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Assessment of Electric Power Consumption of Electric Appliances of Households Utilising the Data from Smart Meter

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ABSTRACT

Smart grid for smart distribution systems will need smart technology and smart devices for reliability and elasticity of power distribution systems. The smart meter is one of these devices which can record, measure and transmit the power consumption of consumers and also gather enough and valuable information for the distribution operators which can be used for monitoring of systems operations. This paper aims at assessing the power consumption of electric appliances of household consumers and performance of the smart meter. A comprehensive survey is conducted on the data gathered by the smart meter. The data is analyzed using a statistical tool and theMean Absolute Error (MAE), Correlation Coefficient (R), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) values are determined.

Keywords- *Smart meter, grid, elasticity, power, consumption, monitoring, distribution.*

I. INTRODUCTION

The single distribution transformer dispatches lower voltage to varied customers depending on the number of customers at a particular location. Reducing high voltage from the main lines for the utilization of the customer who uses different loads is very complex and therefore an efficient distribution system to manage the distribution of the voltage in order to achieve an optimal service or delivery is essential. There is therefore the need to implore the use of Distribution Automation and smart distribution metering to manage the distribution of electricity at the lower voltage which can be utilized by the consumer or the customer.

Smart distribution metering is the system of electrical device that dispatches the correctand required electrical signal or load to a user or consumer and when used, the smart distribution meter receives the response of consumption and then record and convert the quantity consumed into price data. Smart distribution meter makes historical consumption of power available and it helps both the consumer and the supplier in the efficient management of power. It helps the supplier to have a deep and accurate knowledge of the power consumption of the consumer, and which further gives an insight of energy demand forecasting and as a result there is an improvement of network maintenance and planning[1]. Smart meter helps in detecting fraud consumption of energy [2] and the consumer can use the consumption pattern for better planning in order to manage and save power consumption. Consumers records of consumption can be studied based on each electrical device or appliance used and therefore the use of the manual and conventional way of dealing with power distribution to the households is very difficult because of the gathering of large and complex amount of information or data that is used in calculations and hence the need for distribution automation and some machine learning and statistical tools. The Distribution Automation comprises the automation which is used in the planning, engineering, construction, operation, and maintenance of the distribution power system, including interactions with the transmission system, interconnected distributed energy resources (DER), and automated interfaces with end-users [3]. When Distribution Automation and smart grid technologies are employed in power distribution system, power flows efficiently and restores quickly when the power supply is interrupted.

According to [4], smart grid are more efficient electrical networks which are reliable and make way for electricity to be generated and distributed in a friendly environment thereby reducing the gap between demand and supply. The utility providers must adopt the smart grid technology to empower the efficiency, reliability and resiliency of the distribution system. When the demand of electricity by customers is properly estimated and predicted, it helps the service providers, utility owners, power system managers, energy planners and system operators to plan well and can determine the maximum consumption of a customer, hence detect and predict the true power consumption of the customer. Smart distribution will need smart meters and according to the U.S. Department of Energy's report on smart grid system, it is estimated that about sixty-five million smart meters have been installed by 2015 [5] and also by 2020, it is expected that about 830 million of smart meters would be deployed worldwide [6]. The smart meters are able to accumulate greater amount of data that is able to give enough information to monitor operational systems in almost real time [7]. A smart meter is a two-communications electronic device that transmit the data of consumers' energy consumption and system operation information to the distribution operating center automatically [8]. It is very important to get smart meters which will optimize the distribution performance and as distribution grid is becoming very complex, smart meters are needed for recording and measuring of electrical power distribution in the household where distribution will not be interrupted and the user can be provided with very vital information about power consumption [9]. According to [10], it is very important to have smart distribution systems that can perform efficiently without any interruption and can also provide to users the necessary information about the consumption of power and its quality, and smart distribution systems will need smart meters for power distribution. This paper focuses on the assessment of the smart meters in smart distribution and statistical tools are used to assess the performance of the smart meter, and it is organized in sections with introduction as the first section, section two talks about the methodology, section three describes how the design is done and section four as the conclusion.

