Predicting Household Energy Consumption in Smart Grid Based on Seasonality Using Stochastic Markov Chain

J.Jasmine Christina Magdalene[1], Smitha Evelin Zoraida[2]

[1]*Asst.Professor, CA,Bishop Heber College, Tiruchirappalli, India*
[2]*Asst.Professor, CSE, Bharathidasan University, Tiruchirappalli, India*

jjasminebhc@gmail.com[1],b.s.e.zoraida@gmail.com[2]

***Abstract*- In today's scenario the consumption of electricity is ever increasing and the electric grids are being upgraded to smart grids. A smart grid is an enhanced version of electrical grid where digital technology is used to communicate between utilities and consumers. This helps the users to manage the consumption of energy in a better way. Seasons play an important role in the consumption of energy as the home appliances are used based upon seasons. To achieve better energy management there arises the need for prediction. In this paper an attempt is made to use Markov Chain for the prediction of energy consumption during various seasons in a smart grid. Markov chain is one of the stochastic process which is used when random variables are considered. Since the energy consumption during various seasons are random, Markov Chain is used for prediction. The dataset is taken from Pecan Street, Austin, USA and the energy consumed from the grid is combined based on various seasons. The seasons in Austin namely winter, spring, summer and autumn are taken as the state space and a transition matrix is built based on the energy consumed during these seasons. After building the transition matrix, the future data is simulated and by using Markov Chain the energy consumption during various seasons for the forthcoming year is predicted.In this paper prediction is done for five years based on the present state and the RMSE is calculated. The loglikelihood of using Markov Chain is compared with Markov Bayesian and Markov Bootstrap models. Markov Chain has higher loglikelihood indicating that this gives better results for the dataset taken.**

***Keywords*- Smart Grid, Energy Management, Stochastic Process, Transition Matrix, MarkovChain.**

I. INTRODUCTION

Electric energy has become one of the highly prioritized requirements in today's world. All the latest technologies work only with the assistance of electric energy. The consumption of energy is increasing day by day as the usage of smart devices increases in a sturdy pace. Electrical energy can be obtained from various sources like water, air, sun and wind. Usually houses get electricity regularly from the electrical grid and lately smart grids are preferred as an advanced and upgraded grid to effectively endure the task. A smart grid is a digital technology that allows two- way communication between the utility and its customer [1]. This two-way communication helps the consumers to know their exact usage of current and the amount of energy consumed by each smart appliance in their home. So, Energy management has become more vital as it helps in reducing price and to get continuous energy supply at the time of outages. The excess energy can be given back to the grid and the price for the energy given can be obtained. Hence there arises the need for prediction. Energy prediction depends on various parameters like seasons, usage of energy by various appliances in the home, infrastructure of a home, renewable energy resources etc., Since most of the parameters are fluctuating and cannot be deterministic prediction becomes a challenge. Many researches show that traditional forecasting techniques are used for prediction. This paper aims in predicting the consumption of energy during various seasons for the forthcoming year. Since there is uncertainty in the consumption of energy during various seasons, a stochastic process will prove much better than traditional prediction algorithms like neural-network, SVM and ARIMA. The traditional ARIMA algorithms lack incremental learning mechanism. The parameters are learnt by the model and used as the same for all the future data [2]. A stochastic model represents a situation where uncertainty is present [3]. The Markov-Chain technique is used to predict the future based on the

present. It does not depend on the past data. Since the climatic conditions are changing because of global warming, much ahead prediction of weather will reduce the accuracy. Hence Markov- Chain technique is used in this paper to predict the consumption of energy in the forthcoming year based on the energy consumed during various seasons. The main advantage of using this method is, it deals well with random variables which are non-linear and it is a probabilistic method where uncertainty is taken into consideration. The paper is organized as follows. Section II deals with the review of literature where works related to this paper are discussed. Section III gives an overview of the preliminaries that are needed to implement this work. Section IV deals with the methodology that. Section V discusses about the result and finally Section VI describes about the conclusion and the future work that can be carried on with the help of this paper.

