Majid BIABANI[1], Amirhossein SAJADI[2], Masoud Aliakbar GOLKAR[1], Piotr BICZEL[2]

K. N .Toosi University of Technology (1), Warsaw University of Technology (2)

A Two Ways Communication-Based Distributed Control for Direct Load Control in Smart Distribution System

***Abstract**. In this paper a novel approach to accommodate distributed generation resources in the power distribution system is discussed to reduce the peak power demand. Direct load control (DLC) is the capability of aggregate and precisely control individual loads on command. The novel implemented approach in this work is the DLC to demand response. The DLC algorithms in regularity base are used for controllable loads which can be turned on and off with unnoticeable interruption where the load is forecasted and it is dispatched accordingly by using distributed generation resources and controllable loads, thereby it helps to reduce peak demand. Multi-Agent System (MAS) is consisting a group of agents which are capable of perceived environment that they are located and act on it by communicating with each other to achieve the goals. Therefore a MAS has been adopted to manage the direct load control simulation. Load has forecasted in MATLAB and MAS has programmed in ZEUS utilize the forecasted load data to dispatch the load in such a way so as to reduce the peak demand. The agents are located at demand aggregator level, zone level and DG level. They communicate to dispatch the load properly based on resources and load availability.*

Streszczenie.** W niniejszym artykule przeanalizowano nowatorskie podejście do integracji źródeł rozproszonych w celu redukcji szczytów zapotrzebowania na moc. Poprzez precyzyjną kontrolę obciążenia i odpowiednie grupowanie odbiorców możliwe jest kształtowanie zapotrzebowania. Nowatorskie podejście zaprezentowane w artykule polega na kształtowaniu reakcji na zapotrzebowanie. Algorytm kształtujący podstawę obciążenia jest wykorzystywany do kontroli sterowanych odbiorów, które mogą być wyłączane i załączane bez negatywnego wpływu na ich pracę. Obciążenie takie może być prognozowane i odpowiednio kształtowane co pomaga redukować szczyt zapotrzebowania. System wieloagentowy (ang. Multi Agent System (MAS)) składa się z grup inteligentnych agentów osadzonych w konkretnym środowisku, współdziałających z nim i komunikujących się między sobą, w celu osiągnięcia wyznaczonych celów. Taki system został zaadaptowany do symulacji zarządzania kształtowaniem zapotrzebowania. Obciążenie jest prognozowane w środowisku MABLAB, natomiast MAS został wykonany w programie ZEUS w oparciu o prognozy obciążenia, tak by je kształtując wygładzić szczyt zapotrzebowania. Agenci są umieszczeni na poziomach agregacji obciążeń, stref i generacji rozproszonej. Prawidłowe kształtowanie zapotrzebowania odbywa się w oparciu o dostępne zasoby i źródła. (**Bezpośrednie sterowanie obciążeniem w sieciach inteligentnych – sterownie rozproszone z komunikacją dwukierunkową)

Keywords: Multi Agent System, Load Management, Smart Grid**,** Demand Response
Słowa kluczowe: System wieloagentowy, Zarządzanie obciążeniem, Smart Grid, Systemy reagujące na zapotrzebowanie

1. Introduction

The main function of the electrical power system is supplying required power for consumers through highly complex power grid comprising of substations, lines and devices at various power levels and voltage ranges. In addition, it has to deal with the management of highly volatile power generation, power demand and power markets. In recent years ago, with discovery of electromagnetic phenomenon which is still the basic principle of today's power generation, there has been an attempt to generate it with more compatibility. Generation, transmission and distribution are the three very important processes in supplying the power for the consumers in urban areas.

Initially, the power was mainly generated from hydro-electric power and thermal (coal) generating stations. As the technology manifested and also the awareness for the environmental friendly activities increased, the power generation is following various trends. Renewable energy resources like bio-fuel, bio-mass, geothermal, solar energy, tidal power, wave power and wind power have been real area of interests for the power generation. However, the availability of these resources and integration of them to the actual power grid still remains as a complex issue.

