ACTIVE FILTERS APPLICATION FOR METRO A.C SUBSTATIONS

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ABSTRACT

In Cairo METRO subway system, diode rectifiers are commonly used in the front end of a power converter as an interface with the electric utility. Rectifiers are nonlinear in nature and, consequently, generate harmonic currents into the ac power source. The nonlinear operation of the diode rectifiers causes highly distorted input current. The non-sinusoidal shape of the input current drawn by the rectifiers causes a number of problems in the sensitive electronic equipment and in the power distribution network. The distorted input current flowing through the system produces distorted voltages at the point of common coupling (PCC).

The recommended practice, IEEE- 519, and IEC 1000-3 has evolved to maintain utility power quality at acceptable levels. In order to meet requirements, a cost-effective and economical solution to mitigate harmonics generated by power electronic equipment is currently of high interest. One approach is to use 12-pulse converter configuration using a phase shift power transformer to achieve low harmonics at the ac line current and low ripple at the dc output voltage.

This method is currently used in Metro system rectifier station to improve system power quality. The proposed solution for system power quality improvement in this research is to use the usual 12-pulse converter to active harmonic filter by using micro controller model technique. This system reduce THD in the ac source current from 9% to 3% and lower ripple in the dc output voltage with the advantage of simple, lower source voltage THD, size, and cost.

1. INTRODUCTION

The 12-pulse diode-bridge rectifier suffers from operating problems [1-2], such as poor power factor (PF), injection of harmonic currents into the ac mains, equipment overheating due to harmonic-current absorption, input voltage distortion, and malfunction of sensitive electronic equipment due to electromagnetic interference in order to prevent the harmonics from negatively affecting the utility lines, an IEEE Standard 519 and IEC 555-3 [3] has been established to give limits on voltage and current distortions. This has led to the consistent research in innovation of various configurations of ac–dc converters for mitigating these harmonics and to comply with these standards. Several methods based on the principle of increasing the number of pulses in ac-dc converters have been presented which are simple to implement [4]. These methods use two or more converters, where the harmonics generated by one converter are cancelled by the other converter, by a proper phase shift. To reduce the transformer rating, multi-pulse converters have been reported in the literature [7]. The pulse multiplication unit is achieved by multi-step reactor instead of the conventional inter phase transformer with three controlled switches. Mathematical analysis and simulation using ETAP software is presented for twelve and active harmonic filter. Active harmonic filter consists of electronic devices that is capable of completely eliminating reactive power by inserting the inverse of harmonic detection into the network. The active filters are normally available for low voltage networks. The active filters consist of active components such as semiconductor devices and eliminate many different harmonic frequencies. The signal types can be single phase AC, three phase AC. On the other hand, passive harmonic filters consist of passive components such as resistors, inductors and capacitors. The active filters which are used only for low voltages, the passive and active filters are commonly used and are available for different voltage levels[10][5].

2. MAIN SYSTEM FOR METRO SUBSTATIONS

Cairo METRO system consists of three lines, line one, two and three. Line one use the conventional 12-pulse rectifier stations (RS) to achieve the 1500 DC volts at the catenary's head line to feed the METRO traction units. The traction unit driver is a combination of series-parallel DC series motor.

Lines two and three uses the same rectifier station to achieve the same catenary's bus voltage with the difference of METRO traction unit configuration. Lines two and three use variable speed three phase induction motors by using voltage source inverter fed from the 750 DC voltage bus.

Energy of line 1

Rectifier stations : there are 31 stations distributed along the line to transfer the medium voltage (20 KV) to DC voltage (1500 VDC) to feed the catenary with required power for traction.

lighting power station : there are 7 stations to feed lighting works, signaling , communication, electrical gates ………….. etc.

Power stations : there are 3 stations to feed the equipment of the air-conditions and the air inside the tunnel

Energy of line 2

Rectifier stations : there are 21 stations distributed along the line to transfer the medium voltage (20 KV) to DC voltage (750 VDC) to feed the catenary with required power for traction.

lighting power station : there are 5 stations to feed lighting works, signaling , communication, electrical gates ………….. etc.

Power stations : there are 5 stations to feed the equipment of the air-conditions, elevators and the air inside the tunnel.

