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Energy Efficiency Improvement by Raising of Power Factor at Industrial Sector in Palestine

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Abstract: The industrial sector in Palestine represent 15% of the total electric power consumption while the power losses in distribution network amount to 8% and the average power factor amount to 0.7. Implementing of a project aiming at energy efficiency improvement in industrial sector which included wide range of diversified power measurements, had led to creating this paper. Measurement results, had shown that power losses in the distribution network are mainly caused due to low power factor in the industrial and residential sectors varying in the range 0.65 ÷ 0.8. After improvement of the power factor in two factories as "Demonstration Project" (Ch.5), evaluation of measuring results show that the annual saving after installation of the compensation unites and improving the PF to 0.95 will be more than the total cost of the proposed capacitor units, i.e. the simple pay pack period will be less than one year. The electrical losses in the distribution network and transformers will be reduced to 25% by improving the power factor in the industrial sector to 0.95, is possible. This percentage corresponds to 59914000 kWh or to money saving of 6657111 US $ / year. From environmental points of view , the mentioned energy saving corresponds to a reduction of CO2 emission amounting to 64707120 kg/year. This result is not only applicable for Palestinian electrical network but also for other countries where similar conditions are prevailing.

Key Words: Energy Efficiency, Power Factor Improvement, Power Losses, Compensation of Reactive Power, Distribution Network

Introduction

Most electrical loads do not consume only active power but also reactive power. While the active power provides motors, incandescent lamps, all discharge lamps, thyristor controlled devices, and electrical heaters with useful energy, the reactive power is necessary for magnetic circuits of inductive loads represented in transformers, motors, fluorescent lamps and inductive furnace(Mehta, 1998). The power factor is defined as the cosine of the angle between voltage and the current. It is an instantaneous value. Generally, the power supply in industrial sector in Palestine uses 33, 22, 11, and 6.6 kV three phase, which is tapped down to 400V three phase through a delta - way transformer of rating between 150 and 1000kVA. Various aspects of determination of the power factor, the legality of the penalty imposed on the industries, and some practical measurement and correction techniques of the power factor are discussed in this paper.

The Electrical Network in Palestine: The electrical networks in Palestine are all considered as distribution networks. The ranges of voltages of these networks are 33kV, 22kV, 11kV, 6.6kV and 400 volt .

The Israeli Electric Corporation (IEC) supplies electricity to the electrified communities with 33kV or 22kV overhead lines. Electricity is purchased from IEC and then distributed to the consumers.

The power loss, in the West Bank and Gaza electrical systems are very high as shown in table 1, and it can be classified into two main categories, technical losses and non-technical losses(Imad Ibrik and Salam Zagha, 1997; Palestinian Energy Authority, 1999).

Table 1: Power Loss in the Electrical Network in Palestine

Area / district	Losses (%)
Jenin	12
Tul-karem	20 (approx.)
Nablus	10.3
Hebron	19
Qalqiliah	13
Jerusalem	19
Gaza	22

The technical power loss, is the loss resulted from the generation, transmission and distribution of electricity to consumers. In normal electrical systems the percentage of loss up to the consumers will not exceed 6 percent of the total generated power (Hadi Saadat, 1999; Mehta, 1998; Marwan M. Mahmoud and Imad H. Ibrik, 2002).

The importance of loss, comes from penalty added to the consumers bill, due to the low power Factor (PF). The inductive loads connected to the electric supply, like motors and fluorescent lamps, cause the low PF. In Palestine the acceptable power factor to the electricity suppliers is 0.92. When the PF is less than 0.92, the consumer will pay in addition to the electricity bill the following penalties, Table (2).

Table 2: Power Factor penalties in Palestine

Power Factor	Penalty
0.92 or more	None
Less than 0.92 to 0.8	1% of the total bill for every 0.01 of power factor less than 0.92
Less than 0.8 to 0.7	1.25% of the total bill for every 0.01 of power factor less than 0.92
Less than 0.7	1.5% of the total bill for every 0.01 of power factor less than 0.92

Table 3: Energy Consumption in the West Bank and Gaza

Area/district	Energy	No. of Consumers		
	Purchased (kWh/year)	Residential	Industrial and Commercial	Total
Nablus	156818065	30739	8093	38832
Tul-karem	51237520	11300	200	11500
Jenin	39947520	10700	130	10830
Hebron	158674520	16120	7586	23706
Qalqiliah	31946083	5205	1548	6753
Gaza	668107000	102340	11660	114000
Jerusalem	490973524	96000	28000	124000

Most recent indicators show that electricity consumption in Palestine could be estimated at 680 kWh per capita which is considered according to world standards as very low (Palestinian Energy Authority, 1999; Marwan M. Mahmoud and Imad H. Ibrik, 2002). Explanation for this low consumption include insufficient capacity of power sources, high prices of electrical energy supplied by IEC and inadequate quality of electrical energy.

