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Research Article

Passive Filter Solutions and Simulation Performance in Industrial Plants

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Abstract

In this study, the information of the structure and application manners of passive filtration systems (series inductance attached compansation system) that are used in filtration of harmonics in energy systems, was given. In various points of distribution system measurement was made with harmonic analyser. Similarity was made with Simplorer Simulation Center 6.0 (SSC 6.0) programme which presents successful results in power electronics application of harmonic involved energy system. In simulation condition by applying passive filtration on this system, the effects of filter on this system was examined and analysis were made on results.

Keywords: :Harmonics, Harmonic filters, Passive filter.

1. Introduction

The duty of institutions which produce, transmit and distribute, essential energy source, electric energy is to present continuous, economical and high-class electricity to the consumers. However for electricity of high quality, some problems can come out in application. There happens some deviations from comple sine wave due to some elements attached to power system and events as a result of them. Deviation from complete sine wave is generally defined with out coming of components named as harmonic[1-5].

In accordance with the structure of semiconductor and with the effect of some nonlinear loads (transformator, arc furnace etc.) that are used in industry, current and voltage wave forms change. So basic sine wave, frequency and amplitude deteriorate with the effect of different sine . The deforming waves except basic wave are named as "harmonic". It is necessary to destroy or overpower harmonics that have negative effects on energy systems. For this, two different methods are used. The first of them is to design harmonic producing elements in a way to produce no or very little harmonic. The second method is to destroy harmonics that is filtration of them after production.

2. Harmonic Filters

In order to prevent the harmful effects of harmonics, the preventions that are taken during designing stage are limited and generally insufficient. That is why, harmonic filters attached to energy systems are used to filter intended harmonic currents. The aim of harmonic filters is to reduce the negative effects of harmonics in current or voltage. There are two types of harmonic filters as Passive and Active filters [1-5].

Passive filters are circuits that are put between source and receiver and are designed to destroy components except basic frequency, formed by condensator (C), inductance (L) and in some conditions resistance (R). Passive filters have got two types as series passive filters and parallel (shunt) filters. Also in application the most encountered type is series inductance attached compensation system (filtered compensation systems) which is in the system.

2.1. Series Passive Filters

As it is understood its name, series filters are formed of inductance attached in series between source and harmonic source. This impedance which is attached in series prevents transpassing of harmonic frequencies by showing high impedance according to

$$X_L = 2\pi fL \quad (1)$$

connection.

In basic frequency they show low impedance. An example circuit of series filter application was given in Figure 1. In application series filters are attached to input of AC motor drive circuits and high power AC/DC inverters. The difficulties in series filter application are trans passing of complete load circuit on filter, the isolation necessity for complete circuit voltages and causing voltage reduction on circuit.

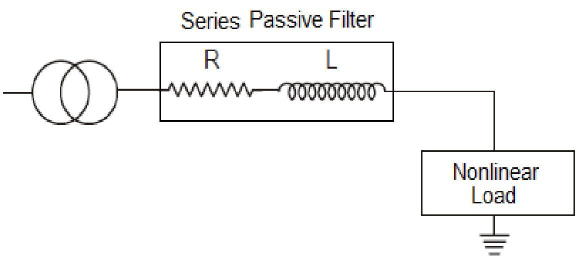

Figure 1. An example of series passive filter

2.2. Parallel (Shunt) Passive Filters

Parallel (shunt) passive filters are circuits that are formed by parallel attachment of C, L and in some cases R elements between harmonic source and network. The aim in parallel passive filters is to attach the circuit that provides resonance condition in order to destroy

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harmonic frequency by calculating L, C values, to the power system. For each harmonic frequency, separate resonance branches should be formed and tied these branches to the power system. However this system should be done for harmonic frequencies whose amplitude values are high. Since forming separate resonance branch for each harmonic component is not an optimum solution, resonance branch is formed just for the ones having high amplitude. In harmonic frequencies having low amplitude, only one resonance branch is formed. An example circuit for passive filter (Single adjusted parallel passive filter) is seen in Figure 2 [2].

