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Peak Electricity Demand Management and Energy Efficiency among Large Steel Manufacturing Firms in Nairobi Region, Kenya

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Abstract

To reduce peak electricity demand and hence reduce capacity costs due to added investment of generating additional power to meet short intervals of peak demand, can enhance energy efficiency. Where it is possible to adjust timing and the quantity of electricity consumption and at the same time achieve the same useful effect, the value of the energy service itself remains unchanged. Peak demand management is viewed as the balance between demand and generation of energy hence an important requirement for stabilized operation of power system. Therefore, the purpose of this study was to establish the correlation between peak electricity demand management strategies and energy efficiency among large steel manufacturing firms in Nairobi, Kenya. The strategies investigated were demand scheduling, Peak shrinking and Peak shaving. Demand scheduling involves shifting predetermined loads to low peak periods thereby flattening the demand curve. Peak shrinking on the other hand involves installation of energy efficient equipment thereby shifting the overall demand curve downwards. Peak shaving is the deployment of secondary generation on site to temporarily power some loads during peak hours thereby reducing demand during the peak periods of the plant. The specific objectives were to test the relationship between demand scheduling and energy efficiency among large steel manufacturing firms in Nairobi Region; to test the correlation between peak shrinking and energy efficiency among large steel manufacturing firms in Nairobi Region; and to test the association between peak shaving and energy efficiency among large steel manufacturing firms in Nairobi Region. The study adopted a descriptive research design to determine the relationship between each independent variable namely demand scheduling, peak shrinking, peak shaving and the dependent variable, the energy efficiency. The target population was large steel manufacturing firms in Nairobi Region, Kenya. The study used both primary and secondary data. The primary data was from structured questionnaires while secondary data was from historical electricity consumption data for the firms under study. The results revealed that both peak shrinking and peak shaving were statistically significant in influencing energy efficiency among the steel manufacturing firms in Nairobi Region, each with Pearson correlation coefficient of 0.903, thus a strong linear relationship between the investigated strategy and the dependent variable, energy efficiency. The obtained results are significant at probability value of 0.005 ($p < 0.05$). The conclusion is that peak shrinking and peak shaving have an impact on energy efficiency in the population under study, and if properly implemented, may lead to efficient utilization of the available energy. The study further recommended that peak demand management practices need to be implemented efficiently as a way of improving the overall plant load factor and energy efficiency.

Keywords

Peak Demand, Demand Scheduling, Peak Shrinking, Peak Shaving, Energy Efficiency

1. Introduction

The need to reduce peak demand and therefore avoid capacity costs incurred due to added investment in new generation, transmission and distribution initiatives calls for enhanced energy efficiency. Reducing peak demand eventually leads to reduction in capacity costs and demand savings. Electricity consumers usually have uneven load profile throughout the day, resulting in load peaks. The power system has to be dimensioned for that peak load while during other parts of the day it is underutilized [1].

In [2] peak demand management is defined as any action that modifies the load profile in order to reduce peak demand, thereby improving the load factor and overall efficiency of the network. The authors note that peak demand mismanagement normally leads to the formulation of bigger peak than what was initially being avoided, hence peak demand management techniques have been formulated to influence electricity demand and increase the usage and operating effectiveness of the available supply facilities. Kenya has been successful in adopting more renewable energy than many other countries in the region whereby less than sixty percent of its electricity supply is provided by fossil fuels and large hydro electric generators. At a national level, twenty-five percent of the population remains without electricity which equates to approximately 3.5 million households. In terms of electricity access, urban areas have higher electricity access rate than the rural areas. The cost of generation, transmission and distribution capacity investment is a contributor to the overall cost of electricity.

In view of the above, this study sought to determine the relationship between peak electricity demand management strategies and energy efficiency among large steel manufacturing firms in Nairobi Region, Kenya.

The specific objectives were to test the relationship between demand scheduling and energy efficiency among large steel manufacturing firms in Nairobi Region, Kenya, to test the correlation between peak shrinking and energy efficiency among large steel manufacturing firms in Nairobi Region; and to test the association between peak shaving and energy efficiency among large steel manufacturing firms in Nairobi Region. The rationale for confining the study to large steel manufacturing firms is pegged on the fact that over 50% of electricity capacity in Kenya is consumed by manufacturing firms. Due to economies of scale, large steel manufacturing firms are able to leverage on current technologies that are applied in managing peak demand and the impact would significantly influence the overall peak demand.

