Optimal resonance-free third-order high-pass filters based on minimization of the total cost of the filters using Crow Search Algorithm

Shady H.E. Abdel Aleem, Ahmed F. Zoba, Murat E. Balci

Abstract

The most common damped filters (DFs) are the second-order, third-order, C-type, and double-tuned filters. Other DFs such as the first-order and band-pass filters exist, but their high operating losses considerably diminish their usage. In this paper, firstly, for the third-order damped filter with equal and unequal capacitors, the relations among their circuit parameters are derived. Secondly, the optimal design problem of the two third-order high-pass filters is formulated by regarding these expressions to minimize the filter cost taking into account both the investment and operating expenses. The total and individual harmonic distortion indices, power factor and the harmonic voltage amplification ratios which measure the filter’s resonance damping capability, are considered as constraints. A recent metaheuristic optimization technique based on the intelligent behavior of crows, known as the Crow Search Algorithm (CSA), is employed for the solution of the formulated design problem. Further, a comparative analysis of the two designs of the third-order high-pass filters and a third-order C-type filter is presented. The results reveal that all the proposed filters guarantee no electrical resonance hazards while maintaining the allowable limits for the various performance indices of the system, load, and filter. Besides, the comparative analysis validates that the C-type filter provides higher power factor, system efficiency and transmission loss improvement than the other two filters, and that the proposed filters achieve almost the same voltage and current harmonic mitigation levels. The solution of the cost minimization problem reveals that the C-type filter and the third-order high-pass filter with equal capacitors have the worst and best resonance damping capabilities respectively, under the worst case conditions. Additionally, the filters with the lowest and highest cost are found as the third-order filter with unequal capacitors and the C-type one, respectively. Besides, the CSA is compared to the genetic algorithm (GA), and particle swarm optimization (PSO) techniques and the results show the fast convergence capability and the effectiveness of the proposed algorithm in solving the problem of optimal design of third-order resonance-free passive filters in distribution networks.

1. Introduction

Harmonic distortion is one of the main power quality problems for power systems, particularly with the advance of power electronic equipment and nonlinear loads that worsen the quality of power. Recently, other developments in power systems have led to new challenges in the quality of the power domain, such as integration of large-scale renewable energy based generation technologies, and the expansion of interconnected power grids [1–6].

Among the numerous solutions and power conditioning devices that improve the quality of power and mitigate harmonics; passive filtering is still widely used for voltage support, reactive power compensation, and harmonic mitigation in transmission and distribution systems due to simplicity, low cost, easy surveillance and maintenance, and high reliability [7]. On the other hand, tuned passive filters suffer from various drawbacks such as parameter variations that may occur due to frequency deviation, manufacture
tolerance, and temperature change. Besides, the filtering performance is affected by the source resistance which may vary and hence leads to resonance occurrence between the filter and system [3,8–10].

Passive filters were firstly installed in the 1940s [9]. In its broadest scene, they are classified based on the method of connection into the series and shunt filters. Series filters present a high-impedance series path to block harmonics at the tuning frequency, while shunt filters present a low-impedance shunt path to divert harmonics at the tuning frequency. Shunt filters are still more employed for harmonics mitigation than the series filters because of the significant fundamental power loss and voltage drop of series filters, as well as their high fundamental voltage-ampere (VA) rating. Moreover, shunt filters are capable of supporting voltage and compensating reactive power at the fundamental frequency [3,11,12].

According to the nonlinear loads being considered, series filters are more suitable for voltage-source nonlinear loads or AC drives [13], while shunt filters are more suitable for current-source nonlinear loads or DC drives [14].

