Demand-Side Management Solutions For Household Electricity Consumption In Ghana: A Case Study of Kpone-Dortia in the Kpone Katamanso Municipality

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**ABSTRACT**

This paper explored the possible solutions for savings in household electricity consumption and reduction of peak load demand through the application of demand-side management strategies. Demand Side Management (DSM) refers to a portfolio of measures employed to influence end-users power consumption profile by optimizing appliance operations and eliminating waste. The benefits of DSM include; reducing electricity consumption, reducing and shifting peak demand, delaying the construction of new generation, transmission, and distribution infrastructure, promote the integration of renewable energy into the power grid thus leading to the reduction of greenhouse gas emissions. Households in Kpone-Dortia were surveyed through questionnaires administered to key household members to determine appliance ownership, time of use of these appliances, knowledge level of energy conservation measures, and the willingness to support and adopt DSM measures. The results of the analysis indicate that phones, TVs, refrigerators, electric fans, electric pressing irons, and food blenders were the most popular appliances among households with about 97.1%, 95.7%, 95.7%, 94.9%, 94.2%, and 85.5% ownership respectively. The time of use of households appliances was mostly within the peak hours of 6 PM-11 PM with a 32.5% increase in load from baseload period to peak load period with the load profile of the study area confirming and reasonably agreeing with the time. However, about 78% of the respondents expressed the willingness to shift loads during this period to reduce the peak load. In addition, close to 90% of the respondents indicated their willingness to throttle the temperature settings on their air conditioners to save energy. Finally, over 92% of the respondents showed a willingness to adopt and practice DSM strategies.

Keywords: Appliance ownership, energy conservation, energy efficiency, energy wastages, demand response, load shifting, load profile

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1. **INTRODUCTION**

Electricity has become an indispensable commodity that drives the socio-economic development of nations and enhances the quality of life of people. This has occasioned a tremendous upward spiral in the consumption of electricity. The widening gap between demand and supply, associated high peak demand, and the negative impact on the environment from pollution and greenhouse gas emissions have become a global concern that has arrested the attention of stakeholders [1]. Demand-side management (DSM) is an effective strategy in addressing the challenges connected with the rise in electrical energy demand. DSM refers to a portfolio of measures employed to influence end-users power consumption profile by optimizing appliance operations and eliminating waste. Measures considered under DSM include peak clipping technology, valley filling technology, load shifting technology, energy-efficient technology, electrification technology, and flexible load shape technology [2]. The benefits of DSM include reduction in electrical demand, delay the time when new generation capacity will be required, reduction of peak demand, mitigating electrical systems emergencies, saving money for households, enabling efficient operations of utilities, allowing the integration of renewable energy and reduction in greenhouse gases which contributes to global warming. DSM also has the potential to perform other services to the electrical supply system such as grid frequency regulation and providing immediate reserves [3].

The demand for electricity in households has risen recently which can be attributed to the stock of electrical appliances and the utilization rate of this stock for lighting, cooking, heating, cooling, ventilation, refrigeration, washing, watching television, etc. The residential sector in Ghana accounts for about 40% of accumulated electricity consumption [4]. However, studies in [5] maintain that over 50% of the total generated electricity in Ghana is consumed in households. A huge proportion of this energy is needlessly wasted making households an important target for DSM measures to be employed to cut down on electricity wastage. The intended reduction in households’ electricity consumption expected from the adoption of DSM measures cannot be realized without the active participation of members of the household. In addition members of the households need to be equipped with knowledge of DSM strategies and further demonstrate a willingness to adopt and practice electricity-saving behaviour.

Electricity conservation is hindered in households mainly by a lack of knowledge and awareness of DSM measures. In [6], the author suggests that people with adequate energy-saving information and stronger awareness of climate change demonstrate a higher propensity to purchase renewable energy and participate in energy-saving activities. Behavioural changes as indicated in [7] can also help in efforts to reduce electricity consumption in households coupled with adequate national policy and technological considerations. There exist great potential to reduce unnecessary electricity consumption in households when members of households are equipped with energy awareness and DSM measures information and effectively encouraged to practice electricity-saving behaviours. This reduction in electricity demand will translate to a reduction in greenhouse gas emissions produced by generation plants [8].

