EXPERMINTAL SIMULATION TO EVALUATE THE IMPACT OF REACTIVE POWER CONTROL ON DISTRIBUTION NETWORKS VOLTAGE AND ENERGY

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ABSTRACT:

Planning and operation of electric distribution networks (EDNs) depend on the apparent current flow (ACF) in their feeders. This ACF is affected strongly by the load power factor (PF). The low PF in electric feeders increases the demand of power supply, power losses and voltage drop at a constant value of the load. On the other wise, this load will decrease at low power factor for the constant value of the power supply (transformers) on EDNs. Therefore, a proposed technique has been introduced and applied in this work to evaluate the impact of PF correction or reactive power control (RPC) on the feeders of EDN. This technique is based on experimental simulation of the feeder, load and RPC.

INTRODUCTION:

The control of reactive power flow in electric distribution networks is essential to keep the voltage drop or voltage regulation within acceptable limit. Capacitors are usually used for this purpose. The capacity of these capacitors (Q_c) depends on the load power factor (PF) and the required value of this factor. Low PF causes higher apparent current in the feeders of EDN, which has a significant effect on the voltage drop, capacity of the power supply (transformers) and losses on these feeders [1]. An efficient technique based on sensitivity analysis had been introduced to determine the minimum requirements of static voltage compensator (SVC) sufficient to keep the system voltage profile within prespecified limit [2]. The ideal location of theses compensators is as near the load as possible because it produces reactive power flow from the source out to the capacitor location [3].

Individual reactive power control (Q_c) may be used for each feeder of the EDN at the bus bar of its installation loads. The main questions to be answered for coordination Q_c with these loads are [4]:

- How Q_c at the fed-in point of electric loads can be assessed and its impact on the power supply capacity?
- How the energy savings and the impacts of Q_c on voltage profile can be achieved?

In this work, a proposed technique based on an experimental simulation has been introduced to asses Q_c and evaluate its impact on voltage ends energy savings of a feeder on the EDN.

1. PROPOSED TECHNIQUE:

The feeder of EDNS can be simulated by an impedance (R+JX), in addition to the load (R_L+JX_L) supplied by this feeder, Figure 1. The phase angle which is used to assess the active (I_r), reactive (I_q) and apparent (I_a) current flows on the study feeder depends on the ratio of XL/R_L . These currents are measured here in terms of initial power as active (AM_1), reactive (RM_1) and apparent (S_1) powers.

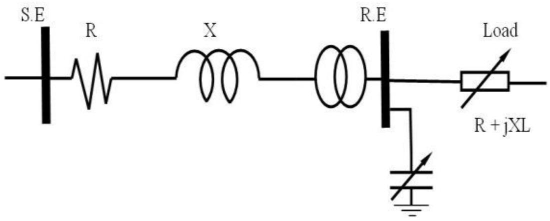

Figure1. Simulation of a feeder on the electric distribution networks

Therefore, this ratio is developed as:

$$\text{Tan } \varphi_1 = RM_1/AM_1 \tag{1}$$

However, the initial load power factor, cos φ_1, (PF_1) is low and varies between 0.5 to 0.7 on most of residential feeders of EDN in Egypt [5]. A capacitor bank (c) is used, Figure 1, for RPC and keeping the desired value of power factor (PF_2) of these feeders. In this case, φ_2 and the capacity of the capacitor bank (Q_c) are developed considering the measurement of active (AM_2) and reactive (RM_2) powers at the desired value of PF_2 as follows. [6]:

$$Tan\varphi_2 = \frac{RM_2 - RM_1}{AM_2 - AM_1} \tag{2}$$

$$Q_c = \frac{(AM_2 - AM_1) * K_L}{24} * K_\varphi \tag{3}$$

Where; $$K_L = \sum_{T=1}^{24} (AM_2 - AM_1) / AM_1 \tag{4}$$

$$K\varphi = \tan\varphi_1 - \tan\varphi_2 \tag{5}$$

1.1.Evaluation of the Impact of RPC on Energy Savings:

The impact of RPC on power losses may be developed as a function of PF_1 and PF_2 as:

$$P_{loss1} / P_{loss2} = (PF_2)^2 / (PF_1)^2 \quad (6)$$

Thus, the decrease in power losses (ΔP_{loss}) is:

$$\Delta P_{loss} = 1- [(PF_2)^2 / (PF_1)^2] \quad (7)$$

Also, the savings of the power supply (ΔS_1) due to Q_c is given as [7]:

$$\Delta S_1 = \frac{X * Q_c}{X \sin\varphi + R\cos\varphi} \quad (8)$$

The value of this ΔS_1(Kva) is used as increase of the load or energy savings.

1.2.Evaluation of the Impact of RPC on Voltage:

The percentage voltage drop ($\%V_d$) at initial power factor (PF_1) is deduced as a base for the percentage voltage rise at the load ($\%V_L$) and the power supply, transformers, ($\%V_T$) due to the *RPC* (Q_c). These voltages are developed as [8]:

$$\%V_d = \frac{(S_1)(L)(R\cos\varphi_1 + X\sin\varphi_1)}{10(kv)^2} \quad (9)$$

$$\%V_L = \frac{Q_c * X * L}{10(KV)^2} \quad (10)$$

$$\%V_T = \frac{Qc}{kVA_T} * X_T \quad (11)$$

Where,
Kva_T : the rating of the power supply (transformer).
S_i : KVA of the load at PF_1.
kV = phase –to- phase kilovolts.
L = length of conductor in km.
R = resistance in ohm per km.
Cos φ_l= uncorrected power factor.
X_T = reactance in ohms per km.

2. EXPERMINTAL STUDY AND RESULTS:

The load resistance (R_L) in Figure 1 is stated to simulate an initial active power of 100 kW, while X_L is varied to develop the measurements of PF_1 . Also, the capacitor bank C is varied to attain the desired value of PF_2 . Thus, the value of Q_c is obtained. Accordinaly, the experimental work is carried out to develop the impact of *RPC* (Q_c) on both the energy savings and voltage profiles of the simulated feeder.

2.1-Impact of RPC on Energy Saving:

Measurements of AM_1 and RM_1 are determined at an initial power factor of 0.7 up to the unity. Also, AM_2 and RM_2 are deduced corresponding to the desired value PF_2. These measurements are used to develop active, reactive and apparent powers from PF_1 equals 0.7 up to the unity and shown in Figure 2. The results of this figure concluded that PF_1 *of* 0.7 causes an increase of 42% of the power supply (S_1). This value is 25% at PF_1 equals 0.8. Also, for each of 100 kW of the load, 102 kVAR of Qc is required. Figure 3 illustrate the value of S_1 at different values of PF_1 with and without Qc. The results of this figure are used to develop the reduction of S due to the *RPC* (Q_c) at different values of PF_1 as shown in Figure 4. This figure denoted that the reduction of S_1 is 27 and 22 kVA at PF_1 of 0.7 and 0.8 respectively. Considering the costs of the power supply is $20,000 per 1 kVA of S_1 , with an intrest rate of 10% and life time of 20 years, the annual savings of S_1 costs at different values of PF_1 is deduced and given in Figure 4. The impact of *RPC* on the change of feeder losses is shown in Figure 5. This figure gives the relation between the load power factor and the decrease in losses due to Q_c. The results of this figure concluded that the improvement of PF_1 from 0.7 to the unity reduces the feeder losses by 50 % of its value.

Considering the average daily load demand is 100 kW and the unit energy cost is 2¢/ kWh, the annual increase in energy supplied and revenue are determined and depicted in Figure 6. This figure gives these increase at different value of the load power factor when it's corrected to the unity.