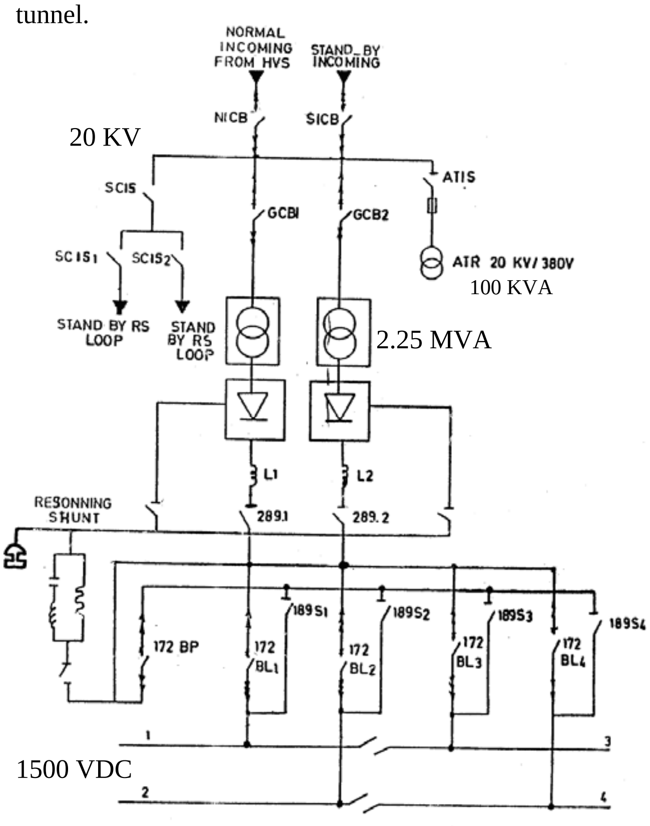

Fig. 1 Rectifier station diagram
20 KV to 1500 VDC

2.1 EQIPMENTS USED

The power system measuring and analysis using type C.A 8334B power analyzer to monitor the rectifier station power quality indicators (PQI's) like source current Is THD, and the voltage at point of common coupling Vpcc. These measured values were taken at the rectifier station inlet to evaluate the individual rectifier effect. On the other hand, the same (PQI's) was measured at the high voltage substation to see the total effect coming from the METRO total load at the same instant. Figures 2 and 3 show the source current and voltage waveforms and their harmonic spectrum for line two at rectifier station and HV substation respectively.

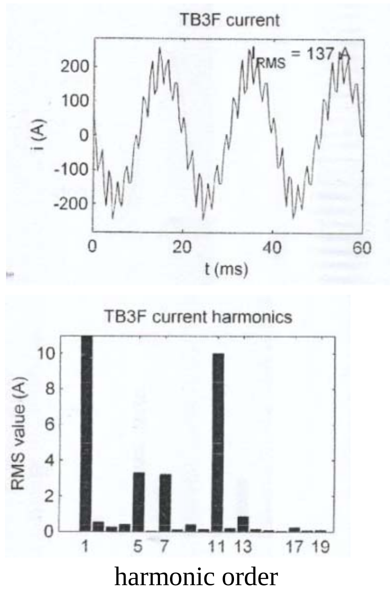

Fig. 2 Measured Is waveform and harmonic spectrum for traction bus-bar # 3F "TB3F"

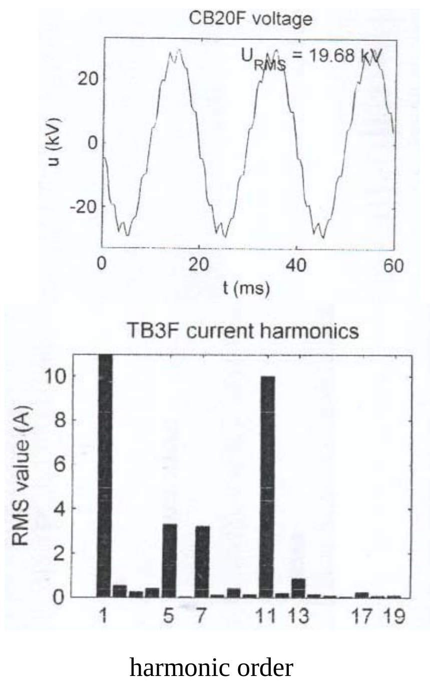

Fig. 3 Measured Vpcc waveform and harmonic for RS

2.2 ADDITIONAL MEASURMENTS

Table 1 shows a summary for the measured PQI in lines one and two. The source current THD was 9.12% in line one and 12.15% in line two. The source voltage THD is 3.2% for line one and 3.18% for line two. The power factor rectifier station (DF) is 0.71 for line one and 0.78 for line two. The total measured power factor (TPF) for line one is 0.74 and for line two is 0.65.

PQI	Line one		Line two	
	20 kv RS	66 kv SS	20 kv RS	220 kv SS
I_s THD %	9.12	7.01	12.15	3.86
V_{pcc} THD%	3.2	8.8	3.18	1.98
DPF	0.98	0.97	0.99	0.97
DF	0.71	0.76	0.78	0.67
TPF	0.7	0.74	0.78	0.65

Table 1 Summary of PQI measured at line one and two Rectifier stations and substations

3. SELECTION OF SUITABLE IPQC's FOR METRO SYSTEM

Selection of Improved Power Quality Converters (IPQC's) for METRO application is an important decision [8]. The following are some of the factors responsible for selection the right method and the selection criteria:

- Required level of power quality in input "The target is improving the TPF from 0.7 to 0.9".
- Type of output dc voltage "METRO system is operated using constant dc voltage at 1.5 kv".
- Power flow may be unidirectional or bidirectional "METRO is unidirectional power flow".
- Nature of output DC "Isolated dc output".
- Required level of power quality in output "voltage ripple, sag, and swell".
- Type of dc load "The load is dc motor in line 1 and three phase induction motor in line 2".
- Cost, size, and weight.
- Rating "The rectifier station rating is 2.25 MW".
- Reliability "High level of reliability is required".