Unlike the generation and transmission, the power transmission system does not really monitor major trends in comparison with the power distribution system. With increase in the urbanization, industrial consumption and Many other factors, the power demand is constantly ascending, although, it has many complexity.

As known, traditionally power is transmitted and distributed from central power generating station through transmission substations, transmission lines, distribution sub-stations and distribution lines. Planning and construction of all these is inherently expensive and complex. With the change in the power consumption and demand, there comes essential for the expansion of the prior mentioned power units which is very pricey. The alternative and eco-friendly option is utilizing installation of small range renewable power generating units close to the consumer location and integrating them with the distribution grid. These small range power generating units are generally called Distributed Generators (DGs) or Distributed Energy Resources (DERs). Introducing DGs to the power grid is applying in order to make power systems more reliable, flexible, and secure. Apart from the above mentioned benefits of the DGs, they are 60 to 80 percent efficient where as traditional generating units are 35 percent efficient [1]. As a complement to traditional electrical power system, DGs are able to afford lower overall cost of the producing and delivering electric power, promote the development and wider use of renewable energy. In addition, it helps to decrease the congestion on power lines resulting in less brownouts and blackouts.

Many attempts and huge value of research are still undergoing to ponder the methods for redacting of peak demand. Various initiatives are taken by different utilities like providing credits to customers who reduce their usage during peak demand period. Load management techniques like peak shifting, peak shaving, peak sharing, etc. are adopted to reduce the peak. Independent System Operators (ISO) or utilities sign the customers for participation during peak demand period, helping them to control the load for managing the peak demand. Integration of DGs into the grid can also help in reducing the peak demand, by supplying the local load and reducing the congestion on power lines, thereby reducing the peak demand. Demand response has been an area of interest since decades. Demand response is simply the customer response in terms of electrical usage to the changes in electricity generation. Demand response can also be the curtailment of load or generating power at local unit which may or may not be connected in parallel to the grid [2].

Traditionally load shedding is the considerable option for decreasing the peak demand, however, in most of the areas during in recent decade, load shedding and prioritizing the loads are forbidden. In such cases the better option is to study the loads and control them in such a way that their usage can be monitored and altered. Besides, customers have control on their loads and utilities or ISOs are given control of the loads in a way that helps them to turn on the loads during off peaks and turn loads off during on peak without noticeable interruption of service. Introducing advance energy management systems and devices would help to achieve this goal. Novel technique which is called MAS can be effectively integrated to the grid to impart intelligence that the monitoring and control of the load can be obtained economically.

In this paper a MAS based (DLC) peak demand reduction algorithm will be developed as a part of smart grid initiative research work. Reduction of peak demand will be achieved by using controllable load dispatch and distributed energy resources (DER). Agents at various levels like agent at load serving entity, DER agents, load agents, etc. heuristically attempt to achieve the peak demand reduction. In the end, results discussion and conclusion close the paper.

2. Multi Agent System

The software agent or the common term ‘agent’ has found its way into a number of technologies and has been widely used. According to Wooldridge [3], an agent is merely “a software (or hardware) entity that is situated in some environment and able to autonomously react to changes in that environment.” An agent which displays flexible autonomy, i.e. an intelligent agent, has the following three characteristics: Reactivity, Pro-activeness and Social ability. A MAS is a system to comprise two or more agents or intelligent agents. It is important to recognize that there is an overall system goal. During recent years, the Foundation for Intelligent Physical Agents (FIPA) standards has become the fundamental standards used by MAS developers [4]. FIPA standard consists of different parts and aspects: MAS architectures, agent communication languages, content languages and ontologies.

The FIPA Agent Management Reference model [5] defines the normative framework within which FIPA agents exist and operate. It establishes the logical reference model for the creation, registration, location, communication, migration and retirement of agents. Under the FIPA model, Fig. 1, an agent resides on a particular agent platform which provides some sort of message transport system to allow the agents to communicate. Each agent platform includes two utility agents: the agent management service (AMS) agent, which is compulsory, and the directory facilitator (DF) agent, which is optional. The AMS acts as white pages, maintaining a directory of agents registered with the MAS platform. The DF acts as yellow pages, maintaining a directory of agents and the services they can offer other agents.

