Problems of energy supply of the main consumers of distributive networks of Iraq

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Abstract. The main purpose in this paper is to study the main features of the distribution network for Iraq, which showed that the distribution network is physically and morally obsolete. Analyzing of electrical distribution networks is considered of highest priority at the present time in Iraq. This paper presents efficient practical methods for calculating the main parameters of the distribution network based on scientific and practical fundamentals. In this work the analysis is based on the advanced RasterWin3 software as a tool for the calculation of a basic parameters for distribution network performing the required analysis. RasterWin3 software is practical and efficient analysis software used by many electrical companies worldwide. The distribution network calculation was implemented (11/33) kV. The calculation results showed that the voltage deviation exceeds the maximum permissible value and is 12% in normal mode and 40% in emergency mode. Power losses in the branches of the power system of Iraq reach 20% of the consumed electricity. This is justified by the low quality of electricity and overload of the power supply system.

1. Introduction

The state of Iraq is located in the Mesopotamian lowland, in the valley of the Tigris and Euphrates rivers in the Middle East, and covers an area of 444,000 km². In the south-east it lies near the Persian Gulf. Most of the territory is occupied by steppe and desert, however, irrigated lands are located in the valleys of the Tigris and Euphrates rivers. The climate is continental, with dry and exceptionally hot summers and relatively rainy, cool winters. Average temperature in winter ranges from 7 to 12 °C, and in summer - 34 °C (on some days they can reach 50 °C). The annual precipitation is 50–150 mm in the plains and up to 1,500 mm in the mountains [1–5].

The history of Iraq’s electric networks dates back to 1918, when the first Alaboukhana power plant built began generating electricity for the needs of the population. Thanks to the energy resources located in the republic, by 1990 the total generation capacity was 12,000 MW.

Iraq’s distributive networks consist of twenty-four 400/132 kV substations with a total transmission capacity of about 17,000 MVA. They are generally located near cities. Electric power networks of class 132 kV are represented by twenty-eight power lines, with a length of about 4,500 km. The system also includes two hundred and eight 132/33 kV substations with a total capacity of 27,000 MVA. The total length of distributive networks of 33 kV voltage class is about 12,000 km. All these substations are interconnected through the central control station. In addition, many 33/11 kV substations are
connected to the distributive networks of Iraq. The largest share of distributive networks falls on the line voltage of 11 kV with a total length of 52,000 km [6-10].

However, after two wars in the Gulf and an economic blockade, the conditions and technical completeness of the networks deteriorated sharply, which led to a significant overload of the power system of Iraq. For example, the electricity demand in Iraq for 2018 is about 18,000 MW, while the Iraqi power system generates about 1,5500 MW. Overloading Iraq’s distributive networks has many negative consequences, the main of which are [11-13]:

- voltage deviation;
- increase in power losses;
- reducing the life of electrical equipment;
- reduction of power quality.

Reducing the cost of electricity, as well as reducing losses in the distributive networks of Iraq is the main problem today.

2. Materials and Methods
To analyze the operation of the Iraqi energy system, a part of the distribution network was considered, containing 33 and 11 kV lines, shown in figure 1.

Figure 1. Fragment of the power supply circuit of Iraq
The calculation of the mode of the considered network is performed in the RastrWin3 software package, for steady-state and emergency operation.

RastrWin allows you to solve various problems, such as calculating, analyzing and optimizing the modes of electrical systems. A special feature of the software complex is a large number of design modules: starting with calculations of steady-state modes of electrical networks of any topology and voltage and ending with structural optimization in terms of voltage level, power loss and distribution of reactive power. The user interface should be mentioned because it is a tabular processor that allows individual or group correction and parameter input, the ability to sort the results of calculations by one or several columns, as well as the ability to “highlight” the data, depending on its value (for example, in the case of its output from normal values) [14-16].

3. Results

The initial data for the calculation of the regime are the topology and parameters of the equivalent circuit, which are presented in figure 2 and in table 1, 2.

