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Step Voltage Regulator and Capacitor Placement to Improve the Performance of Rural Electrical Distribution Systems by CYME Program

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Abstract. There are several techniques used to ensure acceptable values for voltage, reduce energy loss in distribution systems and power factor improvement .In this research, techniques of capacitors placement and the automatic voltage regulator have been used to improve the distribution sys-tems performance and to ensure good serve to all consumers. Where, each technique has been ap-plied in individual case. The proposed tool is CYME 7.1 software which has been applied on a re-alistic distribution system for the Abu Ghraib region. This region is supplied with electric power through the AL Zaitoon secondary station, which is located within the Iraqi distribution network. All results for both cases were recorded in different tables and compared to each other to find the appropriate technique for realistic distribution system for its current status.

1.   Introduction

An Electrical Distribution System (EDS) is the final stage of the electrical power system, consisting of several feeders and branches most of these feeders are radial, because they are low-cost and are not complicated in terms of coordinating the work of protective equipment [1]. The role of EDS is to deliver electricity from overhead transmission lines to each consumer separately, at an appropriate voltage level, the acceptable limits of voltage is ±5% from system voltage according to International Electro Technical Commission standards (IEC) [2].The electrical distribution system suffers from several problems that reduce its efficiency and reliability, such as voltage drop and energy losses [3]. The voltage drop to unacceptable limits is one of the most important issues facing EDS. Many factors, which causing voltage drop such as the increasing demand for electrical energy and expansions imposed for EDS. Maintaining the level voltage of electrical power supplies to all consumers within the acceptable limits is the priorities of EDS planners and designers. The other issue is the high of active power losses in the EDS, which amounts to about 13% of the total power generated at the generation plants. This loss is related to the high R/X ratio [4-5]. These losses are classified as technical losses and commercial losses. Technical loss relates to resistance of conductors to electrical current flow that is wasted as heat, while the commercial losses are caused due to illegal connections to the network (slums), and inaccurate readings of power meters, etc. [6]. Several techniques have been used to improve the performance of the EDS. These techniques are Network Reconfiguration (NR), Load Balancing (LB), Step Voltage Regulator (SVR), Construction New Substation (CNS), Reactive Power Compensation (RPC) Distribution Generation (DG) and Resizing Conductors (RC). In these paper two

techniques have been used in separately approach are RPC and SVR, as voltage controllers, because this type of controller is cheap compared to the reactive power controllers, because the voltage controllers do not need a current sensor [7]. Controlling the system voltage for EDS is very difficult due to the unbalance of the loads distributed to the system's feeders [7]. Capacitors are commonly technique used to improve the performance of the EDS. This technique has been employed as a reactive power compensator, to maintain system's voltage within acceptable limits and to mitigate power losses. Capacitors are placed near the load centers to reduce the reactive power transmitted through feeders, since most of the loads connected to the EDS are the inductive loads [8]. The choice of optimal capacitors size and installing location are very important factors to ensure the optimal performance of EDS. Recently, many researchers have been solved the problem of size and optimally location of capacitors placement. Ahmed Elsheikh [9] used loss sensitivity factors to specify all buses that have unacceptable voltage profile, then use Particle Swarm Optimization algorithm (PSO) to determine the optimal size of capacitors, this algorithm needs a long arithmetic time before results convergence, while K. S. Swarup [10] presented Genetic Algorithm (GA) to solve the size and location optimality problem, this method is economically inefficient due to the large number of capacitors used. Alireza Askarzadeh [11] proposed Crow Search Algorithm (CSA) to finding optimal size and suitable location for capacitors bank, to enhancement the performance of EDS, this algorithm is not requires long computational time to solve the problem, and suitable for large scale of EDS. The feeders of electrical distribution system serves every populated geographical area, and extends to long distances, as is the case in rural areas. In this case, system's voltage control using capacitors will be costly and ineffective, so SVR will be suitable theqnique for this function "system's voltage control". The issue of using SVR to maintain voltages profile for EDS is not new issue, prompting researchers to race to find optimal solutions for this issue [12]. Several algorithms have been used to solve the problem of SVR placement within an EDS, Mehdi Attar [13] used GA to determine optimal number and suitable site of SVR, the tap positions of SVR have been determined by local controller model and through the simulation results proved that the local controller cannot be neglected, while S. Manikandan [14] discussed how to regulate the voltage of an electrical distribution system and reduce energy losses, the algorithm of (DPSO) has been proposed as tool to solve the appropriate location and optimal numbers of SVR required . N. Visali [15] proposed two different methods to select the optimal location and, numbers and tap positions of SVR in EDS. The first method was a Back Tracking Algorithm (BTA), while the second algorithm was Fuzzy logic, the goals of proposed algorithms were minimize the capital cost and reduce the voltage deviation.

