GreenNet: Agent based Energy Load Prediction Techniques for Smart Grid

Ayesha Afzaal, Mohsin Nazir, Ayesha Haider Ali, Aneeqa Sabah

***Abstract*—To maintain the reliable delivery of energy with increasing demand is becoming a challenging task with such a dumb electricity distribution system. The ongoing reformation of ancient distribution infrastructure is an effort to enhance its performance so that energy can be consumed with greater proficiency. Smart grid is an advanced concept, which adds intelligence, networking and bi-directional communication features to the existing energy infrastructure. To efficiently utilize the system capabilities, prediction of upcoming energy load on the network is an important task. With a more accurate load forecasting, the smart grid can enhance the management of its resources and expand the economics of energy commerce with electricity markets. A new agent based energy load prediction technique is proposed in this paper, which will predict the load of smart home, one hour prior use. Agents are divided into a group of experts, which will use weighted average prediction methodology to predict the upcoming demand of energy. Simulation results show that by implementing the proposed methodology; we can get 80 percent accurate results of load prediction that will make the electricity grid more reliable and efficient.**

***Index Terms*—Load Prediction, Peak to average ratio, Demand Response Multi agent system, Short-term Load Forecast.**

I. Introduction

SMart grid is a network of electricity supply that uses digital communication technology and artificial intelligence to convert traditional unidirectional power flow into bi-directional. It has lot of remunerations as information and power both can flow bi-directionally between consumer and supply, which makes the electricity network efficient and reliable [1]. As the electricity network become more adequate, the use of electricity is also increased by advent of new smart devices, and makes it more complex where heterogeneous devices slog together to deliver smart services [2],[3].

Smart grid dramas a momentous role in computerization of power system and plenteous of smart devices are developed even at domestic level like smart home appliances etc. With all these practices the human labor is reduced and fewer manpower is required even to carry out an enormous task [4]. As the use of electricity is increased with all this facilitation so another problem come into front is that electricity demand is going to be higher than supply which is a gigantic issue all over the world. If this problem is not targeted, it may results to power outage or blackouts that are the foulest consequence for the economy of any country [5]. So the need for proper utilization of all smart grid constituents turn into reality.

One of the solutions is the progressive management of upcoming consumers demand. Smart grid can serve more competently by scheduling customers load periodically but all of this is possible if the load on grid is known in advance. Load prediction can play an important role in energy management system; the controlling can be amended if the load of any smart home is forecasted in advance [6]. Many domestic energy management technologies already exist but all the proposed methodologies have their own distinguishing features related to load prediction.

Ayesha Afzaal, Mohsin Nazir, Ayesha Haider Ali, Aneeqa Sabah
Lahore College for Women University, Lahore, Pakistan
ayesha.afzaal@lcwu.edu.pk

The remainder of the paper is structured as follows. A review of problem, the literature, the role of agents and fundamentals of energy load prediction are stipulated in Section II. In Section III, the design of load prediction model is proposed with some infrastructure requirements and detail explanation of system using flow chart is also explained. Detail of agents and proposed load prediction technique is explained in section IV. In Section V, simulation results and discussions are presented. Finally, the concluding remarks and future directions are presented in Section VI.

II. Related Work

Three major factors are touching the electricity network of the entire world; the government policies, user participation in energy scheduling mechanism and the use of information technology [7]. First two factors can be fared by the use of Information technology like with the help of computer science user can contribute in energy routing mechanism to build electric grid a bi-communication network in which both the supplier and consumer can not only transferal energy as well as information can be transferred about the behavior of consumers i.e. energy utilization pattern, future need of electricity, purchasing/selling rate etc. There was a centralized control of energy management beside information technology, energy stream was unidirectional, and consumers alternatives were restricted [8].

