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Simulation-Based Study of Harmonic Distortion from EV Chargers in Low-Voltage Distribution Networks

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Abstract

An electric utility must be able to handle to handle the energy demand as well as the peak demand brought on by EV charging because of the world's growing use of electric vehicles. A utility must be able to keep its THD (use full form) within the specified range in addition to meeting peak demand and energy demands. Stated differently, the penetration of EVs into the power system has the potential to disrupt the system's voltage and current waveforms. Therefore, we need to be able to make the supply side of the EV battery charging circuit harmonic free in order to maintain the system's health. Either an active filter or a passive filter can be used for harmonic compensation. According to design, an active filter can remove any amount of harmonic content; however, it is more expensive. A passive filter with a clever design can be useful for eliminating a fixed harmonic component or specific harmonic content. In this project implementing the filter multiple EV chargers are simulated and the harmonic obtained in the supply side is studied. Both single phase and three phase chargers are simulated and the results analysed. The study uses MATLAB/SIMULINK software.

Keywords— *Electric Vehicles (EVs), EV charging, Total Harmonic Distortion (THD), Power quality*

1. INTRODUCTION

This One of the new issues that a power system engineer must deal with is power quality. It is preferable to avoid exceeding the system voltage and frequency limit. Likewise, the system's harmonic content ought to be as basic as feasible. That is, harmonic distortion in the system can have a number of effects, including heating cables and wires, overloading transformers, and possibly affecting PCC voltage. Both single-phase and three-phase EV chargers are available. The electric vehicle needs to be charged for their daily purpose. This can be either charged at home or can be charged at the charging station which are fed by various feeders. The battery charger acts as the highly nonlinear load due to the use of the semiconductor devices used in the charger circuit [1]. As a result, the supply will introduce harmonics into the charger circuit due to this semiconductor device. This will cause the voltage and current waveforms to diverge from sine waves, which will lead to issues. The acceptable limit should be met by the overall harmonic distortion. The IEEE standard states that THD must not exceed 5%. Power quality issues could arise if the THD is not maintained. Given the increasing number of EVs, it is imperative to investigate the effects of EVs and their chargers on the electrical grid. For various forms of harmonic distortion, it essentially depends on how the electric chargers are configured. This requires simulating various EV chargers [6]. This project builds a simulation model of an electric vehicle charging station and analyzes the characteristics of harmonics produced during the charging process. Additionally, a simulation of a multiple charging station has been conducted, and it has been suggested that the supply-side harmonic be examined.

Furthermore, the analysis is done to study the voltage and the current harmonics. Depending upon ***state-of-charge (SOC)***, ***charge duration (or charge algorithm),*** and ***charging start time*** of the individual equipment, THD may vary. Due to non-coincidence of above quantity current harmonics will not be just algebraic sum but involves consideration of both the magnitudes and phase angles of individual harmonic components. Hence due to this Harmonic phase cancellation effect will take place. A single-phase and three-phase electric vehicle charging station simulation model [9] is constructed for research purposes, and the characteristics of the harmonics produced during the charging process are examined [5]. Additionally, the supply-side harmonic injection has been examined and the multiple EV charger has been simulated.

As shown in the figure 1, The EVk denotes the kth electric vehicle being charged from the charging station. The block EVk denotes either single phase or three phase EV charger.

For proper simulation, the three-phase source is taken from the Matlab/Simulink which generates the electric power at 11kv. This is connected to a 3-phase distribution line having an R/X ratio almost 10. This feeder is then connected to a 11/0.2 kV Delta-Star Distribution transformer. This transformer's LT will provide 3 phase four wire for charging purposes. Hence from this 3-phase four wire we can now connect any kind of chargers of different configurations and hence study will be easy.

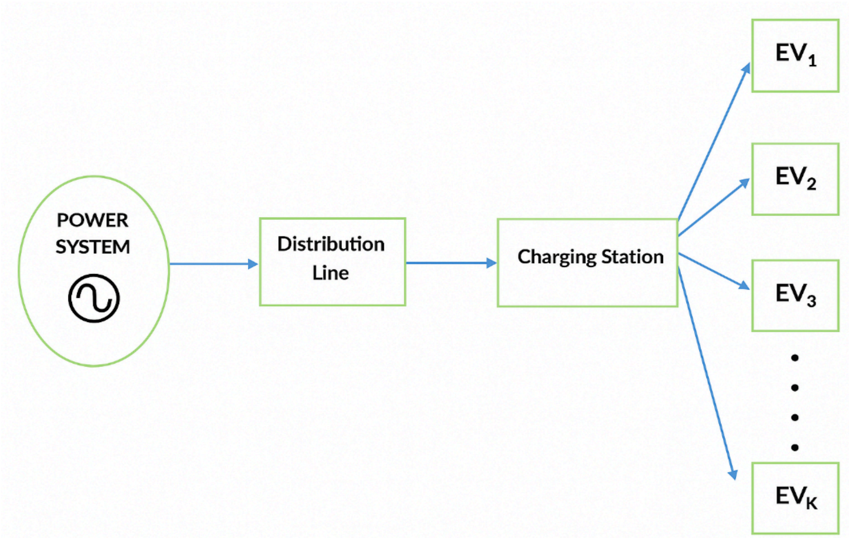

Figure 1: Schematic of Ev charger from Distribution line.

2. OBJECTIVES

This paper discusses results and analyses of simulation of distribution system with multiple EV chargers.

3. LITERATURE REVIEW

The power system load from electric vehicle (EV) chargers is extremely nonlinear [2]. They could pose a threat to power systems by causing high harmonic currents and low power factors. Therefore, it's critical to examine how EV chargers affect the harmonic current of power systems before taking action to raise power systems' loading factors and improve power quality [3].

Figure 2 depicts the high-power charger's general structural diagram. Initially, a rectifier circuit is used to convert the input AC supply into DC. Both controlled and uncontrolled rectifiers are possible. The rectifier itself comes in two varieties: bridge and half wave. The filter circuit and the DC-DC converter are subsequently connected to this rectifier. The system is finally connected to the battery.

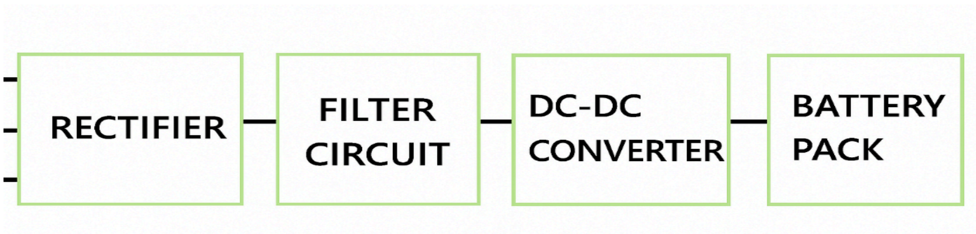

Figure 2: Block Diagram of Battery charger circuit

4. METHODOLOGY

STEP 1: Completion of literary review and figuring out in steps the exact method of accomplishing the project.

STEP 2: At first the only one single phase EV battery charger circuit is modelled in Matlab/Simulink. The THD introduced by such charger is studied. STEP 3: Then after the only one three phase EV battery charger circuit is modelled in Matlab/Simulink. THD introduced due to such charger is also studied.

STEP 4: Then after the distribution feeder feeding different charging station is modelled in the matlab.

