

**POWER QUALITY ISSUES WITH HIGH
PENETRATION OF ELECTRIC VEHICLE CHARGING
IN DISTRIBUTION NETWORK**

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Degree of Master of Science

Department of Electrical Engineering

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Dissertation submitted in partial fulfilment of the requirements for the degree Master
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DECLARATION

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ABSTRACT

Electric vehicles (EV) are becoming the most preferred and rapidly growing mode of transportation all around the world. Development of battery technologies and attention on residential scale renewable energy based distributed generation has accelerated the growth of the EV market. Commercial EV is equipped with energy storage, where a rechargeable battery is the most common type. EV Chargers are located either on board or off board. These chargers are present in different power levels. A regulated DC current shall be supplied to EV charging and the charging current is higher compared to conventional loads. Power electronic converters are used for the AC DC conversion thus a distorted current is drawn by the nonlinear load. This will give rise to power quality issues such as voltage unbalance, voltage fluctuations and harmonics on distribution systems. This research studies and quantifies the power quality impacts of the EV chargers on the distribution system. A detailed power electronic model of a commonly available EV charger is modelled in Matlab and a comprehensive current harmonic analysis is carried out in a standard IEEE LV distribution test feeder. The research focuses on the impact to the feeder with different EV penetration levels as well as different spatial load distribution. From the analysis it was determined for random EV distribution up to 40% of EV penetration is acceptable to the existing feeder at off peak intervals while only 30% is acceptable under nominal load condition as per IEEE 519 limits. If the EV chargers are clustered together, the current harmonic impact is higher and only 20% of EV penetration will be acceptable prescribed limits. The outcome of the research can be successfully used by distribution grid operators to determine to acceptable limits of EV penetration in the existing system. An algorithm encompassing the results of the study shall be employed in coordinated charging of electric vehicles where the operators shall dispatch the EVs based on the feeder loading and spatial distribution of EVs. Encompassed

(Key words – Electric Vehicle, Matlab modelling, Power Quality, Harmonics, LV distribution system)

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LIST OF ABBREVIATIONS

A	Ampere
CAN	Control Area Network
EV	Electric Vehicle
FFT	Fast Fourier Transform
HV	High Voltage
IEC	International Eelctrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
LV	Low Voltage
MV	Medium Voltage
NEC	National Electric Code
PCC	Point of Common Coupling
PI	Proportional Integral
PHEV	Plug in Hybrid Electric Vehicle
PV	Photo Voltaic
PWM	Pulse Width Modulation
SAE	Society of Automotive Engineers
TDD	Total Demand Distortion
THD	Total Harmonic Distortion
V	Volt

CHAPTER 1. INTRODUCTION

1.1 Background

1.1.1 Electric Vehicle

Electric Vehicle (EV) is an automotive-type vehicle primarily powered by an electric motor that draws current from a rechargeable battery, fuel cell, photovoltaic array, or other source of electric current [1]. Electric vehicle can be identified as main emerging media of transport in the recent past which has number of inherent advantages. A derivative of electric vehicle is Plug-In Hybrid Electric Vehicle (PHEV); which has the ability to store and use off-vehicle electrical energy in the rechargeable energy storage system, and having a second source of motive power. Second type of energy source is petroleum fuel such as petrol or diesel in most of the commercial applications.

EVs gained its popularity as a viable alternative to motor vehicles with internal combustion engines fuelled by petroleum fuels. The forthcoming depletion of fossil fuel sources, global warming due to fossil fuel burning and increased attention on renewable energy sources has accelerated the development of electric vehicles. Advantages of an EV in contrast to a conventional motor vehicle such as high responsiveness, zero emission, better fuel economy and higher torques increased the rate of penetration of EVs in the market. Increased popularity and economy of rooftop solar PV systems paved a way for a paradigm change of residential energy usage.

The energy supply of a typical electric vehicle is comprises of energy storage such as battery system, a charging system to recharge the energy storage and charge control system. The type of battery package and charging architecture depends on the standards followed by the manufacturer. Typical layout of an electric vehicle is depicted in Figure 1.1.

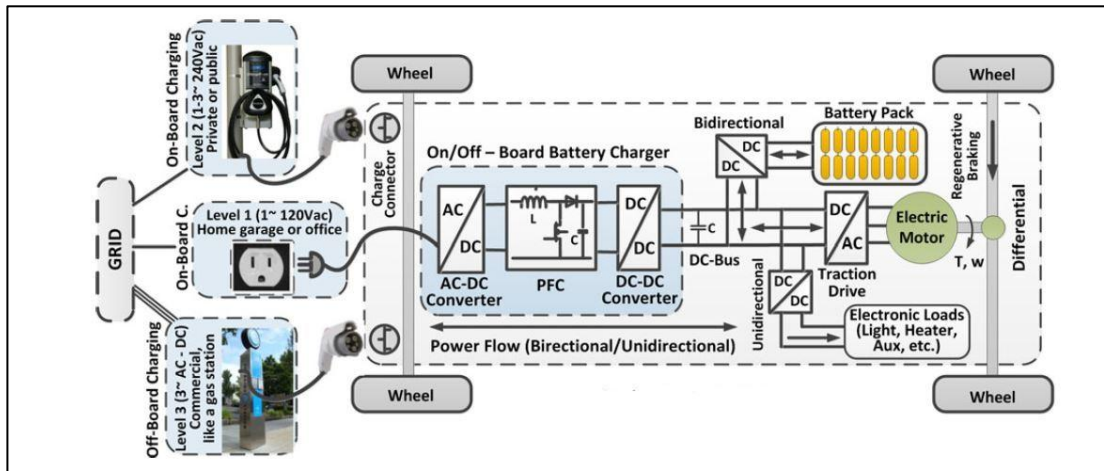


Figure 1.1: Electric Vehicle Configuration [2]

1.1.2 Electric vehicle Penetration

Since the introduction of first commercial scale electric vehicle in 1996 by General Motors, United States, the growth of electric vehicle market was moderate until 2010. After 2010, the introduction of Nissan Leaf electric car and Tesla model S electric car has quickly accelerated the growth. These electric cars have provided a better mileage for a fully charged battery which increased the popularity of electric vehicle. At the end of 2016, global EV sales reached 2 million while more than 90% of the EVs sold were electric cars. The global sales of PHEVs reached 0.8 million in 2016. Table 1.1 below illustrates the global EV volume at the end of the year from 2012.

Table 1.1: Global EV market volume[9]

Year	Cumulative Global EV Sales
2012	100,000
2013	405,000
2014	712,000
2015	1,235,000
2016	2,000,000

1.1.3 Electric Vehicle Penetration in Sri Lanka

Electric vehicles were not popular in Sri Lanka until late 2014. There was an significant increase in EV penetration in 2015. The total EV registration in each year in Sri Lanka is depicted in Table 1.2.

Table 1.2: EV Penetration in Sri Lanka[3]

Year	Total No. of EV registration
2014	90
2015	3,238
2016	1,021

It is to be noted that with the recent development in EV industry as well as the favourable government policy towards EV in Sri Lanka, a substantial increase of EV could be expected in the next decade.

1.1.4 Electric Vehicle Charging

Similar to the fuel refilling to a conventional motor vehicle, the battery of an electric vehicle shall be recharged in order to continue the motion. Electric vehicle charging can be broadly classified to two categories, on board and off board charging. All the charging infrastructure and control are located inside the vehicle in on board charging while the off board charger is located outside the vehicle. In any case, source shall be utility grid, either LV or MV whereas the battery charging current shall be regulated DC current.

Since a regulated DC voltage current and voltage shall be applied to the battery, power electronic converters are used to convert AC voltage to DC voltage. The charging capacity depends on the battery capacity and level of the charger. The minimum charging power level of most popular Nissan Leaf is 3.3kW and there are

number of charging levels and standards which will be discussed in the latter parts of this document.

1.2 Problem Statement

It can be identified that the type of road vehicles are moving towards electric vehicle when the recent trends in transport and energy sectors are studied. One of the main obstacles in the EV industry can be identified as the low capacity of the battery system but there has been a rapid development in battery industry in recent past indicating a favourable future for EVs. Also the hurdles in charging times are significantly decreasing with the development of power electronics for DC fast charging. Thus it can be anticipated that the market share of EV will grow substantially and EV will be more common than conventional motor vehicles in near future.

Since the charging of EV draws a significantly high current and the inherent non linearity and switching effects associated with the power electronic converters, EV charging would cause disturbances to distribution grid. At the present context, many of the EVs shall be charged two to three times per week while heavy users may charge the EV once a day. EV chargers shall be connected to LV or MV distribution network. It is uncommon to have such high capacity power electronic converters in residential distribution grid. At the same time, EV charging as a distinct load draws a significantly high current than a conventional load. Since the current waveform is distorted, the effect will be multiplied.

As a result of increasing penetration of EV in the market and the characteristics of the charging, number of power quality issues will be caused to distribution system. The high capacity of single phase chargers cause voltage unbalance while the power electronic devices emits significant amount current and voltage harmonics to the grid. Increased EV charging would cause transformer and line overloading. Since it is forecasted that the penetration of EV will be continuously increasing, these effects

shall be studied and distribution grid operations and improvements shall be planned according.

In this study, the power quality emission of a commonly available EV charger shall be studied and the power quality effect of the EV charging to the residential distribution grid was studied.

1.3 Objectives

Objective of the research is to study and quantification of power quality emission of electric vehicle charging and study the power quality effect to the distribution grid due to high penetration of electric vehicle charging. At the end of the research, allowable limits of EV penetration at different scenarios were determined. The research was conducted for a partial fulfilment of the degree of the Master of Science in Electrical Engineering.

CHAPTER 2. LITERATURE REVIEW

2.1 Power Quality

The definition of power quality given by IEEE is “Concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment” [4]. The IEC definition on power quality is more related to electromagnetic compatibility which states that “Electromagnetic compatibility is the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment” [5] In general, power quality is the concept of maintaining the voltage and current waveforms in rated magnitude and frequency without distortions.

Power quality can be considered as the combination of voltage quality and current quality [5]. Voltage quality is concerned with the deviations of voltage waveform whereas the current quality is concerned with that of current waveform. Ideal waveform of both current and voltage is a single-frequency sine wave of constant magnitude. Additionally, the current waveform shall be in phase or with supply voltage waveform for a unity power factor situation.

Power quality events can be identified as voltage variations, voltage fluctuations, voltage unbalance, flicker and harmonics in current and voltage waveforms. Voltage variation is the variation in voltage magnitude where voltage fluctuation is associated with the changes in power flow. Voltage unbalance is caused by unbalanced single phase loads or sometimes by poorly transposed transmission lines. Harmonics are caused by nonlinear loads which distorts the current waveform and hence the voltage waveform. Power electronic devices are the main source of harmonics in a power system [6].

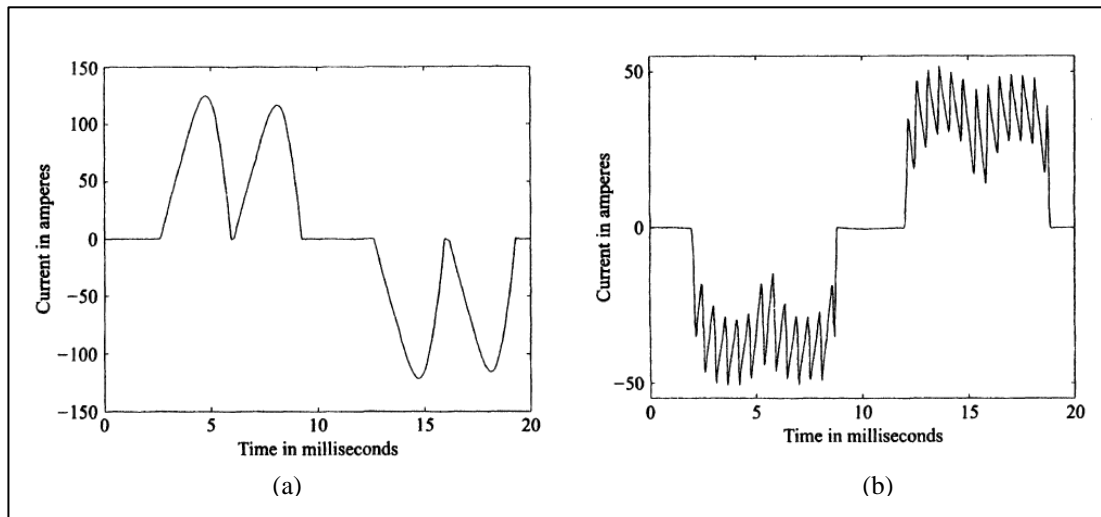


Figure 2.1: Distorted current waveform of motor drive and a inverter[7]

Figure 2.1(a) shows the input current wave form of variable speed drive of an AC motor. The current waveform is distorted with odd harmonics. Figure 2.1 (b) shows the input current waveform of a DC-AC inverter of which the current waveform is distorted with high frequency ripples due to high frequency switching.

Poor power quality would create number of negative effects to the consumer loads. Voltage variations can damage sensitive equipment in the installation. Light flicker as the result of voltage fluctuations is irritating to human eye and decreases the efficiency of people. Harmonic current increases the power loss and heating which would reduce the life time of equipment. Harmonics could short circuit capacitors causing damages to equipment. Thus it is important to maintain the power quality parameters within acceptable limits to provide a high quality service to the end consumers of the electrical network.

2.2 Electric Vehicle Charging

2.2.1 EV Battery

Every EV is equipped with energy storage to provide motive power to the vehicle. Most common type of energy storage in a commercial EV is rechargeable battery system. The cell technology, configuration and capacity of the battery pack will depend on the manufacturer. For instance, 2016 Nissan Leaf model S electric car is equipped with a 24kW Li-Ion battery of 192 cells [8].

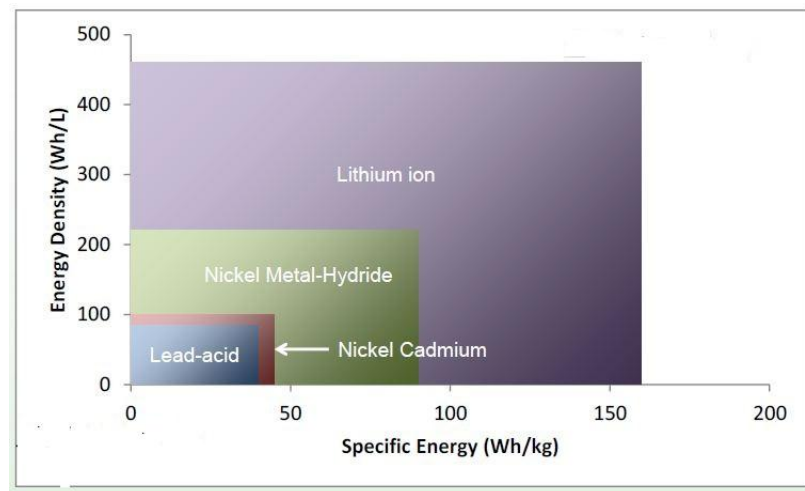


Figure 2.2 : Comparison of Battery Technologies [9]

The improvements of battery technology paved the way to the rapid growth of EV market. One of the main deciding parameters of the battery performance is the energy density which is the amount of energy stored in a unit volume of electrolyte. Figure 2.2 illustrates the comparison of the energy densities of commercially available battery technologies. At the present date, Li-Ion technology has the highest economically feasible energy density enabling more energy in a given cell. This property improves the mileage of an EV attracting more consumers to the EV market.

Table 2.1 : Parameters of Nissan Leaf Battery Pack [10]

Parameter	Value
Nominal Battery Capacity	24kWh / 66Ah
Nominal Voltage	360V
No. of Cells	192
No. of Modules in Series	48
Cell Configuration in a Module	2Series 2Parallel
Electrolyte	LiPF6 EC type

Table 2.1 lists the main parameters of battery pack of 2016 Nissan Leaf model S.

2.2.2 Charging Standards

The energy storage of an EV shall be recharged by means of an electrical power supply to maintain the motive power. The battery shall be charged by supplying a regulated DC voltage to the battery terminals. Since the utility supply is predominantly AC, the utility supply shall be converted to DC in order to meet the charging requirements.

There are two types of charging, conductive charging and inductive/wireless charging. In conductive charging, a connector is coupled with power source and the EV while in wireless charging there is no physical connection between the vehicle and source. Conductive charging is the most common and established mode of charging at present. Inductive charging is getting popular in the recent years. Only the conductive charging was considered for this particular study.

International standards for EV charging define the charging power levels, associated connectors and other configurations. IEC-62196 and IEC-61851 standards are common in Europe while NEC 625 is common in North America. Society of Automotive Engineers (SAE) of United States has developed standard power connectors and defined charging power levels. The charging protocol developed by

the Japanese institute Charge De Move (CHAdeMo) is very common in high power DC charging [11].

IEC standards on EV charging define four modes of charging based on the type of power source, the voltage level, presence or absence of grounding, control lines and device protection. Type of power source can be either DC or single-phase/three-phase AC. Voltage level could be in the range of 110V single-phase to 480V three-phase if the source is AC. The four modes of EV charging are described as

- Mode 1: slow charging from a household-type socket-outlet in AC,
- Mode 2: slow charging from a household-type socket-outlet with an in-cable protection device in AC,
- Mode 3: slow or fast charging using a specific EV socket outlet with control and protection function installed in AC,
- Mode 4: fast charging using an external charger in DC.

Table 2.2: Charging Modes as per IEC standards[11]

Charging Mode	Connection	Power (kW)	Maximum Current (A)	Charger Location
Mode 1	Single phase AC	<3.7	16	On Board
Mode 2	Single of Three Phase AC	3.7-22	32	On Board
Mode 3	Three Phase AC	>22	>32	Off Board
Mode 4	DC	>22	>32	Off Board

Table 2.2 lists the charging connection and power levels as per IEC-62196 and IEC-61851.

SAE has developed standard connectors for EV charging and defined the voltage and power levels of each mode of charging. SAEJ1772 combo connector is found frequently in commercial electric vehicles. The connector could be used with AC connection or DC connection or both in the case of SAE J1772 combo connector.



Figure 2.3 : SAE J1772 Connector[12]

The combo connector is given in Figure 2.3 where both AC and DC chargers can be connected via this connector.

Table 2.3: SAE Standard for EV charging[13]

Charge Method	Nominal Supply Voltage (V)	Maximum Current (A- continuous)	Branch Circuit Breaker rating (A)
AC Level 1	120 ac, 1-phase	12	15 (minimum)
AC Level 2	208 to 240 ac, 1-phase	32	40
DC Charging	600 dc maximum	400 maximum	As required

Table 2.3 lists the charging levels and ratings of EV charging defined by SAE. Level 1 charging is called opportunity charging which is the slowest charging method. The charger cable can be connected to a standard socket outlet like to typical electrical appliance.

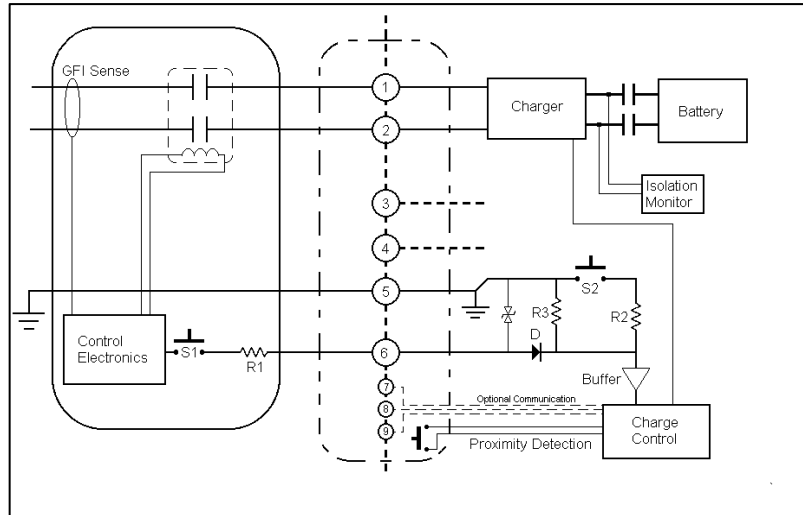


Figure 2.4: SAE Level 2 charger connection[13]

A separate connector is required for Level 2 charging. Charging port is located inside the EV and the connector cable connects the charging dock mounted in the wall and the charging port of EV. The charging dock is wired to the home electrical connection and EV charger is mounted inside the vehicle. Connection configuration of SAE level 2 charging is illustrated in Figure 2.4. In contrast, all the charging equipment in Level 3 charging is located outside the EV and charger cable connects fast DC charger and the Level 3 charging port of EV.

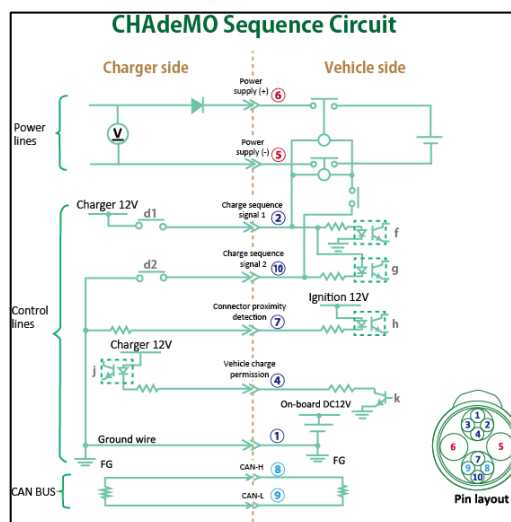


Figure 2.5 : CHAdeMo sequential circuit [14]

Japanese protocol CHAdeMO is very popular in DC fast charging. The protocol has currently enabled fast EV charging with power levels from 6kW to 200kW. The charging current is controlled by the vehicle battery management system. Fast charger controls the output current in real time according to the charging current request from the EV through CAN communication. This mechanism allows different fast charging based on battery performance and usage environment. To do so, CHAdeMO specifies the requirements for response performance, current ripple, voltage ripple, and measurement accuracy of the current and voltage. Figure 2.5 illustrates the charging circuit of CHAdeMO fast charger.

2.2.3 Charging characteristics

In order to charge the EV battery, a regulated DC supply shall be applied to the battery terminals. The regulation would be done in DC side by charge control system. Battery charging voltage and current is controlled by battery management system. From the AC input point of view, the battery is a constant power load with a current limit.

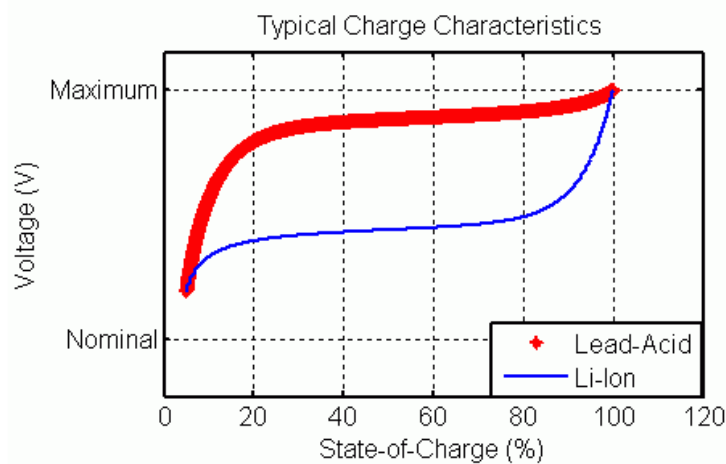


Figure 2.6 : Typical charge characteristics [15]

The charging characteristics of a battery depend on the battery technology. Typical battery charging curve consists of exponential zone and nominal zone. The exponential voltage increases when a battery is charging regardless of the battery

state of charge. When the battery is discharging, the exponential voltage decreases immediately. Nominal zone is typically above 80% of SoC in which the battery voltage is constant. Figure 2.6 shows the typical charging characteristics of Li-Ion and Lead acid battery technologies.

