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The impact of adoption of power factor correction technology on electricity peak demand in Uganda

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Abstract
This paper examines the impact of adoption of power factor correction technology on electricity peak demand in Uganda. Specifically, the paper examines the variability of peak electricity demand in the periods before and after the implementation of power factor improvement schemes and assesses the likely impact of power factor improvement schemes on peak demand. Results suggest that power factor correction technology implemented among industries and commercial enterprises increased the power factor in these industries from an average of 0.68 to 0.95 and saved up to 8.04 MVA of demand as at the end of 2014. Results further indicate that the implementation of the power factor correction scheme has reduced the growth rate and abated the variability of both total maximum/peak demand and domestic peak demand. Finally, with the implementation of power factor correction scheme, there is a noticeable reduction in electricity consumption at peak time of use (TOU) and growth in consumption of electricity at nonpeak time TOU, which was not the case before the implementation of the scheme.

1 Background

Enhancing energy efficiency is a global priority (International Energy Agency (IEA) 2013; Linares and Labandeira 2010; Gillingham et al. 2009). At the production firm level, the benefits of energy efficiency include reduction in resource use, improved production and capacity utilization, and less operation and maintenance costs, which lead to improved productivity and competitiveness (International Energy Agency (IEA) 2013; Ryan and Campbell 2012; Worrell et al. 2003). Indeed, improvements in energy efficiency in manufacturing plants lead to reduced demand for energy and hence releasing the excess demand to other potential users (Ryan and Campbell 2012). The excess energy demand especially at peak time of use zones attracts maximum demand charges from utilities (Schneider Electric 2008), in a two- or three-part tariff structure, which includes energy and demand components.

Electricity shortages are common in many countries in Sub Saharan Africa (Eberhard and Shkaratan 2012; Eberhard et al. 2008). More recently, in 2006, Uganda experienced a deficit in electricity supply owing to a prolonged drought, delayed development of the

250 MW Bujagali hydropower project, and demand growth (Mawejje et al. 2013; Heffner et al. 2010).

Consequently, between 2007 and 2011, the Uganda Ministry of Energy and Mineral Development (MEMD) with support from the World Bank conducted targeted energy audit studies of large manufacturing plants with the highest potential to save electricity (World Bank 2012). These studies evaluated the costs required to implement the energy conservation measures with a special focus on the efficient use of electricity.

Results from the energy audit studies in Uganda showed that most of the large industries in the country were energy inefficient, with the power factor ranging between 0.52 and 0.85 (see Fig 4 in Appendix); yet Uganda's Electricity (Primary Grid Code) Regulations, 2003, require that the power factor for electricity distributors and big consumers should not fall below 0.9. This is because the power factor, which is defined as the ratio of 'active or productive power' (measured in kilowatts—kW) used in the circuit to the 'reactive or apparent power' (expressed in kilo-volt amperes—kVA) is the percentage of electricity that is used to do useful work in electrical equipment (Bhatia 2012). Therefore, the lower the ratio of active to reactive power, the higher the wastage of the energy resource.

All consumers of electricity including domestic, commercial, and industrial consumers contribute to peak demand, though at different magnitudes depending on the rating and efficiency of their electrical appliances. One of the findings from the electricity energy audit studies was that energy efficiency in large industries in Uganda could be attained by installation of power factor correction (PFC) equipment such as capacitor banks. Such power factor correction equipment could be installed as distributed PFC, group PFC, centralized PFC, combined PFC or automatic PFC depending on the underlying causes of the low-power factor in the electrical system. Extensive discussions on power factor correction are provided in ABB (2010).

In an effort to stem the inefficient use of the scarce electricity resource, in 2009, the government of Uganda received funding from the World Bank under the second phase of the Rural Energy Transformation Project (ERT-2) to implement various energy efficiency interventions including the initiative to improve the power factor and hence save energy and associated costs for industrial and commercial electricity consumers—with maximum demand greater than 100 kVA (Mukherji 2014).

The ERT-2 project focusing on the power factor improvement scheme is implemented by the Private Sector Foundation Uganda (PSFU) under the Business Uganda Development Scheme (BUDS). The target power to be saved under this initiative is 10.4 Mega-Volt Amperes (MVA) of demand and associated wasted energy. According PSFU-BUDS, however, as of the third quarter of 2014, up to 21 manufacturing companies (see Fig. 4 in Appendix) had benefited from the scheme leading to a total saving of 8.04 MVA of demand equivalent to 8.4 MW of electricity.

