Investigating the Effect of Using Capacitorsin the Pumping Station on the Harmonic Contents (Case Study: Kafr El-Shikh Governorate, Egypt)

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***Abstract*—**Power Factor (PF) is one of the most important parameters in the electrical systems, especiallyin the water pumping station.The low power factor value of the water pumping stations causes penalty for the electrical bill.Thereare many methods use for power factor improvement. Each one of them uses a capacitor on the electrical power network. The position of the capacitors is varied depends on many factors such as; voltage level and capacitors rating. Adding capacitors on the motor terminals increase the supply power factor from 0.8 to more than 0.9 but these capacitors cause some problems for the electrical grid network, such as increasing the harmonic contents of the grid line voltage.

In this paper the effects of using capacitors in the water pumping stations to improve the power factor value on the harmonic contents of the electrical grid network are studied. One of large water pumping stations in Kafr El-Shikh Governorate in Egypt was used, as a case study. The effect of capacitors on the line voltage harmonic contents is measured. The station uses capacitors to improve the PF values at the 11 kv grid network. The power supply harmonics values are measured by a power quality analyzer at different loading conditions. The results showed that; the capacitors improved the power factor value of the feeder and its value increased than 0.9. But the THD values are increased by adding thesec apacitors. The harmonic analysis showed that; the 13th, 17th, and 19thharmonicsorders are increased also by adding the capacitors.

***Keywords*—**Water pumping stations, power factor improvement, total harmonicdistortions (THD), and power quality.

I. Introduction

POWER factor is a measurement of how efficiently a facility uses of electrical energy [1]. A high power factor means that electrical capacity is being utilized effectively, while a low power factor indicates poor utilization of electric power. However, this is not to be confused with energy efficiency or conservation which applies only to energy. Improving the efficiency of electrical equipment reduces energy consumption, but does not necessarily improve the power factor. Power factor involves the relationship between two types of power. Active Power is measured in kilowatts (kW) and Reactive Power is measured in kilovolt-amperes-reactive (kVAr). Active power and reactive power together make up Apparent Power, which is measured in kilovolt-amperes (kVA). Lightly-loaded or varying-load inductiveequipment such as HVAC systems, arc furnaces, molding equipment, presses, etc., are all examples of equipment that can have a poor power factor. One of the worst offenders is a lightly loaded induction motor (e.g., saws, conveyors, compressors, grinders, etc.).End users should be concerned about low power factor because it means that they are using a facility's electrical system capacity inefficiently. It can cause equipment overloads, low voltage conditions, greater line losses, and increased heating of equipment that can shorten service life. Most importantly, low power factor can increase an electric bill with higher total demand charges and cost per kWh.

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A. Different Methods of Power Factor Improvement

Low power factor is generally solved by adding power factor correction capacitors to electrical distribution system. Power factor correction capacitors supply the necessary reactive portion of power (kVAr) for inductive devices. By supplying its own source of reactive power [2], a facility frees the utility from having to supply it. This generally results in a reduction in total customer demand and energy charges. The main types of capacitors are classified into low voltage power factor capacitors, or low voltage capacitors banks as shown in the following figure;

Fig. 1 Capacitors unit’s and its connections

And also a High Speed Power Factor Correction can be used to ensure that, after switch-off, the capacitors discharge to a safe voltage level before they can be re-energized. This precludes their use on rapidly fluctuating loads which, until recently, have remained uncorrected. It uses thyristors instead of contactors to switch the capacitors and they have ‘zero voltage switching’ system:

B. Impact of Power Factor Correction on Power Quality

A properly designed capacitor application should not have an adverse effect on end user equipment or power quality. However, despite the significant benefits that can be realized using power factor correction capacitors, there are a number of power quality-related concerns that should be considered before capacitors are installed. Potential problems include increased harmonic distortion and transient over voltages.

