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The Effect of Power factor Improvement on Switching Transients: A Case of FUMMAN Agricultural Products Industry Plc.

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Abstract: *Industrial loads are mostly inductive and hence operate at low power factor. Several methods including the installation of capacitor banks are available for improving power factor in order to reduce the kilovolt ampere (kVA) demand of the load and power loss from the power supply system. However, literatures have shown that improvement of power factor has effect on switching transients which is dangerous for industrial loads and operating personnel. In this work, we investigated the effect of improving the power factor of a power system beyond 0.8 (lagging) on switching transient levels using FUMMAN industry power network as a case study. A power factor measuring tool was modelled using the mathematical relation between power factor, reactive power and active power. The modelled equations were simulated Matlab/Simulink software (Version 7.9.0.529 'R2009b'). The characteristics of the system under study namely root mean square (r.m.s) voltage, peak steady state voltage, peak transient voltage and kVA demand were measured during the simulation with and without parallel connection of capacitor bank across the system. The result from the analysis showed that FUMMAN industry power network was operating at a lagging power factor of 0.8 with r.m.s voltage of 412.1 V, peak steady state voltage of 582.8 V, peak transient voltage of 701.9 V and kVA demand of 1878 kVA without the capacitor bank. However, when a capacitor bank was connected across the system and the power factor increased from 0.8 (lagging) to 0.9098 (lagging), optimised performance of the system was obtained with a capacitor bank size of 440 kVar. At lagging power factor of 0.9098, the kVA demand of the system was 1650 kVA, r.m.s voltage was 415.5 V and peak transient voltage was 749.5 V. The analysis therefore showed that increasing power factor beyond 0.8 (lagging) using capacitor banks though improves the r.m.s voltage and reduces the power loss but invariably leads to increase in switching transients which is undesired for optimised system performance.*

Keywords: *Industrial load, Power factor, Capacitor bank, Switching transient, FUMMAN industry power network*

I. Introduction

Power factor is related to power flow in electrical systems and measures how effectively an electrical power system is being used. In order to efficiently use a power system, the power factor should be as close to unity as possible. This implies that the flow of reactive power should be kept to a minimum. Maintaining a high power factor is crucial to obtaining the best possible economic advantage for both utilities and industrial users. Operating a power system at a low power factor is a concern for both the electrical utility and the industry since it increases the magnitude of current in the system which may damage or shorten the life of the equipment and also increases copper losses (I^2R) which is capable of lowering the system efficiency due to increase in reactive power [1]. The major causes of low power factor in power systems are electric motors which are inductive loads [2].

Generally, there are various methods for power factor improvement in power systems. According to Mupparty [1], capacitor bank installation is the most common method of power factor correction due to it being economical and generally trouble free. However, the use of capacitor banks has been found to introduce power quality concerns like switching transients into the power system.

IEEE standard 1100-1992 describes transient as a subcycle disturbance in the alternating current waveform that is evidenced by a sharp, brief discontinuity of the waveform. A transient occurs when a signal network changes from one steady condition to the other like when an electrical system changes state from on to off or vice-versa [3]. A transient is an outward manifestation of a sudden change in the system conditions, as when a switch opens and closes or when there is a fault condition in the system. Transients can be caused by a number of power system switching events or faults such as lightning strikes, short circuits, or equipment failure. Capacitor switching receives special attention when it negatively impacts customer equipment [1]. Application of capacitor banks can lead to the following side effects: increased transient inrush current of power transformers, and prolonged decay rate of the transient, severe harmonic distortion, resonance with load-generated harmonics and capacitors can be stressed due to switching transients [4].

In this work, we aim to investigate the effect of power factor improvement on switching transients using FUMMAN Agricultural Products Industry Plc. in Ibadan, Oyo State, South West Nigeria as a case study.

II. Power Factor Improvement

The four major means of implementing power factor correction in power systems include the use of synchronous alternators, synchronous compensators, static var compensators and banks of static capacitors. The approach considered in this work is the use of bank of static capacitors because it is the most common method of power factor correction [1]. The bank of capacitors when added to the electrical network compensates for the reactive power demand of the inductive load. The capacitor contained in most power factor correction equipment draws current that leads the voltage, therefore producing a leading power factor. According to [1], if capacitors are connected to a circuit that operates at a nominally lagging power factor, the extent that the circuit lags is reduced proportionately.