From the previous analysis and the existing installation, The active filters are used in nonlinear load conditions where the harmonics are dependent on the time. Just like the passive filters, active filters can be connected in either series or parallel depending on the type of sources which create harmonics in the power system. The active filters minimize the effect of harmonic current by using the active power conditions to produce equal amplitudes of opposite phase there by cancelling the harmonics that are caused in the nonlinear components and replace the current wave from the nonlinear load.

3.1 THREE PHASE ACTIVE HARMONIC FILTER

During last four decade (1976), Active filters were been designed, improved and traded. These filters are used to compensate transfiguration of base current such as current harmonics, reactive power and neutral current. Also they are applicable to compensate voltage problems like voltage harmonics, under/over voltage and voltage unbalance [9].
Active filter power circuit consists of a DC capacitor [6], an inverter and an inductor. Capacitor is active filter energy storage device. According to switching algorithm, Inverter obtains direct of energy transmission between DC capacitor and network through inductor. That converts DC capacitor energy to network AC energy and vice versa (Fig. 4).

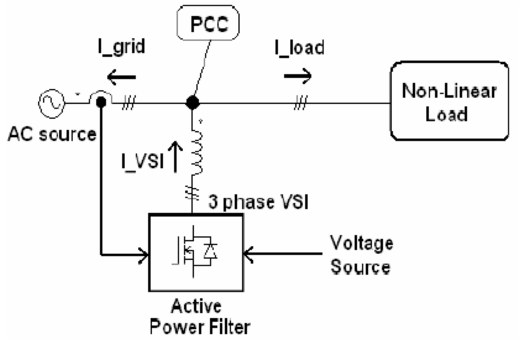

Fig. 4 Shunt active filter single line diagram

4. SYSTEM MODELING AND SIMULATION

System modeling is done by using ETAP software for 12-pulse and active harmonic filter models for line one and line two.

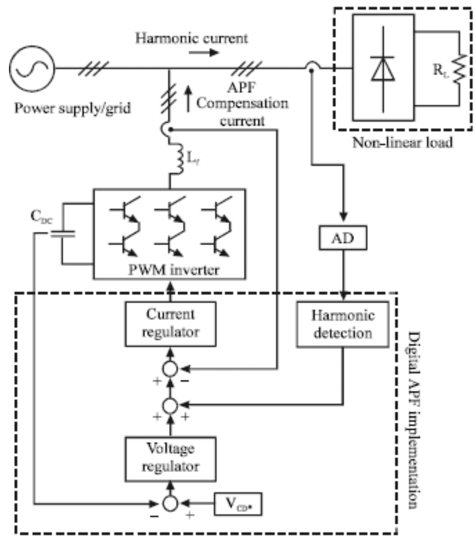

Fig. 5 System modeling of active harmonic filter by micro controller model

4.1 SUMMARY OF SIMULATION

Table 2 shows a summary for the three different techniques from power quality indices point of view to monitor the improvement of the system parameters from the 12-pulse (model A) to the 12-pulse with (model B) active filter. The TPF is improved from 0.81 to 0.95, the source current THD is improved from 8.5 % to 2.7 % and the source voltage THD is improved from 4.4 % to 0.04 % in model A and 0.04% in model B

PQI	12-pulse model A		12-pulse with active filter model B	
	Line 1	Line 2	Line 1	Line 2
Is THD%	10.1	8.5	4.8	2.7
Vpcc THD%	6.2	4.4	0.07	0.04
HV DPF	0.98	0.98	0.98	0.97
RS DF	0.81	0.83	0.92	0.96
Total PF	0.77	0.81	0.89	0.95

Table 2 Summary of simulated 12-pulse and 12-pulse with active filter

Active harmonic filter show the simulated source current waveform with closer to sinusoidal wave shape than the 12-pulse converter.

The source current total harmonic distortion is reduced to 4.8% that represents the source current frequency spectrum.

5. CONCLUSION

This paper has shown, theoretically and simulation, the possibility of supporting the METRO system rectifier stations of 12-pulse by Active harmonic filter by applying the pulse multiplication technique with a simple modification on the existing configuration using the pulse multiplication technique, and therefore emphasing the need for filtering to operate the system at sinusoidal waveform. This is very important because the design of active filters is practically simple . The power quality indices are remarkably improved by means of the active filter. This arrangement will not only lead to benefits for METRO system performance but also for EEA and other customers at the point of common coupling. Moreover, the load and peak penalty for METRO will be cancelled or reduced (from invoice in EGP/year 2013 approximate 3 million EGP/year) . Active Harmonic Filter offers a low cost solution with low power consumption and compact size and high reliability which are the main advantages of this method.

LIST OF SYMBOLS AND ABBREVIATIONS

PCC	point of common coupling
THD	total harmonic distortion
PF	power factor
RS	rectifier stations
HV	high voltage
PQI's	power quality indicators
Tr.	Power transformer
TB3F	traction bus 3 from Tr. F
CB20F	circuit breaker 20 kv Tr. F
DF	power factor rectifier station
TPF	total measured power factor
DPF	high voltage power factor

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