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Estimation and Minimization of Harmonics in IEEE 13 Bus Distribution System

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Abstract

A power quality problem occurs due to the nonstandard voltage, current or frequency this result in failure of user equipments. So the present work is to identify the prominent concerns in this area and hence the measures that can enhance the quality of the power are recommended.

Harmonic analysis of the distribution system is essential to study the behaviour of equipments connected in the non-sinusoidal system environment for designing and optimal location of filters.

In this paper, IEEE 13-bus distribution system is considered for analysis of harmonics. Harmonic analysis of the system gives the harmonic spectrum and THD of currents and voltages at various buses. Mitigation of harmonics is performed by simulation using single tuned, double tuned, reactance one-port filters. Comparative analysis of filter performance is presented. The simulation study show that the best performance of the filter is obtained when positioned at/near the nonlinear load buses. The distribution system model is simulated by using MATLAB SIMULINK version R2009b software with static and adjustable speed drives as loads.

1. Introduction

Now a day's electric distribution system is part of an electric system between the bulk power source or sources and the consumer's service switches. One of the most power quality problems today is voltage sag/swell.

The voltage sag/swell magnitude is ranged from half cycle to one minute. Voltage sags are one of the most occurring power quality problems. For an industry voltage sags occur more often end-user equipment as the main power quality problems. [1]

Harmonic currents cause additional line losses and stray losses in transformers. Watt-hour meter error is often a concern. At harmonic frequencies, the meter may register high or low depending on the harmonics present and the response of the meter to these harmonics. The problems caused by harmonic currents are overloading of neutrals, overheating of transformers, nuisance tripping of circuit breakers, over stressing of power factor correction capacitors and skin effects[4]-[6].

Analysis is commonly done to predict distortion levels for addition of a new harmonic producing load or capacitor bank. The general procedure is to first develop a model that can accurately simulate the harmonic response of the present system and then to add a model of the new addition [6]-[8].

In this paper, modelling of ASD is provided and design of various passive filters and shunt active filter is presented. IEEE 13-bus system model is simulated in PSCAD/EMTDC as a case study and harmonic analysis is performed. Performance of filters in compensating current and voltage harmonics is tested by simulation for variation of load and optimal location of filter in the distribution system is suggested. THDs of current and voltage are used as harmonic indices in this paper. Sensitivity analysis is also performed to analyze the effect of filter parameter variation on THDs at various buses.

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2. Power Quality in Power Distribution System

Most of the more important international standards define power quality as the physical characteristics of the electrical supply provided under normal operating conditions that do not disrupt or disturb the customer's processes. Therefore, a power quality problem exists if any voltage, current or frequency deviation results in a failure or in a bad operation of customer's equipment.

However, it is important to notice that the quality of power supply implies basically voltage quality and supply reliability. Voltage quality problems relates to any failure of equipment due to deviations of the line voltage from its nominal characteristics, and the supply reliability is characterized by its adequacy (ability to supply the load), security (ability to withstand sudden disturbances such as system faults) and availability (focusing especially on long interruptions).

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Power quality problems are common in most of commercial, industrial and utility networks. Natural phenomena, such as lightning are the most frequent cause of power quality problems. Switching phenomena resulting in oscillatory transients in the electrical supply, for example when capacitors are switched, also contribute substantially to power quality disturbances. Also, the connection of high power non-linear loads contributes to the generation of current and voltage harmonic components. Between the different voltage disturbances. that can be produced, the most significant and critical power quality problems are voltage sags due to the high economical losses that can be generated. Short-term voltage drops (sags) can trip electrical drives or more sensitive equipment, leading to costly interruptions of production.

For all these reasons, from the consumer point of view, power quality issues will become an increasingly important factor to consider in order to satisfy good productivity. On the other hand, for the electrical supply industry, the quality of power delivered will be one of the distinguishing factor for ensuring customer loyalty in this very competitive and deregulated market. To address the needs of energy consumers trying to improve productivity through the reduction of power quality related process stoppages and energy suppliers trying to maximize operating profits while keeping customers satisfied with supply quality, innovative technology provides the key to cost-effective power quality enhancements solutions. However, with the various power quality solutions available, the obvious question for a consumer or utility facing a particular power quality problem is which equipment provides the better solution.

3. Reactive Power in Voltage Regulation

3.1 Voltage Disturbances

Voltage sag or dip represent a voltage fall to 0.1 to 0.9 p.u. and existing for less than one minute and voltage swell is the rise in voltage of greater than 1.1 p.u. and exists for less than one minute.

