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
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE IN

ELECTRICAL POWER AND MACHINES ENGINEERING

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Approved by the Examining Committee

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

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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CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF SYMBOLS AND ABBREVIATIONS*

(*According to alphabetic order)

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

q	The quality factor
QCA	Auxiliary capacitor rating in reactive volt-amperes
$\mathbf{Q_{CM}}$	Main capacitor rating in reactive volt-amperes
$\mathbf{Q_{L}}$	Load reactive power per phase in reactive volt-amperes
$\mathbf{Q_{LF}}$	Reactor rating in reactive volt-amperes
R	*C*-type filter resistance in ohms
$\mathbf{R_{F}}$	The *h*th harmonics resistance in ohms of the *C*-type filter
$\mathbf{R_{Lh}}$	Load resistance in ohms at harmonic order *h*
$\mathbf{R_{Sh}}$	Transmission system resistance in ohms at harmonic order *h*
$\mathbf{S_{F}}$	Main capacitor rating in volt-amperes
$\mathbf{S_{FN}}$	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
$\mathbf{U_{C}}$	Capacitor unit cost in Egyptian pounds per reactive volt-amperes
$\mathbf{U_{L}}$	Reactor unit cost in Egyptian pounds per reactive volt-amperes
$\mathbf{U_{V}}$	Cost of power loss in Egyptian pounds per kilowatt hours
$\mathbf{V_{CAP}}$	Auxiliary capacitor peak voltage in volts
$\mathbf{V_{Ch}}$	Average value of the main capacitor voltage in volts at harmonic order *h*
$\mathbf{V_{CN}}$	Nominal RMS main capacitor voltage in volts
$\mathbf{V_{L}}$	RMS value of the load voltage (line to neutral) in volts
$\mathbf{V_{LAP}}$	Reactor peak voltage in volts
$\mathbf{V_{Lh}}$	Average value of the load voltage in volts at harmonic order *h*
$\mathbf{V_{S}}$	RMS value of the source voltage (line to neutral) in volts
$\mathbf{V_{Sh}}$	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
$\mathbf{X_{CA}}$	Auxiliary capacitive reactance of the *C*-type filter in ohms
$\mathbf{X_{CM}}$	Main capacitive reactance of the *C*-type filter in ohms
$\mathbf{X_{F}}$	The *h*th harmonics reactance in ohms of the *C*-type filter
$\mathbf{X_{Lh}}$	Load reactance in ohms at harmonic order *h*
$\mathbf{X_{Sh}}$	Transmission system reactance in ohms at harmonic order *h*
$\mathbf{Z_{Ch}}$	The *h*th harmonics impedance in ohms of the *C*-type filter
$\mathbf{Z_{Lh}}$	The *h*th harmonics load impedance in ohms
$\mathbf{Z_{Sh}}$	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