II. REVIEW OF LITERATURE

Prediction in smart grid has become an important area of research as smart grid plays an important role in energy management. Many authors have contributed towards this area of research. Dima Alberg and Mark Last has presented sliding window-based ARIMA algorithms in smart meters for the forecasting of hourly electricity load at the district meter level [2]. Jiali Mei et.al have given a generic approach to estimate the electric consumption on any geographical zone using k-Means and linear regression model [4]. Elanki sharma has assessed a weather-free forecasting model using data mining techniques [5]. Nurul Nnadiah Zakaria et.at have proposed a forecasting tool with Markov Chain to evaluate the air pollution level in long term [6]. Soumyadip Gosh et.al has proposed new techniques for customers demand response using markov- chain and long term-pricing using probability distributions [7]. S.Elgharbi et.al have used grey- markov which is a combination of grey model and Markov chain model to forecast the production and consumption of electricity in Morocco. It is based on the analysis of the historical data [8]. Wayes Tushar et.al has proposed a stochastic model for the generation of solar energy by using Markov chain approach [9]. Kishore Kumar Senapati has presented a framework for predicting household electricity demand by implementing first order hidden Markov model using Viterbi algorithm considering the population, financial strength and climatic conditions [10]. The related work shows that Markov Chain is not used in forecasting of energy consumption in a smart grid based on seasons. Markov chain is used in this paper as it deals with random variables and consumption of electricity during various seasons is also random.

III. PRELIMINARIES

3.1. Stochastic Process and Markov Chain

A stochastic process is a process in which the output is random. In a simple way a stochastic process is said to be collection of random variables which can be defined in a common state space. The random variables usually change with time.The building blocks of a stochastic process are the probability distribution and random variables. A Markov process is one of the stochastic process in which the next value of a process depends on the current value. Markov Chain is one of the types of Markov process which has a state space and it is discrete in nature. The output of the Markov chain doesn't depend on the historical data but to get the future value, the present value is alone needed. Since the climatic conditions are changing every year because of the exploitation of nature, this Markov Chain is of great use when it comes for prediction based on seasons.

3.2. Problem Definition

Electrical energy consumption is increasing day-by-day. So, energy management has become more important for uninterrupted power supply during various seasons. As the traditional electric grids are getting upgraded to smart grids, it has become more easier to know the exact amount of energy consumed from the grid every day. Power consumption varies based on seasons as certain appliances are used only during a particular season and these appliances have their own rate of energy consumption. Hence there arises the need for prediction of energy consumption during various seasons. This will help the consumers as well as the utilities to know the future demand of electric power during various seasons and by using this forecasted value, the production of electricity through renewable resources can be scheduled. The usage of devices can also be scheduled so that there is no interruption in power supply.

3.3 Notations

Let S,PC are the parameters that provides the consumption of energy during various seasons.

Let f(S,PC) be the function of the variables which is given as an input to construct the transition matrix.

The transition matrix for energy consumption between seasons based on current data is constructed based on

$$T_{(i,j)} = P\,[q_{t+1} = j \mid q_t = i\,]$$

Where q_t = State at time t

q_{t+1} = State at time t+1

i, j = States

Then pattern pre-estimation is done using

$$P\,[X\,(t_{n+1}) = j \mid X(t_1) = 1,\ X(t_2) = 2\ ,\ldots X(t_s) = i]$$

Future Present

$$P\,[X\,(t_{n+1}) = j \mid X(t_s) = i] = p_{i,\,j}\,(t\text{-}s)$$

Future Present

where X = States

i,j = Initial states

t = state at time t

t+1 = state at time t+1

The steady state probability vector is computed using

$$\pi\, T = \pi$$

where π denotes the steady state probability vector for power consumption.

3.3 Loglikelihood

Loglikelihood tells how well a statistical model fits into the dataset taken. The statistical model represents that the data is generated based on the sample data. Higher loglikelihood indicates that the efficiency of the parameters taken maximizes the probability of the sample data that is taken for certain observation.

IV. METHODOLOGY

Generally, the usage of electricity greatly depends on seasons. The usage of various appliances in a smart home varies according to the season and each appliance has its own level of energy consumption. Since energy consumption varies, prediction of energy consumption during various seasons has become important to reduce cost and to get continuous supply of energy during the peak demand time. As there is irregularity in energy consumption during various seasons traditional forecasting methods do not prove good. Hence a probabilistic approach is needed to enhance the accuracy of prediction. Here Markov Chain is used to predict energy consumption based on seasons as it is random and shows non-linearity.

A time series smart grid dataset from the Pecan Street, Austin, USA is taken to predict the consumption of electric energy in a smart home using stochastic Markov-chain Principle. Based on the availability of the dataset and considering the parameters for energy consumption, two variables namely seasons and power consumption are taken for predicting energy consumption. The energy consumption is a function of input variables, f(S,PC) where S and PC are assigned to each input variable. The consumption of energy in a house from January to December is taken as the input. The energy consumption data is combined based on seasonality and this forms the state space to build the transition matrix. The transition matrix simulates the probability of the future state and the energy consumed during various seasons in the forthcoming year is predicted using Markov Chain. Prediction is done for five years. The

RMSE is calculated for each year. The efficiency of this work is checked by loglikelihood and compared with other Markov Bayesian and Markov Bootstrap techniques. This work is implemented using R tool.