3.2 Voltage Control by Reactive Power Compensation

First, we consider an uncompensated line. The current drawn by the load depends on the load itself and the line voltage. The current engenders the voltage drop in the transformer and the line reactance. It results in the decrease in transmission voltage V_T and distribution voltage V_D. Figure 1.1 shows the vector diagram of a single load centre connected to uncompensated line. The voltage drop in the line mainly depends on the current taken by the load as well as the resistance and inductance in the line.

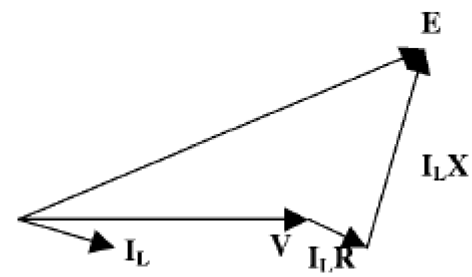

Figure 1.1 Uncompensated Lines with Single Load

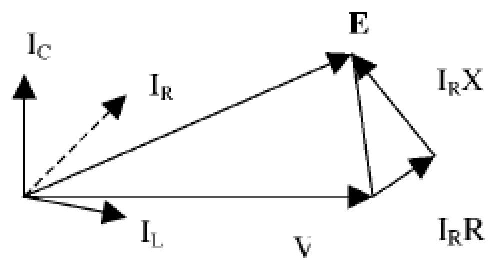

Figure 1.2 Compensated Lines with Single Load

It can also be seen that the angle between the voltage and the current is playing a major role in maintaining the voltage. Let us consider the supply voltage is E. Now due to the voltage drops I_R and I_X the load voltage is V. It is possible to bring V=E, just by making the current to lead so that the vector diagram will get modified as shown in figure 1.2. i.e by the use of shunt compensation (either at the transmission line or at the distribution line) the voltage at the load end can be regulated.

4. Model of Adjustable Speed Drives (ASD)

ASDs consist of an induction motor supplied by variable AC voltage derived from converters. Hence, the ASD consists of three major components; the first is the front end, which is usually a 6 or 12 pulse rectifier. The second is the inverter stage that converts the generated DC voltage to controllable frequency and AC voltage to control the speed of the motor. The last stage is the DC link (shunt capacitor) that couples the two main stages and help in reducing the ripples of the DC voltage in case of VSI and PWM topologies.

The front-end rectifier injects harmonic currents into the AC supply system due to its switching process. The inverter introduces additional ripples in the DC link current, which in turn penetrates into the supply side and hence contributes for harmonics. Like all other non-linear and switching loads, ASDs were normally represented by harmonic current injection. The magnitude of these harmonic currents was taken to be equal to (1/n)th of the fundamental frequency current for the nth harmonic. But this method implies does not consider the interaction between the current and the voltage harmonics generated by the device. This might lead to the wrong estimation of the system distortion level. In order to accommodate these interactions while calculating the system distortion, the ASD model together with the system will be represented in the time-domain to accurately account for the harmonic interactions.

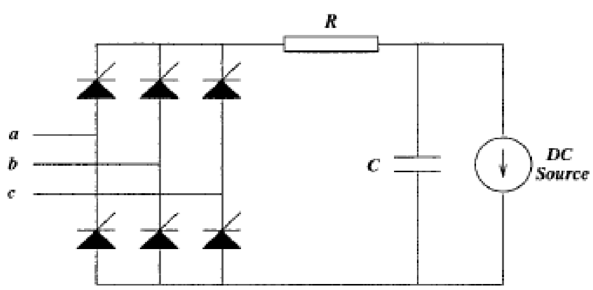

Figure 2: Generic converter circuit for ASD

The harmonics injected by the inverter is mainly dependent on the inverter topology and the motor characteristics. Therefore, the ASD can be modeled with a common three phase bridge converter circuit together with a DC link circuit and a harmonic current source to represent the inverter and the motor as shown in Fig. 2. The DC link capacitor in case of VSI and the DC inductor in case of CSI can block the propagation of the harmonics generated from the inverter side from entering the AC system [7]. This conclusion calls for a simple representation of the converter and the motor collectively by a DC current source instead of a harmonic current source. The direct current into inverter can be estimated from the motor load as (1).

$$I_{dc} = \frac{P}{2.3 V_{ph} \cos\alpha} \quad (1)$$

5. Design of Passive Filters

Passive harmonic filters reduce distortion by diverting harmonic currents in low impedance paths. Passive filters are designed to be capacitive at fundamental frequency, so that they are also used for producing reactive power required by converters and for power factor correction.

