Artificial Neural Network based Demand Side Management for Smart Grids

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***Abstract*—Smart Grid (SG) deployment is a globally emerging trend it has been proved that the technology has massive potential to properly manage and communicate the load profiles data generated within the decentralized power networks. The appropriate use and maneuvering of this vigorous data are the main obstacles involved between the large-scale implementation of SGs. Therefore, the Demand side management (DSM) techniques are usually employed to optimize SG in real time. In this paper we have proposed a novel technique to the appropriate DSM scheme for SG management and present the simulation results which has been carried out by using the power consumption data collected through advance metering infrastructure (AMI). Our proposed method forecasts the consumers load curve patterns and uses these pre-forecasted power consumption patterns data to train and substantiate an Artificial Neural Network (ANN) which then governs the SG process, after which the method continuously repeats this process and uses the pre-defined load computation patterns to categorize newly broadcasted power procurement data. The obtained result from this research proves that, our proposed optimization method intelligently assists the ANN based DSM network, and the extensive performance evolution by simulations shows satisfactory results while classifying the load curves.**

***Keywords*— Demand side management (DSM), Smart Grid, Artificial Neural Network, Power System Stability. Aggregator**

I. INTRODUCTION

The escalating complexity of power grids from past two decades has significantly contributed to enlighten the effectiveness of an efficient power management system, which requires comprehensive information about the existing power networks in real time. Therefore, the deployment of modern monitory technologies has become essential [1]. It has been proved that these technologies can provide very important information (such as, difference between demand and generation) about a power grid in real time, which could be further used to stabilize a power grid instantaneously, and helps leveling the production and consumption difference, as well as simultaneously monitoring each event and contingency occurs on a grid.

A smart grid is the combination of various monitoring and controlling devices, e.g., modern communication, automation and controlling devices which are used for monitoring the power grid, it also integrates the Smart Metering Infrastructures (AMIs), and autonomous managing devices which enables bi-directional implementation of smart optimizing and controlling strategies, which are used to control the power grid the system also processes the required power consumption data in real time [2-4].

The collaboration of these technologies provides a dynamic and highly authentic load data, and it also collects the data of each voltage point, measures current, trace the total energy consumed by load, and calculates energy loss. It enables the energy resources management through modern devices (modern flagships phones) which can be easily controlled by consumers and enables them to choose the power management techniques (using mobile applications) which they think are suitable and should be deployed to fulfill their domestic energy needs in the decentralized power gird. This sort of consistently growing controlling flexibilities is enforcing the development of emerging optimization and controlling techniques for the satisfactory operation of a power grid [5].

Moreover, there are various other emerging techniques that could be presented from different prospects, for instance, differential charging, varying tariffs, and direct load management, enables the DSM deployment for optimal power grid structuring and controlling [6-8].

The data acquisition from different sectors of AMIs which are now installed in the consumers' premises (i.e., in metropolitan areas of Netherlands), enables an effective decentralized load controlling strategy which is considered to be very helpful for energy consumption management. This feature of a SG comprises immense importance, since consumers' role is considered most important in the energy management. Therefore, the consumers' independency in power management enables them to sale, excessively available energy stored in their domestically installed energy battery units back to the grid in a distributed generation environment, if they have roof mounted solar setups [9].

The effective utilization and classification of the acquired data in appropriate manners is considered as the biggest constraint for managing a power grid. For this purpose, there are various tools available to process the acquired data effectively for instance, data mining techniques, ANN system and statistical methods, provides most relevant information about the consumption history and assists the deployment of energy management protocols, which are highly effective for different cases, i.e., the load classification strategies to implement DSM [10].

This paper presents significant literature survey about the existing DSM techniques commonly used for SG networks management. In addition, to evaluate the load leveling performance of these techniques individually we have created a SG structure in MATLAB and tested their behavior individually of each technique in simulations under several power consumption scenarios.

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The data which has been acquired from these simulation tests is then used to create an ANN based power management structure, which efficiently classifies the data types of different power consumption patterns generated and broadcasted by AMIs.

It also selects the appropriate DSM technique which should be applied to deal with a particular power consumption pattern. The basic objective of ANN technique in proposed model, is the assessment of the load profile classifier mechanism, after acquiring suitable results the most appropriate DSM technique is selected, for each consumer who has been allotted a rank in a power network.

