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Design and Analyzing Study of an Energy Saving Scheme For an Industrial Distribution Network in Baghdad Region Using Professional Power System Software (EDSA)

دراسة تحليلية و تصميم مخطط حفظ الطاقة لشبكة توزيع كهربائي لأحد المناطق الصناعية في بغداد باستخدام برنامج نظام القدرة التخصصي (EDSA)

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Abstract

This paper presents an attempt to study and analysis of an existing practical case of power factor correction for an 11 kV industrial distribution network in the Baghdad Region in the State of Iraq. The industrial power distribution networks of the State of Iraq and, also, in any country in the world, would have inductive loads at low power factor. One of the best solutions for the problem of low power factor or lagging current problem is commonly done by connecting shunt VAR compensation elements such as shunt capacitors bank or local capacitors at the desired locations to achieve the power factor correction. Shunt capacitors bank utilization in the power factor correction will produce economic saving in capital expenditures through the reduction of power losses through the distribution network which is the main goal of this study. In this study, the professional power system software (EDSA) has been used in developing the network model for the first time in Iraq. The power flow solution has been used in the determination of the energy after adding the shunt capacitors (i.e. after power factor correction). The on-site power factor enhancements and energy measurements have been conducted and verified by the network model that was developed by the professional power system software (EDSA), while Newton-Raphson method has been used to obtain the Power flow solution. Many goals have been achieved in this study, where in spite of the annual reduction in losses or energy saving of 120.96 MWhr (435456 MJ of energy for every one year), the power factor is enhanced to an excellent value (nearly 95 %), where reaching this value for such industrial loads give a remarkable excellent condition.

Keywords: EDSA program, VAR compensation, and power factor enhancement

المستخلص

تقدم هذه الورقة محاولة لدراسة و تحليل لعملية تصحيح و تحسين معامل القدرة لحالة حقيقية تم تطبيقها على جزء من شبكة التوزيع الكهربائية الوطنية العراقية في احد المناطق الصناعية ضمن مدينة بغداد و على شبكة التوزيع ذات الجهد 11 كيلو فولت. ان مشكلة تأثر قيمة معامل القدرة و تدني قيمته هي مشكلة شائعة في المناطق الصناعية ذات الاحمال الحثية ليس في العراق فقط بل في اغلب بلدان العالم. ان من اهم الحلول الناجعة لحل مشكلة تصحيح و تحسين معامل القدرة تتم بالدرجة الاولى من خلال ربط مجموعة من المكثفات ذات قيمة محددة و كذلك ضمن مواقع محددة ايضا و على التوازي مع احمال شبكة التوزيع. ان ربط هذه المكثفات بقيمها و اماكنها المحددة لايقوم بتصحيح معامل القدرة فحسب بل يقوم كذلك بتقليل خسائر الطاقة و الذي يعتبر الهدف الرئيسي لهذه الدراسة. تم استخدام البرنامج التخصصي في مجال انظمة القدرة EDSA في دراسة و تحليل و استنباط الموديل الخاص بالشبكة و لأول مرة في العراق.اما برامج سريان القدرة فقد تم استخدامها لتحديد سريان القدرة في الشبكة و لمعرفة كمية القدرة الضائعة قبل و بعد ربط مكثفات التحسين في اماكنها المحددة. القراءات الموقعية الخاصة بتحسين معامل القدرة و قراءات الطاقة المصروفة و التحقق من نموذج الشبكة تمت من خلال البرنامج الخاص بانظمة القدرة و المسمى EDSA, بينما استخدمت الطريقة نيوتن – رافسون لحساب سريان القدرة. تم تحقيق عدة اهداف من خلال هذا البحث حيث تم تقليل الخسائر السنوية للطاقة المستهلكة بمقدار 120.96 MWh (435456 MJ من الطاقة لكل سنة), اضافة لتحسين معامل القدرة الى قيمة (95 %), حيث ان الوصول الى هكذا قيمة للمناطق الصناعية يعتبر حالة ممتازة .

Introduction

The main problem in power systems is the power losses in both types, active power losses due to I^2R and reactive power losses due to I^2X, which have two types ,also, inductive reactive power losses I^2X_L or capacitive reactive power losses $I^2X_{C.}$ Electrical power losses in distribution systems correspond to about 70% of total losses in electric power systems [1]. These electrical losses can be considerably reduced through the installation and control of reactive power support equipments, such as capacitor banks, through reducing reactive currents in distribution feeders. Furthermore, voltage profiles, power-factor and feeder capability of distribution substations are also significantly improved. Computational techniques for capacitor placement in distribution systems, have been extensively studied since the 60's with several available technical publications in this research area [2].

