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IoT based Energy efficient system using Hybrid model of electricity dynamic price forecasting

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Abstract — *despite variation in wholesale electricity prices throughout the day, retail prices are typically constant. To address this economic inefficiency, a smart and intelligent energy efficient system can introduce for residential and industrial area to incent customers to shift their load away from peak price periods, at which time wholesale electricity prices are high.*

Usually dynamic pricing programs set different prices for electricity at different times during the day based on anticipated demand, available supply, and estimated cost of production. If dynamic pricing incentivized customers want to decrease their energy use during peak hours to reduce stress on the electric grid, the only requirements to implement an energy efficient system which will use a dynamic pricing program with two way communication between energy provider and consumer.

Dynamic pricing programs introduce a more equitable method of energy pricing wherein those who use the expensive energy pay the truer cost. They also support fairness in retail pricing by providing the means to charge those customers whose consumption patterns cause higher system costs according to their actual energy usage, and rewarding modest consumers with lower prices. Such programs also enhance the economic efficiency of energy usage by reducing peak demand, which in turn mitigates the need for expensive peaking capacity. Dynamic price program will use various data or parameters such as Load forecasting, price forecasting, previous consumption of energy, environment condition, fuel cost, demanded energy and available energy. Among them, price forecasting is complex and important parameter which is used in dynamic pricing. There are various methods used for price forecast but each has its own advantages and limitation. To overcome limitation up to certain extent a hybrid model can be proposed which can forecast price very efficiently. In this paper, we are going to use combination of Artificial Neural Network (ANN) and Fuzzy Inference System (FIS), named as ANFIS.

The proposed energy efficient system using hybrid dynamic tariff model ANFIS consists of Raspberry Pi, Router with Ethernet and WiFi interface, Computer for web server, Mobile for web server access to configure dynamic price.

Keywords *– IoT (Internet of Things), energy efficient, raspberry pi, embedded programming, dynamic pricing, dynamic tariff, ANN, FIS, ANFIS, HTML, PHP web server, Xamp software for local web server.*

INTRODUCTION

Residential and medium scale industry electricity consumers are not willing to participate in volatile or dynamic tariff pool market. They are generally unprepared for forecasting the electricity market price and even predicting their own load forecast.

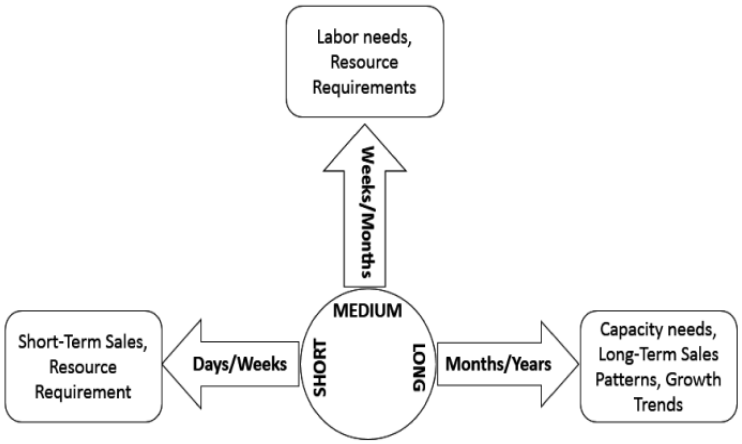
Hence, Retail electricity providers (REPs) bridge the gap between wholesale electricity markets and end consumers. In addition to the forward contracts, they procure part of the demand of their customers through the electricity pool market. Thus they have an intermediary and essential role in electricity markets. The main challenge of REPs is buying power on the wholesale market at volatile prices and selling it to the end consumers at the retail level at fixed agreed rates. Price spikes are a source of great concern for the REPs, who need to buy power at spot prices to fulfill their obligations to their clients. To handle the uncertainties it faces while buying and selling electricity, REP usually keep enough margin in price to ensure no loss. In this way, end consumer pays higher rate of energy and also cannot control energy efficiently.

Hence, the system is proposed in this paper will give total flexibility to end consumer to handle its load efficiently depends on dynamic price decided by energy provider and also eliminate role of REPs which in turn a less cost to end consumer. In this topology, an embedded system is designed which can have access to energy provider dynamic tariff server with security and limited access and control load efficiently as per configured pattern in embedded system. Embedded system will use appropriate algorithm for price forecasting so that user can take reference to configure the system.