2.2-Impact of RPC on Voltage Drop:

The voltage drop is developed with and without *RPC* (Q_c). These voltage drop are deduced here with assuming X per 1 km of the feeder and sending end voltage of 11 kV and shown in Figure 7. This figure gives the percentage voltage drop with and without Q_c at different load power factors. The results of figure concluded that using *RPC* will decrease the voltage drop with a value of 5%.

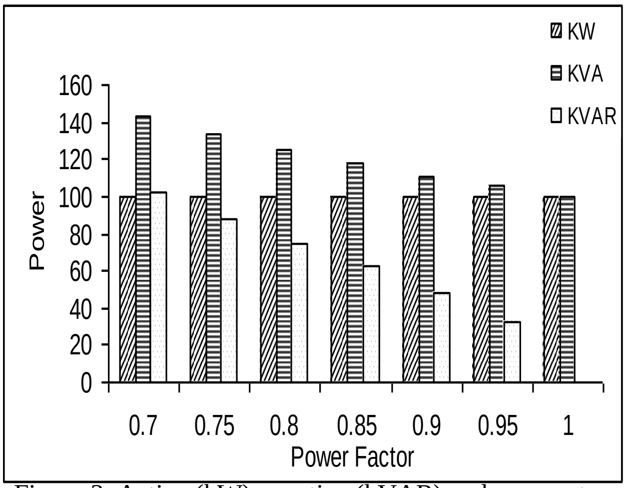

Figure 2. Active (kW), reactive (kVAR) and apparent power (kVA) at different load power factor.

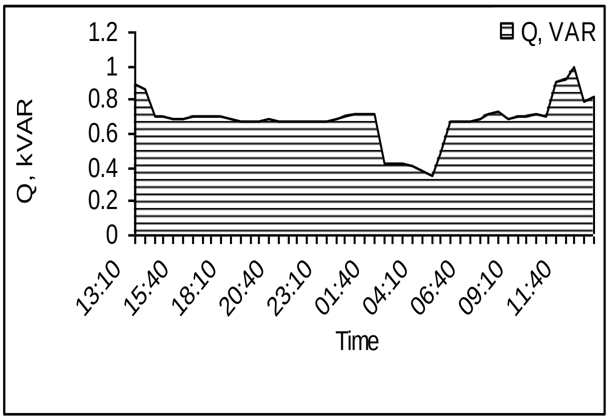

Figure 3. the daily load curve of the study load control (Q_c)

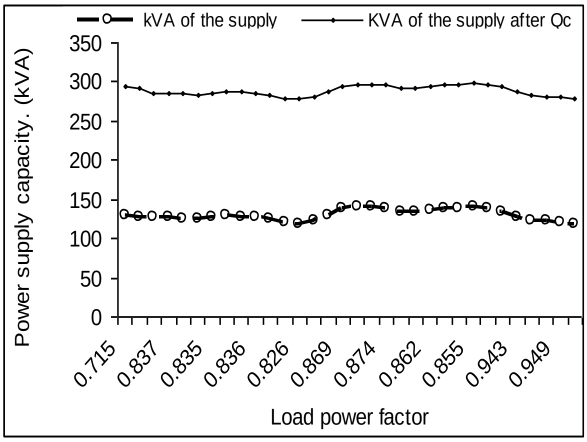

Figure 4. The power supply capacity (kVA) at different load power factor with and without reactive power control (Q_c)

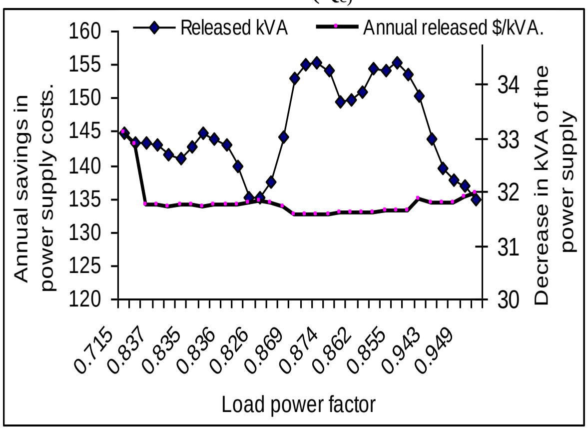

Figure 5. The impact of RPC on the reduction of the power supply capacity and costs at different load power factors.