Iraqi State is known as a one of the summer hottest country in the word. The power losses of the industrial power distribution networks experience is increasing during summer period [3, 4]. The main reason for this huge loss in power is mainly related to the excessive use of air conditioning system and motor drives which reflects an increase in the electric load. The increasing amount in this type of load is always, accompanied with reduction in power factor, where sometimes it reaches the value of (~ 75 %) which leads to huge transfer of reactive power from the utility through the network. The main disadvantages of this case problem are the increasing in the network losses and voltage level reduction. This condition (Low voltage profile) will lead to reduction in the lifetime of electric instruments and devices and will, also, increases the internal losses of line conductors, cables and motors; all of these, will lead to system efficiency reduction. The main goal of the Shunt capacitors is to provide reactive power compensation in power distribution network. They are provided to minimize power and energy losses, maintain best voltage regulations for load buses and improve power network security. The needed amount of compensation is related to the placement of capacitors in the distribution network which is essentially determination of the location, size, number and type of capacitors to be placed in the system [5]. A large variety of research work has been done on capacitor placement problem in the past [6, 7, and 8].

The main objective goal of this paper is to design an energy saving scheme for an industrial distribution network in Baghdad Region (Baghdad – East) which is the main region of Iraqi National Grid (I.N.G). This purpose can be achieved by decreasing or eliminating the distribution network losses and improving the main electric power load operation to a better efficiency level. In this study the designed scheme is related to the power factor enhancement of the distribution network by adding shunt capacitors or capacitor banks to the network at optimal sizes and locations. The load flow modeling is used here to simplify the network and to calculate the network losses and verify the voltage profile. Baghdad industrial distribution network model parameters are obtained through field measurements and then implemented in EDSA program (Trail Version) [9]. After that, the EDSA modeling is validated by comparing the results of load flow with power flow field measurements. The capacitors capacities sizes (VARs compensation) are calculated and verified using EDSA software program [9]. The reduction in the overall network losses will be achieved through the implementation of the designed VAR compensation system. The designed VAR compensation system, the field measurements, software analysis, and overall energy saving are illustrated briefly in this study.

Advantages of Power Factor Correction

The power factor and the reactive power of any part of the electric power system (Generation, Transmission, and Distribution) are concerned with each other. Loads on electric power networks include two components: active power (measured in kilowatts) and reactive power (measured in kvars). Active power has to be provided by power plants, whereas reactive power can be provided by either power plants or shunt VAR compensation such as shunt capacitors bank. It is a well-known fact that shunt power capacitors through a capacitor banks or local capacitor installation are the most economical source to match the reactive power requirements of inductive loads and transmission lines operating at a lagging power factor, while matching the reactive power requirements of capacitive loads operating at a leading power factor need an installation of the inductors in specific values and locations, but this case is rarely happened in Iraqi National Grid nowadays, since the grid loads are more than the provided generation. For this reason, the study in this paper concentrates on the first case, where the power factor is always lagging. There are two main advantages of power factor correction which can be explained as follow:

1- Cost Benefit

The economic justification for capacitors sizes (VARs compensation) is concerned with the degree or level of the power factor reduction due to the inductive loads connected on that grid. When reactive power is provided only by power plants, each system components (i.e., generators, transformers, transmission lines and distribution feeders, switch-gear, and protective equipments) has to be increased in size accordingly. Capacitors can govern these conditions by decreasing the reactive power demand all the way back to the generators [4]. Line currents are reduced from capacitors locations all the way back to the generation equipment. As a result, losses and loadings are reduced in distributions feeders, substation transformers, and transmission lines [10,11]. The installation of these compensating elements (shunt capacitors) in the distribution system can increase generator and substation capability of additional load at least 30 percent, and can increase individual circuit capability, from the voltage regulation point of view, approximately 30 to 100 percent. Furthermore, the current reduction in transformer and distribution equipment and lines reduces the load on these kilovolt ampere-limited apparatus. In general, the economic benefits force capacitor banks to be installed on the primary distribution network rather than on the secondary. The methods used by the utilities to determine the economic benefits derived from the installation of capacitors vary from company to company, but the determination of the total installed cost of a kilovar of shunt capacitors is easy and straightforward. So, the economic benefits due to capacitors installation can be summarized as [3,4]:

