EXPERIMENTAL 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 (Qc) 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 compensated 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 (Qc) 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 Qc with these loads are [4]:
- How Qc 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 Qc on voltage profile can be achieved?

In this work, a proposed technique based on an experimental simulation has been introduced to assess Qc 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+JX) supplied by this feeder, Figure 1. The phase angle which is used to assess the active (Ia), reactive (Iq) and apparent (Ia) current flows on the study feeder depends on the ratio of XL/R [2]. These currents are measured here in terms of initial power as active (AM1), reactive (RM1) and apparent (SN1) powers.

Figure1. Simulation of a feeder on the electric distribution networks

Therefore, this ratio is developed as:
\[
\tan \varphi_1 = \frac{RM_1}{AM_1} \tag{1}
\]

However, the initial load power factor, \( \cos \varphi_1 \) (PF1) 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 (PF2) of these feeders. In this case, \( \varphi_2 \) and the capacity of the capacitor bank (Qc) are developed considering the measurement of active (AM2) and reactive (RM2) powers at the desired value of PF2 as follows [6]:

\[
\tan \varphi_2 = \frac{RM_2 - RM_1}{AM_2 - AM_1} \tag{2}
\]

\[
Q_c = \frac{(AM_2 - AM_1) \cdot K_L \cdot K_\phi}{24} \tag{3}
\]

Where:

\[
K_L = \sum_{T=1}^{n} \frac{(AM_2 - AM_1)}{AM_1} \tag{4}
\]

\[
K_\phi = \tan \varphi_1 - \tan \varphi_2 \tag{5}
\]
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 $PF_I$ and $PF_2$ as:

$$P_{	ext{loss1}} / P_{	ext{loss2}} = (PF_I)^2 / (PF_2)^2$$

(6)

Thus, the decrease in power losses ($\Delta P_{\text{loss}}$) is:

$$\Delta P_{\text{loss}} = 1 - [(PF_I)^2 / (PF_2)^2]$$

(7)

Also, the savings of the power supply ($\Delta S_I$) due to $Q_c$ is given as [7]:

$$\Delta S_I = \frac{X \cdot Q_c}{X \sin \phi + R \cos \phi}$$

(8)

The value of this $\Delta S_I$ (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 ($PF_I$) is deduced as a base for the percentage voltage rise at the load ($\%V_L$) and the power supply, transformers, ($\%V_P$) due to the RPC ($Q_c$). These voltages are developed as [8]:

$$\%V_d = \frac{(S_c)(L)(R \cos \phi_d + X \sin \phi_d)}{10(kV)^2}$$

(9)

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

(10)

$$\%V_P = \frac{Q_c}{kVA} \cdot X \cdot T$$

(11)

Where,

- $kVA_r$: the rating of the power supply (transformer).
- $S_1$: kVA of the load at $PF_I$.
- $kV$: phase to-phase kilovolts.
- $L$: length of conductor in km.
- $R$: resistance in ohms per km.
- $\cos \phi$: uncorrected power factor.
- $X_T$: reactance in ohms per km.

2. Experimental 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 $PF_I$. Also, the capacitor bank $C$ is varied to attain the desired value of $PF_2$. Thus, the value of $Q_c$ is obtained. Accordingly, 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 $AM_I$ and $RM_I$ 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 $PF_I$, equals 0.7 up to the unity and shown in Figure 2. The results of this figure concluded that $PF_I$ of 0.7 causes an increase of 42% of the power supply ($S_1$). This value is 25% at $PF_I$ equals 0.8. Also, for each of 100 kW of the load, 102 kVAR of $Q_c$ is required. Figure 3 illustrate the value of $S_1$ at different values of $PF_I$ with and without $Q_c$. The results of this figure are used to develop the reduction of $S$ due to the RPC ($Q_c$) at different values of $PF_I$ as shown in Figure 4. This figure denoted that the reduction of $S_1$ is 27 and 22 kVA at $PF_I$ 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 interest rate of 10% and life time of 20 years, the annual savings of $S_1$ costs at different values of $PF_I$ 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 $PF_I$ 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 factors.

Figure 8. The voltage drop with and without RPC ($Q_c$) 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 (\( Q_c \)).
5. The approximate voltage rise 3%
6. Increased in feeder capacity of 350 Kva.

REFERENCES