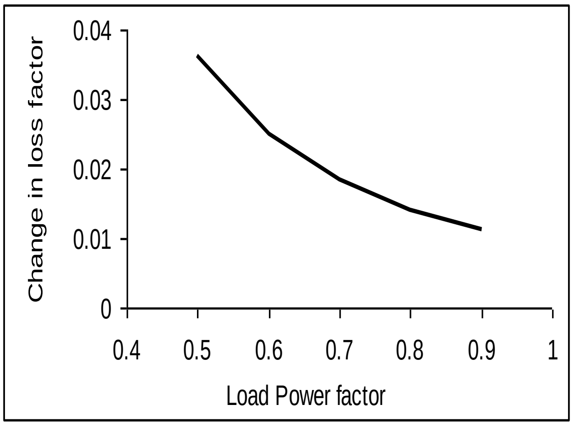

Figure 6. The impact of RPC on the change in the loss factor at different load power factor

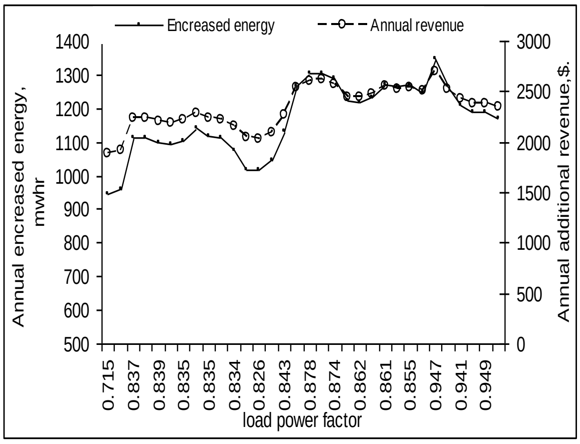

Figure 7. The impact of RPC on the annual increase of energy supplied to the load and revenue at different load power factor

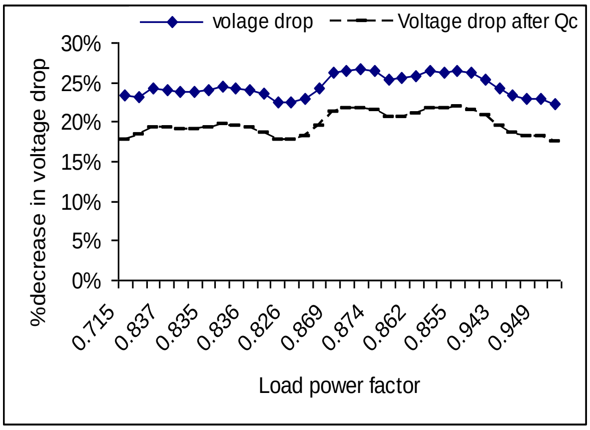

Figure 8. The voltage drop with and without RPC (Qc) at different load power factors.

CONCLUSIONS:

A proposed technique is presented in this work for an experimental simulation of feeder with sending end voltage of 11 kV . Assuming this feeder supplies a load of 100 kW and differ values of power factor, the impact of reactive power control *RPC* (Q_c) on voltage and energy of this feeder are studied experimentally. The results of this study are:

1. When the power factor is constrained to the unity, the capacity of the power supply decreases by about 42% at load power factor of 0.7, while Q_c equals 102 kVAR per 100 kW of the load
2. The decrease in power loss is 50% of its value when the load power factor improved from 0.7 to unity.
3. The voltage drop on the feeder decrease with about 5% with using reactive power control (Q_c).
4. The annual revenue increased from 1000$ to 2500 $ when using reactive power control (Qc).
5. The approximate voltage rise 3%
6. Increased in feeder capacity of 350 Kva .

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