Benefits due to released generation capacity
Benefits due to released transmission capacity
Benefits due to released distribution substation capacity
Benefits due to reduced voltage drops (voltage improvement)
Benefits due to released feeder capacity
Benefits due to reduced energy losses
So, the total benefits can be summarized [4] as given in the following Equation (1):

$$\sum \Delta\$ = \text{Total Benefits} = \text{ Demands Reduction + Energy Reduction +Revenue Increase}$$

$$\sum \Delta\$ = \underbrace{\Delta\$_G + \Delta\$_T + \Delta\$_S + \Delta\$_F}_{\textit{Demand Reduction}} + \underbrace{\Delta\$_{ACE}}_{\textit{Energy Reduction}} + \underbrace{\Delta\$_{GBCE}}_{\textit{Revenue Increase}} \qquad (1)$$

Where:
$\Delta\$_G$ = annual benefits due to released generation capacity, \$/yr
$\Delta\$_S$ = annual benefits due to distribution substation capacity, \$/yr
$\Delta\$_F$ = annual benefits due to released feeder capacity, \$/yr
$\Delta\$_{ACE}$ = annual benefits due to conserved energy, \$/yr
$\Delta\$_{GBCE}$ = additional annual revenue due to increase kWh energy consumption, \$/yr
$\Delta\$_T$ = annual benefits due to released transmission capacity, \$/yr

In this paper, the advantages of the installation of shunt capacitors respective to reduced voltage drops and reduced energy losses will be discussed in details in the following sections.

2- Energy Losses Reduction

As the copper losses are reduced due to the installation of the shunt capacitors, the annual energy losses will be reduced also [4]. So, the conserved energy can be expressed as given bellow, in Equation (2).

$$\Delta ACE = \frac{Q_{C,3\phi} \cdot R(2S_{L,3\phi}\sin\theta - Q_{C,3\phi}) \cdot 8760}{1000 \cdot {V_{L-L}}^{2}} \text{kWh/yr} \qquad (2)$$

Where:

ΔACE = annual conserved energy, kWh/yr

$Q_{C,3\phi}$ = three-phase reactive power due to corrective capacitors applied, kvar

R = total resistance to load center,

$S_{L,3\phi}$ = original, i.e., uncorrected three phase load, kVA

sin θ = sine of original (uncorrected) power factor angle

$V_{L\text{-}L}$ = line to line voltage, kV

From that, the calculated annual advantage costs due to the conserved energy can be stated as in Equation (3).

$$\Delta\$_{ACE} = \Delta ACE \times EC \qquad (3)$$

Where:

$\Delta\$_{ACE}$ = annual benefits due to conserved energy, \$/yr

EC = cost of energy, \$/kWh

Reduced Voltage Drops Advantages

The other important advantages from the installation of capacitors can be summarized as follow: Since, the line current is reduced due to the reduction in load current requirement, where both resistive and inductive voltage drops are decreased, this will result in the enhancement of the system voltage regulation. The power factor enhancement will also, decrease the effect of reactive line voltage drop. Equation (4) gives an expression for the approximated rise of voltage value (in percent value) along the line.

$$\%VR = \frac{Q_{C,3\phi} \times l}{10 \times V_{L-L}^{2}} \qquad (4)$$

Also, there is an additional voltage rise which is happened through every transformer from the generation source to the capacitors occurs due to the capacitors application, this additional rise in voltage is independent of load and power factor of line, and can be expressed as:

$$\%VR_T = \left(\frac{Q_{C,3\phi} \times l}{S_{T,3\phi}}\right) x_T \qquad (5)$$

Where:

% VR_T = percent voltage rise through transformer

$S_{T,3\phi}$ = total three-phase transformer rating, kVA

x_T = percent transformer reactance (approximately equal to transformer’s impedance)

Practical case study: Power Factor Enhancement for an Industrial 11 kV Substation of Iraqi National Grid (I.N.G) – Baghdad Region

In this practical case study, an industrial 11 KV Substation of I.N.G – Baghdad region have been chosen or selected for the power factor correction (enhancement) using shunt reactive power compensator elements (capacitors). The 11 kV substations have two 33kV / 11kV transformers that feeds the industrial customers through 11 kV feeders. The single-line circuit diagram of the distribution substation which supply the industrial loads with its specific loads (active and reactive powers) is shown in Figure (1).