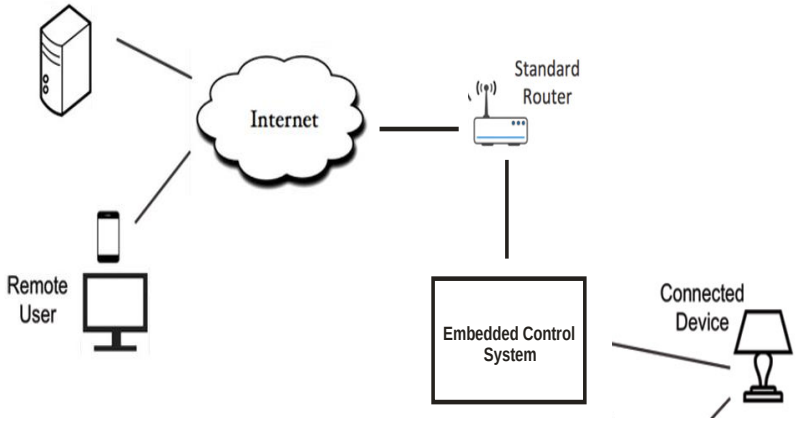
As far as forecasting is concerned electricity prices and load are mutually interlinked, due their dependability on each other and error in one will propagate to other. Non-storability, Seasonal behavior and Transportability are the major issues which makes electricity price so specific. These issues make it impossible to treat the electricity at par with any other commodity and forbid the application of forecasting methods common in other commodity markets.

Electricity price forecasting can be categorized into three different categories based on time horizons: Short-term forecasting, medium-term forecasting and long-term forecasting as shown in figure. Short term price forecasting (mainly one day ahead) will be mainly used by the market players to maximize profits in the spot markets. Knowledge of medium

term forecasting will allow the successful negotiations of bilateral contracts between suppliers and consumer while long term forecasting will influence the decisions on transmission expansion and enhancement, generation augmentation and distribution planning.



I. CONCEPT



Basic diagram of an IoT based Energy efficient System using dynamic tariff

Energy efficient system consist of embedded controller, which will primarily two major tasks : 1) Access remote server for dynamic tariff for efficient energy control 2) It gives user price forecasting using ANFIS algorithm which might be used to configure load patten according end consumer need.

To access remote server, a powerful system in terms of processing speed, is to be used. There are many options available in the market. Among them Raspberry Pi is better option for proto and concept development. Raspberry Pi has Ethernet interface which will be used to access remote server using internet. As per above diagram, a script is written in python to access remote server using HTTP protocol. This script will access particular link for getting instant price. Processing speed of Raspberry Pi helps to access remote server in very short and efficiently.

In this paper we have tried to give the idea regarding the IoT based energy efficient system using dynamic tariff model construction, circuit diagram, and implementation of energy efficient system with the help of dynamic tariff and IoT.

II. DESIGN & IMPLEMENTATION

The concept of Internet of Things (IoT) from its initial stage has changed the current communication scenario.

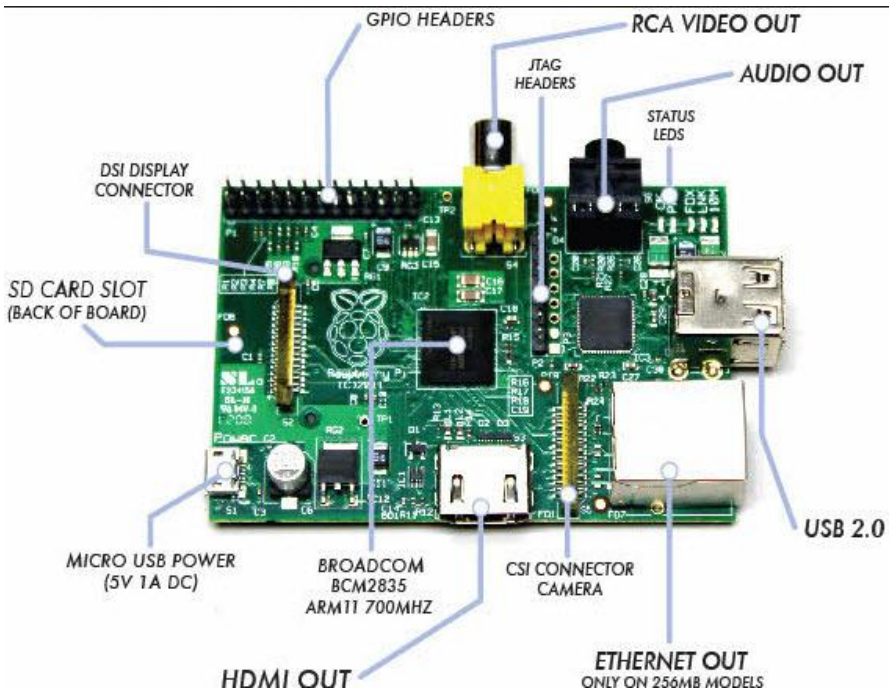
The IoT based energy efficient system using dynamic tariff comprises mainly 4 modules (units).