Table 1. Initial data for branches

| Branch | Wire type     | Length (km) | Specific resistance (ohm / km) | Conductivity (cm / km) |
|--------|---------------|-------------|--------------------------------|------------------------|
| 33 кВ   |
| 0-1    | ACSR-150/24   | 21          | 0,198+j0,406                   | j2,75·10-6             |
| 1-13   | ACSR-120/19   | 19          | 0,249+j0,427                   | j2,66·10-6             |
| 0-22   | ACSR-150/24   | 20          | 0,198+j0,406                   | j2,75·10-6             |
| 22-34  | ACSR-120/19   | 17          | 0,249+j0,427                   | j2,66·10-6             |
| 11 кВ   |
| 2-3    | ACSR-95/16    | 5           | 0,25+j0,43                     | j2,36·10-6             |
| 2-4    | ACSR-95/16    | 4           | 0,25+j0,43                     | j2,36·10-6             |
| 2-5    | ACSR-95/16    | 4           | 0,25+j0,43                     | j2,36·10-6             |
| 2-6    | ACSR-95/16    | 3           | 0,25+j0,43                     | j2,36·10-6             |
| 2-7    | ACSR-95/16    | 3           | 0,25+j0,43                     | j2,36·10-6             |
| 2-8    | ACSR-95/16    | 4           | 0,25+j0,43                     | j2,36·10-6             |
| 2-9    | ACSR-95/16    | 4           | 0,25+j0,43                     | j2,36·10-6             |
| 2-10   | ACSR-95/16    | 5           | 0,25+j0,43                     | j2,36·10-6             |
| 2-11   | ACSR-95/16    | 3           | 0,25+j0,43                     | j2,36·10-6             |
| 2-12   | ACSR-95/16    | 4           | 0,25+j0,43                     | j2,36·10-6             |

Table 2. Passport data of transformers

| Transformer | Power (MVA) | BH (KV) | HH (KV) | RT (Ohm) | XT (Ohm) | ΔPxx (kBr) | ΔQxx (Kva) |
|-------------|-------------|---------|---------|----------|----------|------------|------------|
| T1          | 16          | 33      | 11,5    | 0,52     | 7,4      | 9,2        | 56,7       |
| T3, T4      | 10          | 33      | 11,5    | 0,96     | 11,1     | 14,5       | 80         |
| T2          | 5           | 33      | 11,5    | 1,48     | 15,2     | 60         | 96         |

The calculation results for the 11 kV network are presented on the example of the first transformer substation. The values of the parameters of nodes and branches when calculating the minimum, maximum and emergency modes are presented in table 3, 4.
Figure 2. The replacement scheme of the electrical network of Iraq

From the results of the calculation of the steady-state mode, it can be seen that in the nodes of the power system of Iraq, the voltage deviation from the nominal is about 12%. In emergency situations, the voltage deviation can reach 40%. Normally, the allowable voltage deviation from the nominal value according to IEEE Std 1366-2012 should be no more than ± 5%, and the maximum allowable no more than ± 10%. Non-compliance with the requirements of the standard indicates the unreliability of the electricity grid and the low quality of electricity.

Electricity losses in the branches of the electricity system of Iraq reach about 20% of the electricity consumed. This is due to the low power factor and significant overload of the power supply system.

4. Discussion
To improve the quality of electricity and reduce power losses in the power system of Iraq, you can use various methods such as: voltage regulation with the help of on-load tap-changers, installation of a battery of static capacitors (BSC), installation of longitudinal and transverse compensation devices, installation of static thyristor compensators (STC) or static compensator (STATCOM).
| Mode | №  | S (MVA) | Angle (°) | V (KV) | ΔV, % |
|------|-----|---------|-----------|--------|-------|
| 3    | 1.8+ j0,9 | -10,08  | 9,58      | 12,95  |
| 4    | 1.9+ j    | -9,78   | 9,64      | 12,39  |
| 5    | 1.8+ j0,9 | -9,79   | 9,68      | 12,01  |
| 6    | 1.9+ j    | -9,51   | 9,75      | 11,32  |
| 7    | 1,7+ j0,8 | -9,47   | 9,80      | 10,90  |
| 8    | 2,0+ j0,9 | -9,99   | 9,65      | 12,27  |
| 9    | 2,1+ j1,2 | -9,87   | 9,58      | 12,88  |
| 10   | 1,9+ j    | -10,12  | 9,54      | 13,32  |
| 11   | 1,7+ j0,8 | -9,47   | 9,80      | 10,90  |
| 12   | 2,0+ j    | -9,92   | 9,63      | 12,43  |

