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Study and Analysis of Power Quality for an Electric Power Distribution System– Case Study: Moscow Region

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Abstract—In this paper, a case-study analysis of radial distribution system of Moscow region is presented. This is a part of a research project on Moscow region in Russia. The purpose of this project is to improve the power quality of an important radial distribution system of Moscow region by measuring and analysis the data of the system; and then solving the problems of power quality in this system. This paper shows the practical measurement and analysis of the radial distribution system, which has important loads with high power quality disturbances. In this study, a study and analysis of voltage profile disturbances considering over and under voltage has been provided as power quality disturbance. In addition, the voltage drops and power losses are calculated during simulation. Also, suggestions of a suitable solution to mitigate these problems have been discussed. The power distribution system has been modeled in order to simulation modeling and analysis using Matlab/Simulink.

Keywords—Power Quality; Distribution power system; Capacitor placement; Reactive Power Compensation.

I. INTRODUCTION

An increasing demand for high quality, reliable electrical power, and increasing number of distorting loads may lead to an increased awareness of power quality both by customers and utilities. The problems in power quality have a major

concern among researchers and engineers. It would be useful and necessary to monitor and study the power quality disturbances to mitigate these problems for improving the power quality of the distribution system.

Recently, the importance of power quality has increased because of various reasons [1-3]. There have been amount of changes in the nature of electrical loads. The characteristics of load have become more complex due to integration of the power electronic equipment, which results in a disturbance of voltage and current. On another hand, equipment have become more sensitive to power quality.

According to the IEEE defined standard (IEEE Std. 1100, 1999), power quality is “The concept of powering and grounding electronic equipment in a manner suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment”. Some authors use the term ‘voltage quality’ and others use ‘quality of supply’ to refer to the same issue of power quality. Others use the term ‘clean power’ to refer to an intolerable disturbance free supply. The definition of power quality disturbances according to the standards [3-10] as: IEC (International Electro technical Committee), IEEE Std. 1159:1995, IEEE Std. 1346-1998 and GOST Russian standard are shown in table I.

TABLE I. THE DEFINITION OF POWER QUALITY DISTURBANCES

Disturbance	Short-definition
Interruption	Voltage magnitude is zero
Under voltage	Voltage magnitude is below its nominal value
Over voltage	Voltage magnitude is above its nominal value
Voltage sag	A reduction in RMS voltage over a range of 0.1-0.9 pu for a duration greater than 10 ms but less than 1 s
Voltage swell	An increase in RMS voltage over a range of 1.1-1.8 pu for a duration greater than 10 ms but less than 1 s
Flicker	A visual effect of frequency variation of voltage in a system
Voltage/Current unbalance	Deviation in magnitude of voltage/current of any one or two of three phases
Ringing waves	A transient condition which decays gradually
Outage	Power interruption for not exceeding 60 s duration due to fault or maltripping of switchgear/system
Transients	Sudden rise of signal
Harmonics	Non-sinusoidal wave forms

Since there are various types of power quality disturbances that all users may face, it is necessary to perform analysis in order to evaluate the types of power quality problems with their affection on the distribution system. These analyses include measurement, monitoring and mitigation of the power quality problems in the system.

Installation of shunt capacitors in distribution networks is essential for power flow control, improving system stability, power factor correction, voltage profile management and losses minimization. Many techniques have been developed for solving the capacitor placement problem: analytical techniques, numerical programming, heuristic or artificial intelligence (AI)-based techniques [11]. Among these methods, heuristic or AI optimization techniques have been widely applied to solve the optimal capacitor placement problem. AI is a powerful knowledge-based approach that can address the nonlinearity of practical systems. AI can decrease the mathematical complexity and has a rapid response, which can be utilized for transient analysis. Moreover, optimal capacitor planning based on the fuzzy logic algorithm was implemented to present the imprecise nature of its parameters or solutions in practical distribution systems [12-13]. Reference [13-14] applied the Tabu search technique to determine the optimal capacitor planning in Chiang et al's [14] distribution system, and compared the results of the TS with the SA. In [13, 15], genetic algorithms (GA) were implemented to obtain the optimal selection of capacitors, but the objective function only considered the capacitor cost and power losses without involving operation constraints. The reactive power is minimized using particle swarm optimization (PSO) algorithm [16].

