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Development of Smart Plug and Energy Price Forecasting Technique to Reduce Peak Demand and Cost of Energy in Smart Grid

Hemant Joshi*
School of Engineering, R K University, Rajkot
And Lecturer in Electrical Engineering,
Government Polytechnic, Himatnagar, India

Vivek Pandya
School of Technology.
Pandit Deendayal Petroleum University,
Gandhinagar, India

Abstract*— Real Time Pricing (RTP) based tariff is more advantageous to the flat rate tariff as it encourages customers to use their appliances during off-peak period. By applying this type of tariff, peak load on the power plant reduces and amount of monthly bill of customers also reduces. For this purpose dedicated infrastructure having communication and networking in conjunction with power grid is required. Two-way communication between utility and customers is required to exchange the data like real time price and present load condition. For this purpose Home Area Network (HAN) made of Home Energy Controllers (HEC), smart meters, and smart plugs are required. HEC receives the RTP data from utility and decides the load pattern of schedulable appliances using certain minimization techniques. The schedulable appliances are allowed to switch on during lower priced time slots. Energy price data are required in advance for this purpose. By applying powerful tools, accurate forecasting is possible. Energy price depends on so many factors, so highly accurate forecasting is the challenging task. To restrict the operation during peak-load condition, schedulable appliances receive power through 'Smart Plugs'. In this work the block diagram, circuit diagram and actual hardware of smart plug are presented. Two forecasting techniques are presented in this work. Both forecasting methods are compared using parameter, Mean Absolute Percentage Error (MAPE).

Keywords*— Real Time Pricing, Home Area Network, Smart Grid, Home Energy Controller, Smart Plug, Mean Absolute Percentage Error.

I. INTRODUCTION

Information and communication technology is used in conjunction with power grid in smart grid. Such system model is shown in Fig.1. Different types of tariffs are used today. In India, we are still using flat rate tariff in residential region. In this type of tariff there is no control over consumption pattern of energy used by customers. In such case matching of demand and supply is difficult [1]. If the operation of some appliances (in residential region) is shifted from peak period to off-peak period, higher peak load condition (and hence power cut) can be avoided. Domestic appliances can be divided into two categories. One is schedulable and the other is non-schedulable appliances [2]. Appliances like PHEV (Plug in Hybrid Electrical Vehicle), washing machine, and dish washer can be considered as schedulable appliances. The operation of schedulable appliances can be delayed and shifted from peak period to off peak period. The other category of appliances is non-schedulable appliances. Such appliances must get power when they switched on. Lights, fans, television etc fall under this category.

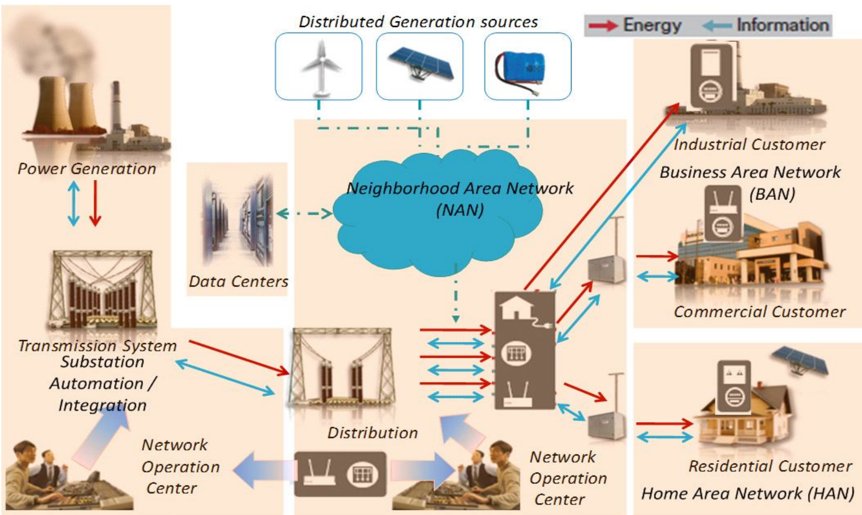

Fig.1 Smart Grid infrastructure [3]

There are various methods suggested in different literature about shifting the operation of schedulable appliances [4]. One of them is Direct Load Control (DLC) [5]. In this method utility is empowered to control the appliances whenever required. This method provides less comfort to consumers. Incentives must be provided to the consumers for utilization of energy during off-peak period. Real Time Pricing (RTP) method is better than former due to its some salient features [6]. In this method utility sends RTP signals regularly to the smart meters of all the consumers. HEC (Home Energy Controller) calculates optimized time slots for the schedulable appliances to reduce cost of energy and Peak to Average Ratio (PAR) [7], [8].

To allow the schedulable appliance to switch on during low cost price time slot, the device like 'Smart plug' should be used. Presently appliances that can communicate with HEC (or direct to utility) are not available in market. For minimization of cost in RTP based tariff, customers must be acknoledged in advance. For this purpose forecasting of energy cost is necessary. Different literatures suggest different forecasting techniques and their features [7], [9], [10]. Mean Absolute Percentage Error (MAPE) is one of the parameter can be used to compare different methods of forecasting [11]. *In Gujarat, UGVCL will conduct a pilot project in Naroda and Deesa region covering 20000 customers [12]. Tendering process is going on. Gujarat is the first state to adopt smart grid in India.* In this work block diagram and schematic diagram of smart plug are presented. Two different techniques of forecasting and method to compare these techniques is presented in this work.