This paper is arranged in a manner where, Section II presents the characteristics overview of significantly used DSM techniques. Section III comprises the ANN technique which we have used for our simulation. Section IV presents the simulation results, and Section V concludes the paper.

II. Demand Side management (DSM)

There are only two types of actions usually performed for power management; primal is the power transmission side management action, in which the installation of new electricity production units is carried out, and second is the load controlling by enforcing power conservational strategies using DSM techniques to reduce energy loss with the help of remote terminal units [9].

Many researchers explain DSM as a power managing protocol, usually governed by utility companies in order to limit the energy consumption of consumers, and they believe that the DSM is providing interfering between numerous energy consumption nodes [10-14] this approach is somehow right.

However, the basic objective of DSM is to minimize the peak load power demand during high consumption hours. Moreover, the DSM is the collection of techniques collectively works to stabilize the grid. The particular target of DSM implementation is the enhancement of economic outcomes in return of the investments which were invested to establish new service units for increasing power system capability and reliability, for the prosperity of consumers. This is usually achieved by increasing the ability of maintaining load factor wherever it is required. DSM controls the load demand on the consumer side and dynamically manages the network, by applying strategies of maintaining load factor (a collaboration between normal load and peak load) [14-16].

A DSM network uses the automation technologies or devices which are capable to change the load controlling policies in accordance with the consumers’ needs, as well as by increasing incentives, to motivate them to divert peak load to off peak hours. This solution is feasible only at those places where AMIs are installed near the consumers’ premises. This facility tracks each detail regarding tariff and measures the kilowatt hour (kWh) consumption during the day of each consumer and accounts at the end of a month, that could surely increase the consumer satisfaction [14, 17,18].

The prosperity of DSM network is calculated by assessing that how much customers are satisfied and how efficient service has been provided to them by assessing the ratio of reduced tariff, suppressed blackout durations, reduced faults and transients [18, 19]. The most commonly used DSM management methods are as follows: -

- Data collection.
- Peak and off-peak demand analysis.
- Market survey prospecting the future growth in short and long terms.
- Exploration of multiple energy resources to supply cheap energy to consumers.
- Characterization of effective modeling schemes for load analysis.
- Customer awareness, defining incentives to motivate customers to participate in DSM, common tariff analysis, developing optimal programs to automatically control the actions taken to modify the power demand.

The core entities of an efficient power management system are the categorization of anomalies that depends on further three steps; Primal is the. data acquirement, Secondary is the load profile analysis, and third is the projection of the peak demand.

- Data acquisition consists of the set of actions, procedures and conventional methods which are normally used to collect data from the power grid. The vibrancy and authenticity of data acquirement are key features of this analysis framework.
- Load profile analysis conducts the scrutiny of an individual customer to classify the load type that selects the suitable policy for load stabilization using analogous characteristics. Moreover, it also analyzes the type of connection, market feasibility, other economic prospects, and the current energy demand.
- The projection of peak demand is carried out after complete analysis of data, this is essential for growth rate anticipation in a developing network.

The collection of daily load profile data of all customers connected to the grid is practically absurd without deploying modern technologies, since conventional monitoring devices are unable to trace such data. Therefore, the data of the load profile curve is collected occasionally after 4 to 5 years by surveying a tiny portion of the population.

The randomly selected consumers section often provides only a little information about the main concentrations of most of the population. The data collected in such manners is considered as an assumption about the interest of whole populations. The main concern about such analysis, arises in such manners that either the analyzed behavior of the surveyed section is defining the overall intentions and either it could be implementable to the rest of population without any problem, which does not exactly assure that whether the representation is accurate and reflects the satisfactory review after four years.

The implementation of the SG significantly eliminates the constraints involves in daily data collection of load curves for different consumers in real time, and also ease the deployment of suitable tools to extract data related to the consumer behavior.