4.1 Input Parameters:

By understanding the influence of the input parameters on energy consumption during various seasons, the following inputs are taken:

(i) Seasons

(ii) Power Consumption

4.1.1 Seasons

Seasons play a vital role in predicting the energy consumption. Seasonal changes have a great impact on the usage of household appliances. Based on various seasons the energy consumption also varies as each appliance has its own level of energy consumption when used. The dataset is taken from Pecan Street, Austin, USA. Austin experiences four different seasons namely Winter, Spring, Summer and Autumn. The months are grouped into three based on the seasons. December to February is considered to be Winter, March to May is Spring, June to August is Summer and Autumn is during the months of September, October and November.

4.1.2 Power Consumption

The energy sources for a smart home are electric grid, solar, windmill etc., For this work energy consumption from the grid is taken and the data shows that the power consumption shows variation in different seasons. From this it is very clear that the energy consumption by household appliances varies based on the season. For example, during winter room heaters are used and during summer air conditioners are used. The level of energy consumed by heaters differ from air conditioners. Hence there is a change in the level of energy consumption during various seasons.

4.2 Building of Transition Matrix

After getting the input, the average energy consumption during various seasons are calculated. Table I shows the average consumption of energy during various seasons for the year 2018.

TABLE I
ENERGY CONSUMPTION FOR THE YEAR 2018

Winter	1.93
Spring	1.45
Summer	3.94
Autumn	2.6

From the table it is clearly seen that energy consumption is the highest in Summer and lowest in Spring. By keeping this value, a transition matrix is constructed. To build a transition matrix State space is required. Here seasons are taken as the State space. Winter is denoted as Win, Spring as Spr, Summer as Sum and Autumn as Aut. The transition from one state to the other is taken into consideration and the transition matrix is built. The transition matrix is built in such a way that the sum of each row should add up to 1.

The transition matrix that is built using the above data is as follows:

	Win	Spr	Sum	Aut
Win	0.12	0.08	0.42	0.38
Spr	0.05	0.02	0.6	0.33
Sum	0.2	0.12	0.4	0.28
Aut	0.17	0.15	0.33	0.35

Once the transition matrix is built the future state is simulated based on the current energy consumption in various seasons. The transition diagram for each state is given in Fig 1.

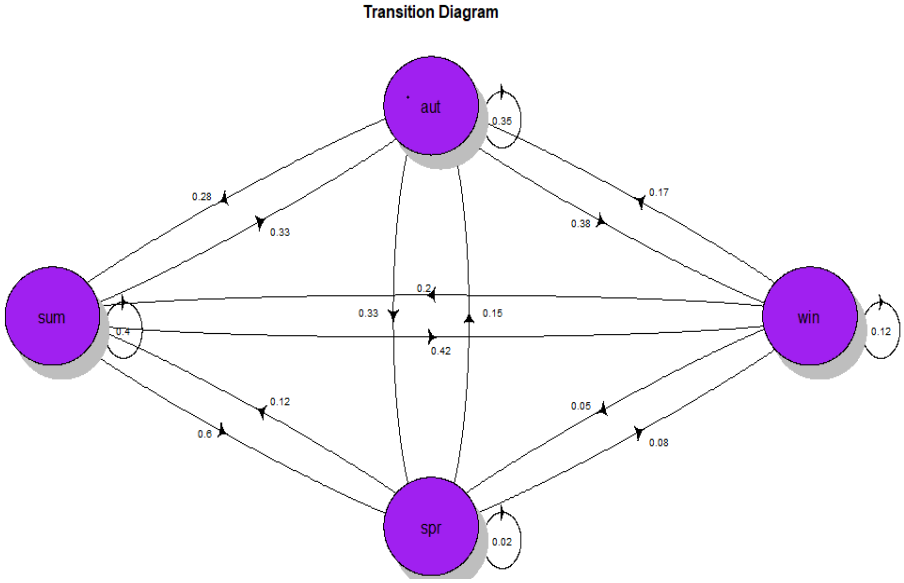

Fig 1. Transition Diagram for various states

Finally, by using the Markov Chain the consumption of energy during various seasons are predicted for the forthcoming year. Similarly, the energy consumption for five years based on various seasons are calculated and the results are depicted in Table 2.