2. Problem Statement

The optimal voltage boosters   is defined by calculating the location, number and size of these boosters along the feeders of the EDS to achieve the desired objectives, acceptable bus voltage with minimum power loss. The behavior of radial EDS should be determined as first to specify all buses that suffers from voltage drop. To determine a voltage drop for radial EDS load flow analysis must be done. One appropriate algorithm for load flow calculations this algorithm known as (forward / backward) sweep, this algorithm based on mathematical expression for voltage drop in a feeder branch [16, 7].' figure 1', shows a Single Line Diagram (SLD) for feeder sections.
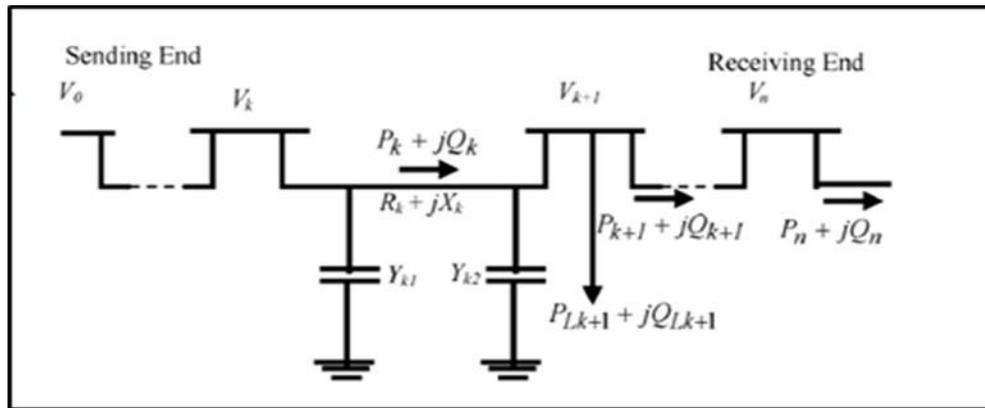
Figure 1. Single Line Diagram of feeder sections.

Active and imaginary power demands instead of currents and angle, the mathematical expression for voltage drop, as given in equation (1) [7].

$$V_{(k)} - V_{(k+1)} = \beta \times (V_{(k+1)})^{-1} \tag{1}$$

Where $\beta = P_{l(k+1)} \times R_{(k)} + Q_{l(k+1)} \times X_{(k)}$

, $P_{l(k+1)} = P_{(k+1)} + P_k$ Is total active power demand and losses at node *(k+1)* in KW, and, $Q_{(k+1)} = jQ_{l(k+1)} + jQ_{(k)}$ is total imaginary power demand and power storage at node *(k+1)* in KVAR.

The receiving end voltage $V_{(k+1)}$ can be obtained by solves the equation (2) [7].

$$V_{(k+1)} = (V_{(k)} \times (2)^{-1}) \times ((V^2_{(k)} \times (4)^{-1} - (\beta))^{\frac{1}{2}} \tag{2}$$

The issue of voltage drop can be given as mathematical expression (3) [7].

$$min \sum_{k=0}^{n} V_{(k)} - V_{(k+1)}$$

(3)

 Where, k= 0, 1, 2…., n   bus number

The power loss is related to voltage drop as shown in equation (1). Accordingly to that, the main goal of proposed techniques is reduce voltage dip at each sections of realistic EDS subject to voltage restriction shown in expression (4).

$$\left(\left| V_k^{lower} \right| \leq V_k \leq \left| V_k^{upper} \right| \right)$$

(4)

Where V_k^{lower} = 0.95 P.U.

V_k^{upper} = 1.05 P.U. According to (IEC).

3.   Adopted Algorithms

CYME international was founded in 1986 with an authorization to offer high-quality power engineering software solutions to the power electrical industry worldwide. CYME was internationally classified as a world-class power engineering software provider during a short period of time. It provides complete solutions to assist consumers in addressing their most demanding engineering requirements. CYME offers a comprehensive suite of software and solutions that address most aspects of power systems analysis in practical method. CYME approved in many countries around the world in addition to the Iraqi Ministry of Electricity.