C. Harmonic Distortion

Harmonic distortion on power systems can most simply be described as noise that distorts the sinusoidal wave shape. Harmonics are caused by nonlinear loads (e.g., adjustable-speed drives, compact fluorescent lighting, induction furnaces, etc.) connected to a facility's power system[8,9,10]. These loads draw non-sinusoidal currents (e.g., on a 60 Hz system, the 5th harmonic is equal to 300 Hz), which in turn react with the system impedance to produce voltage distortion. Generally, the harmonic impedances are low enough that excessive distortion levels do not occur. However, power factor correction capacitors can significantly alter this impedance and create what is known as a "resonance" condition. High voltage distortion can occur if the resonant frequency is near one of the harmonic currents produced by the nonlinear loads. Indications that a harmonic resonance exists include device overheating, frequent circuit breaker tripping, unexpected fuse operation, capacitor failures, and electronic equipment malfunction. Different ways use to avoid excessive distortion levels include altering (or moving) the capacitor size to avoid a harmful resonance point (e.g., 5^{th}, 7^{th}), altering the size (or moving) of the nonlinear load(s), or adding reactors to the power factor correction capacitors to configure them as harmonic filters.

D. Transient over Voltages

Transient over voltages can be caused by a number of power system switching events [7]; however, utility capacitor switching often receives special attention due to the impact on customer equipment. Each time a utility switches the capacitor bank a transient overvoltage occurs. However, high over voltages can occur when customers have power factor correction capacitors. This phenomenon is often referred to as "voltage magnification". Magnification occurs when the transient oscillation initiated by the utility capacitor switching excites a resonance formed by a step-down transformer and low voltage power factor correction capacitors. Magnified over voltages can be quite severe and the energy associated with these events can be damaging to power electronic equipment and surge protective devices (e.g., transient voltage surge suppressors)[8,9].

II. Important of PF Values on the Electrical Pumping System Performance

The ministry of water resources and irrigation has to pay annually perhaps millions or extra to cover the bad quality of the supply and the electricity bill including the penalties imposed by electricity authority for running the pumping stations at a power factor less than the prescribed values: when the average annual 0.7≤PF<0.9, the penalty equals to (.09-PF)(kw) changes, and when the average annual PF is less than .07 the penalty equals to (0.9-0.7)+3/2(0.7-PF)(kwh) changes . If the consumer does not correct the power factor the penalty increases after 3 months as penalty =2(0.9-PF)(kWh)changes [3].

A. Methods of Power Factor Calculations

Ac power flow has the three components: real power (also known as active power) (p), measured in watts (w); apparent power (s), measured in volt-amperes (va); and reactive power (q), measured in reactive volt-amperes (var).

The power factor is defined as [4], [5], [6]:

$$PF = {}^{p}/_{s} \quad (1)$$

In the case of a perfectly sinusoidal waveform, p, q and s can be expressed as vectors that form avector triangle such that:

$$s^2 = p^2 + q^2 \quad (2)$$

IfØ is the phase angle between the current and voltage, then the power factor is equal to the cosine of the angle$|\cos Ø|$and[10]:

$$|P| = |S||\cos Ø| \quad (3)$$

Since the units are consistent, the power factor is by definition a dimensionless number between 0 and 1. When power factor is equal to 0, the energy flow is entirely reactive, and stored energy in the load returns to the source on each cycle. When the power factor is 1, all the energy supplied by the source is consumed by the load. Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle.

B. Distortion Power Factor

The distortion power factor describes how the harmonic distortion of a load current decreases the average power transferred to the load [10].

$$Distortion\ power\ factor = \frac{1}{\sqrt{1+THDi^2}} = \frac{I_{1,rms}}{I_{rms}} \quad (4)$$

THDi is the total harmonic distortion of the load current. This definition assumes that the voltage stays undistorted (sinusoidal, without harmonics). This simplification is often a good approximation in practice. $I_{1,rms}$ is the fundamental component of the current and I_{rms} is the total current - both are root mean square-values.

The result when multiplied with the displacement power factor (DPF) is the overall, true power factor or just power factor:

$$PF = DPF \frac{I_{1,rms}}{I_{rms}} (5)$$

III. Experimental Work

The water pumping station which was used to study the effect of power factor correction on the line voltage harmonics is installed in Drain 8 pumping station in Kafr El-Shiekh Governorate in Delta Egypt

A. Pumping Station Electrical Connection

The station electrical wiring diagram is shown in Fig.2 the station consists of eight pumping units, each one contains (slip ring induction Motor of power: 430 Kw, 6000 V, 989 rpm, 0.8 PF and submersible Pump of: 3.5m, 7.8 M^3/sec). the station is feeding from a power supply consist of a two Electrical transmission lines each 66kv, by using two step down transformers. The voltage decreased down to 11kv to feed each unit. Capacitors of value 75kvar are used and connected at the motor of each unit. The capacitors are connected by using fuse terminals. A power quality analyzer device Fluke 1760 is used to measure all the electrical signals, the device can recorded five reading per second, and calculates the harmonic contents of the supply voltage at different cases of operations.