STEP 5: For purpose of study, at a time multiple single phase EV chargers only is then charged through this distribution system. And then the current and the harmonics is checked and analyzed. From the result we can compare what will be the significant change in the harmonic distortion as we go on increasing the number of similar types of chargers in parallel.

STEP 6: Similarly, at a time multiple three phase EV chargers are then charged through this distribution system. The THD study is made. And then the current and the harmonics is checked and analyzed. From the result we can compare what will be the significant change in the harmonic distortion as we go on increasing the number of similar types of chargers in parallel.

STEP 7: Finally, all the combination of single phase and three phase EV chargers are then simulated in the same distribution system at same time and the harmonic study is carried out. That is, we connect the larger number of different chargers in parallel and charged by the same source and then the harmonics are studied. After checking the result, we can come up to the solution to make the supply side harmonics free

STEP 8: If harmonics still remains present and is not within the acceptable limits filter circuitry must be designed.

5. RESULTS AND DISCUSSION

i. Single Phase Charger (Bridge Type)

At first, we will see what will be the case when we take only one phase being connected to charger. The battery nominal voltage is adjusted to 50VDC and the system line to line voltage is 200V AC. Here the remaining phase are at no load. This is done only for study purpose. The following results were obtained while simulating this system for 30seconds.

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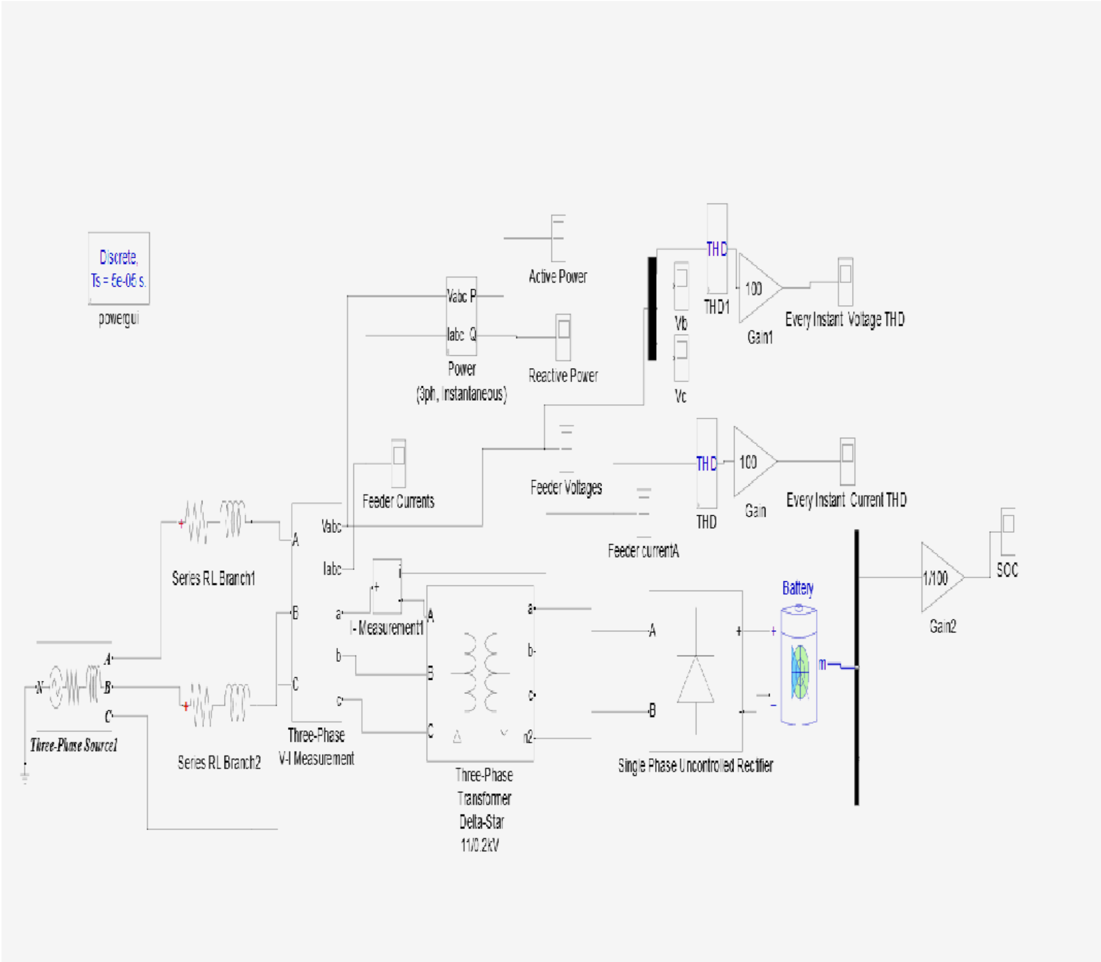

Figure 3: Single phase bridge EV charger

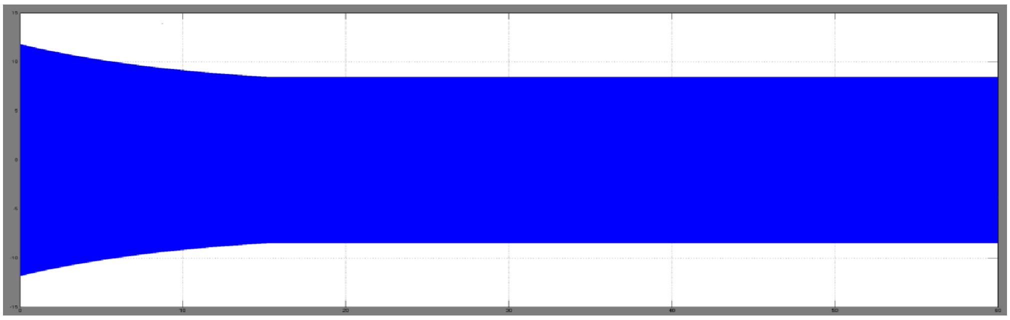

Figure 4: Overall current injected by the supply side.

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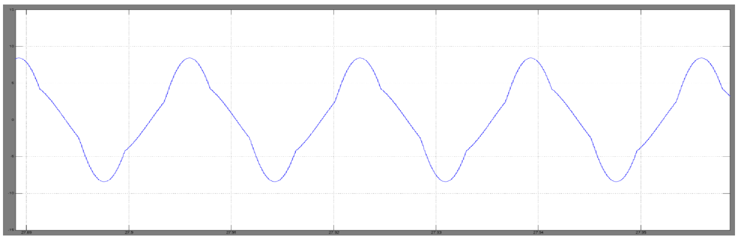

Figure 5: Portion of the supply current

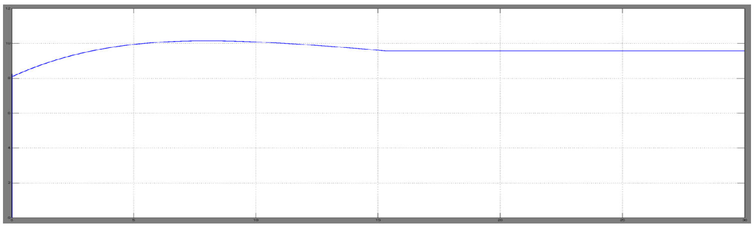

Figure 6: Current THD

Here, we can see that the THD has settled down to almost 9.5%. This THD was obtained in Phase A supply current when only that particular phase A was being connected to the charger. Now we will see what will be the case if all the phases are connected to the identical chargers as shown.

