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Power Factor Correction for ABO-TRABA Desalination Plant Case Study

Zakariya Rajab[a]*, Mohammed Buamud[b] and Mukhtar Elwalid[c]

[a, b, c]*Electrical and Electronic Engineering Department Faculty of Engineering, University of Benghazi, Benghazi - Libya.*
∗E-mail: Zakreia.hassan@uob.edu.ly, and bargathy81@yahoo.com

ABSTRACT

Power factor is a way of measuring the percentage of reactive power in an electrical system. Reactive power represents the wasted energy electricity. Reactive power is used by inductive load (such as, motors, transformers, fluorescent light, arc welders and induction furnaces) to sustain their magnetic fields. Electric systems with many motors exhibit low power factors, increasedconductorandtransformerlosses,andlowervoltages.Utilities must supply both active and reactive power to compensate these losses. However, the influence of voltage and current harmonics on equipment connected to electrical system can cause serious problems in power factor correction; it can be improved by adding shunt capacitors. Capacitors act in opposition to inductive loads,therebyminimizingthereactivepowerrequiredtoservethem.Unfortunately,powerfactorcorrectioncapacitorsmayproduceharmonicresonance and magnify utility capacitor-switching transients. Therefore, it is often desirable to implement one or more capacitor banks in a facility as a harmonic filter [1].

The main objective of this paper is to raise the power factor for ABO TRABA desalination plant to the economic and optimum value. The scope of the paper includes studying the phenomena's that can cause significant damage and distortion to a given power system such as harmonics and resonance.

The study includes billing data monthly collected, which is a plant survey. From the study, some calculations have been done such as power factor penalty savings, Loss savings, payback period, losses reductions and increase system capacity.

Keywords: *Power factor correction, increased System capacity, and harmonics*

1. Introduction

Alternating current (ac) system supply two forms of energy: Active energy, which is converted into mechanical work, heat, light, etc. Reactive energy, which again takes two forms: reactive energy required by inductive circuits (transformers, motors, etc) and reactive energy required by capacitive circuits (Cable capacitance, power capacitors, etc) [2].

All inductive (i.e. electromagnetic) machines and devices that operate on ac. system convert electrical energy from the power system generators into mechanical work and heat. This energy is measured by KWhr meters, and is referred to be active, in order to perform this conversion, magnetic fields have to be established in the machines, and these fields are associated with another form of energy to be supplied from the power system, known as reactive energy. This energy is measured by Kvarhr meters. All ac plants and appliances that include electromagnetic devices, or depend on magnetic coupled windings, required some degree of reactive current to create magnetic flux. Power factor is a ratio of useful power to perform real work (active power) to the power supplied by a utility (apparent power), in the sinusoidal case there is only one phase angle between the voltage and the current since only the fundamental frequency is present; the power factor can be computed as the cosine of the phase angle and is commonly referred as the displacement power factor [2, 3].

In the non-sinusoidal case, the power factor cannot be defined as the cosine of the phase angle. The power factor that takes into account the contribution from all active power, including both fundamental and harmonic frequencies, is known as true power factor. The true power factor is simply the ratio of total active power for all frequencies to the apparent power delivered by the utility. Poor PF due to an inductive load can be improved by the addition power factor correction, but poor power factor due to a distorted current waveform requires a change in equipment design or expensive harmonic filters to gain an appreciable improvement. Many inverters are quoted as having a PF of better than 0.95 while in reality, the true power factor is between 0.5 and 0.75. The figure of 0.95 is based on the Cosine of the angle between the voltage and current but does not take into account that the current waveform is discontinuous and therefore contributes to increase losses on the supply. Many devices such as switch mode power supplies and PWM adjustable-speed drives have a near unity displacement power factor, but the true power factor may be 0.5 to 0.6 [4].

2. Specific Case ABO-TRABA desalination plant

Case study involves ABO-TRABA desalination plant fed at 66/11KV from the utility. The plant consists of motors as main load. Nine of the main motor connected at 11KV and the other at 400V. Thus, the overall KW level tends to be relatively varying for extended periods. The typical peak demand at present is 6 MW. Figure .1 shows a simplified one-line diagram of the facility.