2. Literature Review

2.1. Demand Side Management

Shortage of electricity may be worsened by inefficiencies in the end-use system. The inefficiencies in the end-use system are caused by obsolete technology of industrial procedures and old equipment, lack of awareness of emerging energy practices in the industry and inadequate policy drivers. Handling peak consumption only from supply side may lead to negative environmental consequences. In order to meet the peak demand and avoid blackouts, fossil fuels are most commonly used [3]. Demand side management (DSM) has emerged as an alternative method for energy management in order to maintain the balance while focusing on the consumer side [4]. DSM has different meanings for different categories of stakeholders. For utility companies, DSM means avoiding or delaying the need to build new generating capacity by reducing or shifting consumers' energy use duration. For consumers, DSM presents an opportunity to save money by reduction of their electricity bill by taking advantage of financial incentives provided by the utility company. Introduction of Time of Use tariff enables consumers to further reduce their energy costs through DSM [5]. DSM programs are also thought to be an effective strategy to reduce both economic and environmental impacts due to the increasing electricity demand in the near future [6].

2.2. Peak Demand Management

Peak Demand Management (PDM) involves curtailing of energy consumption during periods of system peak thereby lowering capacity charges, hence reduced overall power costs. Peak demand reduction is a key element in demand management programs targeting the stabilization of the electricity grid [3].

High demand instances cause utilities challenges since they must have capacity to meet the peak which is only required for a fraction of a 24 hour period, in addition to operations and maintenance costs, and power system losses. Traditionally, the peak load problem is often solved by capacity additions whereby a percentage of the total installed capacity must be reserved for managing peak loads, with the rest being dedicated to base loads [7]. Recent years have seen momentum build in the energy industry in favor of introducing more cost-reflective electricity tariffs with energy retailers and distributors, as well as market regulators and policymakers, increasingly calling for more dynamic pricing [8]. In Kenya, the Regulator announced time of use tariff [9]. It may encourage consumers to shift some of their operations to off peak hours. The tariff for industrial consumers has a component of peak demand charges for every billing cycle thus the need for peak demand management practices.

2.3. Demand Scheduling

[10] indicates that producing scientific and reasonable maintenance plans helps to increase the reliability of power distribution system operation. In practice, maintenance scheduling is organized artificially based on the experience of the power department that is monitored by the operations team to ensure stability of power distribution system. The arrangement only focuses on the security of distribution system while neglecting the economic efficiency. The authors further contend that artificial scheduling and maintenance scheduling ought to be an optimized procedure based on scientific and effective mathematical model that can avoid the subjectivity and randomness. In order to meet the needs and benefit from the potential underlying in the energy system, planning processes from production to energy management need to operate seamlessly and with real time data. The energy management system needs to be integrated with production management and mill control systems in order to achieve the desired results [11]. For industrial load, decision makers need to find the optimal scheduling of the industrial load [12]. A study scheduling on a single machine with an energy consumption limit proposed mathematical algorithms [13] that are complex, used on a single machine and small instances; and may not be very applicable in real complex industrial cases. There is still a gap between industrial needs and academic research [14]. This is despite the fact that integration of energy awareness into production scheduling is getting more attention [15].

2.4. Peak Shrinking

Peak shrinking deals with the installation of equipment that uses less energy. Using more efficient equipment reduces the base load of energy used at all times effectively shrinking the entire demand curve in a downward direction. Flattening out daily peak and critical peak demand can improve the cost-effectiveness of the energy infrastructure but requires consumers to alter their behavior to achieve it. In a study on reducing household electricity consumption during evening peak demand times [3] it was noted that there was the strongest behavioral change in consumers who received monetary incentives, with only weak evidence of changes in the non-monetary treatment groups.