To analyze this case before and after adding the required capacitors with its required reactive powers in the specific locations to obtain the best compensation which give the best power factor in spite of the enhancement of the voltage profile with minimum losses in active and reactive power due to the reduction in loads currents, the case study must consists of the following three steps:

First step: Obtaining the required measurements through using the power quality analyzer type (AMEC 3945 PQ Analyzer).
Second step: Obtaining the Computer simulation through using the professional power system analysis software (EDSA software).
Third step: Obtaining the required Calculation of Energy Saving and power factor enhancements

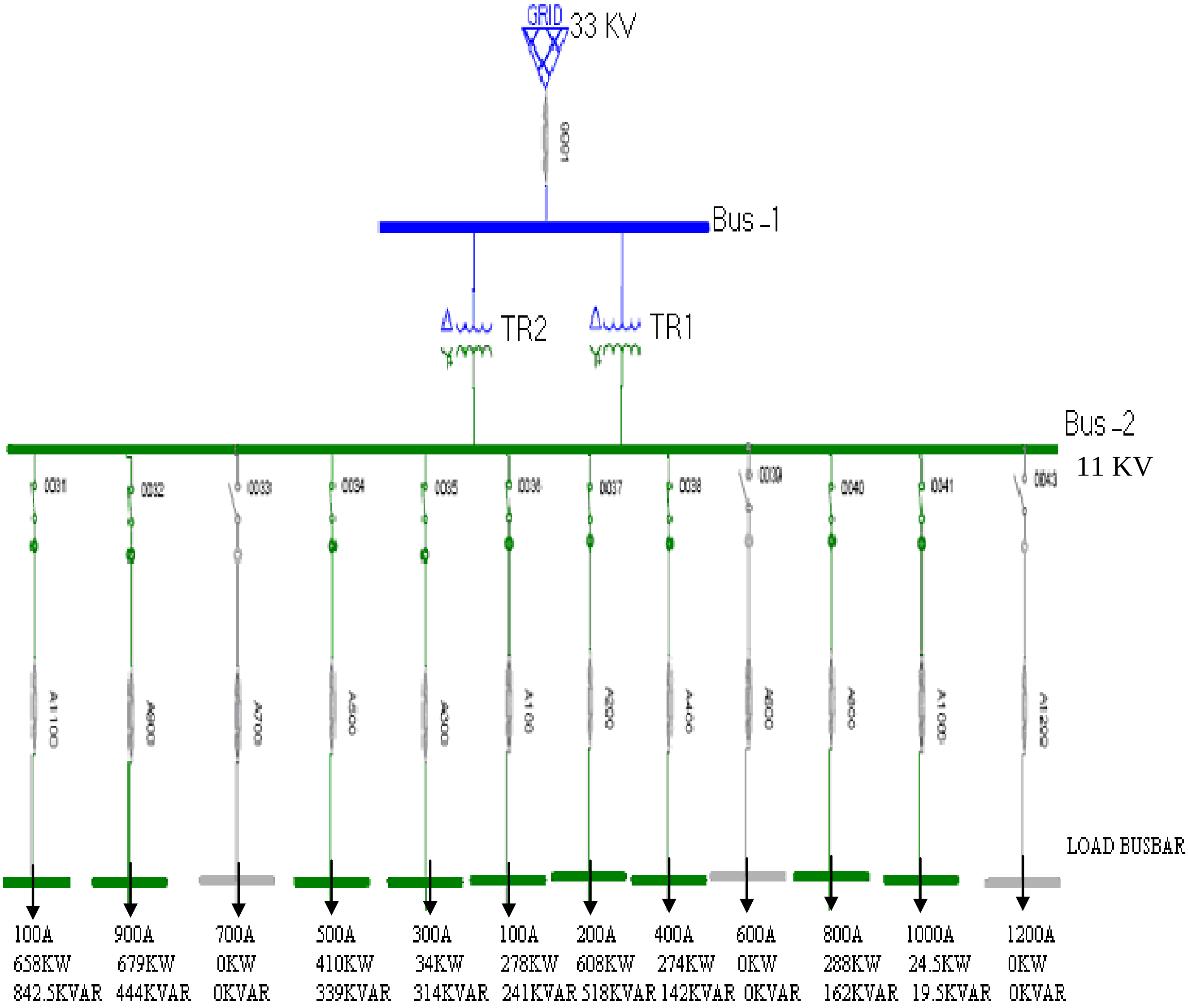

Figure (1): Single-Line Diagram of 11 kV substations

First step: Measurements

In this first step the power quality analyzer has been used to read and measure all the values of the loads requirements and system configuration that needed to simulate the network for power factor correction (enhancement) using EDSA software. The measurements of MW and MVar loads connected to the 11 kV feeders are shown in Figure (1). The required time for the PQ analyzer to record all the power factors readings is 24 hours so the PQ analyzer has been left on the substation for 24hrs recording. Figure (2-a) and Figure (2 - b) show the recorded power factor at the secondary 11kV secondary side of the transformer for a period of 24 hours.