Rehan propositioned the controlling of demand response by instigating multi-agent coordination as shown in figure 1. Agents are grouped into three categories; grid agents, residential agents and control agents positioned at grid, residential area and power control center respectively [9]. Organization can shift the flexible load of residential agents to off peak time through control agents to stun the overall cost of residential power utilization. The load of plug-in hybrid electrical vehicles (PHEV) can also be controlled by the proposed system by allowing them to charge their PHEVS rendering to their battery remaining charging. Results shows; by executing the recommended system the total load on main grid is reduced [10].

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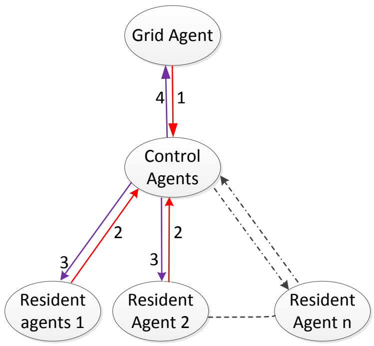

Figure 1: Different types of agents.

Smart meter dramas a vital role in computerization of electric grid with the support of information technology. Smart appliances are connected with smart meter through fewer or veto human interaction; this is imaginable only by machine-to-machine (M2M) communication exploiting standard smart grid protocols. Different kind of gateways is used for this drive in home, neighborhood, and building area network [11]. Zubair perform the comparison of different communication protocols and designates which M2M gate way is best for a specific situation [3].

Short term load forecast (STLF) perform a significant role to acquire information in advance about the forthcoming request of power but its a multifarious process because the shape of load-time succession is non-smooth as well as non-linear. The physiognomies of load-time series and a new bi-level forecasting approach is suggested [11],[12]. System framework consist of:

1) Forecast engine.
2) Enhanced evolution technique.
3) Feature selection method.

Micro-grids are becoming an imperative part of macro-grid due to their utmost effectual independence i.e. consistency, cost bargain and squat carbon emanation etc. While in emergency situation, micro-grids can separate themselves from macro-grid and grind in island mode [1]. Micro-grids can be made more convincing by adding another feature of storage management. The forecasting of predictable load for both macro and micro-grid are most imperative to acquire extreme paybacks from this infrastructure. Power load forecasting for micro-grid is examined by author in [13]. The size of the micro-grid is lesser as relate to macro grid that is the main reason of its with little bit fluctuation in load.

There are two ways to control the rate of electricity for consumer in smart grid i.e. load scheduling and load shedding; load shedding is to switch off the electrical appliance, when the load on the grid is observed and load scheduling is to transfer load for off peak time [6]. Nathan Kowahl also examined the estimation models for power; according to proposed method there are numerous factors which should be predicted to verdict about optimization including inside temperature, wind power, unrestrained load, time, battery level and outside temperature etc as shown in figure 2.

Advance booking of power via internet is explained by

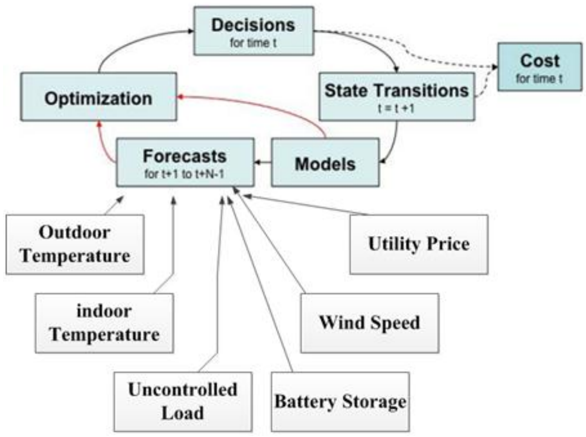

Figure 2: Load Forecasting Model.

tongdan [5]. This process is performed one hour before actual time interval reveals. Power organizations estimate the average mandate of all users to forecast the load of forthcoming hour in advance.