II. DEVELOPMENT OF HOME ENERGY CONTROLLER AND SMART PLUG

Home Area Network (HAN) is presented in Fig. 2. The network between schedulable appliance and Home Energy Controller (HEC) is established using ZigBee. HEC allows schedulable appliances to switch on through ZigBee channels during off-peak period or low priced time slots.

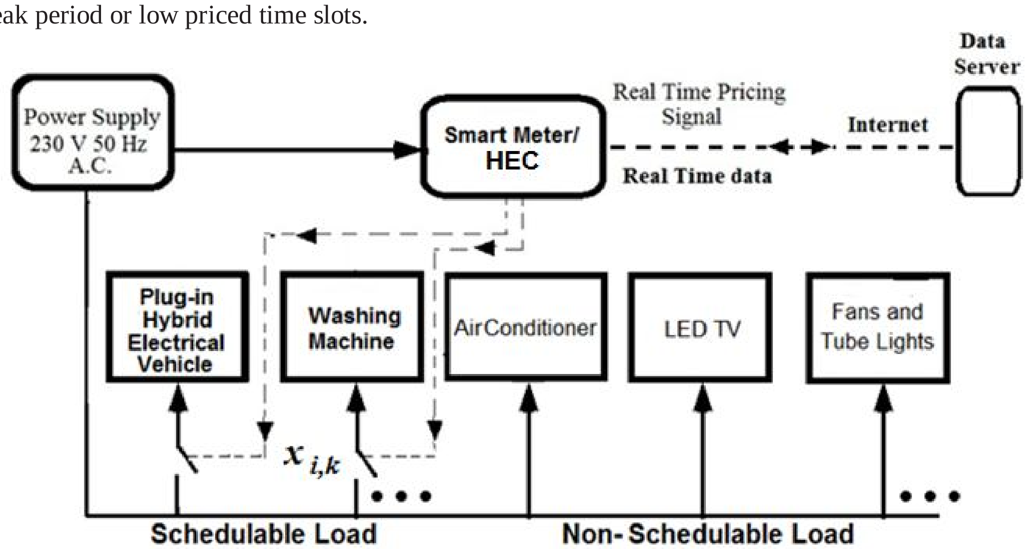

Fig. 2 Home Area Network for user *i* [8]

Fig.3 shows the simple circuit diagram of HAN. LPC 2148, ARM 7 processor can be used in designing HEC. Two DB9 connectors are shown in this figure to connect ZigBee. For serial communication MAX 232 is used.

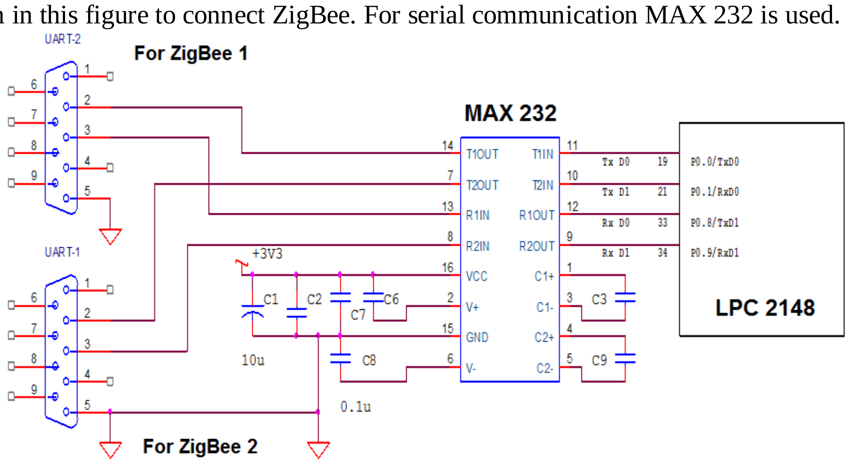

Fig. 3 Circuit diagram of HAN using HEC

A. Home Energy Controller

The architecture of HEC cum smart meter and HAN is shown in Fig.4. In an AMR (Automated Meter Reading) system, communication channels are established between users and utility server through GSM network or WIMAX [13],[14]. For data collection, RS232 or RS485 serial ports are used. In this work Arm Core, Phillips LPC 2148, 32 bit, 64 pin processor can be used. The smart meter unit and HEC will be made in a single hardware. Home Area Network is made using ZigBee. ZigBee is made on the basis of IEEE 802.15.4 standard means for Wireless Personnel Area Network (WPAN) [14],[15].This is low power, low cost and lower data rate (250 kb/s) network. In future the domestic appliances based on IPv 6 will be available in the market that can directly communicate with HEC (or even with utility). However presently such appliances are not available in the market so in this work smart plug is designed that allows power to domestic appliances according to the signals sent by HEC.

