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No. O-179

Investigation on Power Quality Problems of Electrical Substations Feeding CNG Stations in Iran

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Abstract

Power quality characteristics of Electrical substations feeding CNG stations as nonlinear and time variant loads which cause high amount current and power variations and low power factor for their feeding power systems are investigated. The power quality characteristics of the substation are verified through experimental measurements with the help of power quality measurement instruments. In addition, the application of an efficient static var compensator in the structure of TCR-FC has been proposed for voltage fluctuation reduction, reactive power compensation and power factor improvement. Through the simulations done with Matlab-Simulink the efficiency of the proposed SVC is verified.

Keywords: Power Quality, Compressed Natural Gas Site, Reactive Power, Fluctuations, Static VAR Compensator

1 EXTENDED ABSTRACT

The Electrical substation feeding a CNG (Fig. 1) in *Marageh* city in north-west of Iran is investigated and it has been monitored and the electrical data are studied for a length of one week continuously with the application of *Chauvin Arnoux CA8334* power measurement instrument as shown in Fig. 2. There is a *LMF* natural gas compressor utilized in this station as shown in Fig. 3.

The measuring is done at the 20 kV side of the substation (grid side) with a 100kW demand where the load current in much less than the short circuit current amplitude of the grid at the point of connection (i.e. $\frac{I_{1\max}}{I_{sc}} < 0.1$).

The electrical data are sampled every 10 minutes with a sampling frequency of 256 times per cycle.

Figure. 1. CNG station for buses and cars in *Maragheh*, north-west of Iran

Figure. 2. *Chauvin Arnoux* CA8334 power measurement instrument.

Figure. 3. *LMF* natural gas compressor utilized in the station.

The electrical data measured in this experimentation include voltage, current, frequency, flicker, power factor, transients and active, reactive and apparent power. The results were compared with the Iranian Power Quality Standard which is the same as IEC standards on power quality. The results are shown in Tables and Figures were some of them are as below.

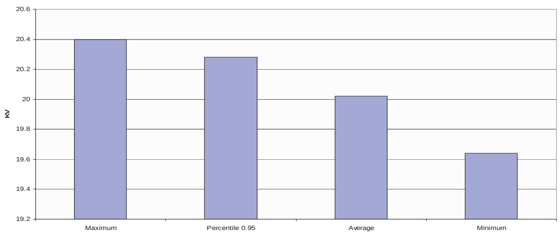

Figure. 4. Maximum, average, minimum and 95% CP of phase-to-phase voltage of electrical substation feeding CNGs.

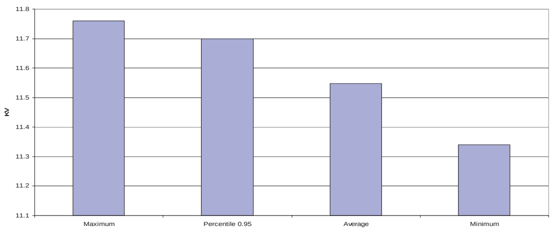

Figure. 5. Maximum, average, minimum and 95% CP of single phase voltage of electrical substation feeding CNGs.

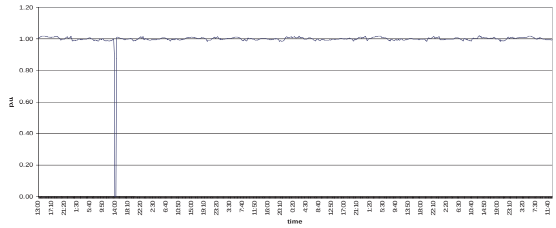

Figure. 6. Phase-to-phase voltage waveform of electrical substation feeding CNGs.

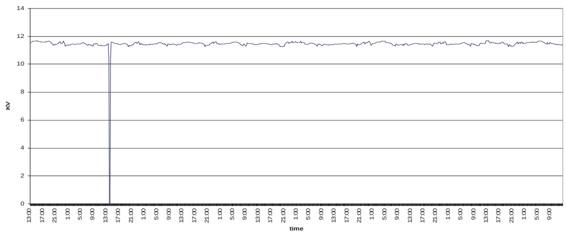

Figure. 7. Single phase voltage waveform of electrical substation feeding CNGs.