Energy consumption in the main districts of Palestine had been estimated according the following Table (3).

Power losses are quite high in the West Bank and Gaza strip, a key source of technical loss results from the low power factors found in the West Bank (Palestinian Energy Authority, 1999). Non - technical losses result from theft, unpaid bills and any other illegal ways of accessing the network.

Identification of the Problem: The Israeli Electricity Corporation (IEC) imposes the municipalities and large consumers in Palestine to pay penalties if they cause a power factor less than 0.92. The Jerusalem Electricity Company (JEDCO) is the only company that imposes the three phase industrial consumers with PF penalties if their PF is less than 0.92. On other hand, several municipalities in West Bank and Gaza strip are in the process of imposing power factor penalties on industrial customers with low PF.

If the total consumed power from an electric distribution network is only active power, then the power factor value will be equal to one. The higher the reactive power transported by the distribution network, the lower will be the PF. With regard to the high cost of electric energy transport it is more feasible to generate the required reactive power at the inductive loads directly by using capacitors, than to obtain it through the distribution and transmission networks. Lowering the power factor has negative impacts on the electric network and the industrial consumers summarized in the following main points:

- The electric current drawn from the network increases inversely with power factor, this increases the power losses in the network, which is proportional to the square of the current (Fig.1). This power loss reduces the efficiency of the network raises its temperature and in the long term will decrease its operating lifetime.
- Increasing the current by lowering the PF causes voltage drop on the distribution lines within the network, since this voltage drop is proportional to the current value (Fig.2). On the industrial consumer side, this leads to decreasing the supply voltage below the nominal value of the equipment and machines and will decrease their efficiencies and may damage them.

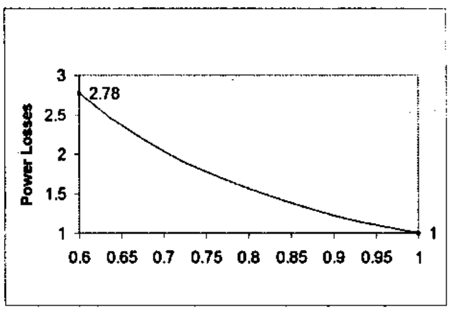


Fig. 1: The Power Losses (per unit) as a Function of PF

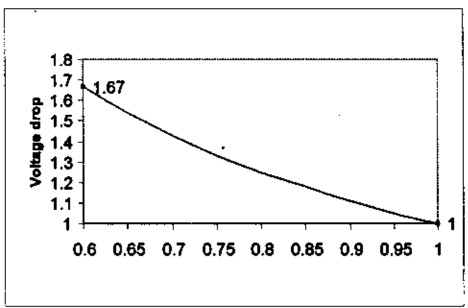


Fig. 2: Voltage Drop as a Function of PF

- Decreasing the power factor below 92% leads to impose high penalty on the municipalities paid to Israeli Electricity Corporation. The penalty value increases as the power factor drops below 92% .

Hence, the municipalities request industrial consumers to improve the power factor in their networks.
The power factor can be improved by installing capacitor banks parallel to the loads to correct the phase angle between the voltage and current, "compensate the inductive loads with necessary reactive power".
The reactive power of the capacitor required for improvement of PF is calculated as:

$$Q_c = P [\tan \Phi_1 - \tan \Phi_2] \quad (1)$$

Where , Q_c the reactive power of the capacitor in KVAR, P the active power (kW); Φ_1 , Φ_2 the angles between voltage and current before and after power factor correction respectively.