To provide DSM measures to find better solutions to appliances usage in households, there is the need to have data on appliance ownership, usage periods, usage habit, knowledge level of energy, and environmental stewardship awareness and DSM measures they are prepared to adopt. Load profile as stated in [9] is also an important ingredient for accurate analysis of DSM in the domestic sector. However, [10] argues that household energy consumption complexity and diversity make it difficult to predict household load profile. The complexity of household energy consumption according to [11] lies in the high volatility and uncertainty associated with load profiles. Unfortunately, Ghana has passed through a severe power crisis and requires measures to be in place to prevent the reoccurrence of the power crisis. However, there is a paucity of studies into household electricity consumption in the direction of finding appropriate solutions to wastages and reducing peak demand through DSM measures. Thus, there is a need for studies to be conducted to find appropriate DSM options for households.

This paper presents the results of a survey conducted in Kpone-Dortia of the Kpone Katamanso Municipality in the Greater Accra region of Ghana. The survey sought to determine appliance ownership, usage periods, knowledge level of energy conservation and environmental stewardship awareness, preferred DSM options, and willingness to support and adopt DSM. The results provide useful input for any policy directed at implementing DSM in households.

1. **METHODOLOGY**

A survey through questionnaire instruments and interviews was used to elicit responses from key household members (e.g. household heads) in the Kpone Katamanso Municipality in the Greater Accra Region of Ghana. Guided oral interviews and explanations of survey questionnaires in languages understood by respondents were adopted in households where illiteracy was encountered. Online questionnaires were also sent via a link to households with formal education. The research questions were simple and understandable devoid of any complexity. The survey questions developed sought to determine the following; a) appliance ownership b) time of use of these appliances c) knowledge level of energy conservation measures d) willingness to support and adopt DSM measures.

The sample size for the survey was determined using the population of households in Kpone Dortia. The population of the household was obtained as 1329 from the Kpone Katamanso district analytical report 2014. Using equation (1) [12] a sample size of 171 was obtained and the 171 questionnaires were distributed both in hard copies and also using an online platform to 171 households.

(1)

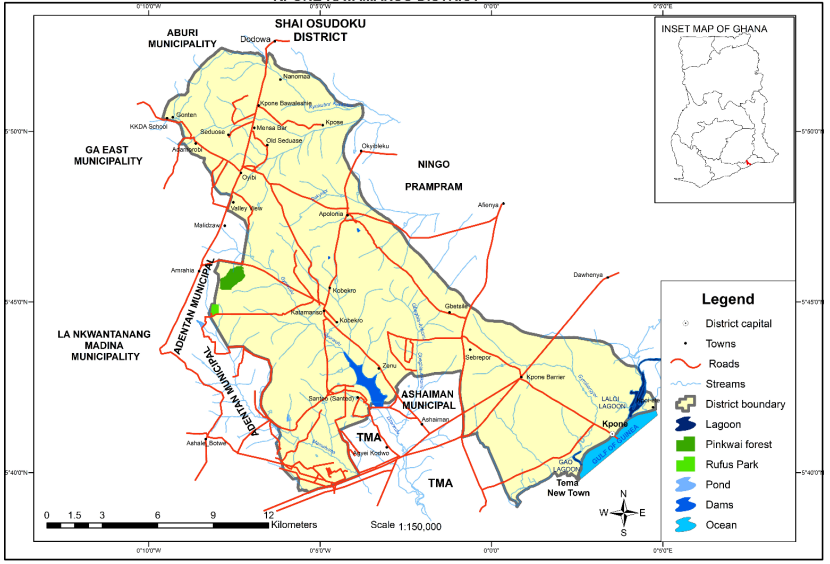
Where “s” is the required sample size, X2 is the table value of chi-square for 1 degree of freedom at the desired confidence level (3.841), N is the population size where the number of households in Kpone Dortia (1329), P is the population proportion (assumed to be 0.50 since this would provide the maximum sample size) d is the degree of accuracy expressed as a proportion (0.07).

The analysis of the data collected was done using Microsoft excel.

In addition, 10 days of load monitoring data on a distribution transformer in Kpone-Dortia obtained from the secure revenue management suite of the Electricity Company of Ghana, Prampram District office was used to generate a load profileto determine if the shape of the profile agrees with the time of use of appliances as reported by respondents. The days were carefully chosen to represent days of the week and weekends (Saturday and Sunday). Public holidays were treated as Saturdays because energy activity use patterns on four different holidays were found to be similar to that of Saturdays [4].