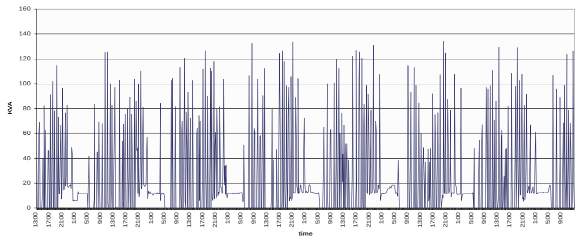

Figure. 8. Total apparent power waveform of electrical substation feeding CNGs.

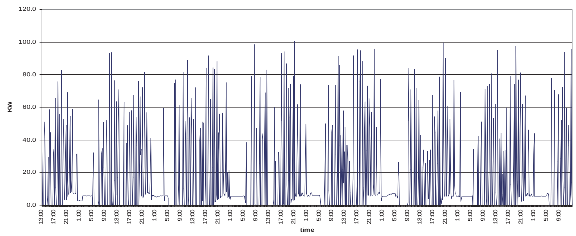

Figure. 9. Total active power waveform of electrical substation feeding CNGs.

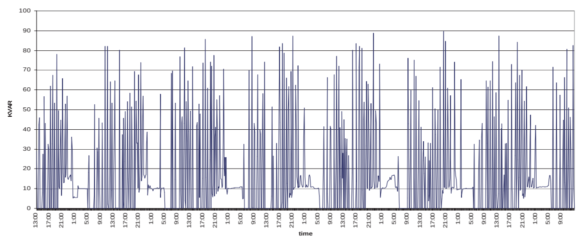

Figure. 10. Total reactive power waveform of electrical substation feeding CNGs.

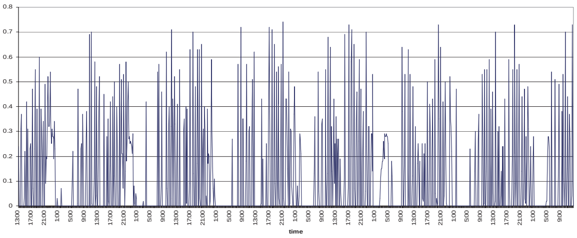

Figure. 11. Single phase power factor waveform of electrical substation feeding CNGs.

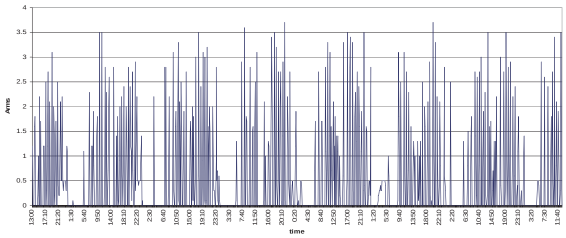

Figure. 12. Single phase current waveform of electrical substation feeding CNGs.

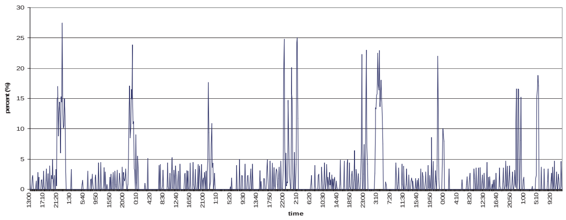

Figure. 13. Single phase current unbalance variation of electrical substation feeding CNGs.

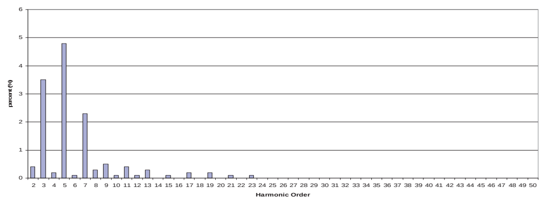

Figure. 14. Single phase current harmonics spectrum of electrical substation feeding CNGs.

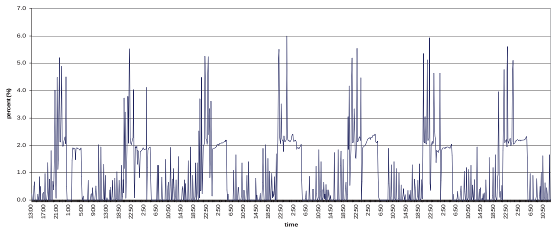

Figure. 15. Single phase current total demand distortion variation of electrical substation feeding CNGs.