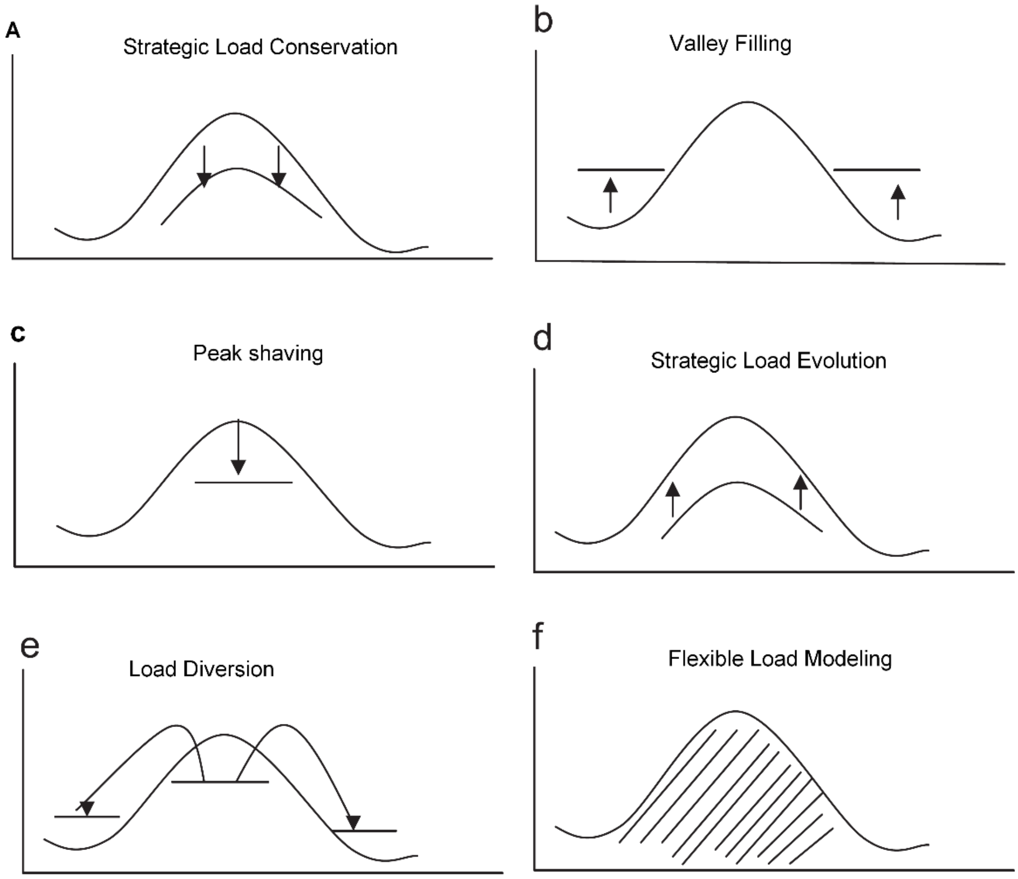

Fig 1 : Demand side management techniques

After analyzing received consumer intentions data, it is classified in such a manner, that it could be further evaluated for future correspondence. So that the actual load on the network and required power in future is predicted, this data is then used to select the appropriate location for smart substation installation.

The most used DSM algorithms [10-16], are shown in Fig 1. These are presented as the water filling, valley filling; peak shaving, load shifting, energy conservation techniques, strategic evolution, and flexible load modeling that are the most commonly used techniques.

A. Strategic Load Conversation

This technique controls the communication strategies, and their implementation to equalize the load between distributors and customers.

B. Valley Filling

The technique encourages consumers to divert loads to off peak hours. It enhances the off-peak consumption, which is significantly adoptable, because in off peak hours the generation cost is minimum. It reduces the overall tariff and enhances the network efficiency. Multiple incentives, for instance discounts on energy consumption, motivates various customers to adopt this strategy.

C. Peak Shaving

It suppresses the seasonal power consumption variations, by significantly enhancing the consumption efficiency through reduction in power losses. This technique is evidently efficient and welcomes the technological advancements.

D. Strategic Load Evolution

It manages the growing change in seasonal power consumption. In this method energy supply companies deploy intelligent monitory devices, highly efficient appliances, and more reliable energy means to maintain services.

E. Load Diversion

It diverts the overall load from peak hours (high demand to low demand periods) to off peak hours without disturbing the overall consumption. This is achieved by introducing distributed generation (DG).