Much as the ERT-2 project was approved in 2009, actual implementation of the power factor improvement scheme started in 2011 but in a slow pace. Implementation of this component gained pace by late 2012 and up to 80 % of the realized savings of 8.04 MVA of demand have been achieved between 2013 and 2014. Comparing the targeted MVA savings vis-à-vis the actual, to-date, the project has achieved up to 77 % of the target 10.4 MVA of demand. However, since ERT-2 project is planned to close on 30th June

2016, PSFU-BUDS officials are optimistic that the power factor improvement scheme of ERT-2 project will achieve 100 % or more of targeted saving of demand.

Energy saving initiatives such as the power factor improvement scheme of ERT-2 project contribute significantly in mitigating and stabilizing peak or maximum demand of electrical network resources (Schneider Electric 2008). In countries such as Uganda where electricity supply barely meets the system demand requirements, policymakers, regulators, system operators as well as distribution network operators are always wary of any likely surge in the maximum demand that may propagate system outages and hence jeopardize the quality of electricity supply. For that reason, any initiatives implemented to improve the energy use efficiency of large consumers of electricity who customarily exert maximum demand on the system, are a welcome relief to the stakeholders in the electricity supply industry.

Much as power factor improvement schemes may be expedient relievers of maximum demand, their attendant impacts on peak demand in general and in Uganda in particular have received little attention. Studies elsewhere have examined impacts of community behavioral issues (Gyamfi et al. 2013); economic (Oldewurtel et al. 2010; Psiloglou et al. 2009) as well as environmental factors (Barker et al. 2012) on peak electricity demand. A recent study by (Never 2015) investigated the role of behavioral factors for the energy management of enterprises in Uganda. In a related study, Never (2014) examined the role of behavioral factors in improving energy efficiency policies directed toward poor populations.

However, as far as we are aware, no empirical study has investigated the impact of power factor correction on electricity peak demand general and in Uganda in particular. Previous studies have focused primarily on the benefits of power factor correction on electricity demand by the companies to which the intervention was directed. A better understanding of these issues will enable public policy to be designed in a direction which improves energy security and efficiency.

It is against this background that this study examined the impact of power factor improvement schemes on peak electricity demand. Specifically, the study examined the level of variability of peak demand in the period before and after implementation of power factor improvement schemes and assesses the likely impact of power factor improvement schemes on peak demand. The rest of the paper is organized as follows: Section 2 presents the data and methods of analysis; results and discussions are presented in Section 3; Section 4 concludes the paper.

2 Data and method of analysis

2.1 Data and source

Since this study essentially compares the quantum (maximum) of electrical energy consumed by all households and firms connected to the electricity distribution grid in the period before and after the government intervention (ERT-2 project power factor correction scheme), the data collected for analysis are from all electricity consumers (population) on the grid. The data are monthly in resolution, for the period of January 2011–August 2014 leading to 44 data points for each variable. The period before project intervention is January 2011–December 2012 (24 observations), while the period after project intervention is January 2013–August 2014 (20 observations).

The data described above were obtained from Uganda Electricity transmission Company Limited (UETCL)[1]. The data included systems demand and energy sales. In particular, systems demand data are on system peak or maximum demand, while energy sales includes data on energy losses, energy exports, and energy sales to Umeme Limited at peak, shoulder and off-peak time of use (TOU) zones. According to September 2014 UETCL energy sales data, Umeme Limited distributes up to 94 % of energy sold by UETCL in Uganda (see Table 6).

2.2 Method of analysis

To analyze the growth and variability of domestic peak demand in the period before and after implementation of power factor improvement schemes, this paper employs the graphical descriptive analysis methods including the two-way fractional polynomial graph, the boxplot graph, and the analysis of variance.

The two-way fractional polynomial graph is a simple and yet powerful parametric model that is an intermediate between polynomials and nonlinear curves (Royston and Sauerbrei 2008). The advantage with fractional polynomial functions is that they use the full information and search for the optimal functional form within a flexible class of functions (Royston and Sauerbrei 2008). In this paper, the fractional polynomial graph is used to compare the growth rate of electrical peak demand in the period before and after implementation of power factor improvement schemes. A lower growth rate in peak demand after implementation of power factor improvement schemes compared to the period before implementation implies stable and normal growth in peak demand arising from expected growth in demand.