II. METHOLOGY

This paper aims at assessing the power consumption of electric appliances of household consumers base on the usage of the smart meter. Sample of consumers were randomly selected and interviewed on the various appliances used. The wattage of these various appliances were recorded as well as the estimated time or hours of usage of the appliances. The monthly consumption was also recorded and the consumption behavior of the consumer analyzed using statistical tool. The Mean Absolute Error (MAE), Mean Square Error (MSE), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) were calculated. MATLAB-Simulink programing environment was used to simulate the distribution of power through these appliances.

Table 1-Wattage of various appliances and the estimated hours and KWH used per month.

APPLIANCES	APPLIANCE'S WATTAGE(W)	ESTIMATED HOURS/MONTH	ESTIMATED KWH/MONTH
Fridge	80	330	26.4
Fluorescent bulb	40	300	12.0
Incandescent bulb	60	300	18.0
Radio	5	360	1.80
Fan	80	450	36.0
TV	40	240	9.60
Iron	1000	10	10.0
AC	900	210	189.0
Hair Dryer	1000	360	360.0
Computer	50	360	18.0
Heater	1500	60	90.0
Bulb	11	360	3.96

Table 1-Energy consumption and simulating time.

PERIOD	ENERGY(KWH)	SIMULATION TIME(SECONDS)
1	48.5	9.70
2	72.5	14.50
3	85.5	17.00
4	97.0	19.40
5	45.0	9.00
6	50.8	11.05
7	75.7	11.30
8	80.4	11.95
9	72.6	19.50
10	96.8	19.30
11	94.9	16.90
12	100.55	19.81

Fig. 1- shows a picture of a smart meter fixed on a pole.

III. DESIGN

Fig. 2 shows the architecture of electrical power distribution through the electrical appliances in a household, where the blue color in rectangular shapes show the smart meter, smart switch and the various appliances or devices and the orange color in round shapes show the switches or control that turn the electric current on and off.