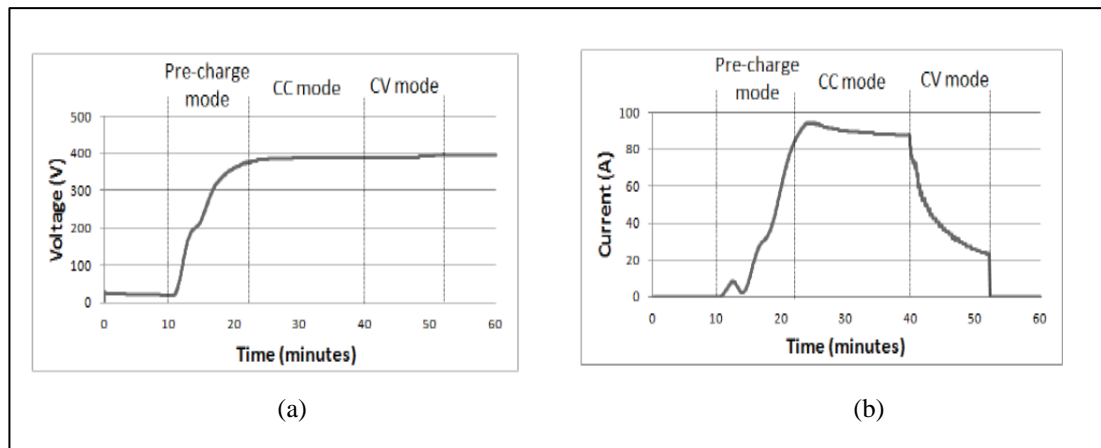


Figure 2.7: Battery Voltage and Current Profile while charging[16]

The battery management system maintains a constant current until the state of charge of the battery reaches 80% while the battery voltage is slowly increasing. This mode is called constant current mode. Once the battery capacity is reached 80%, the battery voltage is maintained at a constant value and input current is gradually decreased until the battery reaches the fully charged level. The voltage and current profile of EV battery charged by a DC fast charger is given in Figure 2.7.

2.3 Electric vehicle charger

The function of the EV charger is to convert the utility AC input to a regulated DC output. At the same time, waveform at the point of common coupling shall be maintained at desired limits. In order to achieve the aforementioned objectives, power electronic converters along with closed loop control system are equipped with an EV charger.

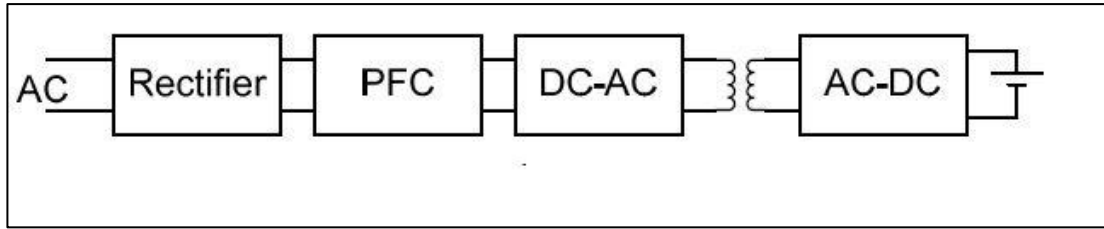


Figure 2.8: Block diagram of Level 2 charger [17]

2.3.1 Level 2 Charger

A level 2 single phase EV charger would consist of AC DC rectifier with a power factor correction (PFC) circuit and isolated DC-DC conversion circuit as depicted in Figure 2.8. The diode rectifier combined with PFC circuit rectifies the input AC voltage to a regulated intermediate dc voltage and powers up the DC link bus while maintaining the input power factor close to unity. The isolated DC-DC stage then converts the DC bus voltage to a regulated output DC voltage for charging the battery.

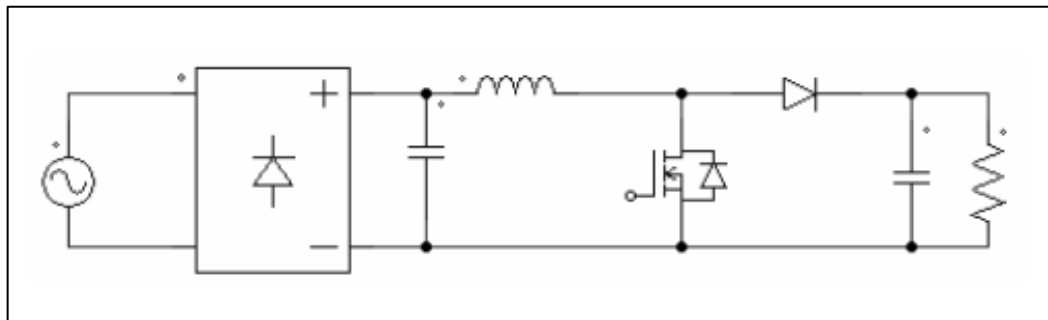


Figure 2.9: Circuit diagram of boost PFC[18]

There are two main approaches of power factor correction, namely active filters and passive filters. In passive filters, a combination of inductor and a capacitor is used while in the case of active filters, a power electronic converter is used. Adding of a inductor in charger side creates a passive filter and hence improves the input current waveform. However, the level of improvement with this method is limited. Further, higher the inductor value the bulkier the system which is not desired to an on board charger.

A DC DC converter can be used to regulate the output voltage while maintaining the input current waveform at desired level. From the available DC-DC converter topologies, boost converter is the commonly used topology in PFC circuits. The reason for the selection is that in many cases output DC voltage shall be higher than in peak of the input AC voltage [18]. The control of the boost converter takes the input voltage waveform as the reference and maintains the inductor current proportional to the same by switching the power electronic switch.

There are a number of switching algorithms for power factor correction available such as constant frequency switching, constant tolerance band switching and variable tolerance band switching. The constant frequency switching is also called peak current control method where the power electronic switch is turned on with a constant frequency and the turned off when the current reaches the reference value. The average current control or the tolerance band switching forced the inductor current to be within the defined band by switching the power electronic switch. Constant frequency switch on control is more common and it allows maintaining a good waveform quality [18].

The isolated DC-DC stage converts the output of PFC circuit to a regulated DC supply. Battery State of Charge (SoC) and the terminal voltage are the inputs to the voltage and current regulation of the converter. Charging strategy of the DC-DC converter shall be either constant voltage or constant current.

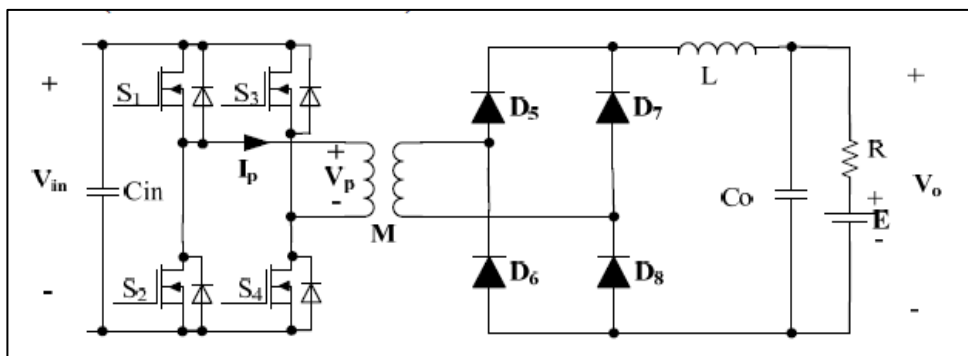


Figure 2.10: Circuit diagram of full bridge converter [17]

There are four common types of DC DCconverters used in regulated power supply applications named forward converter, flyback converter, half bridge converter and full bridge converter. Voltage spike across the semiconductors in forward and flyback circuits is excessive while negligible voltage spikes present in half and full-bridge converters. Therefore, the semiconductors in half-bridge/full-bridge based EV chargers have less voltage stress than those in forward and flyback converters. The current stress and switching loss of full bridge converters is low in full bridge converters. Despite of relatively higher cost, full bridge converters are popular in commercial EV chargers considering the operational advantages. Figure 2.10 shows the circuit diagram of an isolated full bridge DC-DC converter.

Output voltage of the converter is regulated within a narrow band of tolerance. Closed loop control system with PI controller is utilised to generate the control signals from the error between reference value and measured value. Pulse Width Modulation (PWM) is a popular technique in the control of the converter in which the compensated error is compared with the saw tooth waveform in order to determine the switching status.

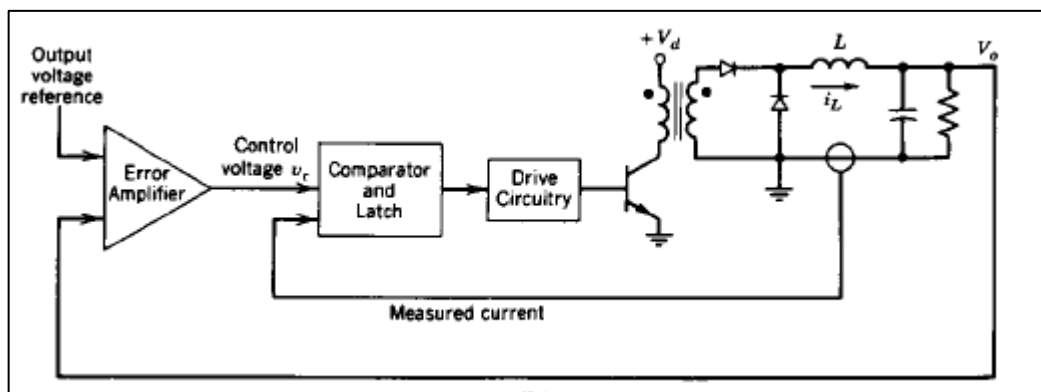


Figure 2.11: Current mode control of DC-DC converter[18]

It is required to regulate the battery current since battery terminal voltage varies with the SoC. An inner current loop would be added to the voltage error feedback system and either peak current or the average current could be employed. The inner current loop is shown in Figure 2.11. The current control methodologies are similar to the

methodologies described in section 2.3.1 and peak current control with constant frequency switch on the most common technique in DC DC converters.

2.3.2 DC fast charger

DC fast chargers are off board chargers which supplies higher voltage and current directly to the battery terminals. Since the power ratings of DC fast chargers are more than 50kW in commercial applications, the charger is typically connected to the MV feeders with a step down transformer.

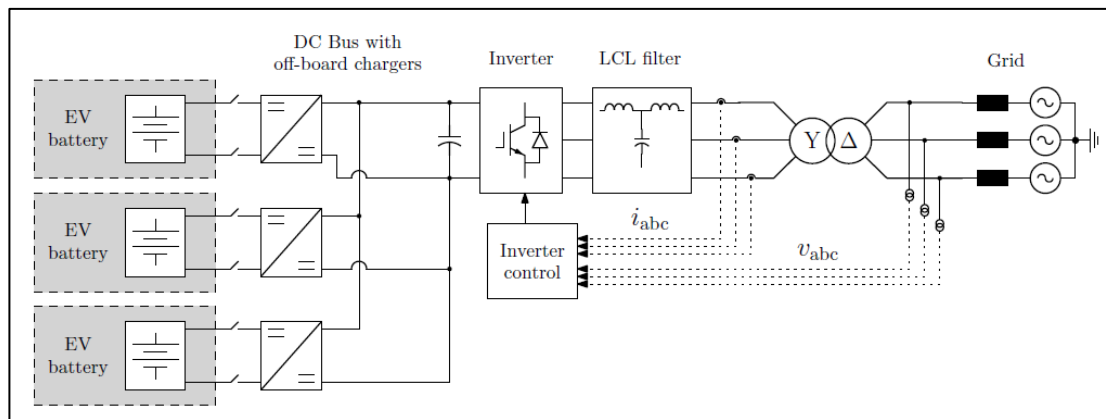


Figure 2.12: Configuration of DC fast charger [19]

Similar to a single phase on board charger, function of the DC fast charger is to provide a regulated DC voltage derived from utility AC voltage. A PWM controlled inverter is common in DC fast chargers for the AC DC conversion. A LCL filter is equipped for harmonic suppression at the point of common coupling. Passive filters are common with high capacity distributed power sources for harmonic suppression and ripple attenuation [19]. DC-DC converter controls the battery current and voltage in constant current or constant voltage mode as desired. Configuration of DC fast charger is given in Figure 2.12.

The control of the inverter is based on vector control in which synchronization of inverter voltage with the grid voltage is performed through a phase locked loop. The

controller of the inverter maintains a constant voltage at the output of the inverter while maintaining the input current waveform close to sinusoidal shape by means of an inner current loop.

2.4 Power Quality Limits

IEEE standard 519 was first introduced in 1981 to provide direction on dealing with harmonics introduced by static power converters and other nonlinear loads so that power quality problems could be averted. IEEE 519 defines three parameters with respect to harmonic distortion [20].

$$V_{THD} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots}}{V_1} \times 100\%$$

$$I_{THD} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \dots}}{I_1} \times 100\%$$

$$I_{TDD} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \dots}}{I_L} \times 100\%$$

Where;

V_{THD} – Total harmonic distortion of voltage

I_{THD} – Total harmonic distortion of current

I_{TDD} – Total demand distortion of current

V_h - rms value of h^{th} harmonic of voltage (current)

I_L – Maximum demand load current

Table 2.4: IEEE 519 limits for current harmonics[20]

Current Distortion Limits for General Distribution Systems (120 V Through 69,000 V)						
Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Where:
 I_{SC} = maximum short-circuit current at PCC.
 I_L = maximum demand load current (fundamental frequency component) at PCC.

IEEE defines that voltage THD level for a general system shall be less than 5%. The level of voltage THD on a system will be the function of the harmonic current drawn by the source and the impedance of the system. To define current distortion limits, IEEE Std 519 uses a short circuit ratio to evaluation the system impedance. The term TDD is used when the current waveform is rich of harmonics at lower currents than maximum demand current to obtain a more meaningful result. Table 2.4 lists the harmonic limits given in IEEE 519. IEEE 1000-3-X series defines the voltage unbalance limits. Unbalance factor shall be less than 2% in MV and LV systems according to IEEE-1000-3. IEEE 1159 standard defines the voltage sag or dips and recommended practices for voltage sag.

2.5 Power Quality Issues with EV charging

As described in earlier sections, with the high penetration of EVs, higher capacity power electronic load share is rising in the distribution network. If the quality of the current drawn by EVs is not within the limits set by relevant standards, this may create unsatisfactory power quality in the connection points of the other consumers

in the network. This could prevent the proper operation of the electrical equipment connected to the network including the source of supply [21].

In the literature, power quality issues of EV charging were investigated in different distribution networks. Most of the methods to determine power quality issues of Level 1 and Level 2 chargers were based on the field measurements. Power quality issues with DC fast chargers were investigated by modelling of chargers as well as by field measurements.

EV charging mainly causes voltage unbalance, voltage deviations and harmonics in the current waveform. Voltage unbalance is caused by single phase chargers. Since the current drawn by the charger is relatively high compared to conventional single phase loads, the effect is significant. Voltage deviations were caused by EV chargers due to higher currents. Since the EV chargers are equipped with power electronic converters, presence of harmonics at PCC and source may create technical issues in the distribution network.

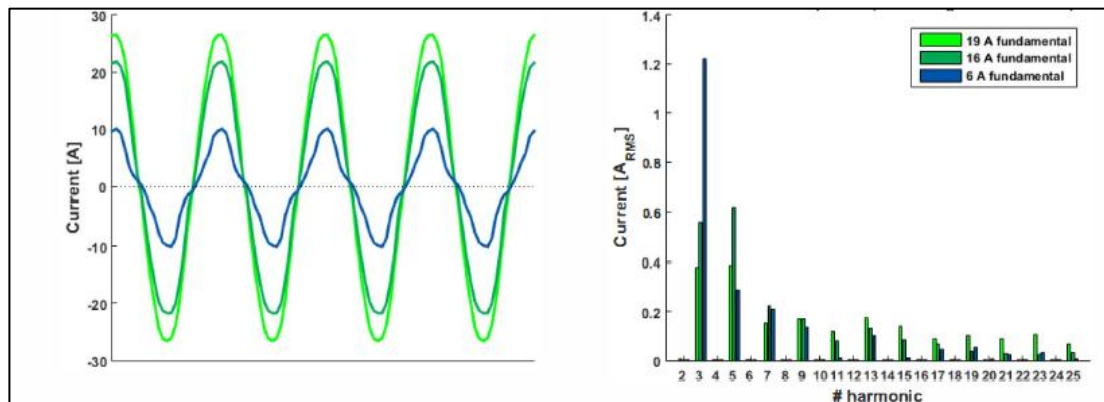


Figure 2.13: Current waveform and harmonics of Nissan Leaf charger [21]

Harmonic profile of commercially available level 2 EV charging was studied in [21]. The harmonic profile observed in [21] is illustrated in Figure 2.13. The measurements were obtained with Opel Ampra, Nissan Leaf and Tesla model S EVs. EV penetration of 30% of total load in the distribution network has caused 11% THD at the point of common coupling.

Impact of the chargers to the system due to harmonics depends on the distribution system infrastructure and charger penetration. THD with charger penetration of 40% was between 25%-30% in the case studied in [22]. The harmonic distortion and voltage deviation of slow, medium and fast chargers were studied in [23]-[24] and depending on the charger type and penetration, THD was reached to 50%. Harmonic spectrum and distortion of single phase and three phase chargers were studied in [25] and showed that individual harmonics may violate IEEE limits.

Studies on impact of network voltage deviations and voltage unbalance were studied in [26]-[29]. Voltage deviation may drop to 0.97p.u which is below the acceptable limits due to DC fast chargers. Voltage unbalance will rise more than IEEE limit of 3% when the charger penetration was increased. It is common to have solar PV systems at residential premises in present day. The charging of EV and when PV system is in operation maintained the voltage unbalance factors within the limits as per [27], however, higher penetration of EV without Solar PV generation in house has exceeded the voltage unbalance factor limits.

It was determined that power quality issues may exceed the limits when the charger penetration is increased. It is important to determine the allowable charger penetration for the existing distribution network in order to maintain the power quality parameters within the prescribed limits.

2.6 Distribution system analysis

Distribution systems shall be simulated analysed with the computer simulation tools and software such as Matlab, DigiSilent, OpenDSS, PSCAD. In order to examine the behaviour of a distribution system when the EV chargers are connected, the distribution system shall be modelled in suitable software. In order to compare and validate results obtained from different tools, IEEE has introduced standard test

feeders [30]. These test feeders are radial and all the source, line and load data is available for modelling [31]. These test feeders are ideal platform to derive generalised result of a distribution system under the considered case.

CHAPTER 3. METHODOLOGY

Two approaches were used for the study of power quality impacts from electrical vehicle charging in distribution networks in the literature. Field measurement approach was used for Level 1 and Level 2 chargers and simulation approach was used for DC fast chargers.

Level 1 and Level 2 chargers are typically connected to the LV feeders. Voltage unbalance, voltage deviations and harmonics impacts were determined by analysing the data obtained from the feeders with EV chargers connected[21]-[23]. Several distribution system analysis software tools were used for voltage unbalance and voltage deviation effects. In such studies chargers were considered as constant PQ loads.

Power electronic models of EV chargers were used in order to study the power quality impacts of DC fast chargers on MV distribution networks, [24]-[28]. Field measurements were used for validation. EV charger was considered as a constant PQ load for voltage unbalance and voltage deviations studies while the detailed model was used for harmonic analysis.

The methodology for the research was determined considering the research gap, absence of comprehensive current harmonic analysis in LV distribution feeders identified in the literature. In this study, a commonly available electric vehicle charger was modelled in Matlab environment to study the harmonic emission of the charger. The charger model consists of power electronic converters, active power factor correction circuit and charge control mechanism. The model was validated with the current harmonic measurement of actual charger connected to a LV distribution feeder.

Power quality impact of EV charging to the distribution system was studied with the developed model. A standard test feeder developed by IEEE was used for the study. Allowable limits of EV penetration at the present level of distribution infrastructure were determined from the results obtained.

CHAPTER 4. MODELLING OF ELECTRIC VEHICLE CHARGER

In order to determine the harmonic impact of EV charging to the distribution network, accurate harmonic model of an EV charger is required. To fulfil this requirement, a commercially available charger was modelled in MATLAB environment taking the necessary aspects of an EV charger in to consideration. The waveforms were analysed and the model was validated with the measurements of an actual charger.

Depending of the charger power level and applicable international standard described in Chapter 2, the configuration of EV charger varies. For the study consideration, a most common type of charger has been considered. In this case, Level 2 charger available in Nissan Leaf with 6.6kW capacity complies with SAE J1772 standard was modelled in order to study harmonic issues.

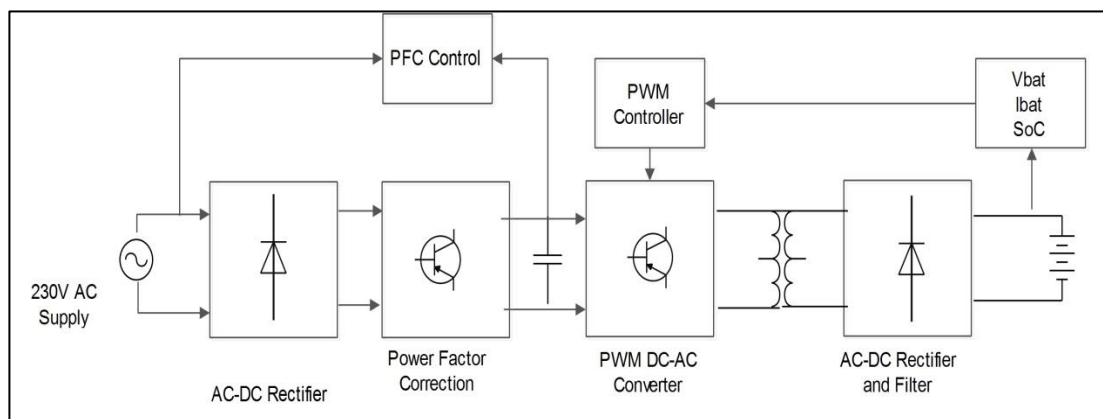


Figure 4.1: Block diagram of 6.6kW single phase EV charger model

The model for the EV charger would essentially include AC-DC converters with applicable controls, battery system along with battery charging control mechanism. The charging control system measures the battery status and controls the charging voltage and current in the desired mode, either constant current mode or constant voltage mode. Modern EV chargers are equipped with active power factor correction

circuit to maintain the desired distortion limits of current and voltage at the point of common coupling. Figure 4.1 shows the block diagram of the 6.6kW single phase EV charger available in a Nissan Leaf.

