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Optimization of the Reactive Energy Compensation of the Guinea Brewerie Company Plant (SOBRAGUI)

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Abstract – In order to reduce power losses due to the transit of strong reactive currents and improve the voltage profile of distribution lines, the use of shunt capacitor banks is indicated. The main results obtained during this study are: a reduction in the subscribed power from 3815.858 kVA to 3349.392 kVA, an increase in the active power transported by the transformer station from 2557.6 kW to 2792.782 kW; a decrease in voltage drop from 3.80% to 1.88%; an increase in the power available at the secondary of the transformer station at full load from 2580 kW to 2820 kW and an annual electrical energy saving of 88580.343 kWh. It is therefore essential that manufacturers be convinced of the need to install capacitors to reduce or even eliminate their reactive energy bill. This is necessarily accompanied by an investment by Electricity of Guinea by setting up active and reactive energy meters in the industrial environment but also by implementing pricing in the direction of reducing the transfer of reactive energy into the network.

Keywords – Optimization, Compensation, Reactive energy, Industrial unit, Brewery of Guinea

I. INTRODUCTION

Reactive energy compensation is the management of reactive power to improve the performance of electrical networks. The notion of reactive power compensation covers a wide range (system problems, customers, power quality…) [1]. Any electrical system using alternating current involves two forms of energy: active energy and reactive energy. In industrial processes, only active energy is transformed within the production tool into mechanical, thermal, light energy, etc. Reactive energy is used in particular to supply magnetic circuits, electrical machines (motors, transformers, etc.). In addition, certain components of the electrical transmission and distribution networks (transformers, lines, etc.) also consume reactive energy in certain cases [2].

The circulation of active and reactive power causes active losses and voltage drops in the conductors. Active losses reduce the overall efficiency of networks and voltage drops are detrimental to maintaining good voltage that the distributor owes to its customers. Thus, it is therefore technically preferable to produce them as close as possible to the places of consumption [3]. Reactive power control (power factor correction) is a simple and inexpensive technology, but it is often overlooked in energy conservation and in the use of industrial electrical loads. Improving the power factor is a very important technique for good power quality [4].

The transmission of electrical energy from production points (power plants) to consumption points (domestic, tertiary and industrial electrical receivers) is always accompanied by losses. Studies have shown that energy losses in distribution networks account for around 13% of total energy produced [5]. This loss of energy occurs at all levels of the electricity system (transmission and distribution) [6]. So the problem is how to generate an optimal amount of reactive power at all times for a given amount of active energy. One way to solve this problem is to install capacitor banks as a source of reactive energy [7]. Compensation of reactive energy by capacitor banks is a reliable technology. The ideal location for these capacitor banks is to be near the loads, to prevent reactive energy from flowing through the power grid. This location also depends on the size and variation of electrical charges. However, for the use of capacitor banks to improve the power factor, the location and size of the capacitor banks must be optimized [8].

For a certain period of time, SOBRAGUI has been subject to a financial penalty linked to the bad power factor of the installation, thus causing an exorbitant demand for current in the network and an increase in the overall energy bill consumed. Thus, the main objective of this work is to optimize the compensation of the reactive energy of the SOBRAGUI.SA, using the electrical characteristics of the installed receivers.

II. Material And Method

2.1 Presentation of the study area

SOBRAGUI is a Guinean company located in Conakry, in the Madina district, municipality of Matam. It produces alcoholic and non-alcoholic drinks. SOBRAGUI is located 7 km south-east of Kaloum commune, with very abundant rainfall, the average temperature is 26°C, the climate is said to be sub-Guinean [9].

The SOBRAGUI site is supplied with electrical energy by the Electricity of Guinea distribution network from the Tombo substation and with a backup diesel power plant of four (4) Caterpillar 3508B groups. . The SOBRAGUI power supply network is a radial type network, made up of: three step-down transformers of 1000 kVA each, electric lines, loads, asynchronous motors, heating and lighting devices, office automation, cold production lines and power electronics devices.

2.2 Work equipment

As part of this work we used the MATLAB 6.5 environment, MATHCAD 2000 Professional, Microsoft Excel software, a database of electrical parameters, nameplates of electrical equipment, index of generator sets from the emergency power plant to through the electronic modules and the index of the SOBRAGUI electric energy meter.