4.   System Modeling

Adopted system has magnitude system's voltage 11 KV with 50 HZ frequency and 293 nodes. The overall apparent power of the adopted system is 29447 KW, 23583 KVAR, while the total loads 27684 KW, 20144 KVAR .Single Line Diagram of tested system shown in 'figure 2'.
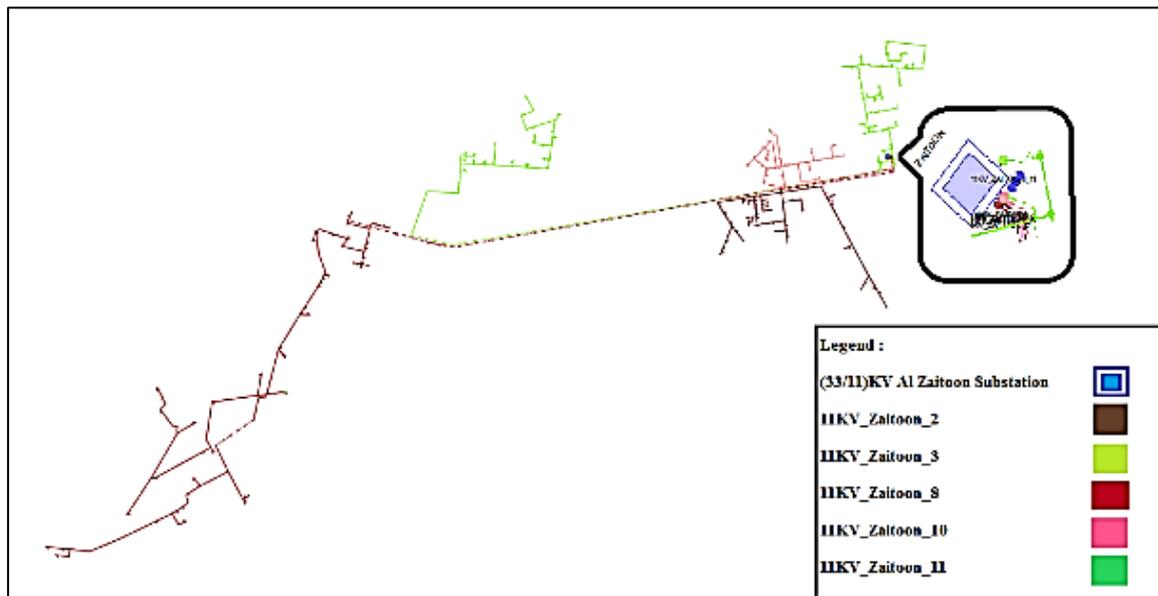
Figure 2. Single line diagram of tested realistic EDS.

5.   Simulation Results and Discussion

All simulation cases have been done using portable computer (laptop), CYME software has been used as tool to apply adopted techniques, and a results have been obtained of sample of Iraqi EDS represented by Abu Ghraib for three different cases as shown:

1. Case One (base case): the tested of EDS, without any improvement techniques, minimum bus voltage at 11KV_ZAITOON_8_113, about 0.874 P.U. , the active power loss   1763 KW divided into:
    1. Line Losses = 716 KW.
    2. Cable Losses = 962KW.
    3. Transformer Losses = 85KW.
2. Case Two: the performance of adopted EDS has been improved using Capacitor placement technique, minimum bus voltage at 11KV_ZAITOON_8_121, about 0.977 P.U. , the active power loss about 1230 KW divided into:
    1. Line Losses = 494 KW.
    2. Cable Losses = 680 KW.
    3. Transformer Losses = 56KW.
3. Case Three : the voltages profile of adopted EDS have been improved using SVR technique ,minimum bus voltage was 0.981 P.U. at bus 11KV_ZAITOON_8_78, the active power loss 1029 KW divided into:
    1. Line Losses = 450 KW.
    2. Cable Losses = 530 KW.
    3. Transformer Losses = 49KW.