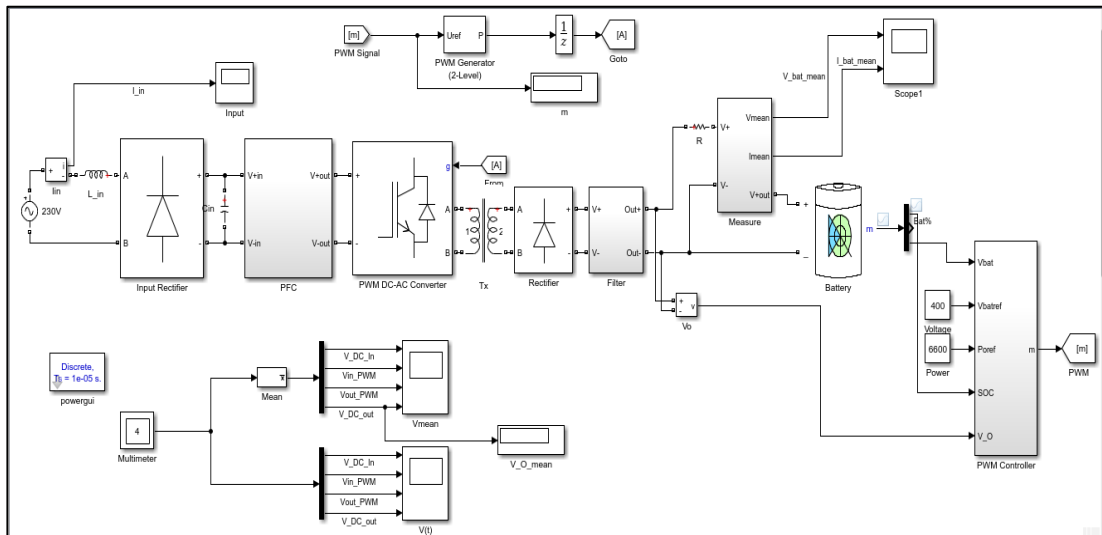


Figure 4.2: Matlab model of EV charger

The system was modelled in Matlab Simulink interface. The developed model is given in Figure 4.2.

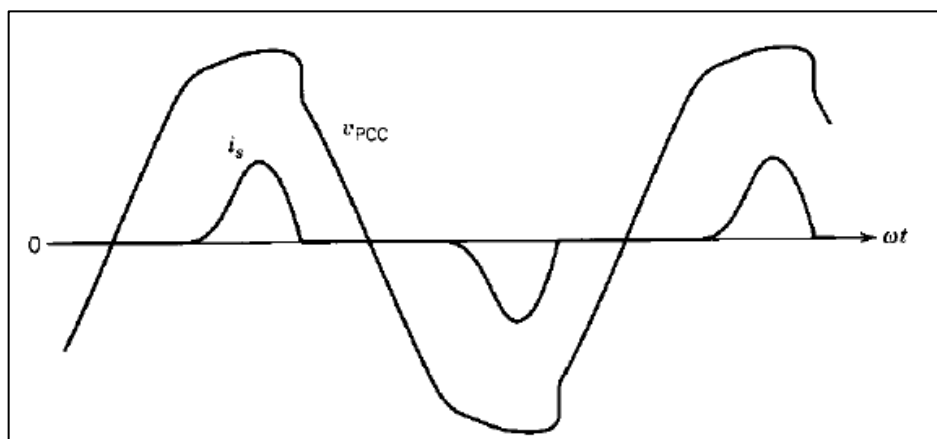


Figure 4.3: Input current waveform of rectifier without p.f. correction[18]

4.1 Input Rectifier and Power factor correction

Power supply for the EV charger is 230V, 50Hz single phase utility AC supply. The supply voltage is converted to DC voltage using a diode rectifier. It is desired to maintain a constant DC voltage with minimum ripples at the rectified end. The conventional way to maintain a constant rectifier output voltage is to use a filter capacitor in the DC side. However, presence of the filter capacitor highly distorts the input current and the total harmonic distortion (THD) may rise to even 90% [18]. The distorted input current waveform of a diode rectifier is shown in Figure 4.3.

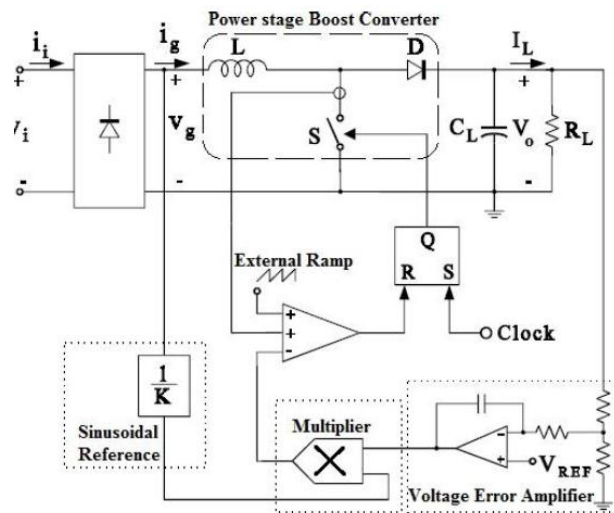


Figure 4.4: Circuit and Control Diagram of Power factor correction[32]

In order to reduce the distortions of the input current waveform, active power factor correction circuit is equipped with the modern EV chargers. Figure 4.4 illustrates the circuit diagram of a power factor correction circuit.

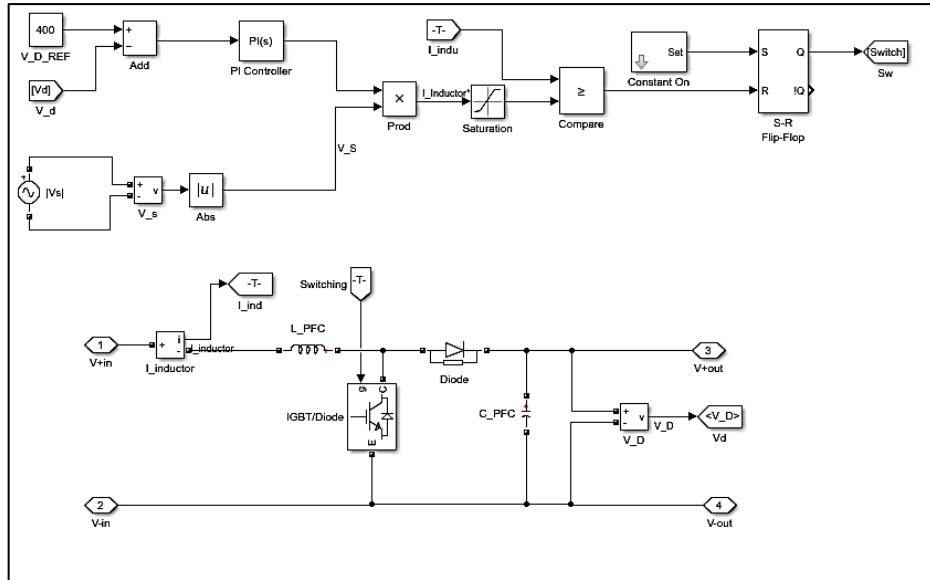


Figure 4.5: Matlab model of power factor correction

The circuit was modelled in Matlab interface to achieve a power factor close to unity in the EV charger model hence the distortions of the input current waveform is minimised. The developed model is illustrated in Figure 4.5.

In this model, the absolute value of the input AC voltage waveform was taken as the reference shape of the inductor current waveform. Thus a sinusoidal waveform with 50Hz frequency and peak amplitude of one with zero degree phase angle was taken as the reference inductor current waveform. The output voltage of the circuit needs to be maintained at a constant value, thus a reference with constant magnitude was used in the outer voltage control loop. The error between constant reference and actual output was fed to the PI controller to generate the control signal.

The multiplication of control signal and the reference waveform provides the reference current waveform of the inductor in the PFC circuit. Thus, the IGBT in the converter is switched to maintain the desired current waveform through the inductor. Constant frequency switch on method was used as the switching approach in which the IGBT is switched on at constant time intervals and switches off whenever the current reaches the set value. A SR flip flop was employed for the switching. Since the inductor in PFC circuit is in series with input diode rectifier, the input current of

the converter circuit is maintained at the desired waveform shape while keeping the output voltage at a constant value.

4.2 Battery Model

A generic battery model is available in the Matlab interface. The model supports for commonly available battery technologies such as Li-Ion, Ni-Cd and Lead Acid. The internal resistance is assumed to be constant during the charge and discharge cycles and does not vary with the amplitude of the current. Further the parameters of the model were derived from discharge characteristics. The capacity of the battery does not change with the amplitude of current. The model does not represent the self-discharge of the battery and the battery has no memory effect.

Battery model outputs the terminal voltage, battery current and SoC. The equation used to calculate the SoC is;

$$SoC = 100 \left(1 - \frac{1}{Q} \int_0^t i(t) dt \right)$$

4.3 PWM Controller

Full bridge DC-DC converter with isolation transformer was used to provide the regulated DC current for battery charging. PWM modulator available in Matlab interface along with a PI controller was used for the control of the voltage and current of the battery.

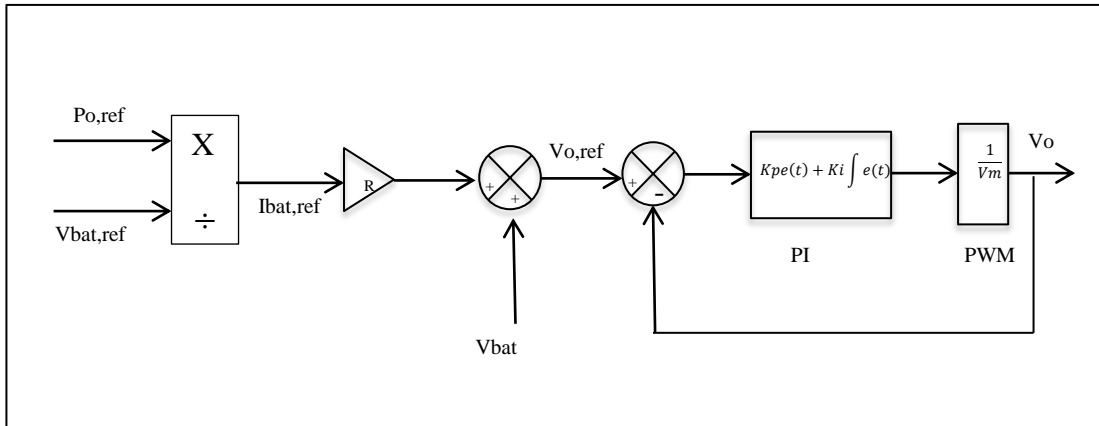


Figure 4.6 - Controller block diagram of Current mode controller

In this case, charger rated power and battery rated voltage was taken as constant values. With those values, battery reference current was calculated. By multiplying the impedance of the circuit, the voltage drop between the converter and the battery was obtained and by adding the battery terminal voltage, reference value of the converter was obtained. The controller is closed loop thus the actual output voltage is fed to the controller to generate the error signal. The block diagram of the controller in current control mode is given in Figure 4.6.

Table 4.1: Converter parameters

Parameter	Value
Charger rated power:	6.6kW
Battery rated voltage:	400V
Battery rated current:	16.5A
Proportional gain:	0.0001
Integral gain:	0.1
Modulation frequency:	1.5kHz
Filter inductance:	1mH
Filter capacitance:	5 μ F

Control signal was generated by the PI controlled compensating the error. The output of PI controller was fed to the PWM modulator to obtain the output voltage. Inbuilt PWM block of Matlab interface was used for the modulation where unipolar

modulation was employed to have a better output waveform. Output LC filter is employed to smooth the output. The parameters of the DC-DC converter are listed in Table 4.1.

4.4 Analysis of waveform

The Matlab model was used to analyse the input and output characteristics of the battery charger. The charger model shall maintain a constant battery current while charging and the input current waveform shall be in phase with voltage waveform.

4.4.1 Input waveforms

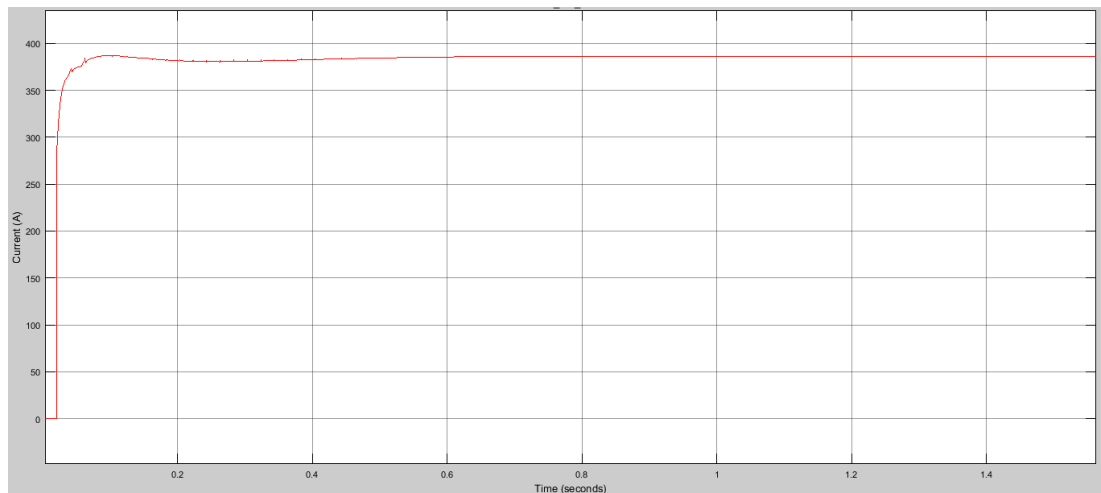


Figure 4.7: Output current waveform of PFC

Figure 4.7 shows the output waveform of power factor correction circuit. The output voltage was set to 400V to match the battery requirement. The diode rectifier converts the input AC voltage to a DC voltage. The boost converter in PFC circuit steps up the input DC voltage while maintaining the desired waveform at the input. The PI controller was tuned to obtain the best possible waveform. It can be observed that the settling time is close to 350ms and overshoot is only 5%.

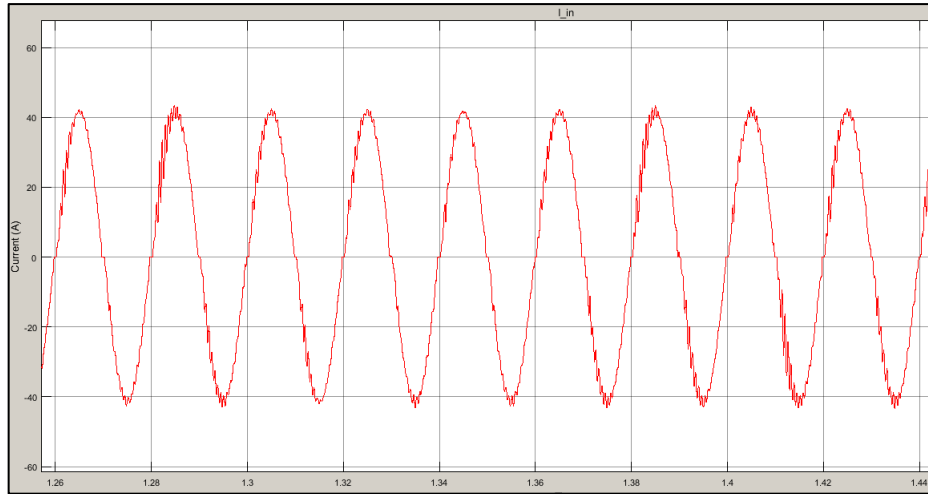


Figure 4.8: Input current of charger model

Figure 4.8 shows the input current waveform of the charger. It can be observed that the input current is sinusoidal with phase angle of zero. Also the distortions in the current waveform are significantly low. Harmonic analysis of the waveform is given in the latter sections.

4.4.2 Output waveforms

The purpose of the isolated DC-DC converter is to provide a constant current to the battery. When the battery is charging, the terminal voltage of the battery increases and hence the current shall be regulated taking the battery terminal voltage as an input.

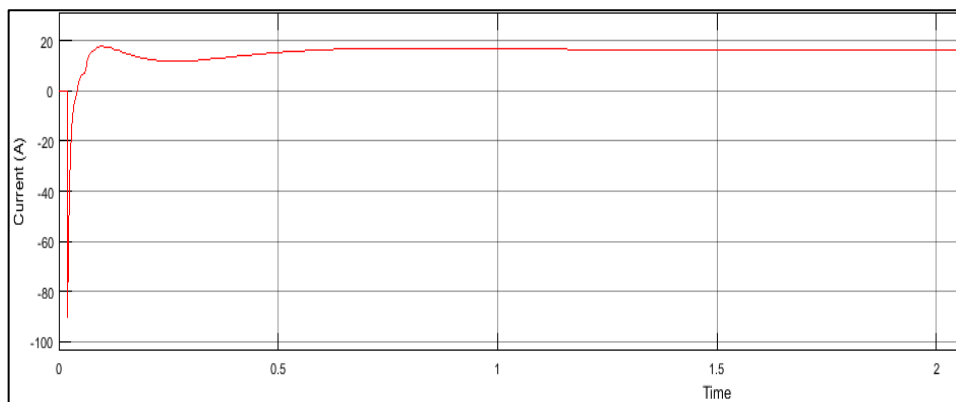


Figure 4.9: Battery Current waveform

Battery current waveform is shown in Figure 4.9. It can be observed that current settles to its set value of 16.5A in 650ms.

4.5 Harmonic analysis

Fast Fourier Transform (FFT) tool in Matlab powergui block was used to analyse the harmonics of the input current waveform. The analysis provides the amplitude of each harmonic as a percentage of fundamental.

Table 4.2: Harmonic spectrum of modeled charger

Harmonic Number	Amplitude
1	100%
3	2.75%
5	1.40%
7	1.11%
9	0.93%
11	0.86%
13	0.74%
15	0.71%
17	0.59%
19	0.41%

Figure 4.10 shows the output of the FFT tool in Matlab. It can be observed that odd harmonics are present since the waveform shape is sinusoidal. Up to the 19th harmonic is shown in the current waveform. The total harmonic distortion of the current waveform is 6.33%. Table 4.3 lists the individual current harmonic values of modelled charger.

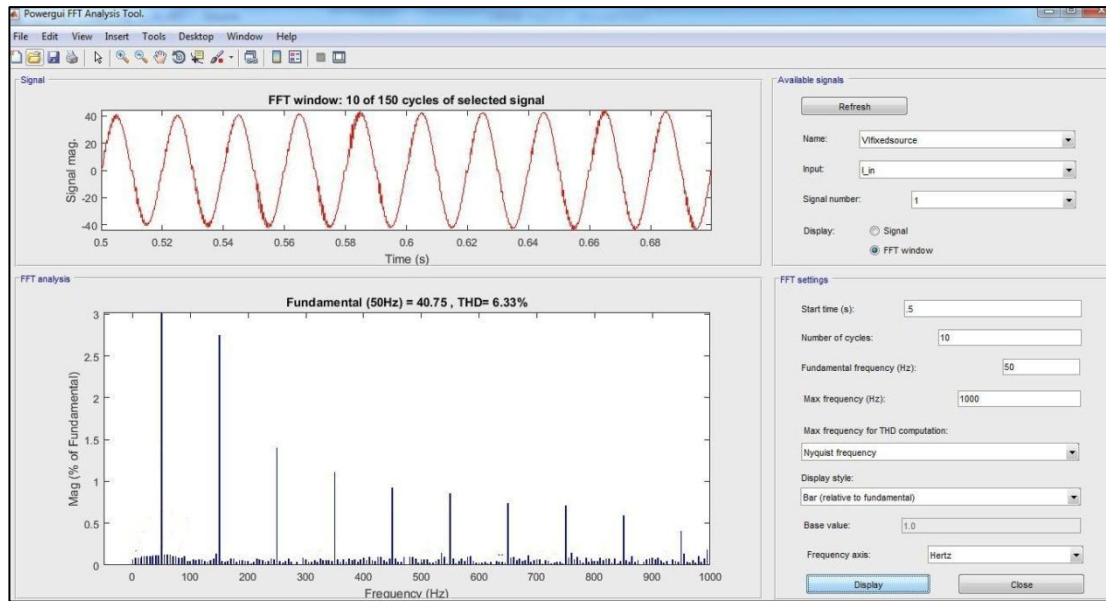


Figure 4.10: FFT Analysis of input current waveform

4.6 Validation of the model

In order to use the developed model for distribution system analysis, it is important to validate the model to ensure that the model behaves in a similar way to an actual charger. The validation was done using a field measurements of charging characteristics of Nissan leaf Level 2 on-board 3.3kW charger.

The measurements were taken using a Yokogawa CW240 clamp on power meter. The power meter is capable of measure and recording of up to 50th voltage and current harmonics. Charging current waveform of Nissan Leaf battery from the state of charge of 30% for eight hours was recorded with the power meter. The measurement interval was two minutes. Part of the data recorded was given in Appendix 1.

Table 4.3 illustrates the comparison of the amplitude of the individual harmonics and THD. The power meter showed up to 11th harmonic as significant harmonic components. It can be observed that individual harmonics in both cases follows a similar pattern.

Table 4.3: Harmonic spectrum comparison

Harmonic Number	Measured value (%)	Matlab model value (%)
1	100	100
3	3.46	2.75
5	2.12	1.4
7	2.01	1.11
9	1.57	0.93
11	0.98	0.77
THD (%)	4.89	3.49

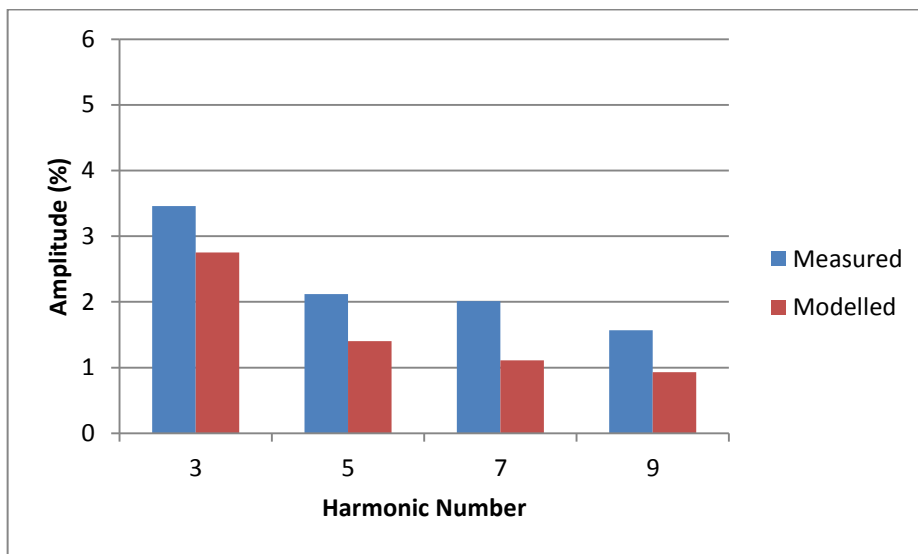


Figure 4.11: Harmonic spectrum comparison

Figure 4.11 shows the graphical representation of individual harmonics. It can be observed that the significant harmonic numbers are same in both cases and their amplitude as a percentage of fundamental component are in a closer range. The modelled charger shows a better waveform than actual value as expected. Also the THD values are very close. Thus, it can be concluded that modelled charger shows a similar behaviour as of an actual charger.

CHAPTER 5. STUDY OF THE IMPACT OF EV CHARGER ON DISTRIBUTION SYSTEM

With the gaining popularity of EV among the residential users, the amount of non-linear loads continuous to be increased in the residential distribution networks. As discussed in previous sections, the EV charging is a new type of load in residential networks in which higher capacity power electronic converters are used. Since these loads inherently give rise to the power quality issues, it is important to determine the EV penetration level that can be absorbed to the present network without violating safe limits. It further paves the way to the distribution system planners to identify when the improvement is required to the present network.

It was observed in the literature that some of the power quality issues were studied and quantified by taking the measurements of the feeders. Some of the studies were carried out by modelling the distribution feeders in a suitable simulation platform and considering the EV charger as an available load model depending on the parameter studied in the research. For instance, for voltage unbalance studies the EV charger was considered as a constant load while for harmonic studies the same was considered as a harmonic source.