5.1 Single Tuned Filter

The most common type of shunt passive filters used in harmonic mitigation is the single tuned filter (STF) which is either a low pass or band pass filter. This type of filter is the simplest to design and the least expensive to implement. The configuration of a single tuned filter is depicted in Fig. 5.1. The major criteria in designing the filter, is the selection of proper capacitor size that gives a reasonable power factor at fundamental frequency. The capacitor reactance value, Xc and reactive power relationship is given by,

$$X_C = \frac{kV_{cap}^2}{MVAr_{filter}} \quad (2)$$

where kVcap is the line-to line rated voltage of the capacitor and MVAr is the reactive power of the capacitor. The filter capacitance is then calculated using (3) as

$$C = \frac{1}{2\pi f X_C} \quad (3)$$

where f is the fundamental frequency. (4) is then used to obtain the reactor value of the filter.

$$L = \frac{1}{(2\pi f n)^2 C} \quad (4)$$

where n is the harmonic order to which the filter is tuned. The value of the resistance R determines the quality factor (Q) of the filter and is equal to the ratio of the inductive or capacitive reactance, at resonance, to the resistance. Typical values of Q range from 15 to 80 for filters used in industrial and commercial applications [12].

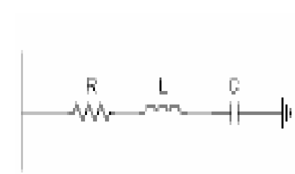

Figure 5.1 Single Tuned Filter

5.2 Double Tuned Filter

The double tuned filter (DTF) consists of a series LC circuit and a parallel RLC circuit. The basic configuration of DTF is shown in below Fig. 5.2. If f1 and f2 are the two tuning frequencies, both the series circuit and the parallel circuit are tuned to approximately the mean geometric frequency $f_m = \sqrt{f_1 f_2}$.

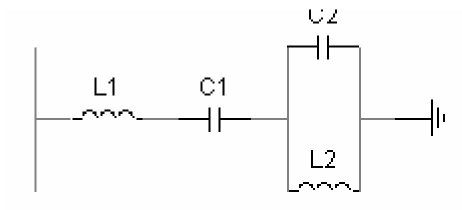

Figure 5.2 Double Tuned Filter

DTF can be used to filter two harmonic components simultaneously. Compared to the STF with the same performance, DTF has a few advantages such as only one reactor is subjected to full line voltage, its losses are much lower and the impedance magnitude at the frequency of the parallel resonance is lower and smaller space needed.

6. IEEE 13 Bus Distribution System

A practical IEEE 13-bus [9] medium voltage industrial distribution system feeding different types of industrial and commercial loads shown in Fig. 6 is considered for harmonic analysis. The system transformer and feeder data [8] are given in Tables I and II. The system is fed from a utility supply at 69kV at bus 4 and a local generator of 13.8 kV operating at bus 1. A power factor correction capacitor rated of 6000 kVAr is connected at the point of common coupling (PCC) at bus 3. Two harmonic producing loads namely the adjustable speed drives of 20 hp each are serving the customers at bus 7 and bus 10.