The boxplot has become the standard technique for presenting the 5-number summary of the distribution of a dataset, which entails the minimum and maximum range values, the upper and lower quartiles, and the median (Potter 2006). The boxplot is a graphical illustration of data distribution in form of a box showing the mean and innerquartile range, which is the area between the upper and lower quartiles and consists of 50 % of the distribution, with lines (also called whiskers) extended to the extrema of the box, showing either minimum and maximum values in the dataset (Potter 2006). In this paper, the boxplot graph is used to compare the variability of domestic peak demand in the period before and after implementation of power factor improvement schemes.

To supplement the boxplot analysis in understanding the variability of domestic peak demand in the period before and after implementation of power factor improvement schemes, a variance ratio test for domestic peak demand before and after implementation of power factor improvement schemes are estimated. The variance ratio test as proposed by Lo and Mackinlay (1989) tests the existence or nonexistence of a significant difference in the size of variance of two or more variables. The null hypothesis being that the ratio of the standard deviation of the parameters being tested is unity and the alternative hypothesis is that the ratio is not unity.

To assess the likely impact of power factor improvement schemes on peak demand, two bootstrapped linear models of total peak demand and domestic peak demand

[1] UETCL is the sole entity in Uganda Electricity Supply Industry mandated to operate the function of systems operator, bulky buyer and seller of electricity, exporter and importer of electricity, and operator of the transmission system above 66 kV.

regressed against electricity energy export, electricity energy sales to distributors, energy losses, and a structural break parameter to take care of the effect of the implementation of the PFCT scheme on peak demand. The structural break parameter is 0 for the period before implementation of the PFCT scheme (Jan 11–Dec 12 = 0) and is 1 for the period in which the PFCT scheme is implemented (Jan 13–Aug 14 = 1). The bootstrapped regression method has been chosen for this analysis so as to improve the efficiency of the estimates given that the sample is relatively small. Mackinnon (2002) provides a detailed discussion of the application of bootstrapping in econometric analysis.

In the first regression, the equation is formulated as in Eq. (1a), while in the second regression the formulation is stated in Eq. (1b).

$$tp_i = \beta_0 + \beta_1 ex_i + \beta_2 umeme_i + \beta_3 other_i + \beta_4 loss_i + \beta_5 SB_i + \varepsilon_i \tag{1a}$$

$$dp_i = \alpha_0 + \alpha_1 umeme_i + \alpha_2 other_i + \alpha_3 loss_i + \alpha_4 SB_i + \varepsilon_i \tag{1b}$$

where by *tp* is the total peak demand, measured in Mega Watts (MW); *dp* is the domestic peak electricity demand which excludes energy exports measured in Mega Watts (MW); *ex* is the total electricity exports measured in Giga-Watts hours (GWh); *umeme* is the UETCL energy sales (GWh) to Umeme; *other* is UETCL energy (GWh) sales to other electricity distribution companies in Uganda as indicated in Table 6 in appendix; *loss* represents transmission level energy losses (as a percentage total energy purchases by UETCL); *SB* is a structural break parameter defined as 0 for the period before implementation of the PFCT scheme (January 2011–December 2012) and 1 for the period in which the PFCT scheme is implemented (January 2013–August 2014); ε is the error term representing any other factors not included in the equation but may have an impact on peak demand; $\beta and \alpha$ are parameters to be estimated while $i = 1, 2, \ldots, n$ is the number of observations from first to the last ($n = 44$).

Now, to assess the likely impact of power factor improvement schemes on the shift in electricity consumption peak TOU zone to nonpeak TOU zone, a structural break equation model stated in Eq. (2) is estimated.

$$pk_i = \beta_0 + \beta_1 np_i + \beta_2 d_i + \beta_3 (np_i * d_i) + \varepsilon_i \tag{2a}$$

$$pk_i = \gamma_0 + \gamma_1 np_i + z_i; \quad \text{for the period January 2011 to December 2012} \tag{2b}$$

$$pk_i = \delta_0 + \delta_1 npi + w_i; \quad \text{for the period January 2013 to August 2014} \tag{2c}$$

where *pk* is the UETCL energy sales (GWh) to Umeme Limited at peak TOU zone; *np* represents UETCL energy sales (GWh) to Umeme Limited at nonpeak (shoulder and offpeak) TOU zone; *d* is a dummy variable; $d = 1$, if time period is January 2011–December 2012, and $d = 0$ if time period is January 2013–August 2014; $np * d$ represents an interaction term between the explanatory variable (*np*) and the dummy variable (*d*); ε, *z*, and *w* are errors terms for the respective specified equations above; $\beta, \gamma and \delta$ are parameters to be estimated; and $i = 1, 2, \ldots, n$ is number of observations from first to the last (n).

