INVESTIGATION OF ELECTRICAL ENERGY EFFICIENCY USE IN AN AUTOMOBILE ASSEMBLY INDUSTRY

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Abstract*: This research work investigated the electrical energy efficiency improvement and cost saving potentials for automobile assembly plant; a case of Peugeot Automobile Nigeria Limited. The study identified lighting system as a major source through which energy is being wasted, hence efficient energy saving lighting systems are being proffered; also saving accrued were determined to justify their deployment. In the course of this work, an energy saving calculating tool was developed to calculate energy saving capabilities using energy efficient lamps. With ample devotion to the implementation of the recommendations made, the cost of energy per car will be drastically reduced while profits are also made simultaneously. In all, more cars will be produced thus translating to more employment opportunities in the industry.*

1. INTRODUCTION

Energy for obvious reasons is regarded as the prime mover of any economy, and the engine of growth around which all sectors of the economy revolve [1]. Thus it becomes imperative that its development, management, and improvement must have predetermined plans and strategies that are capable of driving the economy towards a sure path of sustainable development [2], [6]. By imbibing energy–efficient practices, all energy consuming systems are consistently monitored, cleaned, adjusted, maintained and operated to ensure the most efficient use of energy [3][5]. The major aim of industries around the globe is to make profits, increase productivity, reduce waste, conserve resources and enhance image. With ample devotion to tenets of cost reduction and deployment of energy efficient technologies and practices, all of these can be achieved by proper energy management as articulated by [4].

As a result of technologies usually deployed in automobile industry, induction motors are often referred to as "factory workhorse" which are mostly used. These motors, being inductive loads require current flow to create magnetic fields to produce the desired work; this brings about low power factor. A low power factor is expensive and inefficient. Utility companies charge their customer additional fees when their power factor is less than 0.95 because it reduces electrical system's distribution capacity by increasing the current flow and causing voltage drops. Power factor correction brings the power factor of an Alternating Current (AC) system closer to 1. It is believed that improving power factor will increase energy efficiency and reduce cost. Also by acquiring energy efficient motors, 2% to 8% efficiency can be gotten compared with standard motors. They owe their higher performance to key design improvements and more accurate manufacturing tolerances.

Another system of note in an automobile industry is lighting system. About 21% of the world's electrical energy is used for lighting. That equals a whopping 12 Billion KWh per day. By replacing inefficient fluorescent fittings with LED and compact fluorescent lighting, a lot of energy can be saved with associated cost reduction.

Employment of efficient energy programmes in an automobile manufacturing industry can bring about reduction in fossil fuel use by 12% with attendant reduction in greenhouse gases by more than 70,000 tons of CO_2. The emission reduction which can be of help in fighting climate change is equal to the emissions from the electricity use of more than 80,000 homes in a year [7].

It is a known fact that the industry consumes an average of 1 million litres of diesel annually, translating to a minimum of 33000 litres monthly. Going by the high cost of the commodity in Nigeria, a sum of N90 million was used for its procurement in 2010. It is on factory records that a whooping sum of N 110 million was used to provide electrical energy in 2008 as shown in *fig 1*, the breakdown of which shows that N70.12 million was used to buy diesel, another N37.57 million was used to pay electricity bills while maintenance of generating sets gulped N2.47 million; in the same year, the cost of electrical energy per car was N 200,000.

The manufacturing sector in Nigeria has been bedevilled by this negative trend. This also majorly accounts for the closure of some factories in Nigeria while a couple of others are relocating to other West African countries where cost of energy is affordable in order to break even. Undoubtedly, the aforementioned situation has to be reversed for the continuance of business in the factories. Going by the climate changes occasioned by ubiquitous emissions of green house gasses, there is however the need for this research work towards ameliorating the negative trends by examining the various patterns through which electrical energy in Peugeot Automobile Nigeria (PAN) is being consumed. The sources of energy wastage were identified and the significant technologies that exist to reduce energy utilization were proferred.

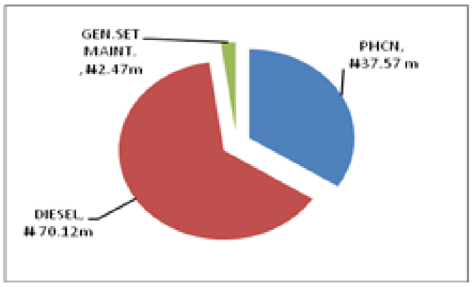

Fig. 1. Cost of Electrical Energy in 2008

2. METHODOLOGY

The method adopted for this research work was to review the current electrical energy consumption in the different unit of the company in order to identify improvement opportunities. Some of the data needed `for the improvement process were directly collected from the nameplate of the site equipment and company record books. Statistical evaluation of the energy and cost-saving potential were then carried out and the results presented in charts and graphic forms. The major improvement opportunities considered in this research were power factor correction, identification of inefficient electric motor in use and the possibility of replacement. Lastly we considered the possibility of energy efficient lighting system and recommended possible ways of reducing energy consumption.

