

A STUDY OF AN URBAN DOMESTIC COMPOSITE LOAD MODEL SUITABLE FOR SOLAR PV AND GRID HYBRID SYSTEM

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Abstract

In every power supply system, the load is a major component to the system voltage stability. For this reason, load modeling is done to predict the behavior of the load. The load behavior in a power system directly affects the voltage profile of the system. In most generation systems in a country, the urban domestic load consumes up to 30% of the total generated power. It is with this fact in mind that this paper carried out an urban domestic load modeling to study the effects of disturbances and perturbations caused by the load to a power generation system. In the study, a solar PV and grid hybrid system is used. An equivalent circuit of an induction motor is used as a dynamic load together with the static domestic load to form the load model. The study uses both quantitative and qualitative analysis methods and also explores the use of trajectory sensitivity concepts. Using load analysis software; Excel and MATLAB the load was modeled. The domestic load used in the study is drawn from a study case suburb; Embakasi Nyayo Estate. Preliminary results obtained indicate accurate predictions for the hybrid solar PV and grid system. The investigations further indicate that load voltage dynamics can significantly influence the damping of modal oscillations. Further, as the system becomes more stressed, sensitivity to parameter variations increase significantly and this can be used to predict marginal stable behavior.

Key words: Load modeling, distribution system, voltage profile, urban domestic load

1.0 Introduction

The load is a major component to the stability of the Voltage of any electrical power system. In most electrical systems, the industrial load forms the bulk of the electrical burden. However, the domestic load also forms a considerable proportion of the entire electrical burden in most countries including Kenya as shown by the Kenya weekly load curves on Figure 1. For this reason, load models are done to enable system engineers to predict the undesirable effects of the load variations. Though accurate load models are normally difficult to achieve due to the dynamic nature of loads, the inaccurate models still serve as an indicator to the predictions. With these predictions system engineers are able to prepare to engage control devices to stabilize the system voltages at the affected load centers.

In this paper a domestic urban load from a case study suburb in Nairobi is aggregated and modeled to demonstrate its effects on the power system. It is important to note from the onset that urban domestic load consists of both static and inductive loads like heating and refrigeration appliances respectively. The refrigerators and freezers have a time constant greater than 0.5seconds so they have been modeled as dynamic loads [1].

The domestic load is normally a parallel interconnection of the static and inductive loads in any homestead. These loads are then connected to the electricity supply system depending on domestic activities in a homestead. Results obtained by the on the preliminary studies at the case study, reveal that domestic activities that demand most electrical power occur in the early morning at 7AM and late evening 8.30PM as observed in Figure 1. Some of these domestic loads are electronic appliances which when energized inject harmonics in the system and cause harmonic distortion in the system voltage waveform [2].

Table 1 shows the load/appliance types, power rating and duty cycle of the loads found in most homesteads in the case study.

Table 1: Domestic load

S/N	Appliance	No	Watt	Duty Cycle	Load Type
1	Cf lamps	10	11	4	Electronic
2	Radio	1	22	2	Electronic
3	TV 21	1	50	8	Electronic
4	Iron	1	1000	4	Static
5	Cooker	1	1000	1	Static
6	Microwave	1	3500	0.5	Electronic
7	Toaster	1	1500	0.5	Static
8	Hair dryer	1	1500	0.5	Inductive
9	Coffee	1	1200	0.5	Static
10	DVD	1	50	0.5	Electronic
11	Computer	1	110	2	Electronic
12	Lap top	1	65	4	Electronic
13	Fridge	1	300	4	Inductive
14	D/ Freezer	1	500	2	Inductive
	Total	23	10808		

Source: Generated by the study

The inductive loads shown above operate at a lagging power factor thereby needing power factor correction attention. On the other hand the resistive loads operate at near unity power factor (0.95lag). When these loads are aggregated, their effect is large enough to require prompt reactive power compensation to avoid voltage collapse at the nearest load bus. Apart from the reactive power demand, these loads demand high current when starting thereby raising the peak demand of the system as shown on the Table 2 and the load curve (2004)[3]. An example is the refrigerator which runs at 300watts at full load but will require 1500watts to start. Figure 1 shows the effects