It is required to have an accurate model that represents an actual EV charger with a higher margin of confidence for power quality analysis. Such detailed model would increase the accuracy of the study. Thus, the developed model as described in Chapter 3 was used for the studies to determine the allowable EV penetration in the distribution network. Harmonic distortion and propagation in the LV distribution feeders were studied and presented in this section.

5.1 IEEE LV Distribution Feeder

In order to study the power quality or any other parameter of a distribution network, distribution feeder shall be modelled in a suitable simulation environment. All the parameters in the distribution system such as source data, transformer data, line data and load data shall be available for modelling. Depending on the system and the

location, these parameters would vary. Hence the results obtained from different systems in a research or study would be difficult to compare.

IEEE Power and Energy Society have developed standard test feeders to study the distribution networks. These test feeders provides all the data required for modelling and analysis of distribution feeders. Both MV and LV test feeders with different number of nodes are available. Most of the test feeders are based on North American systems. However it is common outside of North America to have low-voltage radial and meshed distribution systems. It is important to make sure that tools support both dominant styles of distribution system configurations. IEEE LV test feeder is a test case seeks to fill a benchmark gap by presenting a number of common low-voltage configurations.

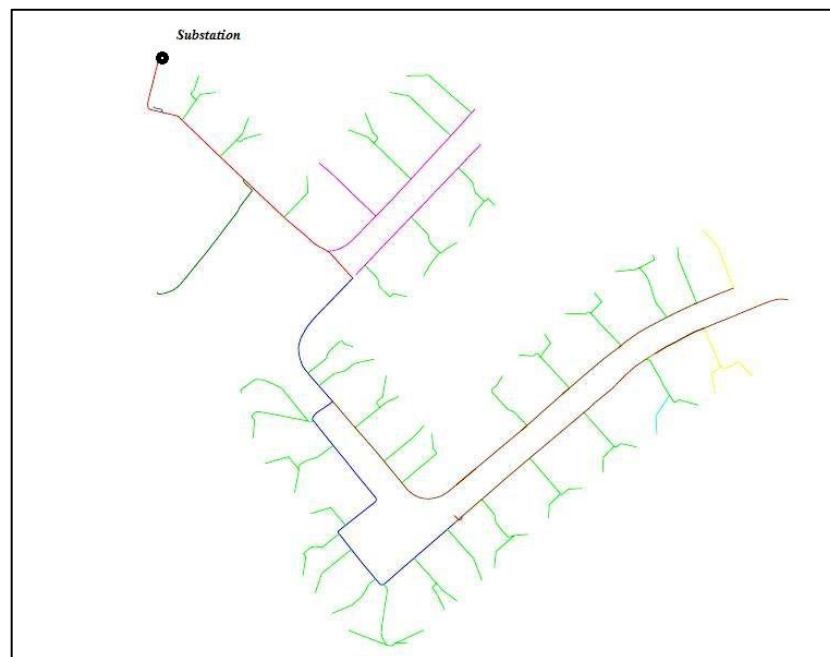


Figure 5.1: IEEE LV Test Feeder

The IEEE LV test feeder is a 416V, 50Hz radial distribution feeder. This feeder is based on an actual feeder in England. Voltage of MV source is 11kV. The three phase transformer at the substation has a rated MVA of 0.8, rated voltages of 11/.416 kV and a delta/grounded-wye connection. The feeder is given in the Figure 5.1 with different line segments represented in different colours and loads are connected at the end of the lines. It was observed that the parameters of the system closely resemble

the distribution network in Sri Lanka. Thus IEEE LV test feeder was chosen for the power quality study in the research.

Table 5.1: IEEE Test Feeder Parameters [31]

Parameter	Value
Source Voltage Base	11kV
Source Voltage	1.05p.u
Transformer Primary Voltage	11kV
Transformer Secondary Voltage	416V
Transformer Capacity	0.8MVA
Transformer Reactance (X) - referred to primary	4%
Transformer Resistance (R) - referred to primary	0.4%
Number of Loads	55
Nominal Demand	329kW
Off Peak Demand	55kW
Short Circuit Current at Bus 1	25kA

Main parameters of the test feeder is summarised in Table 5.1 and complete data set is given in Appendix 2. The distribution feeder was modelled in the Matlab Simulink environment and by connecting the charger models with different considered scenarios the power quality impacts were studied. The ratio I_{SC}/I_L is between 50 and 100 in the cases considered thus the relevant limits of harmonics and TDD given in IEEE 519 were applied.

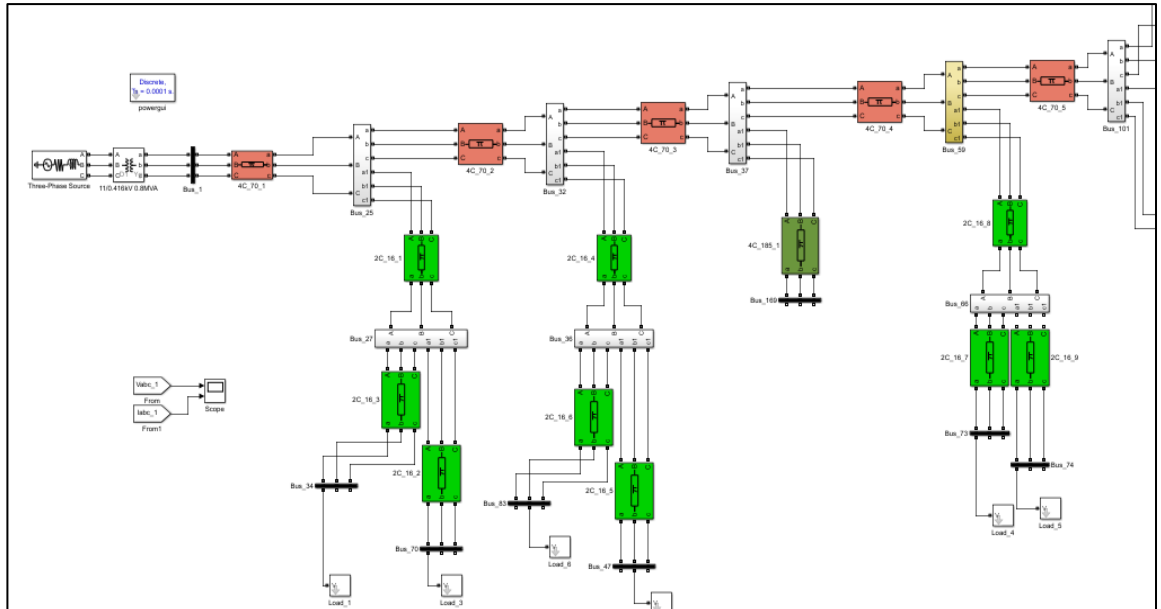


Figure 5.2: Part of the Matlab model of the distribution feeder

The test feeder was modelled and analysed in Matlab environment. Part of the test feeder Matlab model is given in Figure 5.2. The developed model includes three phase source, step down transformer, line segments, non EV loads and EV loads. The three phase source and step down transformer were included by means of standard Matlab library models to the model with the IEEE defined parameters.

IEEE test feeder data set defines the nodes and the impedance parameters of line segments between nodes. The line segments were considered as Pi sections with corresponding impedance values. Distribution system was considered as a three wire system and each single phase load was grounded at the load point.

The feeder consists of fifty five number of non EV loads. All the loads are single phase loads and considered to be constant PQ loads with a power factor of 0.95. Distribution of loads among the phases was given in the feeder data list and loads were connected to the feeder accordingly. The developed charger model was connected to the feeder as EV load with the required penetration and distribution as described in latter parts of this section.

The analysis of charging was considered in two cases; EV charging at nominal load and EV charging at off peak loads. Harmonic analysis in each case for different EV penetration was considered. It was observed that harmonics in the voltage waveform is not significant thus harmonics in the current waveform was analysed in each case.

5.2 EV Charging at Nominal Load

EV chargers were connected to the feeder while the feeder is at nominal load of 329kW. The loads are unbalanced and the loads in phase A, B and C are 112kW, 128kW and 89kW respectively. The current harmonic analysis and propagation were carried out by varying the penetration as well as the spatial distribution of the chargers.

The chargers were connected at random nodes, front nodes and end nodes separately and the impact of charging to the source as well as PCC was considered. The chargers were equally distributed in the phases. FFT tool available in Matlab Simulink was employed to analysis the harmonics in the current waveform.

5.2.1 Case 1: 10% Penetration of EV Chargers

Total load of the feeder is 329kW. Thus six EV chargers each with 6.6kW capacity were connected to the feeder to obtain the desired penetration level. The chargers were connected to the feeder with the following scenarios.

1. Chargers connected to random nodes
2. All the chargers connected to nodes closest to the source
3. All the chargers are connected to the nodes furthest to the source

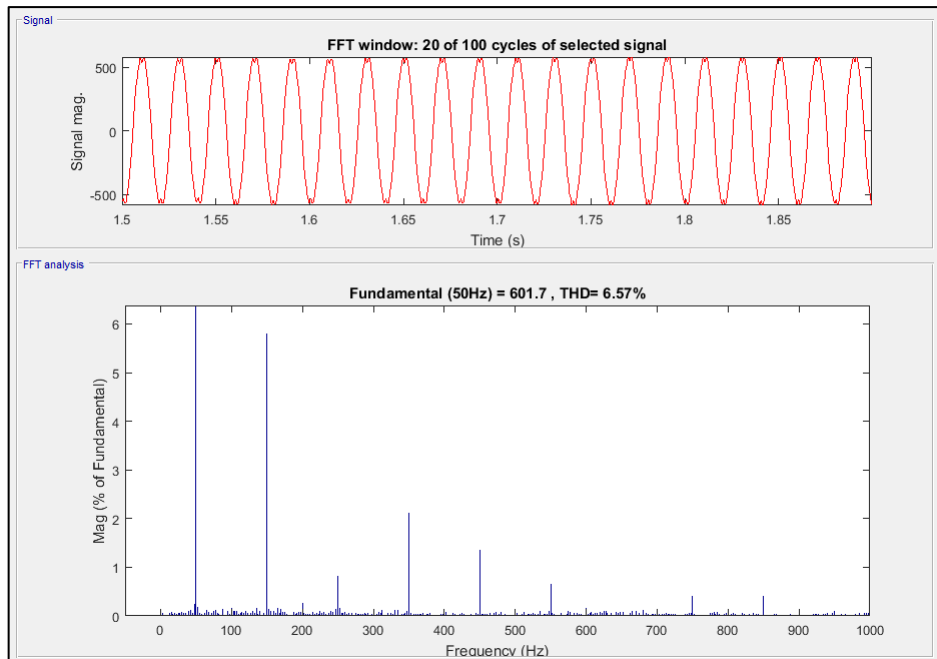


Figure 5.3: Harmonic Spectrum at Source- Case 1 - Random nodes

The total demand distortion and the magnitude of the individual harmonics were studied in this case. First part of the case 01 studied the harmonic spectrum when the chargers are connected to the feeder arbitrary manner. Six EV chargers were connected thus accounting approximately 10% of total load of the feeder. The harmonic profile once the charging current is settled at the set value was taken.

Figure 5.3 shows the harmonic spectrum of phase B current at the source when six EVs were connected at random nodes. Odd harmonics were present in the waveform and TDD is 6.44% which is within the prescribed limits.

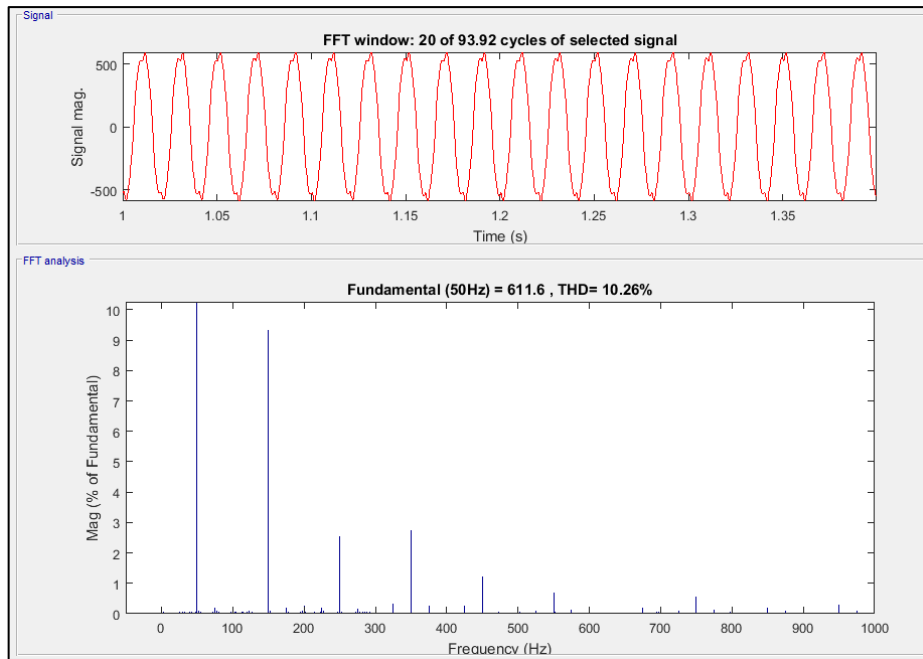


Figure 5.4: Harmonic spectrum at source- Case 1 - Front nodes

The results for other two scenarios of case 1 were obtained. Figure 5.4 illustrates the current waveform of phase B at the source and the FFT of source current waveform when the six chargers were connected to the feeder to the closest nodes. Individual harmonics are given in Table 5.2. The current waveform at the source and FFT analysis when all the EV chargers were connected to furthest nodes of the feeder is given in Figure 5.5.

It can be observed that the depending on the place of connection, the level of harmonic distortion vary at the source. When the harmonic emitting loads are very much close to the transformer or the source, higher THD was present at the source. The current waveform was dominated by 3rd, 5th, 7th and 9th harmonics.

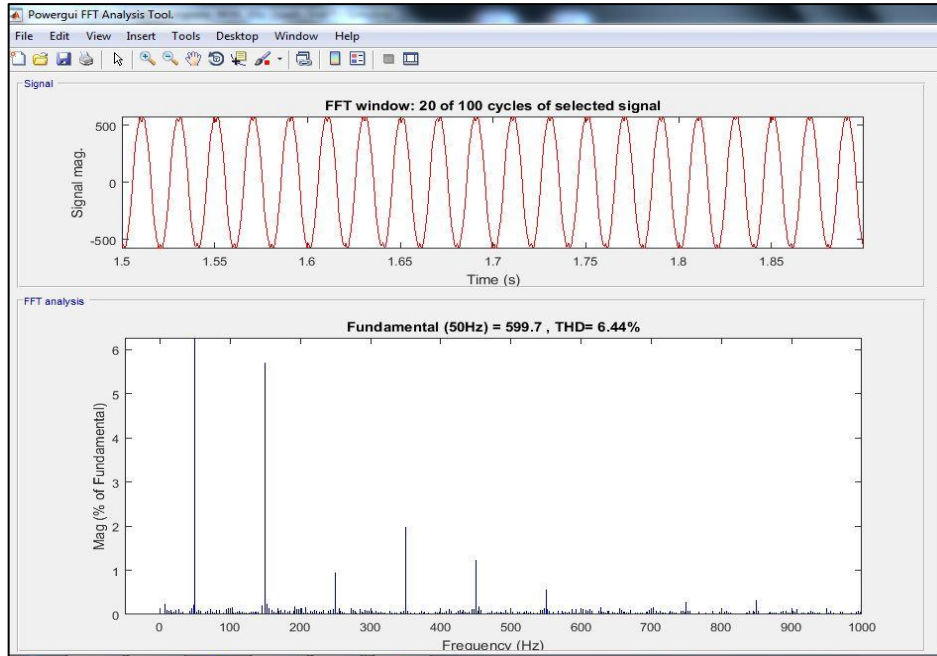


Figure 5.5: Harmonic spectrum at Source - Case 1 - End Nodes

Impact to the source or the transformer is highest when the EVs are connected close to the source. When the EVs are connected to the furthest nodes the impact to the source is comparatively lower. Individual harmonic values are within the IEEE 519 prescribed limits. TDD values of each case are also within the limits defined in IEEE 519.

Table 5.2: Individual harmonics in Case 1

	Random	Front	End
Harmonic Number	Value (%)	Value (%)	Value (%)
1	100	100	100
3	5.80	9.33	5.76
5	0.82	2.56	1.05
7	2.11	2.76	2.15
9	1.36	1.23	1.24
11	0.65	0.71	0.39
13	0.30	0.48	0.20
15	0.41	0.55	0.13
17	0.42	0.20	0.16
19	0.10	0.31	0.18
THD	6.57	10.26	6.44

5.2.2 Impact on Other Loads

Table 5.3: Individual harmonics at PCC - Case 1

Case	Random	Front	End
PCC	Bus 127	Bus 101	Bus 280
Harmonic Number	Value (%)	Value (%)	Value (%)
1	100	100	100
3	4.71	3.90	10.48
5	8.80	0.88	3.55
7	3.70	0.84	2.89
9	6.02	0.35	1.25
11	1.12	0.20	0.64
13	1.04	0.08	0.18
15	0.64	0.14	0.16
17	1.28	0.08	0.68
19	1.61	0.05	0.46
THD	13.03	4.14	12.05

Loads connected to the feeder are comprised of both EV loads and non EV loads. Thus, an EV charger shall maintain an acceptable quality in the current waveform at the point of common coupling. When the EVs are connected to random nodes, PCC can be considered to be the closest node where a non EV load is connected. In the other two cases the EVs are clustered together hence a common node where all the other loads are connected can be considered as the PCC.

Bus 127 provides a generalised PCC for the case of EV chargers were connected to random nodes. EV charger was connected to the phase C and conventional loads were connected to the phase C nodes starting from Bus 127. Table 5.3 lists the harmonic values at PCC for each case. The THD value at the Bus 127 was marginally on the higher side compared with IEEE limit, 13.03% of THD was present at the bus. Individual harmonics at the bus were lower than 10% in magnitude.

5.2.3 Case 2: 20% Penetration of EV Chargers

In this case 12 EV chargers were connected to the distribution feeder. The contribution to the total load by the chargers is around 20%. Harmonic profile of EV charging was considered in three configurations similar to case 1.

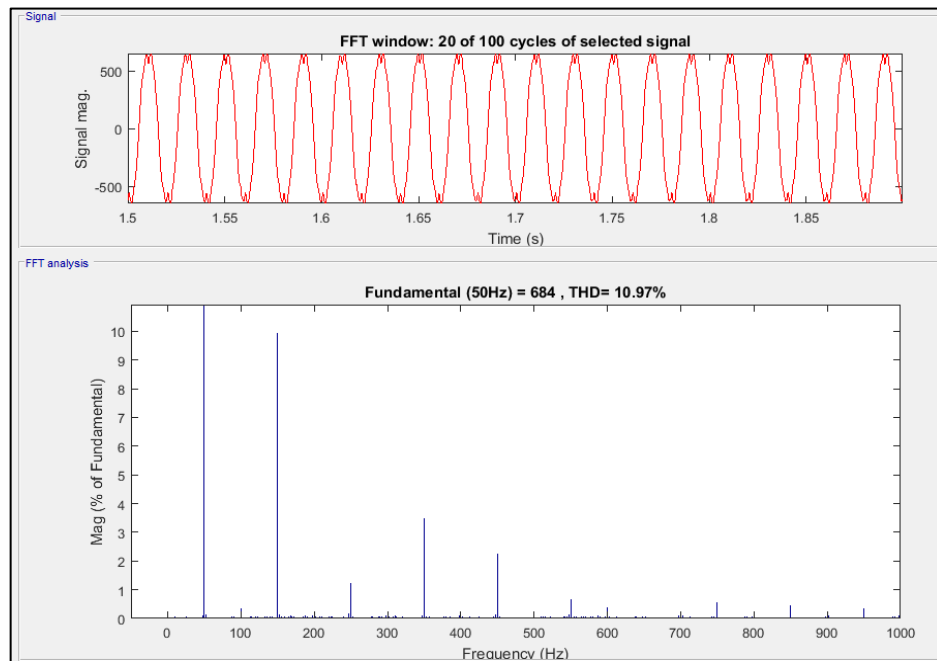


Figure 5.6: Harmonic spectrum at source - Case 2 - Random nodes

The increase of EV penetration has increased the harmonic distortion. Figure 5.6 presents the harmonic profile at the source when 12 EV chargers were connected to random nodes. THD value at this case increased to 10.97%.

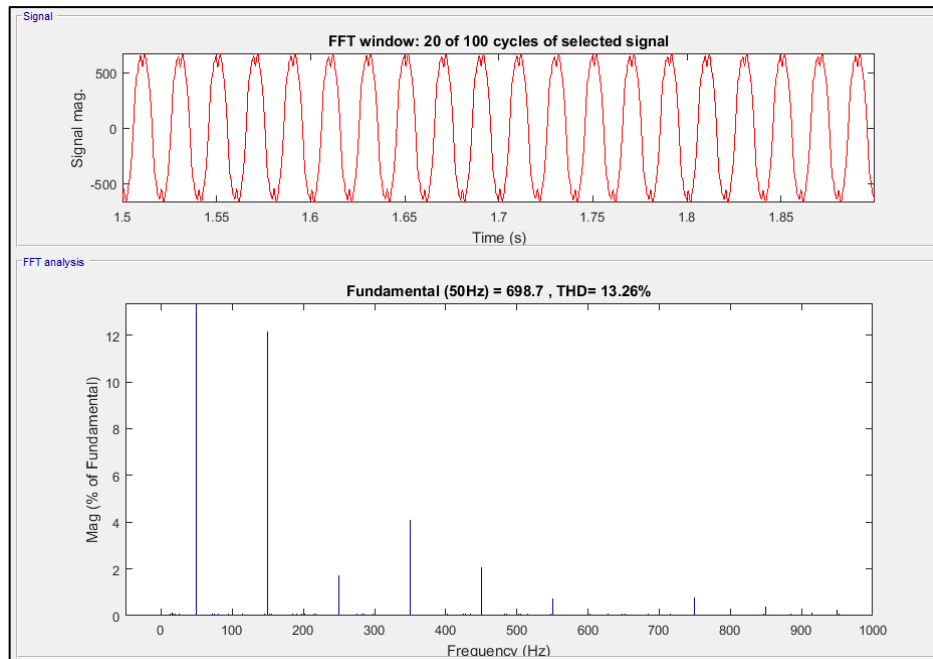


Figure 5.7 : Harmonic spectrum at source - Case 2 - Front nodes

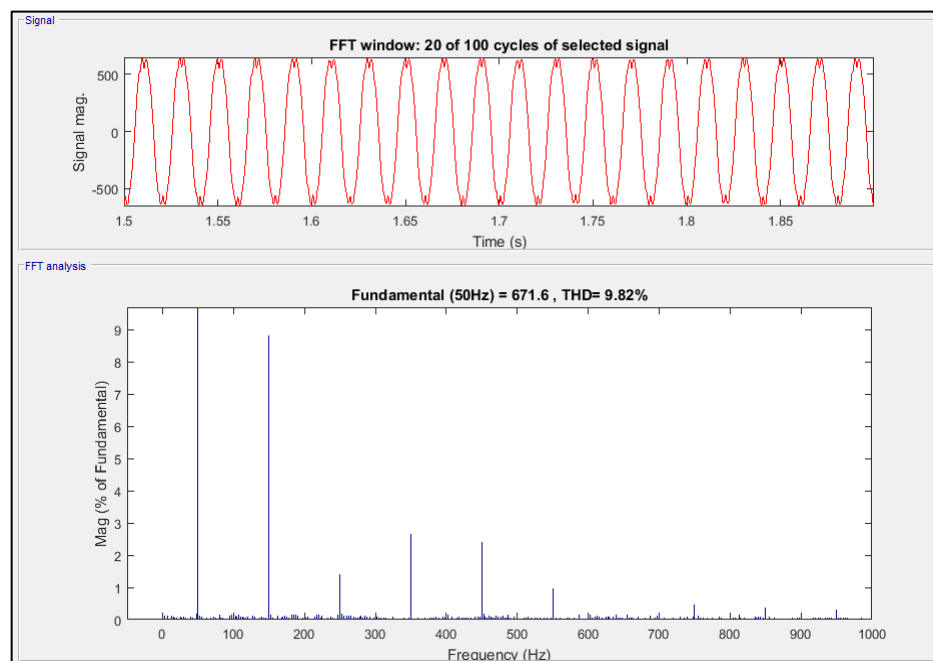


Figure 5.8 : Harmonic spectrum at source - Case 2 - End nodes

The results obtained in case 2 is consistent with case 1 as illustrated in Figure 5.7 and Figure 5.8. The impact to the source is highest when the chargers are closer to the source while the EV chargers at the end nodes pose less impact to the source. When the chargers are at the front nodes, TDD has risen to 13.03%.

