



# **MULTIPLE-ARM PASSIVE FILTERS DESIGN BASED ON DIFFERENT REACTIVE POWER DIVISION APPROACHES**

By  
**Sameh Sayed Kandil Ibrahim**

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**

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY  
GIZA, EGYPT  
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Electrical Power and Machines Department  
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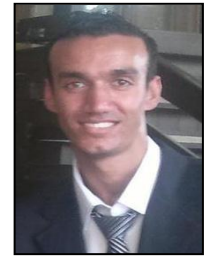
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**Title of Thesis:**

**MULTIPLE-ARM PASSIVE FILTERS DESIGN BASED ON DIFFERENT REACTIVE  
POWER DIVISION APPROACHES**

**Keywords:**

Harmonic distortion, Passive filters, Power factor, Power quality, Crow Search Algorithm.

**Summary:**

This thesis introduces a comparative study of different techniques for reactive power division among shunt passive filter arms. A new optimization algorithm which is known as Crow Search Algorithm (CSA) is applied for 5th, 7th, and 11th harmonic filters design to achieve the parameters that can present the minimum current total harmonic distortion. The investigated test system is simulated using ETAP and Matlab environments, and then an equivalent model is constructed for the case study using Matlab-Simulink for validation purposes. The comparison criteria include network performance indices like harmonic distortion levels, filtering characteristics of the different design techniques, filter effectiveness, harmonic amplification ratio, and the risk of filters outage on the distortion levels. The filtering cost was evaluated to check the most economical technique. Finally, the filters' duties were checked according to the international standards to ensure a safe operation of filters.

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## **DEDICATION**

TO MY MOTHER, MY SOURCE OF INSPIRATION.

TO SPIRITS OF THE MARTYRS: ENG. MOHAMED REDA AND  
ENG. MOHAB SALEH.

TO SPIRITS OF THE MARTYRS OF FACULTY OF ENGINEERING  
– CAIRO UNIVERSITY.

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## **LIST OF ABBREVIATIONS**

PCC	Point of Common Coupling
THDI	Total Harmonic Current Distortion
THDV	Total Harmonic Voltage Distortion
IHD	Individual Harmonic Distortion
HAR	Harmonic Amplification Ratio
PF	Power Factor
CSA	Crow Search Algorithm
NSGA	Non-Dominated Sorting Genetic Algorithm
VSD	Variable Frequency Drive
ASD	Adjustable Speed Drive
OF	Objective Function
FL	Flight Length
AP	Awareness Probability
BA	Bat algorithm
PSO	Particle swarm optimization
SA	Simulated annealing

## LIST OF SYMBOLS

$I_f, I_1$	RMS value of the fundamental current
$I_h$	RMS value of the harmonic current
$Q_C$	total three phase reactive power supplied by the capacitor bank
$P$	total three phase active power
$S$	total three phase apparent power
$\cos \Phi$	load power factor
$R$	internal resistance of the inductor
$L_f$	inductance of the filter inductor
$C_f$	capacitance of the filter capacitor
$F_0$	resonant frequency
$Q$	reactive power supplied by the filter branch
$X_L$	inductive reactance of the filter
$X_C$	capacitive reactance of the filter
$q$	quality factor of the reactor
$H$	harmonic order
$N$	Number of filter arms
$Q_{ith}$	three phase reactive power supplied by the $i$ th filter
$IHD_{ith}$	Individual harmonic distortion of the $i$ th order.
$IHD_{max}$	maximum allowable individual harmonic distortion
$THDI_{max}$	maximum allowable total harmonic current distortion
$THDV_{max}$	maximum allowable total harmonic voltage distortion
$\tan \delta$	loss tangent of the capacitor
$\theta_{ith}$	phase shift of the $i$ th waveform
$\omega_1$	fundamental angular frequency
$C_{ith}$	capacitance of the $i$ th filter capacitor

$V_1$	RMS value of the fundamental phase voltage
$I_{ith}$	RMS value of the $i$ th harmonic current
$V_{ith}$	phase voltage across the $i$ th capacitor
$P_{\delta ith}$	specific power losses of the $i$ th filter branch
$\omega_p$	angular frequency of the parallel resonance
$F_C$	capacitor power losses
$K_{CL}$	loss factor of the capacitor
$P_h$	present value factor
$i$	interest rate
$F_U$	filter utilization factor
$U_U$	cost of the power losses
$U_C$	incremental cost of the capacitor
$U_L$	incremental cost of the reactor
$I_{SC}$	RMS value of the short circuit current
$I_L$	RMS value of the load current
$R_{SC}$	short circuit resistance
$X_{SC}$	short circuit inductive reactance
$V_f(h\omega)$	harmonic voltage percentage after filter installation
$x(i,t)$	position function of the crow $i$ at iteration $t$
$m(i,t)$	memory function of the crow $i$ at iteration $t$
$r_i$	probability function with uniform distribution
$fl(i,t)$	flight length function of the crow $i$ at iteration $t$
$V_{rated}$	rated voltage across the capacitor
$I_{rated}$	rated current through the filter
$Q_{rated}$	rated reactive power of the filter
$V_C$	RMS value of the voltage across the capacitor

$I_C$	RMS value of the current flowing through the filter
$Q_C$	RMS value of the filter reactive power
$X_{C1}$	fundamental capacitive reactance
$Z_{fh}$	filter impedance at the harmonic order $h$
$h_{\max}$	maximum harmonic order
$Q_{\text{desired}}$	required reactive power of the compensation
$x$	Fixed cost (investment) of the filter
$y$	Power losses cost (operating) of the filter
$\delta$	Filter tuning factor