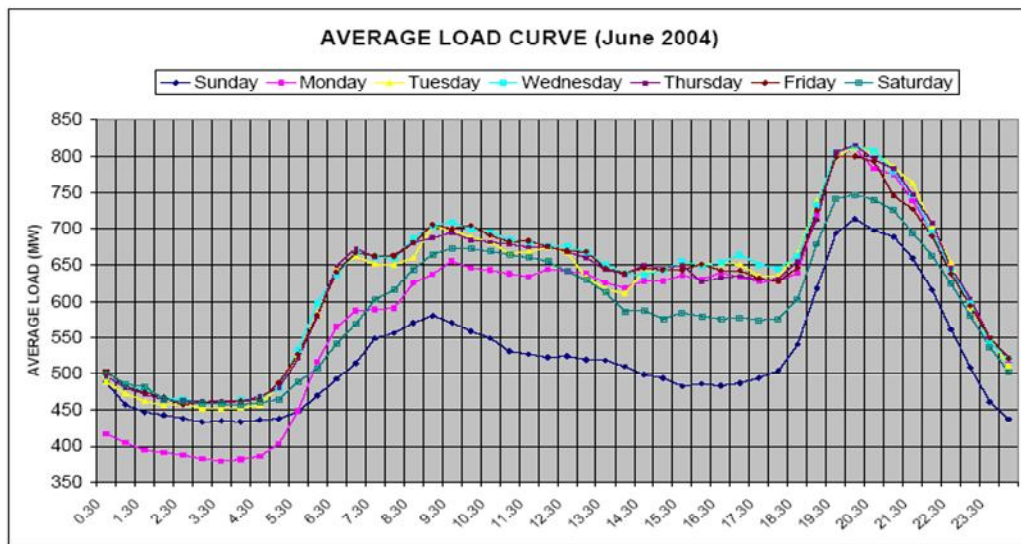
of the domestic load to the national load curve during the domestic peak of 8.30PM. Studies done elsewhere showed that the domestic load contributes up to 30% to some country's national load demand [4].

Table 2: Steady state and surge power

S/N	Type of Load	Power (W)	Surge Power (W)
1	Fridge	300	1500
2	D/Washer	700	1500
3	C/Washer	650	1150
4	D/Freezer	450	1800

Source: Generated by the Study

This national peak is normally supplied by fossil fuel generators which generate expensive energy units. The National peak starts building at 6.30 p. m. and attains its apex at 8.30 p. m. The load peak then starts reducing gradually at 8.30 p. m. when the domestic load is shut down. At 10 p. m. the domestic load is completely shut down leaving only the few industrial and commercial consumers which run 24 hours.



Source: KPLC (2004)

Figure 1: Kenya national weekly load curve

2.0 Theory and Methodology

The methodology applied in the study was:

- (i) To take spot hourly domestic power consumption data and observe the load behavior in MS Excel.
- (ii) To categorize the static loads and the inductive loads and obtain resistance and inductance values for each.
- (iii) Use the obtained data in MATLAB Simulink to simulate and observe the effects to the power supply.

- (iv) Use MATLAB to investigate the effects of harmonics to the voltage profile.
- (v) Aggregate the peak demand and observe the effects to the power system.

For the MATLAB Simulink simulation, the split phase single phase motor is used to represent the refrigerator compressor motor and pure resistances are used to represent the heating loads. Below is an induction motor equivalent circuit.

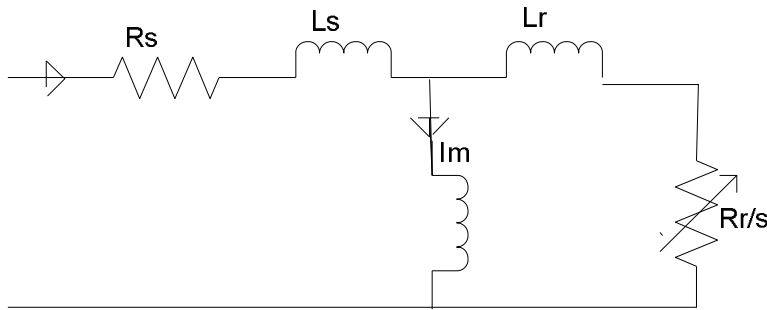


Figure 3: Induction motor equivalent circuit

R_s = Stator resistance, L_s = Stator inductance, L_r = Rotor inductance, R_r/s = Rotor resistance, I_m = Magnetizing current.