$$P_g(t) = \sum_{i=1}^{n} d_i(t) \tag{1}$$

$d_i(t)$ is the demand of consumer i at time interval t and $P_g(t)$ is the total prerequisite generation for n customers. Customer practice On-line Purchase Electricity Now (OPEN) mechanism for on-line procuring of power similarly to purchasing of on-line item like e-shopping. User can demand power by approximating higher and lesser bound of demanded power for a definite time phase. The two boundaries are delivered to power generator to formulate for the imminent demand; exceeded power demand can be fulfilled by virtual power plants. Upper and lower limits of forthcoming demand can be calculated as

$$P_{gL}(t) = \sum_{i=1}^{n} d_{Li}(t) \tag{2}$$

$$P_{gU}(t) = \sum_{i=1}^{n} d_{Ui}(t) \tag{3}$$

$P_{gL}(t)$, $P_{gU}(t)$ are the lower and upper projected power generation established on $d_{Li}(t)$, $d_{Ui}(t)$ lower and upper bounds of predicted demand for hour t. Similarly suppliers of power also compute the maximum and minimum production capability to evaluate that they can fulfill the requirement or not.

III. Design of Load Prediction Model

To avoid power outage, which is caused due to overloading the grid station, the proper management of load scheduling is very important. It is controllable if the future demand of electricity is known in advance. Here to achieve this goal and to overcome human system interaction a very simple and cost efficient agent based energy load prediction technique is proposed. The proposed strategy also postulates individual household consumers freedom to adjust their electricity supplier according to their available budget.

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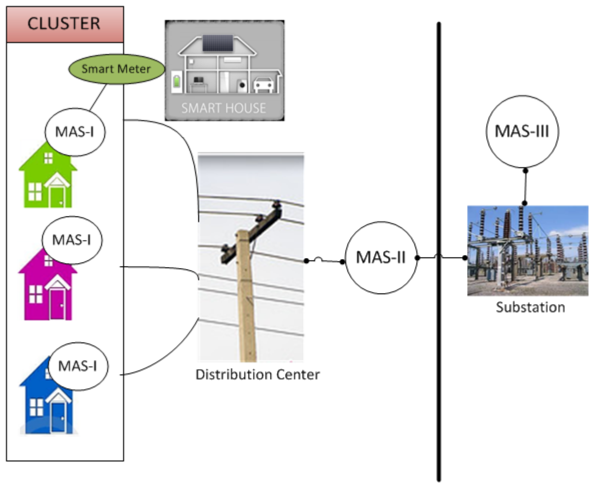

Figure 3: Infrastructure Requirment to implement proposed model.

A. Infrastructure Requirement

The implementation of proposed strategy requires some infrastructure changes at both distribution and consumption level. At consumption level every smart home has a mini micro-grids with in-house power generation and some storage capacity. It can be solar or wind system having some batteries for backup. Smart homes are grouped in the forms of clusters having a micro-grid collectively that are larger in scope as compare to individual mini micro-grids. A demand signal is send to grid through transformer when the demanded electricity exceeds the limit of mini micro-grids generation as shown in figure 3.

At distribution side multi-agents system exists, they not only control the generation capacity but also ensure two-way communication between transformer and the homes it serves. Electricity consumers can buy and sell units of electricity to grid with the help of this bi-directional information and power transfer facility. To reduce the electricity cost for consumers, the overall objective of proposed system is:

- Differentiate between flexible and non-flexible demand of electricity.
- Electricity load prediction one-hour prior use.
- Comparing electricity transfer cost between macro and micro-grid
- Incentive management for actively participating consumers.
- Buy low and sell high is the objective of overall game.
- Explicitly shift task from peak to off peak time.

The scope of this paper is limited to load prediction techniques. The remaining objectives are under research and will be discussed later

B. Description of Proposed model using Flow Chart

In the proposed system agents are placed at three levels according to their functionality, they are (Multi agent system) MAS-I, MAS-II and MAS-III respectively. The functionality of each category of agents is described below.