2.3 Method

The method used focused on the choice of a mathematical representation (objective function) linking the electrical quantities (electrical losses, voltage drop, subscribed power, power reserve, etc.) to the power factor (cosφ) of the installation. . Thus, we have chosen a model which takes into account the increase in the supply capacity of the substation (increase in the active power available at the secondary of the supply transformers) [10].

For the data collection (electrical parameters of the receivers), we made an inventory of the nominal characteristics through the nameplates of all the electrical receivers at the SOBRAGUI plant. Next, determine the total consumption of the plant. Thus, the regression equation allowed us to determine the value of the monthly consumption of the SOBRAGUI plant in July 2020. The equations for optimizing the compensation of reactive energy are as follows [11, 12 and 13].

The available power of transformers is determined by equation (1).

$$P_{disf} = S_T . \cos\varphi \tag{1}$$

The demanded or subscribed power is determined by equation (2).

$$S' = \frac{P_P}{\cos\varphi} \tag{2}$$

The load rate at the transformers is determined by equation (3).

$$T_{XC} = \frac{S}{S_{Tn}} \tag{3}$$

The current in the installation downstream of the circuit breaker is determined by equation (4).

$$I = P_P/(\sqrt{3} \cdot U_n \cdot \cos\varphi) \tag{4}$$

The power of the capacitor bank is determined by equation (5).

$$Q_C = P_t.(\tan\varphi - \tan\varphi') \tag{5}$$

The reactive power in the network is determined by equation (6).

$$Q_F = Q_L - Q_C \tag{6}$$

The reduction in the capacity of the energy supply is determined by equation (7).

$$\Delta s = 1 - (\cos\varphi_L / \cos\varphi_C) \tag{7}$$

Electrical energy losses are determined by equation (8).

$$P_L = 1 - (\cos{\varphi_L}^2 / \cos{\varphi_C}^2) \tag{8}$$

The saving of electrical energy is determined by equation (9).

$$EES = P_L.(1 - \alpha) \tag{9}$$

The increase in the power supply capacity of the transformer is determined by the objective function, equation (10).

$$\Delta KVA_S = S.\left[\sqrt{1 - (Q_C^2.pf^2/S^2)} + (Q_C.\sin\varphi/S) - 1\right] \tag{10}$$

The annual amount of electrical energy saved is determined by equation (11).

$$E_a = [R.Q_C.(2.S.\sin\varphi - Q_C)8760]/(1000.U^2) \tag{11}$$

The capacitance of capacitors is determined by equation (12).

$$C = Q_C/(3.U^2.\omega) \tag{12}$$

The resonant frequency in capacitor banks is determined by equation (13).

$$f_R = f \cdot \left(\sqrt{S_{CC}}/\sqrt{Q_C}\right) \tag{13}$$

The short-circuit power of transformers is determined by equation (14).

$$S_{CC} = (S/U_{CC}).10 \tag{14}$$

The amplification of harmonics is determined by equation (15).

$$F_a = \sqrt{Q_C S_{CC}}/P \tag{15}$$

The increase in blood pressure is determined by equation (16).

$$U = (Q_C/S_T) \cdot X_T \tag{16}$$

The gain in apparent subscribed power is determined by equation (17).

$$G_S = S - S' \tag{17}$$

The annual gain on the fixed premium is determined by equation (18).

$$GA = Gp.Pu/kVA \tag{18}$$

The reactive power gain is determined by equation (19).

$$GQ = Q - Q' \tag{19}$$

The cost of installing and purchasing the compensation system is determined by equation (20).

$$C_T = P_u/kvar.G_Q \tag{20}$$

The payback time for the amount invested for the installation is determined by equation (21).

$$T = C_T/GA \tag{21}$$

Where: S: Apparent power of the transformer; Pf: Desired power factor; sinφ: Sine of the angle of the uncorrected power factor; R: Electrical resistance in ohms; U: Phase-to-phase voltage (voltage between phases); Nh = 8760: Number of hours per year;

III. RESULTS AND DISCUSSIONS

3.1 SOBRAGUI electroenergetic balance

The results of the electroenergetic balance (active power, reactive power, apparent power, current and power factor) of the various SOBRAGUI feeders show that the start of the Polyethylene terephthalate (PET) line uses the largest active power: 630.426 kW of the 3,331.003 kW of the entire plant, i.e. 19% of the plant's active power. The lines: PET (206.510 kVAr); Conditioning 2 (CD2) (206.424 kVAr) are lines with greater reactive power. The PET line has a good power factor (0.93), on the other hand the lighting constitutes the load at low power factor (0.48) and this is due to the use of uncompensated fluorescent lamps.