When the coefficients of dummy variable (β_2) and interaction term (β_3) in Eq. (2a) are statistically significant, it implies that the magnitude of the peak–nonpeak slope (change in peak demand arising from a unit change nonpeak demand) for the period of January

2011–December 2012 and the January 2013–August 2014 is different. The actual magnitudes of the slopes are reflected in the coefficients γ_1 and δ_1 of Eqs. (2b) and (2c), respectively. To prove that the slopes of Eqs. (2b) and (2c) are different and hence there may be a shift in peak demand, the Hausman *F*-test of equality of coefficient of two regression models (Clogg et al. 1995) is estimated.

3 Results and discussion

3.1 Descriptive statistics

The summary statistics at the transmission system level for the period of January 2011–August 2014 are shown in Table 1. The descriptive statistics indicate that for the period under review, electricity total peak demand ranged between 428 MW and 550 MW with average peak demand at 482 MW. Domestic peak demand ranged between 417 MW and 497 MW with average peak demand of 462 MW. For energy losses, the descriptive statistics indicate that in the period under review, transmission losses ranged between 0.2 and 7.2 % and averaged 3.6 % of total energy purchases, Fig. 1.

In terms of Time of Use (TOU) differentiated energy consumption, the results indicate that on average 50 % (113.5 GWh) of the electricity consumption in Uganda is during the shoulder TOU period (05:00–18:00 h), 29 % (65.2 GWh) during peak TOU period (18:00–23:00 h,) and the balance (21 %) during off-peak TOU period (23:00–05:00 h).

3.2 Trend of electricity peak demand before and without PFCT scheme

Figure 1 shows the trend of total peak demand and domestic peak demand before implementation and with implementation of the power factor correction technology (PFCT) scheme. The results suggest that before implementation of the PFCT scheme, both total peak and domestic peak demand were growing exponentially, but the difference between

Table 1 Summary statistics of the variables at system (UETCL) level

Variable	Obs	Mean	Std. Dev.	Min	Max
Power (MW)					
Total peak demand	44	482.00	36.82	428.35	549.63
Domestic peak demand	44	462.45	26.30	417.37	497.20
Energy (GWh)					
Total energy purchases	44	241.93	21.50	198.93	283.58
Total generation	44	238.78	21.76	194.94	282.05
Total imports	44	3.15	1.02	1.53	5.99
Peak energy sales	44	65.18	6.81	45.99	73.55
Shoulder energy sales	44	113.48	8.23	93.27	128.04
Off-peak energy sales	44	47.14	3.61	36.52	53.44
Nonpeak energy sales	44	160.62	11.64	129.79	181.48
Energy sales to umeme	44	221.43	18.98	175.78	252.53
Energy sales to other local distributors	44	2.05	0.52	1.13	2.91
Total exports	44	9.78	3.99	6.38	24.92
Total sales	44	233.26	21.89	184.66	273.54
Energy loss (%)	44	3.62	1.15	0.16	7.17

Data source: UETCL

total peak and domestic peak demand was largely attributed to the energy that is exported.

In the period of implementation of the PFCT scheme, however, the growth in total peak demand remained exponential, while the growth in domestic peak demand became somewhat linear. The continued exponential growth in total peak demand in the later 2013 and in 2014 was driven by high exports to Kenya (Table 6 in Appendix) following the shutdown of Olkaria Geothermal Power for maintenance and the construction of the Olkaria-Lessos-Kisumu Transmission Lines Construction Project[2] by Kenya Electricity Transmission Company (KETRACO). The linear growth in domestic peak demand on the other hand may partly be influenced by the implementation of the PFCT scheme.

3.3 Variability of electricity peak demand before and without PFCT scheme

Figure 2 shows the level of variability of total peak demand and domestic peak demand before implementation and with implementation of the power factor correction technology (PFCT) scheme. The boxplots depict a high level of variability of both total peak demand and domestic peak demand before implementation of the PFCT scheme compared with implementation of the PFCT scheme.

The high variability is evidenced by the wide range between the minimum (lowest point on the graph) and maximum (highest point on the graph) values, and inter-quartile range (height of the box). The crossbar in the boxplot is the median; the lower part of boxplot is the lower quartile; between the lower part and the median is the second quartile; between the median and the upper part of boxplot is the third quartile; and the upper part of the boxplot is the fourth quartile.