Table 5.4: Individual harmonics in Case 2

	Random	Front	End
Harmonic Number	Value (%)	Value (%)	Value (%)
1	100	100	100
3	9.94	12.15	8.82
5	1.23	1.71	1.40
7	3.48	4.09	2.65
9	2.24	2.08	2.40
11	0.69	0.75	0.98
13	0.45	1.24	0.61
15	0.55	0.79	0.45
17	0.45	0.39	0.37
19	0.35	0.27	0.31
THD	10.97	13.26	9.82

Table 5.4 lists the amplitude of individual harmonics as a percentage of fundamental for each case. Third harmonic was most significant while up to eleventh odd harmonic values were considerable.

5.2.4 Impact on other loads

Table 5.5 : Individual harmonics at PCC - Case 2

Case	Front	End
PCC	Bus 114	Bus 280
Harmonic Number	Value (%)	Value (%)
1	100	100
3	5.52	12.66
5	1.00	1.96
7	2.10	3.64
9	1.43	3.24
11	0.57	1.33
13	1.20	0.82
15	0.74	0.62
17	0.64	0.50
19	0.75	0.41
THD	6.52	13.98

Table 5.5 lists the individual harmonics at PCC for case 2. When the chargers were connected to the front nodes, the closest node where other non EV loads are connected is Bus 114. Similarly, Bus 280 can be considered as the PCC when the loads were connected to the end nodes. When the chargers were at end nodes, THD was 13.98% which exceeds the IEEE 519 limits. The maximum allowable value for third harmonic is 10%, however, exceeded at this case even though other harmonics were well within the limits. Harmonic values and THD were within the limits when the chargers are connected at front nodes.

5.2.5 Case 3: 30% Penetration of EV Chargers

In case 3, eighteen EVs were connected to the feeder. Contribution of the EV chargers to the total load is close to 30%. Chargers were connected with three configurations similar to previous cases and the harmonic profile was studied.

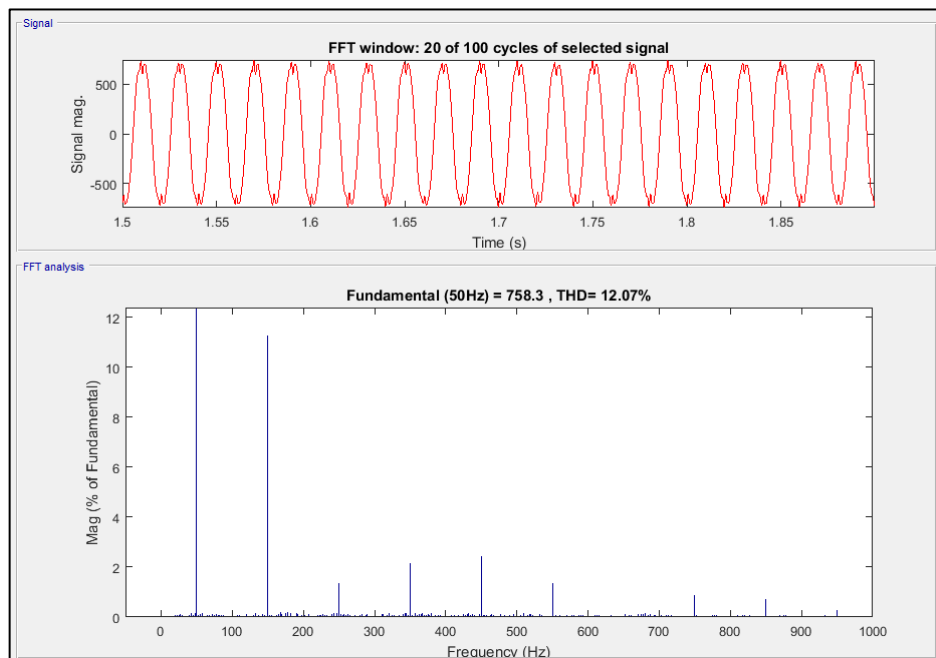


Figure 5.9: Harmonic spectrum at source - Case 3- Random nodes

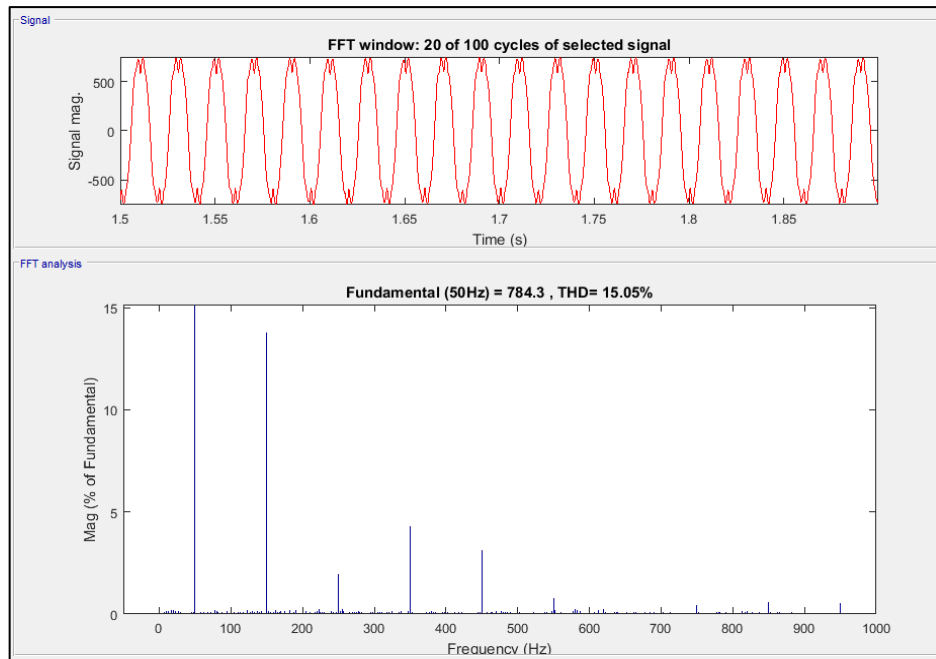


Figure 5.10: Harmonic spectrum at source - Case 3 - Front nodes

Figure 5.9 and Figure 5.10 illustrated the harmonic profile at the source when the eighteen chargers were connected to feeder to random nodes and front nodes respectively. THD has increased in this case for all three configurations due to high penetration of the nonlinear load. THD has reached to 12.07% when the chargers were connected to the random nodes. Thus, further increment of EV penetration would cause the THD to pass the IEEE 519 limits.

THD at source has exceeded the IEEE 519 limits when the chargers are connected at the front. It was observed in the previous case as well where 20% of EV penetration was present at the feeder. Since the impact to the source transformer is higher when the chargers are connected at the front nodes, allowable EV penetration shall be less than 20%. The harmonic profile was dominated by third harmonic component and individual harmonic value exceeded the IEEE 519 limits while other harmonics were within the limits prescribed.

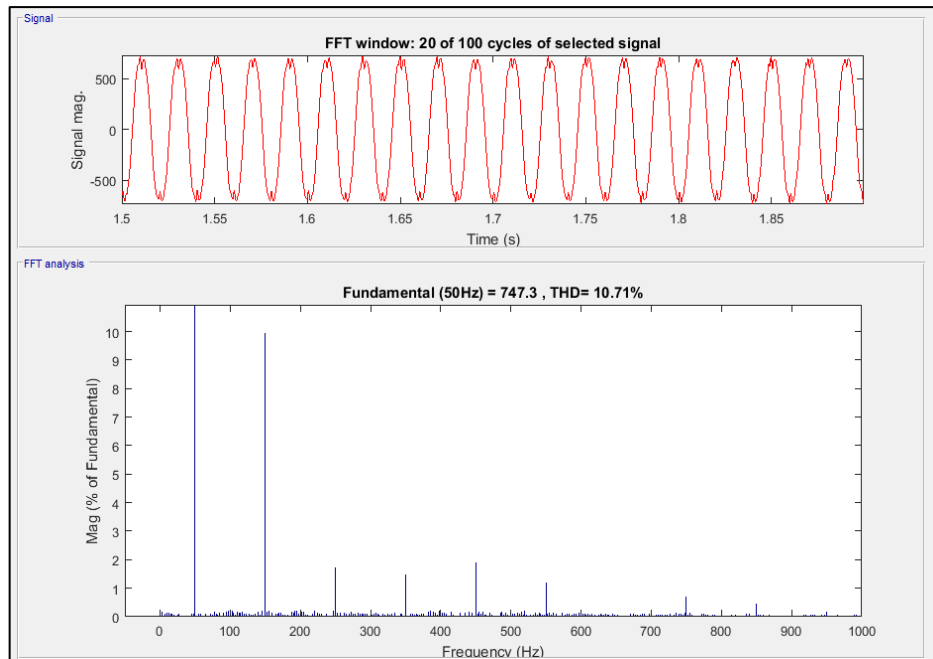


Figure 5.11: Harmonic spectrum at source - Case 3 - End nodes

Figure 5.11 illustrates the harmonic profile at source when eighteen EV chargers were connected at furthest end of the feeder. The impact to the source transformer was relatively lower when the chargers are at the furthest nodes. It can be observed that THD at the source is within IEEE 519 limits at 30% EV charger penetration. Individual harmonic values in case 3 are listed in Table 5.6.

Table 5.6: Individual harmonics in Case 3

	Random	Front	End
Harmonic Number	Value (%)	Value (%)	Value (%)
1	100	100	100
3	11.25	13.77	9.94
5	1.38	1.95	1.74
7	2.18	4.32	1.49
9	2.42	3.11	1.92
11	1.37	0.80	1.21
13	1.08	0.21	0.97
15	0.88	0.45	0.69
17	0.72	0.57	0.45
19	0.28	0.19	0.18
THD	12.07	15.06	10.71

5.2.6 Impact on other loads

Table 5.7 : Individual harmonics at PCC - Case 3

Case	Front	End
PCC	Bus 114	Bus 280
Harmonic Number	Value (%)	Value (%)
1	100	100
3	7.09	16.35
5	0.57	0.45
7	2.50	2.78
9	1.72	2.84
11	0.63	1.46
13	0.63	0.89
15	0.42	1.03
17	0.64	0.58
19	0.28	0.63
THD	8.21	17.95

Table 5.7 lists the individual harmonic values at PCC in case 3. It can be observed that the harmonic levels and THD at the PCC when chargers were connected to front nodes are within the parameters. However, THD and individual harmonics at PCC when the chargers are at the end nodes violated IEEE 519 limits. The third harmonic component in this case was significantly high.

5.3 EV Charging at off peak intervals

It is common to charge EV at the night time. In night time distribution feeder is typically lightly loaded. Residential users of EVs are inherently at homes in night times hence the EV is plugged in once user arrives home. A time of use tariff scheme is typically structured to encourage off peak energy use thus offering a lower tariff. Due to the above mentioned facts EV charging in off peak intervals is convenient and economical. Increase of off peak demand and EV charging at night would be

preferred by the distribution grid operators since it increases the utilisation factors and dilutes the voltage deviation issues.

Impacts of harmonics for a given EV charger penetration would be increased in the off peak intervals since a comparatively lower current is drawn by the lightly loaded feeder. In the proceeding cases, current harmonic profile at off peak EV charging was considered. The feeder was at its minimum load of 55kW with 0.95 power factor.

5.3.1 Case 4: 6 EV chargers at off peak

Similar to previous scenarios, EV chargers were connected to the feeder with three different configurations. In the case 4, six EV chargers were connected to the distribution feeder. Since the feeder is lightly loaded the percentage of EV charger load was approximately 40%. The FFT tool provides only the THD value of the current waveform. In order to compare with previous results, TDD was calculated for each case. Total demand distortion (TDD) was taken with respect to the load current at the nominal load.

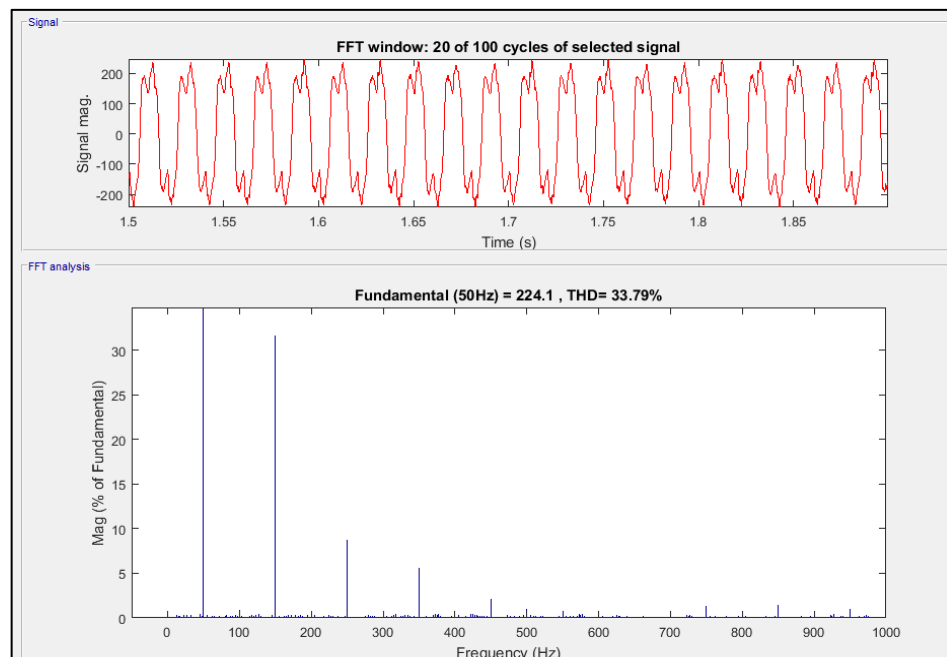


Figure 5.12: Harmonic spectrum at source - Case 4 - Random nodes

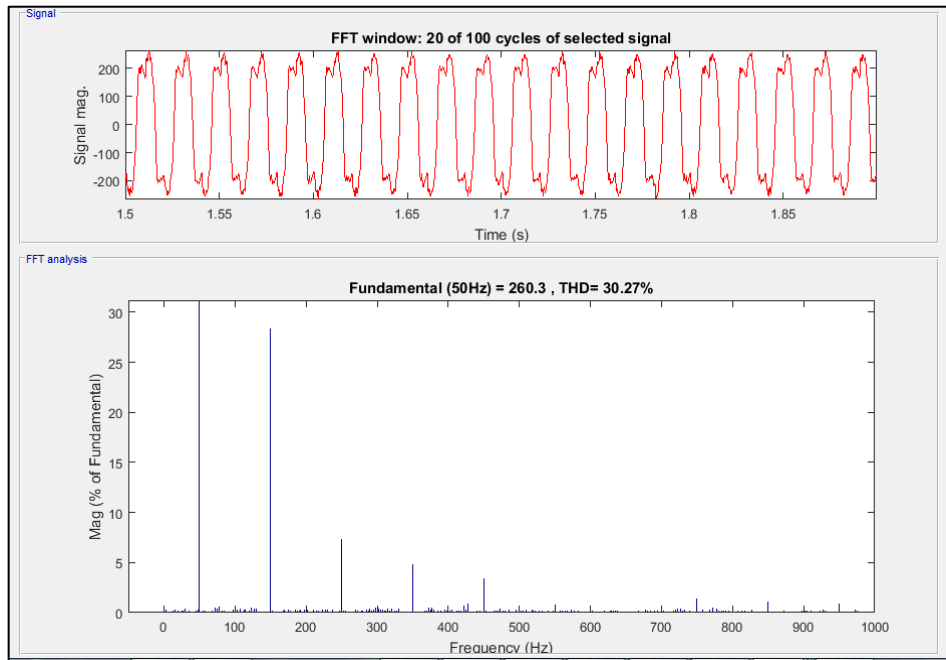


Figure 5.13: Harmonic spectrum at source - Case 4 - Front nodes

Figure 5.12 illustrates the harmonic profile at source when the EV chargers were connected to the random nodes at off peak interval. Individual values of the harmonics were higher since the source current is dominated by the EV chargers. In order to have a meaningful result, TDD was calculated based on load current of the nominal load.

$$I_{TDD} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \dots}}{I_L} \times 100\%$$

$$I_{TDD} = \frac{I_{THD} \times I_1}{I_L}$$

$$I_{TDD} = \frac{33.79 \times 158.5}{425.5}$$

$$I_{TDD} = 12.59\%$$

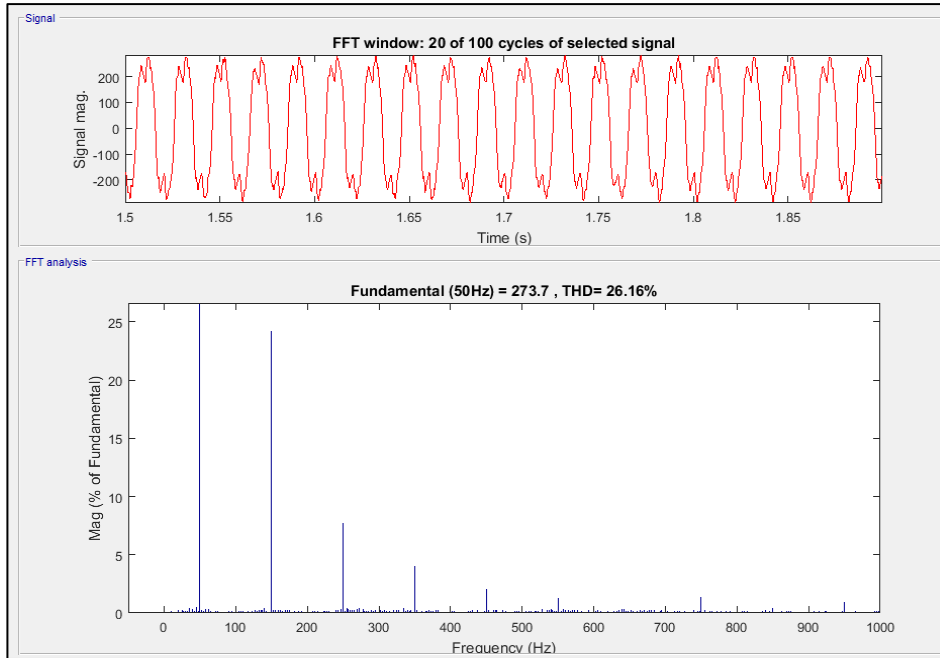


Figure 5.14 : Harmonic spectrum at source - Case 4 - End nodes

Figure 5.13 and Figure 5.14 illustrates the harmonic profile at source when the EV charges were at front and end nodes respectively. As depicted in Table 5.8, TDD value for each case is calculated. The results showed that TDD for all three scenarios was within the IEEE 519 limits.

Table 5.8: Individual harmonics in Case 4

	Random	Front	End
Harmonic Number	Value (%)	Value (%)	Value (%)
1	100	100	100
3	31.64	28.35	24.21
5	8.77	7.36	7.70
7	5.56	4.83	4.04
9	2.12	3.47	2.03
11	0.81	0.80	1.26
13	2.02	0.92	1.10
15	1.29	1.42	1.37
17	1.44	1.06	0.43
19	1.06	0.88	0.91
THD	33.79	30.27	26.16
TDD	12.59	12.88	12.07

5.3.2 Impact on other loads

Table 5.9: Individual harmonics at PCC - Case 4

Case	Front	End
PCC	Bus 101	Bus 280
Harmonic Number	Value (%)	Value (%)
1	100	100
3	3.74	28.24
5	0.74	8.94
7	0.43	4.67
9	0.27	2.35
11	0.04	1.47
13	0.04	1.26
15	0.10	1.58
17	0.10	0.49
19	0.06	1.05
THD	3.88	30.49
TDD	3.51	16.80

Table 5.9 lists the harmonic values at PCC when the EV chargers were connected at the front and end nodes. Harmonic distortion at the PCC when the chargers were connected at the end nodes marginally exceeded the IEEE 519 limits. Impact to the other non EV loads at PCC when the chargers were connected at front nodes is relatively lower and all the harmonics were within the limits prescribed in IEEE 519.

5.3.3 Case 5- 9 EV chargers at off peak

It was observed that connection of six EV chargers to the feeder at off peak interval will considerably distorts the source current waveform. TDD for each case is closer to IEEE 519 limits. In contrast to the first three cases, percentage of load by EV chargers was higher at off peak intervals.

In case 5, nine EV chargers were connected to the feeder to observe the harmonic profile. Contribution by the EV chargers to the total load was approximately 50%

thus the load current is dominated by the EV chargers. Therefore, number of EV chargers connected to the feeder was increased to 9 rather than 12 in contrast with case 2. Further, only random and end nodes were considered since harmonic distortion at source when EV chargers are at front nodes are close to limits at case 5.

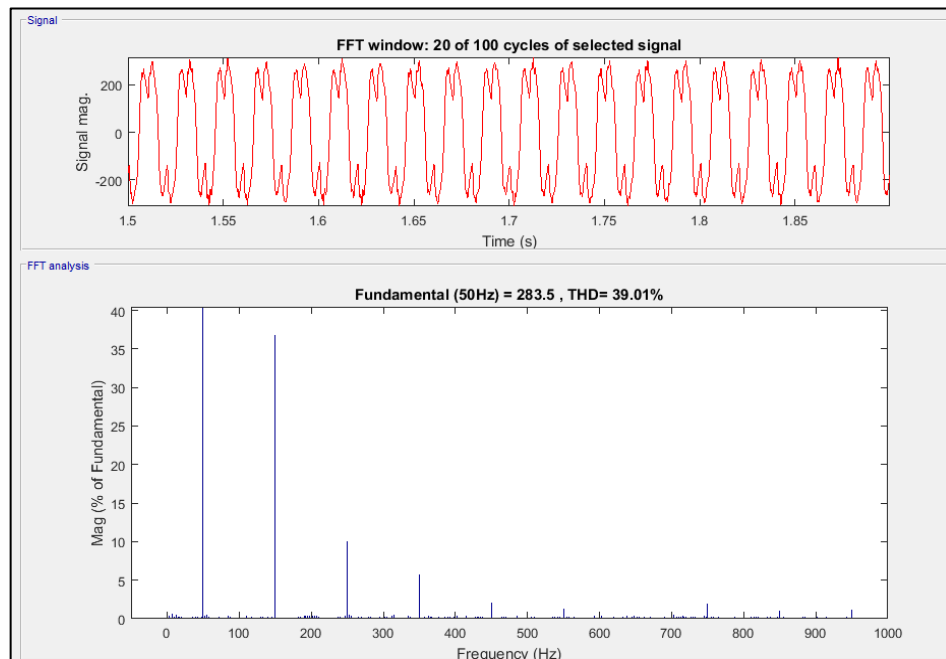


Figure 5.15: Harmonic spectrum at source - Case 5 - random nodes

Figure 5.15 shows the harmonic profile at the source when nine EV chargers were connected at random nodes in off peak interval. TDD was calculated in this case as well to compare the results. It can be observed that harmonic distortion of the source current waveform is relatively higher compared with previous cases.