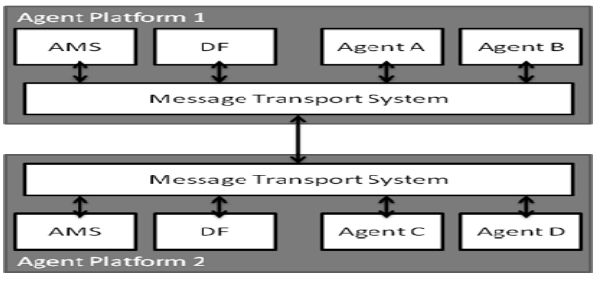

Fig. 1. FIPA Agent Management Reference model

Mechanisms for the communication between agents underpin their sociability. Early MASs used proprietary communication languages. The content of a message comprises two parts: (1) content language and (2) ontology. The content language defines syntax, or grammar, of the content. The semantics or lexicon is drawn from the ontology. The choice of content language is important, as the selected language will shape how a given ontology is expressed. The ontology describes the concepts of a domain and the relationship between those concepts in a structured manner.

2.1 Multi Agent Systems in Smart Grids

The idea of the smart grid is to modernize the electrical power system so that it monitors, protects and automatically optimizes the operation of the elements interconnected to it [6]. The smart grid is expected to have major extraordinary characteristic like self healing, accommodation of DER, enabling new products and services, provide power quality, optimize assets, anticipate and defend system disturbances, and cyber security and resilience against attacks. Implementation of MAS technology can implicitly help to achieve most of the above mentioned functionalities. In [6] the author elucidates how advance computer aided technologies like MAS can help to achieve smart grid goals. The proposed methodology for market interoperability of smart grid helps to achieve the global optimization of energy consumption, hence it can significantly reduce the peak demand and it avoids the transmission expansion costs [6]. It predicts how MAS can be employed in power markets for automatic negotiation and coordination, which can reduce the market period enabling to handle DER easily.

2.2 Multi Agent Systems in Demand Management

Dynamic load management of the power grid is essential to make better and more cost-effective use of electricity production capabilities and to increase customer satisfaction [7]. Demand management plays a critical role not only in the reduction of electricity usage price for the consumer but also to reduce the congestion on the power lines, peak demand, power system expansion expenses and much more benefits contributing to the smart grids. Work related to application of MAS in demand management is discussed in this section.

In [7] authors Frances Brazier et al. proposed a load balancing technique based on MAS negotiating scheme. The idea is to establish a flexible negotiating scheme for individual costumers, utilities and power generating units to optimize the overall electricity cost. The paper proposes different protocols for negotiation and a compositional development system for MAS in DEsign and Specification of Interacting Reasoning (DESIRE) software. The intention of load management makes smooth the total peak load by managing a more appropriate distribution of the electricity usage among consumers. The agents at utility level and consumer level are deployed in this paper which deals prices as a part of peak demand reduction. Monotonic concession protocol is applied for the load management problem and assumption made is consumer behavior can be influenced by financial gain [7]. Three methods of negotiation namely offer, request for bids, and announce reward tables methods in the load management domain are proposed.

Demand response must be adopted in load management to make the future power system to adequately use all the available resources in order to satisfactorily provide quality of service to the customers [8]. In [8], authors presented an approach to deal with all issues associated with integration of available resources in load management. A MAS which is capable of modeling demand side players and their strategic behavior is demonstrated in [8]. The case study of a utility company is shown that reduction of load curtailment is obtained because of previously established load flexibility contracts with their customers.

3. Challenges for Peak Demand Reduction

Please Lots of the research and implementation are focused on peak demand reduction by using load shedding and demand response based on price signal. The problem with the prior approach is that in many utility service areas, according to the consumer service, a commission prioritizing loads are prohibited. Hence, the peak demand reduction using load shedding becomes no more a solution.