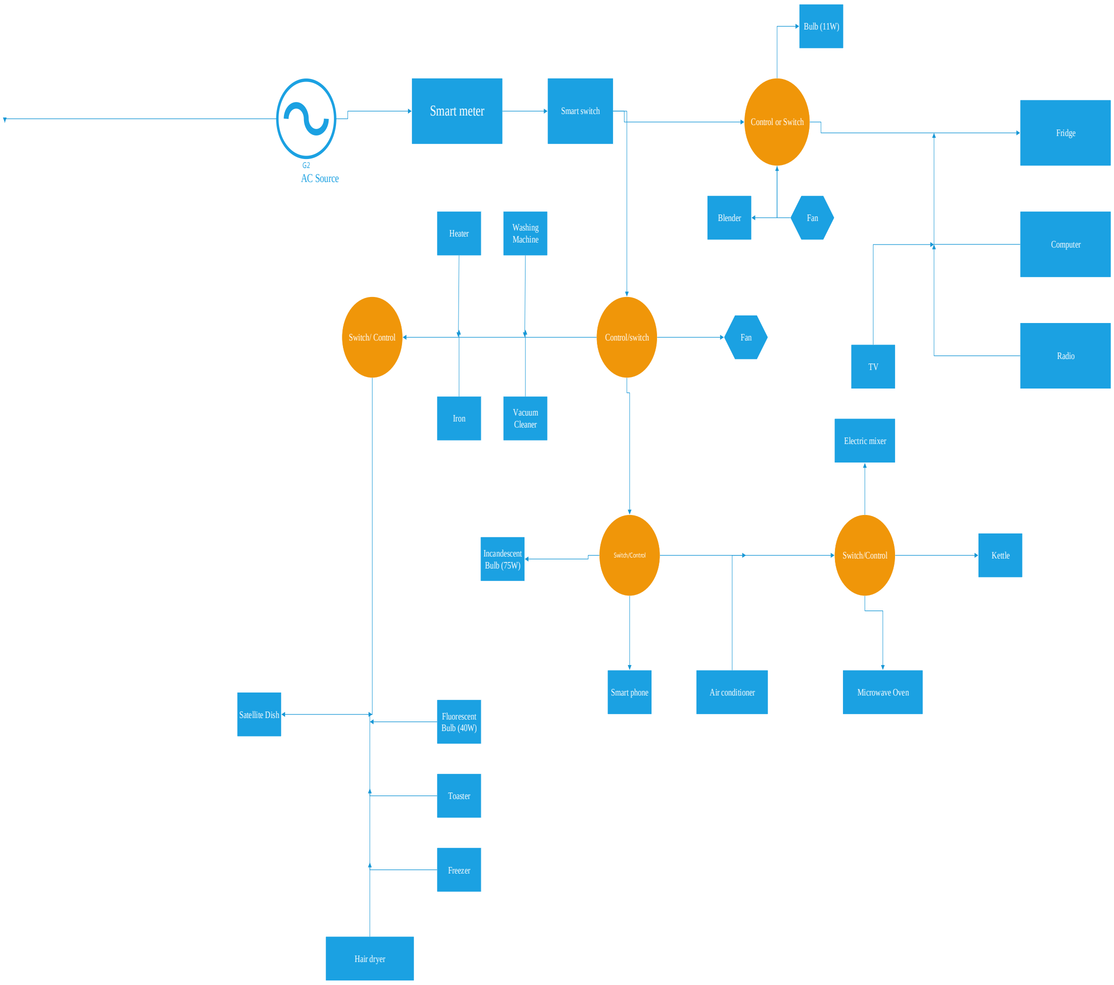

Fig. 2-shows architecture of electrical power distribution in a household.

The signal or the Alternating Current (AC) voltage from the source connects to the smart meter through to the smart switch and it is distributed to the various components according to the needs and the capacity of each component or device. In the distribution process, there is decision on which amount of signal or power should be dispatched to each component and which amount should go back to the source. This is an "Information Intelligence".

The AC power distribution involves a lot of variables such as the load voltage V (t), load with resistance R only or inductance X_L or capacitance X_c. The inductance and the capacitance are put together as reactive power.The instantaneous power in to the load is given as

$$P(t) = v(t)i(t) = \frac{v^2(t)}{R} \quad (1)$$

$$P(t) = \frac{V_m^2}{R}\cos^2 \omega t$$

The average instantaneous power is given as:

$$P(t) = \frac{V_m^2}{2R}(1 + \cos 2\omega t) \quad (2)$$

$$P = \frac{1}{T}\int_0^T p(t)\partial t$$

$$V(t) = V_m \cos(\omega t + \varphi) \quad (3)$$

$$i(t) = I_m \cos(\omega t + \psi) \quad (4)$$

$$P = \frac{1}{T}\int_0^T v(t)i(t)\partial t$$

$$P = \frac{1}{T}V_m I_m \int_0^T \cos(\omega t + \varphi)\cos(\omega t + \psi)\,\partial t \quad (5)$$

$$P = V_{rms} I_{rms} \cos\theta \quad (6)$$

The expression (6) determines the average power delivered to the circuit element or device[11].
Where P is the average power delivered to the load, V_{rms} is the root-mean-square-voltage, I_{rms} is theroot-mean-square-current, $\cos\theta$ is the power factor, where θ is the phase angle which is the measure of how much the applied voltage leads or lags the current in the alternating current (AC) circuit.
The Mean Absolute Error (MAE), Correlation Coefficient (R), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) were determined using the following equations:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|A_i - P_i| \quad (7)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(A_i - P_i)^2}{n}} \quad (8)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|A_i - P_i|}{A_i}x100 \quad (9)$$

Where A_i are the actual values and P_i are the predicted values. These performance indices are used to compare the actual and the predicted values. A graph of consumption in KWH against the simulation time is shown in Fig. 2 which shows the model and the coefficient of correlation R.The surface view in three-dimension of the hourly, daily and monthly consumption is shown in Fig. 3.