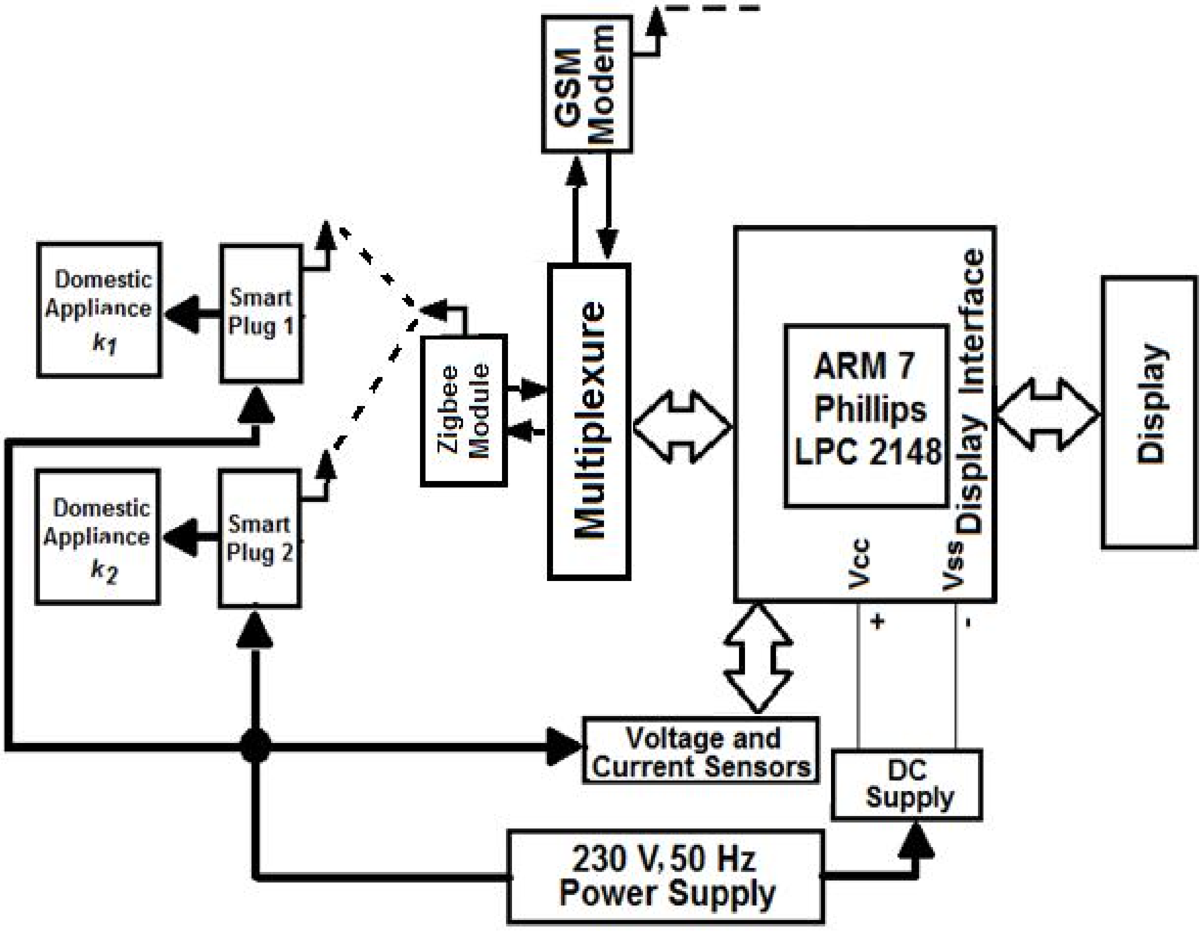

Fig. 4 Architecture showing HEC, Smart Meter and HAN

B. SMART PLUG

Here the flow chart, block diagram, schematic diagram and actual hardware of smart plug are presented. Flow chart for operation of smart plug is presented in Fig. 5. Functional block diagram is shown in Fig. 6. It is tested successfully. Instead of HEC, Laptop is used for testing. When hardware of HEC will be made, smart plug will be tested using it. AT89S52 microcontroller is used here. It is low cost, lower speed microcontroller as compared with modern microcontrollers. Function of microcontroller is to communicate with static switch and HEC (or laptop).

Fig.7 shows the circuit diagram of smart plug. When customer ‘switch on’ any appliance, request signal go to the HEC via ZigBee. At that time red LED of this device will glow. If HEC sends ‘wait’ signal to this plug, red LED will blink. If HEC allows and sends ‘switch on’ command to the microcontroller, it sends low input to the opto-isolator, MOC 3021of static switch. In static switch TRIAC BT 136 is used. When +5 V is applied to the gate of triac, it will fire and schedulable appliance will get power.

