Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2014/03/jls.htm
2014 Vol. 4 (S3), pp. 656-661/Mohammadi et al.

Research Article

OPTIMAL PASSIVE FILTER LOCATION BASED POWER LOSS MINIMIZING IN HARMONICS DISTORTED ENVIRONMENT

[*] Mohammadi M., Mohammadi Rozbahani A., Montazeri M. and Memarinezhad H.
Department of Electrical Engineering, College of Engineering, Borujerd Branch, Islamic Azad University, Borujerd, Iran
** Author for Correspondence*

ABSTRACT

The harmonic problems are mainly due to the substantial increase of nonlinear loads due to technological advances, such as the use of power electronic circuits and devices, in ac/dc transmission links, or loads in the control of power systems using power electronic or microprocessor controllers. Once the harmonic sources are clearly defined, they must be interpreted in terms of their effects on the rest of the system and on personnel and equipment external to the power system. Harmonics increase the equipment losses and thus the thermal stress. Therefore this paper deals with optimal LC passive filter location to reduce the power loss due to harmonics.

Keywords: *Power Loss, Harmonics, Passive Filters, Optimal Location*

INTRODUCTION

In general, sources of harmonics are divided into: domestic loads, industrial loads, control devices (Vishal and Singh, 2010). Increases in harmonic distortion will result in additional heating losses, shorter insulation lifetime, higher temperature and insulation stress, reduced power factor, lower productivity, efficiency, capacity and lack of system performance of the plant (Kawam and Emuel, 1996). Between the different technical options available to reduce harmonic distortions and improve power quality, due to implementation of shunt capacitors to compensate the load power factor; it seems the passive power filters have proved to be an important method to compensate current and voltage disturbances in power distribution system (Ram *et al.,* 1988). The results of related investigations show that the most of voltage and current distortions in distribution networks are arose to harmonics of third, fifth and seventh orders (Akagi, 2006).

Passive Harmonic Filter

Passive filters are inductance, capacitance, and resistance elements configured and tuned to control harmonics and can be classified into tuned filters and high-pass filters (Taher *et al.*, 2014). They are connected in parallel with nonlinear loads such as diode/thyristor rectifiers, ac electric arc furnaces, and so in.

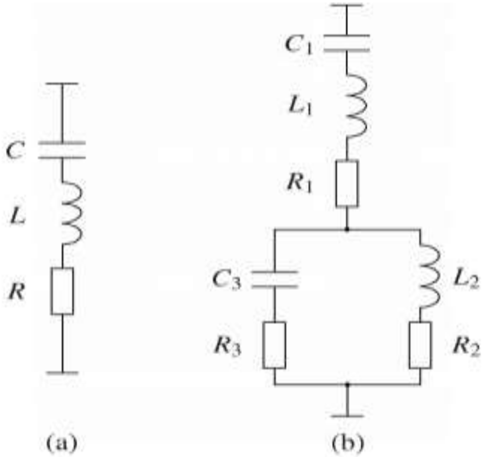

Figure 1: Passive tuned filters: (a) single tuned, and (b) double tuned

Figure 1 shows circuit configurations of the passive filters on a per phase base. Among them, the combination of two or three single-tuned filters to the 5th, 7th, 11th have been used in a high-power three-phase thyristor rectifiers in a nonlinear distribution system. Passive filter is a series combination of an inductance and a capacitance. In reality, in the absence of a physically designed resistor, there will always be a series resistance, which is the intrinsic resistance of the series reactor sometimes used as a means to avoid filter overheating.

Problem Formulation and Simulation Method

Objective Function

$$\mathrm{C} = \sum_{\mathrm{n}=1}^{\mathrm{N}} \mathrm{Cc}\left(Q_{\mathrm{Fil,i}}\right) + \left(\mathrm{Ce} \times \mathrm{P}_{\mathrm{Loss}} \times \mathrm{T}\right) \qquad 1$$

Where first term is investment cost of passive filter installation and second term is the cost of energy lost in distribution feeders.