The objective of this project of Moscow region in Russia is to improve the power quality of the biggest and important distribution systems, which they are suffering from various power quality problems.

In this paper, a case-study of radial distribution system of Moscow region is introduced. This system includes important users (loads), which suffering from many types of power quality problems. The practical measurements of the Moscow region distribution system have been carried-out. Moreover, a study and analysis of voltage profile disturbances considering over and under voltage according to GOST standard and table I. In addition, the voltage drop and power losses are exist in this network and have the same cause with voltage profile disturbances. Also, suggestion of a suitable solution to mitigate these problems has been discussed.

The remainder of this paper can be outlined as follows: section II, the Moscow region distribution system history, section III, the analysis distribution system results and their affection on power quality, section IV, suggesting a suitable solution to improve the power quality by mitigation of its problems, section V, conclusion.

II. THE MOSCOW REGION DISTRIBUTION SYSTEM HISTORY

Most of the current use of distribution networks in the Moscow region was designed and built in the 60th-70th years.

These networks were planned for the future 15-20 years from the date of installation, and did not anticipate a fundamental change in the load nowadays. Generally load in this region was rural or small towns. Density of load was low, and long distribution networks were used.

With the development of electrical appliances and the increasing in the total power of household consumers and technological electro-receivers, causes the networks reconstructed. While the grid structure remained the same.

In the 2000th year there was a new increase in the load, which is accompanied by a change in the structure of energy consumption. Former rural area was rebuilt for residential or industrial complexes and the small towns extended and grew. At the end of the 2000th year, had a situation, where the large loads were connected to "weak" and long networks, which this situation become worse.

In 2014 year, a large-scale research of power quality in distribution networks was in Moscow region. Considering power quality standard of Russian GOST [6-8] as in section I, the measurements have been take place in two weeks, which one week in winter and the other in summer seasons.

In this paper one of the examined feeders is presented, which contains typical power quality disturbances. Power quality was measured on primary substation (6 KV) and on six nodes at secondary substation (0.4 KV) uniformly distributed in the grid as a case study in this paper. Based on the measured results, the network regimes were modeled with maximum and minimum loads.

III. ANALYSIS OF DISTRIBUTION SYSTEM RESULTS AND THEIR AFFECTION ON POWER QUALITY

The disturbances causing power quality degradation arising in power distribution system are shown in Table I. This affects the performance and life time of the end user equipment. To improve the power quality in the distribution system, the problems due to the development of technology and increasing the active and reactive power demand have been measured and analyzed. The monitoring and analysis of the distribution system help us to know the type of problems and how to affect on power quality performance [3], [9] and [18].

The cost of poor or weak power quality has been estimated from tens of thousands to millions of dollars depending on the customers sensitivity and sensitivity of power quality disturbances [17] and [19-23] in small and big networks consequently.

The measurements have been taken place for a lot of distribution systems in Moscow region to assess the power quality and then to mitigate and improve the problems of these systems with considering the Russian GOST standard [6] as in section I.

In Fig. 1, it was show, 111 nodes (buses) have been selected from the power distribution and power quality parameters. They are recorded over two-weeks, one week in summer and the other week in winter season at the important loaded nodes (buses) and evaluate the rest of nodes systems.