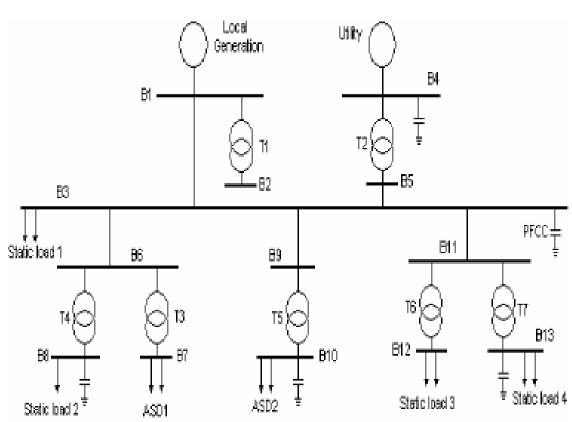

Figure 6 Single line diagram of IEEE 13 bus Distribution System

7. Simulink Model of Test System

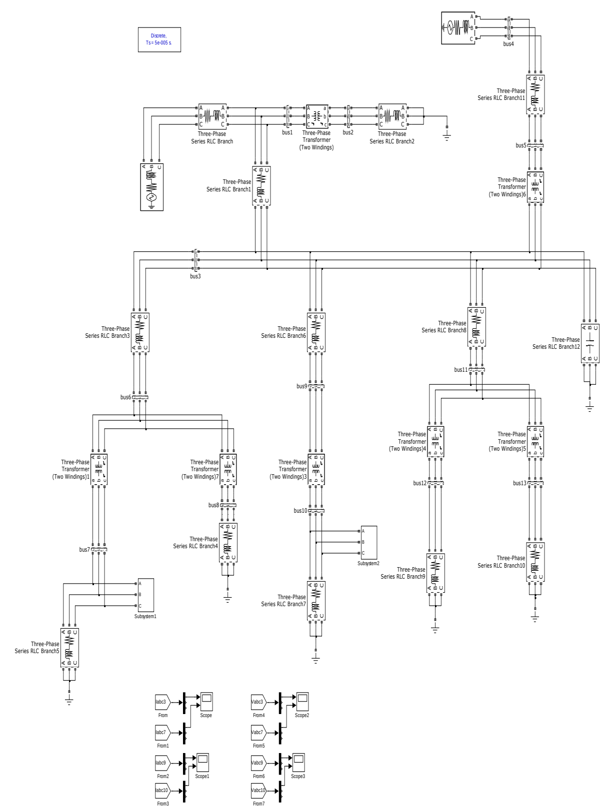

Figure 7.1 Simulink Model of IEEE 13 bus Distribution System

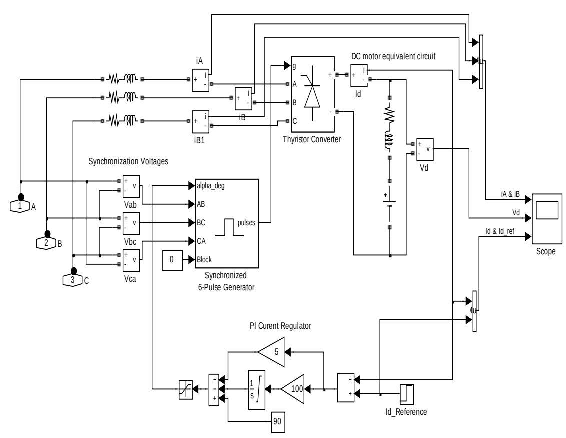

Figure 7.2 Simulink Model of ASD

8. Simulation Results

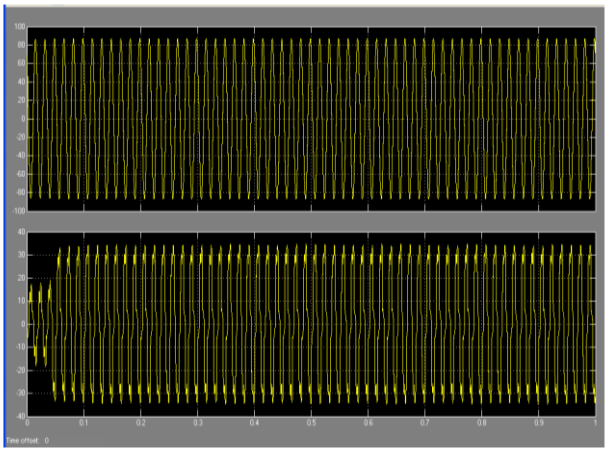

Figure 8.1 Current at bus 3 & 7.

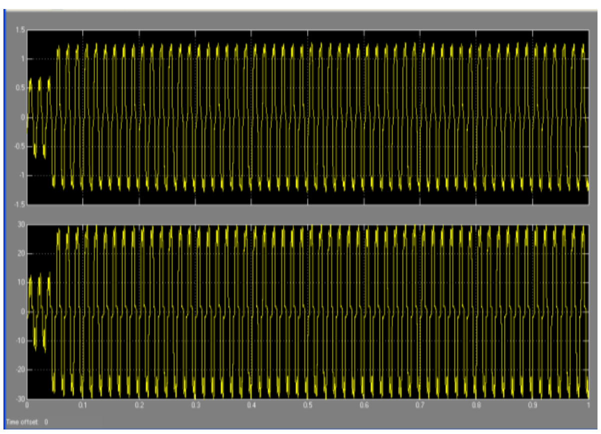

Figure 8.1 Current at bus 9 & 10.