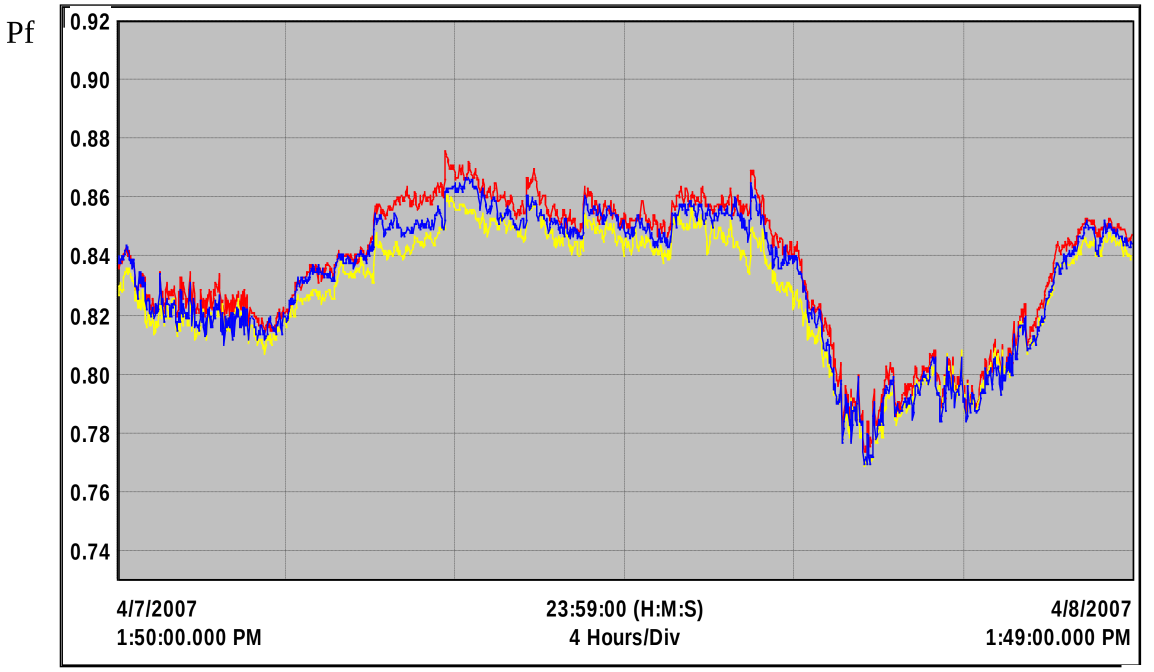

Figure (2-a): Power Factors Time trends over 24 hours (summer Readings)

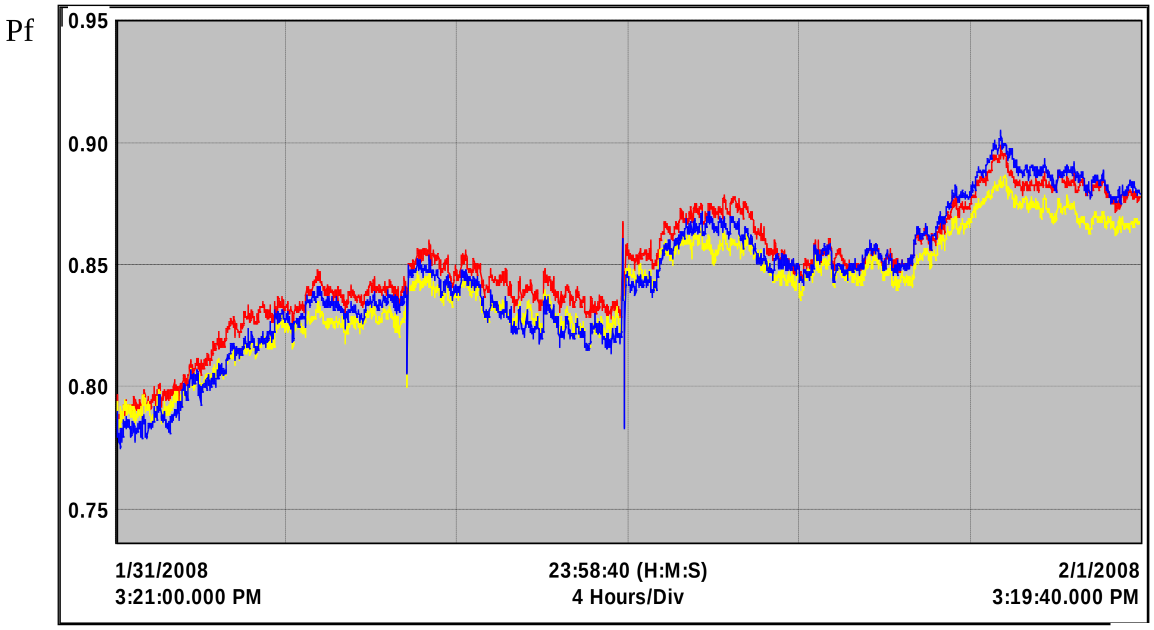

Figure (2-b): Power Factors Time trends over 24 hours (winter Readings)