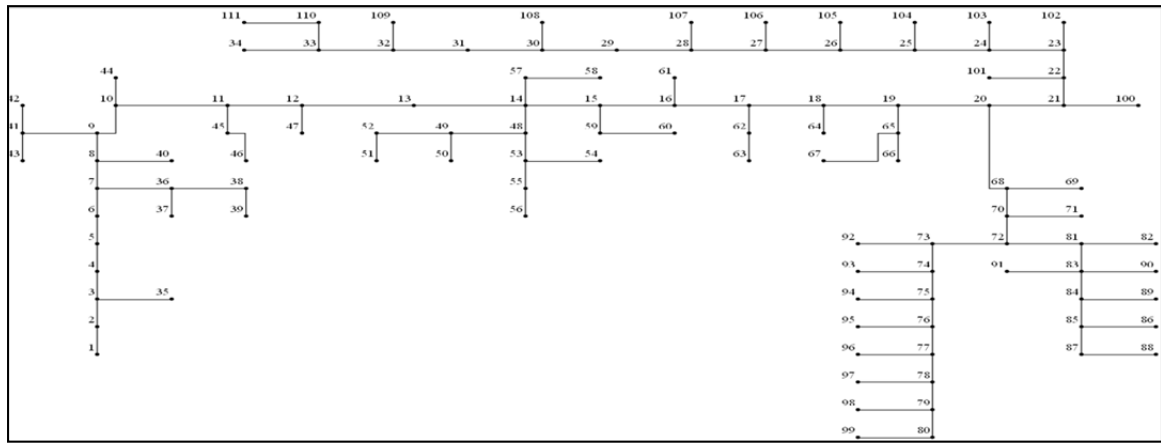


Fig.1. 111 nodes of radial distribution system.

These measurements were done by using a power quality analyzer device that was shown in fig. 2.



Fig.2. The power quality analyzer device (UF2M-3T52-5-100-1000).

To make sure the other nodes were evaluated correctly, the random nodes were tested. In this paper, a case study of our measurements and analysis to show the voltage profile (U), voltage drop (ΔU) and the power losses (ΔP) of the radial distribution system has been provided.

Fig.3 show that, small screenshot of voltage profile with time only at 6 load buses (at buses: 29, 34, 50, 56, 67, 111, and the primary substation bus "PS") from all our measurement as a case study in winter and in summer to show part from the practical project measurement. It is important to know, that the primary substation bus "PS" was measured at medium voltage 6 KV, and the load buses were measured at low voltage 0.4 KV. Because of the transformers and the low voltage buses are not modeled in this case study. As shown in Fig. 3, that in the winter season, the voltage profile below the standard limits than in the summer season, and in summer season, the voltage profile is almost above standard limits, which they increased the power quality disturbances.

Fig.4 shows that, the measurement of Voltage profile in the summer and in winter seasons at the loaded buses of radial distribution system. In the winter the voltage decreases remarkably below the limits ($< 0.9 U_p$) at the loaded buses than in the summer, which caused disturbances in voltage profile and increases in voltage drop and the power losses. So, in this paper the worst case study from our measurements in winter season to show voltage profile, voltage drop, and power losses, has been provided, which they are shown in figs.5, 6, 7, and 8. Note that in our evaluation: The base of the radial distribution system at slack-bus-1: Voltage base=6 KV, Apparent Power (S) =3158,58 KVA, Active load power=2370 KW and Reactive load power=2088 KVAR.

The voltage drops in distribution lines is shown in Fig. 6, where it was higher at distribution lines 2-3, 6-7, and 12-13 than the others, because of the long lengths of these lines.

Always the power losses are accompanied with the delivery of power from sources to the consumers. The amount of losses has a direct effect on the financial issues and the overall efficiency of distribution utility systems. Also, the power losses have a very high impact on the distribution system, which cause the units at the distribution system are lost and increase the electricity cost at the generation side. As shown in Fig. 7, the power losses with buses are higher in distribution lines 2-3, 6-7, 4-5, and 12-13 than the others.

As a result, from figs. 5, 6 and 7, as known, the power flow at the beginning of the distribution system (near the primary substation) is greater than at the end of the system. So, from figures at the beginning of the distribution system, if there were long distribution lines with a big power flow, there will be a big voltage drop and power losses, but if there were long distribution lines at the end of the distribution system, there were a small power flow, so the voltage drop and power losses will be appropriated. So, the long line with a big power flow the worst case. Fig.8 shows the load data of the active load power and the reactive load power at load buses for 111-Bus radial distribution system.