The later approach of introducing price signal as a medium for peak demand reduction also becomes an inefficient option because of various reasons. First of all, there are still so many utility service areas where real time pricing or more tariff rates during the peak demand time does not exists, not at least to the residential customers. Then, the savings of the customers may be so less weighed to their commitment to the power usage reduction. Hence, a direct load control/dispatch method using an advanced technology like MAS can be adopted for peak soothing with minimal customer's effort and less inconvenience for the customers.

4. Simulation software

In this section we put some limelight on the software packages employed in this work in order to design the MAS platform and electric demand forecasting algorithm. Programming the MAS greatly depends on the software package employed to do it. It is very important to pick the right platform to develop MAS. It is because designed system is expected to interact with power system simulation entities which in most of the cases are developed by using different software packages.

As a part of this research work various software packages used to simulate MAS and power distribution system are scrutinized. For the requirement of this work ZEUS is utilized to develop MAS and simulate their behavior. Various engineering toolboxes in MATLAB are employed to obtain the load forecasting model. Therefore, it is very important to select appropriate software packages to successfully achieve interfacing between the MAS platform and PDS platform to study their interaction.

As mentioned earlier, two different layers exist while simulating power system embedded with intelligence. The figure below describes the architecture of simulation model

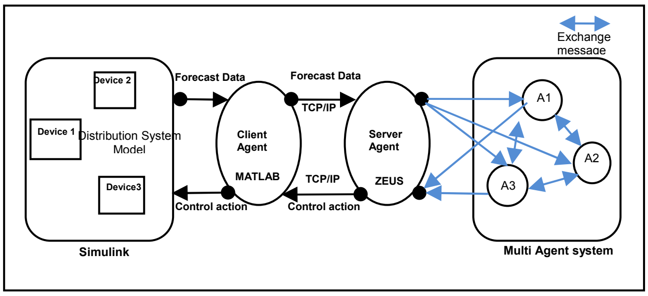

Fig. 2. The proposed real time simulation model

4.1 MATLAB MATLAB is used for power system analysis. Various packages that support analyses of power system using MATLAB are developed and widely utilized. SimPower system is a Simulink toolbox provided by MATLAB to support power system analysis. Apart from toolboxes provided by MATLAB, there are various packages like MATPOWER, PSAT, and PAT etc were developed. However, due the complex nature of power distribution system (PDS), perhaps MATLAB is not a reasonable chosen for large scale power distribution system or for transient analysis on PDS.

In the present work, MATLAB is used to expect electricity load on the system using neural networks toolbox provided.

4.2 ZEUS In the context of the power distribution system, the most important issue is how to select an agent platform that is based on a well-known standard that is the IEEE standard on FIPA. This will help ensure interoperability among different systems and platforms so that the proposed MAS can be universally accepted. As a result, compliance with FIPA should be first criterion for selecting an agent platform to be used in this task. Based on the agent toolkits which are listed above, agent platforms that are FIPA-compliance are ZEUS and JADE. Comparison of these two agent platforms is presented in Table I below.

Table 1. JADE and ZEUS comparison

JADE	ZEUS
Free and open source	Free and open source
FIPA Compliant	FIPA Compliant
JAVA Based	JAVA Based
ACL Communication	ACL & KQML
Provides authentication	Some security capabilities
Decent GUI	User friendly GUI

Note: ACL = Agent Communication Language; KQML = Knowledge Query Manipulation Language (KQML); GUI = Graphic User Interface

In this study, ZEUS is selected for the PDS implementation because it has several user-friendly features that facilitate agent communications and allow negotiations for power exchange to be initiated easily and quickly. The philosophy behind ZEUS development is that it hides intricacies of existing MASs and provides a relatively general purpose and customizable, collaborative agent building toolkit [9] that could be easily used by software engineers having only rudimentary knowledge in agent technology.