4.3 Pictorial Representation

The conceptual diagram of this work is shown in Fig 2.The energy consumption from the smart grid during various seasons is considered for predicting the amount of energy consumption for the forthcoming year.Prediction is done based on Markov Chain and the present year energy consumption data is taken to predict the next year energy consumption.

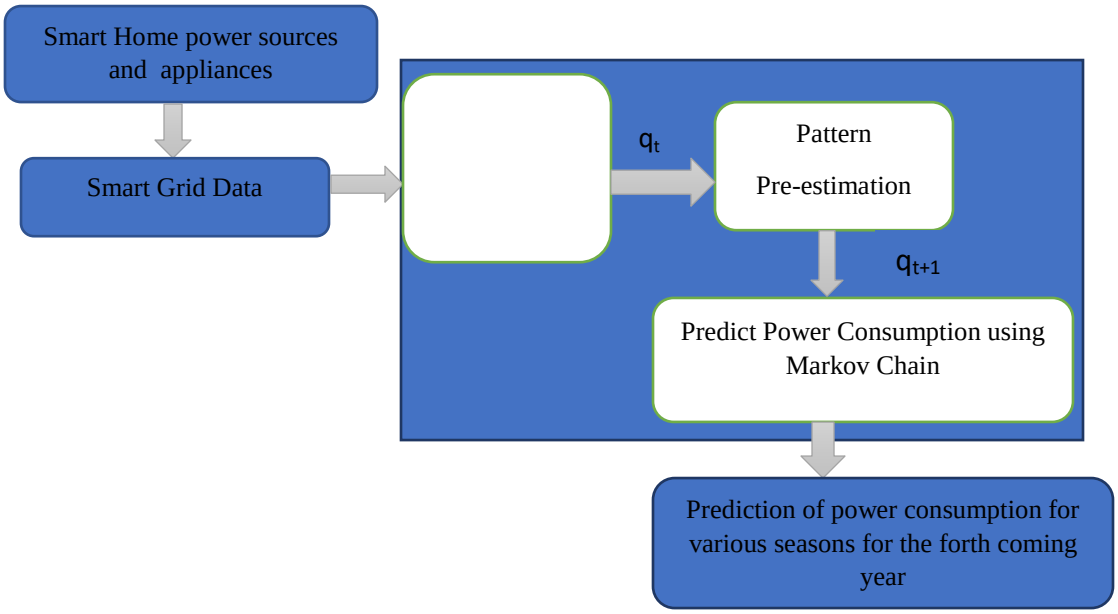

Fig 2. Conceptual Diagram

4.4 Algorithm to Predict Energy Consumption during various seasons by using Markov Chain

---

Step 1: Read the Variables S, PC
Step 2: If (S ∧ PC ¬ = NULL)
Then Go to Step 3
Else
Check the dataset
Step 3: Construct the Power Consumption Transition matrix between Seasons based on Current Data
$T_{(i,j)} = P\,[q_{t+1} = j \mid q_t = i\,]$
Where q_t *= State at time t*
i, j = States
Step 4: Compute the Pattern pre-estimation
$P\,[X_{n+1} = j \mid X_0 = x_{0,\ldots.}\, X_{n-1} = x_{n-1}, X_n = i]$
$P\,(X_{n+1} = j \mid X_n = i) = P(j_{n+1,}\, i_n)$
For all $x_{0,\ldots\ldots}\, x_{n-1,}\, i, j \in D$, *and* $n \geq 0$.
where D is the state space of the Markov chain
Step 5: Compute the steady state probability vector, that uses the stationary distribution,
$\pi = T\pi$
where π *denotes the steady state probability vector for power consumption.*
Step 6: Predict the Power Consumption,
$P = PC * \pi$
Step 7: Stop

V. RESULT

Markov Chain is used to predict the future value by considering only the present value. Based on this principle, prediction is done for the years 2015 to 2019 using the dataset of Austin. To predict the energy consumption for the

year 2015, the energy consumption data of 2014 is taken and the methodology that is discussed above is used. Similarly it is done for the 5 years. The predicted energy consumption during various seasons and the actual energy consumption is taken and the RMSE error is calculated. The result of this work is given in Table II. From the table it is be found that the RMSE is very less for the year 2019 and it is the highest for the year 2016. The graphical representation on the actual and predicted amount of energy consumed during various seasons for the year 2015 to 2019 is given in

Fig 3. The loglikelihood using Markov Chain, Markov Bayesian and Markov Bootstrap for five years(2015-2019) is given in Table III. From the table it is very clear that the loglikelihood shows higher value when Markov Chain is used compared to Markov Bayesian and Markov Bootstrap methods for the dataset taken.