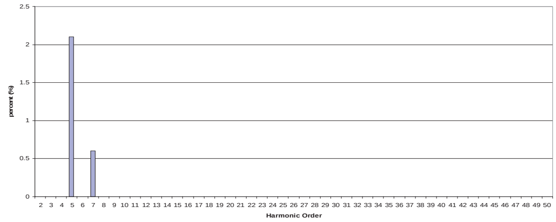

Figure. 16. Single phase voltage harmonics spectrum of electrical substation feeding CNGs.

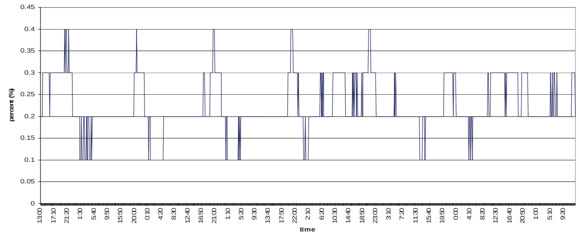

Figure. 17. Single phase voltage unbalance variation of electrical substation feeding CNGs.

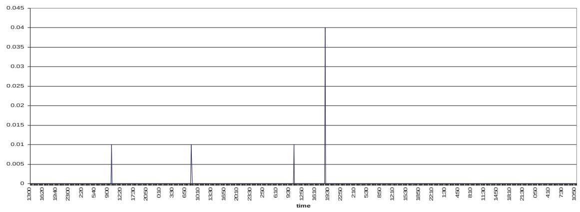

Figure. 18. Single phase voltage short-time flicker of electrical substation feeding CNGs.

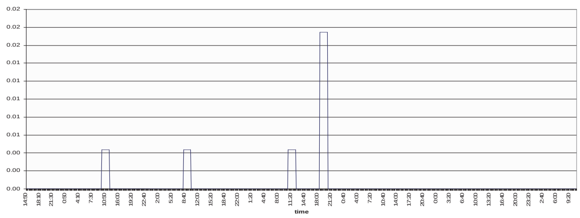

Figure. 19. Single phase voltage long-time flicker of electrical substation feeding CNGs.

The voltage fluctuations at PCC are caused by a change in the reactive power of the CNG load. An efficient SVC can reduce the power and current variations and can be used for improvement of power factor. So with suitable control of the reactive power, the worse characteristics would be prevented. The utilization of a SVC in the structure type of TCR-FC as shown in Figure. 20 is proposed for this purpose. Changing the thyristor turn-on angle, the amplitude of voltage and current of terminals of SVC will change too, where as shown for two different turn-on angles in Figure. 21.

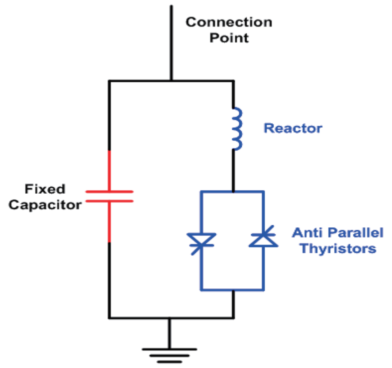

Figure. 20. Schematic diagram of Thyristor-Controlled Reactors with Fixed Capacitor (TCR-FC)

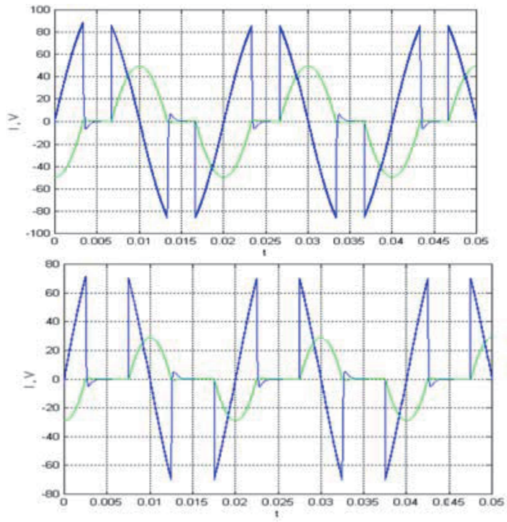

Figure. 21. The Voltage and current waveforms of SVC for two different turn-on angles of the thyristor.