III. Methodology

The methodology employed in this work is shown in Fig. 1. It involves modelling and simulation of the Transmission Company of Nigeria 330/132 kV Ayede power substation and the FUMMAN Agricultural Products Industry Plc. power network in Ibadan with the technical information provided by the two Companies using the Matlab/Simulink software.

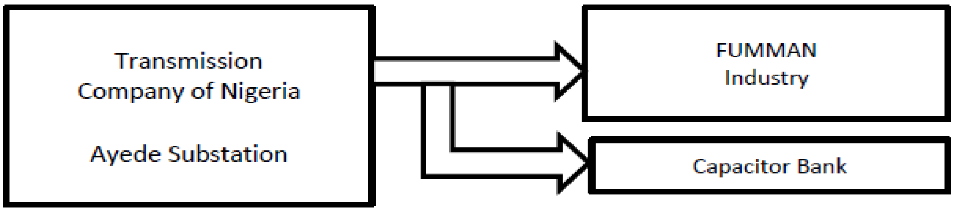

Figure 1: The methodology

3.1 Modelling of a Power Factor Measuring Tool

A power factor measuring tool was modelled in Matlab/Simulink software and then employed to aid the simulation. The process for designing the tool is shown in Fig. 2.

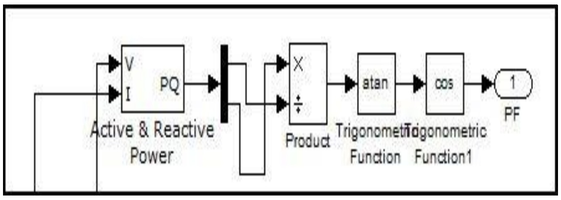

Figure 2: Diagrammatic representation of the power factor measuring tool in Simulink

The kVA conserved due to power factor improvement in a power network is given by equation (1) [5]:

$$kVA = kW\left(\frac{1}{actual\,pow\,factor} - \frac{1}{desired\,pow\,factor}\right) \qquad (1)$$

The percentage reduction of power losses can be expressed equation (2) [5]:

$$\%\text{Reduction in power losses} = 100 - 100 * \left(\frac{initial\ power\ factor}{target\ power\ factor}\right)^2 \qquad (2)$$

The value of reactive power required to raise the power factor of a system to a desired value is obtained from equation (3) [6]:

$$\text{kVAR} = \text{kW}[\tan(cos^{-1}\,present\ power\ factor) - \tan(cos^{-1}\,corrected\ \ power\ factor)] \qquad (3)$$

3.2 Modelling of a Switching Transient Response of a Lagging Power Factor Network

A network running at a lagging power factor elementarily represents a circuit with a dominating inductive effect. The switching transient response of FUMMAN industry power network can therefore be simplified into that of a simple RL circuit shown in Fig. 3.

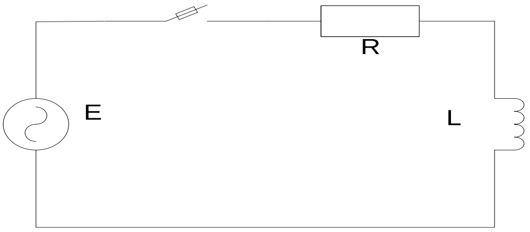

Figure 3: A RL circuit

Application of Kirchhoff's Voltage law to the above Fig. 3 gives equation (4) from which equation (5) is obtained:

$$E = E_{max} Sin(\omega t + \phi) = Ri + L\frac{di}{dt} \qquad (4)$$

$$i(t) = e^{-\left(\frac{R}{L}\right)t}\left\{\frac{-E_{max}}{\sqrt{R^2+\omega^2L^2}}\sin\left[\phi - \tan^{-1}\left(\frac{\omega L}{R}\right)\right]\right\} + \frac{E_{max}}{\sqrt{R^2+\omega^2L^2}}\sin\left[\phi - \tan^{-1}\left(\frac{\omega L}{R}\right)\right] \qquad (5)$$

Where E = Alternating Current (A.C) source voltage in volt
E_{max} = Peak value of A.C source voltage in volt
ω = Angular frequency in radian per second
t = Time in second
ɸ = Phase angle in radian
R = Resistance in ohm
i = Current in ampere
L = Inductance in henry

By installing a capacitor bank for power factor improvement, a capacitive element is introduced into the circuit and hence, the transient behaviour can be compared to that of an LC circuit shown in Figure 4 from which equations (6) is obtained.