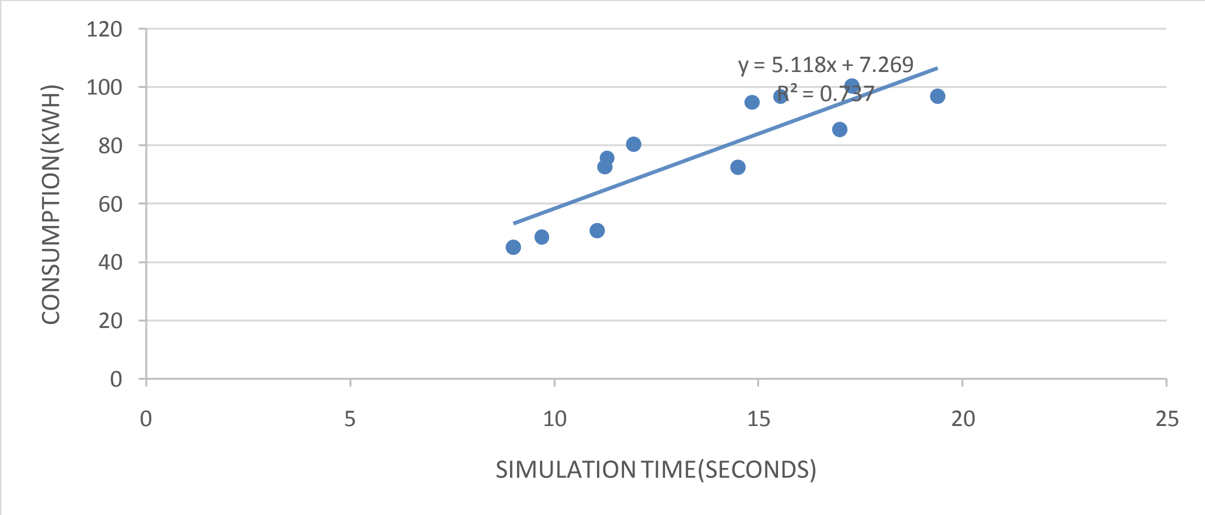

Fig. 2-shows graph of consumption (KWH) against simulation time.

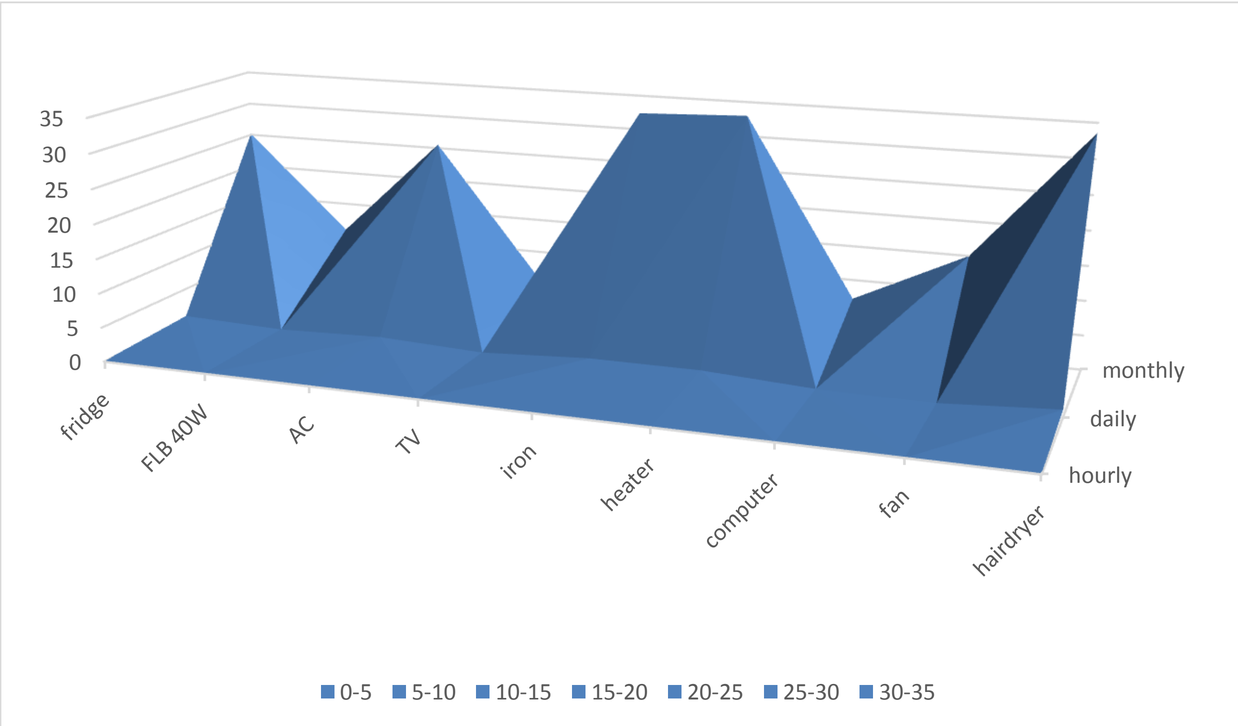

Fig. 3-shows the view of the hourly, daily and monthly consumption of the various devices.