The poor power factor is obviously illustrated in Figure (2 - a) and Figure (2 - b). It can be seen that power factor of the substation is considered a poor power factor since its value between the values (0.75 to 0.87). The goal of this study is to enhance the power factor value from that values to a value vary near to 0.95, in order to minimize the power losses (saving energy) by reducing loads currents, and, also to reduce the voltage drops (enhancement of voltage profile). The required calculated values of the shunt capacitors for power factor enhancements is determined and verified using the software simulations program EDSA.

Second step: Computer Simulations

The network power losses have been calculated by using the software power flow simulations program type EDSA [9]. Newton-Raphson method has been used to obtain the Power flow solution. Figure (4) illustrate the power flow with shunt capacitors connected in the specific locations shown in that Figure. The enhancement of the power factor can be observed, where it had been enhanced to a value of 0.9478 or 0.95 nearly, which is very good value for a power factor for an industrial region. The compensating reactive power (kvar rating) of the shunt capacitors have been determined to enhance the power factor at each feeder to a value of 95% lagging. Figure (4) show the calculated kvar of each shunt capacitor. To explain the computer simulation in details the following two sub-steps are illustrated:

1- Simulation results without adding shunt capacitors

In this step of simulation the software EDSA power flow program has been used to calculate the total network power losses. Newton-Raphson method has been used to obtain the Power flow solution. Figure (3) show the solution with the direction of the power flow without the insertion of the shunt capacitors, it can be observed that the power factor of the network at bus 2 is 0.7889. This poor power factor value need to be enhanced to a value of 0.95 (nearly) which is the target of this simulation. Table (1) gives us the summary of power flow results without shunt capacitors. It appears from the table, that; the total power losses of (P) in the network are (39kW).

Table (1): Generation and Demand without shunt capacitors

	P(MW)	Q(MVAR)	S(MVA)	PF(%)
Swing Buses	10.99	9.001	17.84	75.98
Generators	0	0	0	0
Shunt	0	0	0	0
Static Load	10.89	8.73	13.75	78.89
Motor Load	0	0	0	0
Total Loss	**0.039**	0.498		