1. Raspberry Pi Linux based OS
2. Router with Ethernet and WiFi interfaces
3. HTML, PHP script for web server (Xamp)
4. PYTHON and SHELL script to access web server in Raspberry Pi

Methodology of work done

- For demonstration purpose, a local webserver has been created using HTML and PHP script. Xamp software installed in any PC, offers facility to run web server in local intra network. This server will be accessed using local IP address of PC on which Xamp server is executed.
- A Python and SHELL script in Raspberry Pi will access this Xamp local server for dynamic tariff. Based on dynamic tariff value, a load which is connected to Raspberry Pi GPIO will be turned on and off.
- A facility in terms of web page is given to user to change dynamic price manually. The changed value of dynamic price will be saved locally in PC where web server is executed.
- Raspberry Pi is connected to router using Ethernet port. Web server PC is connected to router using WiFi interface.
- Any other PC / Laptop / Mobile connected to router can access web page of webserver.
- Using this web page a user can change price and save locally.
- A script is continuously polling web server data using HTTP link and parse the current data to Raspberry Pi.
- Based on data Raspberry Pi will control load efficiently.
- Also, for price forecasting, a web page has been created in Raspberry Pi. This will forecast price using ANFIS algorithm and hence in turn use can check price trending to configure it load pattern efficiently.

Raspberry Pi Processor



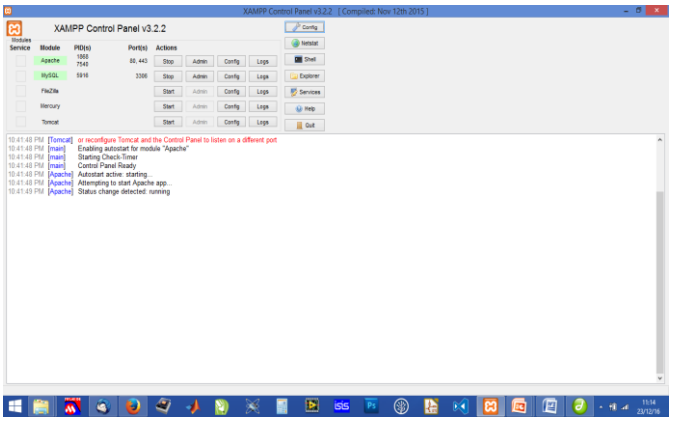
The Raspberry pi is a single computer board with credit card size, that can be used for many tasks that your computer does, like games, word processing, spreadsheets and also to play HD video. It was established by the Raspberry pi foundation from the UK. It has been ready for public consumption since 2012 with the idea of making a low-cost educational microcomputer for students and children. The main purpose of designing the raspberry pi board is, to encourage learning, experimentation and innovation for school level students. The raspberry pi board is a portable and low cost. Maximum of the raspberry pi computers is used in mobile phones. In the 2st century, the growth of mobile computing technologies is very high, a huge segment of this being driven by the mobile industries. The 98% of the mobile phones were using ARM technology.

The raspberry pi board comprises a program memory (RAM), processor and graphics chip, CPU, GPU, Ethernet port, GPIO pins, Xbee socket, UART, power source connector. And various interfaces for other external devices. It also requires mass storage, for that we use an SD flash memory card. So that raspberry pi board will boot from this SD card similarly as a PC boots up into windows from its hard disk.

Essential hardware specifications of raspberry pi board mainly include SD card containing Linux OS, US keyboard, monitor, power supply and video cable. Optional hardware specifications include USB mouse, powered USB hub, case, internet connection, the Model A or B: USB WiFi adaptor is used and internet connection to Model B is LAN cable.

Router with WiFi and Ethernet Interface
This router has Ethernet port, which will be used to connect to Raspberry Pi Ethernet interface. Also, this router has WiFi interface which will be used to communicate with remote web server and configuration device.

HTML, PHP script for web server
Xamp software has been used to create local server using HTMLscript, PHP web scripts. User can access the server using device HTML base web page. It will save configuration of device using its own device. User can configure using HTML web page of device and find configuration will be saved of a data base of local web server.



Local web server
Device configure page can be access from any device which have any browser like mobile, tablet, laptop etc.

III. PRICE FORCASTING

In this proposed system, a feature is given for price forecasting using parameters such as Load forecasting, price forecasting, previous consumption of energy, environment condition, fuel cost, demanded energy and available energy. This feature will help user to estimate future price tracking and using this estimation user can configure his load operation efficiently. Though, it is just estimation and forecasting, exact price value might be differed time to time. However, using appropriate algorithm estimation can be improved.