Table 2-Hourly, Daily and Monthly consumption of the various appliances.

APPLIANCES	HOURLY(KWH)	DAILY(KWH)	MONTHLY(KWH)
Fridge	0.06	0.84	25.2
Fluorescent bulb (40W)	0.020	0.24	7.20
Incandescent	0.030	0.36	10.8

bulb(75W)			
Radio	0.010	0.12	3.60
Fan	0.050	0.50	15.0
TV	0.020	0.20	6.00
Iron	0.090	1.08	32.4
Air Conditioner	0.071	0.852	25.56
Hair Dryer	0.080	1.120	33.60
Computer	0.020	0.24	7.20
Heater	0.100	1.10	33.00
Bulb (11W)	0.010	0.12	3.60

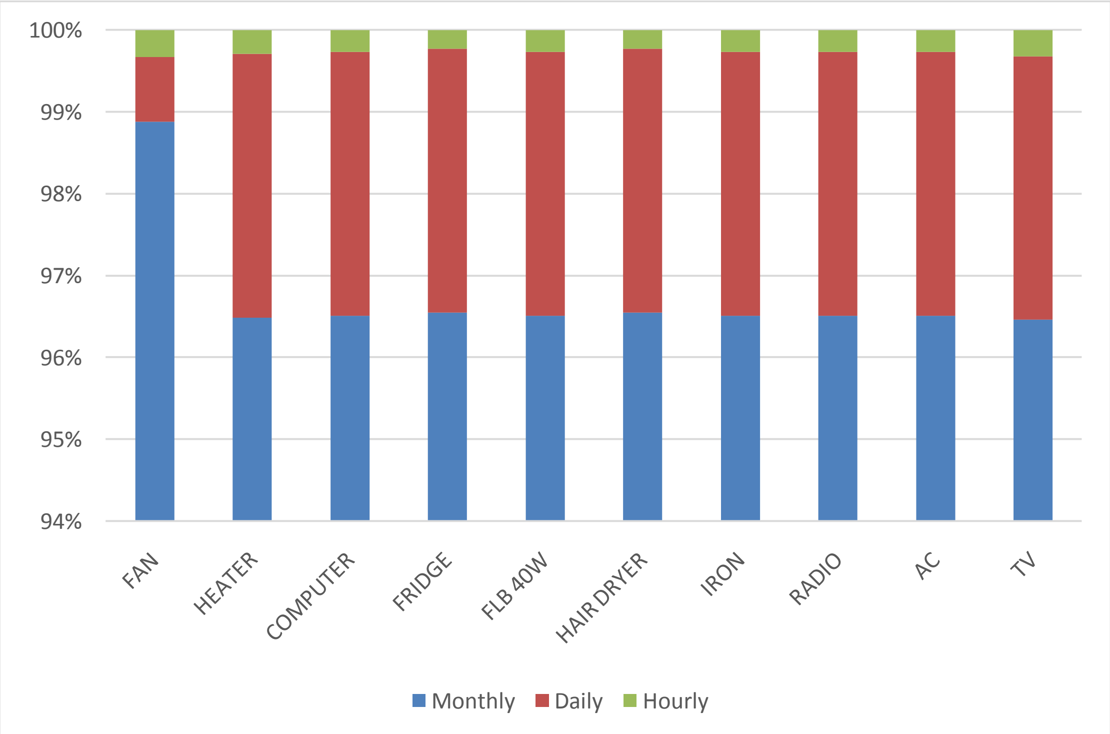

Fig. 3- shows the consumption (kwh) of the appliances in hourly, daily and monthly.

From Fig. 3, it is realized that the monthly consumption which shows in blue color has the highest percentage for each appliance, follows by the daily consumption shown in red color and the least is the hourly consumption which shows green. The smart meter can measure or take record of the smallest consumption and accumulate greater amount of data which can give sufficient or required information to monitor operational systems in almost real time [7], and it can also help the consumer to plan well to save energy in power consumption.