By changing the turn-on angle of thyristors, the effective value of the fundamental component of the reactor current can be expressed as follow:

$$I_l1(\square)=V(2\pi-2\alpha+\sin 2\alpha)/\pi\omega L \qquad (1)$$

where □is turn-on angle of the thyristor, V is effective value of supplied voltage, L is the inductance of reactor and ω is the angular frequency of the applied voltage.
I_L can be expressed as below:

$$I_l1(\square)=V.[(\sigma\text{-}\sin\sigma)/\pi\omega L] \qquad (2)$$

where σ as the conduction angle equals $(2\pi\text{-}2\alpha)$
The effective reactive suseptance $B_L(\sigma)$ is calculated by:

$$B_L(\sigma)=I_L1(\sigma)/V=(\sigma\text{-}\sin\sigma)/\pi\omega L \qquad (3)$$

The equivalent suseptance of SVC is given by:

$$B_{svc}=B_c\text{-}\ B_L(\sigma) \qquad (4)$$

The reactive power absorbed by reactor Q_L equals:

$$Q_L=\text{-}V^2\times B_L(\sigma) \qquad (5)$$

And the capacitive power of TCR-FC can be expended as:

$$Q_c=V^2/X_c=B_c\times V^2 \qquad (6)$$

Then the reactive power flowed through SVC to the network is equal to:

$$Q_{svc}=Q_L+Q_c \qquad (7)$$

The reactive power that should be injected between two buses (Q_s) to equal their voltages can be obtained as follows:

$$|E|^{½}=|V+(R_s.P_L+X_s.Q_s)/V|^{½}+|(X_s.P_L–R_s.Q_s)/V|^{½} \qquad (8)$$

where after some algebraic computation we have:

$$aQ_s{}^2+bQ_s+c=0 \qquad (9)$$

while:

$$a=R_s^{\,2}+X_s^{\,2}, \qquad (10)$$

$$b=2V^2.X_s, \qquad (11)$$

$$c=(V^2+R_s.P_L)^2+X_s^{\,2}.P_L^{\,2}\text{-}(E^2V^2) \qquad (12)$$

Then, B_{Cs} as the capacitive suseptances corresponding with the calculated Q_s is equal to:

$$B_{Cs}=Q_s/(V_{LL})^2 \qquad (14)$$

Some of the results of the simulation carried with Matlab/Simulink about the electrical load characteristics of the compressor in the CNG sites without utilizing and later utilizing the proposed SVC is shown in the following Figures.

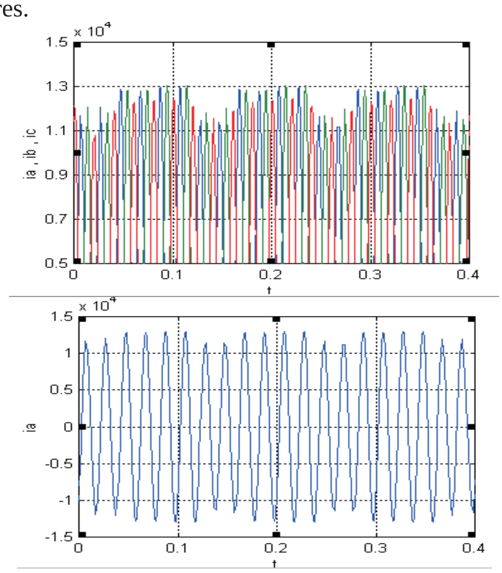

Figure. 22. Three-phase and single-phase currents of the electric load without SVC.

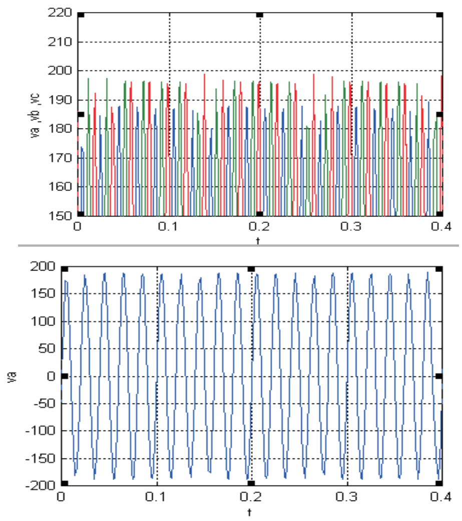

Figure. 23. Three-phase and single-phase voltages of the electric load without SVC.