The PET line represents the largest load of SOBRAGUI with a current of 1603.390 A or 22% of the operating current of the plant. However, this percentage does not give rise to sectoral compensation (compensation by sector).

3.2 Simulation of the objective function

The simulation curves of the objective function (curve of the change in the supply capacity of the transformer station as a function of the compensation) are given in Figures 1 to 2.

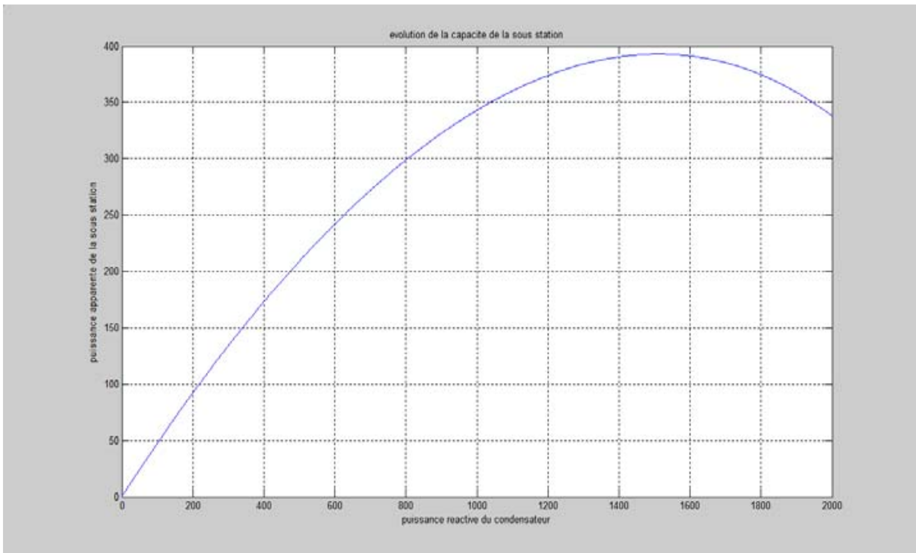

Figure 1. Evolution curve of the transformer substation supply capacity

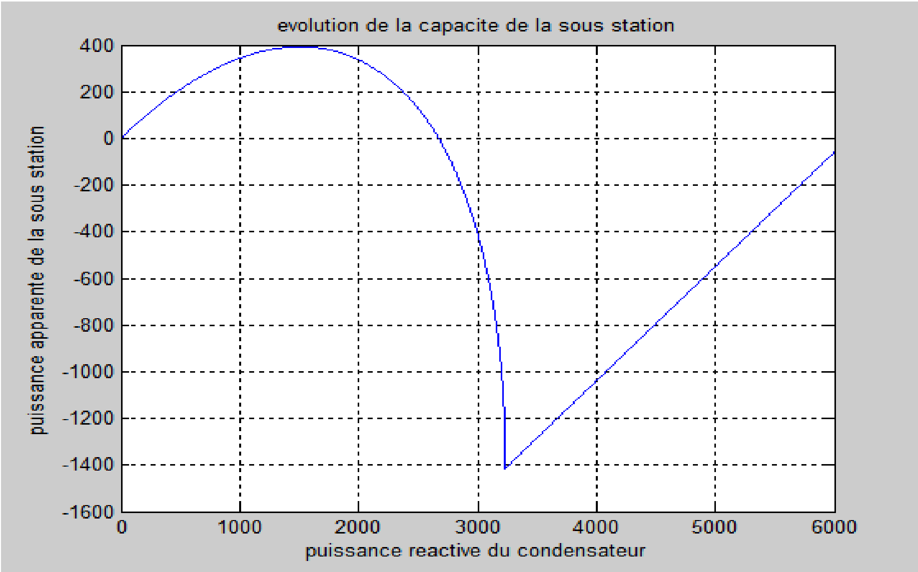

Figure 2. Case of overcompensation

The curves in Figures 1 and 2 show that with compensation, the apparent power available at the secondary of the transformers increases to a certain value and then decreases to cancel out. For the case of SOBRAGUI, we note that this transformer substation supply capacity reaches its optimum value for a reactive power of 1511 kVAr, so to optimize the compensation of the reactive energy of the SOBRAGUI, a battery must be installed of capacitors of power equal to 1500 kVAr. Thus, the power supply capacity of the transformer station reaches an optimum value, an increase of 393.033 KVA. Beyond this value, we observe a decrease, even a cancellation of this increase to approximately 2800 kVAr.