* 1. **STUDY AREA**

The study area for this project is Kpone-Dortia in the Kpone-Katamanso municipality. Kpone-Katamanso is located in the Eastern part of Greater Accra and stretches from the coast to the southern lower slopes of the Akuapim mountains. Kpone-Katamanso is 36 kilometers drive from Accra, the capacity city of Ghana, and falls on longitude 004’0E and latitude 5ᵒ 40’ 60N.



KPONE-DORTIA

(STUDY AREA)

Figure 1. Map of Kpone Katamanso Municipality

1. **RESULTS AND DISCUSSIONS**

Out of the 171 households contacted, 143 completed and submitted the survey questionnaires corresponding to a response rate of 83.63% which is high for a survey of this kind due to the unwillingness of some households to participate due to data privacy, security, and self-abasement prejudices because of social expectations of some appliances in households. However, 4 of the submitted questionnaires were excluded due to multiple answers giving a final number of 139 responses.

Attention needs to be drawn to the fact that some of the information collated in the survey were based on self-reported data of the participants. The risk of inaccuracy in the results obtained could arise due to recollection bias where participants are unable to accurately report data and/or social desirability bias where participants intentionally report incorrect information to conform to social norms or please the interviewer [4].

**3.1 APPLIANCE OWNERSHIP**

The survey results on appliance ownership present the type of appliances in possession of households that participated in the survey. The electric cooker was excluded from the analysis because only 3 households owned the appliance. The data indicated phones, TVs, refrigerators, electric fans, electric irons, and blenders are the most popular appliances present in households corresponding to 97.12%, 95.68%, 95.68%, 94.42%, 94.24%, and 84.89% ownership respectively. The less owned appliances from the survey were water dispensers (8.63%), printers (15.11%), and electric toasters (15.83%). The remaining appliances have an ownership rate between 30% and 70%. Again the data revealed 7% of the respondents owned all the 16 appliances surveyed and 97.9% of the respondents have at least 5 of the appliances in their homes and 74.1% have at least half of the appliances.

Figure 2. Appliance ownership

**3.2 APPLIANCE USAGE PERIODS**

Respondents were asked to indicate which time range they normally use their appliances. The operating periods of appliances varied from one household to the other. However, each appliance in the surveyed households operates at least in one of the time ranges (6 AM-12 PM, 12 PM-6 PM, 6 PM-12 AM and 12 AM-6 AM) with 6 PM-12 AM being the popular usage period which coincides with the period of 7 PM-11 PM [13]. Table 1 shows details of the percentages of respondents’ appliances operating time range for each appliance.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| APPLIANCES | TIME RANGE % | | | |
| 12 AM-6 AM | 6AM-12PM | 12 PM-6 PM | 6 PM-12 AM |
| Television | 2.2 | 20.1 | 10.4 | 76.1 |
| Sounders | 0 | 24.5 | 17 | 64.2 |
| Microwave oven | 0 | 22.7 | 46.7 | 40 |
| Rice cooker | 0 | 21.7 | 72.3 | 25.3 |
| Blender | 0 | 18.7 | 52 | 39 |
| Printer and computers | 4.2 | 18.8 | 18.8 | 78.1 |
| Fan | 17.8 | 11.9 | 23 | 78.5 |
| Electrical Iron | 1.5 | 51.9 | 5.3 | 41.4 |
| Washing machine | 3.3 | 70.5 | 6.6 | 19.7 |
| Air Conditioner | 4.8 | 6.3 | 27 | 69.8 |
| Refrigerator | 3 | 6.8 | 7.5 | 11.3 |
| Refrigerator | 73.7 indicated they always have their refrigerator once there is electricity. | | | |

Table 1. Appliances usage period.

**3.3 ENERGY CONSERVATION AWARENESS**

Respondents were asked to indicate the degree of energy conservation awareness efforts they make in energy saving at home. About 40.7% of the respondents indicated they make a lot of efforts to save energy with 43.7% giving a fair amount of effort while 13.3% give not much effort in saving energy and 2.2% pay no attention to saving energy at home

Figure 3. Energy conservation awareness

**3.4 REASON FOR SAVING ENERGY**

Respondents were asked to indicate the reason they practice energy conservation at home. Figure 4 shows details of the results obtained. About 75% of the respondents mentioned the cost to be the main reason they practice energy conservation whiles 15% indicated their reason to be a reduction in load congestion on the grid with 10% indicating environmental protection to be their reason

Figure 4. Reasons for saving energy

**3.5 ENERGY EFFICIENCY AWARENESS IN APPLIANCE USE**

Energy-efficient appliances contribute largely to energy consumption reduction in homes. The respondents were asked about their knowledge of whether they use energy-efficient appliances. Figure 5 shows the results obtained. Almost 54% indicated they did not know whether their appliances are energy efficient or not. The remainder of 46% mentioned they use energy-efficient appliances.