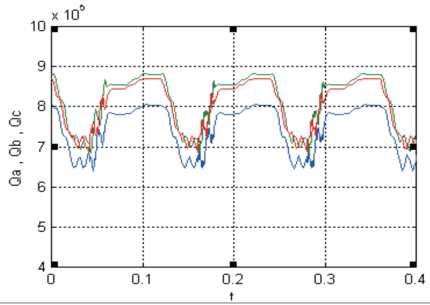

Figure. 24. Three-phase input reactive power variation waveform without SVC.

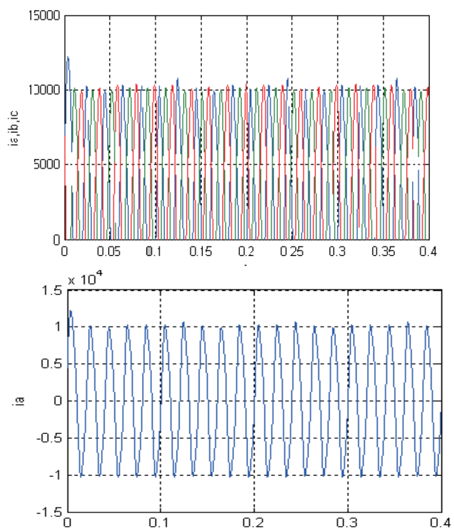

Figure. 25. Three-phase and single-phase currents of electric load with SVC.

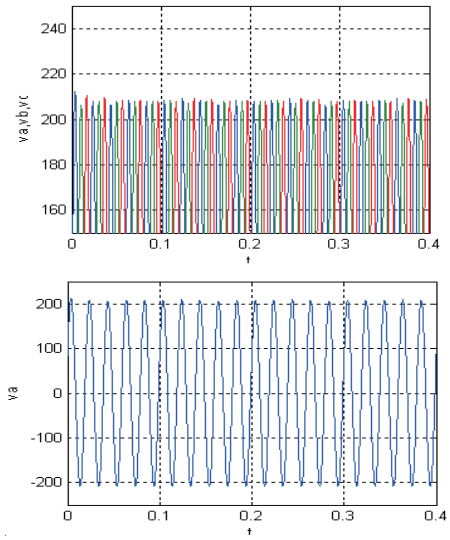

Figure. 26. Three-phase and single-phase voltages of electric load with SVC.

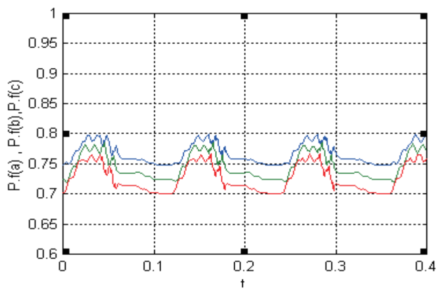

Figure. 27. Three-phase input power factor variation waveform without SVC.

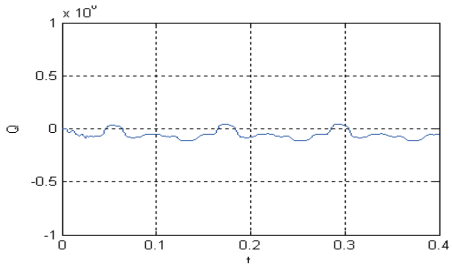

Figure. 28. Three-phase input reactive power variation waveform with SVC.

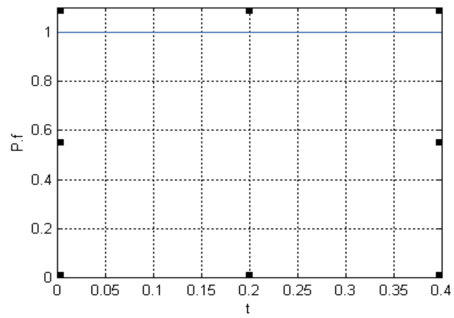

Figure. 29. Three-phase input power factor variation waveform with SVC.

CONCLUSION

Power quality characteristics of Electrical substations feeding CNG stations were investigated in this paper. Such nonlinear and time variant loads which cause high amount current and power variations and low power factor for their feeding power systems affect the voltage profile of the feeding electric systems greatly. Therefore, the application of an efficient static var compensator in the structure of TCR-FC was proposed for current and power fluctuation reduction, reactive power compensation and power factor improvement. Comparing the results of variation waveforms for the system with SVC shown in the Figures and comparing them with the status of without SVC, the efficiency of the proposed structure in reactive power compensation and power factor improvement is verified.

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