B. Test Proceeding

The measurement is done by running the pump without capacitors and measuring all the electrical signals, then the capacitors units were connected and run the pumps were run. Measurements were undertaken to all electrical signals. The maximum number of operated units together is four units.

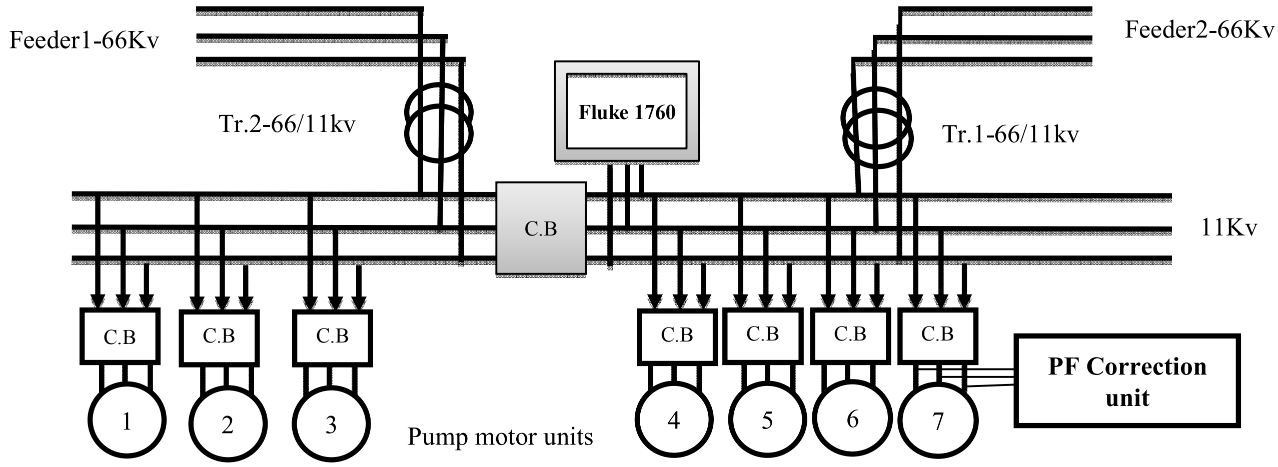

Fig. 2 Electrical wiring diagram of the pump station

IV. ANALYZING AND REPRESENTING THE MEASUREMENT

A. Main Electrical Measured Values

Regarding the mechanical measured values, the following two figures show the operation intervals at different condition of loads. The capacitors are used with a number of units and the other units without capacitors. As shown in Fig. 3.

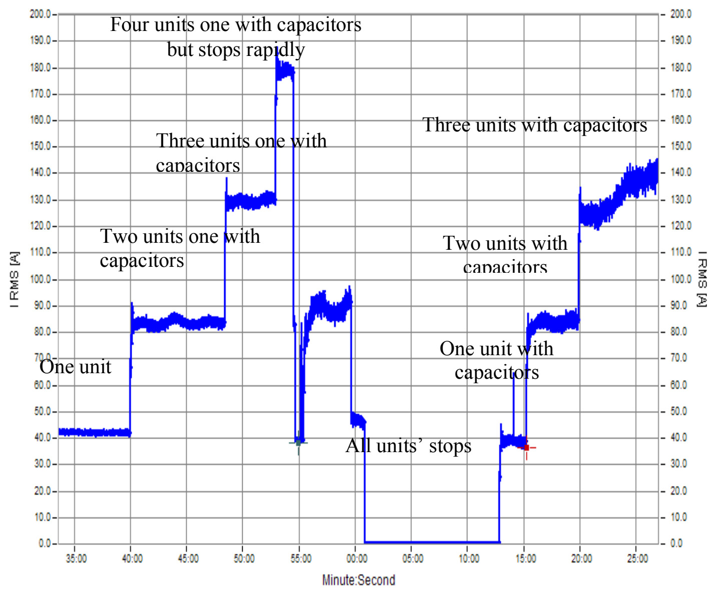

Fig. 3 Line current variation and different cases of capacitors connections

The current values are increased with the number of operating units, and the distortion in the current waveform is large in units which are using capacitors than that without capacitors. Fig. 4 shows the feeder power factor and the total active power. The power factor values are around 0.8 but it increases to about 0.9 when using the capacitors units with the pump system. The voltage values are shown in Fig. 5. Its values are high in units without capacitors, and it decreases with the increasing of the number of units, but its minimum value is not less than 5% from the rated value.