MAS-I is a set of lowest level of agents that are purely belongs to a single smart home or they can be embedded into smart meter. The overall responsibility of MAS-I is to reduce the cost to electricity for a single smart home to which it is connected. To achieve this objective MAS-I will predict the load of electricity one-hour prior use. It will also maintain the record of flexible and non-flexible loads to estimate the flexibility of variation in predicted load. It will also calculate the cost of electricity to get predicted load (PL) from mini micro-grid.

A group of some items combined together is called a cluster. According to proposed system model a fixed amount of smart homes are grouped to form a cluster and agents who will manage a cluster are placed at multi-agent system level II called MAS-II as shown in figure 3 and 4. The main task of MAS-II is to calculate the cost to get PL of a smart home from its neighboring smart homes with in a cluster or from other neighboring cluster if its demanded amount of electricity cannot be fulfilled from MAS-I. They resides at distribution center.

The third and most supervisory group of agents is called MAS-III. They deal directly with main grid. They play the role of communicator between smart homes, clusters and main grid. MAS-III will calculate the cost to get PL from main grid if it cannot be fulfilled from both mini micro-grids and clustered micro-grids also explained in figure.

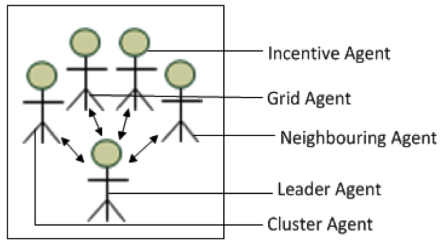

Figure 6: Different types of agents in a cluster.

IV. Role of Agents in Proposed System

In the following, agent based electricity load prediction framework is proposed. Following is the brief overview of our system also explained in figure 5.

1) Every smart home has a micro grid controller (MGC), which schedule all the smart appliances inside a smart home.
2) MGC will not only control the power flow but also monitor the transfer of information between agents and smart appliances/micro-grid (MG) inside a smart home.
3) Smart homes are grouped in the form of clusters, each cluster has its own organizer called control agent (CA).
4) A group of agents in a smart home has a leader agent, which will predict the upcoming load of electricity with the help of expert agents, then predicted load is demanded from electricity service provider in advance if it can not be fulfilled by micro-grid (MG) as shown in figure 6.
5) As according to proposed methodology, Electricity Service Provider (ESP) known in advance about the up-