F. Flexible Load Modeling

The concept governs the action steps which controls the interconnected strategies amidst to customers and power company, in quest to the momentary requirements. This concept regulates the consumer load without altering the basic load requirements. It just limits the energy for an individual customer by installing specific load limiting devices.

This network optimizes the vigorous amount of data that is mandatory to be entertained, for maintaining the record of various network buses and controlling modules. The prosperity of a regulating algorithm directly depends on continuous monitoring for 24 hours. Hence it is evaluated that how different loads performs, as well as it also covers the normal and extraordinary days, which helps in determining the particular action required for each case [11-15]. Although, these accomplishments are the outcome of a precise decision which further differentiates the other types of demands and evaluates the consumption type.

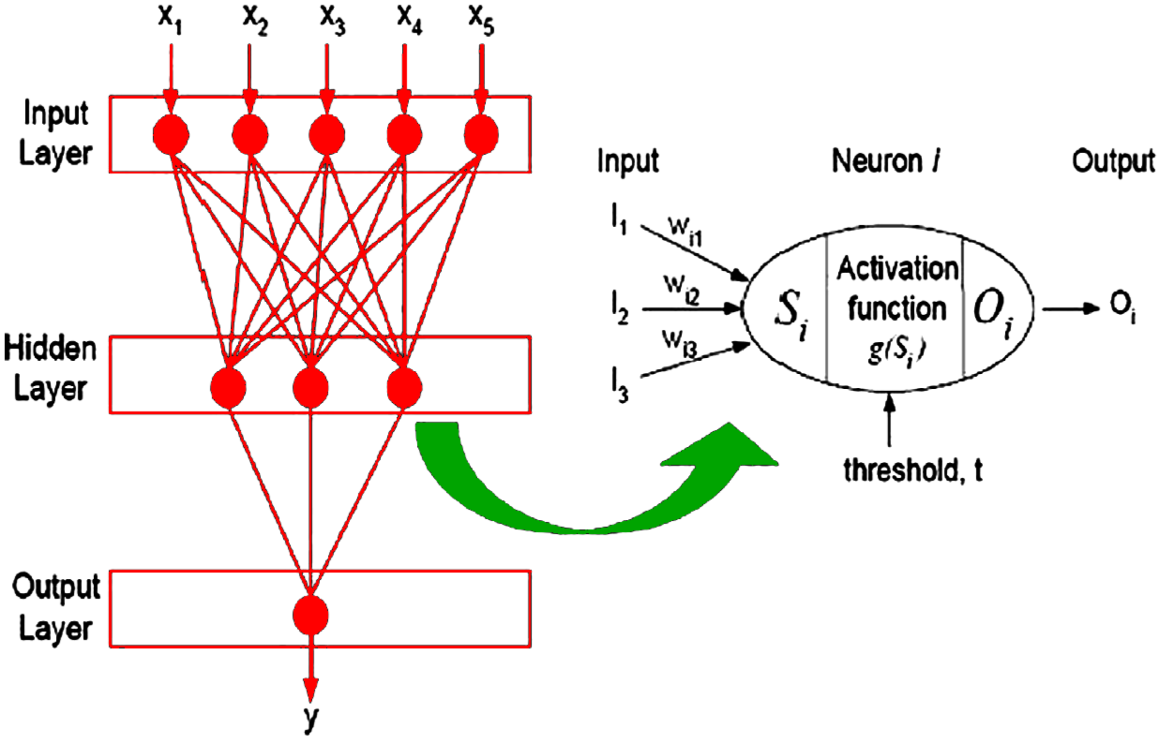

Fig 2 : Proposed Artificial Neural Network (NN) technique

There are various techniques which are used to classify such huge amount of data, including statistical and data mining techniques [16]; for instance, artificial intelligence or dynamic clouding, e.g., Artificial Neural Network (ANN). In this research work we implemented ANN technique due to its robust characteristics and specialization of handling enormous data in real time, various other features are explained in the subsequent paragraphs.