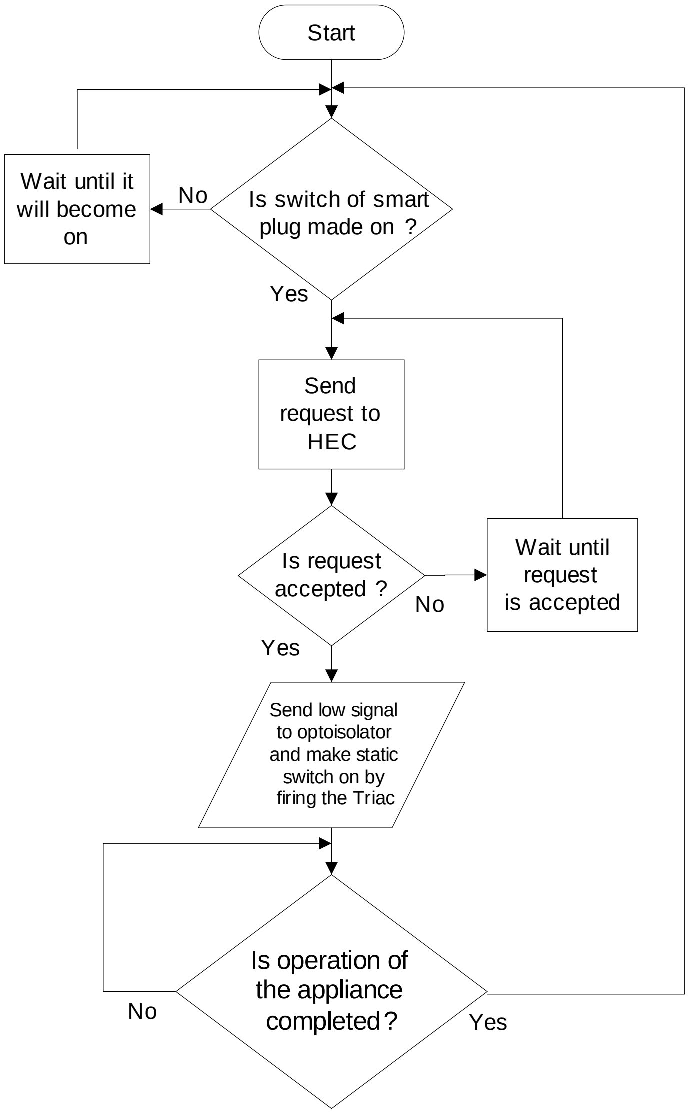

Fig.5 Flowchart for operation of Smart Plug

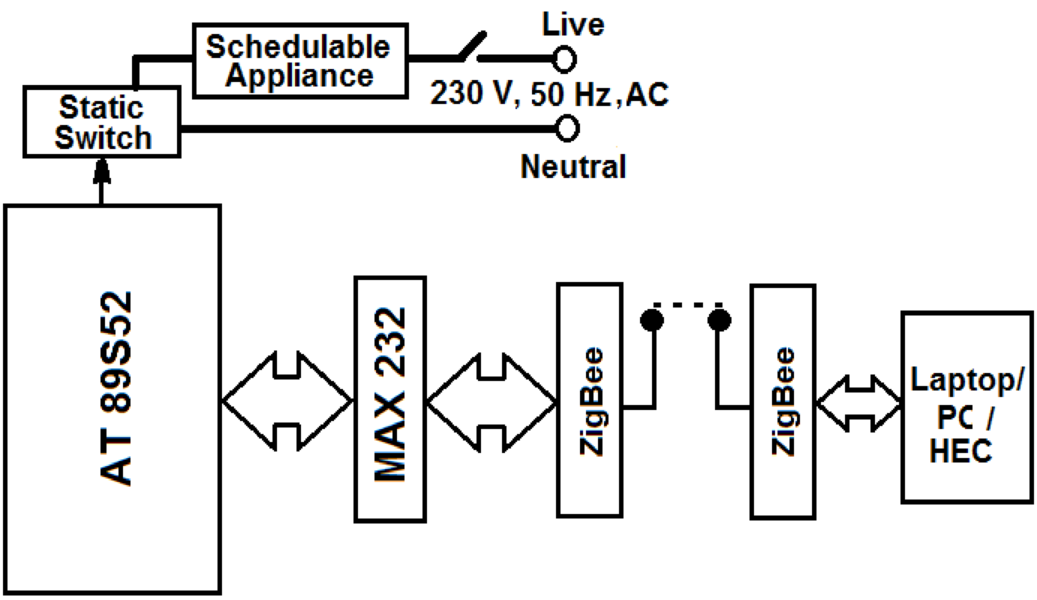

Fig.6 Functional block diagram of Smart Plug

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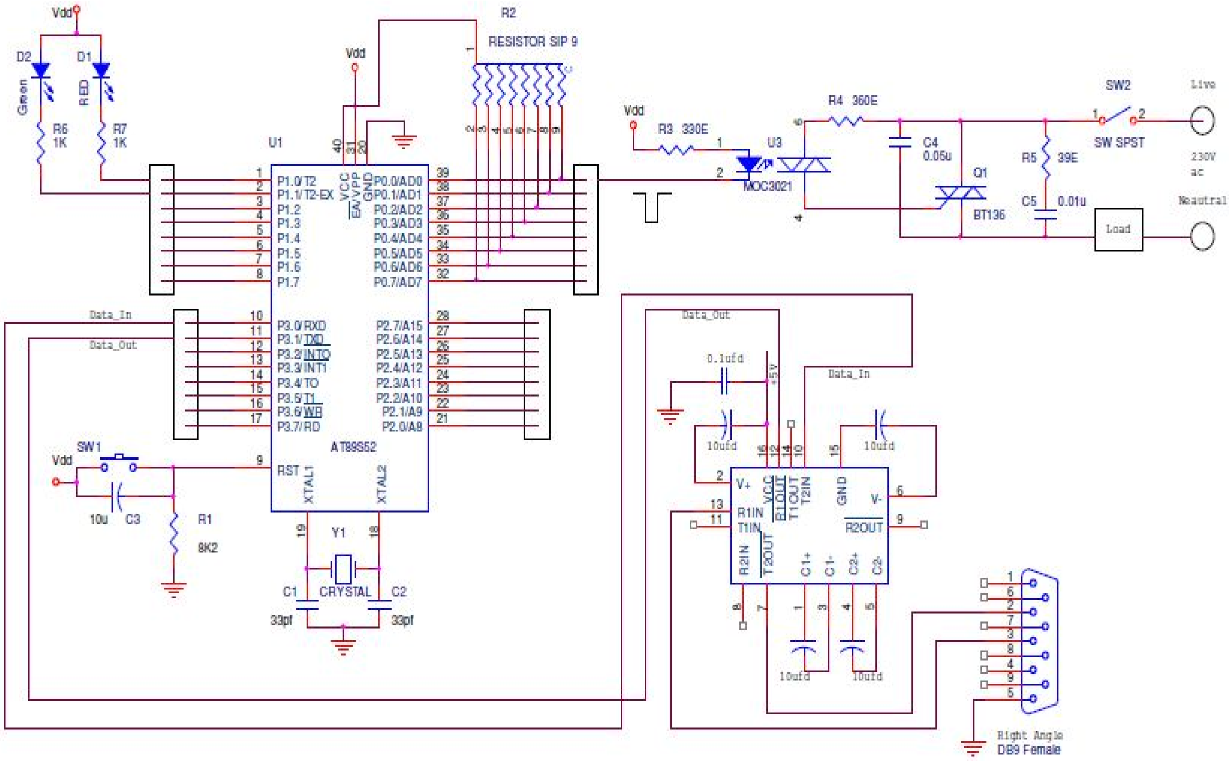