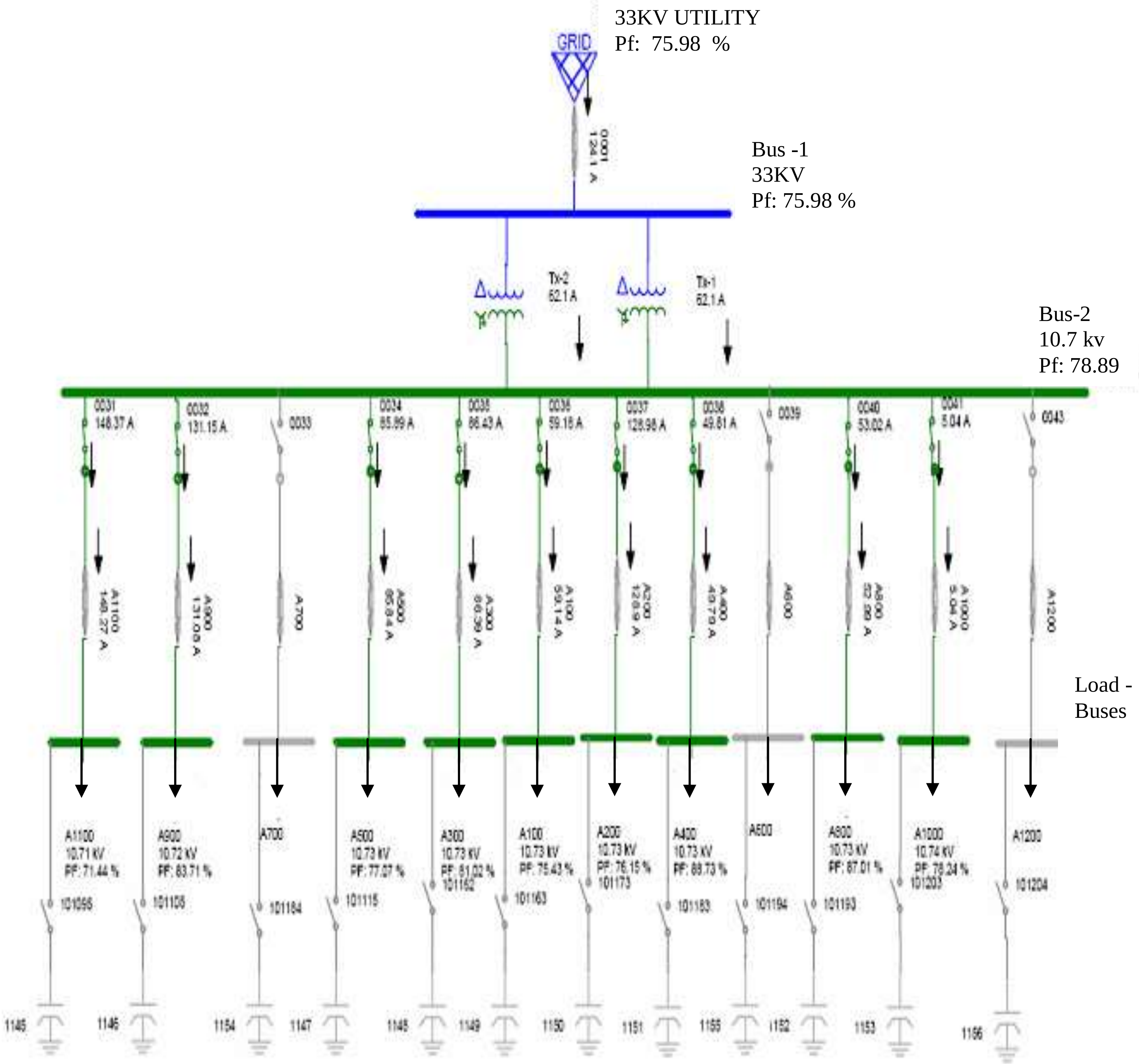

Figure (3): Power flow solution without shunt capacitors

2-Simulation results after the addition of shunt capacitors

The novel application techniques of EDSA power flow program has been used to calculate the total network power losses. Newton-Raphson method has been used to calculate the Power flow solution which is needed to compare the obtaining calculated values. The power flow with shunt capacitors is shown in Figure (4). From this Figure, it can be observed that the power factor has been enhanced to a value of 0.9480. From Table 2, the total power losses in the network are (25kW). The losses reduction is from 39kW to 25kW which means (14kw). It is noticed that; this value of reduction is remarkable when it is measured along the distribution grid operating time which may be extended to many years (sometimes extended to 25 years in its rated condition depending on the protection and preventing maintenance).