III. The Proposed ANN Technique

The core approach of an ANN refers to a signal processing network in which data consists of huge number of casual processing units, termed as cells or neurons that imitate biological nervous system in programming or digital circuitry. These neurons are linked through straight connections, known as synapses, enabling the distributed simultaneous processing, whereas their major function is the adaptive capability, i.e., their tendency to learn and develop accurate and composite relationship established between multiple numerical variables, despite imposing any predetermined model [20-24]. The ANNs are usually deployed in those networks where no mathematical model exists, or the available model is not competent enough to illustrate the phenomenon. The ANN layers could be presented by equation **Error! Reference source not found.**.

$$X_j = \Psi\left(\sum\nolimits_i^n = Y_{ji}Z_{ji} + \theta\_J\right) \qquad (1)$$

Where, Z_{ji} denotes the input vector, X_j represents the output vector, Y_{ji} illustrates the synapse load, θ_J is the constant and Ψ is the activator function.

The expression activator function represents the Ψ function that transforms the input values into output values on the node of a network. The sigmoid function is the one with commonly activated hyperbolic function, linear function, and the step function [20-26].

The Fig 2 presents an implementation model of an ANN system with N number of inputs. The received signals from a Neuron are the action or a state value which is used to activate Neurons; these are multiplied by a matching load Y_i. The present condition of a neural is computed by deploying a threshold function (activator) Ψ_n at that time when an input value is granted to the neuron, i.e., the union of all values involves activation of neurons criterions. These are multiplied according to the loads as presented in equation **Error! Reference source not found.**.

It is considered that the ANN system can provide the slower outcomes, therefore it is compulsory to converge this system after conducting a training phase, where the loads are fixed, hence, it achieves the multiple inputs. The ANN learning process executes while converging to the training phase [24-27].

The training algorithm which anticipates the power demand should have an error near to zero i.e., The objective of the ANN learning algorithm is to establish a record of loads y that reduces the overall sum of squared errors (G), as presented in equation (1).

$$G = \sum_i [X_i - f(y_k, Z_i)]^2 \qquad (1)$$

The ANN Algorithm 1 is exclusively deployed to overcome those constraints for which the data classification is carried out. Since its performance is extremely robust while tackling the faulty conditions and provides stability while handling huge amount of data simultaneously. It is mandatory to be sorted out in real time, it is also used for mathematical modeling, performing load analysis and narrating data time [22-27].

IV. Classifications of the Demand (Load) Curves

The classification of the power demand curves enables the assessment of the costumers and electrical network behavior for better analysis that allows easy computation of the total expenses, which have been spent for managing the power distribution network. The key knowledge of load curves also helps in forecasting the future increase in the power demand on an existing power network (substations and transmission lines) and helps in determining the performance of newly installed systems. It is established to enhance the power distribution ability of the existing system as well as evolution of the increase in computational ability. It also helps in sizing a distribution network and required efforts for optimization, which are then used to form an appropriate financial plan, to accommodate the physical efforts which have been spent for its expansion and management. The lacking information regarding consumer choices, makes it enormously complex to anticipate the outcomes of the incentive programs created for the consumers' motivation to change their power consumption habits. Moreover, for shorter periods, it helps in managing the customer demand and system demands which reduces the overall power procurement cost [11, 20, 21].

Algorithm 1: Proposed ANN based DSM Algorithm

Process Initialization $\{x, i, S_i, O_i\}$
Data inputs $\{x_1, x_2, x_3 \cdots x_n\}$
max: Maximal iterations
$sorting\ (S_i)$: sorting of data
$cleaning$: data cleaning
min: Minimal flaws in data
$Set\ values$: Fixed target
$Output\ (O_i)$: Computed output
loop $\boldsymbol{i}$; $(\boldsymbol{x} = 1\ to\ max)$
    Initialization of the data
    Compute net inputs
    Deploy classification function
    Compute error proportion = $Set\ values - Output$
    if $(s_i \leq min)$ **then**
        Halt the $cleaning$ process
    End
    else
        $sorting$
        $cleaning$
        $mutation$
    End if
Update Input data
Return O_i
end loop

Therefore, the classification of demand profiles is compulsory for the deployment of the appropriate DSM strategies. As it enables the selection of precise network optimization technique for better network management, out of the many possibilities of precise actions that may be selected for different load curves [22 - 24].