2.5. Peak Shaving

Peak shaving involves the leveling out of peaks in electricity use by consumers. The fundamental idea of peak shaving is to limit the amount of power drawn from the grid to some level, and substitute for power demand higher than that level from local on-site power sources. A common practice to reduce these peaks is to introduce energy storage systems into the main electrical system. The energy storage system will be charged during off-peak operation hours and will discharge during peak operation hours thus reducing the peak power drawn from the grid [16].

A key benefit of generating own energy is that it helps to reduce peak demand charges from the utility. Using forms of alternative energy, e.g. solar panels, to generate a portion of the total energy needed is a great way to reduce the power draw from the grid. The challenge with peak shaving is to design a control scheme that detects the peaks on time and fully exploits the capacity of the distribution system [1]. Most of the control schemes found in literature suggest using a predefined shave level depending on the maximum load or how the load looks like. Since load forecasting is quite difficult to achieve, if hard limits are applied there is a good chance to miss the peak or to discharge the battery in smaller peaks leaving the biggest peak intact.

3. Research Methodology

The study adopted a Multi-objective optimization model to optimize more objective functions. A Multi variate Linear Regression model was adopted and presented as per Equation (1), $Y = f$ (demand scheduling, peak shrinking, and peak shaving).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \quad (1)$$

where Y is the dependent variable, representing energy efficiency of the large steel manufacturing firms in Nairobi, while β_0 is the constant term or intercept. β_1, β_2 and β_3 are the regression (beta) coefficients and quantify the effect of the independent variables X_1, X_2 and X_3 representing demand scheduling, peak shrinking and peak shaving respectively. The error term ε captures random error in the relationship between the dependent and independent variables.

Energy costs are directly proportional to energy consumption. From an economic point of view, the study evaluated energy efficiency; the index here proposed is the cost index (ratio of power costs to consumption volume or average unit cost (per kwh) and thus a measure of overall efficiency of the plant. The other factor considered was the load factor, an indicator of energy used in a time period versus amount that could have been used. It is an indicator of capacity utilization. Having a higher load factor is desirable, while a low load factor indicates capacity underutilization. At the consumer side, an improved load factor means that demand is reduced and will essentially decrease the average unit cost per kWh since the Kenyan electricity tariff for industrial consumers has a concept for maximum demand charges. This means that for large industries and commercial operations, increasing load factor will definitely lead to significant amount of cost savings.

A Conceptual framework was developed to show the relationship between the independent variables namely demand scheduling, peak shrinking and peak shaving and the dependent variable, energy efficiency as shown in **Figure 1**.

The study adopted a descriptive research design to determine the relationship between each independent variable namely demand scheduling, peak shrinking and peak shaving with the dependent variable, the energy efficiency. The target population was large steel manufacturing firms in Nairobi Region, Kenya. The study used both primary and secondary data. The primary data was from structured questionnaires while secondary data was from historical electricity consumption data for the firms under study. The questionnaire collected quantitative data using closed ended Likert scale questions relating to peak demand management strategies. Secondary data included the peak demand for each billing period, monthly electricity consumption and cost per unit for the period under review. The questionnaires were self administered, and ethical considerations such as confidentiality of the respondents were observed during the data collection process.