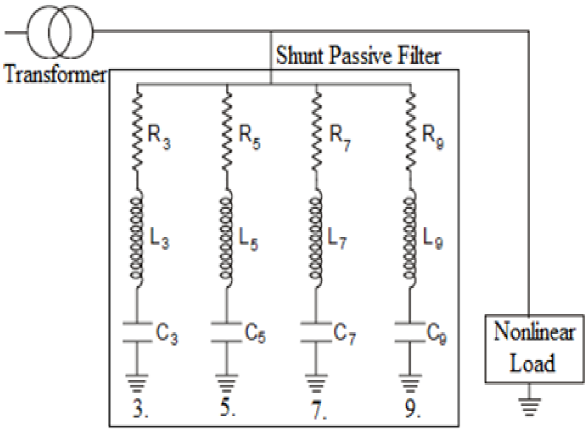

Figure 2. Single adjusted parallel passive filter

The greatest objection in using of shunt filters is they can participate in parallel resonance with power system. That is why before applying parallel passive filter to power system, a detailed analysis of system should be done.

When passive filter is applied to the system, the frequencies except basic frequency of capacity system in the filter and adjusted harmonic frequency, will show compensation effect in the system. For this reason as calculating passive filter, the capacity value that will be used in the filter should be chosen as to provide compensation requirement of the system. Then this value should be calculated with inductance value. These calculations should be done according to process given below. Firstly, the reactive power requirement of system should be obtained. For this,

$$Q_C = P(\tan\theta_1 - \tan\theta_2) \tag{2}$$

formula is used. Here;

Q_C : the condenser power needed to be attached to the system in order to reach intended power factor value (Var),

p: total active power of system (W),

$\tan\theta_1$: tangent of power angle before the compensation of the system,

$\tan\theta_2$: the intended tangent of power angle after the compensation of the system.

This resonance frequency mandatorily should not coincide any important system harmonics. Passive filters are usually adjust to lower values (e.g. in case of malfunction and/or temperature variations) than weakened harmonic in order to provide safety margin in case of changes in system parameters. Therefore these kind of filters are added to the system by starting with the lowest unwanted harmonics. For example before placing of 7th harmonics 5th harmonics should be placed.

In applying passive filter, the capacity elements that are used in filter should fulfil the compensation power necessary for system. At the point where measurement is done, the measured power is 55KW. The momentary power parameter was measured as 0,832. The condenser power necessary to increase 0,832 value to 0,985, was calculated as:

$$Q_C = P(\tan\theta_1 - \tan\theta_2) = 55(\tan 34 - \tan 10) \tag{3}$$

QC ≅ 27,5 KVAR

3. Passive Filtered Series Induction Method to Compensation System

This method is the most useful and economical method as well as making satisfactory filtration to prevent harmonics. The greatest effects of harmonics in electrical energy systems are also seen on compensation systems that are necessarily used in industrial plants. Harmonics cause changes in capacity of condenser and reduce their physical lives. We can observe this as swelling of condensers in other words as disruption of their physical appearances. The most practical and economical way of reducing these effects is to attach series induction to compensation system. So by showing high impedance effect to harmonic currents, the entrance of harmonics to compensation system is prevented. In this way by series induction method, the capacitance of compensation system reduces the effectivity of harmonics by performing a duty of a filter.

As these systems are installed, each firm decides its inductions by looking at the tables prepared for themselves. There are some criteria's for this choice. The most important for them is to decide p factor. This factor is obtained as

$$\text{p} = \frac{X_L}{X_C} \tag{4}$$

equality. Here;

X_L : Basic frequency inductive reactance of induction attached to compensation in series (Ω),

X_C : capacitive reactance in basic frequency of compensation system (Ω).

p factor should be chosen according to effective harmonic degree in the system. For example; if 3rd harmonic is effective in the system, p value should be chosen from 7% inductions to bring this system to 189 Hz (series resonance between induction and compensation system). If 5th harmonic is effective in the system, p value should be chosen from 5,67% inductions to bring this system to 210 Hz. For example if 3rd harmonic is dominant and if we bring 150 Hz which is frequency of 3rd harmonic, in this condition the whole amplitude of 3rd harmonic will flow to compensation and the compensation system will be damaged. Therefore the present system should be brought to resonance near to frequency of dominant harmonic in the system. Therefore the amplitude of dominant harmonic will considerably be reduced. Since this process reduces the effect of other non-dominant harmonics, THD level in the system will reduce considerably (The data's obtained above are from the experiences gained from the application of 210 Hz values for 5th harmonic and 189 Hz for 3rd harmonic).