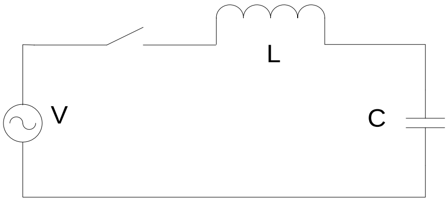

Figure 4: An LC circuit

$$L\frac{di}{dt} + V_c = V \qquad (6)$$

Where V_c = Capacitor voltage in volt

By applying Laplace transform to equation (6), we obtain an expression for the energization inrush current given by equation (7).

$$i(s) = V\left(\frac{C}{L}\right)^{\frac{1}{2}}\frac{\omega_0}{s^2+\omega_0^2} \qquad (7)$$

Where C = Capacitance in Farad

Energization inrush current is a transient occurring when the capacitor bank at the bus is energized [7]. If system resistance is neglected, the natural response component of the inrush current into the capacitor may be approximated by the expressions given by equations (8), (9) and (10):

$$i(t) = \frac{V(0)}{Z_0} \sin \omega_0 t \qquad (8)$$

$$Z_0(t) = \sqrt{\frac{L}{C}} \qquad (9)$$

$$\omega_0 = \frac{1}{\sqrt{LC}} \qquad (10)$$

Where $V(0) = \text{peak source voltage}$ in volt
$Z_0 = \text{surge impedance}$ in ohm
$\omega_0 = \text{inrush current angular frequency}$ in radian per second

IV. Results and Discussion

FUMMAN Agricultural Products Industry Plc. with an estimated load demand of about 1500 kW operates with an r.m.s voltage of 415 volts at a power factor of 0.8. The FUMMAN industry is supplied by the Transmission Company of Nigeria substation located in Ayede, Ibadan. The industry is supplied with a voltage of 33 kV which is further stepped down to 415 volts by a transformer located within the FUMMAN industry premises for use. The power network layout of FUMMAN industry is shown in Fig. 4.

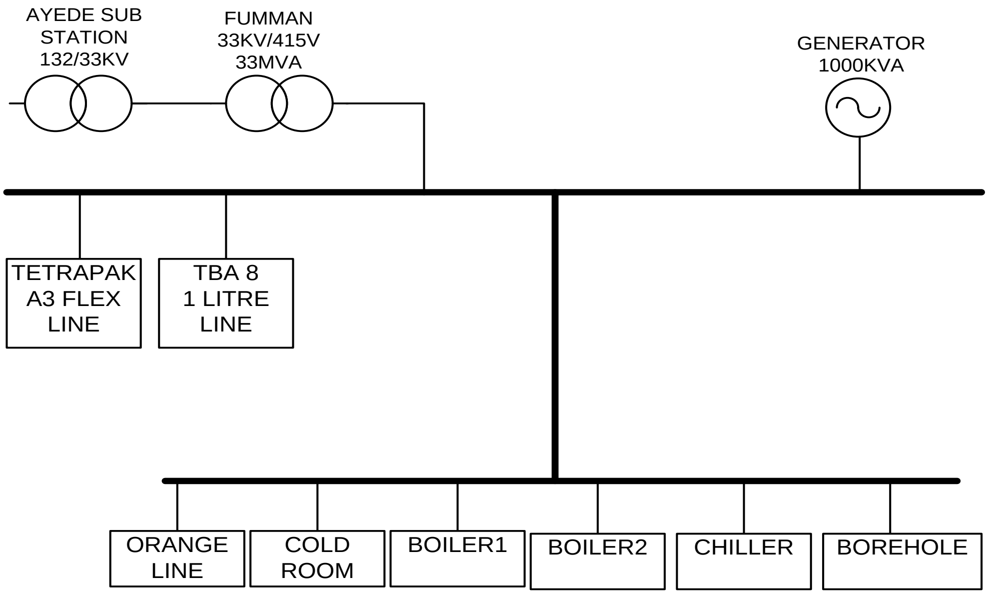

Figure 4: The FUMMAN Agricultural Products Industries PLC Layout

The simulated power factor and voltage waveforms of FUMMAN industry without the installation power factor correction equipment are respectively shown in Figs. 5 and 6. They represent the FUMMAN industry power network response to the energization of its load.