The electricity supply to the factory is from the 33/11kV feeder line of the electricity utility company and three units of 2MVA 11kV Wilson generator. The two sources of electricity supply are terminated in the power control room. The factory loads are shared through five sets of 11/0.415kV transformer (T1, T2, T3, T4 and T5) in three different switch rooms (SW_RM) named SW_RM_A, SW_RM_B and SW_RM_C.

3. ENERGY EFFICIENCY ANALYSIS

A. Power Factor Improvement

The factory being an automobile industry consists of various sizes of electric motors ranging from 1hp to 160hp. Going by this, loads are mainly inductive. *Figure 2* shows the distribution of electric motors in relation to their power rating. While *Figure 3* shows the percentage distribution of electric motors in the factory, paint shop alone contains about 100 motors representing 69% of the total induction motors in the industry. The motors in the industry are the major electrical load used for various applications including treatment of car body, air intakes for humidification system of spraying cabins, fans used for blowing oven, extraction system for spraying cabins, ground and aerial conveyor.

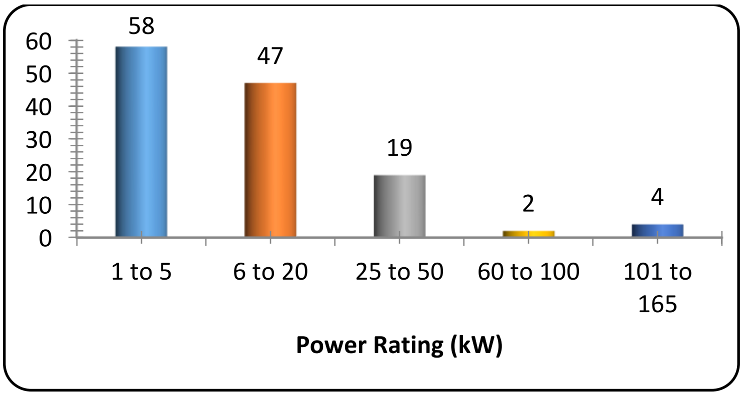

Fig. 2. Electric Motor Distribution by Sizes in Horsepower

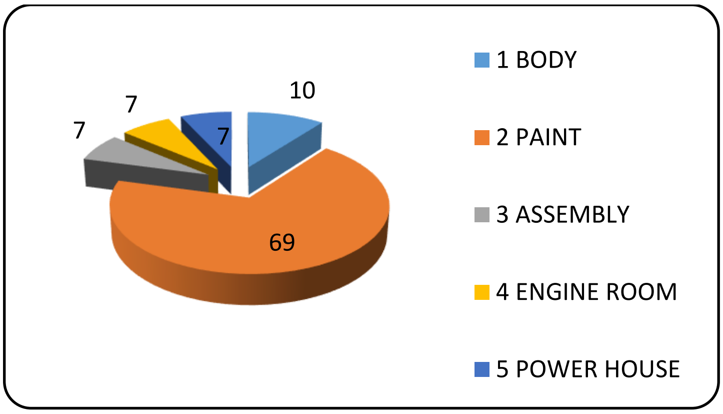

Fig. 3. Percentage Distribution of Electric Motors in the Factory sub units

The switch room A of the industry have the loads' pattern with low power factor of 0.71, 0.78 and 0.80 while switch rooms B and C have 0.78 and 0.92 respectively. Due to this low power factor, the system is grossly inefficient. Hence, there is need to improve the power factor by using capacitors' banks connected across the supply at the point closer to the equipment. Table 1 shows the desired improved power factor PF_2 as against the present power factor PF_1 in each of the switch room of the factory.

Table 1: Desired improved power factor as against present power factor

	SW_RM_A			SW_RM_B	SW_RM_C
	T1	T2	T3	T4	T5
KW	673	400	423	387	420
PF_1	0.71	0.78	0.80	0.78	0.92
PF_2	0.95	0.95	0.95	0.95	0.95

B. Determination of kVAr of Capacitor banks.

The diagram in *figure 4* shows the simple way power factor improvement can be determined.