All voltage buses were improved using capacitor placement (case two) and SVR (case three), the third case is an economically appropriate technique, and because the adopted EDS has several rural feeders extend long distances with fixed loads for long duration ,while to reduce voltage deviation using second technique, large number of capacitor bank have been installed. The 'figure 3', shown comparisons between voltages profile in all applied cases. The tested system has large number of buses, therefor, sample of choosing bus voltage were recorded in 'table 1', to illustrate the effective of applied techniques on system's voltage.
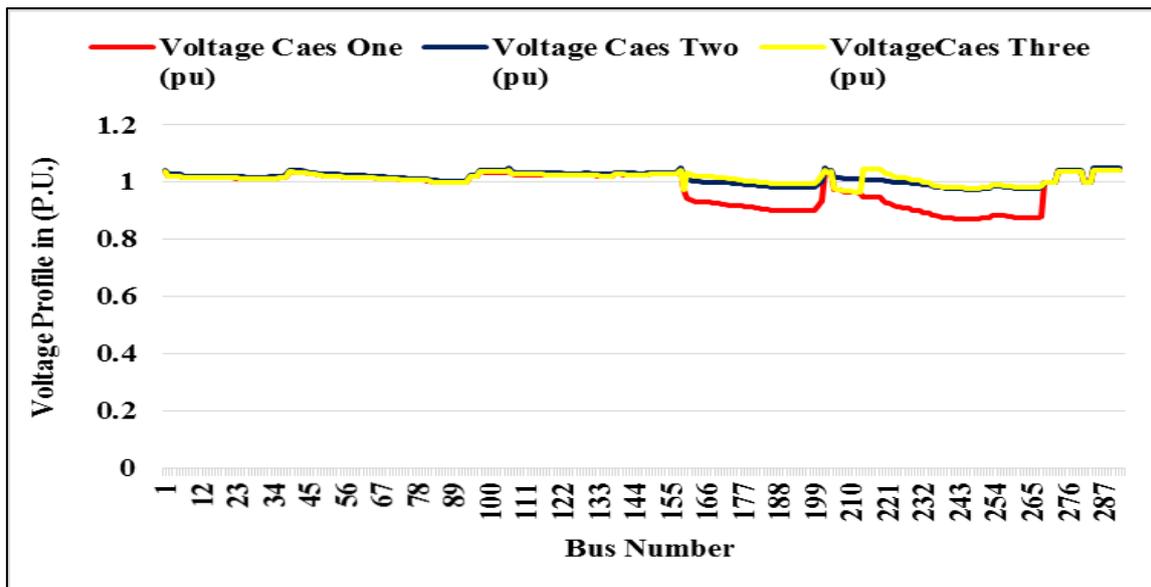
Figure 3. Voltage profile comparison for all cases.

From 'table 1', can noting that, how the techniques used to control system voltages effectively contribute to improving all bus voltages to very acceptable levels, taking into account the number of equipment used in each technique. 'Table 2' illustrates the optimal location, size and type of capacitor placement technique, while 'table 3' illustrates the optimal location, size and type of SVR technique.

Table 1. Simulation results of buses voltage

Bus Name	Case 1 Voltage (P.U.)	Case 2 Voltage (P.U.)	Case 3 Voltage (P.U.)
11KV_ZAITOON_8_79	0.947	1.008	1.046
11KV_ZAITOON_8_80	0.945	1.008	1.044
11KV_ZAITOON_8_132	0.945	1.007	1.044
11KV_ZAITOON_8_133	0.945	1.007	1.044
11KV_ZAITOON_8_134	0.945	1.007	1.044
11KV_ZAITOON_8_135	0.945	1.007	1.044
11KV_ZAITOON_8_81	0.935	1.006	1.035
11KV_ZAITOON_8_82	0.925	1.003	1.026
11KV_ZAITOON_8_83	0.925	1.003	1.026
11KV_ZAITOON_8_84	0.918	1	1.021
11KV_ZAITOON_8_85	0.912	0.998	1.015
11KV_ZAITOON_8_130	0.912	0.998	1.015
11KV_ZAITOON_8_86	0.91	0.997	1.013
11KV_ZAITOON_8_87	0.91	0.997	1.013
11KV_ZAITOON_8_88	0.909	0.997	1.012
11KV_ZAITOON_8_89	0.901	0.995	1.005
11KV_ZAITOON_8_90	0.901	0.995	1.005
11KV_ZAITOON_8_91	0.901	0.995	1.005
11KV_ZAITOON_8_92	0.893	0.991	0.998
11KV_ZAITOON_8_93	0.893	0.991	0.998
11KV_ZAITOON_8_94	0.893	0.991	0.998
11KV_ZAITOON_8_95	0.885	0.986	0.99
11KV_ZAITOON_8_110	0.881	0.983	0.987
11KV_ZAITOON_8_111	0.879	0.982	0.986
11KV_ZAITOON_8_112	0.876	0.979	0.983
11KV_ZAITOON_8_113	0.874	0.977	0.981
11KV_ZAITOON_8_115	0.874	0.977	0.981
11KV_ZAITOON_3_5	0.941	1.007	1.03
11KV_ZAITOON_3_6	0.937	1.005	1.027
11KV_ZAITOON_3_7	0.932	1.003	1.022
11KV_ZAITOON_3_8	0.929	1.001	1.02
11KV_ZAITOON_3_86	0.929	1.001	1.02
11KV_ZAITOON_3_9	0.928	1	1.018
11KV_ZAITOON_3_10	0.928	1	1.018
11KV_ZAITOON_3_11	0.928	1	1.018
11KV_ZAITOON_3_12	0.927	1	1.018
11KV_ZAITOON_3_13	0.925	0.999	1.016
11KV_ZAITOON_3_14	0.925	0.999	1.016
11KV_ZAITOON_3_15	0.922	0.997	1.013
11KV_ZAITOON_3_16	0.922	0.997	1.013