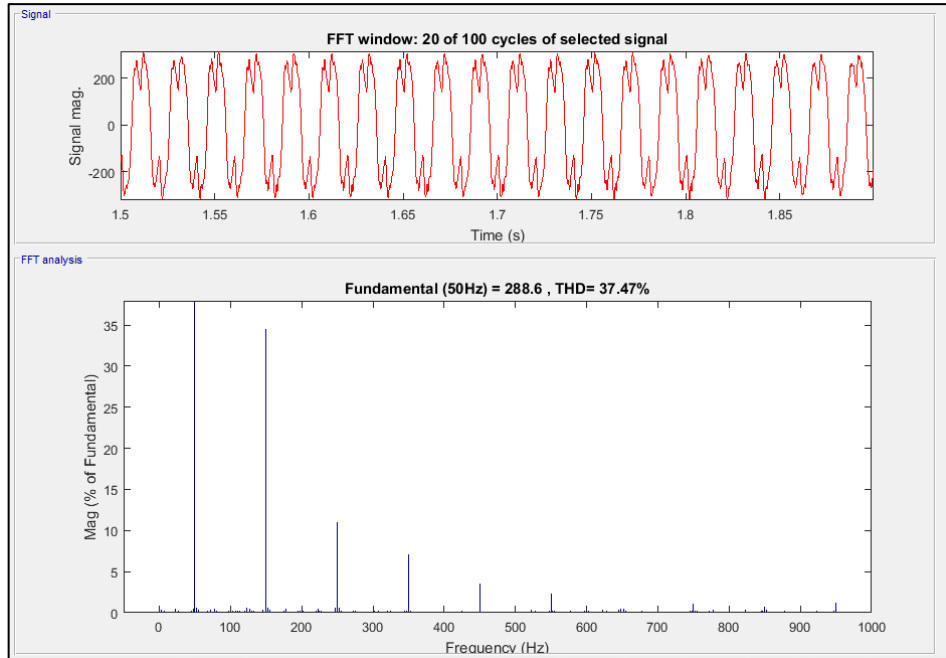


Figure 5.16 : Harmonic spectrum at source - Case 5 - End nodes

Figure 5.16 shows the harmonic profile at the source when the nine chargers were connected to the end nodes. Table 5.10 lists the individual harmonic values and calculated TDD values at source. It can be observed that the TDD values exceeded the IEEE 519 limits in both cases.

Table 5.10: Individual harmonics in Case 5

	Random	End
Harmonic Number	Value (%)	Value (%)
1	100	100
3	36.79	34.49
5	10.11	10.99
7	5.70	7.06
9	2.14	3.49
11	1.24	2.30
13	2.13	2.80
15	1.95	1.09
17	1.04	0.71
19	1.22	1.24
THD	39.10	37.47
TDD	16.17	16.10

5.3.4 Impact on other loads

Table 5.11 : Individual harmonics at PCC - Case 5

Case	End
PCC	Bus 280
Harmonic Number	Value (%)
1	100
3	39.88
5	12.65
7	8.10
9	4.00
11	2.63
13	3.21
15	1.25
17	0.81
19	1.42
THD	43.29
TDD	20.67

Individual harmonic at the PCC; Bus 280 is shown in Table 5.11. The harmonic values exceeded the IEEE 519 limits at the PCC due to high EV penetration. Table 5.12 summarises the results obtained in five cases.

Table 5.12: Summary of TDD at source

Load Level	Case	No. of EV	EV Penetration	Location	TDD at source
Nominal	1	6	10%	Random	6.57%
				Front	10.16%
				End	6.44%
	2	12	20%	Random	10.97%
				Front	13.26%
				End	9.82%
	3	18	30%	Random	12.07%
				Front	15.06%
				End	10.71%
Off Peak	4	6	40%	Random	12.59%
				Front	12.88%
				End	12.07%
	5	9	50%	Random	16.17%
				End	16.10%

CHAPTER 6. CONCLUSION

With the trend to switch to electric vehicle from conventional petroleum fuelled vehicles, penetration of nonlinear and power electronic driven loads in the distribution feeder has been gradually increasing. Charging of an EV draws a relatively higher current than a conventional load in a residential distribution feeder. Power electronic drives are a must to provide regulated DC current for charging thus power electronic load penetration in a residential distribution network has increased significantly.

EV chargers are broadly classified as on board and off board chargers. Three distinct power level segments are available for EV charging. Level 1 and level 2 charges are on board and the maximum power is limited to 22kW. Level 3 chargers offer predominantly fast DC charging while the power levels exceed 50kW. Nissan leaf is the most common electric vehicle model in the Sri Lankan market where the preferred charging method is a 6.6kW on board charger. The charger is equipped with a SAE J1772 connector and home charging of EV is dominated this particular model.

It was identified in the literature that EV charging would raise number of power quality concerns in the distribution feeder. Higher charging currents would cause voltage fluctuations as well as voltage unbalance. The high capacity power electronic converter draws a distorted current from the utility supply and thus harmonics are present in the current waveform. It is important to maintain the parameters of distribution feeders at healthy levels of power quality with the increasing demand of EVs in the residential grid.

The research was focused to determine the allowable EV penetration in an existing distribution feeder. In this research, a commonly available single phase charger, 6.6kW Nissan Leaf charger was modelled in Matlab environment in order to study and quantify the harmonic profile of a charger. The current harmonic profile of the Matlab model was validated with measurements obtained from an actual SAEJ1772

Nissan Leaf charger. Current harmonic impact of EV chargers connected LV distribution feeder was studied with the developed model. IEEE LV test feeder was used to generate results.

Current harmonic profile at source as well as PCC was studied while varying the EV charger penetration and spatial distribution in the distribution feeder. Five cases were considered in the research, three of them were EV charging under the nominal load of the feeder and other two were EV charging at off peak intervals. In each case, EV chargers were connected to random nodes, closest nodes to the source and furthest nodes to the source separately. The harmonic profiles obtained were compared with IEEE 519 limits.

It was observed that the impact to the source by harmonics is the lowest when the EV chargers are connected to the furthest end of the feeder. Harmonic impact to the source is the highest when the chargers are connected closet to the source. Increment of EV penetration increases the amplitude of individual harmonics as well as harmonic distortion. Three cases were studied under the nominal load of the feeder; 10%, 20% and 30% EV penetration. Six, twelve and eighteen EV chargers were connected in the mentioned cases respectively. Up to 30% of EV penetration is acceptable to the feeder without any modification if the EV chargers are connected in random or end nodes. If all the chargers are connected at front nodes, increase beyond 20% will exceed IEEE 519 limits of harmonic distortion and individual harmonic values.

Two other cases considered were EV charging at off peak interval where the feeder is lightly loaded. Six and nine EV chargers were connected to the feeder and the contribution from EV chargers to the total load would rise to 40% and 50% respectively. Up to 40% of EV charging load can be connected to the feeder with any spatial distribution without violating IEEE 519 limits at source.

Harmonic profile at the PCC is important since other loads connected at the PCC shall not be disturbed by distorted current. Harmonic distortion as well as individual

harmonic values at PCC was studied in the research. Impact to a non EV load connected to a PCC with an EV charger for a generalised case was considered and the harmonic values were within the prescribed limits. When all the EV chargers were clustered in either front or end nodes the situation is slightly different. When the EV chargers were connected at front nodes harmonic profile at PCC was observed to be within the IEEE 519 limits for first three cases. However, when the chargers were connected at end nodes, harmonic values at PCC exceeded the limits if the EV charger penetration exceeded 20% of total load.

A comprehensive study on the harmonic profile of EV charging was carried out in this research. In a practical situation, it is mostly likely to have a random distribution of EV chargers along the feeder. Therefore, up to 30% of EV charger penetration at nominal load and up to 40% of EV charger penetration at off peak can be absorbed by the distribution feeder without violating IEEE 519 prescribed limits. In a coordinated operation if the EV chargers are clustered together, only 20% of EV penetration can be absorbed considering harmonic profile at source as well as PCC. It is to be noted that other parameters such as voltage limits and voltage unbalance factors shall be maintained within the desired limits while meeting the mentioned requirements.

The findings of the research provide a benchmarking to determine allowable EV penetration in a distribution feeder with different possible scenarios. Distribution grid operators may determine when and where the modifications are to be done to the existing system based on EV charger penetration. The developed Matlab EV charger model could be integrated with computer simulations of power quality studies parameters of the existing distribution infrastructure.

The research paves a way for the implementation of coordinated charging. System operators shall determine the allowable EV penetration to the system based on the charger location and load of the feeder. The findings are very important especially at off peak interval since the number of EV chargers could be lower when the feeder is

lightly loaded. Operators can dispatch the chargers accordingly such that power quality parameters will be maintained in healthy levels.

6.1 Limitations and Future Works

The current harmonic profile of EV charging in a LV distribution feeder was studied in the research. In order to draw a conclusion on acceptable limits of EV charger penetration and basis for coordinated charging, the results shall be combined with other power quality parameters such as voltage unbalance and voltage deviations. Also other distribution system operation parameters such as transformer loading, line loading etc. shall be taken into the account in order to draw a comprehensive conclusion.

Comprehensive study of EV charging shall be carried out in distribution system software such as DigiSilent or OpenDSS. The results of this research on current harmonic distortion at different load levels and distribution can be incorporated to such further study. A mathematical model of coordinated charging of EV incorporating the technical and economical parameters to optimise the operation shall be considered as a potential future research.

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APPENDIX 2 – IEEE LV TEST FEEDER DATA

Line Sections and Impedance Values

Name	phases	R1	X1	R0	X0	C1	C0	Units
2c_.007	3	3.97	0.099	3.97	0.099	0	0	Ω/km
2c_.0225	3	1.257	0.085	1.257	0.085	0	0	Ω/km
2c_16	3	1.15	0.088	1.2	0.088	0	0	Ω/km
35_SAC_XSC	3	0.868	0.092	0.76	0.092	0	0	Ω/km
4c_.06	3	0.469	0.075	1.581	0.091	0	0	Ω/km
4c_.1	3	0.274	0.073	0.959	0.079	0	0	Ω/km
4c_.35	3	0.089	0.0675	0.319	0.076	0	0	Ω/km
4c_185	3	0.166	0.068	0.58	0.078	0	0	Ω/km
4c_70	3	0.446	0.071	1.505	0.083	0	0	Ω/km
4c_95_SAC_XC	3	0.322	0.074	0.804	0.093	0	0	Ω/km

Line data

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE1	1	2	ABC	1.098	m	4c_70
LINE2	2	3	ABC	0.11511	m	4c_70
LINE3	3	4	ABC	0.10784	m	4c_70
LINE4	4	5	ABC	0.094021	m	4c_70
LINE5	5	6	ABC	0.14812	m	4c_70
LINE6	6	7	ABC	10.0863	m	4c_70
LINE7	7	8	ABC	0.45175	m	4c_70
LINE8	8	9	ABC	0.376	m	4c_70
LINE9	9	10	ABC	0.32997	m	4c_70
LINE10	10	11	ABC	0.24622	m	4c_70
LINE11	11	12	ABC	0.23114	m	4c_70
LINE12	12	13	ABC	0.14213	m	4c_70
LINE13	13	14	ABC	0.35384	m	4c_70
LINE14	14	15	ABC	2.8664	m	4c_70
LINE15	15	16	ABC	0.09654	m	2c_.007
LINE16	15	17	ABC	3.476	m	4c_70
LINE17	16	18	ABC	0.044045	m	2c_.007
LINE18	17	19	ABC	0.23917	m	4c_70
LINE19	18	20	ABC	0.046174	m	2c_.007
LINE20	19	21	ABC	0.26856	m	4c_70
LINE21	20	22	ABC	0.041976	m	2c_.007
LINE22	21	23	ABC	0.43727	m	4c_70

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE23	22	24	ABC	0.051245	m	2c_.007
LINE24	23	25	ABC	0.7955	m	4c_70
LINE25	24	26	ABC	0.055902	m	2c_.007
LINE26	25	27	ABC	5.9049	m	2c_16
LINE27	25	28	ABC	9.9686	m	4c_70
LINE28	26	29	ABC	0.054562	m	2c_.007
LINE29	27	30	ABC	1.6265	m	2c_16
LINE30	27	31	ABC	1.5847	m	2c_16
LINE31	28	32	ABC	2.6538	m	4c_70
LINE32	29	33	ABC	0.14629	m	2c_.007
LINE33	30	34	ABC	3.7248	m	2c_16
LINE34	31	35	ABC	0.053666	m	2c_16
LINE35	32	36	ABC	5.7265	m	2c_16
LINE36	32	37	ABC	8.0244	m	4c_70
LINE37	33	38	ABC	0.13648	m	2c_.007
LINE38	35	39	ABC	0.077162	m	2c_16
LINE39	36	40	ABC	0.40004	m	2c_16
LINE40	36	41	ABC	1.8063	m	2c_16
LINE41	37	42	ABC	5.5684	m	4c_70
LINE42	37	43	ABC	0.21675	m	4c_185
LINE43	38	44	ABC	0.033838	m	2c_.007
LINE44	39	45	ABC	0.098955	m	2c_16
LINE45	40	46	ABC	0.18031	m	2c_16
LINE46	41	47	ABC	4.3463	m	2c_16
LINE47	42	48	ABC	4.2078	m	4c_70
LINE48	43	49	ABC	0.10436	m	4c_185
LINE49	44	50	ABC	0.048104	m	2c_.007
LINE50	45	51	ABC	0.241	m	2c_16
LINE51	46	52	ABC	0.19109	m	2c_16
LINE52	48	53	ABC	0.60668	m	4c_70
LINE53	48	54	ABC	0.63949	m	4c_70
LINE54	49	55	ABC	0.11625	m	4c_185
LINE55	50	56	ABC	0.087664	m	2c_.007
LINE56	51	57	ABC	0.20634	m	2c_16
LINE57	52	58	ABC	0.182	m	2c_16
LINE58	53	59	ABC	2.7481	m	4c_70
LINE59	54	60	ABC	0.065368	m	4c_70
LINE60	55	61	ABC	0.10028	m	4c_185
LINE61	56	62	ABC	0.078	m	2c_.007
LINE62	57	63	ABC	0.98912	m	2c_16
LINE63	58	64	ABC	0.109	m	2c_16

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE64	59	65	ABC	0.55868	m	4c_70
LINE65	59	66	ABC	8.2583	m	2c_16
LINE66	60	67	ABC	0.074	m	4c_70
LINE67	61	68	ABC	0.096042	m	4c_185
LINE68	62	69	ABC	0.083241	m	2c_.007
LINE69	63	70	ABC	3.4962	m	2c_16
LINE70	64	71	ABC	0.21385	m	2c_16
LINE71	65	72	ABC	6.6006	m	4c_70
LINE72	66	73	ABC	4.0366	m	2c_16
LINE73	66	74	ABC	4.0366	m	2c_16
LINE74	67	75	ABC	0.17951	m	4c_70
LINE75	68	76	ABC	0.23551	m	4c_185
LINE76	69	77	ABC	0.38907	m	2c_.007
LINE77	71	78	ABC	1.0838	m	2c_16
LINE78	72	79	ABC	2.3008	m	4c_70
LINE79	75	80	ABC	0.10362	m	4c_70
LINE80	76	81	ABC	0.7469	m	4c_185
LINE81	77	82	ABC	0.51088	m	2c_.007
LINE82	78	83	ABC	4.084	m	2c_16
LINE83	79	84	ABC	0.50211	m	4c_70
LINE84	80	85	ABC	0.11122	m	4c_70
LINE85	81	86	ABC	1.4388	m	4c_185
LINE86	82	87	ABC	0.31045	m	2c_.007
LINE87	84	88	ABC	1.0182	m	4c_70
LINE88	85	89	ABC	0.1048	m	4c_70
LINE89	86	90	ABC	0.34251	m	4c_185
LINE90	87	91	ABC	0.11206	m	2c_.007
LINE91	88	92	ABC	0.96021	m	4c_70
LINE92	90	93	ABC	0.065307	m	4c_185
LINE93	91	94	ABC	0.034785	m	2c_.007
LINE94	92	95	ABC	0.55811	m	4c_70
LINE95	93	96	ABC	0.086052	m	4c_185
LINE96	94	97	ABC	0.03677	m	2c_.007
LINE97	95	98	ABC	0.36859	m	4c_70
LINE98	96	99	ABC	0.037216	m	4c_185
LINE99	97	100	ABC	0.089588	m	2c_.007
LINE100	98	101	ABC	0.50892	m	4c_70
LINE101	99	102	ABC	5.0819	m	4c_185
LINE102	100	103	ABC	0.28583	m	2c_.007
LINE103	101	104	ABC	0.28838	m	4c_.35
LINE104	101	105	ABC	0.33602	m	4c_70

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE105	102	106	ABC	0.22108	m	4c_185
LINE106	104	107	ABC	0.3489	m	4c_.35
LINE107	105	108	ABC	0.19054	m	4c_70
LINE108	106	109	ABC	0.45085	m	4c_185
LINE109	107	110	ABC	0.4044	m	4c_.35
LINE110	108	111	ABC	7.5182	m	4c_70
LINE111	109	112	ABC	11.9766	m	4c_185
LINE112	110	113	ABC	0.61659	m	4c_.35
LINE113	111	114	ABC	0.75316	m	4c_70
LINE114	112	115	ABC	10.6613	m	4c_185
LINE115	113	116	ABC	0.79271	m	4c_.35
LINE116	114	117	ABC	1.1056	m	4c_.35
LINE117	114	118	ABC	3.6556	m	4c_.1
LINE118	115	119	ABC	0.99464	m	4c_185
LINE119	116	120	ABC	0.56909	m	4c_.35
LINE120	117	121	ABC	0.19481	m	2c_.007
LINE121	117	122	ABC	0.53831	m	4c_.35
LINE122	118	123	ABC	6.5924	m	4c_.1
LINE123	119	124	ABC	0.7248	m	4c_185
LINE124	120	125	ABC	0.80412	m	4c_.35
LINE125	121	126	ABC	0.16869	m	2c_.007
LINE126	122	127	ABC	2.5288	m	4c_.35
LINE127	123	128	ABC	2.9646	m	4c_.1
LINE128	124	129	ABC	0.62512	m	4c_185
LINE129	125	130	ABC	0.87	m	4c_.35
LINE130	126	131	ABC	0.11915	m	2c_.007
LINE131	127	132	ABC	3.8212	m	2c_16
LINE132	127	133	ABC	7.1782	m	4c_.35
LINE133	128	134	ABC	0.88205	m	4c_.1
LINE134	129	135	ABC	1.9203	m	4c_185
LINE135	130	136	ABC	0.82048	m	4c_.35
LINE136	131	137	ABC	0.18436	m	2c_.007
LINE137	132	138	ABC	0.32908	m	2c_16
LINE138	133	139	ABC	5.3402	m	4c_.35
LINE139	134	140	ABC	0.99566	m	4c_.1
LINE140	135	141	ABC	1.4127	m	4c_185
LINE141	136	142	ABC	1.349	m	4c_.35
LINE142	137	143	ABC	0.21781	m	2c_.007
LINE143	138	144	ABC	0.32289	m	2c_16
LINE144	139	145	ABC	3.5762	m	4c_.35
LINE145	140	146	ABC	0.9364	m	4c_.1

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE146	141	147	ABC	0.24053	m	4c_185
LINE147	142	148	ABC	6.4142	m	4c_.35
LINE148	143	149	ABC	0.19401	m	2c_.007
LINE149	144	150	ABC	0.26072	m	2c_16
LINE150	145	151	ABC	3.5713	m	4c_.35
LINE151	145	152	ABC	5.1314	m	2c_16
LINE152	146	153	ABC	1.0926	m	4c_.1
LINE153	147	154	ABC	0.083096	m	4c_185
LINE154	148	155	ABC	1.3973	m	4c_.35
LINE155	149	156	ABC	0.2191	m	2c_.007
LINE156	150	157	ABC	0.39132	m	2c_16
LINE157	151	158	ABC	9.4713	m	4c_.35
LINE158	152	159	ABC	0.31233	m	2c_16
LINE159	153	160	ABC	0.31439	m	4c_.1
LINE160	154	161	ABC	0.12256	m	4c_185
LINE161	155	162	ABC	11.7422	m	2c_16
LINE162	155	163	ABC	5.2844	m	4c_.35
LINE163	156	164	ABC	0.20342	m	2c_.007
LINE164	157	165	ABC	0.47178	m	2c_16
LINE165	158	166	ABC	3.2899	m	4c_.35
LINE166	159	167	ABC	0.28533	m	2c_16
LINE167	160	168	ABC	1.7861	m	4c_.1
LINE168	161	169	ABC	0.24958	m	4c_185
LINE169	162	170	ABC	2.2183	m	2c_16
LINE170	163	171	ABC	7.0156	m	4c_.35
LINE171	164	172	ABC	0.1727	m	2c_.007
LINE172	165	173	ABC	0.35642	m	2c_16
LINE173	166	174	ABC	3.9183	m	4c_.35
LINE174	166	175	ABC	4.2045	m	2c_16
LINE175	167	176	ABC	0.11853	m	2c_16
LINE176	168	177	ABC	1.0088	m	4c_.1
LINE177	170	178	ABC	4.5768	m	2c_16
LINE178	171	179	ABC	1.1818	m	4c_.35
LINE179	171	180	ABC	2.4224	m	2c_16
LINE180	172	181	ABC	0.17961	m	2c_.007
LINE181	173	182	ABC	0.41244	m	2c_16
LINE182	174	183	ABC	0.58763	m	4c_.35
LINE183	175	184	ABC	0.45409	m	2c_16
LINE184	176	185	ABC	0.25549	m	2c_16
LINE185	177	186	ABC	0.74886	m	4c_.1
LINE186	179	187	ABC	4.6507	m	4c_.35

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE187	180	188	ABC	10.0258	m	2c_16
LINE188	181	189	ABC	0.15412	m	2c_.007
LINE189	182	190	ABC	0.3878	m	2c_16
LINE190	183	191	ABC	2.3151	m	4c_.35
LINE191	183	192	ABC	0.27791	m	4c_.35
LINE192	184	193	ABC	0.43923	m	2c_16
LINE193	185	194	ABC	0.65073	m	2c_16
LINE194	186	195	ABC	0.67326	m	4c_.1
LINE195	187	196	ABC	8.3036	m	4c_.35
LINE196	188	197	ABC	1.9595	m	2c_16
LINE197	188	198	ABC	1.1325	m	2c_16
LINE198	189	199	ABC	0.19148	m	2c_.007
LINE199	190	200	ABC	0.41725	m	2c_16
LINE200	191	201	ABC	0.9314	m	4c_.35
LINE201	192	202	ABC	0.16447	m	4c_.35
LINE202	193	203	ABC	0.35134	m	2c_16
LINE203	194	204	ABC	0.38178	m	2c_16
LINE204	195	205	ABC	0.83638	m	4c_.1
LINE205	196	206	ABC	3.2475	m	2c_16
LINE206	196	207	ABC	2.1371	m	4c_.35
LINE207	197	208	ABC	4.9541	m	2c_16
LINE208	198	209	ABC	0.16008	m	2c_16
LINE209	199	210	ABC	0.44838	m	2c_.007
LINE210	200	211	ABC	0.63785	m	2c_16
LINE211	202	212	ABC	0.15526	m	4c_.35
LINE212	203	213	ABC	0.27987	m	2c_16
LINE213	204	214	ABC	0.2674	m	2c_16
LINE214	205	215	ABC	1.5434	m	4c_.1
LINE215	206	216	ABC	10.6295	m	2c_16
LINE216	207	217	ABC	3.8571	m	4c_.35
LINE217	209	218	ABC	0.1291	m	2c_16
LINE218	210	219	ABC	0.67215	m	2c_.007
LINE219	211	220	ABC	1.7419	m	2c_16
LINE220	212	221	ABC	0.17006	m	4c_.35
LINE221	213	222	ABC	0.59169	m	2c_16
LINE222	214	223	ABC	0.51437	m	2c_16
LINE223	215	224	ABC	1.3456	m	4c_.1
LINE224	216	225	ABC	4.5822	m	2c_16
LINE225	217	226	ABC	1.3772	m	4c_.35
LINE226	218	227	ABC	0.10317	m	2c_16
LINE227	220	228	ABC	0.14852	m	2c_16