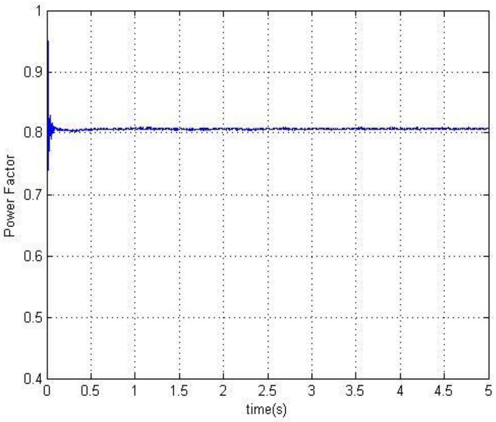

Figure 5: The simulated FUMMAN industry power factor waveform at 0.8

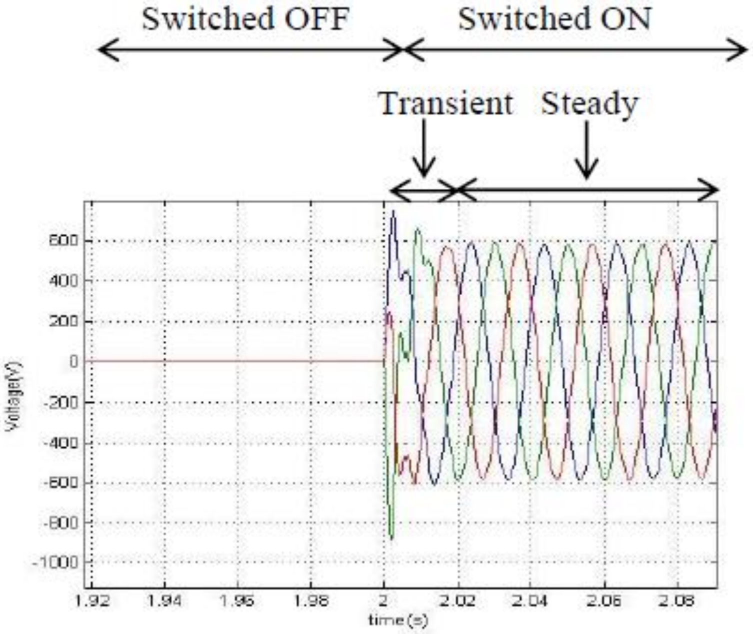

Figure 6: The simulated voltage waveform of FUMMAN industry

Analysis of FUMMAN industry power network indicated it operates at a power factor of 0.8 which could still be improved further with the installation of power factor correction equipment. The installation of capacitor bank in FUMMAN industry power network improved its power factor. The simulated power factor and voltage waveforms of FUMMAN industry power network after the installation of capacitor bank are respectively shown in Figs. 7 and 8. The AB portion of the Figure 7 indicates the power factor at which the industry before the installation of capacitor bank while CD portion indicates the power factor after the installation of capacitor bank.

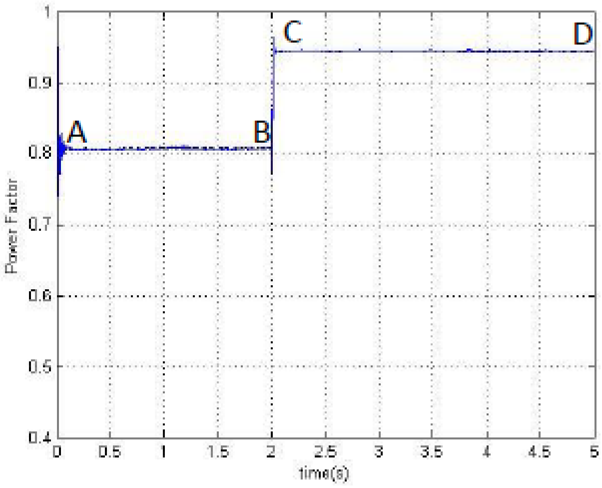

Figure 7: The simulated FUMMAN industry power factor waveform after the installation of capacitor bank