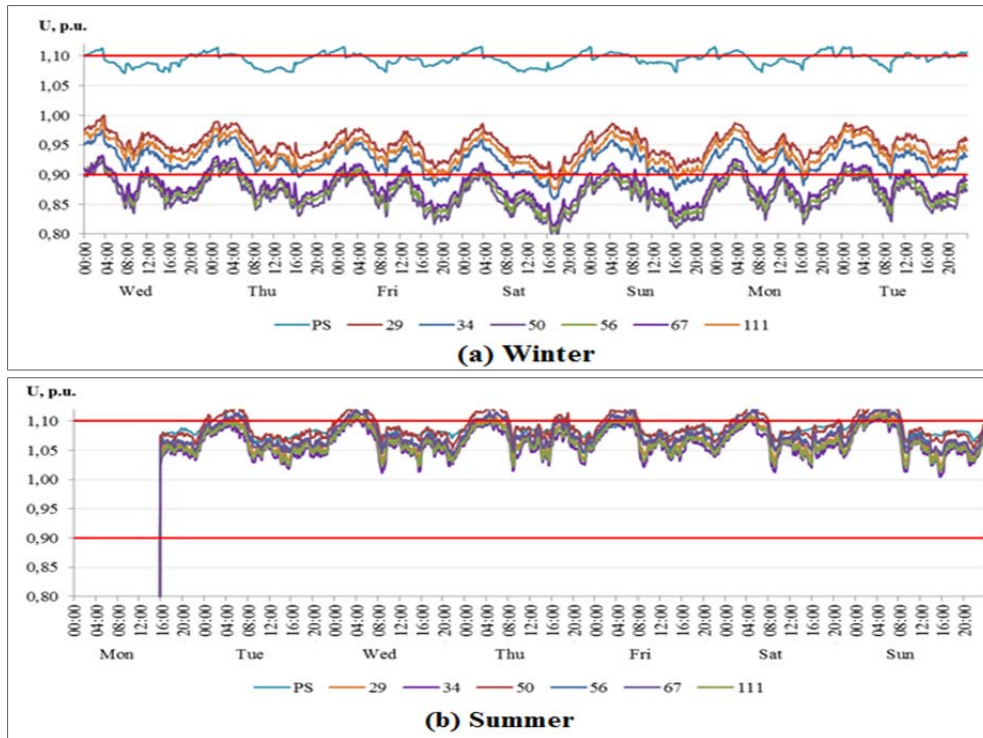


Fig.3. Measurement of voltage profile of radial distribution system in the (a) winter & (b) summer

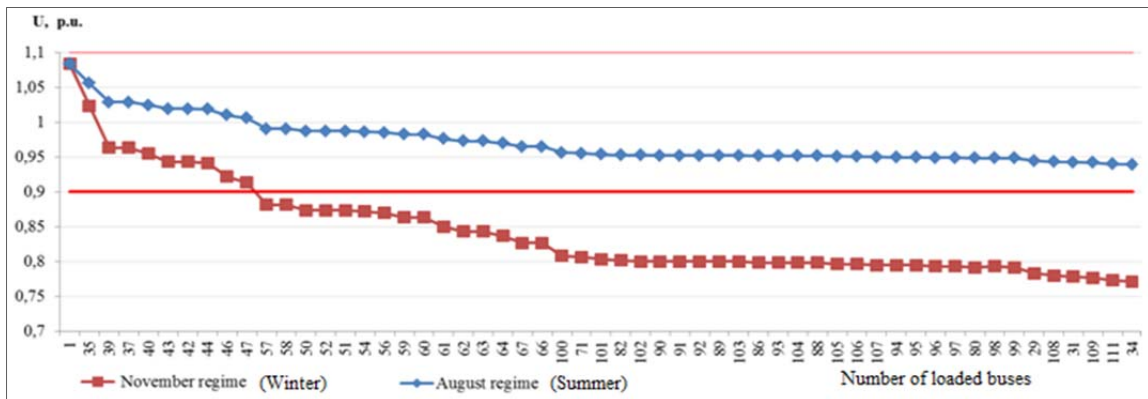


Fig.4. Measurement of voltage profile at the loaded buses of radial distribution system in the summer and winter seasons