C_C* *(Fil, i) is cost of capacitor installed at location ***i*** and ***Ce*** is the cost of energy per unit and Ploss is active power loss and is calculated as follows (IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems, 1993):

$$P_{Loss} = \sum_{k=1}^{L} P_{Loss}^{(k)} = \sum_{k=1}^{L} \left[\sum_{j=1}^{n} \sum_{\substack{m=1 \\ m>j}}^{n} V_j^{(k)} V_m^{(k)} Y_{jm}^{(k)} \cos(\delta_j^{(k)} - \delta_m^{(k)} - \phi_{jm}^{(k)}) \right] \qquad 2$$

Where $V_j^{(k)}$ and $\delta_j^{(k)}$ are magnitude and phase of kth harmonic voltage at bus *j*, respectively. $Y_{jm}^{(k)}$ and $\phi_{jm}^{(k)}$ are also magnitude and phase of kth harmonic line admittance between buses *j* and *m*, respectively.

$KVA_{Filter,i}$ is the reactive power capacity of filters versus KVA.

K_P is the equivalent annual cost per unit of power loss in $/(kW-year), K_C is cost per unit of filter for 1 KVA installed filter.

Constraints

Voltage and Stability Limits

Voltage constraints will be taken into account by specifying lower (e.g., V_{min} =0.9 pu) and upper (e.g., V_{max} =1.1 pu) bounds of effective voltage (e.g., V) as below:

$$V_{\min} \le V_i \le V_{\max} \qquad 3$$

Where rms magnitude voltage is:

$$V_{i\,rms} = \sqrt{\sum_{k=1} \left(V_i^{(k)}\right)^2} \qquad 4$$

So that *i* and *k*, are the bus number and harmonic order, respectively.

Stability limits, which are dominant for lines between bus n and m, are expressed as follows,

$$\delta_{\min} \le \delta_i \le \delta_{\max} \qquad 5$$

Passive Filters Capacity and Number Constraints

The maximum capacity and number of LC passive filters constraints is formulated as:

$$\begin{aligned} &\mathrm{N}_{\mathrm{Fil}} \le \mathrm{N}_{\mathrm{Max\_Fil}} \\ &\mathrm{Q}_{\mathrm{Fil,i}} \le \mathrm{Q}_{\mathrm{Fil,max}} \end{aligned} \qquad 6$$

Harmonic Distortion Constrains

The distortion of voltage is considered to be bounded by maximum total harmonic distortion of voltages (THDv):

$$THD_V \le THD_V^{max} \qquad 7$$

Where

$$THD_V = \left(\frac{\sqrt{\sum_{k \neq 1} \left(V_i^{(k)} \right)^2}}{V_i^{(1)}} \right) \times 100 \qquad 8$$

And $THD_V^{max} (= 5\%)$ is the standard value of THD. Bounds in Eqs. (3) and (7) are according to IEEE-519 standard (Seyed, *et al.*, 2011).

RESULTS AND DISCUSSION

Simulation and Results

In practice, the available values of capacitance for filters design are discrete, because they correspond to commercially standardized values of capacitive modules available. As described in pervious section, L and C values of passive filters are mutually dependent, so the size of filter is discrete in the same way as the capacitors (Rao *et al.*, 2011). These values also depend on the localization of filter on feeder. On the other hand, the points of possible installation are the buses of the feeder and therefore, they can also be considered as a discrete variable and form a finite group. In that way, the problem is especially of combinatory optimization. This problem should also take in consideration the distributed nature and variable of linear loads and harmonic sources of system.