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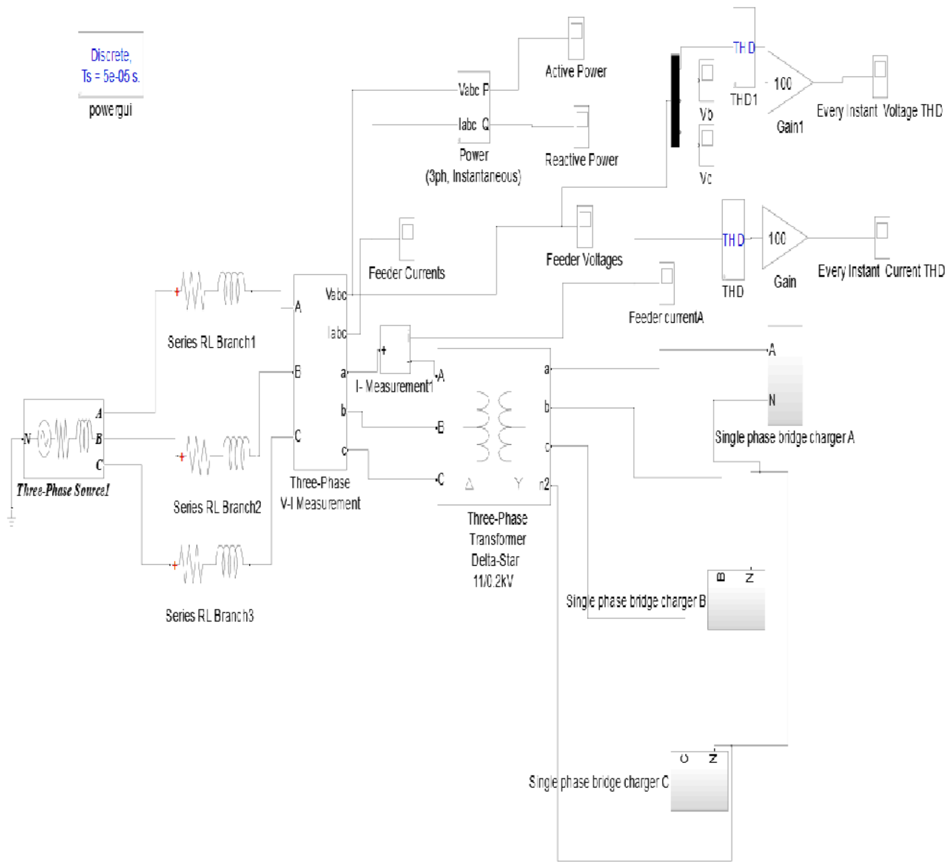

Figure 7: All the phases are connected to single phase bridge type EV charger.

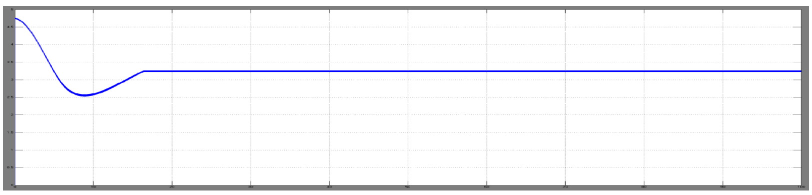

Figure 8: THD of the above simulated system.

As we see from the above analysis the THD is drastically improved if the transformer is balanced loaded in each phase. In the first case it was found that THD was almost 9.5 % when only one Phase A was connected. However, in second case when we connected all the phase to the similar charger and it was found that the THD of supply current of Phase was almost 3.3%. This was obtained from the simulation result.

ii. Single Phase Charger (half wave)

Here we have connected only one single phase half wave EV battery charger in Phase A, keeping Phase B and Phase C at no load condition. In next simulation we have considered the balanced loading and analyzed the THD. Similarly, we have again considered the unbalance Single phase chargers being fed by the distribution transformers.

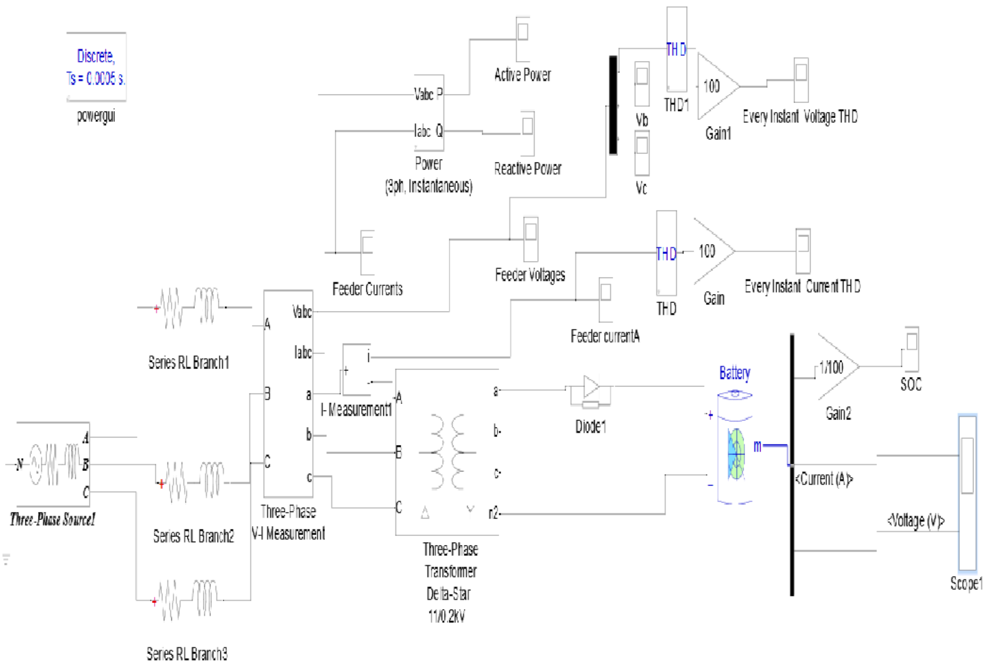

Figure 9: Single Phase Half wave EV battery charger Simulink model

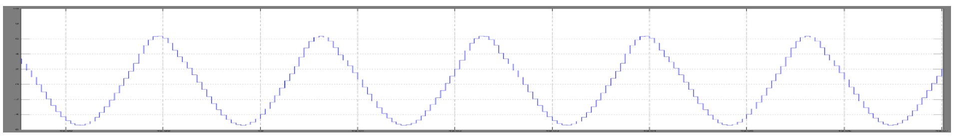

Figure 10: Current Drawn by phase A

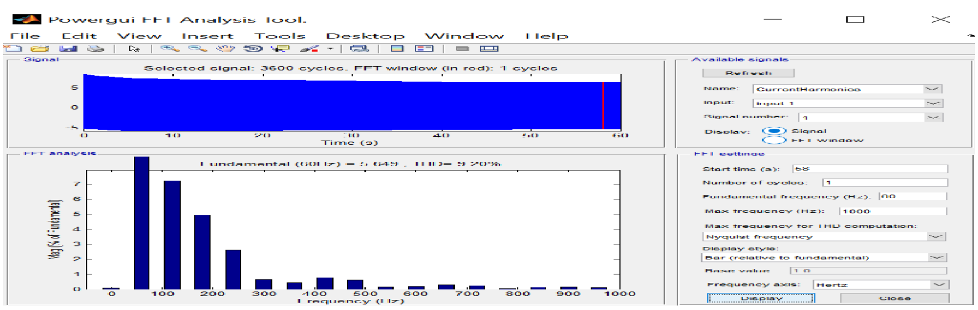

Figure 11: FFT analysis of Current at steady state condition (THD=9.20%)

Now we will again see what will be the case if all the phases are connected to the identical chargers as shown.