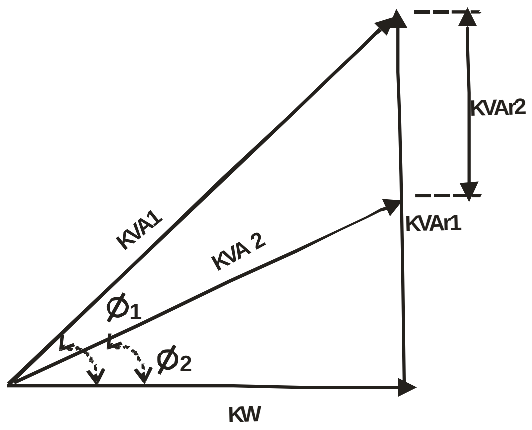

Fig. 4. Power Factor Improvement Triangle.

In *Figure 4*:

kW = Power consumed by the system

kVA_1 = Apparent power before correction.

kVA_2 = Apparent power after correction.

$kVAr_1$ = Inductive kVAR

$kVAr_2$ = Capacitive kVAR

$Cos\ \varphi_1$ = PF before correction.

$Cos\ \varphi_2$ = PF after correction.

$$\cos\varphi = kW / kVA \tag{1}$$

$$\tan\varphi = kVAr / kW \tag{2}$$

$$kVAr = kW \times \tan\varphi \tag{3}$$

From equation 3,

$$kVAr_2 = kW \times (\tan\varphi_1 - \tan\varphi_2)\,. \tag{4}$$

To determine the required KVAr to raise PF from 0.71 to 0.95

$$\phi_1 = \cos^{-1} PF_1 = \cos^{-1} 0.71 = 44.76° \tag{5}$$

Also,

$$\phi_2 = \cos^{-1} PF_2 = \cos^{-1} 0.95 = 18.19° \tag{6}$$

By using (4)

$$kVAr_2 = 673 \times (\tan 44.76° - \tan 18.19°) = 445.12 kVAr \tag{7}$$

Therefore 445 KVAr capacitor bank would raise the PF from 0.71 to 0.95.

C. Energy Efficiency Analysis of Motor

Motor energy efficiency is defined by the motor manufacturer as how efficiently a motor turns electrical energy into mechanical energy. To the end user, motor efficiency is important because it is directly related to the cost of operating the motor. The higher the motor efficiency, the less power is required; using less power conserves energy and saves money. The efficiency of a motor is the ratio of the mechanical power output to the electrical power input [1]. The industry was established in 1975, it means virtually all the electric motors are very old and of standard types. All these dovetail into low efficiency of the motors used in the industry and lead to high cost of production. To reduce the energy cost we either improve on the power factor of the motors or replace the old motors with recent energy efficient once. Energy saving potential for a typical situation is demonstrated, following the same procedure for the motors in the industry the results for Cataphoresis oven tunnel motors are tabulated in table 2.

Determination of annual energy saving for motor

$$kW_{saved} = (kW \times (L / E_{st})) - (kW \times (L / E_{pr})) \tag{8}$$

$$kW_{saved} = kW \times L \times (100 / E_{st} - 100 / E_{pr}) \tag{9}$$

where,

E_{st} = Efficiency of a standard motor,

E_{pr} = Efficiency of a premium motor,

L= load factor.

For example, for a 9KW motor, E_{st} =86%, E_{pr} = 90%, taking L =75%, using (9) above:

$$kW_{saved} = 9 \times 0.75 \times (100/86 - 100/90) = 0.35 \text{ KW}.$$

$$kWh_{saving} = kW_{saved} \times A_{oh} \tag{10}$$

where A_{oh} is the annual operating hour taken as 1840 hours

$$kWh_{saving} = 641.86 \text{ kWh/Year}$$

$$\cos t_{saved} = kWh_{saving} \times E_{charge} \tag{11}$$

where E_{charge} is the local energy charge taken as N12.9

$$cost_{saved} = 641.86\text{KWh/Yr} \times \text{N}12.9 = \text{N}8279.99\text{K}$$