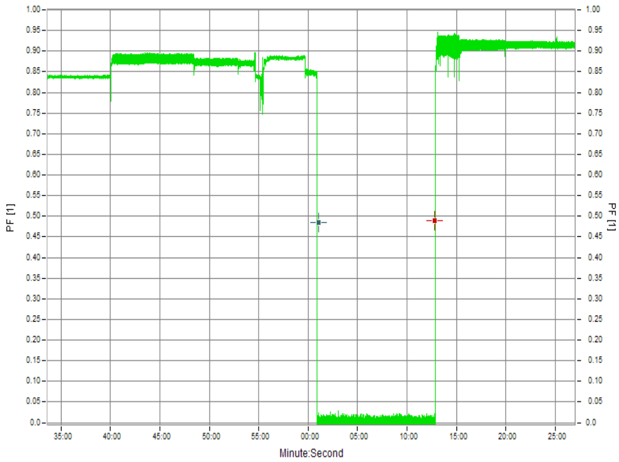

Fig. 4 Line votage power factor

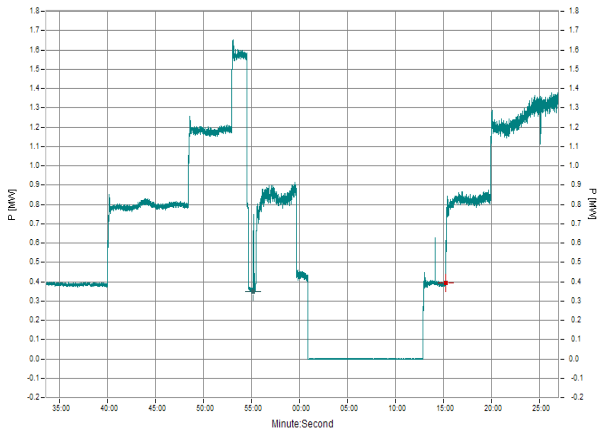

Fig. 5 (a) Total active power

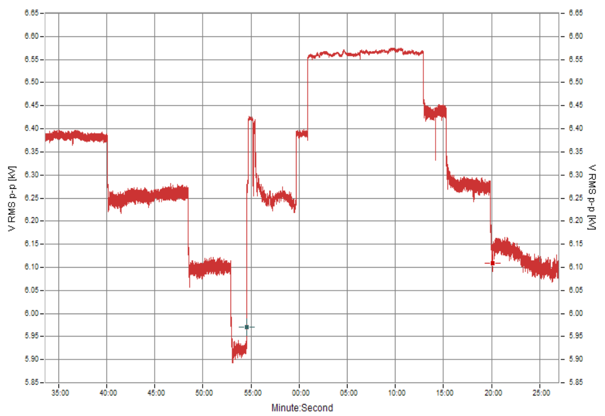

Fig. 5 (b) Line voltage values

B. Harmonic Measurements and Analysis

As for the harmonic measurements and analysis, the total harmonics distortion is shown in Fig.6. The THD value is less than 5% but there are large distortions in its value. It is seen the intervals that has a high oscillation due to connection of the capacitors. The harmonic contents are shown in Fig. 7, Fig. 8, and Fig. 9 at each operation intervals.

