

Optimal Sizing of C-Type Passive Filters under Non-Sinusoidal Conditions: A Techno-Economic Study

by

ISLAM FARAG MOHMED EL-SYD FARAG

**A Thesis Submitted to the
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in Partial Fulfillment of the
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MASTER OF SCIENCE IN**

ELECTRICAL POWER AND MACHINES ENGINEERING

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Key Words: Harmonics, passive filters, power factor

Summary:

Genetic Algorithm toolbox (GA) provided by MatLab software is selected to find the optimal sizing of parameters of C-type passive filter. The optimal design of the proposed filters considers three optimization problems- minimization of the total current, voltage harmonic distortion and maximizing power factor. Each optimization problem considers practical constraints such as load power factor , total current and voltage harmonic distortion limitation at certain specified ranges, considering source and load nonlinearities, while taking into account compliance with IEEE Standard 519-1992 and IEEE Standard 18-2002. Finally, the effectiveness of C-type harmonic passive filters is demonstrated by means of various study cases, including a comparison between the results of the three objective functions. A comparative study between C-type filter and single tuned passive filters is represented, comparing with the uncompensated system configuration under non-sinusoidal conditions.

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LIST OF SYMBOLS AND ABBREVIATIONS*

(*According to alphabetic order)

B_{LH}	Load susceptance in mhos at harmonic order h
C_{CA}	Auxiliary capacitor cost in Egyptian pounds of the C -type filter
C_{CM}	Main capacitor cost in Egyptian pounds of the C -type filter
C_E	Present value cost of energy losses in Egyptian pounds
C_L	Reactor cost in Egyptian pounds of the C -type filter
D_{pf}	Displacement power factor in percent
η	Transmission efficiency in percent
F_V	Filter utilization factor
GAIN	Power saved due to the transmission power loss reduction in the supply network compared to the uncompensated system
G_{Lh}	Load conductance in mhos at harmonic order h
H. P.	Harmonic pollution percent, describing the fitness of the power harmonic filters
i	Interest rate
I_A	RMS value of the auxiliary capacitor current in amperes
I_{Ah}	Average value of the auxiliary capacitor current in amperes at harmonic order h
I_F	RMS value of the main capacitor current in amperes
I_{Fh}	Average value of the main capacitor current in amperes at harmonic order h
I_{FN}	Nominal RMS main capacitor current in amperes based on the rated kilovolt-ampere reactive (kVAr) and voltage
I_L	Rated RMS load current in amperes
I_{Lh}	Average value of the load harmonic current in amperes at harmonic order h
I_S	RMS value of the supply current in amperes
I_{Sh}	Average value of the supply current in amperes at harmonic order h
ITHD	Current total harmonic distortion in percent
k	Filter life time in years
MVA_{SC}	System short circuit capacity in megavolt-amperes
PCC	Point of common coupling
PF	Load power factor in percent
P_{FILTER}	C -type filter power loss in watts
P_L	Load active power per phase in watts
P_{LOSS}	Transmission power loss in watts
P_S	Supply active power per phase in watts
PV	Present value factor

q	The quality factor
QCA	Auxiliary capacitor rating in reactive volt-amperes
Q_{CM}	Main capacitor rating in reactive volt-amperes
Q_L	Load reactive power per phase in reactive volt-amperes
Q_{LF}	Reactor rating in reactive volt-amperes
R	C-type filter resistance in ohms
R_F	The h th harmonics resistance in ohms of the C-type filter
R_{Lh}	Load resistance in ohms at harmonic order h
R_{Sh}	Transmission system resistance in ohms at harmonic order h
S_F	Main capacitor rating in volt-amperes
S_{FN}	Nominal main capacitor rating in volt-amperes
TDD	Total demand distortion in percent
TOTAL COST	Total cost in Egyptian pounds of the C-type filter
U_C	Capacitor unit cost in Egyptian pounds per reactive volt-amperes
U_L	Reactor unit cost in Egyptian pounds per reactive volt-amperes
U_V	Cost of power loss in Egyptian pounds per kilowatt hours
V_{CAP}	Auxiliary capacitor peak voltage in volts
V_{Ch}	Average value of the main capacitor voltage in volts at harmonic order h
V_{CN}	Nominal RMS main capacitor voltage in volts
V_L	RMS value of the load voltage (line to neutral) in volts
V_{LAP}	Reactor peak voltage in volts
V_{Lh}	Average value of the load voltage in volts at harmonic order h
V_S	RMS value of the source voltage (line to neutral) in volts
V_{Sh}	Average value of the source voltage in volts at harmonic order
VTHD	Voltage total harmonic distortion in percent
X	Inductive reactance of the C-type filter in ohms
X_{CA}	Auxiliary capacitive reactance of the C-type filter in ohms
X_{CM}	Main capacitive reactance of the C-type filter in ohms
X_F	The h th harmonics reactance in ohms of the C-type filter
X_{Lh}	Load reactance in ohms at harmonic order h
X_{Sh}	Transmission system reactance in ohms at harmonic order h
Z_{Ch}	The h th harmonics impedance in ohms of the C-type filter
Z_{Lh}	The h th harmonics load impedance in ohms
Z_{Sh}	The h th harmonics transmission impedance in ohms

ABSTRACT

Harmonic pollution of electrical distribution systems is not new; it can be found in all industrial facilities. Non-linear loads seem to be the main source of harmonic pollution in a power distribution system. Degradation of the load power factor, increases in transmission line losses, and reduction of the transmission network efficiency are all expected due to the advance and sophistication of non-linear loads; the level of voltage harmonic distortion in distribution networks will also increase significantly. Harmonic passive filters have a dual job as they compensate the load reactive power improving the load power factor, but they also distract harmonic currents through a low impedance shunt path with very slight flowing back into the system. Thus, they minimize the voltage distortion caused by nonlinear loads and prevent the proliferation of indistinct currents within the power system. Shunt passive filters are the most used item in the power quality market, due to their simplicity, economical cost and their possible different frequency response characteristics that can achieve a certain required harmonic filtering target. *C*-type filter is investigated as an alternative approach, to avoid some of the disadvantages of traditional shunt passive techniques. In this thesis, the essential equations required for the *C*-type filter design, advantages, and disadvantages are identified. Genetic Algorithm toolbox (GA) provided by MatLab software is selected to find the optimal sizing of parameters of *C*-type passive filter. The optimal design of the proposed filters considers three optimization problems- minimization of the total current, voltage harmonic distortion and maximizing power factor. Each optimization problem considers practical constraints such as load power factor , total current and voltage harmonic distortion limitation at certain specified ranges, considering source and load nonlinearities, while taking into account compliance with IEEE Standard 519-1992 and IEEE Standard 18-2002. Finally, the effectiveness of *C*-type harmonic passive filters is demonstrated by means of various study cases, including a comparison between the results of the three objective functions. A comparative study between *C*-type filter and single tuned passive filters is represented, comparing with the uncompensated system configuration under non-sinusoidal conditions.

CHAPTER (1)

INTRODUCTION