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE228	221	229	ABC	0.23273	m	4c_.35
LINE229	222	230	ABC	0.46597	m	2c_16
LINE230	223	231	ABC	0.25602	m	2c_16
LINE231	224	232	ABC	0.91534	m	4c_.1
LINE232	226	233	ABC	11.8949	m	2c_16
LINE233	226	234	ABC	1.1273	m	4c_.35
LINE234	227	235	ABC	0.15749	m	2c_16
LINE235	228	236	ABC	0.0686	m	2c_16
LINE236	229	237	ABC	0.20742	m	4c_.35
LINE237	230	238	ABC	0.32322	m	2c_16
LINE238	231	239	ABC	0.18179	m	2c_16
LINE239	232	240	ABC	0.6013	m	4c_.1
LINE240	233	241	ABC	1.7274	m	2c_16
LINE241	235	242	ABC	0.18461	m	2c_16
LINE242	236	243	ABC	0.073376	m	2c_16
LINE243	237	244	ABC	0.16881	m	4c_.35
LINE244	238	245	ABC	0.32245	m	2c_16
LINE245	239	246	ABC	2.0796	m	2c_16
LINE246	240	247	ABC	1.2941	m	4c_.1
LINE247	241	248	ABC	5.3022	m	2c_16
LINE248	241	249	ABC	5.3022	m	2c_16
LINE249	242	250	ABC	0.28355	m	2c_16
LINE250	243	251	ABC	0.070114	m	2c_16
LINE251	244	252	ABC	0.13297	m	4c_.35
LINE252	245	253	ABC	0.47173	m	2c_16
LINE253	246	254	ABC	0.61324	m	2c_16
LINE254	247	255	ABC	4.5618	m	2c_16
LINE255	247	256	ABC	0.85678	m	4c_.1
LINE256	250	257	ABC	1.0376	m	2c_16
LINE257	251	258	ABC	0.07811	m	2c_16
LINE258	252	259	ABC	0.17323	m	4c_.35
LINE259	253	260	ABC	1.7742	m	2c_16
LINE260	254	261	ABC	0.1372	m	2c_16
LINE261	255	262	ABC	0.6306	m	2c_16
LINE262	256	263	ABC	3.2128	m	4c_.1
LINE263	257	264	ABC	5.05	m	2c_16
LINE264	258	265	ABC	0.16123	m	2c_16
LINE265	259	266	ABC	0.19436	m	4c_.35
LINE266	260	267	ABC	0.4141	m	2c_16
LINE267	261	268	ABC	3.4578	m	2c_16
LINE268	261	269	ABC	0.11871	m	2c_16

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE269	262	270	ABC	0.28991	m	2c_16
LINE270	263	271	ABC	4.2547	m	2c_16
LINE271	263	272	ABC	1.0792	m	4c_.1
LINE272	265	273	ABC	0.16792	m	2c_16
LINE273	266	274	ABC	0.17888	m	4c_.35
LINE274	267	275	ABC	0.18971	m	2c_16
LINE275	268	276	ABC	3.4268	m	2c_16
LINE276	269	277	ABC	0.13918	m	2c_16
LINE277	270	278	ABC	0.34433	m	2c_16
LINE278	271	279	ABC	0.30927	m	2c_16
LINE279	272	280	ABC	3.9121	m	4c_.1
LINE280	273	281	ABC	0.63854	m	2c_16
LINE281	274	282	ABC	0.60542	m	4c_.35
LINE282	275	283	ABC	0.12472	m	2c_16
LINE283	277	284	ABC	0.12578	m	2c_16
LINE284	278	285	ABC	0.53126	m	2c_16
LINE285	279	286	ABC	0.25491	m	2c_16
LINE286	280	287	ABC	1.7542	m	4c_.06
LINE287	280	288	ABC	0.91306	m	4c_.1
LINE288	281	289	ABC	3.3901	m	2c_16
LINE289	282	290	ABC	0.81044	m	4c_.35
LINE290	283	291	ABC	0.87618	m	2c_16
LINE291	283	292	ABC	0.10807	m	2c_16
LINE292	284	293	ABC	0.12739	m	2c_16
LINE293	285	294	ABC	0.47339	m	2c_16
LINE294	286	295	ABC	0.36208	m	2c_16
LINE295	287	296	ABC	0.80742	m	4c_.06
LINE296	288	297	ABC	3.8266	m	4c_.1
LINE297	291	298	ABC	0.40248	m	2c_16
LINE298	292	299	ABC	0.076485	m	2c_16
LINE299	293	300	ABC	0.13697	m	2c_16
LINE300	294	301	ABC	0.36805	m	2c_16
LINE301	295	302	ABC	1.6263	m	2c_16
LINE302	296	303	ABC	5.2746	m	4c_.06
LINE303	297	304	ABC	0.84468	m	4c_.1
LINE304	298	305	ABC	0.68119	m	2c_16
LINE305	299	306	ABC	0.089006	m	2c_16
LINE306	300	307	ABC	0.79435	m	2c_16
LINE307	301	308	ABC	0.45813	m	2c_16
LINE308	302	309	ABC	0.31308	m	2c_16
LINE309	303	310	ABC	0.39397	m	4c_.06

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE310	304	311	ABC	0.28067	m	4c_.1
LINE311	305	312	ABC	1.3075	m	2c_16
LINE312	306	313	ABC	0.17024	m	2c_16
LINE313	307	314	ABC	3.3598	m	2c_16
LINE314	308	315	ABC	0.47384	m	2c_16
LINE315	309	316	ABC	0.23181	m	2c_16
LINE316	310	317	ABC	0.64903	m	2c_16
LINE317	310	318	ABC	7.2163	m	4c_.06
LINE318	311	319	ABC	0.14649	m	4c_.1
LINE319	312	320	ABC	3.8495	m	2c_16
LINE320	313	321	ABC	0.6529	m	2c_16
LINE321	315	322	ABC	0.55892	m	2c_16
LINE322	316	323	ABC	0.26702	m	2c_16
LINE323	317	324	ABC	3.3427	m	2c_16
LINE324	318	325	ABC	3.4631	m	4c_.06
LINE325	319	326	ABC	0.1254	m	4c_.1
LINE326	321	327	ABC	2.2281	m	2c_16
LINE327	322	328	ABC	0.31851	m	2c_16
LINE328	323	329	ABC	0.26488	m	2c_16
LINE329	324	330	ABC	1.167	m	2c_16
LINE330	325	331	ABC	9.1332	m	2c_16
LINE331	325	332	ABC	6.6729	m	4c_.06
LINE332	326	333	ABC	0.14262	m	4c_.1
LINE333	328	334	ABC	1.4389	m	2c_16
LINE334	329	335	ABC	2.327	m	2c_16
LINE335	330	336	ABC	2.5399	m	2c_16
LINE336	331	337	ABC	3.6172	m	2c_16
LINE337	332	338	ABC	6.8067	m	2c_16
LINE338	332	339	ABC	1.2129	m	4c_.06
LINE339	333	340	ABC	0.11236	m	4c_.1
LINE340	334	341	ABC	0.55999	m	2c_16
LINE341	335	342	ABC	4.7567	m	2c_16
LINE342	336	343	ABC	2.082	m	2c_16
LINE343	336	344	ABC	0.9796	m	2c_16
LINE344	338	345	ABC	3.4221	m	2c_16
LINE345	339	346	ABC	1.0391	m	4c_.06
LINE346	340	347	ABC	0.094202	m	4c_.1
LINE347	341	348	ABC	0.19454	m	2c_16
LINE348	343	349	ABC	3.1153	m	2c_16
LINE349	344	350	ABC	0.1364	m	2c_16
LINE350	345	351	ABC	0.31846	m	2c_16

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE351	346	352	ABC	0.73091	m	4c_.06
LINE352	347	353	ABC	0.085	m	4c_.1
LINE353	348	354	ABC	0.14656	m	2c_16
LINE354	350	355	ABC	0.14814	m	2c_16
LINE355	351	356	ABC	0.13152	m	2c_16
LINE356	352	357	ABC	0.92352	m	4c_.06
LINE357	353	358	ABC	0.070349	m	4c_.1
LINE358	354	359	ABC	0.10723	m	2c_16
LINE359	355	360	ABC	0.12976	m	2c_16
LINE360	356	361	ABC	0.092801	m	2c_16
LINE361	357	362	ABC	0.57867	m	4c_.06
LINE362	358	363	ABC	0.081609	m	4c_.1
LINE363	359	364	ABC	0.054452	m	2c_16
LINE364	360	365	ABC	0.13787	m	2c_16
LINE365	361	366	ABC	0.094921	m	2c_16
LINE366	362	367	ABC	0.88861	m	4c_.06
LINE367	363	368	ABC	0.089694	m	4c_.1
LINE368	364	369	ABC	0.080056	m	2c_16
LINE369	365	370	ABC	0.19677	m	2c_16
LINE370	366	371	ABC	0.112	m	2c_16
LINE371	367	372	ABC	0.88584	m	4c_.06
LINE372	368	373	ABC	0.48898	m	4c_.1
LINE373	369	374	ABC	0.1342	m	2c_16
LINE374	370	375	ABC	0.23921	m	2c_16
LINE375	371	376	ABC	0.14128	m	2c_16
LINE376	372	377	ABC	0.99394	m	4c_.06
LINE377	373	378	ABC	3.6848	m	4c_.1
LINE378	373	379	ABC	1.4115	m	2c_16
LINE379	374	380	ABC	0.59859	m	2c_16
LINE380	375	381	ABC	1.4827	m	2c_16
LINE381	376	382	ABC	0.12653	m	2c_16
LINE382	377	383	ABC	0.71925	m	4c_.06
LINE383	378	384	ABC	3.5292	m	4c_.1
LINE384	379	385	ABC	8.6668	m	2c_16
LINE385	379	386	ABC	1.4561	m	2c_16
LINE386	380	387	ABC	2.2004	m	2c_16
LINE387	381	388	ABC	5.0734	m	2c_16
LINE388	382	389	ABC	0.10012	m	2c_16
LINE389	383	390	ABC	0.85728	m	4c_.06
LINE390	384	391	ABC	0.15711	m	4c_.1
LINE391	385	392	ABC	3.1675	m	2c_16

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE392	386	393	ABC	7.8335	m	2c_16
LINE393	389	394	ABC	0.17183	m	2c_16
LINE394	390	395	ABC	1.2439	m	4c_.06
LINE395	391	396	ABC	4.0601	m	2c_16
LINE396	391	397	ABC	2.8793	m	4c_.1
LINE397	392	398	ABC	0.32241	m	2c_16
LINE398	393	399	ABC	0.5688	m	2c_16
LINE399	394	400	ABC	0.59984	m	2c_16
LINE400	395	401	ABC	0.9222	m	4c_.06
LINE401	396	402	ABC	0.37201	m	2c_16
LINE402	397	403	ABC	1.3891	m	4c_.1
LINE403	398	404	ABC	0.225	m	2c_16
LINE404	399	405	ABC	0.24807	m	2c_16
LINE405	400	406	ABC	3.6672	m	2c_16
LINE406	401	407	ABC	0.88961	m	4c_.06
LINE407	402	408	ABC	0.21148	m	2c_16
LINE408	403	409	ABC	4.1907	m	4c_.1
LINE409	403	410	ABC	0.3791	m	4c_.1
LINE410	404	411	ABC	0.23308	m	2c_16
LINE411	405	412	ABC	0.16706	m	2c_16
LINE412	407	413	ABC	0.87066	m	4c_.06
LINE413	408	414	ABC	0.1436	m	2c_16
LINE414	409	415	ABC	5.9686	m	4c_.1
LINE415	410	416	ABC	0.094921	m	4c_.1
LINE416	411	417	ABC	0.9788	m	2c_16
LINE417	412	418	ABC	0.27954	m	2c_16
LINE418	413	419	ABC	1.0471	m	4c_.06
LINE419	414	420	ABC	0.23403	m	2c_16
LINE420	415	421	ABC	1.249	m	4c_.1
LINE421	416	422	ABC	0.066573	m	4c_.1
LINE422	417	423	ABC	0.239	m	2c_16
LINE423	418	424	ABC	3.1944	m	2c_16
LINE424	419	425	ABC	1.7537	m	4c_.06
LINE425	419	426	ABC	1.7537	m	4c_.06
LINE426	420	427	ABC	0.77793	m	2c_16
LINE427	421	428	ABC	0.31923	m	4c_.1
LINE428	422	429	ABC	0.082873	m	4c_.1
LINE429	423	430	ABC	0.22798	m	2c_16
LINE430	424	431	ABC	1.1331	m	2c_16
LINE431	425	432	ABC	5.9151	m	4c_.06
LINE432	425	433	ABC	5.9151	m	4c_.06

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE433	427	434	ABC	0.86608	m	2c_16
LINE434	428	435	ABC	0.16724	m	4c_.1
LINE435	429	436	ABC	0.071344	m	4c_.1
LINE436	430	437	ABC	0.22674	m	2c_16
LINE437	431	438	ABC	0.384	m	2c_16
LINE438	432	439	ABC	8.3663	m	4c_.06
LINE439	432	440	ABC	8.3663	m	4c_.06
LINE440	434	441	ABC	0.48708	m	2c_16
LINE441	435	442	ABC	0.13864	m	4c_.1
LINE442	436	443	ABC	0.078	m	4c_.1
LINE443	437	444	ABC	0.2601	m	2c_16
LINE444	438	445	ABC	0.67858	m	2c_16
LINE445	439	446	ABC	6.0033	m	4c_.06
LINE446	439	447	ABC	6.0033	m	4c_.06
LINE447	441	448	ABC	0.45756	m	2c_16
LINE448	442	449	ABC	0.11236	m	4c_.1
LINE449	443	450	ABC	0.079246	m	4c_.1
LINE450	444	451	ABC	0.89824	m	2c_16
LINE451	445	452	ABC	0.59366	m	2c_16
LINE452	446	453	ABC	1.8214	m	4c_.06
LINE453	446	454	ABC	1.8214	m	4c_.06
LINE454	448	455	ABC	0.43655	m	2c_16
LINE455	449	456	ABC	0.17175	m	4c_.1
LINE456	450	457	ABC	0.054231	m	4c_.1
LINE457	451	458	ABC	4.3773	m	2c_16
LINE458	452	459	ABC	0.67064	m	2c_16
LINE459	453	460	ABC	5.3905	m	4c_.06
LINE460	453	461	ABC	5.3905	m	4c_.06
LINE461	453	462	ABC	3.6859	m	2c_16
LINE462	455	463	ABC	0.71675	m	2c_16
LINE463	456	464	ABC	0.15483	m	4c_.1
LINE464	457	465	ABC	0.040311	m	4c_.1
LINE465	459	466	ABC	0.63421	m	2c_16
LINE466	460	467	ABC	5.9891	m	4c_.06
LINE467	460	468	ABC	5.9891	m	4c_.06
LINE468	460	469	ABC	0.88292	m	4c_.06
LINE469	462	470	ABC	0.53828	m	2c_16
LINE470	463	471	ABC	0.49923	m	2c_16
LINE471	464	472	ABC	0.14736	m	4c_.1
LINE472	465	473	ABC	0.049497	m	4c_.1
LINE473	466	474	ABC	3.201	m	2c_16

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE474	467	475	ABC	2.1947	m	4c_.06
LINE475	467	476	ABC	2.1947	m	4c_.06
LINE476	470	477	ABC	0.29351	m	2c_16
LINE477	471	478	ABC	0.35077	m	2c_16
LINE478	472	479	ABC	0.16601	m	4c_.1
LINE479	473	480	ABC	0.063953	m	4c_.1
LINE480	474	481	ABC	0.18984	m	2c_16
LINE481	475	482	ABC	4.6432	m	4c_.06
LINE482	475	483	ABC	4.6432	m	4c_.06
LINE483	475	484	ABC	10.2769	m	2c_16
LINE484	477	485	ABC	0.19883	m	2c_16
LINE485	478	486	ABC	0.1676	m	2c_16
LINE486	479	487	ABC	0.17536	m	4c_.1
LINE487	480	488	ABC	0.11163	m	4c_.1
LINE488	481	489	ABC	0.1713	m	2c_16
LINE489	482	490	ABC	6.6548	m	4c_.06
LINE490	482	491	ABC	6.6548	m	4c_.06
LINE491	484	492	ABC	0.57796	m	2c_16
LINE492	484	493	ABC	4.0726	m	2c_16
LINE493	485	494	ABC	0.30201	m	2c_16
LINE494	486	495	ABC	0.10617	m	2c_16
LINE495	487	496	ABC	0.38342	m	4c_.1
LINE496	488	497	ABC	0.13972	m	4c_.1
LINE497	489	498	ABC	0.23283	m	2c_16
LINE498	490	499	ABC	4.0612	m	4c_.06
LINE499	490	500	ABC	4.0612	m	4c_.06
LINE500	492	501	ABC	0.24429	m	2c_16
LINE501	493	502	ABC	2.606	m	2c_16
LINE502	494	503	ABC	0.45833	m	2c_16
LINE503	495	504	ABC	0.071784	m	2c_16
LINE504	496	505	ABC	8.6961	m	4c_.1
LINE505	497	506	ABC	0.096167	m	4c_.1
LINE506	498	507	ABC	0.30564	m	2c_16
LINE507	499	508	ABC	0.69938	m	4c_.06
LINE508	499	509	ABC	0.69938	m	4c_.06
LINE509	501	510	ABC	0.14354	m	2c_16
LINE510	503	511	ABC	0.32517	m	2c_16
LINE511	504	512	ABC	0.10013	m	2c_16
LINE512	505	513	ABC	5.5648	m	2c_16
LINE513	505	514	ABC	1.3369	m	4c_.1
LINE514	506	515	ABC	0.085492	m	4c_.1

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE515	508	516	ABC	1.8857	m	4c_.06
LINE516	508	517	ABC	1.8857	m	4c_.06
LINE517	508	518	ABC	4.7316	m	2c_16
LINE518	510	519	ABC	0.1321	m	2c_16
LINE519	511	520	ABC	0.22216	m	2c_16
LINE520	512	521	ABC	0.07642	m	2c_16
LINE521	513	522	ABC	4.9074	m	2c_16
LINE522	514	523	ABC	0.72122	m	4c_.1
LINE523	515	524	ABC	0.066573	m	4c_.1
LINE524	516	525	ABC	1.3881	m	4c_.06
LINE525	516	526	ABC	1.3881	m	4c_.06
LINE526	518	527	ABC	2.796	m	2c_16
LINE527	519	528	ABC	0.11769	m	2c_16
LINE528	520	529	ABC	0.17555	m	2c_16
LINE529	521	530	ABC	0.54535	m	2c_16
LINE530	523	531	ABC	0.10771	m	4c_.1
LINE531	524	532	ABC	0.060803	m	4c_.1
LINE532	525	533	ABC	1.8899	m	4c_.06
LINE533	525	534	ABC	1.8899	m	4c_.06
LINE534	527	535	ABC	2.2154	m	2c_16
LINE535	528	536	ABC	0.12209	m	2c_16
LINE536	529	537	ABC	0.56286	m	2c_16
LINE537	530	538	ABC	1.9227	m	2c_16
LINE538	530	539	ABC	5.5837	m	2c_16
LINE539	531	540	ABC	0.082219	m	4c_.1
LINE540	532	541	ABC	0.065513	m	4c_.1
LINE541	533	542	ABC	1.3374	m	4c_.06
LINE542	533	543	ABC	1.3374	m	4c_.06
LINE543	535	544	ABC	0.91542	m	2c_16
LINE544	536	545	ABC	0.36857	m	2c_16
LINE545	537	546	ABC	4.5527	m	2c_16
LINE546	538	547	ABC	2.1231	m	2c_16
LINE547	540	548	ABC	0.076896	m	4c_.1
LINE548	541	549	ABC	0.086145	m	4c_.1
LINE549	542	550	ABC	3.7401	m	4c_.06
LINE550	542	551	ABC	3.7401	m	4c_.06
LINE551	544	552	ABC	0.28804	m	2c_16
LINE552	544	553	ABC	3.789	m	2c_16
LINE553	545	554	ABC	0.37143	m	2c_16
LINE554	546	555	ABC	0.22672	m	2c_16
LINE555	547	556	ABC	5.7548	m	2c_16

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE556	548	557	ABC	0.082	m	4c_.1
LINE557	549	558	ABC	0.061612	m	4c_.1
LINE558	550	559	ABC	2.7082	m	4c_.06
LINE559	550	560	ABC	2.7082	m	4c_.06
LINE560	552	561	ABC	0.10599	m	2c_16
LINE561	553	562	ABC	2.8664	m	2c_16
LINE562	554	563	ABC	3.4705	m	2c_16
LINE563	555	564	ABC	0.17889	m	2c_16
LINE564	557	565	ABC	0.07256	m	4c_.1
LINE565	558	566	ABC	0.12021	m	4c_.1
LINE566	559	567	ABC	0.60068	m	4c_.06
LINE567	559	568	ABC	0.60068	m	4c_.06
LINE568	559	569	ABC	3.8482	m	2c_16
LINE569	561	570	ABC	0.15788	m	2c_16
LINE570	564	571	ABC	0.20224	m	2c_16
LINE571	565	572	ABC	0.074216	m	4c_.1
LINE572	567	573	ABC	0.14223	m	4c_.06
LINE573	567	574	ABC	0.14223	m	4c_.06
LINE574	569	575	ABC	0.48648	m	2c_16
LINE575	570	576	ABC	0.095	m	2c_16
LINE576	571	577	ABC	0.18	m	2c_16
LINE577	572	578	ABC	0.38305	m	4c_.1
LINE578	573	579	ABC	3.8558	m	4c_.06
LINE579	573	580	ABC	3.8558	m	4c_.06
LINE580	573	581	ABC	0.31979	m	4c_.06
LINE581	575	582	ABC	0.35899	m	2c_16
LINE582	576	583	ABC	0.11463	m	2c_16
LINE583	577	584	ABC	0.20718	m	2c_16
LINE584	578	585	ABC	4.7318	m	2c_16
LINE585	578	586	ABC	0.82623	m	4c_.1
LINE586	579	587	ABC	2.7022	m	4c_.06
LINE587	579	588	ABC	2.7022	m	4c_.06
LINE588	581	589	ABC	0.11628	m	4c_.06
LINE589	582	590	ABC	0.3493	m	2c_16
LINE590	583	591	ABC	0.10065	m	2c_16
LINE591	584	592	ABC	0.21243	m	2c_16
LINE592	585	593	ABC	0.27268	m	2c_16
LINE593	586	594	ABC	3.9483	m	4c_.1
LINE594	587	595	ABC	5.4142	m	4c_.06
LINE595	587	596	ABC	0.64238	m	4c_.06
LINE596	589	597	ABC	0.089275	m	4c_.06