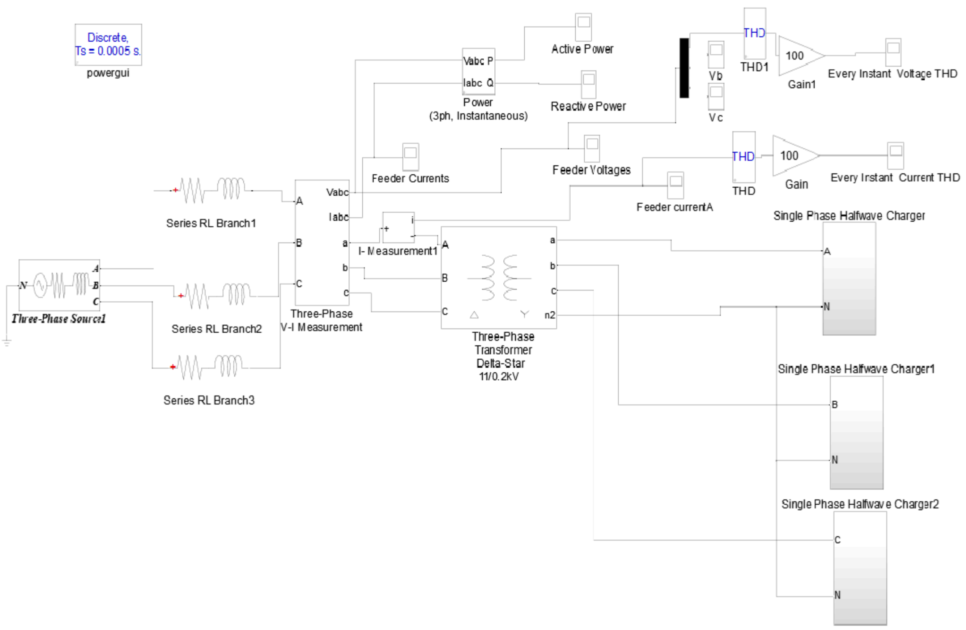

Figure 12: Single Phase Half wave EV battery charger connected in all phases

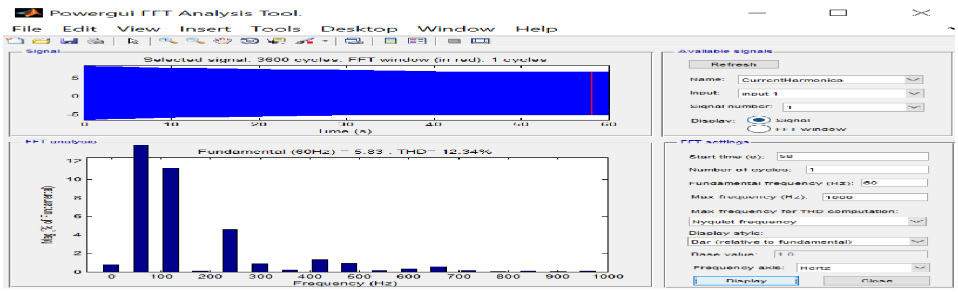

Figure 13: FFT analysis of Phase A Current at steady state condition (THD=12.34%)

Comparing these two results THD is slightly increased if we connect identical half wave chargers in all phases.

iii. Multiple single-phase charger (Bridge Type)

For studying this, at first balanced loading on each phase of the transformer was considered and simulation was carried out. Initially only one EV charger was connected to each phase of the system. After 30sec of the simulation 6 identical chargers was connected to the system with the help of a breaker. Similarly, after 60sec of the simulation another 18 identical chargers was again connected to the

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system. After that THD analysis of current and voltage was done. Some important observations that was obtained are discussed below.

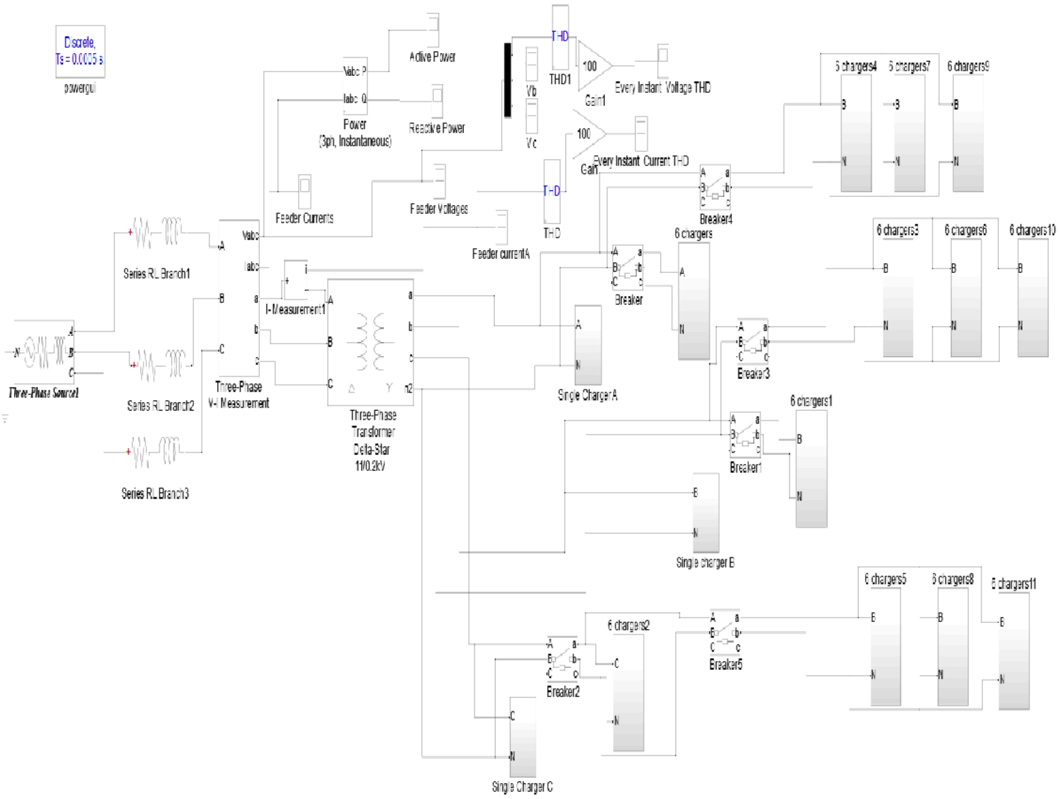

Figure 14: Overall simulation with multiple single phase bridge type charger

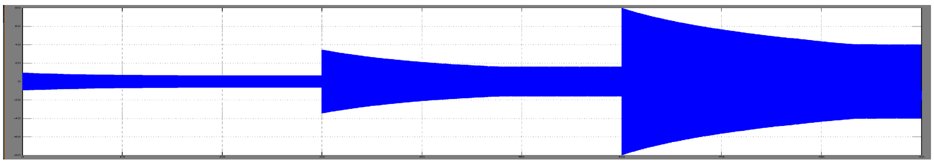

Figure 15: Current waveforms with breaker operation at 30sec and 60sec respectively