Also, using IoT based energy efficient system and price forecasting algorithm, a need for REP as a mediator can be eliminated and end consumer can directly take part in bid with electricity provider.

With introduction of the deregulated electricity markets major emphasis is on maximizing the profits of the various market players. As far as forecasting is concerned electricity prices and load are mutually interlinked, due their dependability on each other and error in one will propagate to other. Non-storability, Seasonal behavior and Transportability are the major issues which makes electricity price so specific. These issues make it impossible to treat the electricity at par with any other commodity and forbid the application of forecasting methods common in other commodity markets.

Electricity price forecasting can be categorized into three different categories based on time horizons: Short-term forecasting, medium-term forecasting and long-term forecasting as shown in figure. Short term price forecasting (mainly one day ahead) will be mainly used by the market players to maximize profits in the spot markets. Knowledge of medium term forecasting will allow the successful negotiations of bilateral contracts between suppliers and consumer while long term forecasting will influence the decisions on transmission expansion and enhancement, generation augmentation and distribution planning.

IV. PRICE FORCASTING METHODS

Survey reveals that various methods have been developed for forecasting. A rough tree of classification is shown in the Figure, this classification is not comprehensive and other approaches or methods are possible, these methods can be used for load forecasting as well as price forecasting. Mainly for price forecasting the approaches can be classified into two categories : 1) time series and 2) simulation approach, time series mainly relies on the historical data of market prices. In simulation approach requires precise modeling of power system equipments and their cost information, because of large amount of data involved simulation method can be computationally intensive. Time series approach can be further

classified into the following, linear regression based models and non linear heuristic models. Regression-based models include auto-regressive moving average (ARMA) models, and its extension, auto regressive integrated moving average (ARIMA) models, and their variants. While these models are aimed at modeling and forecasting the changing price itself, generalized autoregressive conditional heteroskedasticity (GARCH) is aimed at modeling the volatility of electricity prices.

Nonlinear heuristic based models uses artificial neural network and other artificial intelligent techniques for modeling the input-output data relation without complete information of the connections. Other soft computing methods are also used to extend the data representation capability of the regression based or ANN models.

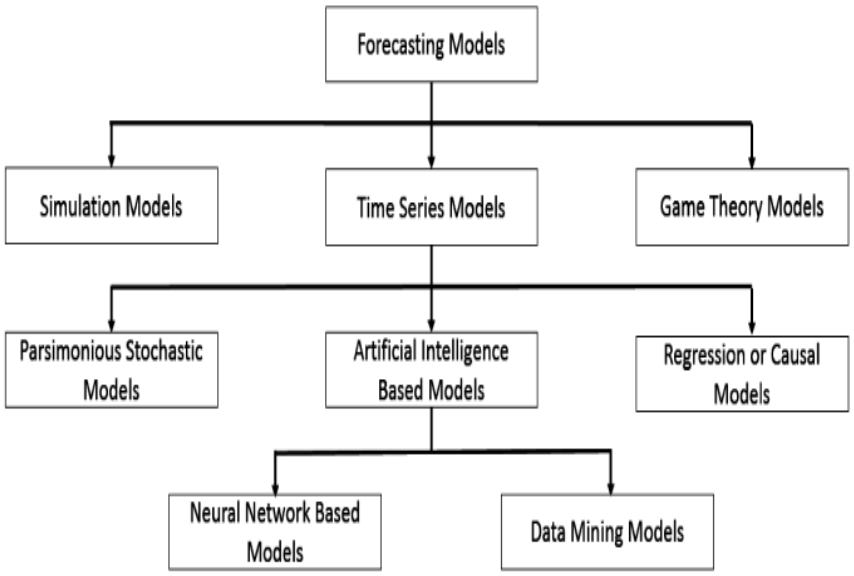


Figure 3. Classification of forecasting techniques.

1) ARIMA Model – Linear Regression Model

ARMA stands for Auto-Regressive Moving Average, ARMA is suitable model for stationary time series but most of the price series are non-stationary. To overcome this problem and to allow ARMA model to handle non-stationary data, the new model is introduced for non-stationary data, the model is called Auto-Regressive Integrated Moving Average (ARIMA), it has been successfully applied to forecast the commodity prices. The application of ARIMA methodology for the study of time series analysis is due to box and Jenkins.