The Power Factor in Industrial Sector of Palestine: Research related to energy management and conservation in industrial sector is one of the main activities of the Energy Research Centre at An Najah National University. In this framework, a measuring campaign to assess the power consumption, the reactive power and the power factor of 50 factories was carried out by the authors of this paper. Programmable computer aided measuring equipment had been used to perform this task.
A representative sample of the obtained measuring results for Q , P, I, and PF in function of day time, for two different representable factories, are illustrated in Fig.3 (a, b) . As obvious the consumed reactive power is high and leads to low PF value varying as seen for these two factories as well as for other tested factories, in the range (0.65 ÷ 0.85).As seen at constant active power increasing of reactive power is always combined with decreasing the power factor and vice versa. Furthermore, it is recognizable that the load current increases when PF decreases, which results in increasing the power losses in the distribution networks . For the Palestinian territories, (West Bank and Gaza) the Israeli Electric Corporation (IEC) fixed the penalty limit at a power factor value of 0.92 . Each consumer has a power factor lower than 0.92 will be imposed with a penalty, whose value increases the lower the power factor falls below 0.92 as shown in Table (2).
Power factor correction should be performed by using automatic capacitor banks, where the switched capacitor steps are matched accurately with the load requirement as well as to avoid over compensation which result in a leading power factor and consequently to an over voltage as shown in Fig.4 (a,b) .
The Energy Research Centre had studied and analyzed the technical situation of many industrial companies and establishments and all studies were based on actual technical measurements carried out by the centre. Table 4 summarizes the results concerning the PF problem for some of selected companies, (SPBP: is the simple pay back period of the necessary capacitor banks).
As shown in Table 4, most of the companies have relatively low PF in the range from 0.65 ÷ 0.9, which impose them with high annual penalties in the range from (1000 ÷ 106000) NIS / year (corresponding to (250-25000 US $/year)); and the simple pay back period of the investment to realize a power factor above 0.92 for each company is relatively low, since it varies between 2 and 12 month for all audited companies.
Solving the problems of the power factor and improving its value are not limited to technical measures by using capacitors bank, since not technical measures are also important for this aim, such as provocation of awareness on the benefits gained through improving the PF in the media of decision - makers, municipalities, electrical and mechanical engineers. Awarding incentives and imposing penalties - to inspire the consumers to invest in the improvement of power factor belong also to these measures.

Improvement of the Power Factor in Two Representable Factories as a "Demonstration Project": In the framework of the energy saving policies and activities in energy efficiency improvements through several programs within the scope of institution encompassing factories in the different industrial sectors, demonstration projects were recommended for improving the power factor at Plastic Factory, and Aluminium Factory in Palestinian territories. The following analysis illustrates more details about the recommended measures from technical and financial point of view.
The Plastic Factory is supplied with electricity from municipality through 6.6/0.4 kV transformer and 3x120 mm² XLPE cable with a maximum allowable supply current of 250A. The factory has a diesel generator operated in addition to the main feeder of the municipality to cover the current of all needed loads which reaches 320A in maximum demand.
The authors of this paper had studied and analyzed the technical and financial situation of this company. All studies were based on actual technical measurements and had shown that the energy produced by the diesel generator amounts to 113979 kWh / year at an energy cost of 0.62 NIS / kWh, while the energy cost from the municipality amounts to 0.5 NIS/kWh. This factory has no PF correction capacitors, and the PF value is about 0.79 in maximum demand as shown in Fig. (3, a).

Table 4 : Results of Separately Measured Power Factor for Selected Companies in the West Bank

No.	Load kW	Energy consumption kWh/year	Installed capacitor(kVAR)	Real PF	Recommended PF	Recommended (kVAR)	SPBP Month
(1)	350	1,000,000	75	0.8	0.92	120	11
(2)	200	1,800,000	-	0.7	0.92	120	1
(3)	250	700,000	150	0.85	0.92	40	8
(4)	450	600,000	-	0.75	0.92	200	3
(5)	700	1,500,000	-	0.8	0.92	230	3
(6)	450	2,000,000	160	above0.92	0.92	-	-
(7)	40	11,900	-	0.82	0.92	10	9
(8)	250	850,000	-	0.85	0.92	50	2
(9)	100	600,000	-	0.6	0.92	240	5
(10)	150	800,000	-	0.75	0.92	250	4