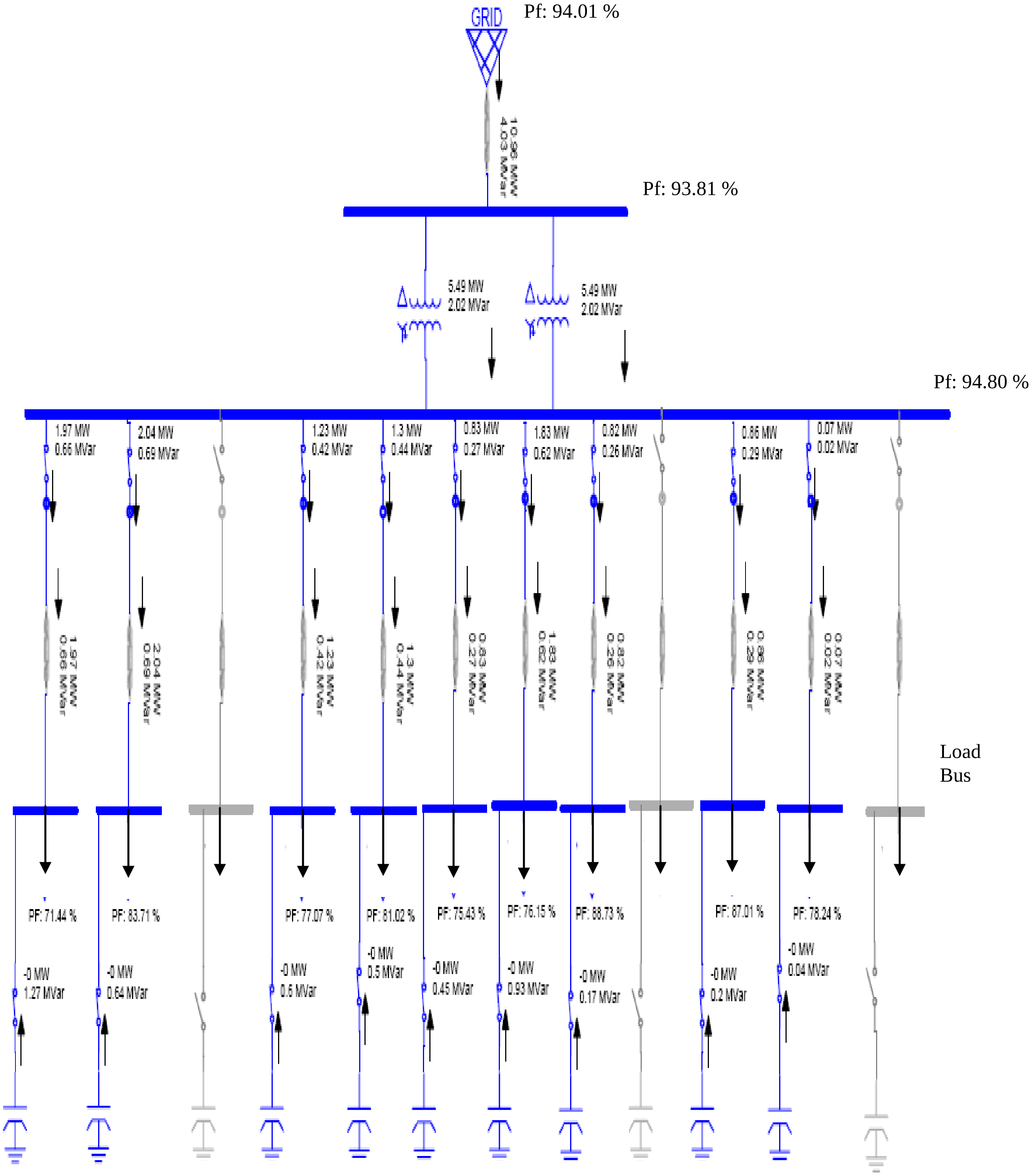

Figure (4): Power flow solution after shunt capacitors addition

Table (2): Total Generation and Demand after shunt capacitors insertion

	P(MW)	Q (MVAR)	S(MVA)	PF (%)
Swing Buses	10.96	4.103	11.636	94.01
Generator	0	0	0	0
Shunt	0	4.792	4.792	0
Static Load	10.89	8.73	13.75	94.80
Motor Load	0	0	0	0
Total Loss	**0.025**	0.399		

Third step: Power losses and Energy Reduction Calculation

The total reduction in the power losses due to the reactive power compensation using capacitors in specific location to enhance the power factor is calculated as follow:

$\Delta P_{loss} = P_{loss,\ before\ cap} - P_{loss,\ after\ cap}$

$P_{loss} = 0.039 - 0.025 = 0.014$ MW = 14 kW

The final energy saving calculation after capacitors insertion to the Iraqi National Grid distribution system in Baghdad region where an industrial 11 kv system had been chosen is shown in Table (3), from which it is obviously appears that; the insertion or addition of the shunt capacitors to the industrial network will save around 120.96 MWhr or 435456 MJ of energy every year. The major advantage of this compensating simulation method show that; the shunt capacitors cost can be recovered within few years, if we know that the operating age for these compensating elements (capacitors) extended to 25 years old.

Table (3): Energy Saving Calculations

Period	Saved energy
One day	14 * 24 = 336 KWhr
One month	336 * 30 = 10080 KWhr
One year	10080 * 12 = 120960 KWhr

Conclusions

Power Factor Enhancement for an existing industrial power distribution network in the state of Iraq- Baghdad Region using an advanced measurement and a modern specialist scientific program to obtain accurate results, for the values and the locations of the required capacitors has been introduced and investigated in this study. The required compensating elements, here, are the shunt capacitors which are used for power factor correction or enhancement. Many goals have been achieved in this study, where in spite of the annual reduction in losses or energy saving of 120.96 MWhr (435456 MJ of energy for every one year), the power factor is enhanced to an excellent value (nearly 95 %), where reaching this value for such industrial loads give a remarkable excellent condition. The measurements for the On-site of the network loads and power factor have been conducted using power quality analyzer. The recorded power factor values has also been measured and recorded over 24 hours and for two cases, first in summer while the second in winter . The results of these measurements show a power factor for all network loads. An advanced program named EDSA power system analysis software has been used to model the network and to determine the network power losses and this has been done for the first time in Iraq for an existing actual case (in Baghdad Region). The reduction of the energy losses in that distribution 11 kv network has been obtained through the determined location and rating of shunt capacitors. The insertions of these compensating elements (shunt capacitors) have been located at the end of each 11 kV feeders.

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