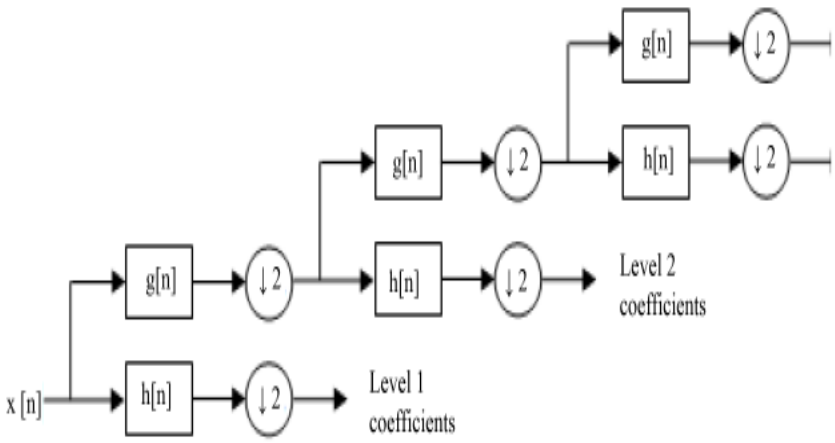


Figure 5. Level 3 wavelet decomposition.

ARIMA models are derived from autoregressive (AR), moving average (MA) and auto-regressive moving average (ARMA). In AR, MA and ARMA models conditions of stationary are satisfied; therefore they are applicable only to stationary series. ARIMA model captures the incremental evolution in the price instead of price value.

2) GARCH Model – Linear Regression Model

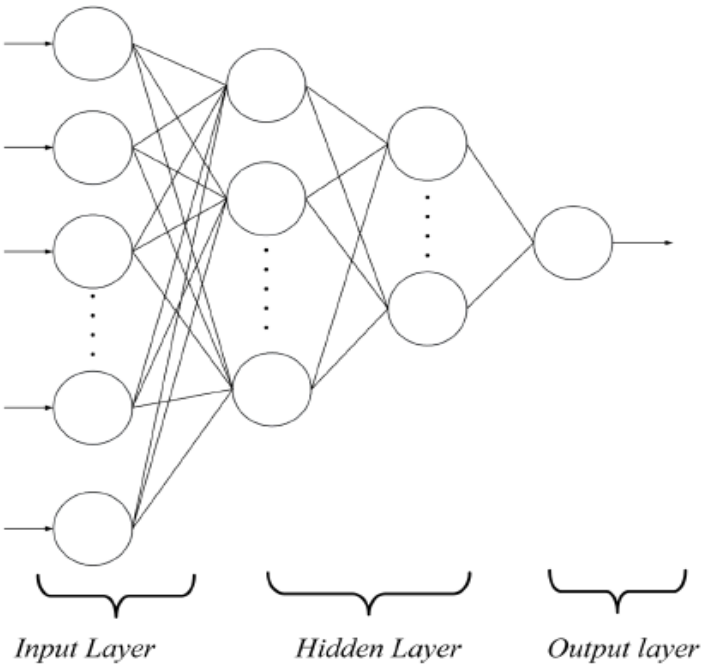
GARCH stands for Generalized Autoregressive Conditional Heteroskedasticity while the (ARIMA) models are aimed at modeling and forecasting the changing price itself, (GARCH) model is aimed at modeling the volatility of prices. GARCH models consider the moments of a time series as variant (i.e. the error term: real value minus forecasted value does not have zero mean and constant variance as with an ARIMA process). The error term is now assumed to be serially correlated and can be modeled by an Auto Regressive (AR) process. Thus, a GARCH process can measure the implied volatility of a time series due to price spikes.

3) ANN Model – Non-Linear Regression Model

Most of the time series models are linear predictors, while electricity price is a non-linear function of its input features, making it difficult for the time series techniques to completely capture the behavior of price signal. Therefore the researchers have come up with the idea of using Neural Network (NNs) for electricity price forecasting. Neural networks are highly interconnected simple processing units designed to model how the human brain performs a particular task.

Basic structure of the neural network is shown in the Figure. The network generally consists of three to four layers and during training process, the neurons in the input layer pass the raw information onto the rest of the neurons in the other layers. The connection weights between different layers keep on updating with the ongoing learning process.

A neural network uses a learning function to modify the variable connection weights at the input of each processing element i.e. neuron. The ANN models could be differentiated based on type of learning function, learning algorithm and no. of hidden layers etc. Generally a three layered neural networks are chosen for forecasting the electricity price.