The typical model used for an individual homestead is a parallel connection of the resistive loads and the inductive loads as shown in Figure 4:

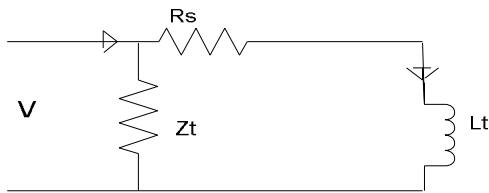
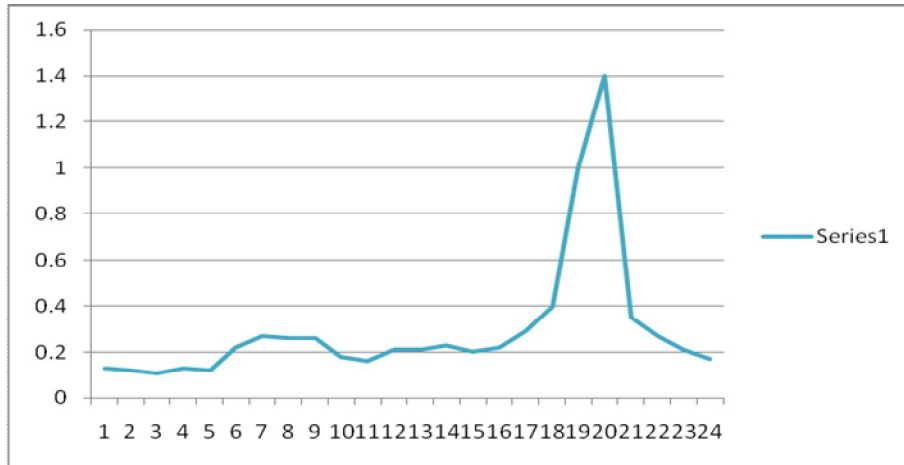


Figure 4: Domestic load model

Z_t = Total connected resistive load in the home,
 L_t = Total connected inductive load in the home.

3.0 Results and Discussions

The data collected on spot measurements was used to generate a graphical response. Figure 2 is the curve showing the average hourly power consumption for the case study (Embakasi Nyayo Estate). The peak power consumption occurs at 8.30PM and the power is 1.4 kWp. The power demand starts rising from 7.30 p. m. reaching the peak at 8.30Pm and reducing to 400 Wp level at 9.00 p. m.



Source: Generated by the Study

Figure 2: Average hourly power consumption (kW)

Note that this domestic peak coincides with the national peak observed in Figure 1. This phenomenon supports the argument that the national peak observed at 8.30 p. m. is driven by the domestic load. When this domestic peak power is aggregated in the entire estate of 4774 units [5], the case study estate peak power is 6.683 MW. This is a substantial power demand peak for one urban estate.

Table 3 shows the categorized data that was used in the MATLAB Simulink simulations. These loads were simulated as intermittent load considering domestic activities.

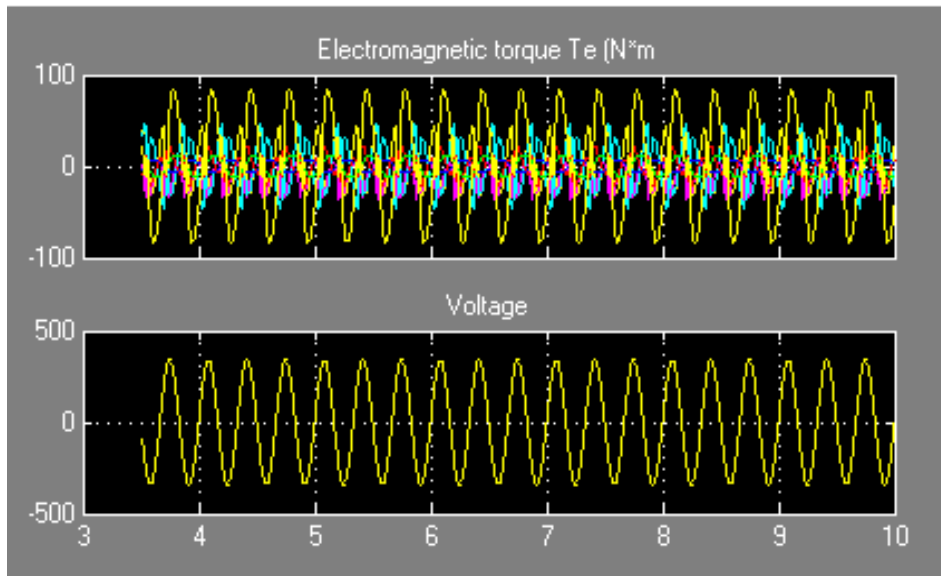
Table 3: Domestic load data that was used