This section briefly elucidates the software packages used in this work to solve the problem. MATLAB is used to forecast the load. With MATLAB toolboxes a excel standalone Load Forecaster has been implemented. ZEUS is used to model the MAS which manages the load and distributed generations in order to reduce peak demand. Agents developed in ZEUS will make use of forecasted load outputted as excel sheet using MATLAB.

5. Simulation and results

In this section, load management algorithm and its simulation are discussed. MAS has been developed in ZEUS and its deployment is discussed in this section. MAS form a load management module which is employed to reduce the peak electricity demand by 15 percent. MATLAB is used to develop short-term load forecasting tool.

5.1 Database for Load Forecasting

Historical hourly load data, dew point, dry bulb, seasonality (holiday, hour, and weekday), and type of the day data is used as the database to develop load forecaster. System load data obtained from test distribution feeders in TEHRAN during one year is used as base database. The database connection is made using Microsoft access database files. Once the forecaster is deployed, forecasted temperature, day and type of the day is given as an input to the forecaster to forecast the load in upcoming time horizon.

5.2 Neural Network Load Forecaster

Neural network toolbox provided by MATLAB is used to implement the load forecast model in this work. The Neural Network Fitting Tool will help to select data, to create, to train a network, and to evaluate its performance using mean square error and regression analysis with a two layer feed forward neural network. Neural network fitting tool is used to perform the load forecast task where the elements are trained using Levenberg-Marquardt back propagation algorithm.

In the process of forecasting the load using neural network toolbox, the following steps are performed,

- Selecting data: Inputs and targets are defined initially. In this present work, 8760 samples of 8 elements (dry bulb, dew point, hour, weekday, is working day, previous day same hour load and previous 24 hour average load) are given has input and 8760 samples of 1 element (system load) is given as target.
- Validation and testing data: Validation and testing of the neural network elements is an important criterion in the load forecasting process. 6132 samples are used for training purpose, 1314 for validating, and 1314 for testing. The training samples are presented during the training process and the network error is adjusted accordingly. The validating samples are used to measure the network generalization. The testing samples provide network performance during and after training.
- Network size: Network size determines number of neurons in the hidden layer. In order to improve the performance of the network, the number of neurons in the hidden layer should be increased. Figure 3 represents the neural network layers adapted in this present work.

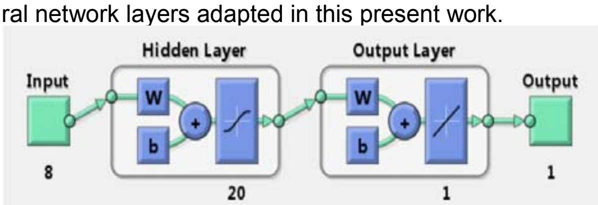

Fig. 3. Neural network layers with number of neurons

- Training network: The network is trained to fit inputs and targets. In the present work, default Levenberg-Marquardt back propagation algorithm is used for training. Mean squared error (MSE) is the average squared error between the outputs and the targets in which its lower value is desirable. Regression value shows the correlation between outputs and targets (1 representing perfect match and 0 representing no match). Figure 4 shows the training results of neural networks with available data.

Results

	Samples	MSE	R
Training:	6132	1.78457e-0	9.56801e-1
Validation:	1314	2.31341e-0	9.45417e-1
Testing:	1314	2.41483e-0	9.47609e-1