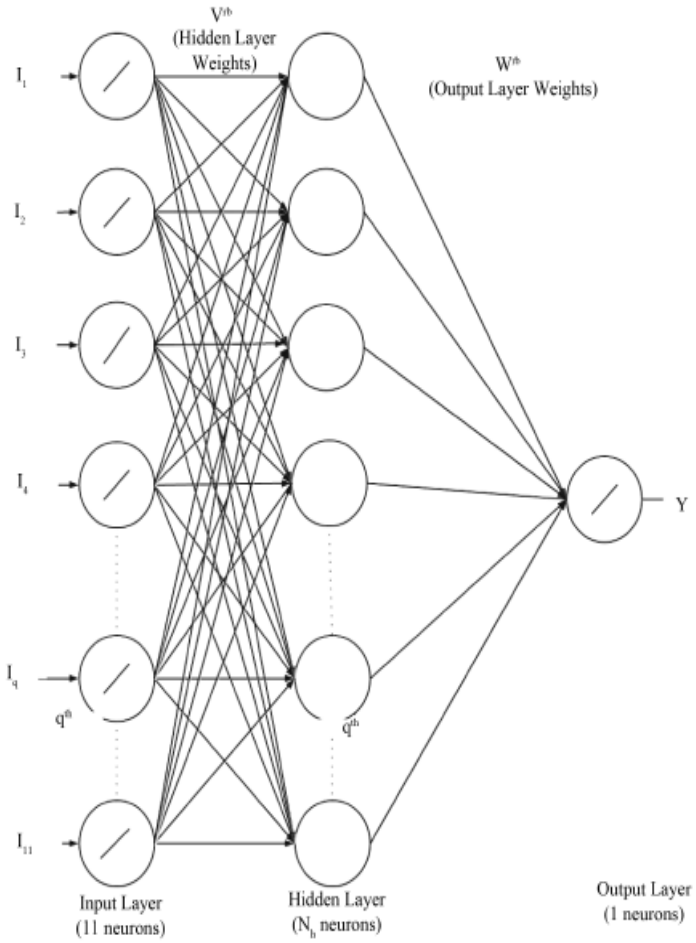


ANN based models have gained popularity due to their property to solve undefined relationship between input and output variables, approximate complex nonlinear function and implement multiple training algorithms. However, neural network also suffers from the disadvantage that the network will not be flexible enough to model the data well with too few units, and on the contrary, it will be over-fitting with too many units.

In order to overcome such weakness, different evolutionary techniques have been combined with ANNs recently. ANN model with feature selection technique and relief algorithm and particle swarm optimization is used for ANN training.

4) RBFNN Model – Non-Linear Regression Model

Radial basis function Neural Network (RBFNN) has comparatively less chance to trap in local minima and has faster learning rate. RBFNN uses radial basis function as the activation for the hidden layer neurons as compared to the artificial neural network (ANN). Similar to the ANN architecture the RBFNN also contains three layers i.e. input layer, output layer and only one hidden layer. The difference arises in terms of center neurons activation function and training method. The training of RBFNN consists of three steps: 1) centre selection; 2) width selection of basis function and 3) weight calculation for output layer.



5) FIS (Fuzzy) Model

An FIS performs input-output mapping based on fuzzy logic. Fuzzy evaluates the intermediate states between discrete crisp states and is able to handle the concept of partial truth instead of absolute truth. Traditional adaptive fuzzy system include ANFIS and neuro-fuzzy methods are intended to combine the advantages of ANN and fuzzy logic with the difference that ANFIS architecture has linear output function, whereas neuro-fuzzy systems are essentially a subset of ANN applied to controls and classification problem.

Wang-mendel suggested an algorithm for implementing FIS for time series prediction and the same approach was extended to forecast the electricity price. The approach is model free and heuristic in nature. A common framework called the fuzzy rule base is constructed to combine both numerical and linguistic information. The numerical information is sampled from measurements, and the linguistic information interprets the numerical information. The FIS is able to bridge the gap between interpretability and accuracy by providing a verbally interpretable rule base and numerical accuracy through training.

The FIS using wang-mendel learning algorithm does not require iterative training making it more efficient than ARMA or GARCH time series techniques and ANN or neuro-fuzzy intelligent systems. Compared to the black box nature of Artificial Neural Network (ANN) the Fuzzy Inference System (FIS) provides a transparent linguistic rule base instead of a black box. The rules may be modified manually to include expert knowledge. The rule base provides FIS the advantage of interpretability and transparency. FIS also provides flexibility in choosing predefined membership function. The FIS algorithm can be modified for higher accuracy and efficiency.