**Steady**

| Mode | №  | S (MVA) | Angle (°) | V (KV) | ΔV, % |
|------|-----|---------|-----------|--------|-------|
| 3    | 1,8+ j0,9 | -23,63  | 5,57      | 49,36  |
| 4    | 1,9+ j    | -22,90  | 5,68      | 48,37  |
| 5    | 1,8+ j0,9 | -22,90  | 5,75      | 47,74  |
| 6    | 1,9+ j    | -22,26  | 5,88      | 46,58  |
| 7    | 1,7+ j0,8 | -22,15  | 5,95      | 45,91  |
| 8    | 2,0+ j0,9 | -23,38  | 5,70      | 48,18  |
| 9    | 2,1+ j1,2 | -23,14  | 5,59      | 49,22  |
| 10   | 1,9+ j    | -23,75  | 5,50      | 50,00  |
| 11   | 1,7+ j0,8 | -22,15  | 5,95      | 45,90  |
| 12   | 2,0+ j    | -23,22  | 5,67      | 48,45  |

**Emergency**

| Mode | №  | S (MVA) | Angle (°) | V (KV) | ΔV, % |
|------|-----|---------|-----------|--------|-------|
| 3    | 1,8+ j0,9 | -10,08  | 9,58      | 12,95  |
| 4    | 1,9+ j    | -9,78   | 9,64      | 12,39  |
| 5    | 1,8+ j0,9 | -9,79   | 9,68      | 12,01  |
| 6    | 1,9+ j    | -9,51   | 9,75      | 11,32  |
| 7    | 1,7+ j0,8 | -9,47   | 9,80      | 10,90  |
| 8    | 2,0+ j0,9 | -9,99   | 9,65      | 12,27  |
| 9    | 2,1+ j1,2 | -9,87   | 9,58      | 12,88  |
| 10   | 1,9+ j    | -10,12  | 9,54      | 13,32  |
| 11   | 1,7+ j0,8 | -9,47   | 9,80      | 10,90  |
| 12   | 2,0+ j    | -9,92   | 9,63      | 12,43  |

**Table 4.** Branch parameters values

| Mode | №  | №  | S (MVA) | Angle (°) | V (KV) |
|------|-----|-----|---------|-----------|--------|
| 3    | 1,8+ j0,9 | -10,08  | 9,58      | 12,95  |
| 4    | 1,9+ j    | -9,78   | 9,64      | 12,39  |
| 5    | 1,8+ j0,9 | -9,79   | 9,68      | 12,01  |
| 6    | 1,9+ j    | -9,51   | 9,75      | 11,32  |
| 7    | 1,7+ j0,8 | -9,47   | 9,80      | 10,90  |
| 8    | 2,0+ j0,9 | -9,99   | 9,65      | 12,27  |
| 9    | 2,1+ j1,2 | -9,87   | 9,58      | 12,88  |
| 10   | 1,9+ j    | -10,12  | 9,54      | 13,32  |
| 11   | 1,7+ j0,8 | -9,47   | 9,80      | 10,90  |
| 12   | 2,0+ j    | -9,92   | 9,63      | 12,43  |

**Steady**

| Mode | №  | №  | S (MVA) | Angle (°) | V (KV) |
|------|-----|-----|---------|-----------|--------|
| 3    | 1,8+ j0,9 | -23,63  | 5,57      | 49,36  |
| 4    | 1,9+ j    | -22,90  | 5,68      | 48,37  |
| 5    | 1,8+ j0,9 | -22,90  | 5,75      | 47,74  |
| 6    | 1,9+ j    | -22,26  | 5,88      | 46,58  |
| 7    | 1,7+ j0,8 | -22,15  | 5,95      | 45,91  |
| 8    | 2,0+ j0,9 | -23,38  | 5,70      | 48,18  |
| 9    | 2,1+ j1,2 | -23,14  | 5,59      | 49,22  |
| 10   | 1,9+ j    | -23,75  | 5,50      | 50,00  |
| 11   | 1,7+ j0,8 | -22,15  | 5,95      | 45,90  |
| 12   | 2,0+ j    | -23,22  | 5,67      | 48,45  |

**Emergency**
Different sections of the power system are characterized by different values of voltages, which are determined primarily by the load and the network diagram. The on-load tap-changer provides for voltage regulation in various limits depending on the power and voltage of transformers (from ± 10 to ± 16% in steps of approximately 1.5%). The adjustment steps are carried out on the high voltage side, since the lower value of the current makes it easier to switch the device. To extend the control range without increasing the number of branches, coarse and fine adjustment steps are used.