To understand if there is any significant difference in the variability of peak demand before implementation and with implementation of the PFCT scheme, the variance ratio test (*F*-test of equivalence for the variances) is presented in Table 2. The results indicate that the variation in domestic peak demand before implementation and with implementation of the power factor correction (PFCT) scheme is highly statistically significant ($p < 0.01$), while variation in total peak demand before implementation and with implementation of the power factor correction (PFCT) scheme is not statistically significant at the 5 % level.

3.4 Effect of PFCT scheme on peak demand

Table 3 presents the bootstrapped regression of total peak demand and domestic peak demand against UETCL disaggregated energy sales to domestic distributors and export market. A structural break parameter reflecting the period before (Jan 11–Dec 12 = 0) and with implementation (Jan 13 –Aug 14 = 1) of the PFCT scheme is included in the regressions to test if there is a statistically significant correlation between implementation of the PFCT scheme and the direction and magnitude of peak demand. Starting with the robustness of the results, Wald Chi Square results in Table 3 for both total peak demand and domestic peak demand regressions are robust and the models explain up to 79 % (Adjusted R^2) of relationships between the total peak demand and the explanatory variables.

[2] More details on this and other developments in Kenya's electricity transmission projects are available at: http://www.ketraco.co.ke/projects/ongoing/olkaria-lessos-kisumu.html.

Table 2 Test of equivalence of variances

	Obs	Mean	Std. Err.	Std. Dev.
Total Peak demand				
Before PFCT scheme	24	459.78	6.44	31.55
With PFCT scheme	20	508.67	4.95	22.15
Combined	44	482.00	5.55	36.82
Degrees of freedom	23, 19			
F-statistic		2.03*		
Domestic Peak demand				
Before PFCT scheme	24	444.21	4.51	22.09
With PFCT scheme	20	484.35	1.57	7.03
Combined	44	462.45	3.96	26.30
Degrees of freedom	23, 19			
F-statistic		9.87***		

*, **, and *** are statistically significant at 10, 5, and 1 % levels

Table 3 Bootstrapped regression results

Explanatory variables	Dependent variables			
	Total peak demand		Domestic peak demand	
	Coef.	*z*-value	Coef.	*z*-value
Exports (log)	0.08***	3.18		
Sales to Umeme (log)	0.69***	2.52	0.52***	3.35
Sales to other Dist. (log)	0.01	0.22	0.02	1.29
TX energy loss (log)	0.00	−0.08	0.00	0.65
Structural break	−0.01	−0.49	−0.02	−0.96
Constant	2.29	1.6	3.28***	3.93
Obs.	44		44	
Replications	100		100	
Wald chi^2 (5)	198.02***		237.33***	
R-squared	0.82		0.85	
Adj. R-squared	0.79		0.83	
Root MSE	0.03		0.02	

*, **, and *** are statistically significant at 10, 5, and 1 % levels

The regression results for both total peak demand and domestic peak demand indicate a slight (1 %) but not statistically significant reduction in peak demand that is associated with implementation of PFCT scheme. The results are not statistically significant most likely due to the somewhat low monthly savings of energy (about 5 GWh as of end of 2014) arising from the PFCT scheme compared to total energy sold by UETCL.

As would be expected, the results indicate that both total peak demand and domestic peak demand are strongly influenced by growth in UETCL energy sales to Umeme Limited. Exports are also shown to have a significant effect on total peak demand. This is expected given that most of Uganda's electricity exports occur during the peak time of use period. For example, Fig. 5 in the Appendix shows that 1st July 2014 at 21 h, the country exported 40.3 MW of electricity after netting off some limited imports from Kenya.

3.5 PFCT scheme and shift in electricity consumption by TOU

Figure 3 shows UETCL peak TOU sales and total energy sales to Umeme Limited before and with PFCT scheme. For comparison purposes, peak energy by UETCL to Umeme Limited has been amplified by a factor of three. The results suggest that before implementation of the PFCT scheme, on average, the proportion of UETCL energy sales to Umeme Limited at peak TOU zone were growing faster than overall UETCL sales to Umeme Limited. The graphs associated with implementation of the PFCT scheme on the other hand indicate a slightly higher growth in UETCL overall sales to Umeme Limited compared to sales at peak TOU zone. This kind of reversal in the growth trends imply some possible impact of the PFCT scheme on electricity consumption at peak TOU zone compared to consumption at nonpeak TOU zone.