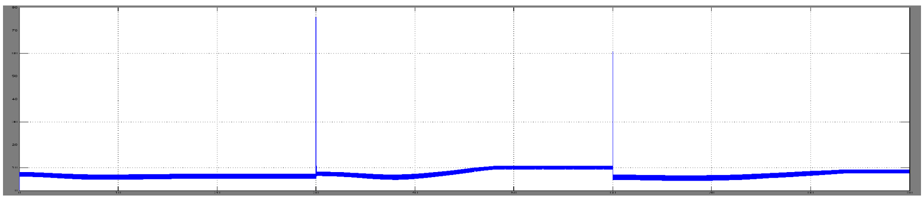

Figure 16: Current THD vs Time with breaker operation at 30sec and 60sec respectively

Here we can see that the THD obtained is about 3.27% when each of the phase was connected to only one bridge charger. However, when the additional 6 identical chargers were connected to the system with help of a breaker the THD increased to about 8.23%. Hence this showed that additional chargers increased system harmonics to some higher level. But as we went on increasing the additional number of chargers the result was quite different and current THD began to decrease. That is when additional 18 chargers were connected to the system at about 60sec of the simulation period the THD was drastically dropped down to 6.94%. If we increase additional chargers further then the THD will obviously reduce from this latter value. However, the voltage THD was obtained to be increased as shown in the figure below. This was also due to the fact that the SOC of chargers were different during breaker operations.

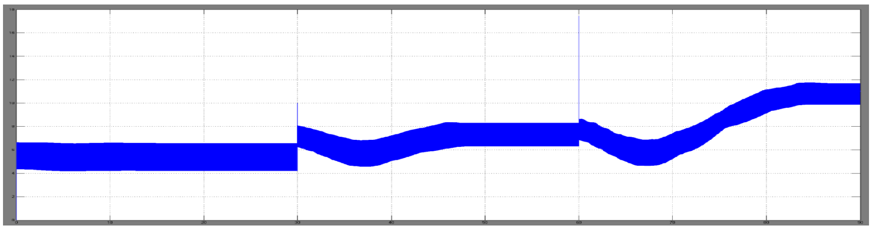

Figure 17: Voltage THD variation with time

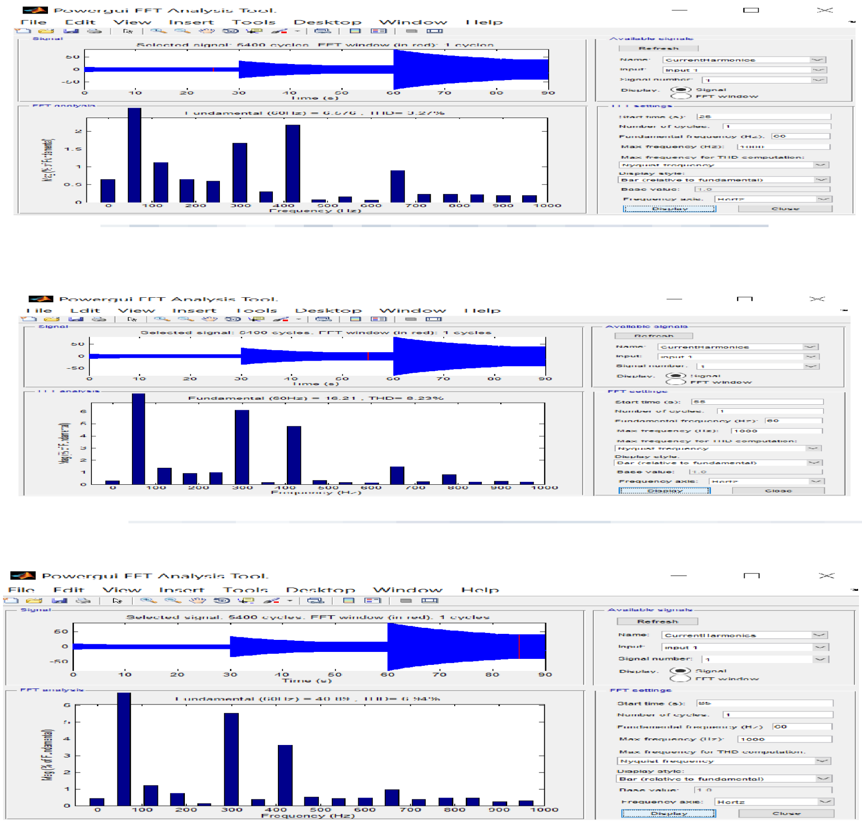

Figure 20: FFT of the supply current with 25 EV charger with additional 18 charger connected at 60sec

Now if we consider the unbalanced loading in this same case we obtained the following results.

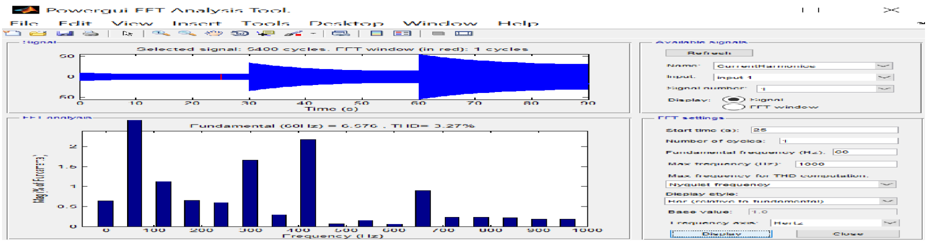

Figure 21: FFT analysis with 3 identical chargers in each phase

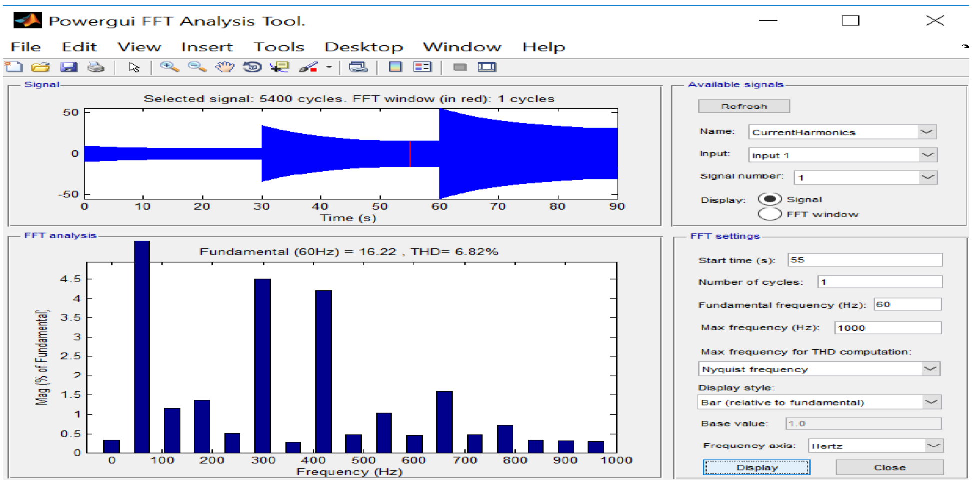

Figure 22: FFT analysis with additional 6 chargers in Phase A and Phase B and no change in Phase C i.e. Unbalanced Loading.