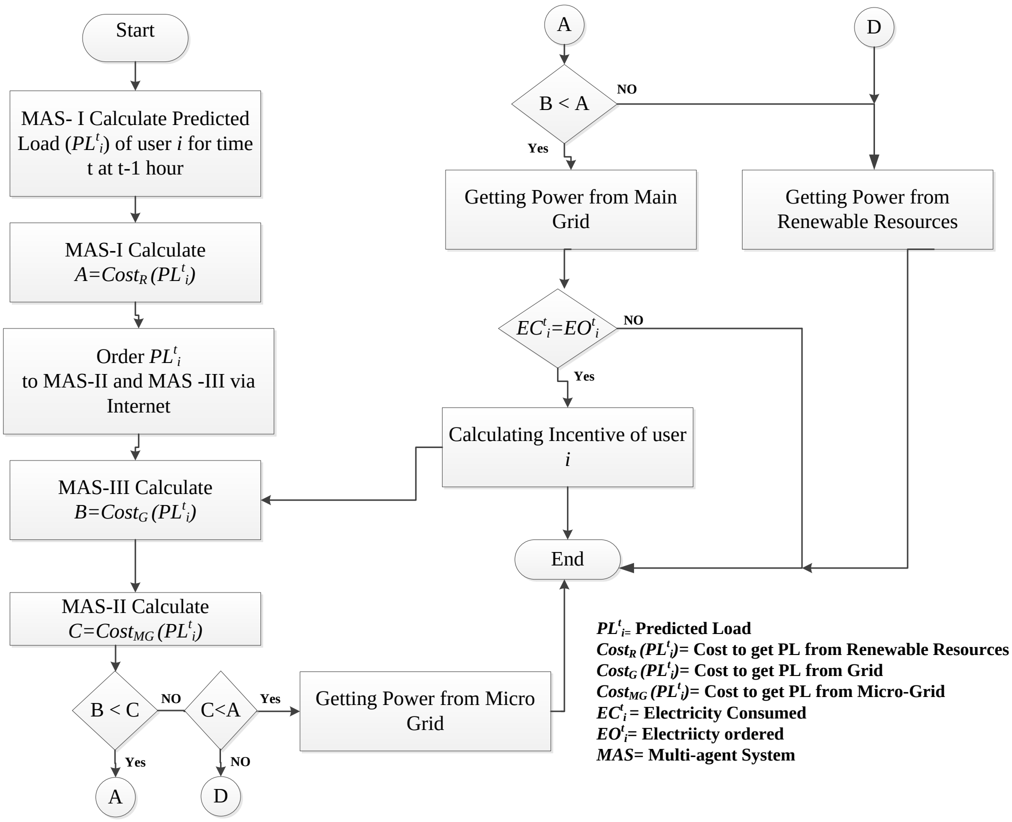

Figure 4: Flow chart of proposed plan of work.

coming demand of electricity by using load prediction technique, which will be explained, later in this section.

6) ESP can communicate with CA about the percentage of electricity, which can be provided by ESP prior demanded time interval (one hour before use/demand). This step is supplementary important to avoid power outage.
7) CA communicates with micro-grid controller and group of agents to schedule their smart appliances according to provided amount of electricity from energy service provider.

All the above steps are performed one hour before actual time interval $(t-1)$ hour, which makes the electricity network more reliable and efficient. Proposed load prediction technique is explained below.

Agents are divided into different types according to their functionality, all the agents are controlled by leader agent, neighboring agent is responseible for all type of communication between neighbouring homes, similarly grid agent will calculate the cost to get predicted load from main grid as well as communicate with incentive agent for inducement information of any particular user.

A. *Agent based Load Prediction Technique for Smart Grid*

A new smart home load prediction methodology is introduced based on expert agent's advice using weighted average prediction technique. To calculate the predicted load

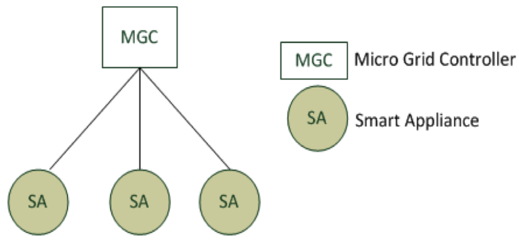

Figure 7: Role of microgrid controller.

of electricity in advance with the help of agents is likely a problem of finding an unknown sequence of electricity loads $L_1, L_2, ..., L_n$ of an outcome space L, for time interval t, the forecaster makes his guesses E_t for L_t (Electricity load at time t) in $(t-1)$ hour. When the time t occurs the forecaster can check whether his prediction was true or not. To calculate E_t forecaster will get the help of expert's advice.

The advice of expert i, $(f_{i,t})$ belongs to the set of expert advices $(f_{1,t}, ..., f_{n,t})$. The goal is to minimize the number of mistakes when actual load at time t $(L_t \neq E_t)$ is not equal to predicted load demand E_t for the time interval t. Assume that we are known in advance that there is a group of expert agents that make no mistake in this particular scenario i.e.