Figure 5. Responses to the use of energy-efficient appliances

**3.6 ENERGY-EFFICIENT AWARENESS IN LIGHTING**

The use of energy-efficient lighting technologies was identified as energy conservation measure adopted by the respondents. About 48.5% of the respondents reported the use of compact fluorescent lamps (CFLs) whiles 37.5 indicated using light-emitting diode bulbs (LEDs) as a means of illuminating their homes. The remainder of 13% reported using fluorescent tubes.

**3.7 STANDBY MODE POWER CONSUMPTION AWARENESS**

Electronic devices put on standby mode consumes electricity, which contributes significantly over a long period to the electricity consumption in households. Respondent’s awareness of this fact can lead to significant energy savings. Respondents were asked whether electronic appliances that remain plugged still consume electricity when the appliance is turned off. From figure 6, the results show 62% of the respondents are ignorant of this fact while the remaining 38% indicated knowledge of this fact.

Figure 6. Standby mode electricity consumption awareness

**3.8 WILLINGNESS TO THROTTLE TEMPERATURE SETTINGS ON AC**

Air conditioners’ power consumption can be adjusted within a temperature range during their fixed operational period. Throttling the temperature set point on an AC upwards could bring about significant energy savings. Respondents were asked whether they are willing to adjust the temperature setpoint upwards to save energy. Figure 7 shows the results. Close to 90% of the respondents indicated their willingness to do that whiles remainder of about 10% declined to do so.

Figure 7. Response to the willingness to throttle temperature settings on AC.

**3.9 WILLINGNESS TO ADOPT LOAD SHIFTING MEASURE**

Appliance’s operational period can be delayed and shifted usually from peak period to off-peak period without any adjustment in their power consumption to reduce the peak demand. Respondent’s willingness to adopt the load shifting measure was investigated. Figure 8 shows the results. Close to 78% of the respondents showed a willingness to shift some loads during peak hours whiles 22% declined to shift their loads.

Figure 8. Response to the willingness to adopt load shifting measure

**3.10 DEMAND RESPONSE**

Consumption Information feedback plays a significant role by serving as a reminder to draw consumers’ attention to their electricity usage hence influencing consumer behaviour positively. Respondents were asked whether feedback on their consumption will help them respond in a manner to save energy. About 84.1% of the respondents indicated regular feedback on their consumption would help them save energy and the remaining 15.9% indicated it will not help them save energy.

## 3.11 LOAD PROFILE OF A 315kVA DISTRIBUTION TRANSFORMER (H99C) IN KPONE- DORTIA

Analyses of the data from the load monitoring of the distribution transformer at Dortia reveals a steady load from 12 PM to 5 PM, however, there is a spike in load from 6 PM to 11 PM. . The period between 11 PM and 6 PM is characterized by a relatively steady lower consumption pattern. The peak hour consumption is mainly due to residential consumption with little contribution from commercial loads as no industrial facility is situated in this area. The average for baseload period (11 PM-6 PM) and peak load period (6 PM-11 PM) is 119.25A and 158A respectively. This represents a percentage load increase of 32.5% from the base period to the peak period.

**4.0 CONCLUSION**

This paper has presented and discussed the results of a study conducted to determine DSM measures that will be appropriate for households in Ghana, and assess their willingness to adopt these measures using Kpone-Dortia in the Kpone Katamanso Municipality as a case study. The study again considered knowledge gaps in energy conservation awareness. It was realized that per household appliances ownership, throttling of the temperature settings upwards on air conditioners and shifting loads from peak periods to off-peak periods was the popular choice for the respondents with 90% and 78% respectively for these two measures. Also, about 41% indicated making a conscious effort to save energy at home and 46% indicated using energy-efficient appliances at home. Again, about 84% suggested frequent feedback of electricity consumption by the utility companies will help them in conserving energy at home. About 62% of the respondents lacked knowledge about standby mode power consumption losses. However, over 92% of the respondents showed a willingness to adopt and practice DSM strategies. The results of this study will be a useful input in formulating Demand-Side Management policies in households.

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