Fig. 7. Circuit diagram of Smart Plug.

The actual view (internal and external) of smart plug is presented in Fig.8. In real application this device is put near the schedulable appliance. The power cord of this appliance is connected to the smart plug.

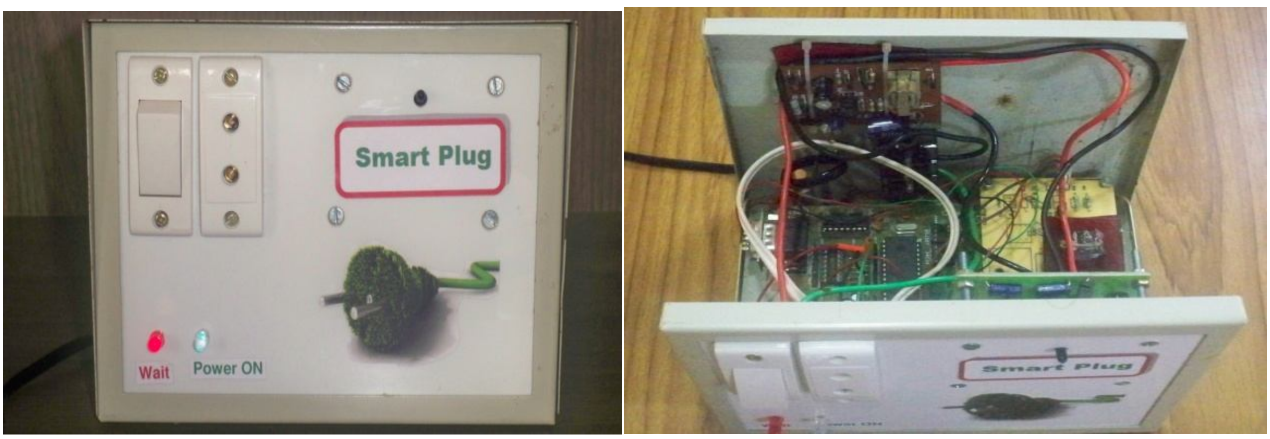

Fig.8 View of Smart Plug

The smart pug is given electrical power by conventional switchboard. When customer switches on this device, red LED will blink. It indicates that request is sent to HEC. If the HEC don't allow the schedulable appliance due to peak load or higher energy price slot, wait signal is sent to appliance and red LED will illuminate. When request of appliance is accepted, schedulable appliance will get power and green LED will be illuminated. IEEE 1901.2010 standard is applicable for such smart plug [16].

III. FORECASTING OF ENERGY PRICE

The energy price depends on numbers of parameters. Consumption of energy is highly uncertain. Bidding of energy in electricity market requires energy price data in advance. For this purpose accurate forecasting of energy price is necessary. Today the system demand is the main factor for volatility of energy price [9]. In future the implementation of smart grid will play a key role in meeting of demand and supply.

Using smart appliances or switching on conventional schedulable appliances through smart plugs, large fluctuation in demand can be minimized. In India, Indian Energy Exchange provides trading platform for bidding of energy [17].
In this work two methods are discussed.

A. FORECASTING BASED ON PRIOR KNOWLEDGE (CASE-I)

As discussed earlier, energy price depends on several factors like demand, wholesale market price, whether etc. It also depends on weekends or working days. This method is simple and having less computations. Normally pattern of energy demand (and hence energy price) is more similar to previous day and same day last week. Up to certain extent it is also similar with the load pattern of two days ago. From statistical analysis of the real time prices of Illinois Power Company from January 2007 to December 2009, the optimal daily coefficients are obtained [6]. The coefficients for price predictor filters are given in Table-I. Fig. 9 shows the process of good forecasting technique.

TABLE-I

Optimal daily coefficients [7]

Day	k_1	k_2	k_7
Monday	0.355	0.465	0.359
Tuesday	0.858	0	0.126
Wednesday	0.837	0	0.142
Thursday	0.943	0	0.050
Friday	0.868	0	0.092
Saturday	0.671	0	0.196
Sunday	0.719	0	0.184