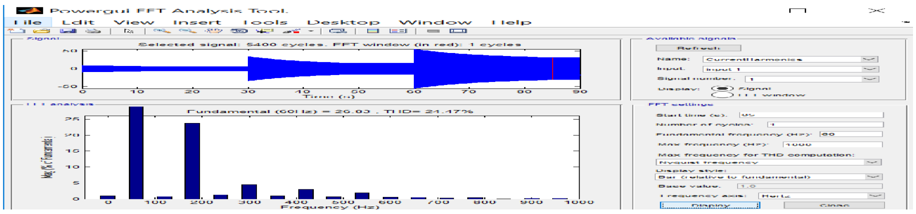

Figure 23: FFT analysis with additional 18 chargers in Phase A and additional 6 charger in Phase B and no change in Phase C i.e. Unbalanced Loading.

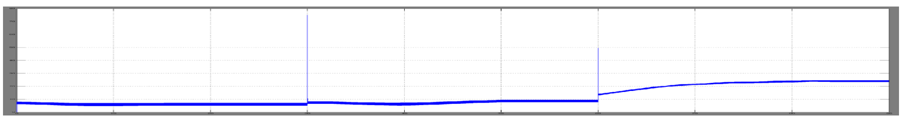

Figure 24: Current THD variation of Phase A for the above given simulation diagram.

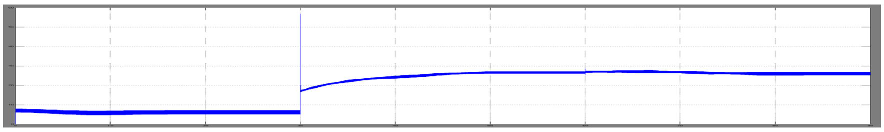

Figure 25: Current THD variation of Phase B for the above given simulation diagram.

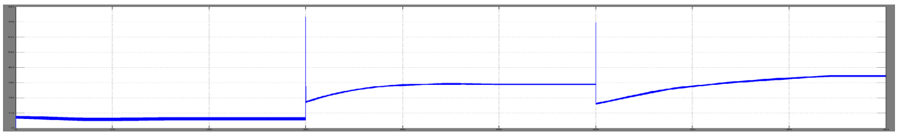

Figure 26: Current THD variation of Phase C for the above given simulation diagram.

Hence from the above observation we can see that in case of an unbalanced loading the THD is likely to be increased in the lightly loaded phase. Here in this case the Phase C is lightly loaded and hence the current THD of the phase C is also drastically increased. The current THD in the individual phase are as shown as obtained from the FFT analysis and above.

THD at Phase A= 3.27 %, when All phase Balanced. THD at Phase A= 6.28 %, unbalanced case when phase A and B equally loaded. THD at Phase A= 24.47 %, unbalanced case when Phase A is heavily loaded. THD at Phase B= 3.27 %, when All phase Balanced. THD at Phase B= 25.31%, unbalanced case when phase A and B equally loaded. THD at Phase B=24.88%, unbalanced case when Phase A is heavily loaded. THD at Phase C=3.23%, when All phase Balanced.

THD at Phase C=28.13%, unbalanced case when phase A and B equally loaded.

THD at Phase C=34.70 %, unbalanced case when Phase A is heavily loaded.

This showed THD is also highly dependent on the balanced condition. Unbalanced condition deteriorates the THD of the lightly loaded phase in this case.

iv. Multiple single-phase charger (half wave)

Here we simulated the single-phase half wave EV charger in all the phases. At first until 50sec only one EV charger is connected in the individual phases. After 50sec additional 6 chargers are connected in each of the phases. Similarly at the 70 sec of simulation period additional 18 chargers were connected to the distribution transformer for study purpose. The harmonics during this stated period are shown in the figures below under this heading.

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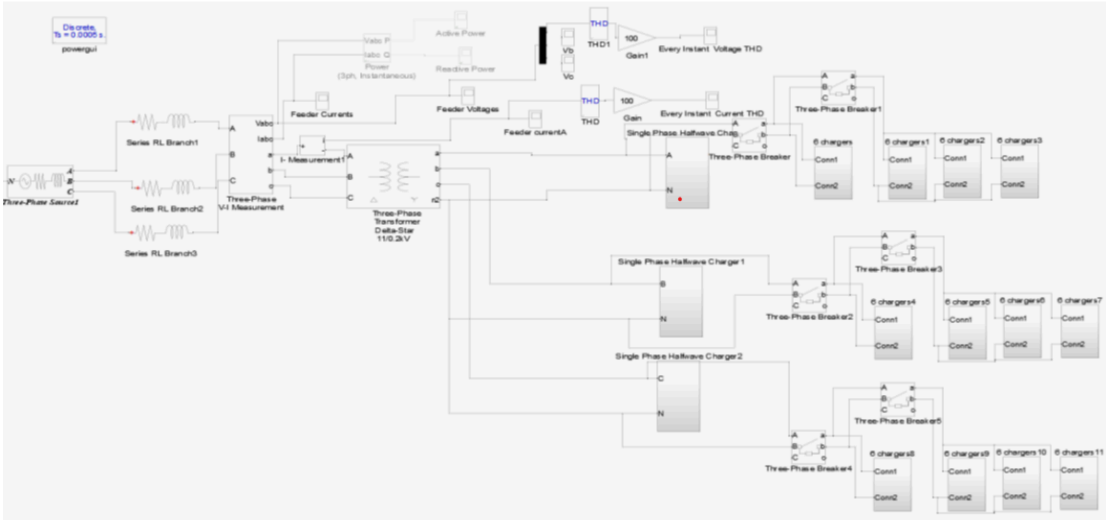

Figure 27: Simulation of Multiple halfwave type single phase charger with balanced loading of EV chargers.

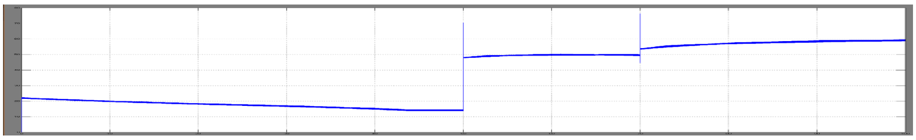

Figure 28: THD of the Phase A current when the breaker operates at 50sec and 70sec

Here we can see that the current THD is increased when the number of Half wave EV chargers operating in parallel is increased gradually.

v. Combined multiple single-phase charger (Half wave and Bridge)

Here under this we have simulated the combined half wave and full wave single phase EV battery charger. For this at first all the three phases are connected with 6 full wave battery chargers. After 30sec of the simulation period another 6 numbers of half wave chargers are introduced in the system. Finally, at 100sec of simulation study we have again introduced 6 bridge rectifiers and 6 half wave rectifiers in parallel. That is at 100sec of simulation study we have altogether 12 full wave chargers and 12 half wave chargers being connected to each of the phases. The simulation results are also shown below.