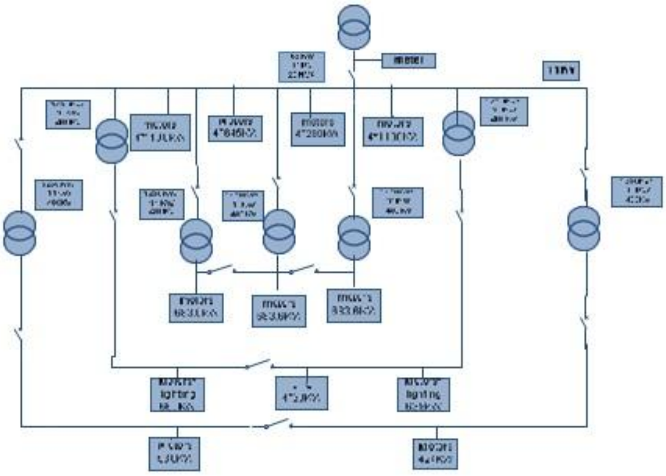

Fig. 1: ABO-TRABA plant single line diagram.

3. Plant survey

Site survey for ABO TRABA desalination plant has been done in order to study the power factor correction:

- Monthly bills consumption.
- Measurements of active and reactive power and instantaneous power factor.

- Load type.
- The existing electrical installation and equipment.
- Harmonic level (Total harmonic distortion).
- Size of the main cables.
- The motors in the plant were identified and monitored

4. Preliminary Evaluation

During the study, the history of the plant consumption has been checked. Table 1 shows the monthly bills consumption of KWh, Kvarh, and average power factor of ABO TRABA desalination plant for the previous one year that obtained from the plant.

Table 1: Monthly consumption of the plant

month	MWh	Mvar	Pmax	PF
2/2014	41241.2	18956.8	4.4	0.9
3/2014	44429	20972.3	4.49	0.9
4/2014	47617.8	22950.5	5.35	0.9
5/2014	49823.6	24336.9	3.9	0.9
6/2014	52018	25706.2	3.61	0.89
7/2014	54722.2	27374.9	4.45	0.89
8/2014	57642.1	29210.8	4.4	0.89
9/2014	60776.8	31166.3	4.45	0.89
10/2014	63268.4	32703.1	5.81	0.88
11/2014	59902.7	34330.8	4.4	0.89
12/2014	67462.1	35303.1	5.16	0.89

The saving of electricity cost per month under two power factor improvements levels

Table 2: The electricity saving under two values of power factor correction.

Power factor	Penalty saving LD	Losses saving LD	Total saving LD
0.93	3861.98	33.03	3895.01
0.95	5406.77	87.25	5494.08

5. Measurements

There are two energy digital meters installed in the plant's main feeders. Both are capable of reading in KWh and KVarh, the names of these meters are:

1. VIP MK3 energy and harmonic analyzer.
2. EMH-COMBI.

Using these meters, different measurements were performed to study the power factor of the plant. Namely, these measurements are active power measurement. Reactive power measurement. Power factor measurement. Harmonic distortion measurement. The plant was monitored and measurements were made during a period of one week, in steps of 30 minutes. These measurements are shown in figures for one day.

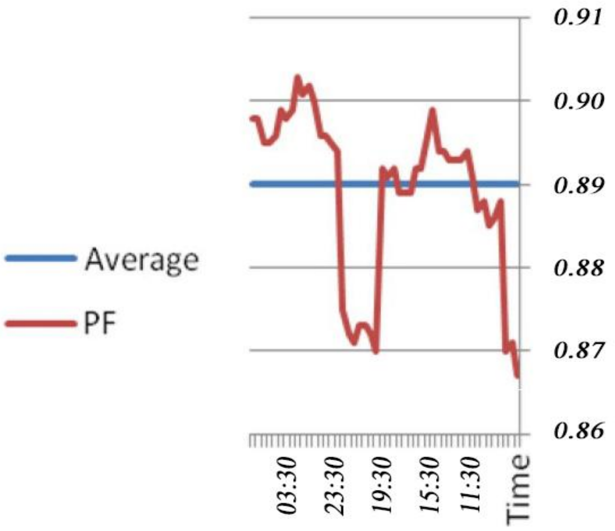

Fig. 2: Power factor for one day.

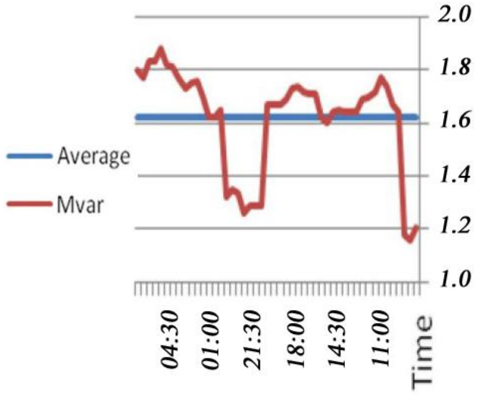

Fig. 3: Power factor for one day.