Whatever the conditions of the core type, primary or secondary attachment or attachment of star to neutral cable of transformators, the 1st, 5th, 7th, 11th and 13th harmonics are always withdrawn from the system. If system load is balanced, it is possible to prevent the possible 3 and more than multiples of 3 harmonics in the system. Power distribution unit primary star attachment does not ground and/or if one of the primary and secondary coils is attached as delta, harmonic circuits that belong to 3 and the multiples of 3 do not pass to system whatever transformer attachment is.

The inductions which attach to compensation system in series cause an increase of voltage at the ends of compensation. Since the power is constant, when the circuit from compensation system reduces, the voltage will increase. Accordingly, the capacitates chosen for system should stand on higher voltages than system voltage. This is calculated with

$$U_C = \frac{U}{(1-\mathrm{p})} \qquad (5)$$

expression

U_C : capacitance voltage (V),

U : system voltage (V),

p : constant value in Equality 5.

According to this method by looking at compensation values, induction choice tables are benefitted. The series induction choice table is given in Table 1. By choosing available induction values in Table 1, it should attach in series to compensation system. As it was calculated in equality 4, the capacity power requirement of sample system has a value of 27,5 kvar and 4 graded compensation system was established. According to this, the power of condenser was designed as 2,5+5+10+10 kvar. Since sample system was designed for full load, filters were applied according to all stages in the system are on. Among harmonic ranks in the sample system, for the 5th harmonic which has the highest amplitude, inductions which their p value is 5.67% from Table 1 should be chosen. Induction choice table is given in Table 1. The condensers in the system were chosen as to work at 440 V. According to this the values of inductions are 3.06 mH and the capacity of condensers can be chosen up to 3x66 μF values. The inductions at these values when attached in series to compensation as separate for each face, this filter is able to be created [3].

Table 1. Series inductance choice table.

Power of Capacitor (kVAr)			Capacitor Capacity (μF)	The inductance of the coil (mH)		Nominal Current (A)	Reactor Power (W)
400 V	440 V	525 V		P =%5.6	P = %7		
5	6	9,6	3x33	6,12	7,66	7,65	50
10	12	17,2	3x66	3,06	3,84	15,3	65
15	18	25,8	3x89	2,04	2,56	23	76
20	24	34,4	3x133	1,53	1,92	30,06	100
25	30,2	43	3x166	1,22	1,53	38	130
30	36,3	51	3x186	1,02	1,28	46	140
40	48,4	68	3x266	0,76	0,96	61	150
50	60,5	86	3x333	0,61	0,77	76,5	160

3. Application of Distribution System

In this section, the reaction of system to the filter by applying series inductance attachment to compensation system on a sample energy system, was examined. This examination was done by using SSC 6.0 programme over THD values belonging to the circuit. The only circuit scheme belonging to distribution system is given in Figure 3. At the point where passive filter is attached to distribution system the load was calculated by considering the power of system as basis and suitable simulation was done according to this. Although a measurement was done by harmonic analyser up to 40th harmonic, the simulation was done by considering 3rd, 5th, 7th, 9th and 11th harmonics are in the system.

Also it was considered that the load in electric distribution system is separated into three balanced face. The simulation was operated without filter and in unfiltered condition THD rate in the system was obtained from simulation circuit. According to this, in unfiltered condition 51.356% of THD was seen in present simulation circuit.