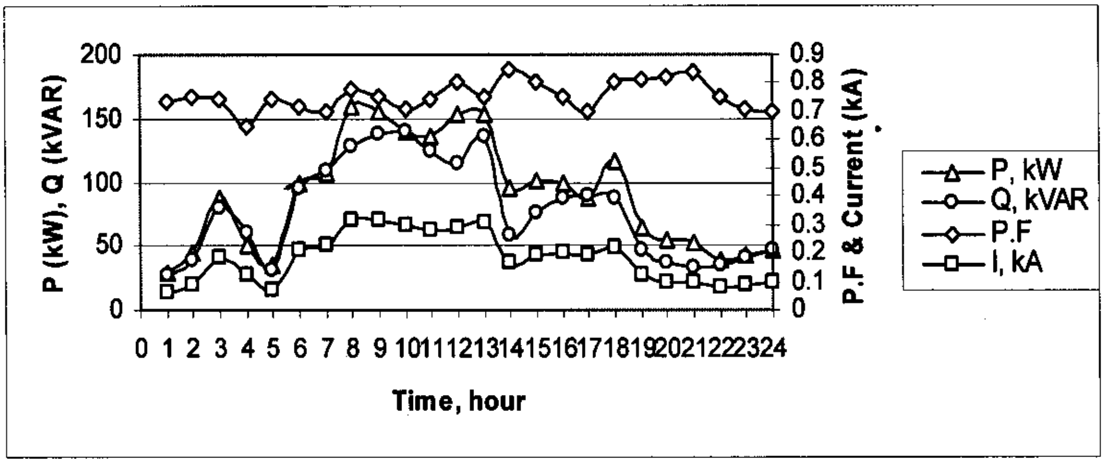


Fig.3 (a)

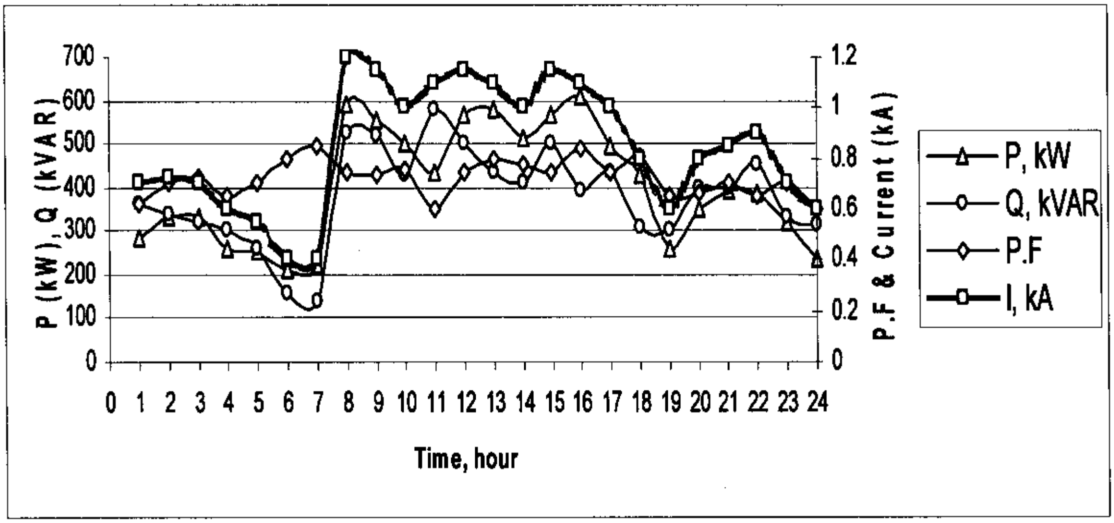
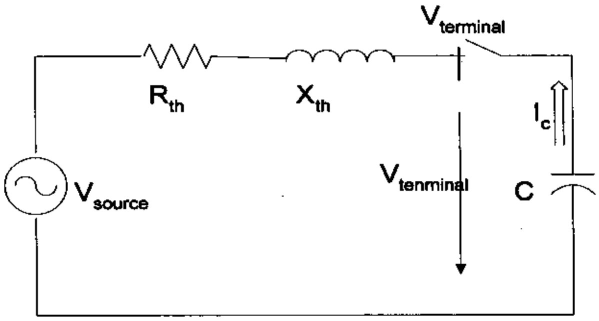


Fig.3 (b)

Fig.3(a, b): Measuring Results of I, P, Q and PF in Function of Day Time for Two Different Representable Factories in the West Bank in Palestine



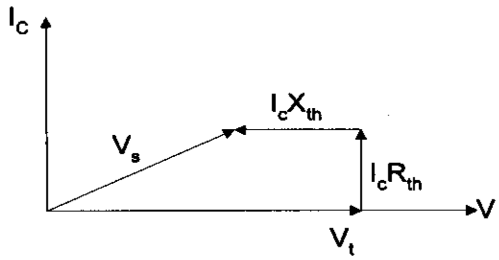


Fig.4:a

Fig.4:b

Fig.4(a,b): Equivalent Circuit and Phasor Diagram of an Over Compensation

Table 5: Results of power Factor Correction of the Plastic Factory

Power factor before improve-ment	Power factor after improve-ment	Needed capacitor banks	Peak current before improve-ment	Peak current after improve-ment	Electrical losses before improvement (kW.h) / year	Electrical losses after improvement (kW.h) / year
0.65÷ 0.84	0.96	120 kVAR	320 A	247 A	18800	11201