4. Results and Analysis

4.1. Historical Analysis

As part of the study, historical electricity consumption data of the Steel firms

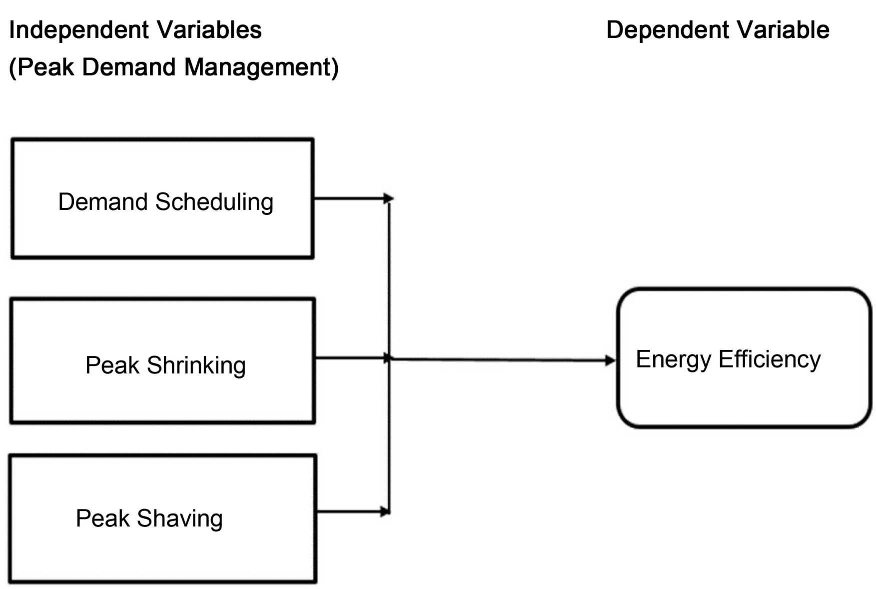

Figure 1. The relationship between peak electricity demand management strategies and energy efficiency among large steel manufacturing firms in Nairobi region, Kenya. [Source: Author (2023)].

under study was analyzed based on monthly billing data. The monthly consolidated electricity costs for each firm were compared with monthly energy consumption and cost index computed as per Equation (2). For each firm, Monthly Load factor, which is an indicator of the amount of energy used in a time period versus amount that would have been used, was computed as per Equation Number (3).

$$\text{Cost Index} = \frac{\text{Monthly bill}\left(\text{ksh}\right)}{\text{Monthly energy consumption}\left(\text{kwh}\right)} \tag{2}$$

$$\text{Load Factor} = \frac{\text{Monthly energy consumption}}{\text{Peak demand} \times 30\text{ days} \times 24\text{ hours} \times \text{pf}} \tag{3}$$

For the purposes of the study, the formula assumes unity power factor (pf).

From the historical data analyzed, there was a direct relationship between cost index and peak demand as per **Figure 2** thus a higher cost index for the billing cycles when the peak demand was high and vice versa. The Pearson correlation was found to be 0.557 with p-value of 0.044, thus statistically significant at significance of less than 0.05.

4.2. Research Responses

A questionnaire designed to identify the extent of use of the three peak demand management strategies namely demand scheduling, peak shrinking and peak shaving in the firms under study was issued. The respondents were asked to indicate the extent to which they agreed on the items of the statements relating to demand management strategies. Each item had a 5-point Likert-type scale ranging from "no extent" (1) to "very large extent" (5).

This section began by first analyzing the descriptive statistics and then inferential statistics. The descriptive statistics was used to summarize features of

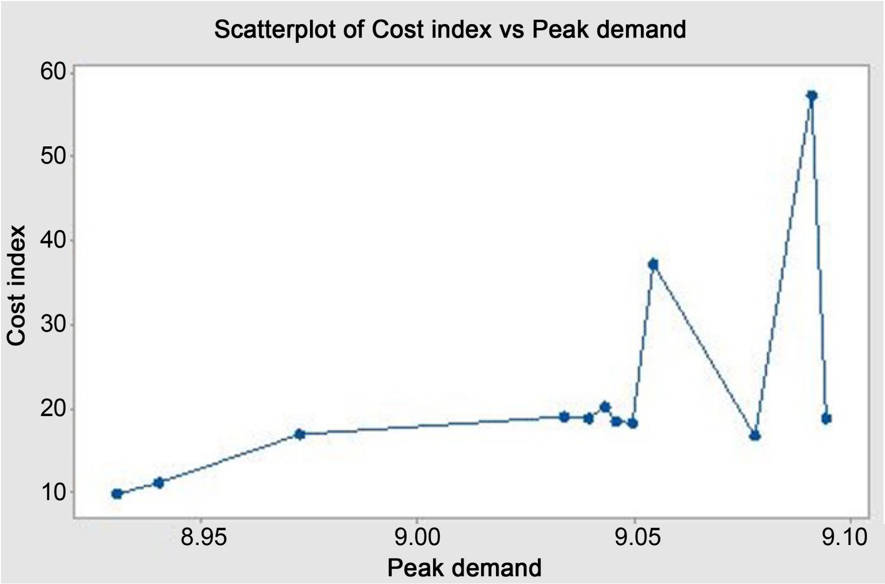

Figure 2. Scatter plot of cost index versus peak demand.

central tendency of the analyzed data while the inferential statistics was used for correlations and regression analysis.

