ghaziabad Vol. 2, Issue 1, April 2015.
10. Javier Campillo, "*From Passive to Active Electric Distribution Networks",* Mälardalen University, 20.16.
11. Amir-Hamed Mohsenian-Rad, Vincent W.S.Wong, Juri Jatskevich, Robert Schober, Fellow, and Alberto Leon-Garcia, Fellow*,"Autonomous Demand Side Management Based on GameTheoretic Energy Consumption Scheduling for the Future Smart Grid",*July 5, 2010.
12. M.Nageswar Rao, "*Energy Conservation Opportunities in Power Distribution System"*, 21st oct 2005.