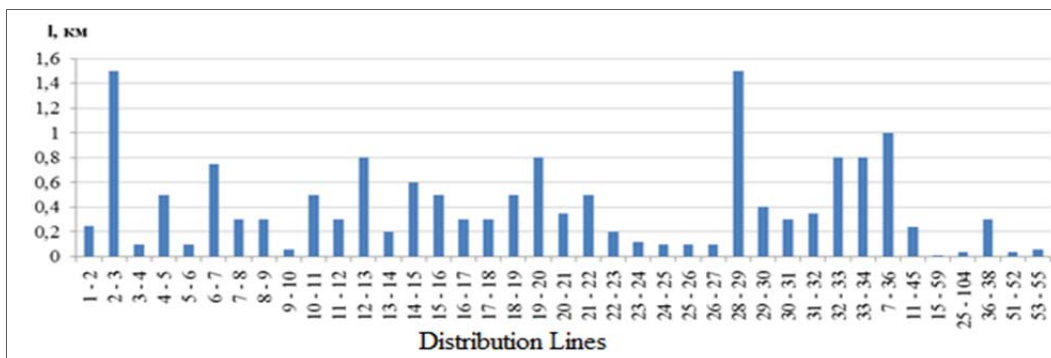


Fig.5. The lengths (L, KM) of distribution lines

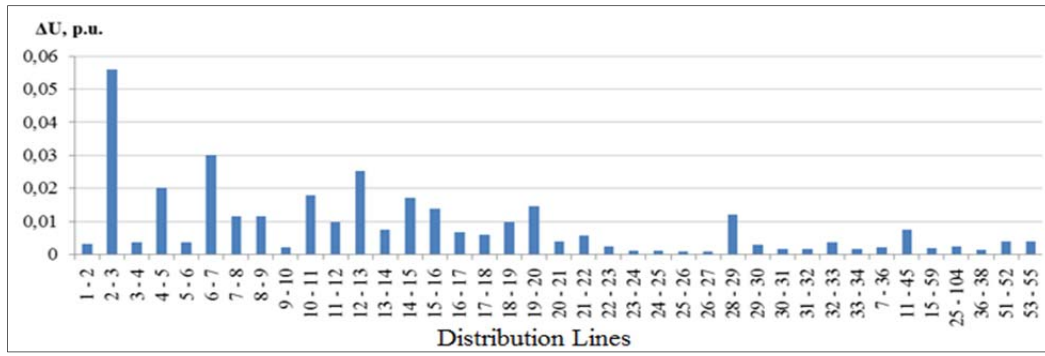


Fig.6. Voltage drop (ΔU , p. u.) in distribution lines

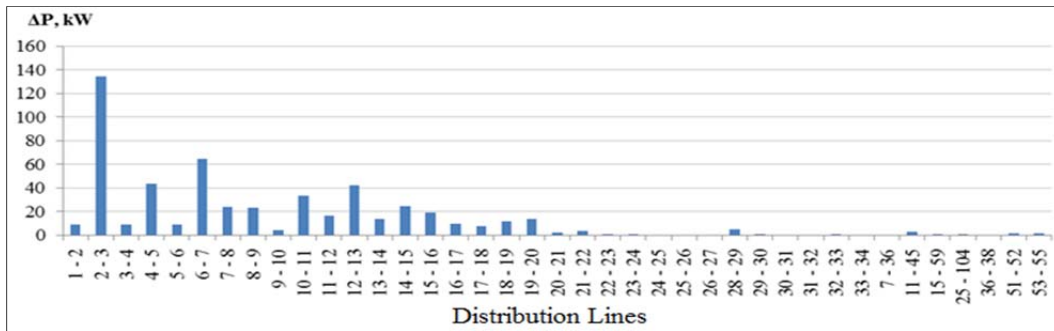
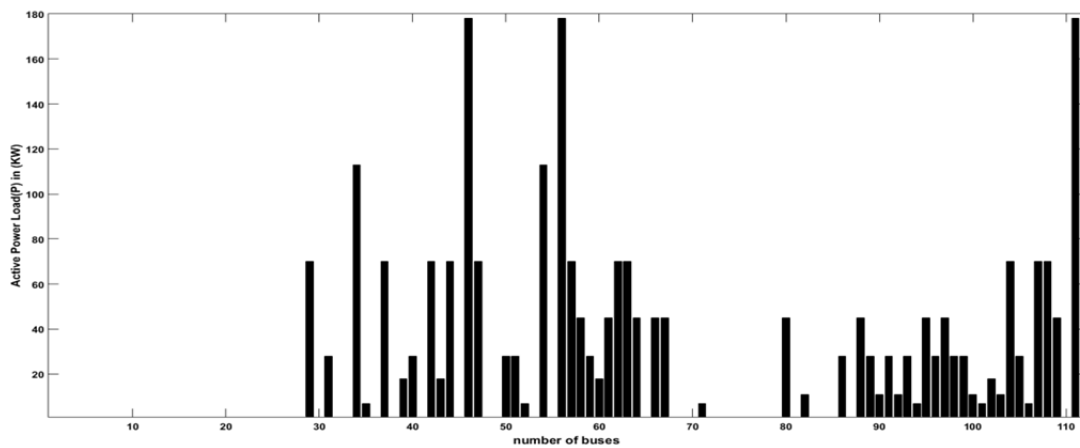