Electric power suppliers impose a certain reactive power in industrial installations according to the active power. This constraint is imposed by the (tgφ = Q/P), if Q/P is greater than the value of tgφ imposed by the supplier, the industry needs a capacitor bank of power Qc, which will be cut off at Q This will decrease tgφ and approach the value imposed to satisfy the constraints of the supplier. However, when the reactive energy Qc supplied by the capacitor bank becomes greater than that requested by the factory, approximately 1861.502 kVAr, reactive power overcompensation is obtained (the installation becomes a producer of reactive power on the network). This results in the fact that the overall installation will have its current ahead of its voltage. It will therefore have a front and not rear phase shift, and the factory will be assimilated to a capacitive receiver, and not an inductive one.

Determining the power of the capacitor bank allows us to choose the type of battery (fixed or automatic battery). So the Qc/Sn ratio gives us 0.5 or 50 %. This allows us to choose automatic compensation. As the factory's need for compensation fluctuates, this type of compensation is gradually adjusted as needed (response time less than a minute).

3.3 Power absorbed by the plant

Without the installation of the capacitor banks (without compensation), a large reactive current is drawn into the network by the factory, ie a power of 3815.858 kVA (Figure 3). The installation of capacitor banks for reactive energy optimization allowed a reduction in the current, thus called a decrease in the power absorbed (3349.392 kVA), or a decrease of 466.466 kVA (Figure 4).