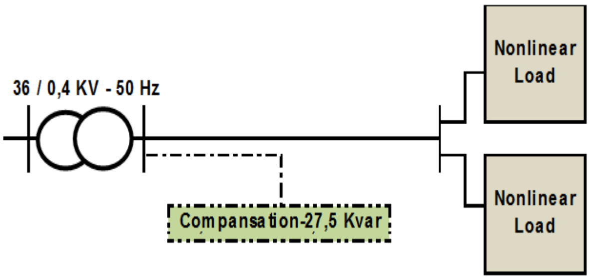

Figure 3. Sample electric energy system

The preparing circuit of the designed passive filtered system in SSC 6.0 was given in figure 4.

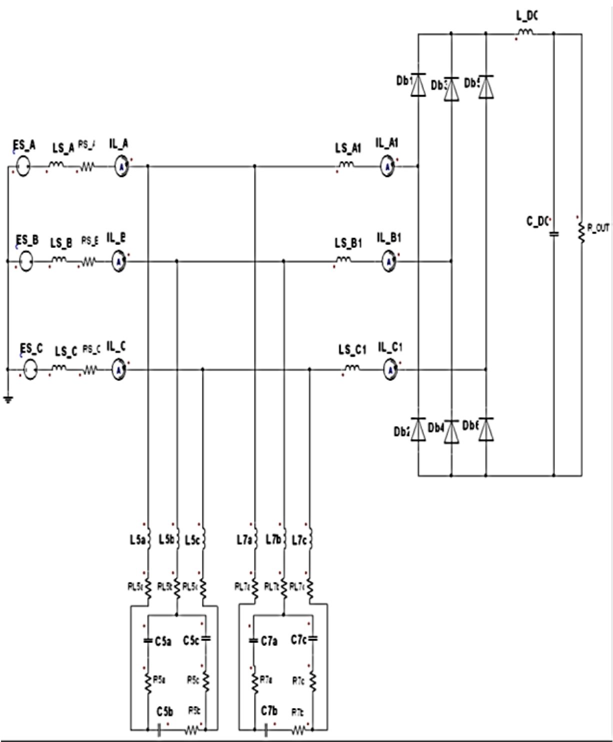

Figure 4. The simulation circuit of passive electric system prepared in SSC 6.0

In figure 5 THD value belonging to circuit is seen. According to this, THD value in circuit is at 51.356% level which is rather higher than accepted levels. That is why it is necessary to reduce THD rate by doing filtration. By this losses will decrease and efficiency will rise [1-6].

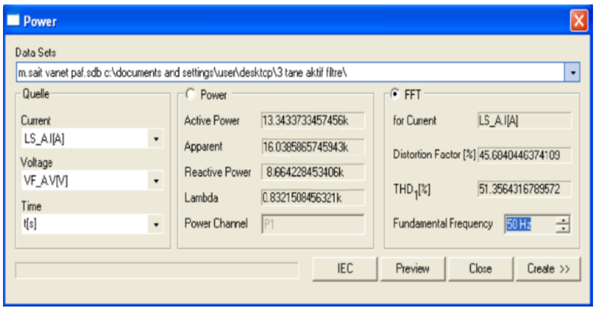

Figure 5. THD rate for circuit before passive filter

In Figure 6 the amplitude spectrum of harmonic system before passive filter.

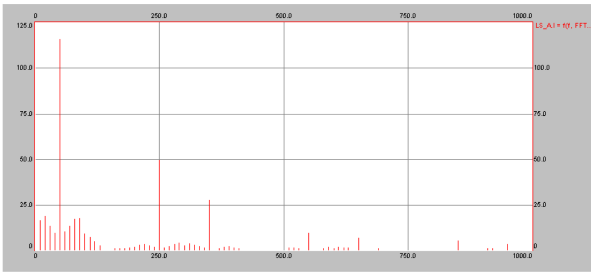
Figure 6. The circuit amplitude spectrum of system before passive filter

The voltage of system in Figure 7, filter output voltage for passive filter in Figure 8, filter output voltage when passive filter is on in Figure 9, load circuit that passive filter takes from system in Figure 10 and circuit wave form occurs when passive filter is on in Figure 11, the circuit that passive filter infiltrates and the situation of load circuit in Figure 11 and output voltage and output voltage when passive filter is off was given in Figure 12.

It is seen in Figure 7 that before filtration system voltage is approximately 350 V.