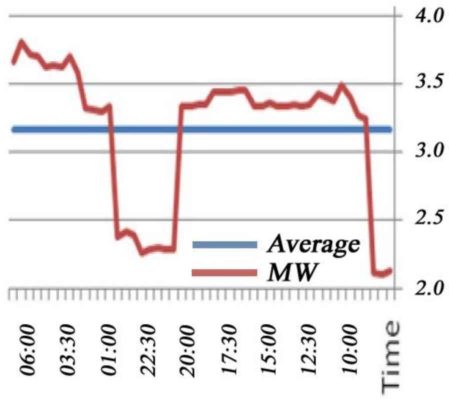

Fig. 4: Power factor for one day.

It is noticed that the instantaneous power factor level vary from 0.867 to 0.903 and is to be low. In addition, the percentage harmonic distortion has been measured and vary from 0.02 to 0.81.

6. Calculations

It is found from the measurement that the maximum percentage harmonic distortion is 0.81. This value is within the acceptable limits according to IEEE 518-1992 recommendation. 5% [8].

The required KVAr for improving the power factor from 0.88 to 0.93 is 900KVar. From the load curve, the minimum load is 2.1MW. The average correction step can be calculated as follows:

$$KW\ (\tan\theta 1 - \tan\theta 2) + C \qquad (1)$$

Where θ1and θ2 are the phase angle of initial and final power factor. Moreover, C is the capacitor ratings connected to transformers for magnetizing current compensation [8]. Since the transformer is not connected directly to the load, therefore the value of C is ignored. The value of C in the equation above equal 20 KVar [8].

The average step = 2.1MW *(0.540-0.395) =304.5 KVar.

The available standard= 300 Kvar. The required KVar capacitive load under the two standard cases of target power factor are shown in the table 3 below.

Table 3. Required KVar for two cases of target power factor

Initial PF	Target PF	KVAr	Number of stages
0.88	0.93	900	3*300
	0.95	1300	4*325

7. Results

The total power factor correction cost can be calculated with respect to required KVAr using capacitor fixed cost and capacitor running cost under the two case of power factor improvement monitoring above as shown in the table below. Study cost equal 10% of capacitor cost and installation cost equal 20% of capacitor cost [6].

Table 4: Total power factor cost under two cases of improvement.

Initial PF	Target PF	Capacitor fixed cost LD	Capacitor running cost LD
0.88	0.93	109675.38	5221
0.88	0.95	158420.00	7542
Study cost	Installation Cost	Total cost in LD	
10967. 538	21935.076	147799	
15842	31684	213488	

8. Payback period

The simple payback indicates approximately how many years it will take to recover the investment in the capacitors. Typically, industrial facilities prefer to see this number no higher than 2-3 years for simple capacitor installations and 3-5 years for more complex installations with automatic controllers and filters. [1, 7].

Table 5: Show the benefits that achieved by correcting power factor.

Target PF	Penalty Saving LD	Losses Saving LD	Increased system capacity %	Losses Reduction%
0.93	3861.98	33.03	5.4	10.5
0.95	5406.77	87.25	7.4	14.2

It is clear from tables 5 that as PF increases the total saving increases, System capacity increases and losses saving increase. Then the optimum power factor is 0.95 from both technical and economical side of view.

Table 6:payback period corresponding to target power factor.

Initial PF	Target PF	Total saving LD	Total saving LD*12	Total capacitor cost LD	Payback period Year
0.88	0.93	3895.01	46740.12	147799	3.16
	0.95	5494.08	65928.96	213488	3.24

It is found from the measurement in table 6 that the maximum percentage harmonic distortion is 0.81. This value is within the acceptable limits according to IEEE 518-1992 recommendation. 5% [10, 11].

9. Conclusions

Power factor correction provides several technical and economic advantages for customer and utilities and it has been presented in the paper, which has offered the following achievements: Penalty saving, Losses saving, and released system capacity. Power factor cost analysis study for ABO- TRABA desalination plant was conducted in order to determine the economic and optimum power factor. Power factor rates have been tested and it has been noticed that, the tested power factor values were slightly low even. As a result of that, an increase in both electrical energy cost and power losses is highly expected, in addition to system overloading and voltage decreasing. During the study of this research, the following are recommended for future research. The plant has two transformers rated 20MVA 66/11K. One of these transformers is stand by. Therefore, in future study the measurements of all the transformers supply the plant should be taking into account. The devices of the measurements are not capable to measure individual harmonics. Therefore, in the future the measurements should be conducted using more accurate devices denoting all electrical measurements of KW, KVAr, KVA, PF, THD and the individual harmonics.

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