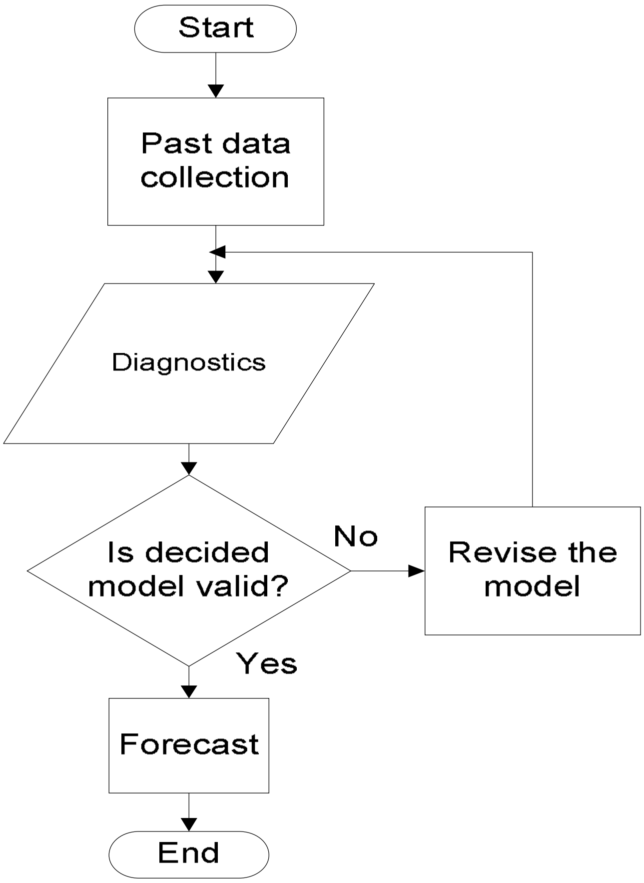

Fig. 9 Flow chart for process of good forecasting

For each hour h of the day t, the predicted cost of energy can be given by,

$$\hat{p}^h(t) = k_1 p^h(t-1) + k_2 p^h(t-2) + k_7 p^h(t-7), \forall h \epsilon \mathcal{H} \quad (1)$$

Where $\hat{p}^h(t)$ is predicted cost of energy, $p^h(t-1)$ is the cost of energy of previous day (of h^{th} time slot), $p^h(t-2)$ is the cost of energy for the day before previous day and $p^h(t-7)$ is the cost of energy for same day last week.

The data of energy prices from 25th November, 2013 to 3rd Dec, 2013 are taken from Indian Energy Exchange [17]. These are listed in Table II. Energy prices for 3rd Dec, 2013 are predicted for 24 hour time slots. Actual and forecasted prices are compared using first method is shown in Fig. 10.

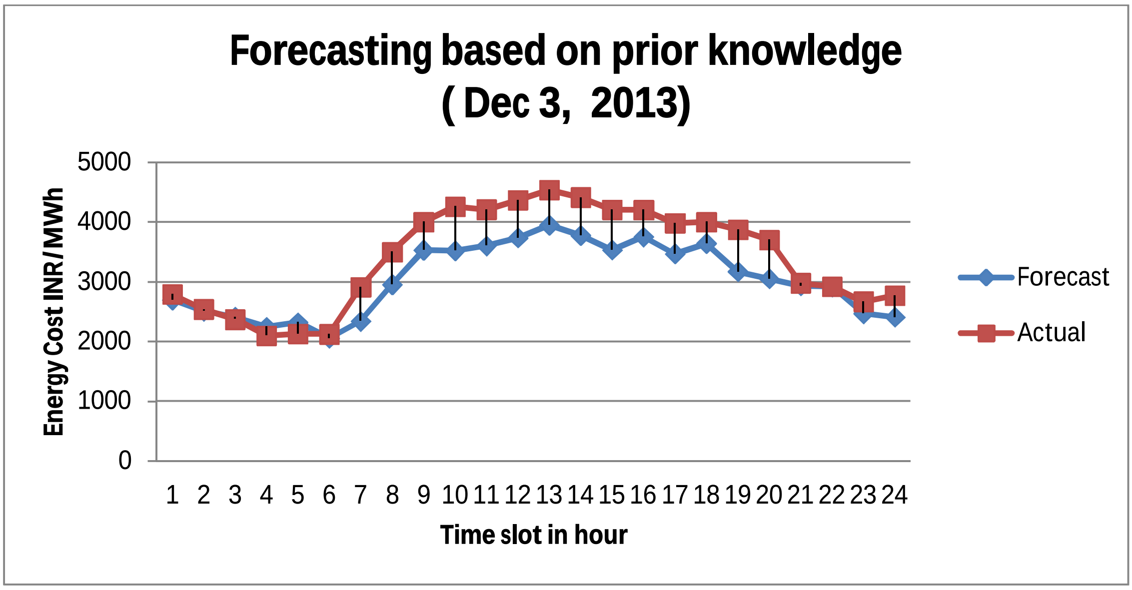

Fig.10 Forecasting based on prior knowledge

The trend of variation of forecasted prices is similar to the actual one. However higher deviation in energy price is observed in some time slots.

B. Forecasting using Ms-Excel (Case-II)

In Microsoft Excel, tool is available for forecasting the time series data for sales, rainfall etc having uncertainty. Using Moving Average (MA) or Centered Moving Average (CMA), forecasting is possible in Ms-Excel. Here forecast function is used. Data from 25th November, 2013 to 3rd Dec, 2013 are taken from Indian Energy Exchange [17]. These are listed in Table II.