D. Energy Efficient Lighting Analysis

It has been recommended that working areas where visual tasks are only occasionally performed be illuminated with Illuminance in the range between 100-150lm/m^2. For example, Toyota, a pacesetter in the automotive industry sets a standard of 100lm/m^2 in the quality check areas. With this, Toyota is saving about 30% on lighting energy use. Ford, as part of assessment programs, announced to the world that it would invest over $25 million (nearly €20 million) in energy-efficient lighting, is aiming to reduce energy costs of the company by as much as 70%. More precisely, the automaker expects to save around 56 million kilowatt-hours annually. Typical 56W fluorescent lamps has luminous efficacy of 66lm/W, this translates to 3696 lumen. Assuming surface area to be illuminated corresponds to the working height of 2.5 m^2, [8]:

$$Illuminance = \frac{Luminous\ \ flux\,(Lumen)}{Surface\,Area\ (m^2)}$$

$$= \frac{3696}{2.5^2} \quad = \quad 591.36 lm/m^2 \tag{12}$$

Also, 22W LED fluorescent has luminous efficacy of 40lm/W. Hence, 22W produces 40lm/W x 22 = 880lumen.

In the same way, Illuminance is

$$Illu\min ance = \frac{880}{2.5^2} \quad = \quad 141\, lm/m^2$$

The resultant value falls within the range recommended for energy efficiency that is void of waste. The result is better than that specified by Toyota Production System (TPS).

Calculation on replacement of 56W fluorescent fitting with 22W LED bulbs unit

Fluorescent Fitting (56W):	Fluorescent Fitting (22W):
$Power_{76\ units}$ = 56 × 76 = 4256W	$Power_{76\ units}$ = 22 × 76 = 1672W

$$Energy_{saved} = 4256 - 1672 = 2584W \tag{13}$$

Energy saved per day (10hours)

$$Energy_{saved/day} = 2584 \times 10 = 25.84 kWh \tag{14}$$

Energy saved per Annum (184 days average)

$$Energysaved\ /\ annum = 25.84 \times 184 = 4754.56 kWh \tag{15}$$

Amount saved in Naira per annum (N12.9/kWh)

$$\text{Amount saved annually} = 4754.56 \times \text{ N12.9} = \text{N61,333.82} \tag{16}$$

Payback is given by:

$$\text{Cost of energy saving units} \times \text{Discount/Annual saving} = \tag{17}$$

= N 76000 × 0.75/ N 61,333.82 = 0.93Years, 1 yr Approx.

E. Development of Energy Saving Calculator

The energy saving calculator developed *figure 5* automatically calculates the energy saving capabilities of replacements done. This is achieved by changing the variables indicated by the rectangles. The tool was developed using Excel application software.

ENERGY SAVING CALCULATOR

No of working days in a month	20		12-Nov-11		
No of working days in a Year	184	1	2	3	4
Power Consumption (W) CFL		9	22	15	100
Power Consumption (W) - Incandescent Lamp		40	56	75	400
Replaced Quantity (PCS)		6	76	6	9
Saving /Type (W)		186	2584	360	2700
Average daily use (hrs)		8	10	8	10
Electricity Cost Naira/KWh			12.9		
Energy Saving/Type/Day (KWh)		1.49	25.84	2.88	27.00
Energy Saving/Type/Month(KWh)		29.76	516.80	57.60	540.00
Energy Saving/Type/Year (KWh)		273.79	4754.56	529.92	4968.00
Total Saving/Year (Naira)		3531.92	61333.82	6835.97	64087.20
Cost Of CFL (Naira)		250.00	1000.00	1200.00	1300.00
Discount (%)		25	25	25	25
Payback (Years)		0.32	0.93	0.79	0.14

Figure 5. Energy saving calculator

4. RESULTS AND DISCUSSION

A. Result of Power factor Correction and the use of efficient motors.

The result in table 2 shows the compares kVA demand after power factor was corrected with the one before the correction. There is a mark reduction in the demands. The resuilt shows the electric motors in relation to their sizes for the Cataphoresis Oven tunnel of the industry. A total gain of 48.0 kVA is recorded.

Table 2: A reduction in kVA demand with Premium energy efficient motors and power factor improvement from 0.8 to 0.95 in Cataphoresis Oven tunnel of the industry.

PROCESSES	Hp	RPM	RATING (kW)	Avg. Eff. Std.%	Avg. Eff. Prem. %	kVA DEMAND BEFORE CORRECTION (PF=0.8)	kVA DEMAND AFTER CORRECTION (PF=0.95)
Air intake	50	1800	37	91	93	50.8	41.9
Air intake	12	1800	9	86	89	13.1	10.6
Air intake	5	1800	4.05	83	87	6.1	4.9

PROCESSES	Hp	RPM	RATING (kW)	Avg. Eff. Std.%	Avg. Eff. Prem. %	kVA DEMAND BEFORE CORRECTION (PF=0.8)	kVA DEMAND AFTER CORRECTION (PF=0.95)
Exhaust VE1	15	1800	11	86	90	16.0	12.9
Exhaust VE2	15	1800	11	86	90	16.0	12.9
Exhaust VE3	15	1800	11	86	90	16.0	12.9
Exhaust VE4	15	1800	11	86	90	16.0	12.9
Exhaust VE4	5	1800	3.5	83	87	5.3	4.2
Exhaust VE5	1	1800	1.1	77	83	1.8	1.4
Burner	1	1800	0.76	77	83	1.2	1.0
Burner	15	1800	11	86	90	16.0	12.9
Burner	15	1800	11	86	90	16.0	12.9
Oven seal VRA 1	10	1800	7.5	86	89	10.9	8.9
Burner	1	1800	0.76	77	83	1.2	1.0
Burner	20	1800	15	88	92	21.3	17.2
Cooler unit	22	1800	16.2	89	93	22.8	18.3
Oven seal VRA 2	20	1800	15	88	92	21.3	17.2
					TOTAL	**251.7**	**203.7**
						GAIN	**48.0**

Table 3 shows the total amount of electrical energy saved per year and the corresponding amount of money that will be saved in each of the production line in the industry when using energy efficient motors. The cost saved is based on the tariff of electricity in Nigeria based on kilo watt hour.

Table 3: Total Amount to be saved Per Annum in Each Production Line as a Result of Using Energy Efficient Motors.

Production line	kW/Year (Saved)	Cost Saved (N)
Cata Oven Tunnel	10848.60	139946.94
TTS	15149.40	195427.26
Antigravel	5205.20	67147.08
Primer line	16008.20	206505.78
Top Coat 1	10795.00	139255.50
Top Coat 2	8532.70	110071.83
	Total	**858354.39**

B. Results of using energy efficient lighting

The following results shows the effect of using energy saving fitting of 22W LED bulbs as against 56W fluorescent fitting and halogen bulb in the Body shop, paint shop and assembly units of the industry. Table 4 shows energy saved, cost saved and payback of using energy saving fittings in Body shop, while Table 5 and Table 6 shows that of the Paint shop and Assembly units of the industry.

Table 4: Energy Saved, Cost Saved and Payback by Using Energy Saving Fittings in Body Shop

Sub-units of the Body shop	Fitting in use (W)	No. of fitting	Power consumed (W)	Power consumed Using 22W	Cost (N)	kWh saved	kWh Annual	Cost Saving	Payback
307 main line	56	76	4256	1672	76000	25.84	4754.56	61333.82	0.92
406 main line	56	98	5488	2156	98000	33.32	6130.88	79088.35	0.92
Metal Finish line	56	252	14112	5544	252000	85.68	15765.12	203370.04	0.92
UEP Zone	56	24	1344	528	24000	8.16	1501.44	19368.576	0.92
Retouch zone	56	16	896	352	16000	5.44	1000.96	12912.384	0.92
Maintenance zone	56	162	9072	3564	162000	55.08	10134.72	130737.88	0.92
Maintenance office	56	78	4368	1716	78000	26.52	4879.68	62947.872	0.92
Jig shop	56	44	2464	968	44000	14.96	2752.64	35509.056	0.92
Engine room	56	14	784	308	14000	4.76	875.84	11298.336	0.92
Halogen	400	324	129600	32400	324000	972	178848	2307139.2	0.10
	TOTAL		**172384**	**49208**	**1088000**	**1231.76**	**226643.84**	**2923705.536**	**8.46**

Table 5: Energy Saved, Cost Saved and Payback by Using Energy Saving Fittings in Paint Shop

Sub-units of the Paint shop	Fitting in use (W	No. of fitting	Power consumed (W)	Power consumed Using 22W	Cost (N)	kWh saved	kWh Annual	Cost Saving	Payback
Hanging TTS & Cata	56	57	3192	1254	57000	19.38	3565.92	46000.37	0.92
Mastic	56	66	3696	1452	66000	22.44	4128.96	53263.58	0.92
Antigravel	56	114	6384	2508	114000	38.76	7131.84	92000.74	0.92
Dry Sanding/Primer	56	234	13104	5148	234000	79.56	14639.04	188843.6	0.92
Wet Sanding	56	344	19264	7568	344000	116.96	21520.64	277616.3	0.92
Wet Sanding Retouch	56	20	1120	440	20000	6.8	1251.2	16140.48	0.92
Top Coat 1	56	582	32592	12804	582000	197.88	36409.92	469688	0.92
Top Coat 2	56	204	11424	4488	204000	69.36	12762.24	164632.9	0.92
Top Coat retouch	56	39	2184	858	39000	13.26	2439.84	31473.94	0.92
Omia Oven	56	69	3864	1518	69000	23.46	4316.64	55684.66	0.92
Rest Zone	56	10	560	220	10000	3.4	625.6	8070.24	0.92
Halogen	400	86	34400	8600	8600	258	47472	612388.8	0.01
	TOTAL		**131784**	**46858**	**1747600**	**849.26**	**156263.8**	**2015804**	**10.23**

Table 6: Energy Saved, Cost Saved and Payback by Using Energy Saving Fittings in Assembly

Sub-units of the Assembly	Fitting in use (W)	No. of fitting	Power consumed (W)	Power consumed Using 22W	Cost (N)	kWh saved	kWh Annual	Cost Saving	Payback
Trim line	56	312	17472	6864	312000	106.08	19518.72	251791	0.93
Chassis line	56	288	16128	6336	288000	97.92	18017.28	232422	0.93
ACOM	56	402	22512	8844	402000	136.68	25149.12	324423	0.93
Quality Acceptation	56	24	1344	528	24000	8.16	1501.44	19368.	0.93
Wheel Alignment	56	16	896	352	16000	5.44	1000.96	12912.	0.93
UEP Zone	56	24	1344	528	24000	8.16	1501.44	19368.	0.93
Halogen	400	270	108000	27000	270000	810	149040	192261	0.11
		TOTAL	**167696**	**50452**	**1336000**	**1172.44**	**215729**	**278290**	**5.68**

C. Discussion of Results

The results show that by improving the power factor in Cataphoresis oven tunnel of the industry from 0.8 to 0.95 and replacing standard motors with premium energy efficient motors, kVA demand drops from 251.7kVA to 203.7kVA translating to the saving of 48kVA. Also, in TTS, kVA demand drops from 380.4kVA to 300.8kVA. In paint shop, total gain of 396.3kVA is achieved; this results to a saving of N162, 027.25.

In the same vein, using energy efficient lighting fittings in Assembly shop, 1172kWh will be saved translating to 215729kWh annually with cost saving of about N2.7million. Also, N2 million and N2.9million will be saved in Paint shop and Body shop respectively. It is on record that in 2010 alone, PAN spent about N90 million on provision of electrical energy for her services. Going by the aforementioned, more savings can be made with attendant increase in annual productions thus improving national Gross Domestic Product (GDP).

Industries all over the world are established in order to garner profits; this is also attainable if maintenance cost subsides, a situation occasioned by reduction in breakdown of power equipment, without which the aim would be a mirage. Efficient electrical power supply will reduce downtime, rework duties in the production facilities will be greatly abated; all resulting to increase in production, and hence more energy will be channeled into production of cars.

Industrial electrical energy efficiency do dovetails into reduction of carbon dioxide to be emitted into the atmosphere, this is because the higher the unwanted loads, the greater the activity of prime movers of the generators to meet the demands, also more diesel is consumed. In PAN's case, when a set of 2MVA is on load, in order to meet higher demand, other generating units automatically come on to shoulder the new demands, thus translating to higher emissions of carbon dioxide, one of the culprits of global warming and climate change. If the proffered solutions are adhered to, the efficiency will be improved while our environment will be saved from pollutions and their resultants.

5. CONCLUSIONS

Investigation of electrical energy saving potential of Peugeot Automobile Nigeria Limited has been carried out in this research work. The results obtained from the study undoubtedly justify the need to improve poor power factor and replacement of aging standard motors with premium energy efficient motors. Also, the proposed replacement of ballast fluorescent fittings and halogen bulbs with energy saving types will bring about major reductions in energy consumption for lighting. This coupled with implementation of Total Productive Maintenance (TPM) methodology is sine qua non to improvement of electrical energy efficiency in the industry.

The developed energy saving calculating tool provides a very useful tool for energy auditing particularly, for lighting systems. This tool can be used by engineers and consumers alike to calculate energy consumption and gains accruable from lighting energy saving.

It has also been shown that reduction in energy consumption will bring about reduction in cost of producing cars in the factory with affiliated profits. The investment in energy saving technology will have short period of payback and can as well propel the development of modern cars.

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