$$f_{i,t} = L_t \tag{4}$$

But we donot know that which expert agent is best fit so

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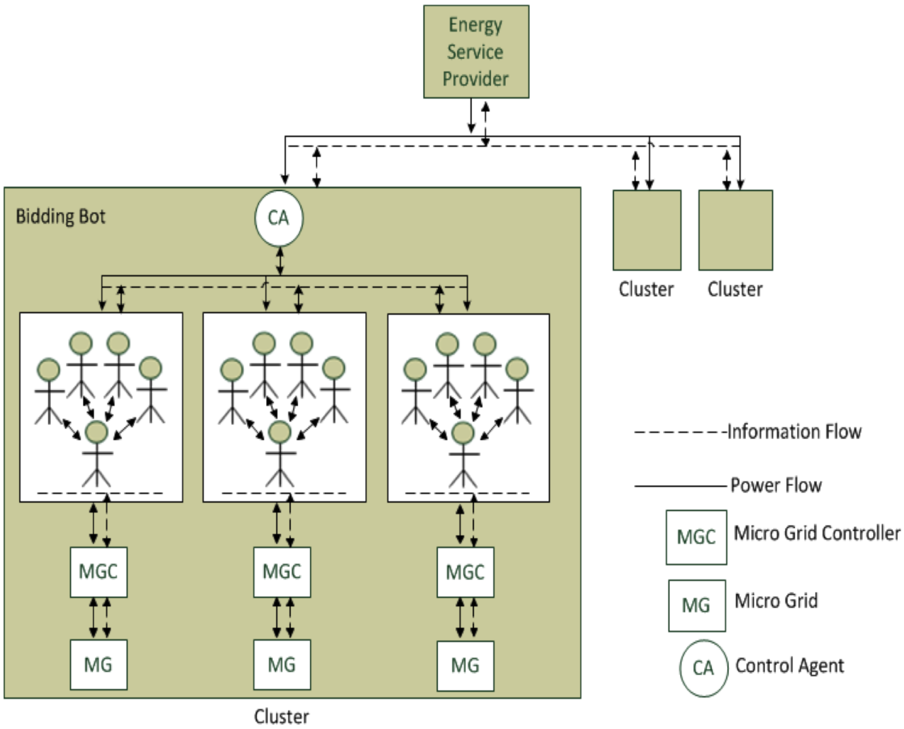

Figure 5: Detail Model

forecaster will start by assigning weights W_j = 1 to expert agents j= 1, . . . , n. Each time the forecaster predict E_t based on expert agent with higher weight, if $E_t \neq L_t$ then the forecaster perform the reassignment of weights for expert agent k. Simply the forecaster keep track of which expert make the mistake and predict according to majority of experts that has less chances of mistakes. This analysis is immediate.

Algorithm 1 Experts Weights Re-Assignment

Parameter: forecaster guess E_t, set of expert weights W, $f_{i,t}$ expert agent i advice, actual Load L_t for time t.
Get actual value of L_t (when load for the time t reveals).
Define threshold S, for difference between actual and forecasted load.
Let n be the total number of experts.
Initialize i with first expert; $i = 1$.
while $(i <= n)$ **do**
    Compare $f_{i,t}$ with L_t.
    if $f_{i,t}$=L_t || $(f_{i,t} - L_t) <= S$ **then**
        Re-assign the weight of e_i.
    end if
    Increment i by 1.
end while

The forecaster prediction $E_1, E_2 ..., E_t$ belongs to a decision space D, which is the convex subset of a vector space. In ideal case $D = Y$ which is a subset of outcome space L, but it is different to attain. Here the forecaster agent computes his prediction in a sequence and the predictive value is compared to the set of reference experts. Any time the forecaster agent can access the set of experts prediction $f_{E,t} \epsilon D$.

On the bases of experts prediction the forecaster agent calculate his own prediction or guess E_t for the time interval t at (t-1) hour. Suppose we have a set A of expert agents related to load prediction $(e_1, e_2, ..., e_n)$ having weights $(W_{e1}, W_{e2}, .., W_{en})$ respectively. Then the forecaster will calculate weighted average prediction based on the following.

$$E_t = \{f_{1,t} * W_{(1,t-1)}e_1 + f_{2,t} * W_{(2,t-1)}e_2 + f_{3,t} * W_{(3,t-1)}e_3 + ... + f_{n,t} * W_{(n,t-1)}e_n\}/N \quad (5)$$

$$E_t = L_1 + L_2, ... + L_n/N \quad (6)$$

Here E_t is the predicted load for time interval t. When the actual L_t reveals, compare the L_t with every value of $f_{i,t}$ it is also explained in algorithm 1.