The use of BSC allows reducing the reactive power flows in the network, which leads to a significant reduction in active energy losses in the networks of 11-132 kV, and this, in turn, reduces the load on power lines and network transformers. Increasing the power ratio in the trunk and distribution power facilities makes it possible to increase their throughput without increasing the power of transformers and building or upgrading power lines. The main functions of BSC are voltage regulation and reduction of energy losses [17-18].

Longitudinal compensation devices (LCD) (figure 3) contribute to increasing the capacity of overhead lines and ensuring more efficient operation of existing power lines. The composition of the LCD in the form of batteries includes longitudinal compensation capacitors, which are included in the electric transmission lines in series to compensate for some part of the inductive longitudinal resistance. Due to this, the capacity of overhead lines increases significantly [19-20].

![Figure 3. Longitudinal compensation device](image)

For longitudinal reactive power compensation, the capacitors are connected in series with the load via isolating or booster transformers. Longitudinal compensation provides automatic regulation of the voltage depending on the load current. However, with longitudinal compensation, emergency modes occur. Their causes may be Ferro resonance oscillations, over voltages during capacitor bypassing, internal damage to capacitors.

Static thyristor compensator (STC) is a device for smooth control of reactive power and keeping its value within the specified limits. The principle of operation of the STC is based on the parallel inclusion in the network of filter-compensating circuits that perform the function of high-harmonic filters and thyristor-reactor reactors switched by thyristors.

STC functions when it is installed on power lines [21-24]:
- voltage stabilization;
- lower harmonic levels;
- reduction of voltage fluctuations in the supply network;
- load balancing.

STATCOM is a controlled static device, connected between two AC systems, consisting of a connecting transformer connecting the power supply system with a synchronous controller that generates
voltage pulses, comparing them with one of the electrical systems to realize the exchange of reactive power (figure 4) [25].

![Connecting diagram STATCOM](image)

**Figure 4.** Connecting diagram STATCOM

The control system STATCOM at each time of the reverse voltage regulates so that the power supplied to the network, in these conditions were equal to zero.

5. Conclusion
Based on the analysis performed, it can be concluded that the voltage deviation in the networks of Iraq exceeds the permissible maximum, which indicates the need to use distributed generation.

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References
[1] Averbukh M A and Abdulwahhab M W 2018 Influence of Non-Sinusoidality of Voltage on Electricity Loss in Distribution Networks *Journal of Physics: Conference Series* IOP Publishing 1066(1) pp 12-4
[2] Saeed I M, Ramli A T and Saleh M A 2016 Assessment of sustainability in energy of Iraq, and achievable opportunities in the long run *Renewable and Sustainable Energy Reviews* 58 pp 1207-15
[3] Ter-Martirosyan A and Kwoka J 2010 Incentive regulation, service quality, and standards in US electricity distribution *Journal of Regulatory Economics* 38(3) pp 258-73
[4] Rao L, Liu X, Xie L and Liu W 2010 Minimizing electricity cost: optimization of distributed internet data centers in a multi-electricity-market environment *INFOCOM Proceedings IEEE*. pp 1-9
[5] Branker K, Pathak M J M and Pearce J M 2011 A review of solar photovoltaic levelized cost of electricity *Renewable and sustainable energy reviews* 15(9) pp 4470-82
[6] Saeed I M, Ramli A T and Saleh M A 2016 Assessment of sustainability in energy of Iraq, and achievable opportunities in the long run *Renewable and Sustainable Energy Reviews* 58 pp 1207-15
[7] Hu J, Zhu J and Platt G 2011 Smart grid-the next generation electricity grid with power flow optimization and high power quality *Electrical Machines and Systems (ICEMS) International Conference on IEEE* pp 1-6
Sadorsky P 2009 Renewable energy consumption and income in emerging economies Energy policy 37(10) pp 4021-8.