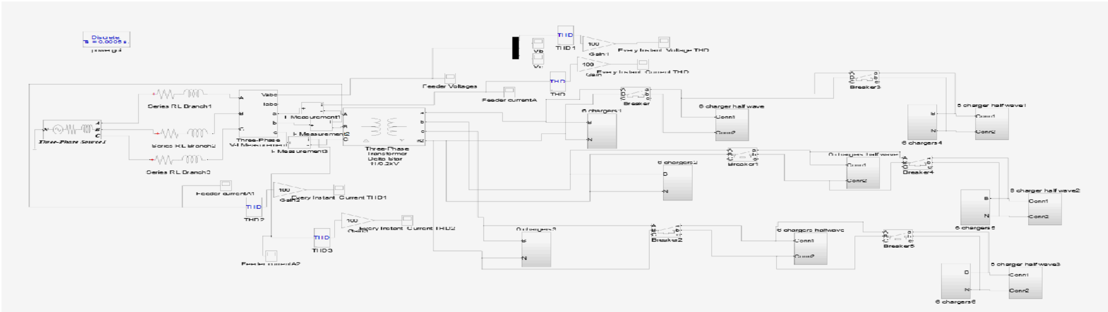

Figure 29: Combined Full wave and Half wave single phase EV battery charger

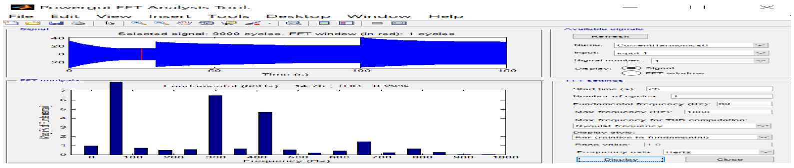

Figure 30: FFT due to 6 full wave chargers connected on each phase

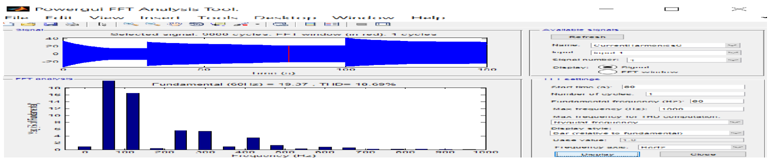

Figure 31: FFT due to 6 full wave chargers and additional 6 half wave chargers connected on each phase at 30sec

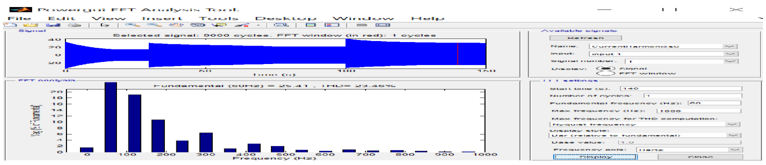

Figure 32: FFT due to additional 6 full wave chargers and additional 6 half wave chargers connected on each phase at 100sec (Total chargers 12 half wave and 12 full wave).

Hence this result showed that the THD is increased if we incorporate the half wave chargers in the system which has previously used full wave single phase chargers. Or in other words the THD rises if both single-phase chargers (half wave and full wave) are more in the system. Here the final value of THD is about 23.46% when the 12-half wave and 12 full wave chargers are operated simultaneously at about 100sec.

vi. Single Three phase charger Simulation

Here the line-to-line voltage of the system considered is 200V AC and battery nominal voltage is 50V dc.

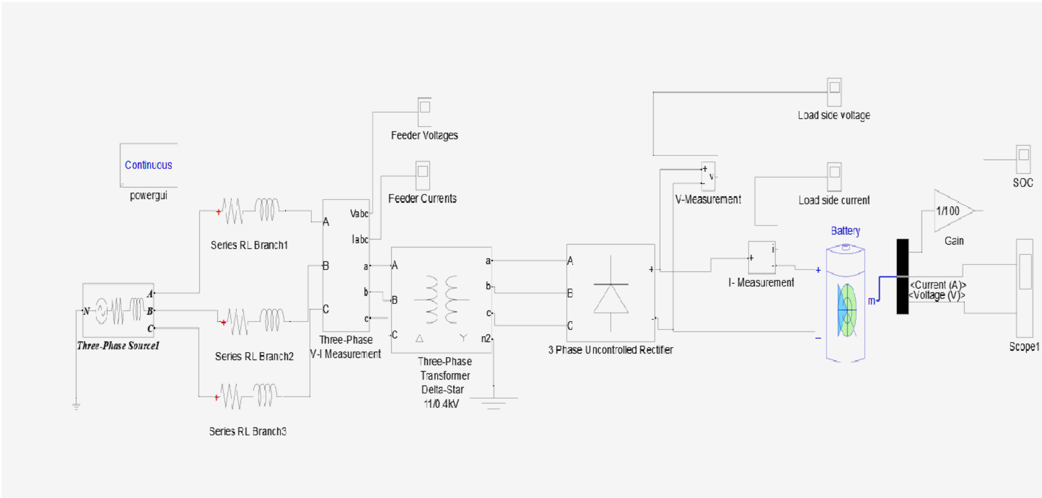

Figure 33: Simulink model of Battery charger with uncontrolled rectifier

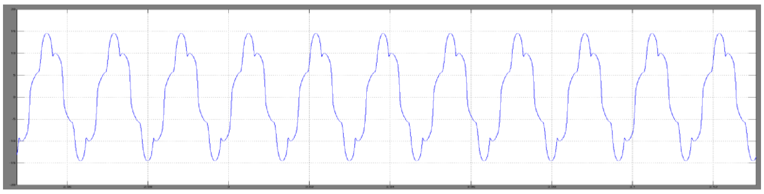

Figure 34: High Voltage (HV) side Current Vs Time

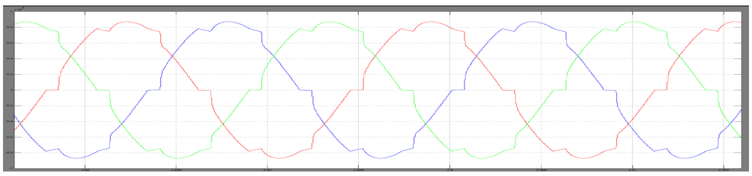

Figure 35: HV side Feeder Voltages Vs Time

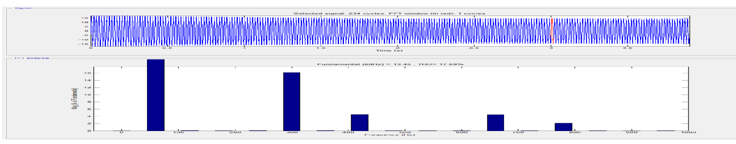

Figure 36: FFT Analysis of injected current of three phase uncontrolled battery charger circuit

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From this we can see that THD is 17.69% when only one three phase bridge type EV charge is connected to the supply.

For studying this, at first only one three phase bridge type charger was connected to the distribution transformer. Then after 4sec of simulation additional 2 EV chargers were connected to the system with the help of Breaker. Similarly, after 8sec of simulation additional 20 EV chargers were brought into the system with the help of the three-phase breaker. And again, after 16sec of simulation additional 20 EV chargers were connected. That is at 16sec the system was serving altogether 43 EV chargers. The simulation results are discussed here below.

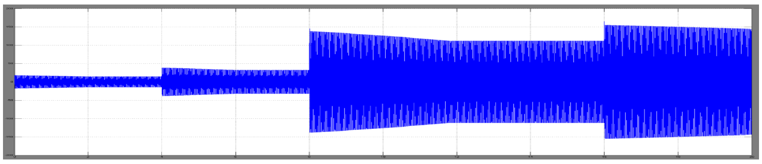

Figure 37: Current waveform with breakers operation at 4s, 8s and 16s respectively

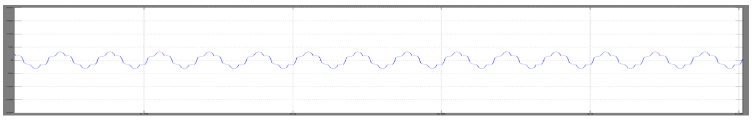

Figure 38: HV side Current Vs Time with 3 EV chargers

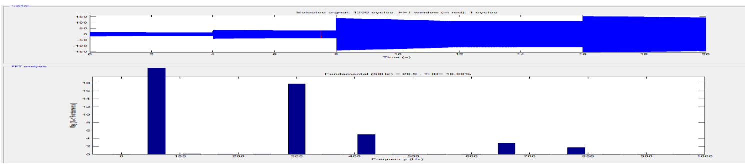

Figure 39: FFT Analysis of injected current of Multiple EV charger for breaker operation beyond 4s with all total 3 EV chargers in operation

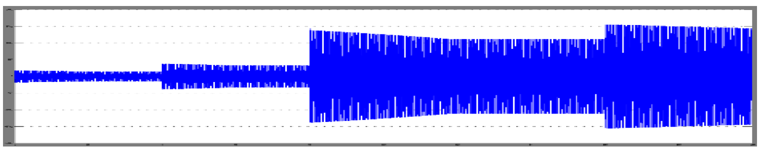

Figure 40: Portion of HV side Current Vs Time with 23 EV chargers and breaker closed at 8s

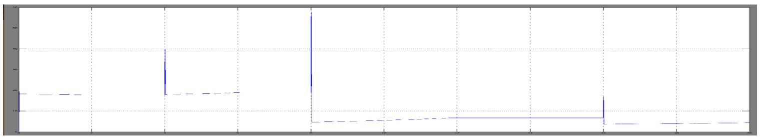

Figure 41: Current THD variation with time with breaker operation at 4s, 8s and 16s respectively

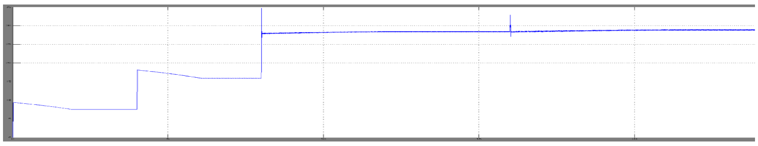

Figure 42: Voltage THD variation with time with breaker operation at 4s, 8s and 16s respectively

Here in this case, we found that initially when only one three phase charger was connected to the system the supply current THD was about 17.8%. Now when the additional two EV chargers were connected at 4sec the THD was increased slightly to 18.88%. Similarly, when additional 20 EV chargers were again brought into the system through the help of a breaker, the THD dropped down to 6.69%. This THD was again dropped to 4.53% when additional 20 EV chargers were further brought into the system at 16sec of simulation. Hence, we can say that current THD was decreased with the increase in the number of EV chargers when the state of being charged was different.

vii. Combined single phase and three phase charger simulation

Here up to 16 second 43 three phase EV chargers are connected to the system. For this we have already studied the harmonic behavior in the previous section. But here we again introduced the single-phase chargers at the period of 22 sec. About 6 half wave chargers and 6 full wave chargers were introduced in the system. This was done only to see the effect that can be introduced by the single-phase chargers on THD when they are combinedly operated with the three phase chargers.

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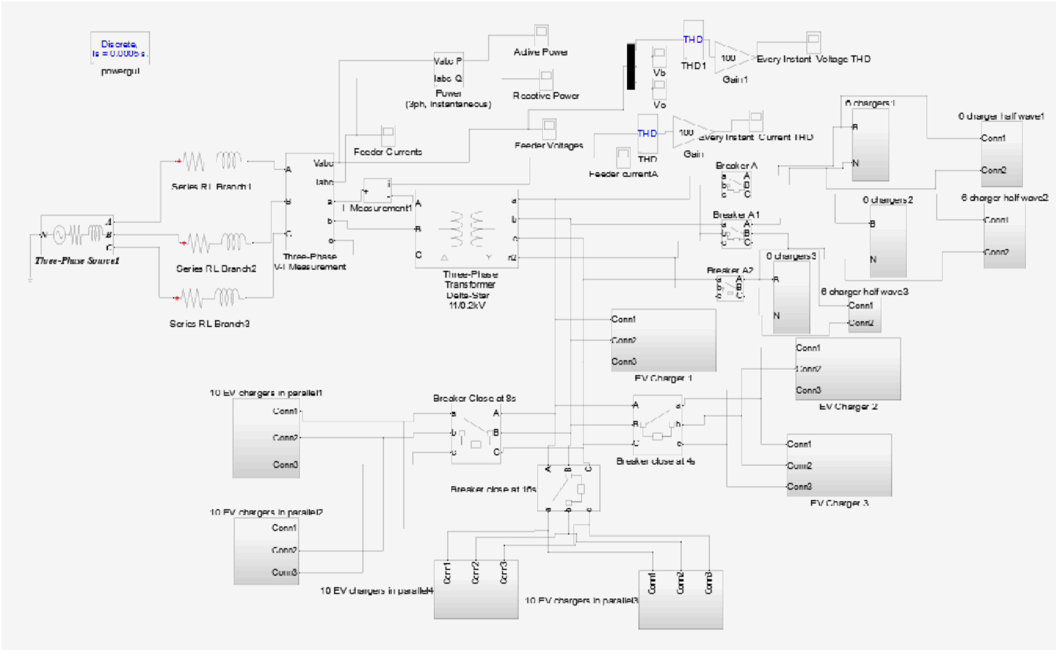

Figure 43: Combined operation of single phase and three phase EV chargers.

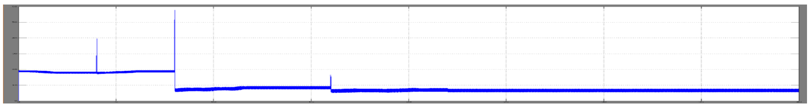

Figure 44: Current THD vs time of phase A

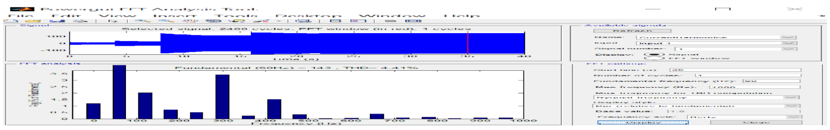

Figure 45: FFT analysis for the given simulation study

Here we can see introducing the single-phase chargers where there are more number of three phase chargers have almost negligible effect in THD variation. Since 3 phase chargers are more in this case the THD variation is not more due to more cancellation effect introduced by these chargers.

6. CONCLUSION

From the above results we can conclude that the current THD is dependent upon the type of chargers involved. And also, it was noted that in the case of a three-phase charger, increasing the number of chargers at certain intervals of the simulation period tends to decrease the THD. As this was obtained because of the fact that the SOC of the new incomer charger will be different from the previously charged one. Hence in this case the current harmonics will not be just the algebraic sum but involves the consideration of both the magnitudes and phase angles of individual harmonic components. Hence due to this Harmonic phase cancellation effect will take place. Also, it was noted that if the number of single-phase half wave chargers were introduced in the system THD level rises. Depending upon the loading condition, the type of chargers involved, the nominal voltage level of the battery, the voltage level of supply and the SOC of the batteries involved the THD can vary.

7. RECCOMENDATION

Future research should focus on developing optimized charging strategies that leverage the harmonic phase cancellation effects observed in multi-charger systems to minimize THD. A deeper understanding can be achieved by comparing single-phase and three-phase chargers under various SOC conditions. Furthermore, advanced control strategies and intelligent charging algorithms should be explored to ensure grid stability and maintain power quality with large-scale EV integration.

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