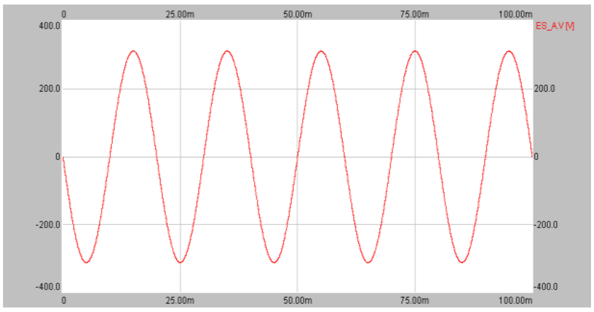

Figure 7. The change of system voltage for passive filter

After filtration process the voltage of system reached up to 380 V value. The output voltage of passive filter is shown in Figure 8 and 9.

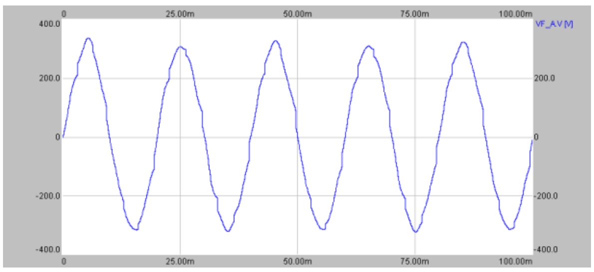

Figure 8. Passive filter output voltage.

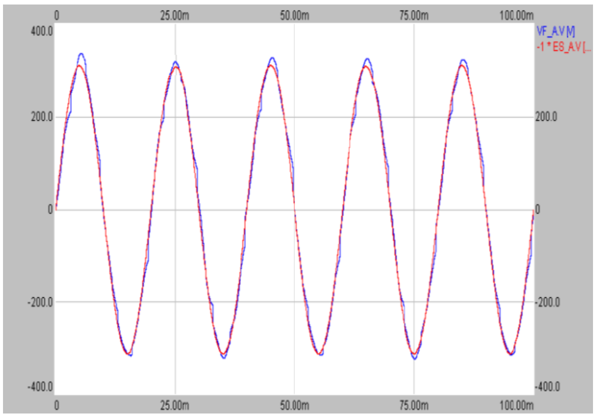

Figure 9. System voltage and filter output voltage when passive filter is on

The status of unfiltered load circuit away from sine wave form which carries harmonic circuit is seen in Figure 10. After passive filtration process, it is seen in Figure 11 that load circuit of system appears similar to sine wave form. So it is seen that passive filtration removes waving in load circuit.

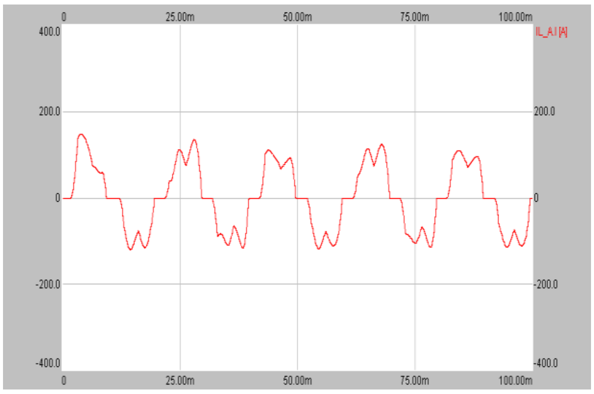

Figure 10. The changing of load circuit that passive filter takes from the system

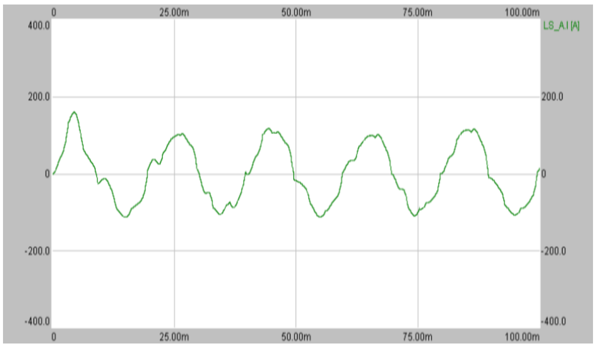

Figure 11. The change of load circuit occurred when passive filter is on.