Fig. 4. System load forecast results using neural network

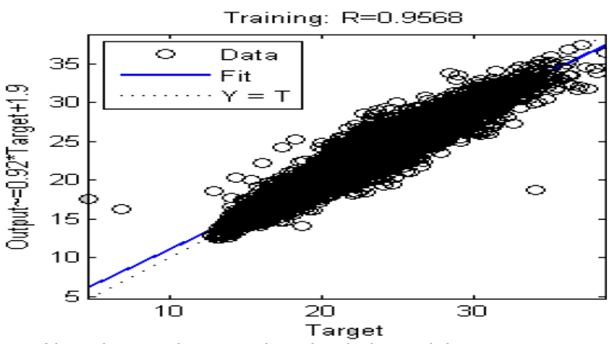

Fig. 5. Neural network regression plot during training

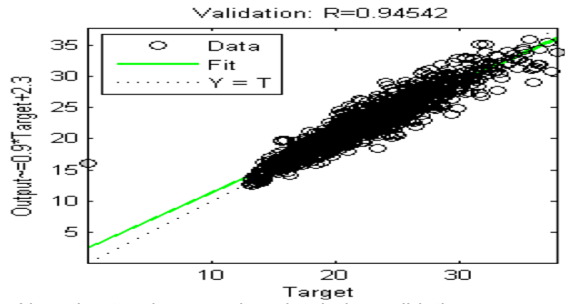

Fig. 6. Neural network regression plot during validation

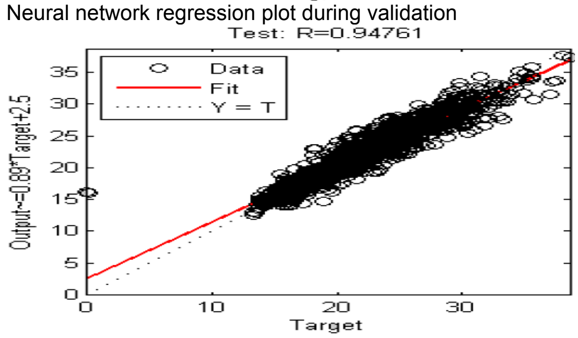

Fig. 7. Neural network regression plot during validation

Figure 5 represents training regression plot, Figure 6 represents validation regression plot, and Figure 7 represents test regression plot with regression value R=0.9568, 0.94542, and 0.94761.

5.3 Load Forecasting with Neural Network Prediction

Load forecasting is performed with the pre-trained neural networks. Date, temperature, and whether the day is a holiday or not, the information are given as an input to forecast the load.

When the neural networks are trained as explained in section C, the trained model is saved as MATLAB data file and it is accessed to forecast the load as shown below. Figure 8 predict the peak demand occurring time and peak demand level.

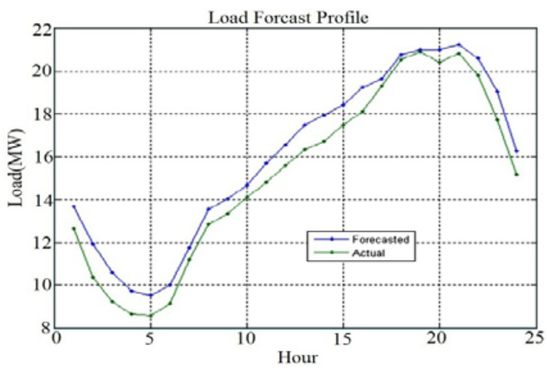

Fig. 8. Load Forecast Predicted by Neural Network Model and Actual Load

5.4 Multi Agent System Architecture

The proposed MAS have hierarchy of agents at different layers as depicted in Figure 9.

The service area is assumed to be divided into four zones with one agent pertaining to each zone. Zone Agent (ZA) has the capability to communicate with Load Management Agent (LMA) and any agents of that particular zone. Every zone has one Load Aggregator Agent (LAA) and a Distributed Generation Agent (DGA) associated with respective load and DG. The Load Management System (LMS) proposed in this work uses a centralized approach. The responsibilities and communication capabilities of each agent are discussed below:

- LMA is the head agent of the load management system proposed in this work which is decision maker agent. LMA takes the day-ahead forecasted load predicted by the load forecaster and identifies the peak demand level, limit, and time in which peak demand is occurring. Accordingly LMA requests controllable loads availability and DG availability from the zone agents. When LMA receives all needed information from ZAs controllable load and DG operation time are allocated. LMA is majorly responsible for the peak load reduction allocation and it can communicate only with zone agents so as to reduce the communication traffic.
- ZA has the information about DG and controllable loads available in its respective zone. The zone agent is the only agent which can communicate with LMA, DGA and LAA. As soon as ZA receives the request from LMA, it in-turn sends request to DGA and LAA to check Kilo Watt (kW) capability and controllable load availability respectively. After the necessary information is received, ZA sends the details to the LMA.
- LAA has the information about controllable load availability, charging rate, and required Kilo Watt Hour (kWh). It can be any number of LAA in a given zone, but only one LAA is considered in each zone. The requirements of all the controllable loads are aggregated and the information is fed to LAA. Then it communicates only with ZA.
- DGA has information about the DG, with which it is associated with. Ideally it also has kW capacity and availability time of DG. Minimum start up time required for the DG to be connected to grid is assumed to be included in the time from which DG can be available.

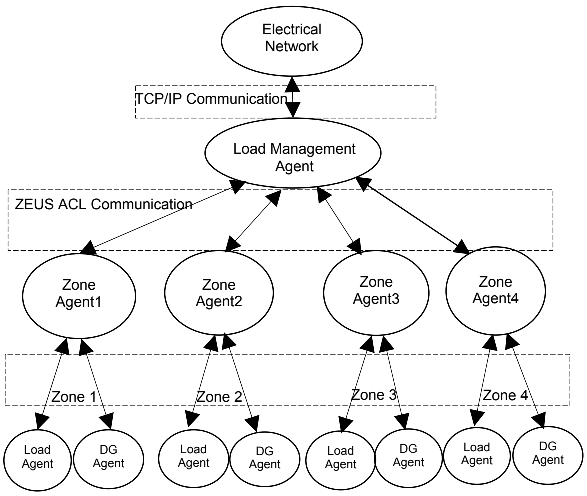

Fig. 9. Proposed MAS architecture

5.5 Load Management System

The proposed load management algorithm includes electric load forecasting using MATLAB and peak demand reduction using MAS. Figure 10 shows the inputs needed to calibrate the MATLAB load forecaster, to forecast the load, and the output.

Peak load reduction is handled by MAS which is developed by using ZEUS. The forecasted load is given as an input to MAS.

Peak demand reduction using MAS is performed by adopting a strategy in which price signal as bid sent by DGs and loads are considered as well. Moreover it is assumed that DGs and loads are available during the peak time and load management is done in the cheapest way possible using optimization technique.

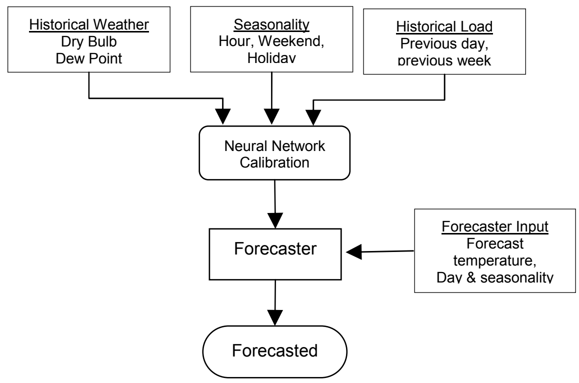

Fig. 10. Load Forecasting Flowchart

The proposed MAS have 13 agents located in different layers. With respective to the devices with which agents are associated with, various data has been given as an input to all the agents for the purpose of simulation.

This data can be related to the real time zone, DG, and load data. LMA however has all the data needed for it to dispatch the load for the purpose of peak demand reduction. LAA has the aggregated data of all the controllable loads. As well, DGA has the DG characteristics, its availability, capacity and bid. Once the LMA identifies the peak demand constraints (Peak demand level, occurring time, and cut-off limit), it initiates the communication process for the peak reduction.