6) ANFIS Model – A Hybrid Model

An adaptive neuro-fuzzy inference system or adaptive network-based fuzzy inference system (ANFIS) is a kind of artificial neural network that is based on Takagi–Sugeno fuzzy inference system. Since it integrates both neural networks and fuzzy logic principles, it has potential to capture the benefits of both in a single framework. Its inference system corresponds to a set of fuzzy IF–THEN rules that have learning capability to approximate nonlinear functions. Hence, ANFIS is considered to be a universal estimator. For using the ANFIS in a more efficient and optimal way, one can use the best parameters obtained by genetic algorithm.

Assume that the fuzzy inference system has two inputs x and y and one output z. A first-order Sugeno fuzzy model has rules as the following:

- Rule1:
  If x is A1 and y is B1, then f1 = p1x + q1y + r1
- Rule2:
  If x is A2 and y is B2, then f2 = p2x + q2y + r2

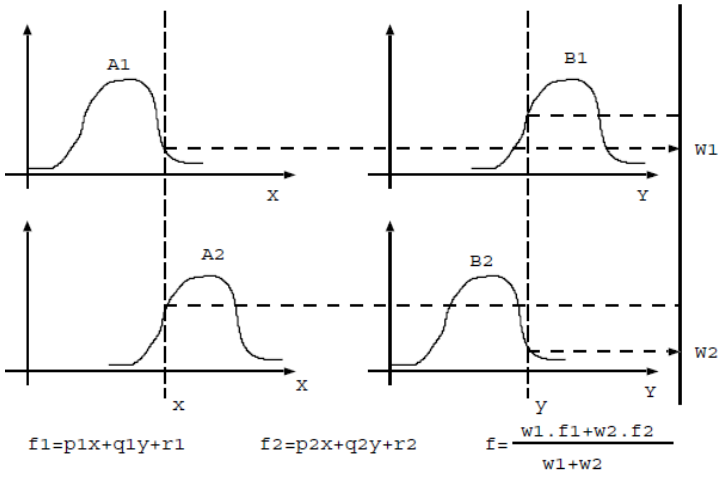


FIG: SUGENO MODEL – I

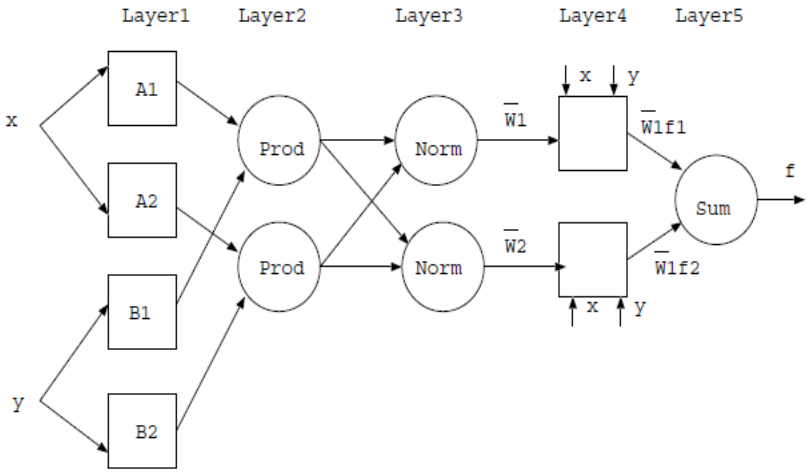


FIG: ANFIS ARCHITECTURE

The ANFIS model will have advantage of ANN model having highly interconnected simple processing units designed to model how the human brain performs a particular task. However, the neural network will not be flexible enough to model the data well with too few units, and on the contrary, it will be over-fitting with too many units. To overcome this disadvantage, a combined hybrid model ANFIS is proposed. FIS system will allow arbitrary input and relationship between input and output. Using this, user can also configure the system as per his need for non-linear and slab wise price variations. This model gives user the flexibility to configure load operation very efficiently against much complex dynamic price / tariff variations.

7) Model based on Simulation methods

Simulation methods usually simulate generator dispatch patterns over an extended period of time. These methods mimic the actual dispatch with system operating requirements and constraints. Despite of the high data requirement by these models, they can provide detailed insights into the price curve. The simulation methods which are currently being used by the electric power industry range from the bubble-diagram type contract path models to production simulation models with full electrical representation, such as GE-MAPS software . The production simulation models by nature of their chronological simulation patterns, will consider time varying systems limits and characteristics. Some important issues that must be addressed in any market simulation program that forecast the LMPs for the electricity market are:

- Detailed transmission model
- Unit commitment
- Economic dispatch with transmission constraints
- Secure dispatch
- Chronological simulation
- Large-scale study capability
- Data resources
- Benchmark and application

Simulation model known as MAPS, has been develop which stands for market assessment and portfolio strategies, this model incorporates a full representation of the electrical transmission model. The detailed power flow data and secure dispatch of generators, tracking transmission line flows, loss determination, and transaction evaluation are well integrated, providing an accurate through time simulation of system operation.