Recently, no such method has been implemented in any part of Pakistani power regulating points, and no DSM methodology is in use to classify the load curves. Therefore, conventional visual analysis techniques are being used to manually select the load curves [25]. This study is carried out by a specific group, who works on set targets of preparing full system power consumption and procurement profile. Some of the Pakistani power supplying companies use commercially available software, that works on the dynamic clouding method containing various algorithms and encourages the reduction in group variances, it enhances the distance between different managing groups. The procedure has a massive computing burden and needs capability to meet the requirements [26, 27].

In this study, we have used an ANN system to classify the power demand curves, since it is extremely robust, efficient and exhibits high processing speed for huge data volumes.

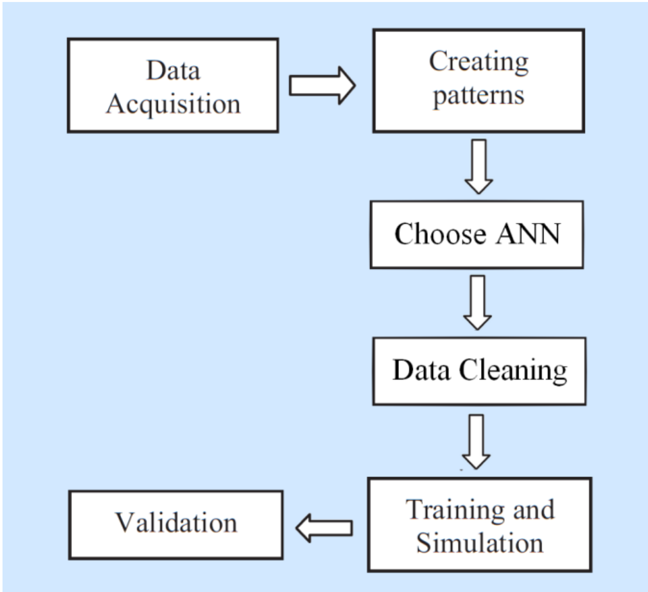

Fig 3 : The classification process of ANN

The simulation of load curves is performed according to the procedure presented in Fig 3. These classifications can also be deployed to the load curves at substations or on the consumers' premises.

The load curves classifications at power supplier end defines that the management or process controlling group should conduct their own load studies to govern the system optimization procedure smoothly [28]. the research work analyzes different classifications models to classify the consumer demand curves.

A. Data collection

The input data was acquired by a local power distribution company who gathered this data after conducting power generation and consumption measurements every year [29], to evaluate the increase in tariffs. A total of 96 measurements are performed each day in this research for 2100 conventional low-profile consumers, comprising industrial, commercial, and residential customers for a period of one month. However, the weekend load data were arranged separately since it is totally different from normal day's data.

This data was processed to achieve a median load curve for the upcoming 5 days. After analyzing and comparing data, which was received from each consumer it has normalized the arbitrary load curve profiles instead of absolute load consumption profiles.

B. Generating patterns

By using the acquired data as mentioned in previous section, we have defined an array which standardizes this data. MATLAB has been used to analyze the performance of the defined standard curve models to simulate different policies by deploying *k*-means technique.

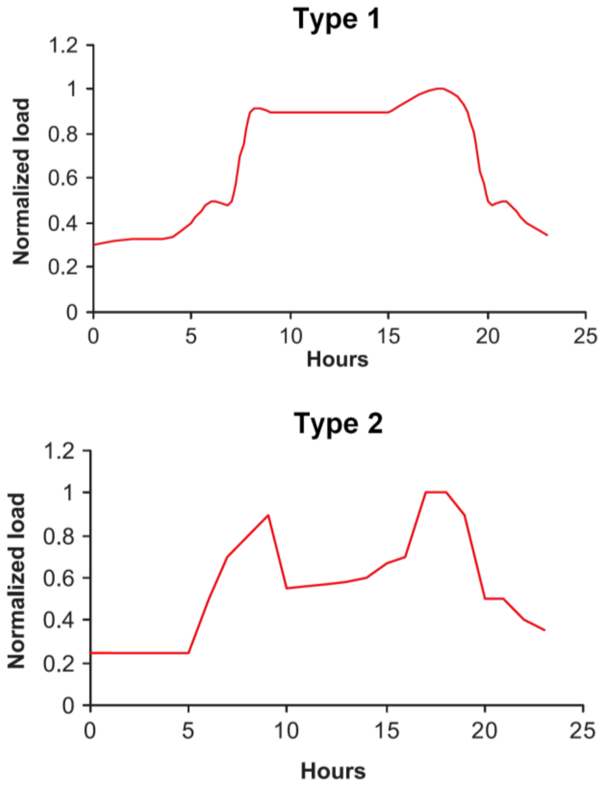

Fig 4 : Load Curve Profile (1)