To affirm the reliability of the conclusion drawn above, a test of the statistical significance of the difference in the slopes of the curves in Fig. 3 is presented in Table 4. The table shows the results of a regression of UETCL energy sales to Umeme at peak TOU zone against energy sales at nonpeak TOU zone. The test for the difference in the slopes is accomplished by adding including a structural break parameter in equation in regression. Similar to previous analysis in Sect. 3.4, the structural break parameter is 0 for the period before implementation of the PFCT scheme (Jan 11–Dec 12 = 0) and is 1 for the period in which the PFCT scheme is implemented (Jan 13–Aug 14 = 1). In this particular analysis, the structural break parameter is included both as a dummy variable and as an interactive term with explanatory variable (nonpeak TOU sales).

Table 4 Structural break regression of relationship between system peak and nonpeak demand

Dependent variable = Peak energy sales			
	Coef.	**Std. Err.**	***t***
Nonpeak energy sales (NP)	1.30***	0.12	10.72
Dummy (D)	130.11***	44.74	2.91
Interaction (NP*D)	−0.79***	0.27	−2.95
Constant	−75.66***	18.38	−4.12
Obs.	44		
F (3, 41)	103.59***		
R-squared	0.88		
Adj. R-squared	0.87		
Individual results			
M1_Before Jan 2013 (Jan 2011–Dec 2012)			
	Robust Std.		
	Coef.	Err.	Z
Nonpeak energy sales (NP)	1.30***	0.10	12.88
Constant	−75.66***	16.01	−4.73
M1_log variance constant	3.65***	0.22	16.88
M2_After Jan 2013 (Jan 2013–Sept 2014)			
Nonpeak energy sales (NP)	0.51***	0.08	6.11
Constant	54.44***	14.06	3.87
M2_log variance constant	1.60***	0.20	7.84

***, **, and * are statistically significant 1, 5, and 10 % levels, respectively

Table 5 *F*-test results that D = 0 and (NP*D) = 0

F(2, 41)	4.56**
Prob > F	0.016

***, **, and * are statistically significant 1, 5, and 10 % levels, respectively

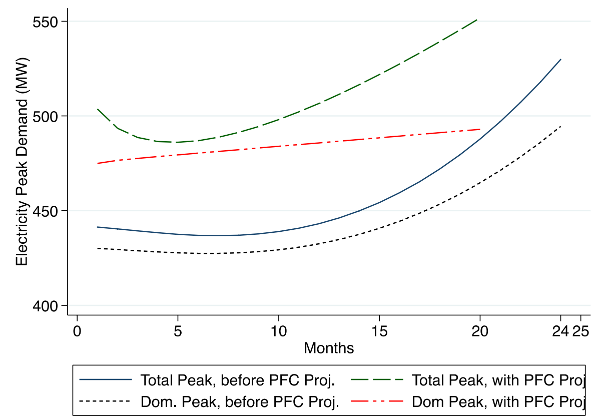

Fig. 1 Trend of electricity peak demand before and with PFCT scheme

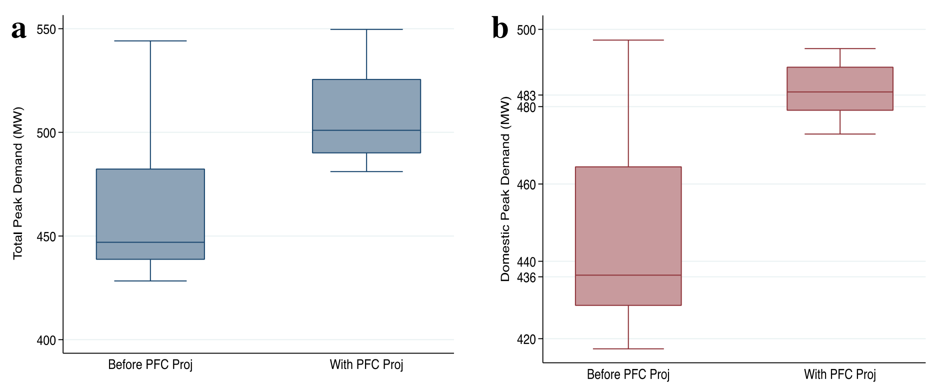

Fig. 2 Boxplot of peak demand before and with PFCT scheme. **a** Total peak demand, **b** domestic peak demand

In Table 4, the overall model is robust as represented by a high F-statistic and the relationship between the dependent and explanatory variable is strong as shown by the high adjusted R square of 0.87 %.