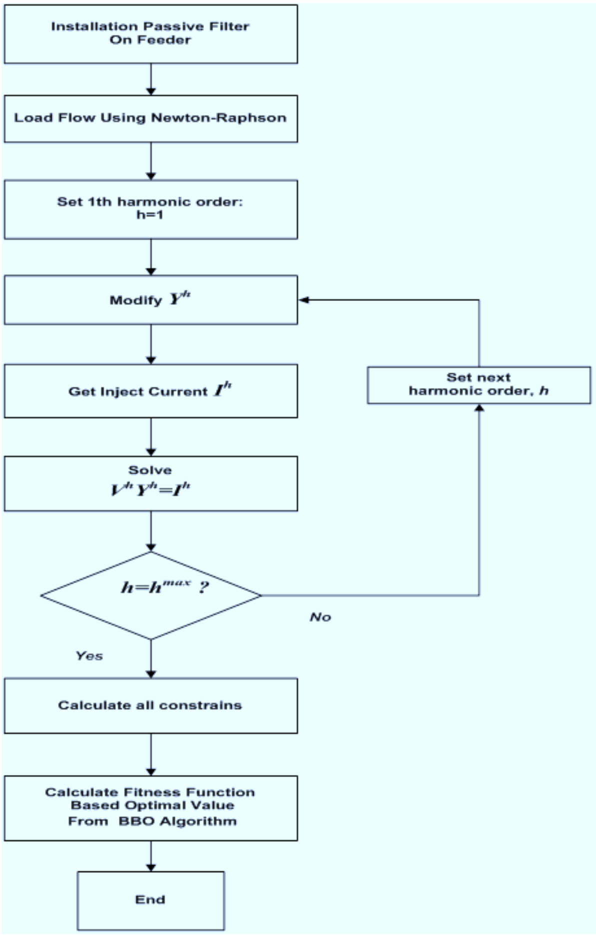

Figure 2: The flowchart of optimal passive filter design

In this example, the problem consists of planning three passive harmonic filters, whose harmonic tuning orders are 4.7 (for 5th harmonic), 6.7 (for 7th harmonic) and 10.7 (for 11th harmonic), respectively.

As presented earlier, the reactive power capacity of passive filter is a function of harmonic tuning orders and the reactive capacity of pre-installed fixed shunt capacitors in busses of system. On the other hand the investment cost of filter is related to filter capacity, so the proposed algorithm must calculate the optimum harmonic tuning orders until the objective function is minimized. At the same time, constraints include voltage limits, number/size of installed LC passive filters, limit candidate buses for LC installation and the minimum harmonic voltage distortion must satisfied by this procedure. The flowchart of optimization procedure for passive power filter design is shown in Figure 2.

The proposed method for LC passive filter sizing and sitting in the presence of linear and nonlinear loads has been applied on a 23 kV, 10-bus radial distribution test system (Figure 3).

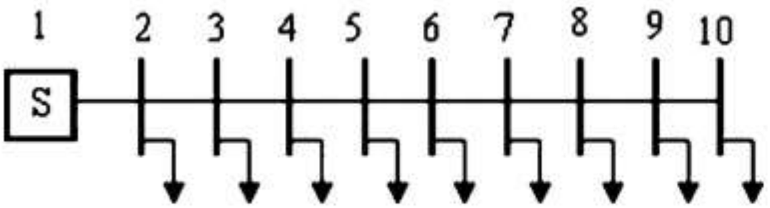

Figure 3: Single line diagram of the 10-bus radial distribution test system

Line data and Load data in 10-bus test system is given in Tables 1 and 2 respectively.

Table 1: Line data in 10-bus test system

From Bus	To Bus	R (p.u)	X (p.u)	From Bus	To Bus	R (p.u)	X (p.u)
1	2	0.00431	0.01204	6	7	0.02222	0.02877
2	3	0.00601	0.01677	7	8	0.04803	0.06218
3	4	0.00316	0.00882	8	9	0.03727	0.04593
4	5	0.00896	0.02502	9	10	0.02208	0.06753
5	6	0.00295	0.00824				

Table 2: Load data in 10-bus test system

Bus number	P Liner Load (kW)	Q Liner Load (kVar)	P Nonlinear Load (kW)	Q Nonlinear Load (kVar)	Nonlinear Device type
1	0	0	--	--	------
2	300	220	1000	500	6puls
3	400	250	--	--	------
4	150	640	350	230	6puls
5	800	500	400	650	12puls
6	500	390	450	310	6puls
7	500	310	800	450	6puls
8	250	180	--	--	------
9	600	300	800	400	6puls
10	150	240	1100	840	6puls

The load data includes the active and reactive power of linear and nonlinear loads of system, as well as the nonlinear load type. Table 3 lists the harmonic current spectrum data in 10-bus test system.

Table 3: Harmonic current spectrum data in 10-bus test system

Order	5	7	11	13	17	19	23	25	29
Value (%)	20	14.3	9.5	8.3	6.7	5.7	4.2	3.8	1.9

Optimal results of LC passive filter sitting and sizing in 10-bus test system are shown in Tables 4.

