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RELAY COORDINATION AND HARMONIC ANALYSIS IN A DISTRIBUTION NETWORK WITH SINGLE-TUNED FILTER DESIGN FOR HARMONIC MITIGATION

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Abstract: This paper focuses on the impact if integrating renewable energy sources into the radial distribution system. One radial distribution network is proposed with less penetration of DG and without a single tuned filter in the network, while the second network has high penetration of DG with a single tuned filter in the network. Harmonic analysis of the two network was carried out in ETAP. When there is addition of DG with less penetration without a single tuned filter there is high harmonic distortion and with a single tuned filter in the network, harmonic distortion is less as its filtered out the distortion caused due to the penetration of DGs. The paper also discusses about the Radial Distribution System in MATLAB/SIMULINK with different filter design and implemented four different cases to observe the effect of different filter on Harmonic distortion. The paper also focuses on the concept of mis-coordination of protective devices due to the presence of DG in a grid under the fault condition. The results are studied using ETAP software where radial distribution system is considered for the study.
Keywords: Distribution Networks, Relay Coordination, Harmonic Analysis, Filter Design, Power Quality, Single-tuned filter

I. INTRODUCTION

There are many various energy forms to produce and utilize but electric power plays the main role. To receive more consistent electrical power supply with less expenses was one of their concerns due to increase the alertness and commercial concern of consumers in the past few years. Utilities are aiming a system with less operation and maintenance costs, cut of resources cost and decreasing the system losses. There are a few phases for electric utilities to convey electric energy to shoppers. At the principal arrange the power is produced in expansive estimated age stations that are put far from the heaps to conquer the ecological issues. Transmission is the second stage which is done using equipment's like transformers, transmission lines and underground cables. This stage consumes a lot of money to transfer the generated electricity to the distribution system which is the last stage. The most crucial part of the power system is the end user and the utility system which is the link of the distribution system. There is power interruption to customers due to a percentage of end user power outages because of distribution networks. DG is added to the network in order to increase the network's reliability and to cover the supply of some loads. There are many different types of Distributed Generation's used nowadays such as micro-turbines, fuel cells, rotating machines, wind turbine and photovoltaic systems. Renewable energy like PV and wind turbine don't need fossil fuel to operate as PV uses the sun and wind turbines work with the help of wind.

II. TYPES OF DISTRIBUTION SOURCES

A. Photovoltaic System

There is a large amount of electricity is produced when the PV modules are connected in large amounts and they also produce constant DC voltages which are reliable sources for power generation. A large number of solar cells are used for the array which is called as a OV system. Electricity is generated by converting the solar energy with the help of photons which are made of silicon. It performs the switching operation using an inverter circuit which is present in the PV system. The voltage is a change from DC to AC using the inverter circuit at a frequency of 60Hz.

B. Wind Turbine

In a wind turbine, the wind is used as its input which is converted to useful electricity as the output of the system. It converts the available kinetic energy which flows due to earth's motion into mechanical energy. The turbine which is associated with the pole of the generator is pivoted because of wind and gives an AC yield voltage. This yield voltage is reliant on the wind speed and thusly it must be changed over to DC with the assistance of inverter. Depending on the wind speed the power generated by the wind energy system varies from 10MW to 2.5MW.

C. Micro-Turbine

Micro-turbines produce a high frequency output voltage which is based on very high speed rotating turbines along with a generator. It is the clean operation with low emission produced which is operated by natural gas. The disadvantage of micro-turbine is that it produces the high level of noise. The efficiency of the system is low as compared to other distribution generation sources. The output voltage from micro-turbine has to be first converted to DC using the inverter as it has to be transferred to the nominal voltage with the nominal frequency. They have to be designed to supply a fixed power output micro-turbines in the case of parallel operation with the utility grid.

D. Fuel Cells

Energy component utilizes the concoction response procedure of oxygen and hydrogen to create power with least contamination. The consequence of the substance response is water which does not make any contamination in the earth. To accelerate this substance response hydrogen which is considered as the base fuel responds with oxygen in closeness of an impetus. Incited DC voltage is created with the assistance of a particle directing electrolyte which is corresponding to the quantity of power devices. Inverter is utilized to change over created DC voltage to AC. The significant inconvenience of the power module is high running expense yet it likewise creates warmth and water alongside the power. They give spotless and productive vitality and along these lines they are considered as sustainable power source asset.

III. IMPACT OF DG ON POWER SYSTEM

Distributed Generations (DG) is one of the new technology seeking the attention of utilities because of its benefits. There are many forms of DG such as PV(solar), Wind farms and fuel cell. Small scale ratings for this DG is up to 10MW.
The advantages of DG are:

- It is environmental friendly as it uses the renewable energy resources like solar, wind, biogas.
- The Equipment cost for DG is less.
- Reactive power compensation, Voltage regulation are the secondary aids provided by DG.
- DG can be used during intentional islanding, during peak times the consumer can be provided with electricity and which will allow a customer to operate apart from a grid.
- With the use of DG, consumers have the option for upgradability.

These and other advantages make the DG to be used widely in distribution networks. But there are some issues that should be considered while integrating the DG with utility because DG has some disadvantages also.

A. Effect of DG on Voltage Regulation:

Voltage at the different load points which are connected to DG may increase and to maintain the desired voltage levels in the system: load tap changers, line regulators, switching capacitors are used on feeders. The radial characteristics of the system is change due to integration of DG in the system which will change the power flows in different directions. "The principles of voltage regulation are centered on radial power flow from the substation down to all loads". Voltage regulation performance is exaggerated due to loss in radial characteristics and change in power flow. For example, if the DG is installed with a voltage regulator (as shown in figure 1.1) or Load tap changer then the observed load from the line drop compensator control side will be reduced and this will create misperception for the regulator to make the proper settings for regulating the voltages. The curve explains the drop in percentage of voltage regulation due the addition of DG to the system.

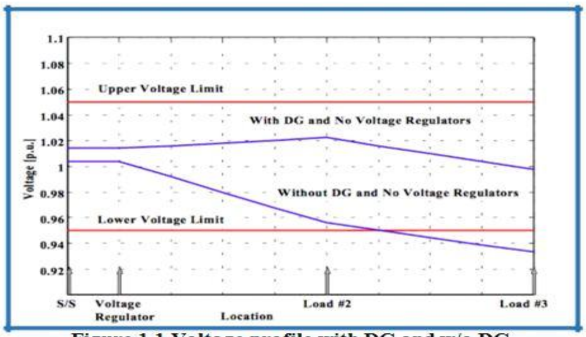

Figure 1.1 Voltage profile with DG and w/o DG

Moving the DG above the voltage regulator or compensate the DG output using regulatory control is the possible solution of this problem.

B. Impact of DG on Losses;

Location of DG is important in a grid. The location of the DG plays an important role to reduced loss and the finest performance of the network. The performance of the DG is also improved due to the proper location of the Dg in the network. Mostly all the generator operates at a power factor 0.85 lagging and unity. Due to inverters which is able to contribute to reactive power compensation. Performing the load flow analysis, the best location for the DG can be found. Hence flexibility of the location for DG installation makes its impacts worse as most of the DG are owned by an individual.

C. Impact of DG on Harmonics:

Harmonics is produced from the generator (generation unit itself) or from the inverter which is used to transfer the generated DC electricity to AC which is injected to the network. Harmonics in the network can be produced due to the DG. IGBT's (insulated a gate bipolar transistor) is the new inverter technology which generates sine wave using the pulse width modulation technique produces less level of harmonics as compared to old inverter technologies such as SCR based inverter.

D. Impact of DG on Short circuit Level of the network:

At the point when the DG is presented in a system, it has coordinate effect on the short out levels of the system. The blame streams are expanded for this situation when contrasted with the ordinary system conditions in which substation is the main producing unit. There are numerous components in charge of commitment of DG to blame current, for example,

- Higher DG size
- The Location of DG in the network
- Different source of DG
- Generating capacity of DG

E. Failure of Recloser-Fuse Coordination due to DG:

In case of temporary faults, the fuse is coordinated with recloser or circuit breaker so that these devices will save the fuse from blowing out. Recloser is located at substation side while the fuse is located at the distribution transformer. For the proper coordination between the recloser and fuse for a fault at any bus, the fault current sensed by the recloser should be more and it should take less time to act as compared to fuse. If the fault is not cleared in the first attempt, the fuse should sense the fault current first and act before recloser. When the fault is occurred, the fault current is first sensed by recloser and it acts to clear the fault. If the fault is not clear, the recloser will close and the fuse is melt. If there is still a fault in the network after the first attempt, the fuse will operate first to clear the fault and recloser will act as standby protection. Recloser will isolate the system if the fuse is melt or fail to clear the fault.

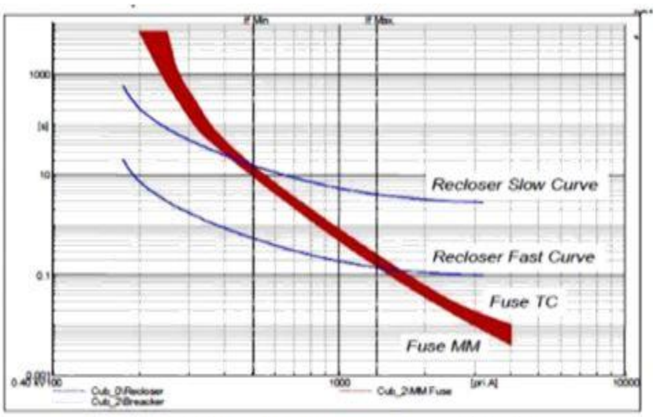

Figure 1.2 Fuse-Recloser mis-coordination

IV. HARMONIC ANALYSIS AND FILTER IN A NETWORK

Harmonics are defined as voltages or currents at certain frequency which are the multiples of the fundamental frequency. THD (Total Harmonic contortion) is characterized as the rms estimation of sounds separated by the rms estimation of the key, and afterward increased by 100% and it applies to both current and voltage. It is the most widely recognized measurement files of consonant mutilation.

$$THD = \frac{\sqrt{\sum_{h>1}^{hmax} M_h^2}}{M_1} \times 100$$

There are many harmonic problems in the power system due to constant increase in the utilization of power electronics equipment's. There are many problems caused by harmonic in the power system:

- Power Quality of the system
- Distortion
- Power losses
- System unbalancing

A. Design of a Single tuned filter:

Single tuned filter is inexpensive and easy to design as compared to other filter. It is also the most common used filter in company. In order to design the filter, the value of resistor, capacitor and inductor need to be calculated. The resonant frequency is calculated as:

$$f_r = \frac{1}{2\pi \times \sqrt{LC}}$$

To design the single tuned passive filter,

Step 1: Determine the three phase capacitive reactive power (Q_c):

$$Q_c = P\{tan(cos^{-1}(Pf_0) - \tan(cos^{-1}(Pf_1) = 289.37\ kVAR$$

where,

$$Pf_0 = 0.85$$

$$Pf_1 = 0.96$$

Step 2: Determine the Capacitive reactance at the fundamental frequency:

$$X_c = \frac{V^2}{Q_c}$$

$$= \frac{0.416^2}{289.37} = 7.98$$

$$C = \frac{1}{2\pi f X_c} = 0.3995F$$

Step 3: Determine the inductive reactance and inductance:

$$X_L = \frac{X_c}{h_n^2} = 0.319$$

$$L = \frac{X_L}{2\pi f} = 1.10145H$$

Step 4: Calculate the resistance using the quality factor:

$$R = \frac{X_n}{Q} = 0.053$$

$$X_n = \sqrt{X_L X_c} = 1.59$$

where,
Quality factor = 30

V. SIMULATION RESULTS

A. Matlab simulation of a Radial distribution System:

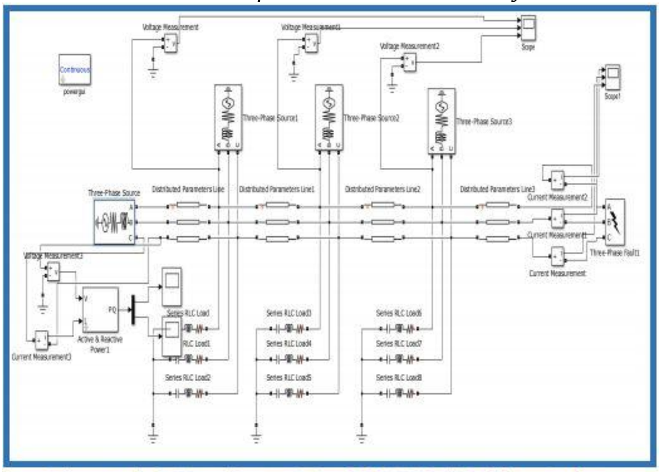

Figure 1.3 Detail model of MATLAB Simulation

For MATLAB simulation, we have considered a radial distribution system which is shown in figure 1.3. The load on each PQ bus is 1MW and the power factor is 0.92. The values of resistance and reactance for each feeder segment in the radial distribution system is as follows: R=0.3444 per unit and X=0.6535 per unit. The following system is proposed using SIMULINK (MATLAB) software.

Simulation for Radial Distribution System with one single tuned Filter:
From the above simulation result, we can clearly see that distortion level in the figure 5.2 which without any filter is higher than the figure 5.4 (single-tuned filter). The harmonic current with one single tuned filter is 6.78×10(at 60Hz frequency.

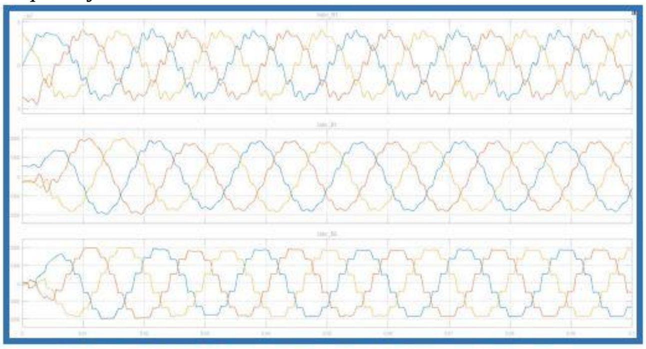

Figure 1.4 Voltage and current wave simulation

Simulation for Radial Distribution System with two single tuned Filter:
As we can clearly see, the figure 5.6 with two single tuned filter has less distortion than the figure 5.4 which has only one filter in the network. In the figure 5.5, two single tuned filters are used in the system which reduces the voltage and current distortion as they filtered out the lowest order harmonics at a single frequency. The RMS value of Harmonic current in this case is 4.86×10(which is less as compared to the harmonic current in the first case (one single tuned filter).

Simulation for Radial Distribution System with three single tuned Filter:
In this case, the voltage and current waveform is much better than the other three cases. Because in this case there is one high pass filter, which remove the high order harmonics and the C-type filter and a single tuned filter removes the harmonics at two different frequencies. The RMS value of harmonic current is least in this case which is 1.296×102

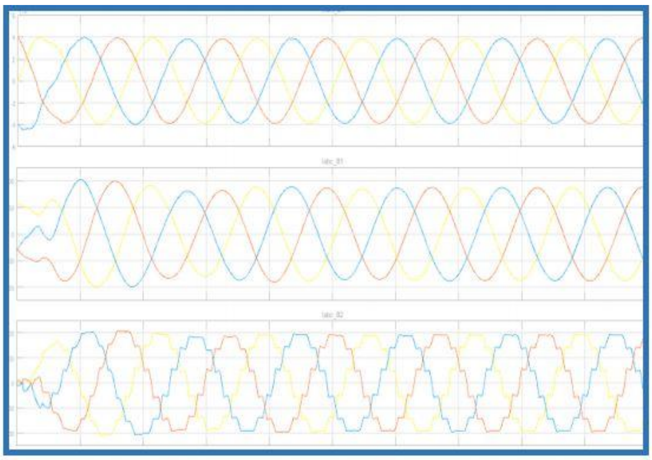

Figure 1.5 Voltage and current wave simulation

B. ETAP Model for the Harmonic Analysis:

The radial distribution system of 24 bus system is implemented in ETAP with a (33KV&11KV) network. There are 3 main feeders with the total load in the system is 10.9MW and four different types of DG are connected namely:. The total load in the system is around 10.9MW which includes 6.99MW at a peak, and the load from DG is 10.45MW.

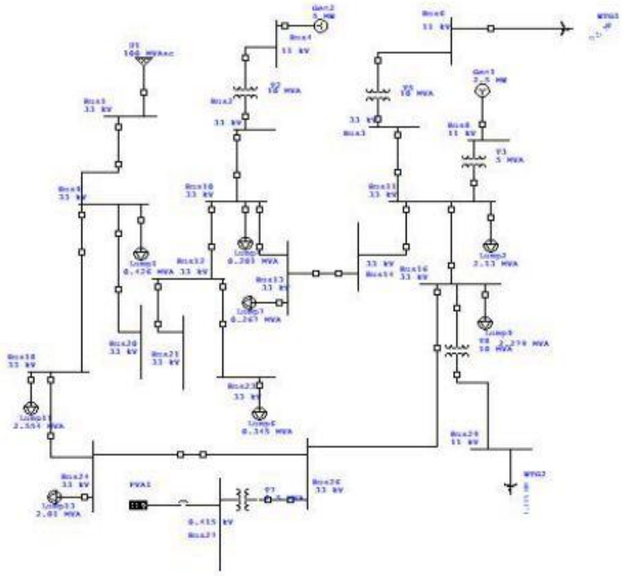

Figure 1.6 ETAP Model

ETAP Model for Harmonic Analysis without filter:
We carried out the Harmonic analysis without a filter in the model to observe the Voltage waveform and frequency spectrum of the bus.

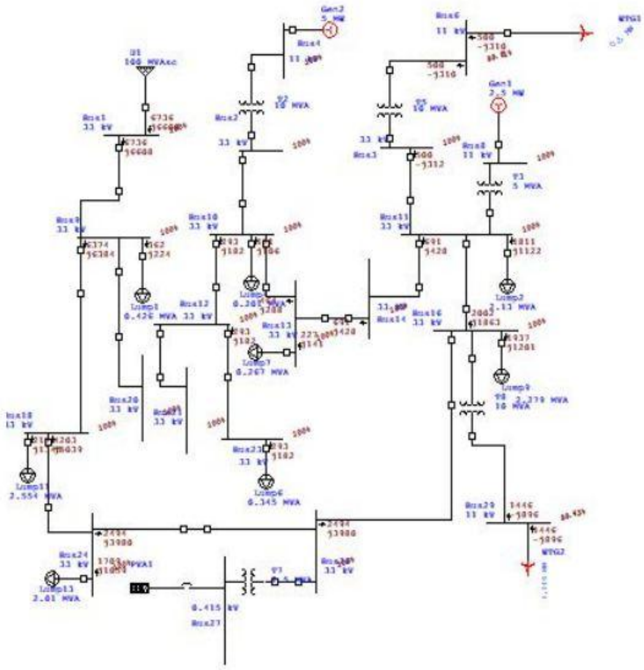

Figure 1.7 ETAP Model without filter

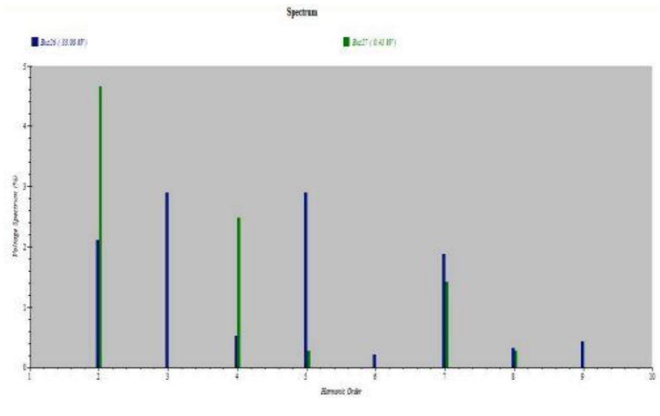

Figure 1.8 Frequency Spectrum at bus 26 & 27

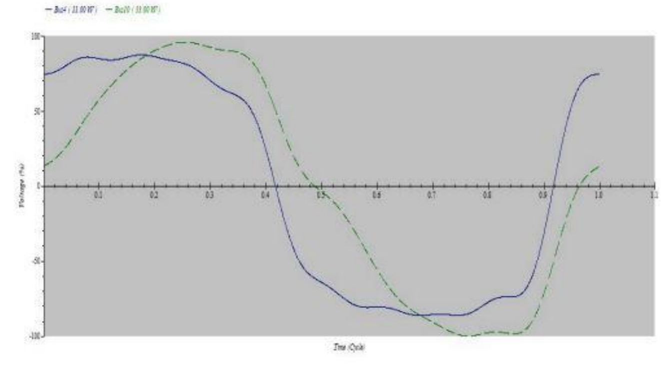

Figure 1.9 Voltage Waveform

From the Figure 1.8, the frequency spectrum at bus 26 and bus 27 with different harmonic order. As we can see, voltage distortion for the 2nd order harmonic is highest which is more than 5% and also we can see the distorted voltage waveform in Figure 1.9.

The harmonic voltage spectrum of all the 10 buses which are connected to the step-up transformer of all the DG. THD % in the system as we can see is above 3% which is not acceptable. In order to reduce the harmonic distortion, we will use a single tuned filter.

ETAP Model for Harmonic Analysis with filter:
After using the 2nd order harmonic single tuned filter the voltage spectrum for 2nd order is reduced from 25% to 3% which is acceptable. THD% in this case for all the buses is below 3%.

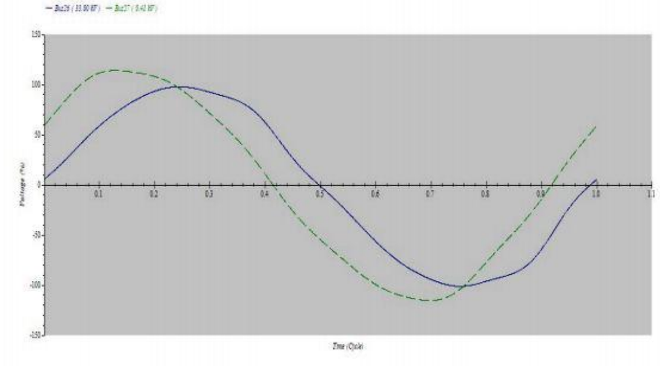

Figure 1.10 Voltage waveform with filter

In order to reduce THD% and improve the voltage spectrum waveform we will use a single tuned filter at bus 27. We will carry out the load flow analysis with a filter in order to check the losses at the bus.

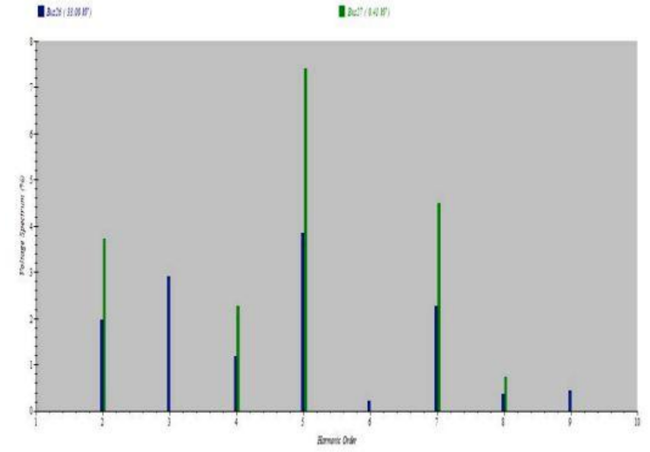

Figure 1.11 Frequency Spectrum

C. ETAP Model for Relay mis-coordination:

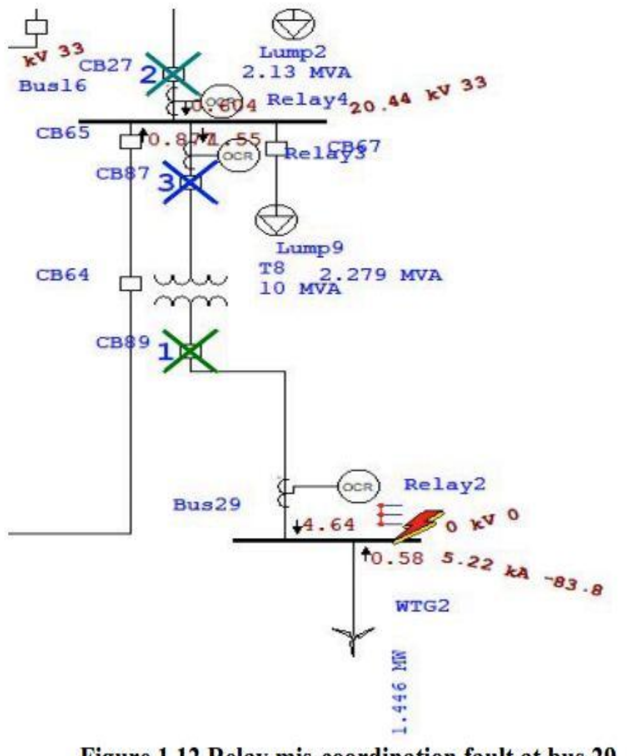

Figure 1.12 Relay mis-coordination fault at bus 29

When the fault is inserted at bus 29 as shown in figure 5.23 in the presence of wind turbine, there is a high fault current of 4.64kA. As the fault occurred at bus 29, the Relay 2 should be the first one to sense and act as a primary protector. The fault current sensed by relay 2 is 4.64kA and It will act within 1.036sec.
The second relay which will sense the fault current should be relay 3 but as seen in the figure due to the presence of DG, relay 4 sensed the more fault current which is 1.54kA and therefore it will act before relay 3. This is the mis-coordination due to the presence of DG.

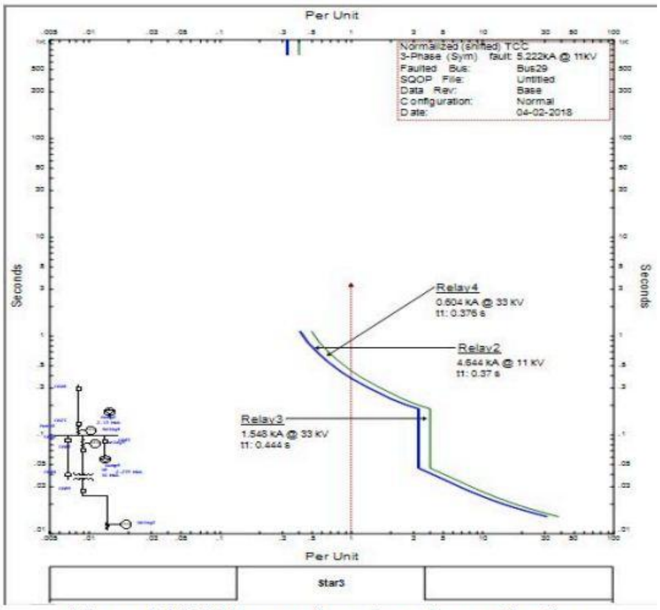

Figure 1.13 TCR curve for relay mis-coordination

D. ETAP Model for Relay Coordination:

When the fault is inserted at bus 29 as shown in figure 5.23 in absence of wind turbine, there is high fault current of 4.34kA. as the fault occurred at bus 29, the Relay 2 should be the first one to sense the fault current and act as a primary protector. It will clear the fault 0.391 sec. Relay 3 sensed the fault current of 1.44kA and It will act within 0.476 sec. and the end, the fault is cleared by relay 4 within 0.564 sec.

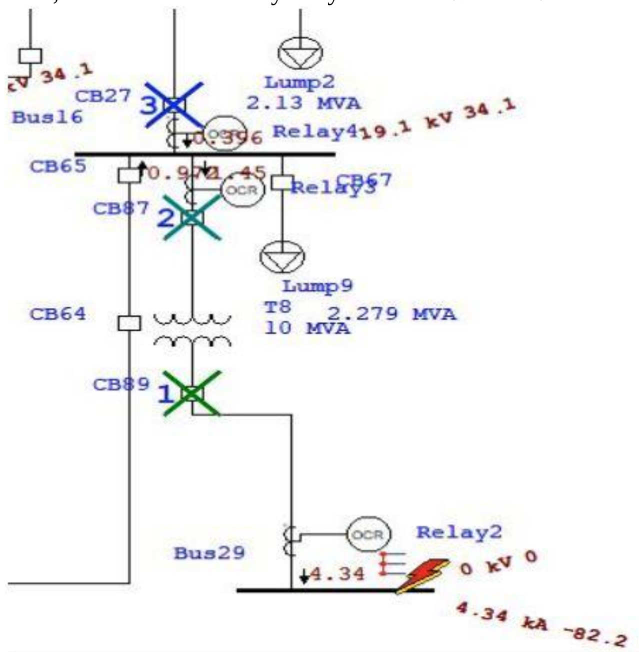

Figure 1.14 Relay Coordination fault at bus 29

VI. CONCLUSION

In this project, we have observed the effect of different filters on the Harmonic distortion and the voltage and current waveform. There are four different cases of filter are considered in MATLAB Simulink in order to achieve an acceptable distortion. To study the relay co-ordination and Harmonic analysis in the distribution system, we have considered a radial distribution network in ETAP. There are many factors like location, size and capacity of Dg for studying the impact of DG on the coordination of protective device. We carried out a fuse-recloser coordination without any Dg and with DG in the system in ETAP. We also carried out a harmonic analysis in the network, THD in the network on each bus is more than 3% which is not acceptable and also there is distortion in the voltage waveform. In order to reduce this THD, we introduce a single tuned filter in the circuit which will bring down the THD below 3%.

REFERENCES

[1] J. A. Sa' ed, S. Favuzza, M.G. Ippolito, F. Massaro, "Verifying the effect of distributed generators on voltage profile, power losses and protection system in Radial distribution networks" 4th International conference on Power Engineering, Energy and Electrical drives, 2013

[2] C.L.T. Borges, and D.M. Falcao, "Impact of distributed generation allocation and sizing on reliability, losses and voltage profile," IEEE Bologna Power Technology Conference, Italy, 2003.

[4] P. P. Barker, and R.W. De Mello, "Determining the impact of distributed generation on power systems: Part 1 - Radial distribution systems," IEEE PES Summer Meeting, vol.3, pp 1645-1656, 2000.

[5] S. M. Moghaddas-Tafreshi, and E. Mashhour, "Distributed generation modelling for power flow studies and a three-phase unbalanced power flow solution for radial distribution systems considering distributed generation," Electric Power Systems Research, vol. 79, no. 4, pp. 680-686, April 2009.

[6] L. F. Ochoa, and G. P. Harrison, "Minimizing energy losses: Optimal accommodation and smart operation of renewable distributed generation," IEEE Trans. Power Systems, vol. 26, no. 1, pp. 198-205, February 2011.

[7] H. Cheung, A. Hamlyn, L. Wang, C. Yang, and R. Cheung, "Investigations of impacts of distributed generations on feeder protections," IEEE Power & Energy Soc. Gen. Meet., 2009.

[8] S. Chaitusaney, and A. Yokoyama, "Prevention of reliability degradation from recloser–fuse miscoordination due to distributed generation," IEEE Transaction on Power Delivery, vol. 23, no. 4, October 2008.

[9] S. Chaitusaney, and A. Yokoyama, "Impact of protection coordination on sizes of several distributed generation sources," IEEE Power Engineering Conference, IPEC, Vol. 2 , pp. 669 – 674, 2005.

[10] C. F. Henville, ''Power Quality Impacts on Protective Relays –and Vice Versa,'' Power Engineering Society Summer Meeting, 2001 vol.1 pp. 587 – 592

[11] T. Gallery; I. Martinez; D. Klopotan, ''Impact of Distributed Generation on Distributed Network Protection,'' Item 515 of the 40th International Universities Power Engineering, Conference, Cork Ireland, UPEC2005, 7th - 8th September, 2005

[12] H. Tin; Abu-Saida; M. S. Masoum, ''Impact of Harmonics on the Performance of Over-Current Relays, '' Universities Power Engineering Conference (AUPEC), 21st Australasian, 2011, pp. 1 – 4