4.2.1. Results of Descriptive Statistics

1) Demand Scheduling

According to the results in Table 1, the item with the highest mean was "To what extent has your corporation established a Switch-off policy to reduce standby energy of the machines" ($M = 3.57$, $SD = 0.535$). The statement with the lowest mean score was "To what extent does your production department switch off loads during periods of maximum demand" ($M = 2.14$, $SD = 0.378$). In terms of variability, the item with the highest variability was "To what extent does the unit cost/price you are paying Kenya power for electricity consumption depend on the time/season of the day?" and "To what extent has your company put in place a system that efficiently allocates power to machines" (CV = 32.24). The implication is that the mean score is more likely to change using another sample data than the item with the lowest variability "To what has your corporation

Table 1. Mean, standard deviation and coefficient of variation for measures of demand scheduling.

	Descriptive Statistics				
		N	Mean	Std. Deviation	CV (%)
1	To what extent has your company identified Sheddable loads?	7	2.57	0.787	30.62
2	To what extent does your production department switch off loads during periods of maximum demand?	7	2.14	0.378	17.66
3	To what extent does the unit cost/price you are paying Kenya power for electricity consumption depend on the time/season of the day?	7	2.14	0.690	32.24
4	To what extent has your company put in place a system that efficiently allocates power to machines?	7	2.14	0.690	32.24
5	To what extent has your company put in place a program of power for under loaded to fully loaded machines?	7	2.29	0.488	21.31
6	To what extent has your organization adopted real-time control of the energy consumption by having a flexible production system?	7	2.57	0.787	30.62
7	To what has your corporation established a Switch-off policy to reduce standby energy of the machines?	7	3.57	0.535	14.99

established a Switch-off policy to reduce standby energy of the machines" (CV= 14.99).

2) Peak Shaving

According to the data summarized in Table 2, item 1 "To what extent has your company implemented systems aimed at reducing electricity usage during periods of maximum demand" had the highest mean score (M = 4.00, SD = 0.00) while items 4 and 5 had the lowest mean score (M = 1.00, SD = 0.00). Variability revealed that item 1, 4 and 5 had variability of zero percent while item 3 "To what extent has your company established energy storage systems" had the highest variability of 33.16%.

3) Peak Shrinking

The items on peak shrinking revealed that item 1 "To what extent has your company used behavior change to reduce energy consumption among the workers" had the highest mean score (M = 2.43, SD = 0.535) as shown in Table 3. The item with the lowest mean score was "To what extent do the operatives avoid using high energy consuming appliances/tools during high demand periods/hours" with a mean score of 1.86 associated with a standard deviation of 0.690. The results of the coefficient of variation revealed that item 5 had the highest variability (CV = 37.10%) while item 4 had the lowest variability of zero.

Table 2. Mean, standard deviation and coefficient of variation for measures of peak shaving.

Descriptive Statistics					
		N	Mean	Std. Deviation	CV (%)
1	To what extent has your company implemented systems aimed at reducing electricity usage during periods of maximum demand?	7	4.00	0.000	0.00
2	To what extent has your organization utilized price incentives offered by Kenya power?	7	2.00	0.577	28.8
3	To what extent has your company established energy storage systems?	7	1.14	0.378	33.16
4	To what extent does the production management charge energy storage systems when demand is low (off-peak period) and discharge them when demand is high (peak time)?	7	1.00	0.000	0.00
5	To what extent has your company integrated Photovoltaic Energy systems in its power system?	7	1.00	0.000	0.00

Table 3. Mean, standard deviation and coefficient of variation for measures of peak shrinking.