It is seen in Figure 12 that output voltage and output circuit momentarily increased and decreased in first 25 ms time period when passive filter is about to on. After passive filter is on, circuit and voltage values become constant.

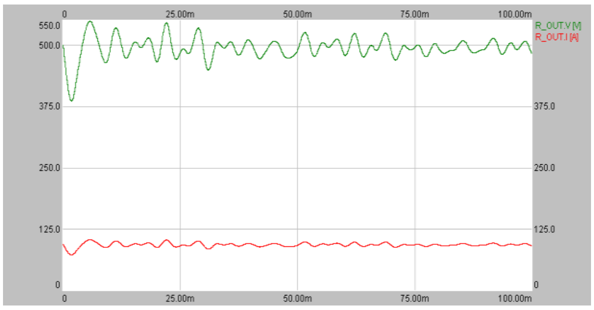

Figure 12. The outlook of output voltage and output circuit when passive filter is on

When passive filter is on THD rate of system is seen in Figure 13 and amplitude spectrum of circuit is seen in Figure 14.

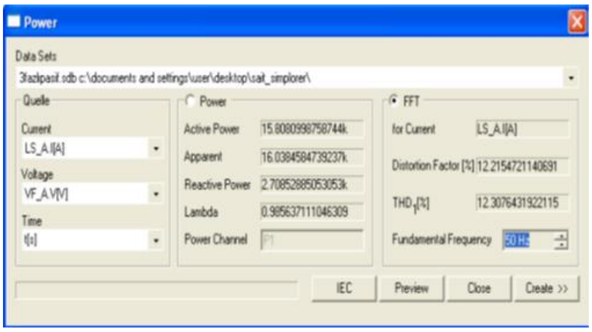

Figure 13. THD rate of system when passive filter is on

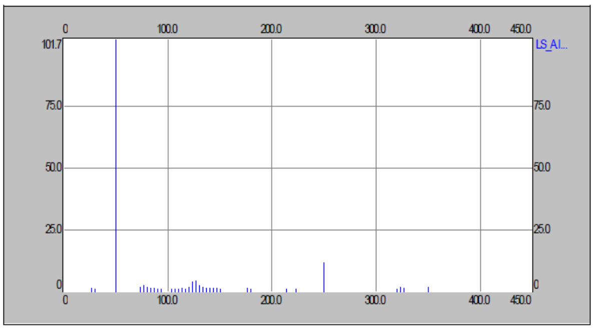

Figure 14. The amplitude spectrum of system when passive filter is on

Many studies have been done both in our country and in the world to contribute energy productivity by using smart and micro networks [6-12].

With this aim in recent years in scientific literature the number of researches about elecrical devices and on usage of renewable energy sources in industrial plants has been increasing to benefit from sun energy at maximum level [11-14].

Today theoretical studies towards productivity in energy-optimization by using either artificial neural nets (machine learning) or other statistical estimation methods (gamma, castigating etc.) with different methods have been continuing in science world besides all these applied conservation and productivity studies [10-16].

In many studies new suggestions are given for economical usage of equipments having high consumption such as compression, lightining, pump, motor with filtration methods especially in industrial plants. In our country studies of electrical train and rail systems having high electrical consumption that are planned to be built by public by the year 2016, are encountered [10-15].

4. Results

It is not convenient to evaluate harmonic filters by just looking at their filtration performances. There are advantages and disadvantages of these filters towards each other from various aspects.

Passive filters having series induction attachment (filtered compensation) are preferred because of:

- Their filtration results are satisfactory,
- Easy montage to present systems,
- Reducing resonance risk in the systems
- Low installation costs

This method is a method that does not present in literature but is frequently used in practical application.

In this study THD in the system reduced after passive filtration. Power factor increased from (Cosϴ) 0.823 to 0.985 value. While reactive power decreased, active power increased. As a result with passive filter application the system was cleaned from harmonics on acceptable level. As system losses decreased, efficiency increased.

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