Turning to the statistics of interest, the dummy variable and interaction variable are statistically significant ($p < 0.01$), thereby suggesting that there is statistically significant difference in the magnitude of the slopes of the graphs depicted in Fig. 3 representing UETCL peak TOU sale and total energy sales to Umeme Limited before and with PFCT scheme. In particular, the actual magnitude (coefficients) of the individual regression results is shown in the lower panel of Table 3.

In the table, the coefficient for the first regression is 1.3, while that for the second regression is 0.51. This implies that in the period January 2011–December 2012, a unit

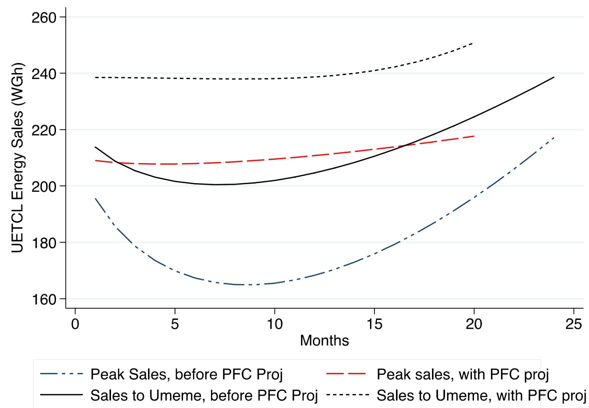

Fig. 3 UETCL peak vis-à-vis total energy sales to Umeme before and with PFCT scheme

(1 GWh) increase in nonpeak energy sales to Umeme Limited was matched by 1.3 GWh increase in peak energy sales. On the other hand, in the period January 2013–August 2014, a unit (1 GWh) increase in nonpeak demand was matched only 0.51 GWh increase in peak demand. This suggests that there was a decline in the growth of peak TOU energy sales in the period of implementation of the PFCT scheme.

To conclude that the coefficients 1.30 and 0.51 from the first (M1) and second (M2) regressions, respectively, are statistically different and hence a likely shift in energy consumption more at nonpeak compared peak TOU zone in 2013 and 2014, an *F*-test of the statistical equivalence of the coefficients 1.30 and 0.51 is performed. The null hypothesis is that coefficients of the dummy variable (D) and the interaction term (NP*D) were jointly zero or alternatively that coefficients 1.30 and 0.51 are equal. That is, D = 0 and (NP*D) = 0. The results of the test are shown in Table 5 and the F-statistic is statistically significant at less than 5 % level.

Apart the PFCT scheme, there may be other factors influencing consumption of more energy at nonpeak TOU zone in Uganda. For example, another possible contributor may be the incentive-based regulatory regime offered by the Electricity Regulatory Authority (ERA) to industrial and commercial consumers. The incentive regime involves lower tariffs at off-peak TOU zone and proportionately higher tariffs at peak TOU zone. In 2014, for example, ERA increased the weighting factor for peak TOU zone from 110 to 120 and in 2015, this factor has been increased to 130.

4 Conclusions

This paper set out to address two specific objectives of interest. That is to examine the level of variability of peak demand in the period before and after implementation of power factor improvement schemes and to assess the likely impact of power factor improvement schemes on peak demand. Using various descriptive and statistical analysis methods on data obtained from Uganda's electricity transmission and system operator, the results in this paper suggest the following:

(1) The power factor improvement project implemented by PSFU on behalf of the government of Uganda that is targeting to save 10.4 MVA of demand and wasted electri-

cal energy due to low-power factor rating in target industries and commercial enterprises has as of end of 2014 realized energy savings of up to 8.04 MVA of demand or 7.72 MW;

(2) In the industries where the power factor correction equipment has been installed, the power factor increased from an average of 0.68 to 0.95, which is an improvement of 40 % in energy efficiency;

(3) The implementation of the power factor correction scheme has contributed to the reduction in the growth rate of peak demand and minimized the level of variability of both total maximum/peak demand and domestic peak demand; and

(4) In the period of implementation of power factor correction scheme, there is a noticeable growth in consumption of electricity at nonpeak time of use (TOU) and slight slump in electricity consumption at peak TOU compared the period before the implementation of the scheme.

The major limitation of the study is the rather short time span (January 2011–August 2014) for the analysis. Nevertheless, we believe that the results provide useful and novel insights into the impact of power factor correction technology adoption on electricity peak demand in Uganda.