	Descriptive Statistics	N	Mean	Std. Deviation	CV (%)
1	To what extent has your company used behavior change to reduce energy consumption among the workers?	7	2.43	0.535	22.02
2	To what extent has your company installed equipment that uses less energy?	7	2.14	0.378	17.66
3	In your opinion, to what extent are employees in this company likely to reduce electricity use in your daily tasks at any working day?	7	2.00	0.577	28.85
4	To what extent do employees in this company feel morally obliged to take actions that reduce electricity consumption at their workstations?	7	2.00	0.000	0.00
5	To what extent do the operatives avoid using high energy consuming appliances/tools during high demand periods/hours?	7	1.86	0.690	37.10

4.2.2. Correlation Analysis

The study sought to examine how the variables of the study: demand scheduling, peak shaving, peak shrinking and energy efficiency were related. The analysis was done using Pearson product moment correlation. The results of the analysis as presented in Table 4 revealed a significant positive correlation between peak shrinking, peak shaving and energy efficiency (Pearson's $r = 0.903$ $p = 0.005$, $p < 0.05$).

4.2.3. Regression Statistics

This section presented and discussed the results of the inferential statistics of the study variables. The researcher sought to answer the research questions of the study. According to Table 5 the independent variables explained 85.2% of the variation in energy efficiency ($R^2 = 0.852$). The ANOVA Table 6 also revealed the dimensions of the study were statistically significant in prediction of energy efficiency ($F = 11.507$, $p = 0.022 < 0.05$).

The result of the model in Table 7 revealed that only peak shrinking was statistically significant in predicting energy efficiency ($\beta = 33.85$, p-value $= 0.022 < 0.05$). The conclusion therefore is that there is evidence to suggest that peak shrinking has a significant impact on energy efficiency among large steel firms in Nairobi.

Table 4. Correlation matrix for peak demand management strategies and energy efficiency.

Correlations					
		Demand Scheduling	Peak Shaving	Peak Shrinking	Energy Efficiency
Demand Scheduling	Pearson Correlation	1	0.471	0.471	0.596
	Sig. (2-tailed)		0.286	0.286	0.158
	N		7	7	7
Peak Shaving	Pearson Correlation		1	1.000**	0.903**
	Sig. (2-tailed)			0.000	0.005
	N			7	7
Peak Shrinking	Pearson Correlation			1	0.903**
	Sig. (2-tailed)				0.005
	N				7
Energy Efficiency	Pearson Correlation				1
	Sig. (2-tailed)				
	N				7

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. Model summary for goodness of fit of the effect of peak demand management strategies.

Model Summary							
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	Sig. F Change
1	0.923[a]	0.852	0.778	7.54506	0.852	11.507	0.022

a. Predictors: (Constant), peak shrinking, demand scheduling.

Table 6. ANOVA for the significance of the effect of peak demand management strategies on energy efficiency.

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1310.143	2	655.071	11.507	0.022[b]
	Residual	227.712	4	56.928		
	Total	1537.855	6			

Dependent Variable: Energy efficiency.

Table 7. Regression results for the relationship between peak demand management strategies and energy efficiency.

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	−47.152	18.863		−2.50	0.067
	Demand scheduling	6.568	6.534	0.219	1.005	0.372
	Peak Shrinking	33.850	9.241	0.799	3.663	0.022

a. Dependent Variable: Energy efficiency.

5. Conclusions

The main objective was to determine the correlation between peak electricity demand management strategies and energy efficiency among large steel manufacturing firms in Nairobi Region, Kenya. The study adopted demand scheduling, peak shrinking and peak shaving as the peak demand management strategies. The study used cost index as an indicator of the energy efficiency.

The results revealed that there was an insignificant correlation between demand scheduling and energy efficiency (Pearson's $r = 0.596$ $p = 0.158$, $p > 0.05$). The correlation analysis revealed a significant correlation between peak shrinking and energy efficiency (Pearson's $r = 0.903$ $p = 0.005$, $p < 0.05$). The regression analysis also revealed a significant relationship between peak shrinking and energy efficiency ($\beta = 33.85$, $p = 0.022 < 0.05$). The correlation between peak shaving and energy efficiency was also found to be significant (Pearson's $r = 0.903$ $p = 0.005$, $p < 0.05$).

The conclusion is that peak shrinking and peak shaving have an impact on energy efficiency in the population under study, and if properly implemented, may lead to efficient utilization of the available energy. Peak demand management practices, therefore, need to be implemented efficiently as a way of improving the overall plant Load factor and energy efficiency.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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