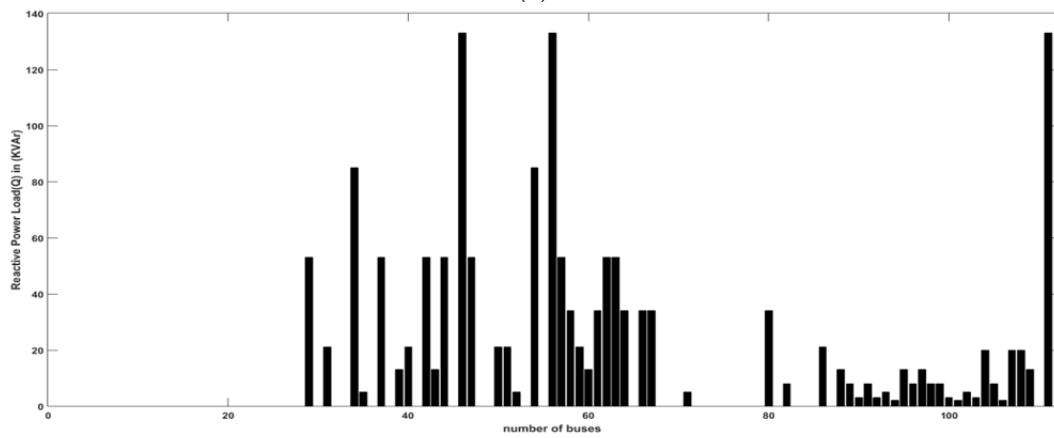


Fig.7. Power losses (ΔP , kW) distribution lines of radial system



(a)



(b)

Fig.8. Load data: (a) Active Power Load at load buses and (b) Reactive Power Load at load buses for 111-Bus radial distribution system.