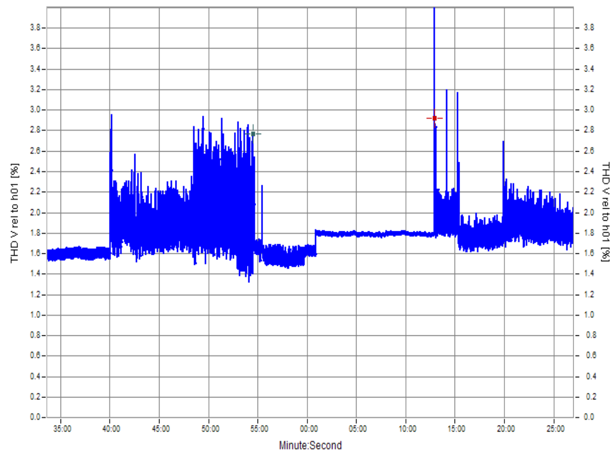

Fig. 6 Total harmonic distortion in line voltage

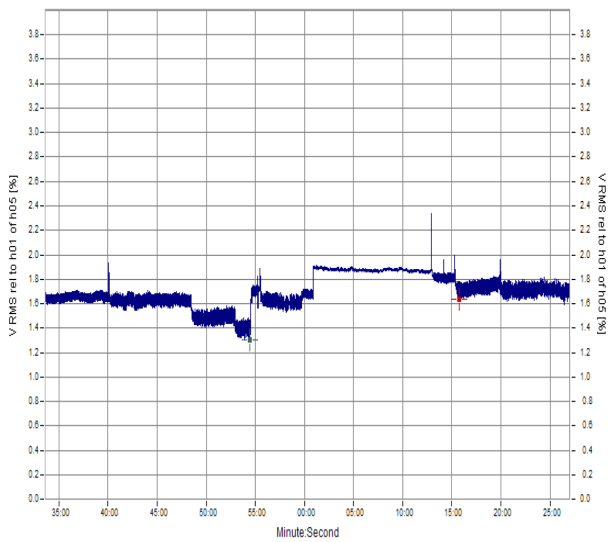

Fig. 7 (a) 5th harmonics

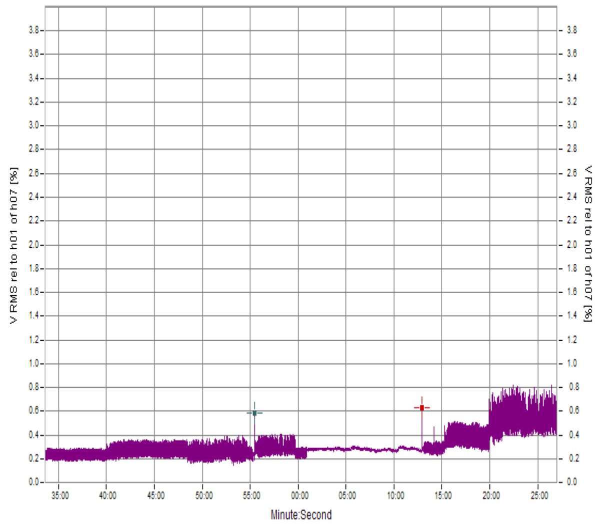

Fig. 7 (b) 7th harmonics

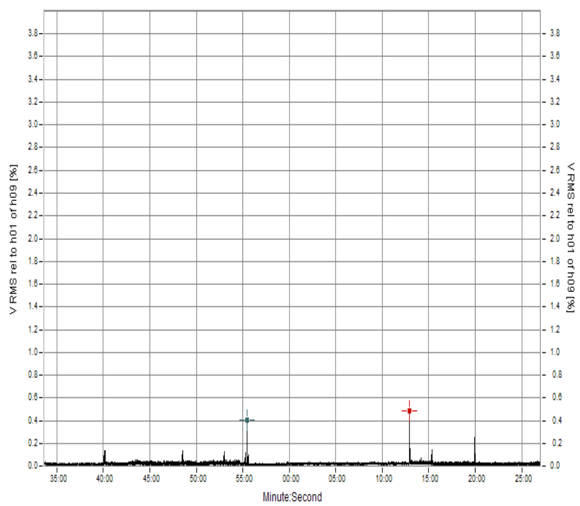

Fig. 7 (c) 9th harmonics

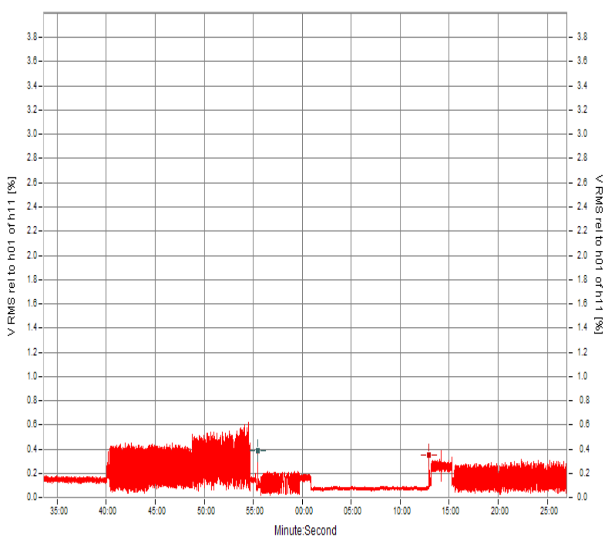

Fig. 8 (a)11th harmonics

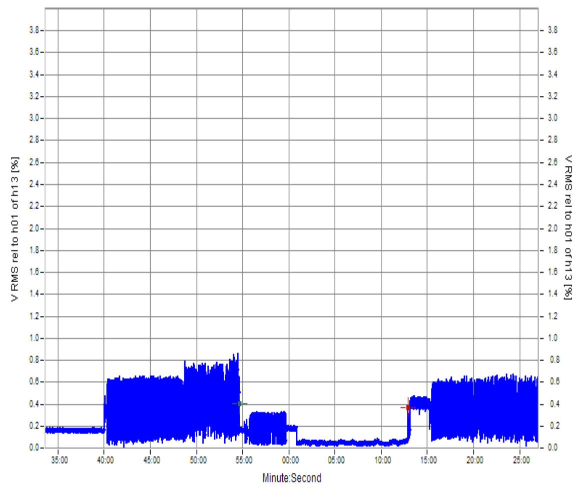

Fig. 8 (b) 13th harmonics

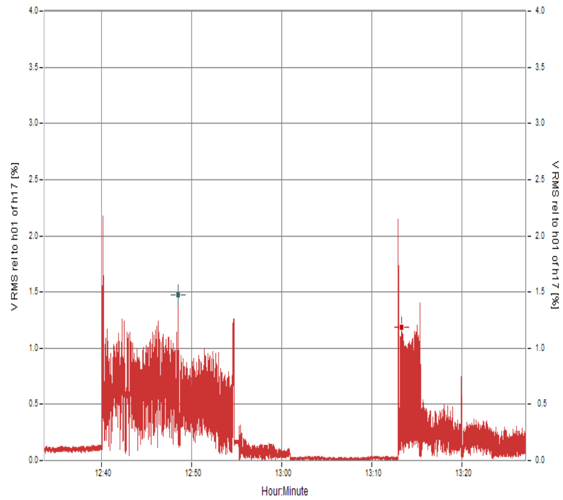

Fig. 8 (c) 17th harmonics time variations

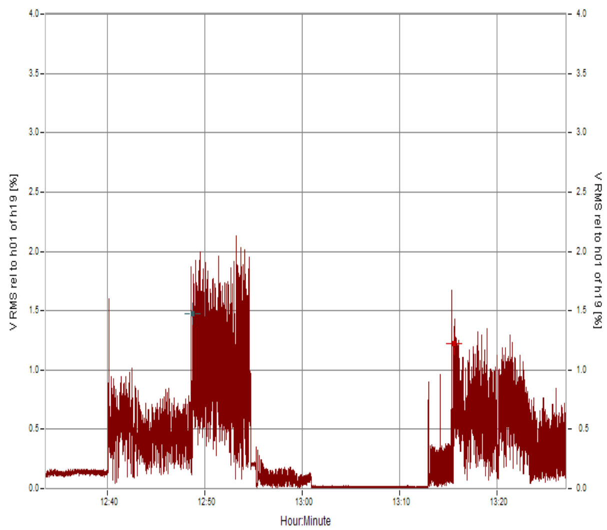

Fig. 9 19th harmonics time variations

Noticeable that; there are oscillation in the harmonics of order 11th, 13th, 17th, and 19th, as shown in Fig.8 and inFig.9.The harmonic values are increases in case of two units operation (one with capacitors, and the other without cpacitors). The 3rd and 9th are nigligibale due tothe circulation inisid the delta connction of motor winding. The 5th harmonics is not high during all intrvales of operation and does not increse than the standred limits in 11 kv voltage level.

V. Conclusion

The performance of the water pumping system in case of using capacitors to improve the power factor was investigated. A modern power quality analyzer is used to calculate the effects of adding capacitors on the feeding electrical system harmonic contents. The results showed that; the capacitors improved the power factor value of the feeder and its value increased than 0.9. But the THD values are increased by adding the capacitors. Based on the experimental measurements, it was found that

- The harmonic analysis showed that the 13th, 17th, 19th orders of harmonics increased by the adding capacitors.
- The harmonic values should be measured and calculated when using capacitors to improve the power factor, due to its side effect on the harmonic contents and THD values of the line voltage.

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