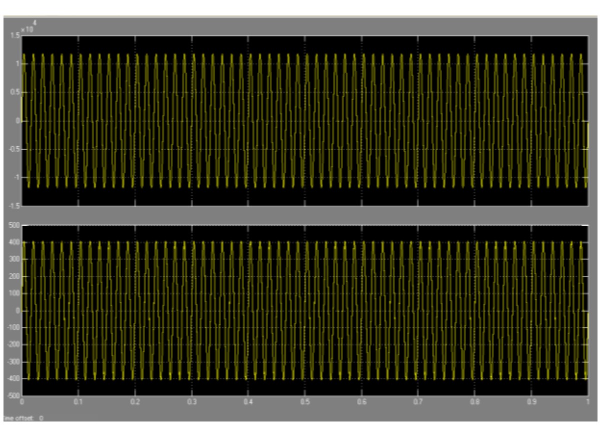

Figure 8.3 Voltage at bus 3 & 7.

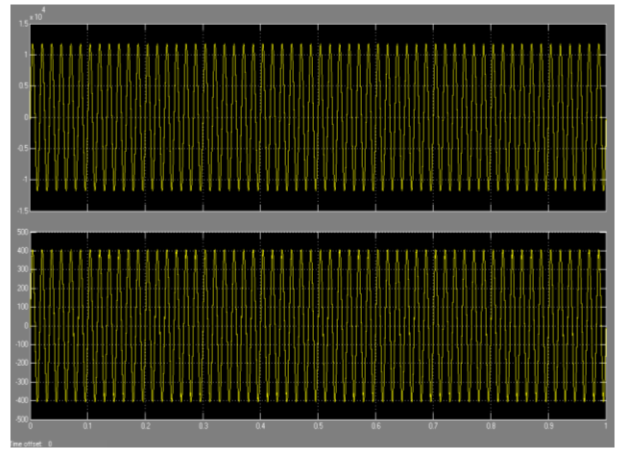

Figure 8.4 Voltage at bus 9 & 10.

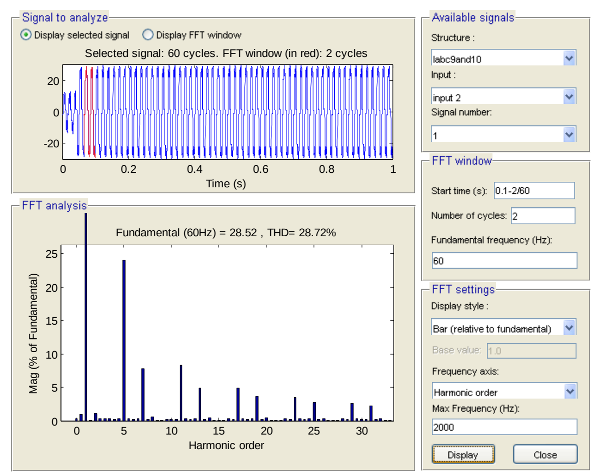

Figure 8.5 THD at bus 10 without filter (28.72%).

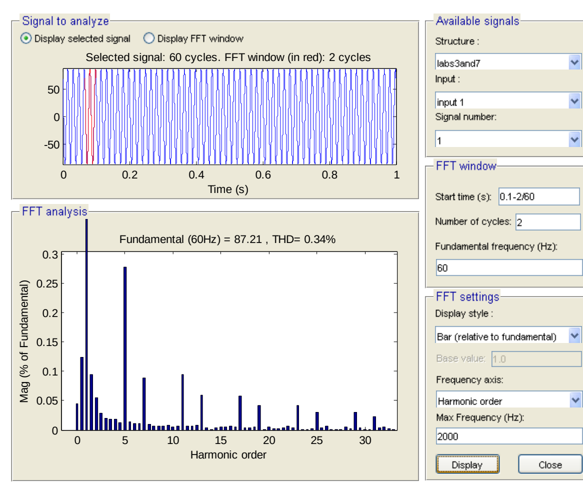

Figure 8.6 THD at bus 10 with single tuned filter (0.34%).

9. Conclusion

In this paper, a method for placement for a different types of filter in IEEE 13 bus distribution system for estimation and minimization of harmonics is presnted. Two types of filters (Single tuned filter & double tuned filter) have been modeled. The THD is calculated before the filter connected and after the filter connected.

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