IV. SUGGESTING A SUITABLE SOLUTION TO IMPROVE THE POWER QUALITY BY MITIGATION OF ITS PROBLEMS

Nowadays, with increase in load demand, the distribution system is becoming more complex and due to increase in loads it tends to increase the systems losses and for that reason the voltage profile is decreasing badly. At heavily loaded conditions the reactive power flow causes significant losses and also causes reduction in voltage level. So, it is the duty of an electrical engineer in distribution companies to minimize the power loss and also to make appropriate voltage profile. Many mitigation techniques are recommended to mitigate the problems of power quality [3]. But in our case study, there are major problems: low voltage and heavy losses, due to a large extent of the network and large overflows of active and reactive power. There are the following possible solutions in our distribution system case study: (i) Increase the rated voltage of the network for example to 10 kV instead of 6 kV as in the case study with increasing in cross section wires, but this method is very expensive ((un-logical solution)). (ii) Active power generating by distribution source (distribution generators) for example in Ref. [24], but it is very expensive also. (iii) Line voltage regulator [4] to improve the voltage profile, but the power losses are still found. (iv) The compensation of reactive power is a suitable solution for our case study, because of the major problems occurring in the distribution system [19] such as: high reactive power (VAR) demand, high voltage drop, reduced system capacity, high amount of losses in the system, and inherently unbalanced distribution system. Also, the need of reactive power in distribution system [3] and [7-8], because: the reactive power (VARs) is required to maintain the voltage to deliver active power (WATTS) through the grid, "Indexing of Active Power consumption is called reactive power", electro-mechanical devices and other loads require reactive power, and reactive power deficiency causes the voltage to sag down.

The importance of Reactive power compensation [3] and [7-8] has a strong effect on system voltages, which it must balance in the grid to prevent voltage problems. Also, reactive power levels have an effect on voltage collapse, due to deficiency of reactive power in the grid the blackout occurs. The types of reactive power compensation sources are considered in Table II [26-28].

So, the lowest cost and economical is capacitor banks [26-28]. The problem of slow speed of response was solved by special applications as in Ref [26], where they will be reconnected to introduce the supporting voltage for the power system. The other problems are the ability of capacitor banks is poor and drops with U^2 . In addition to the installations of shunt capacitors leads to a reduction in total amount of current that would need to be transferred through the equipment of distribution network. These problems are due to the capacitor allocation (Placement) in distribution system [3]. These problems can be solved by [3], [25] and [29- 33]: The determining of the optimal locations, sizes, and number of capacitors banks to be installed within a distribution system based on intelligent technique. Also, to increase the reliability and reduction in monthly demand charge of capacitor banks,

they should be installed near the consumers' points. It's an economically viable project as cost savings.

The capacitor banks types in radial distribution system are series or shunt capacitors [31], where the Series capacitors cause increasing in the maximum power limit, while shunt capacitors have several benefits. Some benefits of the shunt capacitors are [29-31]: reduce real and reactive power loss in the system, improve voltage regulation, increase voltage level at the load and power factor of source, improve stability, and improve power factor of the system, etc.

There are a lot of methods implemented for capacitor placement problem solutions; these include Artificial Intelligence and Conventional [30]. The methods based on Conventional Approach includes (a) Numerical Programming, (b) Heuristic Method, (c) Analytical Approach method, where the Artificial Intelligence methods contain (a) Artificial Neural Network, (b) Genetic Algorithm, (c) Ant Algorithm, (d) Particle Swarm Optimization, (d) Fuzzy Logic, (e) Simulated Annealing. It is found in Ref. [30] that the Artificial Intelligence methods are better than the classical methods.

CONCLUSION

A practical distribution power system has been considered under study and analysis. The practical measurements of the Moscow region distribution system have been presented. The power distribution system has been modelled. The power flow is calculated based on the practical measurements and data. A suggestion of the suitable methods to improve the power quality by using capacitor banks compensation. Moreover, the best allocation and size of capacitor banks can be determined based on optimization techniques such as PSO and genetic algorithm.

Voltage profile disturbances are very spread in Russian distribution grids. In the networks with high demand of reactive power this problem can be solved by compensating of reactive power. For regulating reactive power in steady states could be used capacitors banks. These devices are most economical and appropriate solution for this issue.

There should be used intelligent optimization methods for proper placing and choosing rated power. Also, should be considered load curve to define number of fixed and variable capacitors banks.

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