Minimize J

(1) $$J = \sum_{i=1}^{4} a_i * x_i + \sum_{j=1}^{4} b_j * Y_j$$

Subject to

(2) $$\sum_{i=1}^{4} X_i + \sum_{j=1}^{4} Y_j = A$$

Bounds

$l_i \le X_i \le U_i; i = 0,1,2,4$

$m_i \le Y_j \le N_j; j = 0,1,2,4$

where

X_i - supply MW of i_{th} DG, Y_i - reduced MW of j_{th} Load a_i - Bid of i_{th} DG to supply load ($/MWh), b_j Bid of j_{th} Load to reduce load ($/MWh), A -Peak demand MW that needs to be reduced (MW), l_i & U_i - Lower and Upper Limit of i_{th} DG respectively, m_j & N_i -Lower and Upper Limit of j_{th} Load respectively.

Figure 11 explains the LMA action sequence in the peak management strategy.

Steps in the peak management strategy:

Step 1: LMA sends request to ZAs for peak shifting after Identifying peak constraints from MATLAB load forecast;

Step 2: ZA sends message to DG agents and LAA agents with KW requirement and timing of the peak;

Step 3: DGA and LAA sends capacity and their bid to participate in the load management;

Step 4: All the four ZAs send the obtained loads and DG information back to LMA;

Step 5: LMA checks the load and DG bids in all of the zones. Then it allocates the load in such a way that peak is reduced in cheapest way possible and sends the decision to all ZAs;

Step 6: ZA sends DG and load operation time to their respective agents.

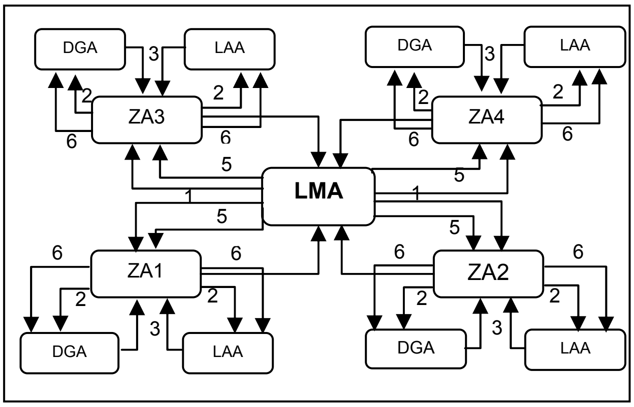

Fig. 11. Collaborative diagram for peak load reduction

Figure 12 depicts actual system load, forecasted system load (system load before peak management) and system load after peak management. As is shown, the real data shows 21.8 MW for peak value, forested data before implementing the proposed approach 22.1 MW, and forested data after implementing the proposed approach 17.1 MW. This is evidence for reduction in load for about 22.6 percent on the peak demand.

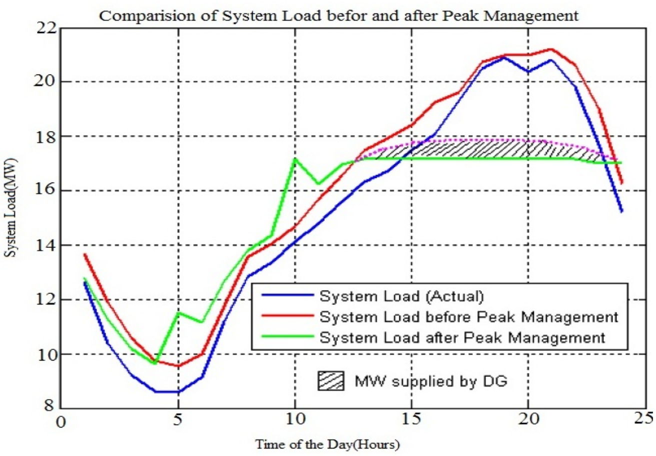

Fig. 12. Actual, forecasted and peak managed system load curves

6. Conclusions

This study discusses the approach and its results in implementing load management system for smart distribution system. Load forecasting module is developed using neural networks toolbox and statistic toolbox provided by MATLAB. MAS is implemented by using ZEUS for peak demand reduction. Test case is executed to see the load forecast and peak demand reduction. 22.6 percent of peak demand reduction has been achieved on the forecasted data.

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