The basic objective of *k*-means algorithm is to classify the data at approximately centered point named "centroids", which create partitions of new groups, and generate new partitions. This cycle concludes only when these partitions could not be enhanced or until they achieve a predefined precision level. This algorithm allows an autonomous classification which does not require human supervision. This technique is among one of the most commonly used techniques by Pakistani power companies for comprehending consumption patterns while computing the energy cost.

A total of 4 curves have been created with patterns having different characterizations. It has been observed that, the data analyzed by four different standards is significant to illustrate the precise DSM technique, because of its constraints which clearly defines the characteristic of a peak time, or more than two peaks.

The level is predefined to enable the selection of most precise strategy for DSM implementation during each unit of power consumption, e.g., load management, power efficiency, peak diversion controlling or distributed generation. Obviously, the option for different selection numbers must be considered according to the requirement of a power company. The Fig 4 and Fig 5 presents the 4 curve patterns which exhibits the following specifications:

1. Type 1

It shows a quite stable consumption throughout 24 hours, with a slightly increase in peak hours' energy consumptions. The management decisions in this case are based on energy consumption strategies and energy efficiency, despite the deployment of differential tariff and distributed generation.

2. Type 2

It presents two distinct peaks in the total load, which signifies the requirement of suitable action to manage the peak load by offering incentives e.g., tariff minimization. The direct load controlling from the aggregator side is also an option where an aggregator agent can divert the peak load or it can utilize the generated power on the consumer side (roof mounted solar power plant, or V2G facility if available), or aggregation negotiations between stakeholders to generate cost incentives. However, it is linked to the authenticity of the data received from the consumer end.

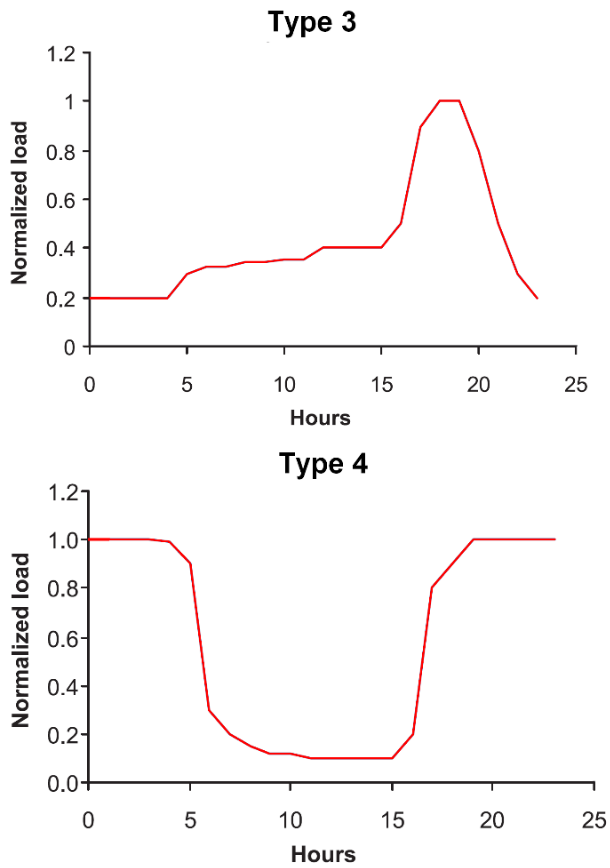

Fig 5 : Load Curve Profiles (2)

3. Type 3

It illustrates an abrupt change in the consumption, enforcing the deployment of suitable policies to suppress peak demand for valley filling, for this purpose direct load management and distributed generation (DG) could be used, moreover the use of differential tariff and DG is also a feasible option.

4. Type 4

It shows the peaks during night hours. This load is classified as street LED lights load. In this scenario, the actions could be the replacement of lights with better and efficient ones.