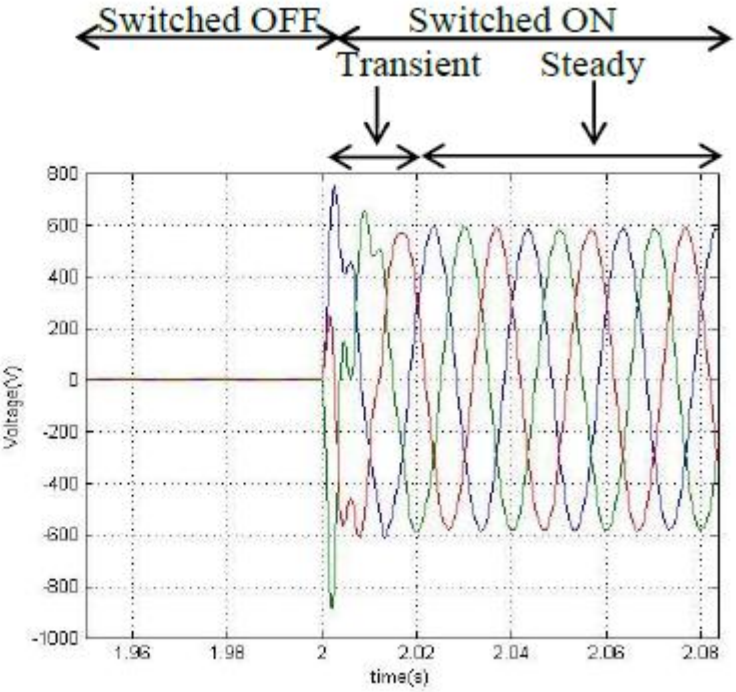

Figure 8: The simulated voltage waveform of FUMMAN Industry after the installation of capacitor bank

The results shown in Figs. 7 and 8 represent a case of a 440 kVar capacitor bank size. A 440 kVar capacitor bank is chosen from a series of simulations carried out on the condition that it is the most appropriate capacitor bank size because it gave an optimized performance of FUMMAN industry power network when compared the results of other capacitor banks.

The effects of power factor improvement on the FUMMAN industry power system performance are shown in Figures 9, 10, 11, 12 and 13.