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE597	590	598	ABC	3.2812	m	2c_16
LINE598	591	599	ABC	0.65862	m	2c_16
LINE599	592	600	ABC	0.25534	m	2c_16
LINE600	593	601	ABC	0.13695	m	2c_16
LINE601	594	602	ABC	9.1669	m	2c_16
LINE602	594	603	ABC	4.6424	m	4c_.1
LINE603	595	604	ABC	4.8283	m	4c_.06
LINE604	595	605	ABC	4.8283	m	4c_.06
LINE605	595	606	ABC	4.7719	m	4c_.06
LINE606	596	607	ABC	11.6642	m	2c_16
LINE607	596	608	ABC	11.6642	m	2c_16
LINE608	597	609	ABC	0.11037	m	4c_.06
LINE609	598	610	ABC	1.5271	m	2c_16
LINE610	599	611	ABC	4.8562	m	2c_16
LINE611	600	612	ABC	0.16008	m	2c_16
LINE612	601	613	ABC	0.11484	m	2c_16
LINE613	602	614	ABC	4.8374	m	2c_16
LINE614	603	615	ABC	4.4466	m	4c_.1
LINE615	604	616	ABC	3.9301	m	2c_.0225
LINE616	604	617	ABC	3.1088	m	4c_.06
LINE617	604	618	ABC	3.1088	m	4c_.06
LINE618	607	619	ABC	2.7454	m	2c_16
LINE619	609	620	ABC	0.06364	m	4c_.06
LINE620	610	621	ABC	0.71673	m	2c_16
LINE621	612	622	ABC	0.68797	m	2c_16
LINE622	613	623	ABC	0.093648	m	2c_16
LINE623	615	624	ABC	1.6322	m	2c_16
LINE624	615	625	ABC	1.2511	m	4c_.1
LINE625	616	626	ABC	5.3537	m	2c_.0225
LINE626	620	627	ABC	0.077897	m	4c_.06
LINE627	621	628	ABC	0.47807	m	2c_16
LINE628	622	629	ABC	2.9004	m	2c_16
LINE629	623	630	ABC	0.147	m	2c_16
LINE630	624	631	ABC	0.40022	m	2c_16
LINE631	625	632	ABC	0.28784	m	4c_.1
LINE632	626	633	ABC	1.5703	m	2c_.0225
LINE633	627	634	ABC	0.065299	m	4c_.06
LINE634	628	635	ABC	0.73088	m	2c_16
LINE635	630	636	ABC	0.35053	m	2c_16
LINE636	631	637	ABC	0.27482	m	2c_16
LINE637	632	638	ABC	0.14284	m	4c_.1

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE638	633	639	ABC	5.1974	m	2c_.0225
LINE639	634	640	ABC	0.069123	m	4c_.06
LINE640	635	641	ABC	1.4274	m	2c_16
LINE641	636	642	ABC	0.24251	m	2c_16
LINE642	637	643	ABC	0.38096	m	2c_16
LINE643	638	644	ABC	0.15697	m	4c_.1
LINE644	640	645	ABC	0.068593	m	4c_.06
LINE645	641	646	ABC	0.39457	m	2c_16
LINE646	642	647	ABC	0.30835	m	2c_16
LINE647	643	648	ABC	0.90337	m	2c_16
LINE648	644	649	ABC	0.18112	m	4c_.1
LINE649	645	650	ABC	0.093984	m	4c_.06
LINE650	646	651	ABC	0.11455	m	2c_16
LINE651	647	652	ABC	0.18732	m	2c_16
LINE652	648	653	ABC	0.68671	m	2c_16
LINE653	649	654	ABC	0.1831	m	4c_.1
LINE654	650	655	ABC	0.12394	m	4c_.06
LINE655	651	656	ABC	0.099368	m	2c_16
LINE656	651	657	ABC	0.52781	m	2c_16
LINE657	652	658	ABC	0.16911	m	2c_16
LINE658	653	659	ABC	0.48206	m	2c_16
LINE659	654	660	ABC	0.20299	m	4c_.1
LINE660	655	661	ABC	0.36466	m	4c_.06
LINE661	656	662	ABC	0.093	m	2c_16
LINE662	657	663	ABC	0.69648	m	2c_16
LINE663	658	664	ABC	0.28521	m	2c_16
LINE664	659	665	ABC	0.505	m	2c_16
LINE665	660	666	ABC	0.29519	m	4c_.1
LINE666	661	667	ABC	0.26019	m	4c_.06
LINE667	662	668	ABC	0.095802	m	2c_16
LINE668	663	669	ABC	2.8935	m	2c_16
LINE669	664	670	ABC	0.2804	m	2c_16
LINE670	665	671	ABC	0.41461	m	2c_16
LINE671	666	672	ABC	0.4801	m	2c_16
LINE672	666	673	ABC	0.81161	m	4c_.1
LINE673	667	674	ABC	0.20184	m	4c_.06
LINE674	668	675	ABC	0.69267	m	2c_16
LINE675	669	676	ABC	1.2288	m	2c_16
LINE676	670	677	ABC	0.13267	m	2c_16
LINE677	671	678	ABC	0.68648	m	2c_16
LINE678	672	679	ABC	0.2883	m	2c_16

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE679	673	680	ABC	5.1393	m	4c_.1
LINE680	674	681	ABC	0.40252	m	4c_.06
LINE681	675	682	ABC	5.0441	m	2c_16
LINE682	677	683	ABC	0.14572	m	2c_16
LINE683	678	684	ABC	2.2185	m	2c_16
LINE684	679	685	ABC	0.26744	m	2c_16
LINE685	680	686	ABC	3.6787	m	4c_.1
LINE686	683	687	ABC	0.13986	m	2c_16
LINE687	684	688	ABC	5.1838	m	2c_16
LINE688	685	689	ABC	0.26095	m	2c_16
LINE689	686	690	ABC	8.1445	m	2c_16
LINE690	686	691	ABC	10.5254	m	4c_.1
LINE691	687	692	ABC	0.16867	m	2c_16
LINE692	689	693	ABC	0.19573	m	2c_16
LINE693	690	694	ABC	0.76157	m	2c_16
LINE694	690	695	ABC	2.1261	m	2c_16
LINE695	691	696	ABC	9.4817	m	2c_16
LINE696	691	697	ABC	2.1907	m	4c_.1
LINE697	692	698	ABC	0.26905	m	2c_16
LINE698	693	699	ABC	0.31093	m	2c_16
LINE699	694	700	ABC	0.2383	m	2c_16
LINE700	695	701	ABC	4.3312	m	2c_16
LINE701	696	702	ABC	5.493	m	2c_16
LINE702	697	703	ABC	2.4	m	4c_.06
LINE703	698	704	ABC	0.73636	m	2c_16
LINE704	699	705	ABC	0.52424	m	2c_16
LINE705	700	706	ABC	0.15322	m	2c_16
LINE706	703	707	ABC	6.3308	m	4c_.06
LINE707	703	708	ABC	0.11132	m	4c_.06
LINE708	704	709	ABC	0.97996	m	2c_16
LINE709	705	710	ABC	3.9281	m	2c_16
LINE710	706	711	ABC	0.092418	m	2c_16
LINE711	707	712	ABC	7.5025	m	4c_.06
LINE712	707	713	ABC	3.9448	m	2c_16
LINE713	708	714	ABC	0.10474	m	4c_.06
LINE714	709	715	ABC	0.093338	m	2c_16
LINE715	710	716	ABC	3.2225	m	2c_16
LINE716	711	717	ABC	0.093408	m	2c_16
LINE717	712	718	ABC	7.7434	m	4c_.06
LINE718	713	719	ABC	0.4223	m	2c_16
LINE719	714	720	ABC	0.097	m	4c_.06

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE720	715	721	ABC	0.073817	m	2c_16
LINE721	716	722	ABC	1.021	m	2c_16
LINE722	717	723	ABC	0.083433	m	2c_16
LINE723	718	724	ABC	3.2535	m	4c_.06
LINE724	718	725	ABC	9.3475	m	2c_16
LINE725	719	726	ABC	0.16124	m	2c_16
LINE726	720	727	ABC	0.10977	m	4c_.06
LINE727	721	728	ABC	0.071694	m	2c_16
LINE728	722	729	ABC	0.92949	m	2c_16
LINE729	723	730	ABC	0.094	m	2c_16
LINE730	724	731	ABC	4.421	m	4c_.06
LINE731	725	732	ABC	1.2539	m	2c_16
LINE732	726	733	ABC	0.17056	m	2c_16
LINE733	727	734	ABC	0.089889	m	4c_.06
LINE734	728	735	ABC	0.076792	m	2c_16
LINE735	729	736	ABC	0.50625	m	2c_16
LINE736	730	737	ABC	0.075313	m	2c_16
LINE737	731	738	ABC	5.1761	m	4c_.06
LINE738	732	739	ABC	0.65877	m	2c_16
LINE739	733	740	ABC	0.14155	m	2c_16
LINE740	734	741	ABC	0.13761	m	4c_.06
LINE741	735	742	ABC	0.071	m	2c_16
LINE742	736	743	ABC	0.40432	m	2c_16
LINE743	737	744	ABC	0.090338	m	2c_16
LINE744	738	745	ABC	4.1562	m	4c_.06
LINE745	739	746	ABC	3.7387	m	2c_16
LINE746	739	747	ABC	0.12202	m	2c_16
LINE747	740	748	ABC	0.16763	m	2c_16
LINE748	741	749	ABC	0.16427	m	4c_.06
LINE749	742	750	ABC	0.06691	m	2c_16
LINE750	743	751	ABC	0.34477	m	2c_16
LINE751	744	752	ABC	0.09735	m	2c_16
LINE752	745	753	ABC	1.5434	m	4c_.06
LINE753	745	754	ABC	5.9227	m	2c_16
LINE754	746	755	ABC	3.0391	m	2c_16
LINE755	747	756	ABC	0.088238	m	2c_16
LINE756	748	757	ABC	0.16348	m	2c_16
LINE757	749	758	ABC	0.12454	m	4c_.06
LINE758	750	759	ABC	0.093059	m	2c_16
LINE759	751	760	ABC	0.40459	m	2c_16
LINE760	752	761	ABC	0.17761	m	2c_16

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE761	753	762	ABC	2.1279	m	4c_.06
LINE762	754	763	ABC	4.9506	m	2c_16
LINE763	756	764	ABC	0.074465	m	2c_16
LINE764	757	765	ABC	0.22475	m	2c_16
LINE765	758	766	ABC	0.12167	m	4c_.06
LINE766	759	767	ABC	0.11404	m	2c_16
LINE767	760	768	ABC	0.36969	m	2c_16
LINE768	761	769	ABC	1.3288	m	2c_16
LINE769	762	770	ABC	5.2347	m	4c_.06
LINE770	763	771	ABC	3.6007	m	2c_16
LINE771	763	772	ABC	0.13038	m	2c_16
LINE772	764	773	ABC	0.12578	m	2c_16
LINE773	765	774	ABC	0.30918	m	2c_16
LINE774	766	775	ABC	0.07931	m	4c_.06
LINE775	767	776	ABC	0.54052	m	2c_16
LINE776	768	777	ABC	0.57353	m	2c_16
LINE777	769	778	ABC	4.0721	m	2c_16
LINE778	770	779	ABC	4.2428	m	4c_.06
LINE779	771	780	ABC	3.5283	m	2c_16
LINE780	772	781	ABC	0.12466	m	2c_16
LINE781	773	782	ABC	0.17614	m	2c_16
LINE782	774	783	ABC	0.3272	m	2c_16
LINE783	775	784	ABC	0.097	m	4c_.06
LINE784	776	785	ABC	4.6216	m	2c_16
LINE785	777	786	ABC	1.1579	m	2c_16
LINE786	779	787	ABC	3.3152	m	4c_.06
LINE787	781	788	ABC	0.13439	m	2c_16
LINE788	782	789	ABC	0.1307	m	2c_16
LINE789	783	790	ABC	0.21735	m	2c_16
LINE790	784	791	ABC	0.091984	m	4c_.06
LINE791	786	792	ABC	0.34588	m	2c_16
LINE792	786	793	ABC	2.062	m	2c_16
LINE793	787	794	ABC	2.9963	m	4c_.06
LINE794	788	795	ABC	0.12	m	2c_16
LINE795	789	796	ABC	0.21651	m	2c_16
LINE796	790	797	ABC	0.22121	m	2c_16
LINE797	791	798	ABC	0.091706	m	4c_.06
LINE798	792	799	ABC	0.30164	m	2c_16
LINE799	793	800	ABC	3.2995	m	2c_16
LINE800	794	801	ABC	0.20555	m	2c_16
LINE801	794	802	ABC	2.8031	m	4c_95_SAC_XC

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE802	795	803	ABC	0.13252	m	2c_16
LINE803	796	804	ABC	1.5028	m	2c_16
LINE804	797	805	ABC	0.10577	m	2c_16
LINE805	798	806	ABC	0.12311	m	4c_.06
LINE806	799	807	ABC	0.24947	m	2c_16
LINE807	800	808	ABC	2.8191	m	2c_16
LINE808	801	809	ABC	0.20609	m	2c_16
LINE809	802	810	ABC	3.0749	m	4c_.06
LINE810	802	811	ABC	3.0749	m	4c_.06
LINE811	803	812	ABC	0.08544	m	2c_16
LINE812	804	813	ABC	3.3195	m	2c_16
LINE813	805	814	ABC	0.16824	m	2c_16
LINE814	806	815	ABC	0.42086	m	4c_.06
LINE815	807	816	ABC	0.194	m	2c_16
LINE816	808	817	ABC	1.5955	m	2c_16
LINE817	809	818	ABC	0.20649	m	2c_16
LINE818	810	819	ABC	2.5782	m	4c_.06
LINE819	810	820	ABC	2.5782	m	4c_.06
LINE820	812	821	ABC	0.13123	m	2c_16
LINE821	814	822	ABC	0.15794	m	2c_16
LINE822	815	823	ABC	0.48651	m	4c_.06
LINE823	816	824	ABC	0.19731	m	2c_16
LINE824	818	825	ABC	0.20524	m	2c_16
LINE825	819	826	ABC	2.7715	m	4c_.06
LINE826	819	827	ABC	2.7715	m	4c_.06
LINE827	821	828	ABC	1.0794	m	2c_16
LINE828	822	829	ABC	0.22567	m	2c_16
LINE829	823	830	ABC	0.49659	m	4c_.06
LINE830	824	831	ABC	0.17123	m	2c_16
LINE831	825	832	ABC	0.20602	m	2c_16
LINE832	826	833	ABC	2.2755	m	4c_.06
LINE833	826	834	ABC	2.2755	m	4c_.06
LINE834	828	835	ABC	3.7201	m	2c_16
LINE835	829	836	ABC	2.3821	m	2c_16
LINE836	831	837	ABC	0.12298	m	2c_16
LINE837	832	838	ABC	0.20588	m	2c_16
LINE838	833	839	ABC	2.443	m	4c_.06
LINE839	833	840	ABC	2.443	m	4c_.06
LINE840	836	841	ABC	0.95278	m	2c_16
LINE841	837	842	ABC	0.14278	m	2c_16
LINE842	838	843	ABC	0.20601	m	2c_16

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE843	839	844	ABC	4.8092	m	2c_.0225
LINE844	839	845	ABC	3.6212	m	4c_.06
LINE845	839	846	ABC	3.6212	m	4c_.06
LINE846	841	847	ABC	0.48382	m	2c_16
LINE847	842	848	ABC	0.2151	m	2c_16
LINE848	843	849	ABC	0.10056	m	2c_16
LINE849	844	850	ABC	0.7036	m	2c_.0225
LINE850	845	851	ABC	4.364	m	4c_.06
LINE851	845	852	ABC	4.364	m	4c_.06
LINE852	847	853	ABC	0.10706	m	2c_16
LINE853	848	854	ABC	0.35143	m	2c_16
LINE854	849	855	ABC	2.2601	m	2c_16
LINE855	850	856	ABC	1.9822	m	2c_.0225
LINE856	851	857	ABC	6.8621	m	4c_.06
LINE857	851	858	ABC	6.8621	m	4c_.06
LINE858	853	859	ABC	0.084315	m	2c_16
LINE859	854	860	ABC	2.82	m	2c_16
LINE860	854	861	ABC	7.5091	m	2c_16
LINE861	855	862	ABC	1.4697	m	2c_16
LINE862	856	863	ABC	2.3276	m	2c_.0225
LINE863	857	864	ABC	2.7888	m	4c_.06
LINE864	857	865	ABC	2.7888	m	4c_.06
LINE865	859	866	ABC	0.090338	m	2c_16
LINE866	862	867	ABC	1.2854	m	2c_16
LINE867	863	868	ABC	0.30194	m	2c_.0225
LINE868	864	869	ABC	1.7373	m	4c_.06
LINE869	864	870	ABC	1.7373	m	4c_.06
LINE870	866	871	ABC	0.072277	m	2c_16
LINE871	867	872	ABC	1.3483	m	2c_16
LINE872	868	873	ABC	0.37952	m	2c_.0225
LINE873	868	874	ABC	0.84439	m	2c_.0225
LINE874	869	875	ABC	1.2	m	4c_.06
LINE875	869	876	ABC	1.2	m	4c_.06
LINE876	871	877	ABC	0.070178	m	2c_16
LINE877	872	878	ABC	2.3022	m	2c_16
LINE878	873	879	ABC	0.35118	m	2c_.0225
LINE879	874	880	ABC	1.9761	m	2c_.0225
LINE880	875	881	ABC	1.0112	m	4c_.06
LINE881	875	882	ABC	1.0112	m	4c_.06
LINE882	877	883	ABC	0.07	m	2c_16
LINE883	878	884	ABC	0.56468	m	2c_16

Name	Bus1	Bus2	Phases	Length	Units	LineCode
LINE884	879	885	ABC	0.534	m	2c_.0225
LINE885	880	886	ABC	4.6879	m	2c_.0225
LINE886	883	887	ABC	0.069181	m	2c_16
LINE887	884	888	ABC	0.62293	m	2c_16
LINE888	884	889	ABC	3.1574	m	35_SAC_XSC
LINE889	885	890	ABC	0.67483	m	2c_.0225
LINE890	887	891	ABC	1.2371	m	2c_16
LINE891	888	892	ABC	1.0228	m	2c_16
LINE892	889	893	ABC	2.6779	m	35_SAC_XSC
LINE893	890	894	ABC	2.6271	m	2c_.0225
LINE894	891	895	ABC	5.8249	m	2c_16
LINE895	891	896	ABC	3.2587	m	2c_16
LINE896	892	897	ABC	0.20223	m	2c_16
LINE897	893	898	ABC	4.501	m	35_SAC_XSC
LINE898	894	899	ABC	4.7723	m	2c_.0225
LINE899	895	900	ABC	3.8684	m	2c_16
LINE900	897	901	ABC	0.17088	m	2c_16
LINE901	901	902	ABC	0.144	m	2c_16
LINE902	902	903	ABC	0.18732	m	2c_16
LINE903	903	904	ABC	0.33902	m	2c_16
LINE904	904	905	ABC	0.5878	m	2c_16
LINE905	905	906	ABC	4.8147	m	2c_16

Load Data

Note: All the loads are single phase and constant PQ. The actual capacity will be taken by multiplying the kW value with the corresponding multiplier.

Name	Bus	phases	kV	Connection	kW	PF	Yearly
LOAD1	34	A	0.23	wye	1	0.95	Shape_1
LOAD2	47	B	0.23	wye	1	0.95	Shape_2
LOAD3	70	A	0.23	wye	1	0.95	Shape_3
LOAD4	73	A	0.23	wye	1	0.95	Shape_4
LOAD5	74	A	0.23	wye	1	0.95	Shape_5
LOAD6	83	B	0.23	wye	1	0.95	Shape_6
LOAD7	178	B	0.23	wye	1	0.95	Shape_7
LOAD8	208	C	0.23	wye	1	0.95	Shape_8
LOAD9	225	A	0.23	wye	1	0.95	Shape_9
LOAD10	248	B	0.23	wye	1	0.95	Shape_10
LOAD11	249	B	0.23	wye	1	0.95	Shape_11
LOAD12	264	C	0.23	wye	1	0.95	Shape_12
LOAD13	276	B	0.23	wye	1	0.95	Shape_13

LOAD14	289	A	0.23	wye	1	0.95	Shape_14
LOAD15	314	B	0.23	wye	1	0.95	Shape_15
LOAD16	320	C	0.23	wye	1	0.95	Shape_16
LOAD17	327	C	0.23	wye	1	0.95	Shape_17
LOAD18	337	C	0.23	wye	1	0.95	Shape_18
LOAD19	342	C	0.23	wye	1	0.95	Shape_19
LOAD20	349	A	0.23	wye	1	0.95	Shape_20
LOAD21	387	A	0.23	wye	1	0.95	Shape_21
LOAD22	388	A	0.23	wye	1	0.95	Shape_22
LOAD23	406	B	0.23	wye	1	0.95	Shape_23
LOAD24	458	C	0.23	wye	1	0.95	Shape_24
LOAD25	502	A	0.23	wye	1	0.95	Shape_25
LOAD26	522	B	0.23	wye	1	0.95	Shape_26
LOAD27	539	C	0.23	wye	1	0.95	Shape_27
LOAD28	556	C	0.23	wye	1	0.95	Shape_28
LOAD29	562	A	0.23	wye	1	0.95	Shape_29
LOAD30	563	A	0.23	wye	1	0.95	Shape_30
LOAD31	611	A	0.23	wye	1	0.95	Shape_31
LOAD32	614	C	0.23	wye	1	0.95	Shape_32
LOAD33	619	C	0.23	wye	1	0.95	Shape_33
LOAD34	629	A	0.23	wye	1	0.95	Shape_34
LOAD35	639	B	0.23	wye	1	0.95	Shape_35
LOAD36	676	B	0.23	wye	1	0.95	Shape_36
LOAD37	682	B	0.23	wye	1	0.95	Shape_37
LOAD38	688	B	0.23	wye	1	0.95	Shape_38
LOAD39	701	C	0.23	wye	1	0.95	Shape_39
LOAD40	702	B	0.23	wye	1	0.95	Shape_40
LOAD41	755	B	0.23	wye	1	0.95	Shape_41
LOAD42	778	C	0.23	wye	1	0.95	Shape_42
LOAD43	780	C	0.23	wye	1	0.95	Shape_43
LOAD44	785	B	0.23	wye	1	0.95	Shape_44
LOAD45	813	B	0.23	wye	1	0.95	Shape_45
LOAD46	817	A	0.23	wye	1	0.95	Shape_46
LOAD47	835	C	0.23	wye	1	0.95	Shape_47
LOAD48	860	A	0.23	wye	1	0.95	Shape_48
LOAD49	861	A	0.23	wye	1	0.95	Shape_49
LOAD50	886	B	0.23	wye	1	0.95	Shape_50
LOAD51	896	A	0.23	wye	1	0.95	Shape_51
LOAD52	898	A	0.23	wye	1	0.95	Shape_52
LOAD53	899	B	0.23	wye	1	0.95	Shape_53
LOAD54	900	A	0.23	wye	1	0.95	Shape_54
LOAD55	906	A	0.23	wye	1	0.95	Shape_55