The option of selecting the required policy relies on the company objectives which are defined after load curves classifications, e.g., to classify the tariff for DSM implementation, or to optimize the power procurement the load scheduling is considered as main priority to stabilize the network. To implement any of these objectives, preliminary load classifications are essential for determining the more precise policy for different sets of loads having homologous characteristics.

TABLE 1
Error Proportion of the Proposed ANN model

Types	'Mean Error'	'Max Error'	Success Rate (%)
0	0.0125	0.0352	96.3%
1	0.0261	0.0360	94.4%
2	0.0178	0.0270	98.1%
3	0.0103	00153	100%

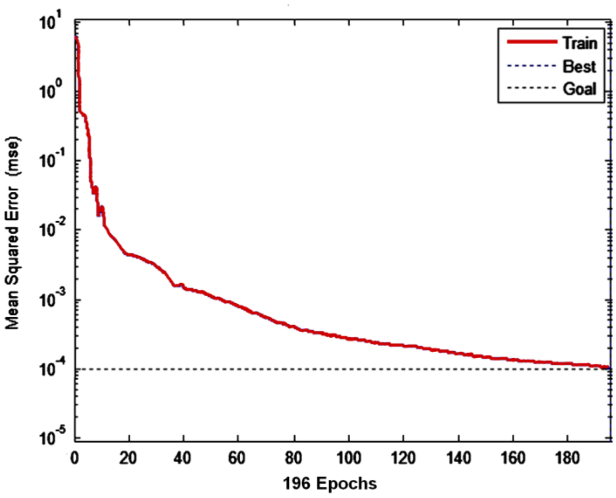

Fig 6 : Training Results

C. ANN Selection and Data Cleaning

In the case of simulation, we have used the ANN toolbox of MATLAB. The feed-forward architecture was implemented with three different layers (input, hidden and output, consists of 10, 20 and 1 neurons respectively), while for neural activation the hyperbolic tangent function is used.

In the case of performance, evaluation various architectural design was used with different schemes, which were containing diverse neuron numbers in each layer, but the selected architecture shows the significant result (dynamic computational speed and reduced errors) while classifying the data.

D. Training the Network

In order to train the network, a combination of 100 load curves was selected arbitrary, involving their particular classification (type 1, 2, 3 or 4). Various training algorithms were analyzed, e.g., back-propagation scheme was tested with and without time; although, that training algorithm, whose results were most appropriate, was the learning vector quantization algorithm (LVQA) [27]. The LVQA concentrated to the quadratic constraint of 10^{-4} at 197[th] step, as presented in Fig. 6, this algorithm exhibits the best performance as compared to the conventional algorithms [20-25].

E. Network Validation

To validate the procedure, we performed a simulation test by implying 220 samples taken from the ANN training data. TABLE 1 shows the constraints computed from the disparities, exists between projected and estimated values, which show that the highest constraint is minimum from the tracking types. It also illustrates the prosperity percentage as a highest tolerable constraint of 1%. These results endorse that the proposed scheme is efficiently anticipating the required samples.

V. Conclusion

Due to massive penetration of smart grid networks, the power supplying companies are receiving huge amounts of data about consumer's power consumption patterns in real time. Therefore, the load management with appropriate controlling strategies has become a complex task. It is anticipated that by the deployment of AMI devices, the large amount of consumer data can be processed leniently using the smart DSM strategies. This network up-gradation can motivate consumers to be more responsible in power procurement, this corporate/consumers' partnership can enable the deployment of suitable policies to control the network to make the power grid more robust and reliable.

The basic approach which we have implemented in this paper is the deployment of the ANN scheme as a load classification tool, which efficiently classifies the load curves of each consumer, being fed by the utility grid, and have connection with the central database. After classifying the individual load consumption data, we have grouped this data by linking multiple consumers load profiles after registering and analyzing the data collected form connected substations. Furthermore, after assessing the authenticity, the data is processed in such manners that it helps in making policies in quest to optimize the power grid in future.

In this research, the proposed ANN system showed perfect performance while evaluating load profile curves of individual consumers and whole substations. It could be deployed on broader scale to handle much more data relative to the power grid processes. This enables multiple applications, for instance, the assurance of precise and accurate DSM method selection for different loads handling (i.e., peak and off-peak load) as well as for network optimization using the dynamic pricing technique to accommodate consumers.

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