TABLE II
ACTUAL AND PREDICTED VALUES OF ENERGY CONSUMPTION AND RMSE

Year		Winter	Spring	Summer	Autumn	RMSE
2015	Actual	12.05	10.45	46.01	31.49	0.55
	Predicted	13.01	10.23	45.53	31.23	
2016	Actual	13.25	10.35	44.06	32.34	0.83
	Predicted	14.04	11.26	43.25	31.45	
2017	Actual	13.84	9.26	44.01	32.89	0.73
	Predicted	14.13	10.02	44.18	31.67	
2018	Actual	14	9.75	43.25	33	0.8
	Predicted	15.02	10.08	42.05	32.85	
2019	Actual	15.76	11.23	40.01	33	0.03
	Predicted	16	11.41	39.74	32.85	

Fig 3. Graphical representation of the actual and predicted values for five years (2015 – 2019)

TABLE III
LOGLIKELIHOOD VALUES

Year	Markov Chain	Markov Bayesian	Markov Bootstrap
2015	-12698	-12700	-12701
2016	-12690	-12691	-12692
2017	-12701	-12703	-12704
2018	-12703	-12704	-12705
2019	-12706	-12708	-12709

VI. CONCLUSION

This paper deals in using Markov Chain to predict the amount of energy consumption in a smart grid for various seasons.Further from the result it can be concluded that Markov Chain can be used for prediction when random variables are considered and the accuracy rate is also high based on the RMSE value that is obtained.In this work acomparison is also made on the loglikelihood of the given dataset by using Markov Chain, Markov Bayesian and Markov Bootstrap. Based on the value it is found that the loglikelihood is better when using Markov Chain rather than Markov Bayesian and Markov Bootstrap. For this prediction work only energy from smart grid is taken as the power source whereas energy from solar is not considered. In future energy source from solar can also be considered. The total energy consumption by all the smartappliances in a smart home are taken for prediction in this algorithm. Energy consumed by each household device can be taken for further research and predicting the usage of appliances based on energy used by each appliance can also be done so that pricing can be reduced and uninterrupted power supply can be got at the time of outages.

REFERENCES

[1] https://www.smartgrid.gov/the_smart_grid/smart_grid.html.
[2]Dima Alberg1 Mark Last, Short-term load forecasting in smart meters with slidingwindow-based ARIMA algorithms, 2018.
[3] https://www.statisticshowto.datasciencecentral.com/stochastic-model/.
[4]Jiali MeiX'Y, Yannig Goude,y, Georges HebraW and Nicolas KongZ,,Spatial Estimation of Electricity ConsumptionUsing Socio-demographic Information,2016 IEEE PES Asia-Pacific Power and Energy Conference - Xi'an – China.
[5]Ekanki Sharma, Energy forecasting based on predictivedata mining techniques in smart energygrids, Sharma Energy Informatics 2018 https://doi.org/10.1186/s42162-018-0048-9.
[6]Nurul Nnadiah Zakaria, Mahmod Othman , Rajalingam Sokkalingam, Hanita Daud,Lazim Abdullah2 and Evizal Abdul Kadir,Markov Chain Model Development for ForecastingAir Pollution Index of Miri and Sarawak,,Sustainability 2019, 11, 5190; doi:10.3390/su11195190.
[7] Soumyadip Ghoshl, Xu Andy Sun2, Xiaoxuan Zhang3*, Member, IEEE,Consumer Profiling for Demand Response Programsin Smart Grids IEEE PES ISGT ASIA 2012 1569543359.
[8]S. Elgharbi1, M. Esghir1(B), O. Ibrihich2, A. Abarda3, S. El Hajji1,and S. Elbernoussi1, Grey-Markov Model for the Predictionof the Electricity Productionand Consumption.
[9] Wayes Tushar∗, Shisheng Huang∗, Chau Yuen∗, Jian (Andrew) Zhang†, and David B. Smith§,Synthetic Generation of Solar States for Smart Grid: A Multiple Segment Markov Chain Approach, 5th IEEE PES Innovative Smart Grid Technologies Europe 2014.
[10] Kishore Kumar Senapati, A Pattern Prediction on Electricity Consumption using Hidden Markov Model,IJERCSE, 2018.