The forecaster main objective is to keep regret as small as possible. For expert E it can be defined as

$$R_{E,t} = \sum_{t=1}^{n} (L(E_t, L_t) - L(f_{e,t}, L_t)) \quad (7)$$

Here $L(E_t, L_t)$ is the loss function of forecaster agent and $L(f_{e,t}, L_t)$ is the loss function of expert agent. The overall objective is to maintain regret $R_{E,t}$ small.

V. SIMULATION

In this section the performance of proposed system is evaluated based on the accuracy of predicted load. Matlab simulation test bed is used to construct smart grid environment. Smart homes are grouped in the form of clusters. During testing phase agents in a smart home can communicate with other agents with in a smart home as well as other agents in the neighboring cluster to share load prediction information between expert agents.

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During simulation, at initial stage a dataset of random numbers are generated for load prediction, the elements of array are modified after each iteration of algorithm based on the set of experts advise. This process goes through for the time interval t- 0 to 24 and the prediction is going to refine iteratively.

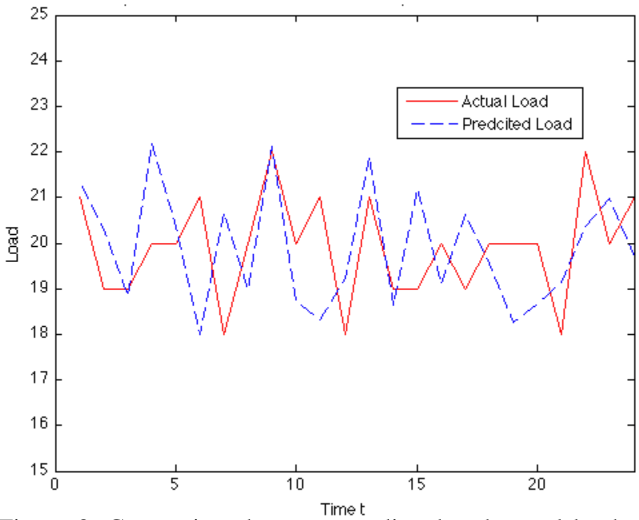

Figure 8: Comparison between predicted and actual load.

The number of smart homes selected for simulation varied from 1 to 15 having flexible and non-flexible loads. The proposed algorithm runs iteratively for the time interval of 24 hours, after each iteration the weights of experts are modified depending on the accuracy of actual load of time interval $(t-1)$ according to proposed algorithm.

From the results shown in figure 8 it is clear that by using proposed methodology the predicted load is almost 80 percent closest to the actual load for a specific time interval t.

VI. Conclusion and Future Work

Smart grid is the accumulation of information technology and intelligence in the existing electricity network. With the increase of population demand is also going to be increased day by day so the proper management of resources in smart grid is essential to get the full exploitation of the system.

To efficiently utilize the system capabilities, prediction of upcoming energy load on the network is a significant task. Different load prediction techniques already exist but all has its own limitations as discussed in literature review. A new agent based load prediction technique is proposed which uses weighted average expert based prediction methodology to predict the load of upcoming hour. In this way grid known in advance about the upcoming demand of power and can respond accordingly, which makes the grid reliable and reduce the chances of power outage.

Smart grid set bed is developed in matlab for simulation of proposed methodology and graph shows that the proposed prediction technique provided almost 80 percent accurate results.A remaining variation is also with in the limits of threshold.

In future more utilization of the system can be achieved by expanding the work of cost optimization. As explained in system model after calculating the predicted load, agents will work on finding optimal source of energy to fulfill consumers demanded amount of electricity. This work is under research and will be published soon to achieve full utilization of the proposed infrastructure.

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