TABLE II

Energy prices of different days (in INR/MWh)

Time slot/ Date	25-Nov-13	26-Nov-13	27-Nov-13	28-Nov-13	29-Nov-13	30-Nov-13	1-Dec-13	2-Dec-13	Actual	Forecast (MsExcel)
									3-Dec-13	3-Dec-13
1	2299.38	2512.62	2460.48	2762.66	2741.95	2476.99	2900.34	2776.93	2794.26	2859.85
2	2039.49	2424.37	2310.11	2334.85	2444.56	2382.49	2592.25	2571.94	2542.35	2587.89
3	1999.72	2274.76	2212.07	2152.25	2021.3	2110.7	2519.65	2479.64	2372.2	2422.66
4	1999.56	2104.65	2012.46	1999.78	1999.49	1999.74	2397.29	2307.04	2099.51	2313.89
5	1999.83	2211.92	2067.23	2099.79	1999.59	1999.68	2397.38	2378.57	2133.87	2316.33
6	1999.91	2454.5	2419.39	2391.11	2099.47	1999.19	2223.02	2039.37	2125.89	1942.29
7	2389.89	2499.72	2919.78	2812.22	2672.97	2384.86	2121.9	2362.03	2914.6	2191.04
8	2429.45	2447.2	2499.14	3749.6	3647.27	3138.29	2569.63	3085.32	3499.87	3225.78
9	2399.33	2389.67	2389.39	2642.52	3769.2	2800.61	3258.81	3764.3	4001.04	3862.19
10	2399.8	2411.83	2389.58	2899.4	3769.38	3089.44	3499.81	3749.22	4258.07	4033.05

11	2399.38	2429.08	2389.45	2429.58	3769.41	3499.67	3592.47	3843.63	4212.71	4239.01
12	2399.52	2429.56	2399.37	2429.69	3769.66	3736.94	3769.98	4000.84	4370.45	4471.19
13	2429.38	2499.27	2429.55	2489.38	3769.77	3769.47	4000.69	4235.69	4539.87	4689.35
14	2399.84	2429.46	2389.54	2399.82	3769.16	3449.66	3735.12	4045.72	4415.76	4401.18
15	2399.44	2397.43	2389.32	2399.42	3769.19	3399.61	3474.64	3769.88	4208.53	4126.81
16	2399.81	2429.45	2389.76	2414.55	3769.45	3367.6	3179.78	4019.28	4206.17	4124.64
17	3087.03	2624.85	2399.8	3050.15	3640.44	2972.5	2599.82	3661.93	3985.57	3483.30
18	3263.51	3187.75	3349.48	3400.4	3750.36	3180.24	2887.32	3780.56	4000.77	3452.87
19	2895.06	3195.07	3170.62	3126.33	3403.98	2935.19	2650.02	3229.55	3874.78	2940.27
20	2989.73	2999.7	3209.86	3162.8	2947.66	2700.18	2761.81	3118.12	3700.55	2842.38
21	3002.35	2857.24	3012.3	2874.49	2934.59	2661.92	2661.98	3001.57	2980.22	2789.12
22	2869.55	2749.25	2994.38	2786.84	2699.41	2499.68	2724.9	2999.51	2919.79	2768.38
23	2499.85	2269.88	2499.42	2499.23	2499.37	2441.62	2499.68	2544.71	2669.77	2574.47
24	2259.55	2259.49	2287.13	2396.93	2304.81	1999.56	2462.01	2479.63	2772.01	2400.34

Forecasting is done for 3rd Dec, 2013. The actual and forecasted data (using Ms-Excel) are given in Table-I. Fig. 11 shows the comparison of actual and forecasted data using this second method.

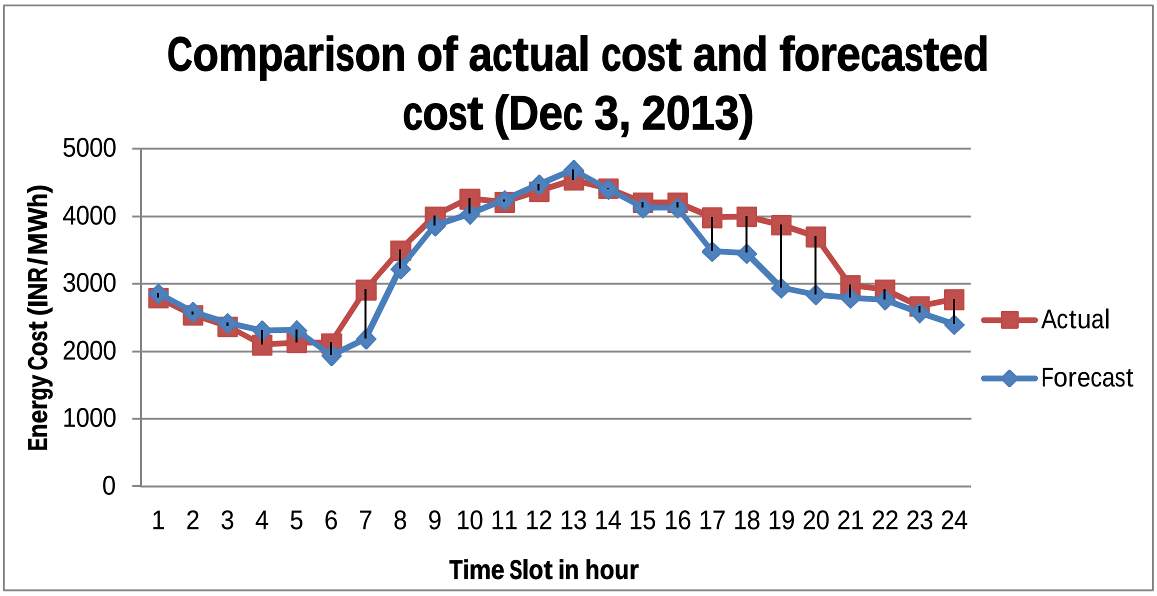

Fig.11 Comparison of actual and forecasted energy price using 2nd method

IV. Comparison of Two Methods

In Fig.12 comparison between two methods is presented. Any methods for forecasting can be compared by the parameter, Mean Absolute Percentage Error (MAPE).