Dihrab S S and Sopian K 2010 Electricity generation of hybrid PV/wind systems in Iraq Renewable Energy. 35(6) pp 1303-7.

Payne J E 2010 A survey of the electricity consumption-growth literature Applied energy 7(3) pp 723-31.

Averbukh V A, Zhilin V E and Roschubkin P V 2017 Experimental Analysis of Electrical Modes in a Residential Estate Electrical Power Supply System Journal of Engineering and Applied Sciences 12 pp 3446-51.

AL-TAHIR A L I A L R 2008 Methods of improving perfomance for electrical power systems in Iraq Journal of kerbala university 6(4) pp 14-32.

Obais A M and Pasupuleti J 2011 Harmonics reduction of thyristor controlled reactor with minimal no load operating losses IET Generation, Transmission & Distribution 2(7) pp 261-9.

Bliznyuk D I, Bannykh P Y and Khalyasmaa A I 2015 Power Flow Calculation Realization in Software for Grids with Four-Phase Power Lines Applied Mechanics and Materials. – Trans Tech Publications 698 pp 694-8

Averbukh M, Prasol D and Khvorostenko S 2017 E’kperimental’naya ocenka parametrov rezhimov v vy’ sokovol’nny’x shaxtny’x setyax s moshhny’m nelineiny’m c’lektricheskim priemnikom [Experimental estimation of parameters of regimes in high-voltage mine networks with powerful non-linear electric receiversol] Vestnik Irkutskogo gosudarstvennogo tehnicheskogo universiteta vol 2 pp 75-84 [In Russian]

Dolinger S, Lyutarevich A and Goryunov V 2013 Ocenka dopolnitel’ny’x poter’ moshhnosti iz-za snizheniya kachestva e’lektricheskoy e’nergii v e’lementax sistemy’ e’lektrosnabzheniya [Estimation of additional power losses due to a decrease in the quality of electrical energy in the elements of the power supply system] Omskij nauchnyj vestnik vol 2 pp 178-83 [In Russian]

Kartashev I, Tulsky V and Chamonov R Upravlenie kachestvom e’lektroe’nergii [Electricity quality management] (Izdatel’stvo ME’I) vol 3 [In Russian]

Averbukh M, Kuznetsov V and Korzhov D 2013 Problemy’ obespecheniya e’lektromagnitnoj sovmestimosti v e’lektroustanovkax promy’shleny’x predpriyatiy [Problems of ensuring electromagnetic compatibility in electrical installations of industrial enterprises] Bulletin of Belgorod State Technological University named after V G Shukhov vol 5 pp 203-7 [In Russian]

Demirci T et al 2011 Nationwide real-time monitoring system for electrical quantities and power quality of the electricity transmission system IET Generation, Transmission & Distribution 5(5) pp 540-50.

Dihrab S S and Sopian K 2010 Electricity generation of hybrid PV wind systems in Iraq Renewable Energy 35(6) pp 1303-7.

Hazaa H K et al. 2011 Evaluation of electric energy losses in kirkuk distribution electric system area Iraqi Journal for Electrical And Electronic Engineering. 7(2) pp 144-50

Ostovar F and Legha M M 2013 An imperialist competitive algorithm for siting and sizing of distributed generation in radial distribution network to improve reliability and losses reduction Iraqi Journal for Electrical And Electronic Engineering 9(2) pp 59-66

Zehra E J A, Moghavvemi M, Hashim M M I and Muttaqi K 2010 Network reconfiguration using PSAT for loss reduction in distribution systems Energy, Power and Control (EPC-IQ), 2010 1st International Conference on IEEE pp 62-6

Kazem H A and Chaichan M T 2012 Status and future prospects of renewable energy in Iraq Renewable and Sustainable Energy Reviews 16(8) pp 6007-12

Rao P, Crow M L and Yang Z 2000 STATCOM control for power system voltage control applications IEEE Transactions on power delivery 15(4) pp 1311-7