The MAPS model is able to simulate large power system for one or multiple year within optimum period. The MAPS model can be applied to solve the following issues:

- Analyze market power issues
- Evaluate alternative market structures
- Estimate stranded generation investments
- Assess economics of building new generation
- Assessing transmission costs
- Understanding market behavior

The general input output structure of MAPS is shown in the Figure. The data requirement of MAPS is similar to any free-standing production cost program or load flow models. Through its integration of generation and transmission models, it captures hour by hour market dynamics while simulating the transmission constraints of the system. Market simulation programs minimize the system cost to serve loads subject to transmission constraints, unit commitment and economic dispatch with transmission constraints are the core functions of typical market simulation programs. The program automatically provides the location market clearing prices for any bus, identifies the bottlenecks of transmission networks, and produces the generation schedules and power flows on the transmission grid, which are important in deregulated markets. Simulation methods are intended to provide detailed insights into system prices. However, these methods suffer from two drawbacks. First they require detailed system operation data and second simulation methods are complicated to implement and their computational cost is very high.

8) Model based on Game Theory

There has been great deal of research to understand electric power markets, and various methods for modeling, analyzing and selecting bidding strategies for power suppliers. Gaming theory is a natural platform for market competition. It is of great interest to model the strategies of the market participants and identify solution to those games. Since participants in oligopolistic electricity markets shift their bidding curves in order to maximize their profits, these model provides the solution to these games and profit can be considered as the outcome of the power transaction game. In this group of models, equilibrium models, take the analysis of strategic market equilibrium as the key point. The gaming models are generally used by the market operators for deciding the market strategies.

V. SECURITY CONCERN

Security is a major concern when any system deals with internet. However, nowadays, many security options are available which will make this system more powerful. Also, this system runs on Linux OS, so that most latest and power security layers (TLS/SSL) can be easily implement with this system. Remote server can also be configured so that a consumer will have access to its own historical data. No one can access others data. Also, remote server will have flexibility to keep different electricity price considering Rural or Urban region.

VI. CONNECTIVITY CONCERN

As this system can efficient work only when it will have dynamic price from remote server using internet. In case of failure of internet, this system cannot access current electricity price. However, a facility in the system can be given to end consumer to configure load operation in case of internet failure. Once configured, it will operate the load as defined.

VII. CONCLUSION

Usually dynamic pricing programs set different prices for electricity at different times during the day based on anticipated demand, available supply, and estimated cost of production. If dynamic pricing incentivized customers want to decrease their energy use during peak hours to reduce stress on the electric grid, the only requirements to implement an energy efficient system which will use a dynamic pricing program with two way communication between energy provider and consumer.

Also, system with price forecasting facility helps end user to estimate price more appropriately and hence in turn elements the need of Retail Energy Provider (REP). Therefore, it is not only provides economic options for end consumer to participate in bid, but also help consumer to control its various load more effectively and efficient.

Raspberry Pi powerful processor can efficiently handle various task of communicating remote server using internet and computational task of price forecasting.

For price forecasting, ANFIS algorithm will be the best choice as per following conclusion:

- Time series models, econometric models and intelligent systems methods are three main statistical models.
- Non-statistical methods include equilibrium analysis and simulation methods. Methods based on time series are more commonly used for electricity price forecasting due to their flexibility and ease of implementation.
- The main drawback of time series models is that they are usually based on the hypothesis of stationary, whereas the price series violates this assumption.
- A neural network uses a learning function to modify the variable connection weights at the input of each processing element i.e. neuron. The ANN models could be differentiated based on type of learning function, learning algorithm and no. of hidden layers etc. Generally a three layered neural networks are chosen for forecasting the electricity price.
- ANN based models have gained popularity due to their property to solve undefined relationship between input and output variables, approximate complex nonlinear function and implement multiple training algorithms. But, the neural network will not be flexible enough to model the data well with too few units, and on the contrary, it will be over-fitting with too many units.
- The ANFIS model will have advantage of ANN model having highly interconnected simple processing units designed to model how the human brain performs a particular task. However, the neural network will not be flexible enough to model the data well with too few units, and on the contrary, it will be over-fitting with too many units. To overcome this disadvantage, a combined hybrid model ANFIS is proposed. FIS system will allow arbitrary input and relationship between input and output. Using this, user can also configure the system as per his need for non-linear and slab wise price variations. This model gives user the flexibility to configure load operation very efficiently against much complex dynamic price / tariff variations.

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