Table 3-Excel workbook showing how MAE, RMSE and MAPE were calculated.

Period	A	P	A-P	ABS(A-P)	(A-P)^2	|A-P|/A
1	48.52	56.92	-8.4	8.4	70.56	0.173124
2	72.54	81.48	-8.94	8.94	79.9236	0.123242
3	85.51	94.28	-8.77	8.77	76.9129	0.102561
4	97.06	106.56	-9.5	9.5	90.25	0.097878
5	45.03	53.33	-8.3	8.3	68.89	0.184322
6	50.82	63.83	-13.01	13.01	169.2601	0.256002
7	75.75	65.1	10.65	10.65	113.4225	0.140594
8	80.47	68.43	12.04	12.04	144.9616	0.149621
9	72.68	64.85	7.83	7.83	61.3089	0.107733

As shows in table 3, the absolute values of the difference between the actual values and the predicted values are a bit big values and that affect the values of the MAE, RMSE and MAPE. Figure 4 shows the performance values against the performance parameters or indices

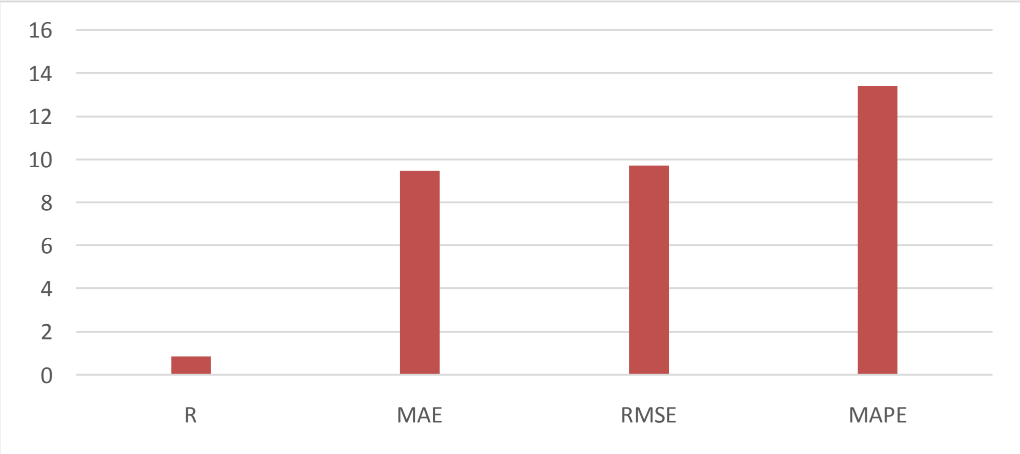

Figure 4, performance parameters or indices.

IV. CONCLUSION

Smart meters in smart distribution help to gather relevant information for both distribution operators and consumers which can manage in monitoring and preserving power consumption. This paper studied the performance of the smart meter using statistical tools to examine the data accumulated by the device over some period of time, that is from January to December. Some of the appliances such as blender, toaster, and microwave oven were not very often used and the usage of the fan and water heater depended on how cold or hot the weather was. At high temperature, the fan and the air conditioner were largely used but the water heater was not often used and vice versa. The MAE, R, RMSE and MAPE for a whole year were respectively determined to be 9.4867, 0.86, 9.7203 and

13.40238. The absolute values of the deviations or errors are a bit high and that affect the performance indices such as the MAE, RMSE and MAPE. This shows that the smart meter performs better and actually measure and record the real consumption if the distribution of power is constant and uniform. There are several problems associated with distribution of power such as faults, supply and demand imbalance, system of equipment which are old and weak and such vulnerability which cause unpredictable power outage for a long time affect the power consumption pattern of consumer [12]. This mean that the true consumption can be predicted ifthe power distribution is constant and reliable. The linear regression which is a conventional machine learning algorithm is practically used to make prediction of linear functions, and therefore the nonlinear signal could not be considered. The percentage of hourly, daily and monthly consumptions were determined and that also shows that the smart meter can collect data at the lowest minutes and accumulate it over time which can be used in monitoring power consumption, efficiency and network planning and management. It would be better that more smart meters are installed by the utility providers that will help in efficiency, reliability and resiliency in distribution system.

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