Table 4: Optimal results of LC passive filter sitting and sizing in 10-bus test system

Bus number	Pre-installed Qc (Kvar)	Filter Capacity QF (Kvar)	Harmonic tuning orders	V1 (p.u)	Vrms (p.u)	THDv (%)
1	--	--	--	1.0602	1.0635	3.74
2	--	--	--	1.0615	1.0647	3.31
3	600	810/740	5th / 11th	1.0627	1.0656	3.11
4	--	--	--	1.0612	1.0631	3.64
5	1200	1380/1600/1900	5th / 7th/ 11th	1.0602	1.0613	3.12
6	--	--	--	1.0502	1.0521	3.84
7	700	650/780	5th/ 7th	1.0419	1.0445	3.00
8	--	--	--	1.0434	1.0478	3.71
9	800	1100/1340	5th / 7th	1.0401	1.0412	3.13
10	1000	1100	11th	1.0521	1.0587	3.04

In this table the results of passive filters locations, harmonic tuning orders, filter capacity, fundamental component of voltages, rms voltages and total harmonic distortion of voltages in all buses, have been listed.

In table 5 the comparison results of proposed method based on power loss, maximum total harmonic distortion, minimum bus voltage and system cost is shown.

Table 5: Comparison results of proposed method for 10-bus test system

Results	Before Optimization	After Optimization
Power loss [kW]	467	185
THDmax (%)	12.6	3.84
Vmax (p.u)	1.0112	1.0656
Vmin (p.u)	0.9536	1.0412
Total Cost ($/year)	316423	123423

Conclusion

This study deals with optimizing the placement and size of passive filters by BBO algorithm, economically. The algorithm constrains are number/size of installed LC passive filters, limit candidate buses for LC installation, the limitation voltage limits and the voltage total harmonic distortion (THDv) in all buses define by standard IEEE-519.

In this example, the problem consists of planning three passive harmonic filters, whose harmonic tuning orders are 4.7 (for 5th harmonic), 6.7 (for 7th harmonic) and 10.7 (for 11th harmonic), respectively.

Due to dependency of reactive capacity of passive filter to harmonic tuning orders and the reactive capacity of shunt capacitors and on the other hand because of dependency the investment cost of filter to filter capacity, so the proposed algorithm optimize the optimum location, size and harmonic tuning orders. Results of simulation before and after optimizations are compared, which indicate power loss, maximum THD and annual cost after optimization using proposed method, decreased to 60.38%, 69.52% and 60.99% in 10-bus system.

REFERENCES

Akagi H (2006). Modern active filters and traditional passive filters. *Bulletin of the Polish Academy of Sciences Technical Sciences* **54**(3) 220-232.

IEEE Industry Applications Society (1993). IEEE *Recommended Practices and Requirements for Harmonic Control in Electric Power Systems* (*IEEE Std* 519-1992, New York, NY).

Kawam C and Emuel AE (1996). Passive Shut Harmonic Filters For Low and Medium Voltage: A Cost Comparison Study. *IEEE Transactions on Power System* **11**(4) 1825-1831.

Ram BS, Forrest JAC and Swift GW (1988). Effect of harmonics on converter transformer load losses. *IEEE Transactions on Power Delivery* **3**(3) 1059-1066.

Rao RS, Narasimham SVL and Ramalingaraju M (2011). Optimal capacitor placement in a radial distribution system using Plant Growth Simulation Algorithm. *International Journal of Electrical Power and Energy Systems* **33**(5) 1133-1139.

Seyed Abbas Taher, Mohammad Hasani and Ali Karimian (2011), A novel method for optimal capacitor placement and sizing in distribution systems with nonlinear loads and DG using GA. *Communications in Nonlinear Science and Numerical Simulation* **16** 851-862.

Seyed Abbas Taher, Mohammad Hasani and Ali Karimian (2014). Optimal allocation of capacitors in radial/mesh distribution systems using mixed integer nonlinear programming approach. *Electric Power Systems Research* **107** 119-124.

Vishal Verma and Bhim Singh (2010). Genetic algorithm-based design of passive filters for off shore applications. *IEEE Transactions on Industry Applications* **46**(4) 210-218.