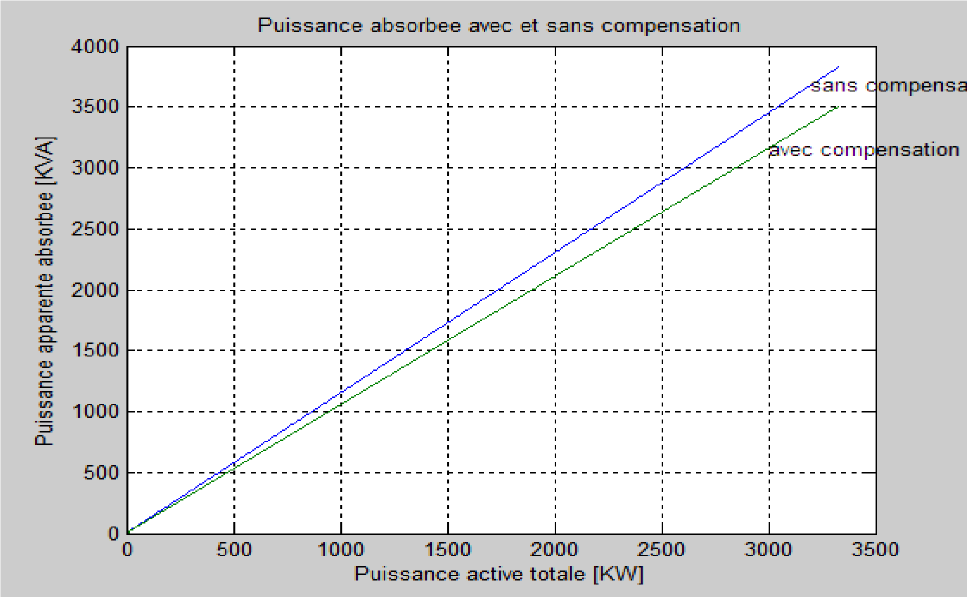

Figure 3. Power absorbed before and after compensation

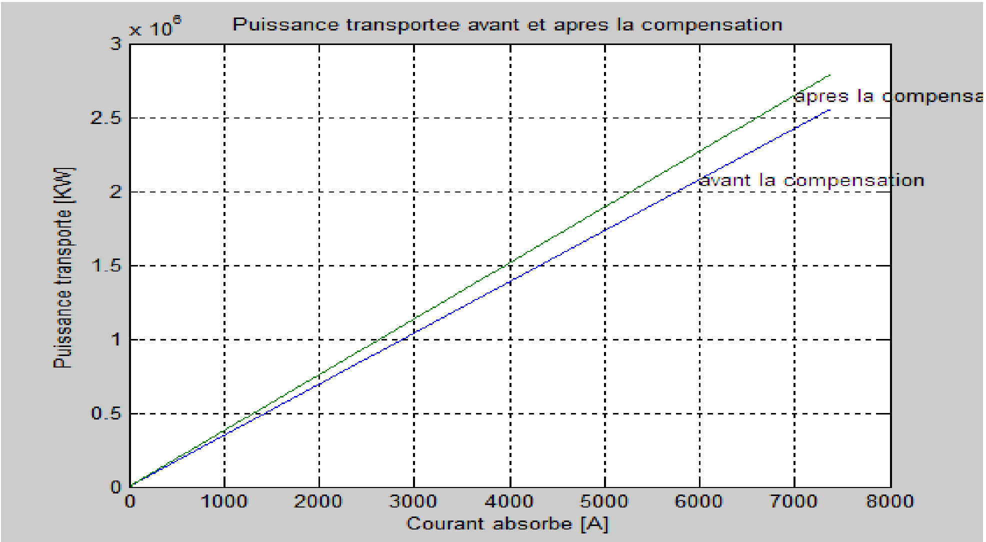

Figure 4. Active power transported with and without reactive energy compensation

The efficiency of a transformer is a function of its load and the power factor of the receivers it supplies. The installation of a 1500 kVAr capacitor bank at the secondary of the transformer substation will make it possible to transport an active power of 2792.782 kW. This power is greater than that transported by the transformer station, before reactive energy compensation (2557.6 kW).

The relative voltage drops in transformer substation transformers with and without compensation are given in TABLE I.

TABLE I. Impact Of Compensation On Voltage Drop In Transformers

Sizes	Before Compensation	After compensation	Unit
Nominal phase-to-neutral voltage	230	230	V
Total active power of the plant	3331.003	3331.003	kW
Total reactive power of the plant	1861.502	361.502	kVar
Total active resistance of the substation	0.676	0.676	mΩ
Total reactance of the substation	2.72	2.72	mΩ
Voltage drop	3.80	1.88	%
Power factor	0.87	0.95	-
Apparent power subscribed	3815.858	3349.392	kVA
Gain in apparent power subscribed	0	466.466	kVA
Available active power	2610	2850	kW
Reactive power consumed	1861.502	361.502	kVar
Tangent phi	0.57	0.33	-
Phase shift	29.54	18.19	°
Load rate of transformers	116.87	69.12	%
Drawn current (conveyed)	7.379467	5.327	kA
Gain obtained ($) on the fixed premium	0 $	18285.4672	$
Compensation Index	-	221	-

Installing the capacitor banks downstream of the transformers will reduce the voltage drop from 3.8% to 1.88%. Thus, the installation of the capacitor banks will give a voltage increase of 1.36% which is far from an overvoltage which could be harmful for the receivers. With the reduction in losses due to the installation of capacitor banks, we obtain an annual saving of 88,580.343 kWh of electrical energy. Therefore, fuel savings and a reduction in CO_2 and SO_2 emissions due to this energy saving will be obtained.

3.4 Graphical synthesis after improvement of the power factor

Before the compensation, the installation consumed a reactive power of 1861.502 kVr. After increasing the power factor, the installation would consume a reactive power of 361.502 kVAr. The capacitors must provide a power of 1500 kVAr. Graphically (Fig. 5), for an installed power of 3331.003kW, the composition of the powers, before and after improvement of the power factor gives respectively: $S1 = 3815.858$ kVA; $QC1 = 1861.502$ kVAr; $S2 = 3349.392$ kVA; $QC2 = 361.502$; $\varphi 1 = 29.54$; $\varphi 2 = 18.19$. After compensating for reactive energy by placing fixed capacitors, the reactive power taken from the network is lower. Part of the reactive power shuttles between the capacitors and the load and therefore no longer constitutes a load for the network. The transformer, cables, etc., are partly unloaded. We are therefore thinking of installing an automatic compensation system with the ratio $Qc/Sn = 50\% > 15\%$ (authorized value).