$$\text{MAPE} = (100)/n \sum_{h=1}^{h=n} \left| \frac{A_t - F_t}{A_t} \right| \quad (2)$$

To find MAPE, sum of absolute error of each time slot is divided by n (n=24 in this case) and multiplied by 100. A_t and F_t are actual and forecasted energy cost of t^{th} day. MAPE in the case of first method 10.49% and in second method it is 7.82%. In this case study second method is proved more accurate. Table III shows the calculation of MAPE for both the cases. It is observed from Fig.12 that energy prices obtained from second case are very closer with actual price than first one.

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TABLE III

Calculation of MAPE for both cases. Values of energy costs are in INR/MWh.

Time slot	Actual Value	Forecasting (Prior knowledge)	Absolute error |(A-F)|/A (Case-I)	Forecasting Ms-Excel	Absolute error |(A-F)|/A (Case-II)
1	2794.26	2699.20	0.03402115	2859.85	0.02347312
2	2542.35	2512.20	0.01186102	2587.89	0.01791088
3	2372.2	2414.15	0.01768438	2422.66	0.02127139
4	2099.51	2244.63	0.06911909	2313.89	0.10211022
5	2133.87	2319.51	0.08699920	2316.33	0.08550595
6	2125.89	2059.05	0.03144261	1942.29	0.08636584
7	2914.6	2341.59	0.19660109	2191.04	0.24825313
8	3499.87	2955.55	0.15552527	3225.78	0.07831352
9	4001.04	3530.87	0.11751249	3862.19	0.03470383
10	4258.07	3520.72	0.17316499	4033.05	0.05284621
11	4212.71	3603.90	0.14451775	4239.01	0.00624301
12	4370.45	3738.85	0.14451709	4471.19	0.02305091
13	4539.87	3949.13	0.13012266	4689.35	0.03292605
14	4415.76	3777.34	0.14457767	4401.18	0.00330181
15	4208.53	3536.63	0.15965118	4126.81	0.01941771
16	4206.17	3754.65	0.10734636	4124.64	0.01938445
17	3985.57	3472.67	0.12868999	3483.30	0.12602141
18	4000.77	3645.38	0.08883116	3452.87	0.13694971
19	3874.78	3173.53	0.18097731	2940.27	0.24117867
20	3700.55	3053.31	0.17490396	2842.38	0.23190298
21	2980.22	2935.36	0.01505281	2789.12	0.06412134
22	2919.79	2919.99	0.00006681	2768.38	0.05185794
23	2669.77	2469.37	0.07506412	2574.47	0.03569489
24	2772.01	2412.22	0.12979452	2400.34	0.13408012
	MAPE		10.49185293 %		7.82035454 %

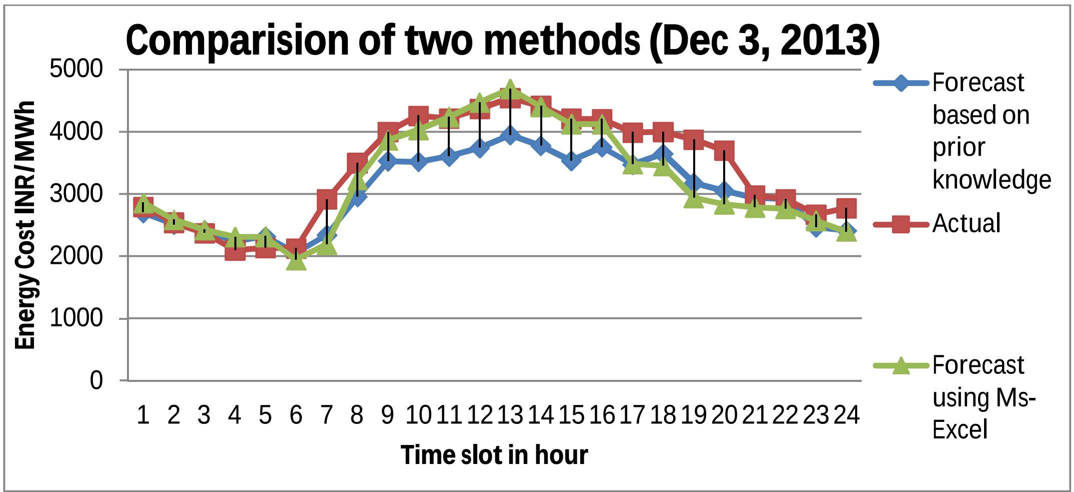

Fig.12. Comparison of energy price obtained from first and second method

V. CONCLUSIONS

Presently in the market, the appliances that direct interact with HEC are not available. Based on the signal received from HEC, to allow or not to allow power to schedulable appliances like PHEV and Washing machine; Smart Plug is necessary. For effective implementation of RTP based tariff, smart plugs should be used. In this work hardware of smart plug is made and tested. For energy cost minimization technique, energy price data must be available in advance. For this purpose accurate forecasting technique should be adopted. Here two different methods are presented and compared using MAPE parameter. Among two energy price forecasting methods analysed in this work, second one based on Ms-Excel is more accurate than other.

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