Table 2. Location, size and type of capacitor bank.

Location	Size (KVAR)/phase	Type
11KV Zaitoon_3_5	300	Switched
11KV Zaitoon_3_8	300	Switched
11KV Zaitoon_3_17	300	Switched
11KV Zaitoon_3_20	300	Switched
11KV Zaitoon_3_29	300	Switched
11KV Zaitoon_8_81	300	Switched
11KV Zaitoon_8_82	300	Switched
11KV Zaitoon_8_89	300	Switched
11KV Zaitoon_8_95	300	Switched

Table 3. Location, size and type of SVR.

Location	Size (KVA)	Type
11KV Zaitoon_3_5	165	A
11KV Zaitoon_8_69	165	A

The improvement of the system voltage has contributed to the reduction of energy loss and increases efficiency of the system. 'Figure 4' shows the low power lost, when adopted techniques have been applied.
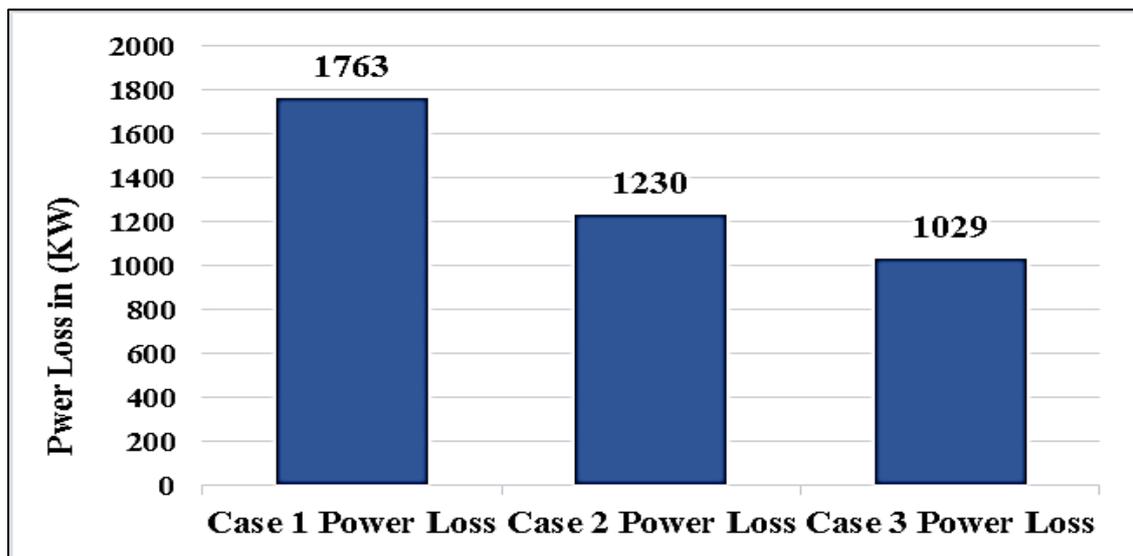
Figure 4. Active power loss for all cases.

6.   Conclusions

The issue of controlling voltage of EDS is one of the most important issue that facing the designers and planners in this field. This issue has been solved in this work .Two alternative techniques have been applied separately (capacitor placement and SVR). These techniques have been used as voltage controllers. CYME software version 7.1 has been used to determine the solutions for optimal locations, size and type of adopted techniques. The effectiveness of CYME has been investigated on realistic EDS consist of 295 bas, five rural feeders extends to long distance. Simulation results prove that, SVR technique is more appropriate than capacitor placement technique in case enhancement performance of EDS that serve rural area for long distance.

7.   Recommendation

Re-use SVR technology to improve voltage profile in ESD, especially those serving rural areas.

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