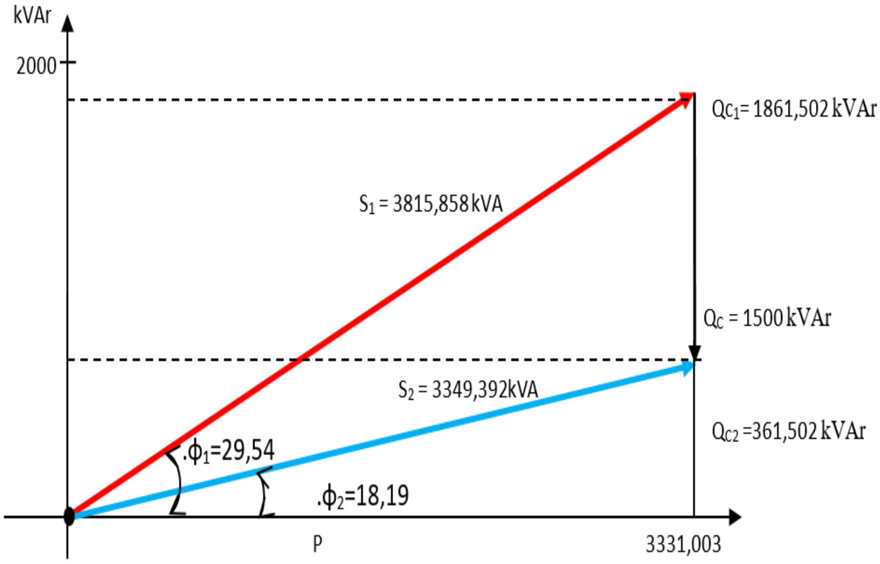

Fig. 5. Composition of the powers before and after improvement of the power factor.

Where: S1 and S2 are the apparent powers subscribed before and after reactive energy compensation; QC1 and QC2 are reactive energies absorbed before and after reactive energy compensation; P is the active power of the installation 1 and 2 are the phase shift angles between the current and the voltage before and after reactive energy compensation.

3.5 Economic parameters of the compensation system

The economic benefit of increasing the power factor is measured by dividing the cost of installing capacitor banks against the savings they provide. The gain in apparent power subscribed (difference between the subscription of the apparent power before and after improvement of the power factor) is: 466.466 kVA, for an amount of $ 39.2 / kVA, including VAT, the annual gain on fixed premium would be $ 18,285.4672.

The gain in reactive power and the total cost (difference in reactive power consumed before and after raising the power factor) is 1500 kVAr. For a reactive power to be compensated of 1500 kVAr and a unit price / kVar to be installed of $ 28, the cost of installing and purchasing the compensation system would be $ 42,000. The payback time for the amount invested for the installation of the compensation system would therefore be 2.29 years or 28 months.

3.6 Power factor correction

By reducing the Cosφ from 0.87 to 0.95, the load at the secondary level of the supply transformer is further reduced and thus an apparent power of 466.466 kVA is released which can be used to supply energy to other users. This increases the power available at the secondary of the transformer.

For these reasons, it is therefore necessary to reduce the energy consumption as much as possible, that is to say to have the power factor as high as possible. Depending on the pricing applied by the electricity supplier, the minimum average monthly power factor must be 0.9 to 0.95 to avoid charging the surcharge for reactive consumption.

IV. Conclusion

This study made it possible to get an idea of the energy consumption of SOBRAGUI and to propose solutions applicable to real situations. In the energy context of our country, optimizing energy consumption by compensating reactive energy which results in a 19.42% reduction in the monthly reactive energy consumption of SOBRAGUI should not leave the authorities indifferent. This compensation provides for an amount of $ 39.2 per kVA, including VAT, an annual gain on the fixed premium of $ 18285.4672 (American), or 164569204.8 GNF. In this study, for the optimization of the correction of the power factor or the compensation of the reactive energy of the SOBRAGUI plant, we used a model which allowed us to obtain positive impacts of the compensation. Reactive energy on the supply capacity of a transformer station, energy savings, therefore fuel savings and consequently a reduction in environmental pollution, an improvement in the voltage profile of power supply by reducing voltage drops across the secondary terminals of transformers.

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