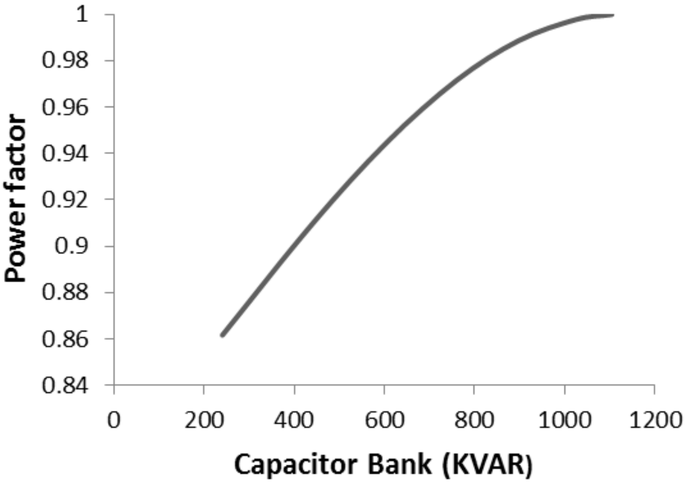

Figure 9: Effect of capacitor bank size (kVar) on FUMMAN power factor

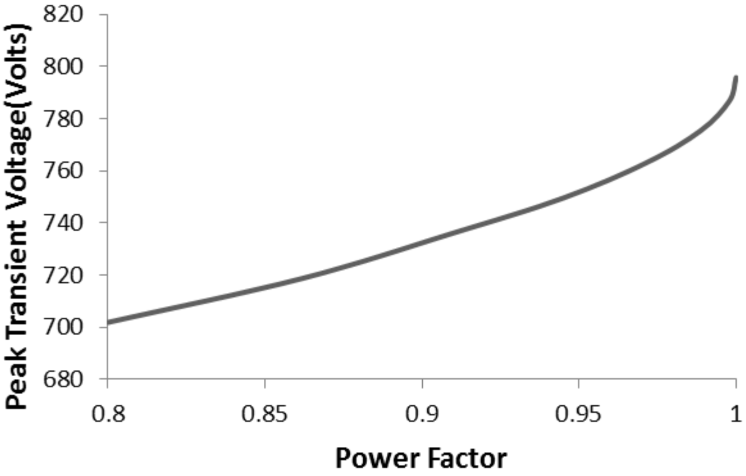

Figure 10: Effect of power factor improvement on the peak transient voltage

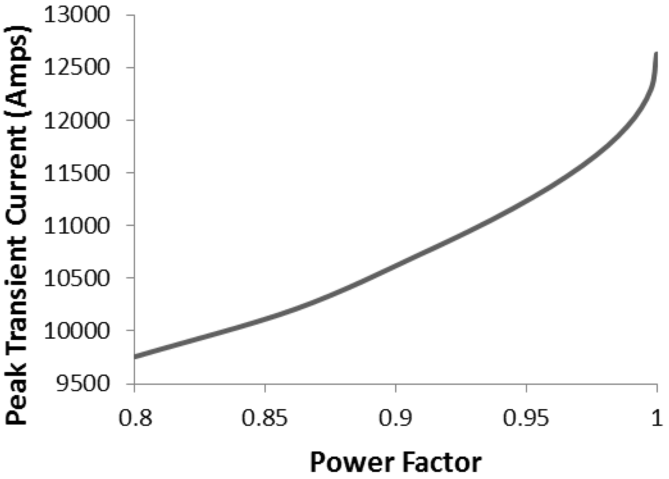

Figure 11: Effect of power factor improvement on the peak transient current

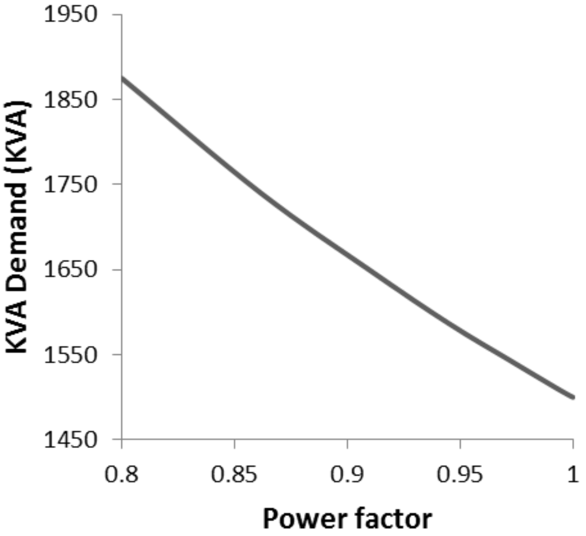

Figure 12: Effect of power factor improvement on FUMMAN industry kVA demand

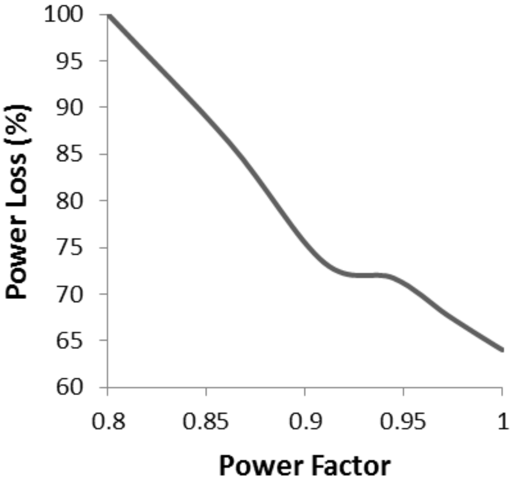

Figure 13: Effect of power factor improvement on FUMMAN industry power loss

From Figure 9, it is observed that increasing the size of capacitor bank for power improvement beyond certain limit may result in the drop in value of the power factor of the FUMMAN industry power network which is undesired for the system operation. Figures 10, 11, 12 and 13 showed that increasing the power factor of FUMMAN industry power network towards unity though may cut down on the kVA demand and power loss of the industry but leads to increase in peak transient voltage and current of the industry which is undesired for the optimised performance of FUMMAN industry.

V. Conclusion

Operating a power system at a low power factor is a major concern to both the electricity supply utility and the end-users. In this work, the effect of power factor improvement on switching transients using FUMMAN Agricultural Products Industry Plc. was investigated. Increase in power factor of the power network of the industry by the installation of capacitor bank across the network led to a reduction in kVA demand and power loss by the industry. It however discovered that improvement in power factor of FUMMAN industry led to an increase in switching transients which is undesired for the system operation. The magnitude of switching transient generated increases as the size of the capacitor bank increased. Therefore, when power factor correction is being installed in an industry, there is need to pay attention to adequate sizing of capacitor banks to prevent degradation of system power quality due to switching transient generation. The results from this work revealed that the maximum size of capacitor bank suitable for installation on the FUMMAN Industry premises for power factor correction which will offer an optimum level of power quality performance is a 440 kVar capacitor bank. The peak transient voltage observed for all values of kVar simulated was less than 2 per unit which is within the IEEE recommended limit for transient voltage surge.

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