Load	Load Type	Power Rating Watts	Rating in Ohms
1	Resistive (Electric Irons, Electric cooker, Heaters, Toasters)	4700	177.6
2	Electronic (Television, Radio, DVD, Computers and Lap tops, CFC lamps)	297	214.5
3	Inductive (Refrigerators, Freezers, mixers, Blenders, Microwave oven)	4350	Reactance = 89.7 Reactive Q = 3262.5

Source: Generated by the study

Preliminary results obtained reveal that though domestic loads connection to the supply occurs at random; there is more concentration between 7.30 p.m. and 8.30 p. m. when domestic operations are intense. The results also show that the domestic load can be predicted very accurately thereby providing an opportunity to its mitigation or control.

The Simulink simulations results reveal some harmonic distortion of third and second order harmonics which affect the voltage profile adversely [6]. The graph on Figure 3 for the electromagnetic torque developed by the compressor motor shows torque pulsations occurring at 40, 30, 10, 2 Nm. These pulsations reduce the efficiency of the machine thereby requiring more power for the same task. The Voltage profile is smooth when the compressor motor and resistive load are connected to the supply.



Source: Generated by the study

Figure 3: Electromagnetic torque –Nm and voltage

When Simulations were done with the entire domestic load including the electronic devices the graphs on Figure 4 were obtained. The same pulsations were observed on the electromagnetic torque T_e (Nm) while on the voltage waveform harmonic distortion of the 3rd and 2nd order were observed on the lower graph of Figure 4. These distortions affect the voltage profile adversely by distorting the fundamental waveform.

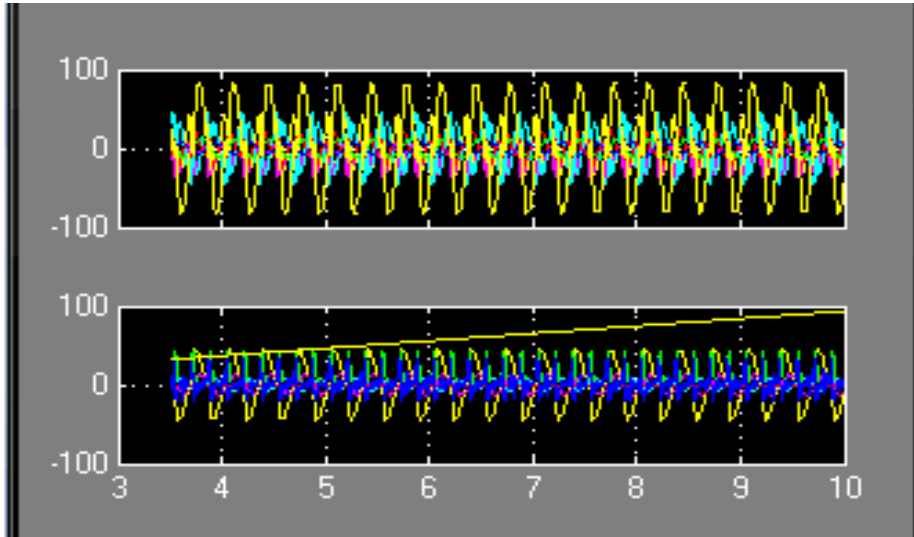


Figure 4: Electromagnetic torque –Nm and voltage

From the preliminary results obtained conclusions were drawn and recommendations made.

4.0 Conclusions and Recommendations

The conclusions and recommendations of this paper are summarized as follows.

- (i) The case study results have shown that the domestic electricity peak load power is large enough at 6.683MWp to deserve attention and management.

- (ii) The results obtained so far reveal that domestic equipment causes some harmonic distortion to the supply voltage. There is need for filtering mechanisms.
- (iii) For use with solar PV systems, it is recommended that the solar PV system in cooperate second and third order harmonic filters.
- (iv) The national urban domestic load is substantial and needs to be addressed to mitigate the national peak power demand.
- (v) Further studies will be done to investigate other effects and mitigation methods.

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