Further, shunt filters are classified based on their function, into tuned and damped filters. Tuned filters are filters that are adjusted to mitigate harmonics by providing a low impedance path at one, two, or even three tuning harmonic frequencies, known as single-tuned, double-tuned, and triple-tuned (less common) filters, respectively. Single-tuned filters are common in distribution systems and industrial applications, while the double-tuned and the triple-tuned filters are common in high-voltage applications and high-voltage direct current (HVDC) transmission systems [3,11]. On the other hand, damped filters such as the first-order, second-order, third-order, C-type, damped double-tuned, and bandpass filters, are high-pass filters (HPFs) that provide a low impedance path to a broad range of harmonics [3,15]. They are widely used in transmission systems, HVDC links, and recently in distribution and industrial systems [16,17]. Compared to the tuned filters, they are less sensitive to variations that may occur due to frequency deviation, manufacture tolerance, and temperature change. Also, they can dampen the harmonic amplification which may occur by the

---

**Nomenclature**

- **AP**: Awareness probability
- **DPF**: Displacement power factor
- **E Sn**: The harmonic system background voltage at harmonic order n
- **FC**: Total cost of the filter
- **fl**: Flight length
- **F P**: Power losses associated with the filter
- **FS**: Impedance-frequency response index
- **FV**: Filter utilization percentage
- **h**: Tuning order of the filter
- **HDI n**: Individual harmonic distortion of the line current at harmonic order n in percent
- **HDI std**: The IEEE standard 519’s limit of the HDI n in percent
- **HDV**: Individual harmonic distortion of the load voltage in percent
- **HDV n**: Individual harmonic distortion of the load voltage at harmonic order n in percent
- **HDV std**: The IEEE standard 519’s limit of the HDV n in percent
- **HMC**: Harmonic mitigation capability of the filters in percent
- **HVAR**: Harmonic voltage amplification ratio
- **HVAR ref**: Reference (limit) value of HVAR
- **HVAR worst**: HVAR value for the worst case scenario
- **i**: Interest rate
- **I C**: Rms current of the main capacitor (C 1) of the filters
- **IC**: Investment cost of the filter
- **I N L(ω)**: Harmonic nonlinear load current at the angular frequency (ω)
- **I rated**: Rated current of the main capacitor (C 1) of the filters
- **I sn**: The nth harmonic line current
- **k**: Lifetime of filter in years
- **OC**: Operating cost of the filters
- **n**: Harmonic number
- **PF**: Power factor in percent
- **P V**: Present value
- **Q C 1, Q C 2**: Reactive power drawn by the main capacitor (C 1) and auxiliary capacitor (C 2) of the filters
- **Q rated**: Rated reactive power of the main capacitor (C 1) of the filter
- **Q x**: Reactive power drawn by the inductor (L) of the filters
- **R F(ω)**: The filter’s equivalent reactance at the angular frequency (ω)
- **R Fn**: The nth harmonic resistance of the nth harmonic filter impedance Z fn
- **R Sn**: The nth harmonic resistance of the nth harmonic Thevenin equivalent impedance of the source side
- **t**: Iteration number
- **t max**: Maximum number of iterations
- **THDI**: Total harmonic distortion of the line current in percent
- **THDV**: Total harmonic distortion of the load voltage in percent
- **TP L**: Transmission power loss
- **U C, U X**: Unit costs of the capacitors and inductors of the filters, respectively
- **U V**: Consumption charge rate
- **V**: Nominal voltage of the system
- **V C**: Rms voltage of the main capacitor (C 1) of the filters
- **V Ln**: The nth harmonic load voltage
- **V peak**: Peak voltage of the main capacitor (C 1) of the filters
- **V rated**: Rated voltage of the main capacitor (C 1) of the filters
- **X F(ω)**: The filter’s equivalent reactance at the angular frequency (ω)
- **X Fn**: The nth harmonic reactance of the nth harmonic filter impedance Z fn
- **X Sn**: The nth harmonic reactance of the nth harmonic Thevenin equivalent impedance of the source side
- **Z F(ω)**: The filter equivalent impedance at the angular frequency (ω)
- **Z L(ω)**: The linear load impedance at the angular frequency (ω)
- **Z n**: The nth harmonic equivalent impedance seen from the harmonic current source side
- **Z S(ω)**: The system Thevenin equivalent impedance at the angular frequency (ω)
- **α, β, γ**: Collective variables used for expressing R F(ω) and X F(ω)
- **η F**: Transmission efficiency in percent
- **ψ n**: The harmonic phase difference between the nth harmonic load voltage and line current
- **ω h**: Angular frequency at the tuning harmonic order (h) of the filter
دریافت فوری متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات