# A NOVEL DESIGN FOR ADAPTIVE HARMONIC FILTER TO IMPROVE THE PERFORMANCE OF OVER CURRENT RELAYS

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***ABSTRACT***

*Due to the ever-increasing in non linear loads and the worldwide trend to establish smart grids, harmonic level in the electricity grids is significantly increased. In addition to their impact on power quality, harmonic current can have a devastating effect on the operation of over current relays as they are designed to operate efficiently at the fundamental frequency. The distorted waveform will affect the operation of the over current rely and may cause the relay to trip under normal operating conditions. To solve this problem, power passive and active filters are employed to eliminate the harmonics and purify the relay operational signal. Passive filters are not cost effective choice to solve this issue. On the other hand, active filters are more complex and need proper and complicated controller. This paper introduces a new and simple approach for adaptive filter design. This approach is economic, compact and very effective in eliminating harmonics in the grid. It can be easily attached with any protective relay to improve its performance. Application of this design to improve the performance of over current relays in the IEEE-30 bus system with heavy penetration of non-linear loads is investigated.*

***KEYWORDS:*** *Over current relay, harmonic filters, IEEE-30 bus system*

## I. INTRODUCTION

Most of the litratures reveal that the performance of relays in presence of harmonic currents is not significantly affected for total harmonic distortion (THD) less than 20% [1]. As there has been a tremendous increase in harmonic sources in the last few decades, harmonic levels of 20 % and higher are expected. Moreover overcurrent relays have to operate with current transformers which may saturate and distort the current waveform causing a relay to trip under conditions which would normally incur smooth running of the system without interruption [1-5]. Current transformer saturation may occur due to the presence of harmonics which may cause a current transformer failure to devliver a true reproduction of the primary current to the relay during fault conditions and thus may cause undesirable operations [6-8]. Electromechanical relays are nowadays considered obsolete in most of developing countries, however they are still used in some places. Electromechanical relays time delay characteristics are altered in the presence of harmonics. Another type of relays that is affected by harmonics is the negative-sequence overcurrent relay which is designed to specifically function with the negative sequence current component and it cannot perform upto its standard when there is a significant waveform distortion. Digital and numerical relays usually have built-in filters to filter out harmonics and thus are less prone to maloperation [9].

Active power filters which are more flexible and viable than passive filters have become popular nowadays [10]. However, active power filters configuration is more complex and require appropriate control devices to operate [11]. This paper introduces a novel active filter design that is compact, simple and reliable. Application of this design to improve the performance of over current relays in the IEEE-30 bus system with heavy penetration of non-linear loads is investigated.

The proposed filter design with the detailed circuit components is elaborated in section 2. To prove the reliability of the proposed filter, the simulation results of two case studies are illustrated in section 3. Application of the proposed filter to the IEEE-30 bus system is examined in section 4. Section 5 draws the overall conclusion of the paper.

## II. PROPOSED FILTER DESIGN

To purify the current signal received by the current transformer (CT), the distorted current signal which consists of a fundamental current component ($I_0$) and harmonic current components ($I_{hs}$) in the secondary side of the step down transformer is extracted and the fundamental current component is filtered out using a narrow band rejected filter while the remaining harmonic components will be used to cancel the harmonic components in the other path by using a shifting transformer as shown in Fig. 1. In this way the current signal fed to the relay will only contain the fundamental current component. The overall circuit is shown in Fig. 2.

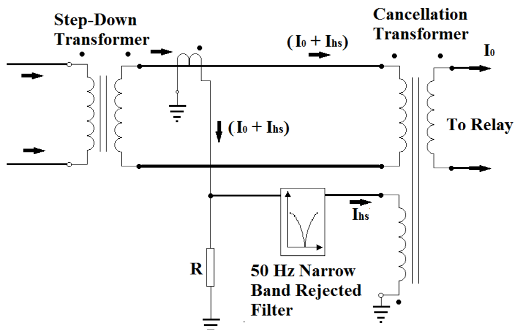


Figure 1. Proposed harmonic design

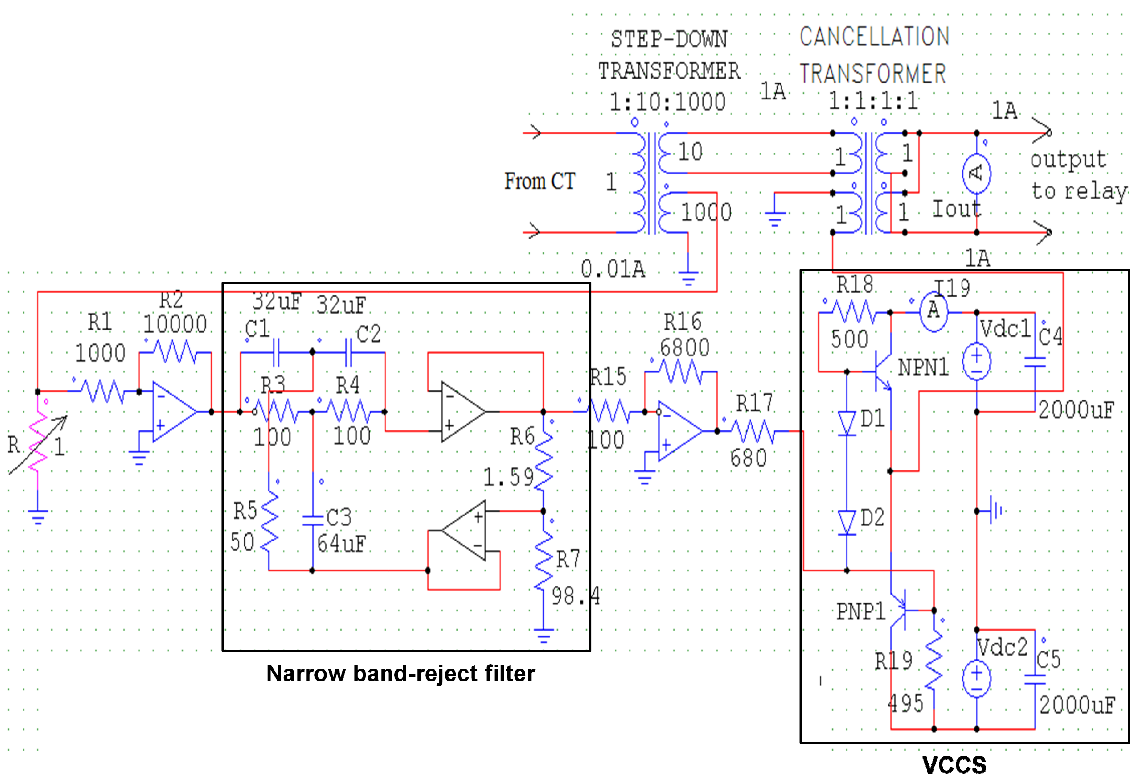


Figure 2. Filter components

In the circuit shown in Fig. 2, the current transformer measures the distorted current from the step-down transformer secondary. The resistor *R* with its value of 1Ω is used to convert the current signal to a voltage signal which is amplified by 10 times using an operational amplifier. The key component of the active filter is the narrow band-reject 50 Hz filter which suppresses the 50Hz fundamental component. The filter compresses low-pass and high-pass filter components with a summing amplifier (twin-T notch filters). The filter transfer function and the value of its components are calculated based on the required specifications. The output signal of the filter is amplified using an operational amplifier and then is converted to a current signal (comprising harmonic components only) using a voltage controlled current source (VCCS). The harmonic components are then fed to one terminal of the cancellation transformer where the original current component (comprising fundamental and harmonic components) is fed to another terminal for harmonic cancellation. In this way, a pure fundamental current signal is guaranteed to be fed to the over current relay.

## III. SIMULATION RESULTS

To examine the filter capability in suppressing all undesired current harmonics while retaining the fundamental component, the circuit shown in Fig. 2 is simulated using PSIM software and 2 case studies are performed.

*Case study 1*: The primary side of the (1:1000) current transformer was fed by a distorted current signal compressing sub frequencies of high amplitude at 10 Hz and 35 Hz as shown in Table 1. The 4th column in table 1 shows the ideal values of the output signal where all sub harmonic components are assumed to be eliminated and 100% (1 A) of the fundamental component will be supplied to the relay. The 5th column in Table 1 shows the output current components of the proposed filter. The performance of the filter in eliminating harmonic components can be examined by comparing the filter output current components with the ideal output current. The waveforms of the input current, ideal output current and filter output current along with their harmonic spectrums are shown in Fig. 3.

Table 1. Filter performance with Sub-harmonic components

| Harmonic Order | Frequency ( Hz ) | Input ( A ) | Ideal output ( A ) | Output the filter ( A ) |
|---|---|---|---|---|
| 1 | 50 | 1000 | 1.0 | 0. 95 |
| 0.2 | 10 | 500 | 0 | 0.0213 |
| 0.7 | 35 | 500 | 0 | 0.0816 |

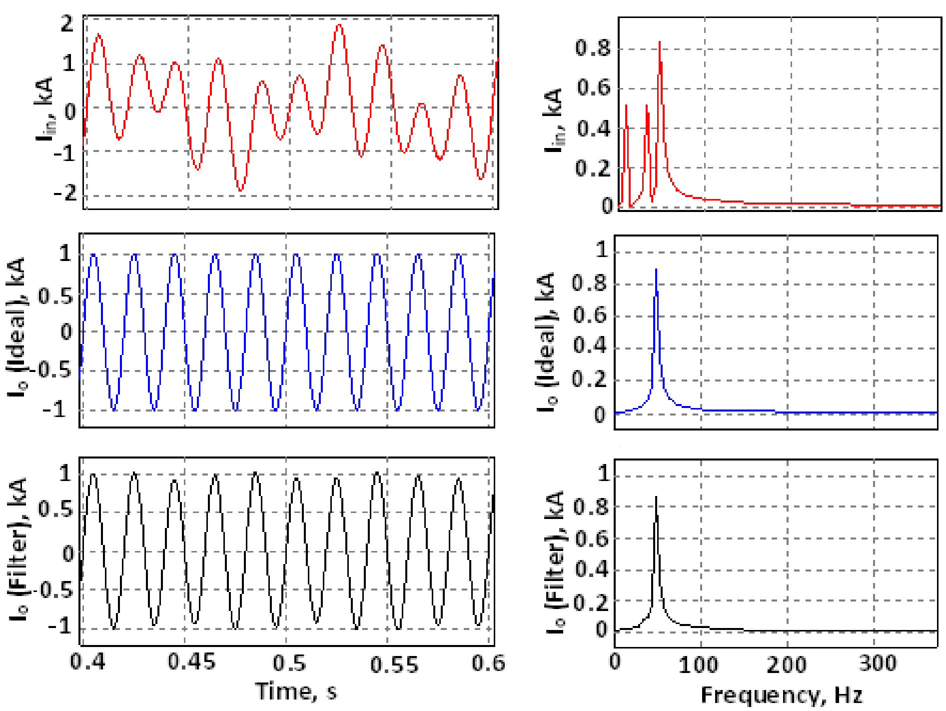


Figure 3. Waveforms and spectrum analysis for case study 1

Table 2. Filter performance with sub-harmonic and harmonic components

| Harmonic Order | Frequency ( Hz ) | Input ( A ) | Ideal output ( A ) | Output the filter ( A ) |
|---|---|---|---|---|
| 1 | 50 | 1000 | 1.0 | 0. 9863 |
| 0.2 | 10 | 500 | 0 | 0.0101 |
| 0.6 | 30 | 500 | 0 | 0.3293 |
| 2 | 100 | 500 | 0 | 0.0102 |
| 3 | 150 | 500 | 0 | 0.0023 |
| 5 | 250 | 300 | 0 | 0.0079 |
| 7 | 350 | 300 | 0 | 0.0131 |
| 9 | 450 | 300 | 0 | 0.0055 |
| 11 | 550 | 100 | 0 | 0.0067 |
| 13 | 650 | 100 | 0 | 0.0079 |

*Case study 2*: The amount of harmonic contents in the input signal is significantly increased to include the harmonic and sub harmonic orders shown in Table 2. It can be shown from table 2 that the difference between the ideal output current and the actual filter output current is negligible. The waveforms of the input current, ideal output current and filter output currents along with their harmonic spectrums for this case are shown in Fig. 4.

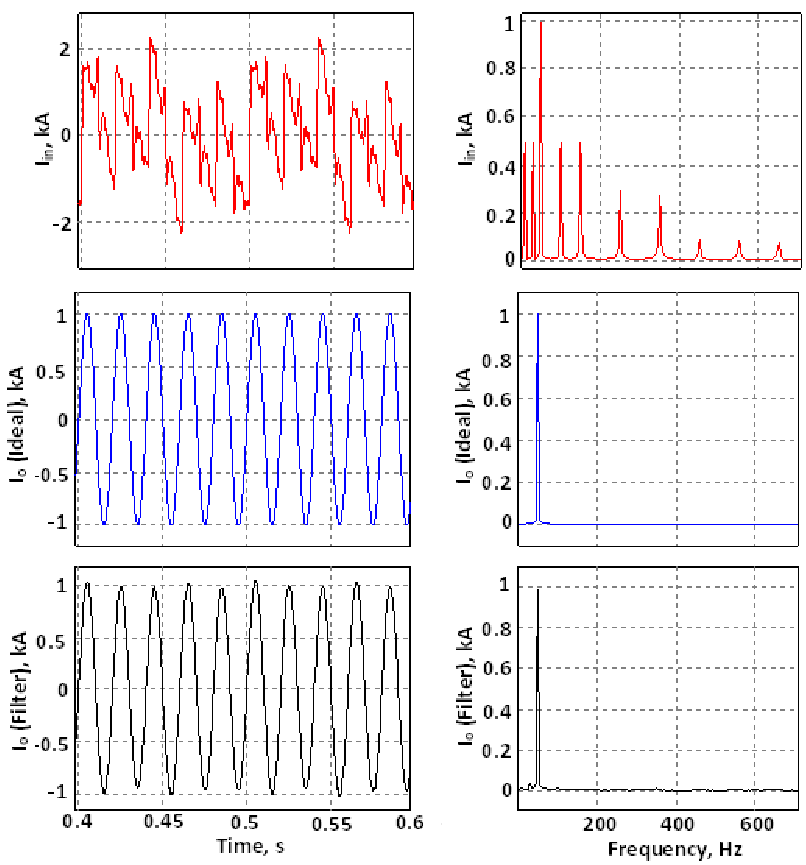


Figure 4. Waveforms and spectrum analysis for case study 2

## IV. Application of the Proposed Filter on the IEEE-30 bus system

To investigate the impact of the proposed filter on relay's operation, the IEEE 30-bus system [12] (shown in Fig. 5) is simulated using ETAP Software and the THD is measured as 3%. Relays coordination is performed as in [13, 14]. A 3-phase short circuit fault is applied at bus 10 and as a result, relays 8, 9 and 10 will trip in the sequence shown in Fig. 5 to isolate the faulty bus.

Non-linear loads were then connected to the system at different buses such that the THD is reaching 20%. The same three phase short circuit fault is applied on bus 10. As can be seen from Fig. 6, under such significant THD, the relays will have undesired tripping sequence and they will not isolate the faulty bus. The tripping sequence in this case starts with relay 9 on bus 10. However, relays 8 and 9 will not trip and relays 19 and 20 on bus 25 will trip instead. As a consequence, under such heavy harmonic level, the relays will have a malfunction operation and they will not isolate the faulty zone.

To promote a correct sequence of relays tripping operation in the existence of significant THD, the proposed filter design was connected at the locations shown in Fig. 7. As a result, the THD was reduced to only 3.1%. Fig. 7 shows a right sequence of relays tripping operation which is similar to Fig. 5. The relay pickup values become much sensible to the relay operation after the installation of harmonic filters. It can be concluded that the proposed filter is very effective in rectifying relays operation in the existence of significant harmonic currents as it eliminate a significant amount of harmonic currents.

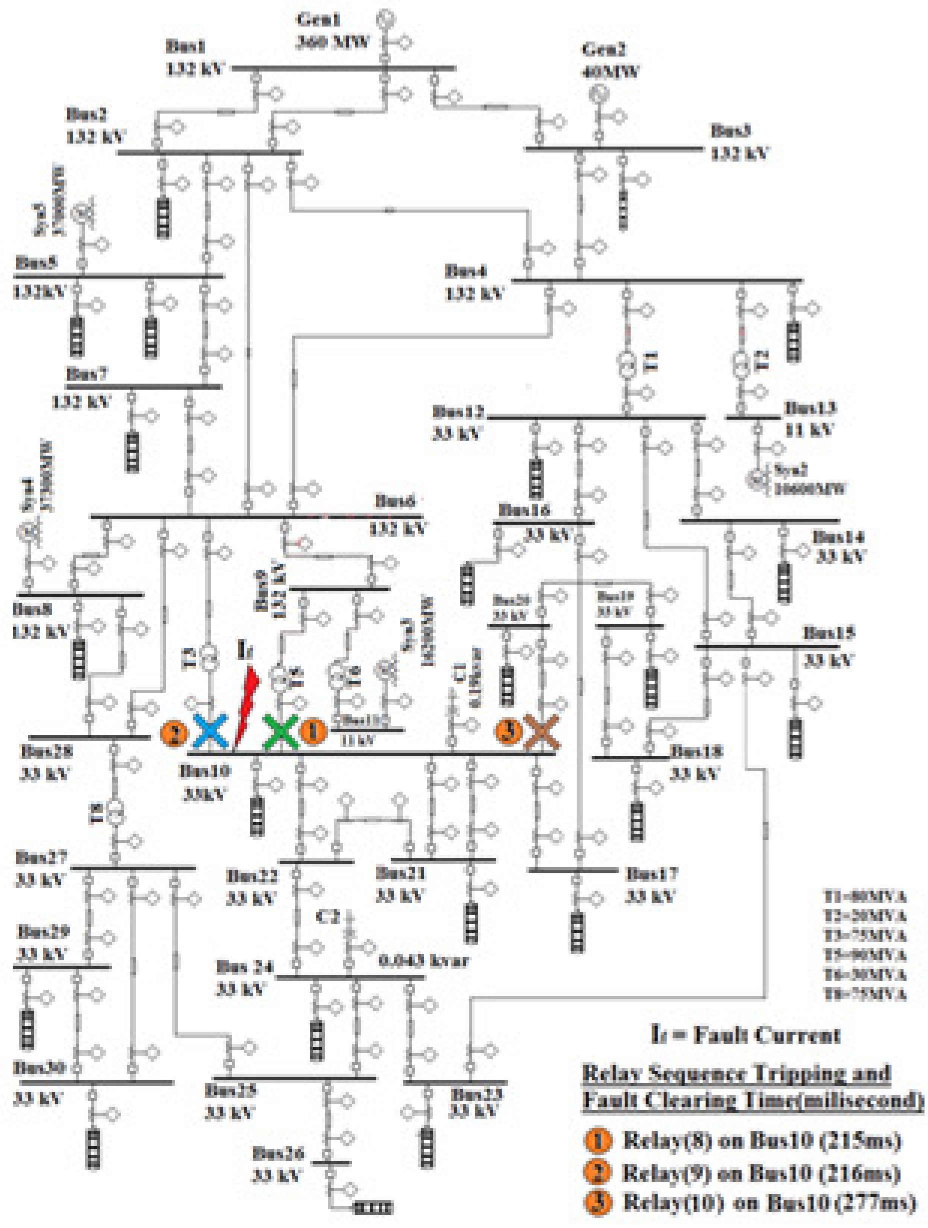


Fig. 5 Tripping Sequence during 3 Phase Fault on bus 10 (THD = 3%)

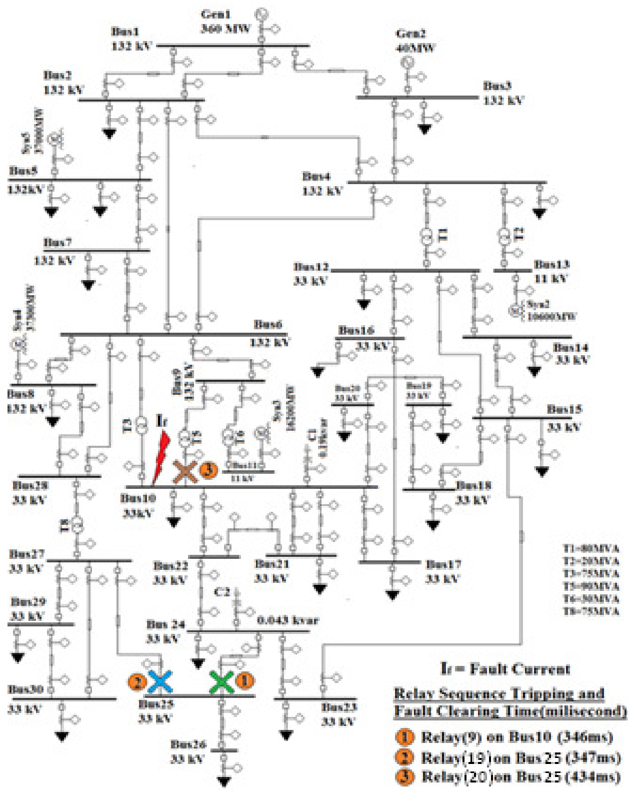


Figure 6. Tripping Sequence during 3 Phase Fault on bus 10 (THD = 20%)

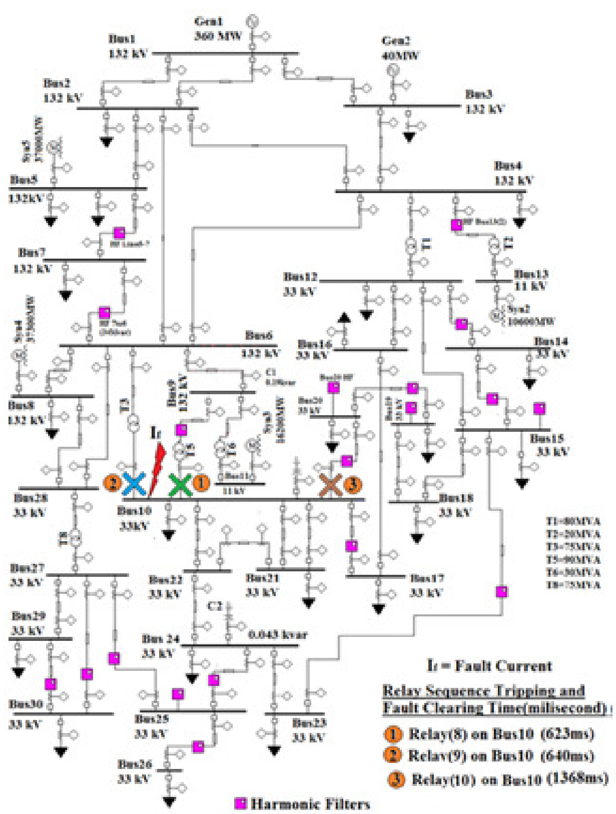


Figure 7. Tripping Sequence during 3 Phase Fault on bus 10 (THD = 3.1%)

## V. CONCLUSION

Simulation results show that, when the THD is more than 20%, the over current relay's performance is significantly affected and a malfunction will be caused. When a fault occurs in the system, the over current relay will not be able to isolate the faulty location as they will trip in an undesired way. Reducing THD to a level below 20% will mitigate this problem and a proper relay's operation can be retained. Passive harmonic filters are not a cost effective solution to solve this problem. The proposed filter design is very effective in reducing the THD in the system to almost negligible level and will rectify relays operation in the existence of significant harmonic currents. The proposed filter is compact, cost effective, technically sound and easy to be implemented.

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