Based on these findings, it is not unreasonable to conclude that the adoption of the power factor correction technology in Uganda has had a positive effect on the reduction in growth and variability of electricity peak demand. It is, therefore, expected that further promotion and adoption of the technology following judicious energy audits of energy inefficient manufacturing industries and commercial enterprises in the country will go a long way in saving energy and calming the maximum demand growth rate.

Our findings have important policy implications for increased promotion and adoption of power factor correction technology in Uganda as a means of increasing energy efficiency within the target industries as well as abating on the growth electricity peak demand in the country. As noted earlier, there are other schemes such as the incentive-based regulatory regime offered by the Electricity Regulatory Authority (ERA) to industrial and commercial consumers that may influence consumption of more energy at nonpeak TOU zone in Uganda. Future research should, therefore, examine the effect of incentive regulation on electricity peak demand.

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Appendix

See Figs. 4, 5 and Table 6.

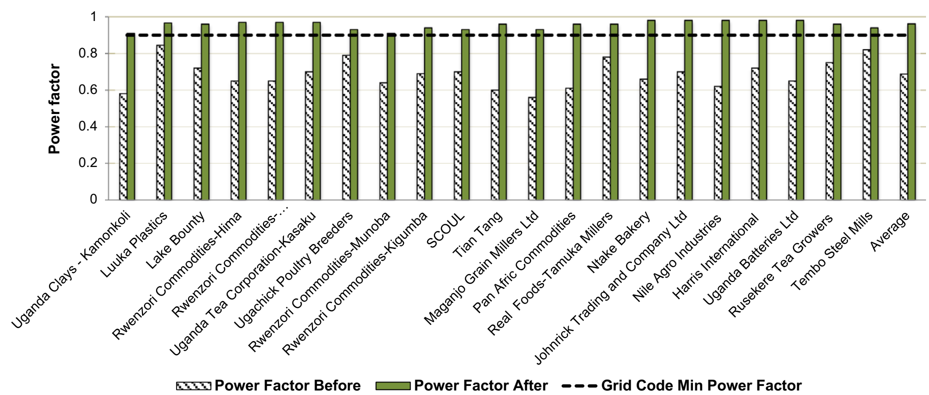

Fig. 4 Power factor of selected industries in Uganda before and after ERT-2 intervention and grid code requirement

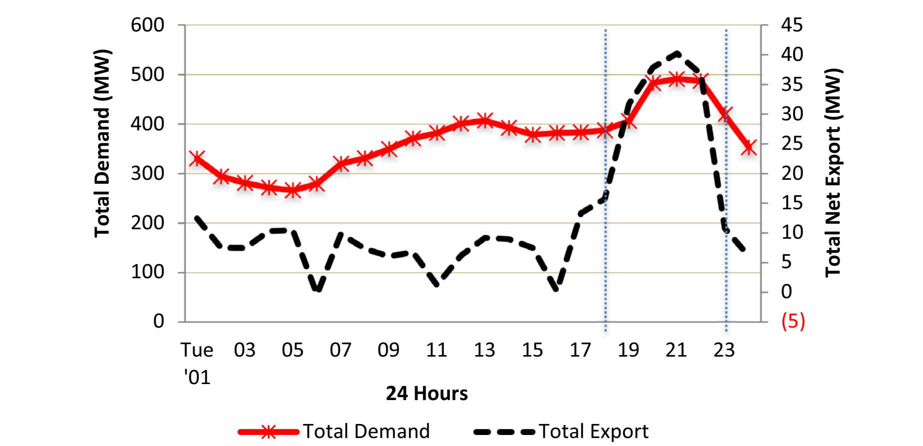

Fig. 5 Load profile of total demand and net export demand on 1st July 2014. Data source: UETCL systems data

Table 6 UETCL Energy sales to distributors in September 2014

Distribution company	GWh	Percent of total sales
Domestic		
Umeme Limited	255	93.99
Other distributors		
Ferdsult Engineering Services Limited	2.00	0.74
Kilembe Investments Limited	0.34	0.13
Bundibugyo Electricity Cooperative Society	0.16	0.06
Pader-Abim Community Multi-purpose Electricity Cooperative Society	0.13	0.05
Uganda Electricity Distribution Company Limited	0.12	0.04
Total other distributors	*2.76*	*1.02*
Exports		
KPLC, Kenya	8.08	2.98
TANESCO, Tanzania	4.96	1.83
REG, Rwanda	0.30	0.11
SNEL, DR Congo	0.21	0.08
Total exports	*13.55*	*4.99*
Total monthly sales	271.30	100

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