Table 6: Results of power Factor Correction of the Aluminium Factory

Company plants	Power factor before improve-ment	Power factor after improve-mint	Needed Capacitor banks	Electrical losses before improvement (kWh) / year	Electrical losses after improvement (kWh) / year
Anodizing	0.76	0.96	230 kVAR	619845	389060
Powder	0.53	0.96	150 kVAR	92880	28096
Extrusion	0.84	0.96	120 kVAR	336474	258000

In this case, the PF can be improved and thereupon the transformer and cables capabilities will be upgraded resulting in reducing the input current to be < 250 A, which means that it can be dispensed with the diesel generator as illustrated in Table (5) .To calculate the effect of improving PF on reducing the power losses in low voltage distribution networks in Plastic Factory, the following data can be considered:

Total feeder length = 100 m.
Electrical resistance ($R_{\text{.}}$) = 0.153 Ω /km.
Power factor before improvement = 0.75.
Power factor after improvement = 0.9 6.
Maximum operating time = 4000 h/ year.
Energy cost (C) = 0.5 NIS/ kWh,(1US$=4.5 NIS).

Annual energy loss per year before PF improvement is ΔE_1:

$$\Delta E_1 = \Delta P_1 \times t = 3 \quad I_1^2 \times R \times t \qquad (2)$$
$$\Delta E_1 = 18{,}800 \text{ kWh.}$$

Annual energy loss per year after PF improvement is ΔE_2:

$$\Delta E_2 = \Delta P_2 \times t = 3 \quad I_2^2 \times R \times t \qquad (3)$$
$$\Delta E_2 = 11{,}\ 201 \text{ kWh.}$$

The total energy saving in network through improving the power factor is (S):

$$S=\Delta E_1-\Delta E_2 \qquad (4)$$
S=7599kWh/year
(which is equivalent to 3800NIS/ year)

The total cost of the proposed capacitor units is estimated to be around 13000 NIS. The annual saving after installation of the compensation unites and supply all loads from municipality will amount to 17477 NIS / year. This means that the simple pay back period of the capacitor units will be less than one year, without considering the additional advantages related to avoiding power factor penalties.
The Aluminium Factory is connected directly with the IEC through 33/0.4 kV transformer with rating capacity of 1 MVA, and has also 4 diesel generators of total capacity of 3.5 MVA to supply all the needed power. The factory consists of three main plants, extrusion plant, powder plant and anodizing. The diesel generators are connected together and with the main feeder through automatic synchronizer to supply all loads through 3x150 mm² XLPE cables. The factory pays about 5000 NIS / month as low power factor penalty to the IEC (the PF is about 0.8), and the penalty value increases the lower the power factor value from the value 0.92.
Based on actual technical tests and measurements carried out by the authors, and on the electricity bills of the factory, the technical situation of the Aluminium Factory had been studied and analyzed. In this case, the PF could be improved by using automatic capacitor banks, where the switched capacitor steps are matched accurately with the load requirement. Table (6), summarizes the results concerning power factor correction.
The total estimated cost for the PF correction panels is about 50000 NIS, the expected saving is 60000 NIS / year, and the simple pay back period will be less than one year.

Conclusion

Results of measurements carried out on numerous different size factories in the west bank in Palestine show that PF is low, since its average varies in the range 0.65 ÷ 0.8 .In this regard, same situation prevails in the industrial sector of all Palestinian cities. The improvement of PF in industrial sectors in neglected and the attention is mostly limited on the municipalities and electrical companies where penalties are imposed.
The implemented investigations had shown that the pay back period of improving PF to reach the outlined acceptable value is mostly less than one year.
The positive impacts of improving PF in industrial sectors, represented in saving money and in improving system efficiency by reducing the power losses in the low voltage distribution networks at about 25%, are verified in this paper. Hence, we recommend the municipalities to develop an appropriate power factor penalty and bonus tariffs, considering the ways mentioned, to oblige the consumers (industrials) to improve their PF to a high acceptable value above 92%.
This action will save yearly a large amount of energy and money (6657111 US $/year for West Bank and Gaza) and will cause reduction of CO2 emission (amounting to 64707120 kg/year) especially because the low voltage distribution networks in Palestine are characterized with high losses.

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