PERFORMANCE ANALYSIS OF GRID INTEGRATED SPV SYSTEM USING MATLAB SIMULINK

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CERTIFICATE OF APPROVAL

The forgoing thesis is hereby approved as a credible study of a technological subject carried out and presented in a satisfactory manner to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned persons do not necessarily endorse or approve the thesis only for the purpose for which it has been submitted.

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"PERFORMANCE ANALYSIS OF GRID INTEGRATED SPV SYSTEM USING MATLAB SIMULINK"** by **"ATINDRA KOLAY"** in partial fulfilment of requirements for the award of **M.Tech. in Energy Science & Technology** submitted in the **School of Energy Studies at JADAVPUR UNIVERSITY, KOLKATA,** is an authentic record of my own work carried out during a period from 2021 to 2022 under the supervision of **Dr. Ratan Mandal.** The mater presented in the thesis has not been submitted by me in any other University / Institute for the award of M.Tech. Degree.

All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

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Abstract

Fossil fuel is going to end very quickly from the earth. So, scientists are looking for alternative sources of energy. Solar energy, wind energy, biomass energy, geothermal energy, Ocean wave energy, and solid waste energy can be the alternative source of energy that will never be dying out from the earth. So, day by day mankind is interested in them.

Solar energy must be converted to electrical energy to get a better advantage of it. We can use solar panels to convert electrical energy either directly using the electricity or using the electricity connecting to the grid. We must keep in mind that solar energy is not available at night and when there is a cloud in the sky. So, for the night, if we want to use solar energy, we must have to use battery bank. What we can do is we have to charge the battery bank during the daytime.

Now the main aspect of this thesis is what should we do if the battery bank is charged fully or there is instant requirement of high load in a particular area. In this scenario, for more economic operation we can connect the solar panels converted electricity to the grid so that electricity is accessible to the people of the broader area.

In this scenario, we must keep in mind about power factor, THD, voltage regulation, frequency, and harmonics in the grid. In this thesis what are the effect of power factor, THD, voltage regulation, frequency, harmonics are discussed in detail.

Now how can we mitigate those effect which is harmful to grid, and which caused low power quality is also discussed in this thesis.

And we will create a MATLAB model for renewable energy grid integration, and we will do input-output analysis of the MATLAB model and efficiency will be calculated. Here we have taken five cities like Kolkata, Delhi, Bangalore, Shillong and Mumbai. And the efficiency is the highest in Delhi because total sunshine hour is high in that area and the lowest in Shillong as total sunshine hour is low in that area.

Contents

Chapter 1: INTRODUCTION

INTRODUCTION

1.1 Background

The integration of a significant amount of variable renewables into power grids requires substantial transformations to increase the flexibility of the existing grids: a) to allow electricity flow, not only from centralised power plants to users, but also from small users or producers to the grid, which is aimed to ensure grid stability when installing distributed generation; b) to establish intelligent grid and demand management mechanisms aimed at increasing flexibility and responsiveness and reducing peak-loads in order to deal with increased variability; c) to improve grid interconnection at the regional and international level aimed at increasing balancing capabilities, flexibility, stability and security of supply; and d) to introduce energy storage capacity to store electricity (energy) from variable renewables generation when production exceeds demand. An “enabler” for these transformations is the implementation of smart grid technologies, which incorporate grid elements with “smart” functionality to balance supply and demand, together with information and communication technologies to increase flexibility, improve reliability and support the integration of renewables.

1.2 Power

We can define power as the rate of doing work, it is the work done in unit time. The SI unit of power is Watt (W) which is joules per second (J/s). Sometimes the power of motor vehicles and other machines is given in terms of Horsepower (hp), which is approximately equal to 745.7 watts.

Power is defined as the rate at which work is done upon an object. Power is a time-based quantity. Which is related to how fast a job is done. The formula for power is mentioned below.

Power = Work / time

P = W / t

1.3 Energy

Energy is defined as the capacity of a physical system to perform work. However, it's important to keep in mind that just because energy exists, that doesn't mean it's necessarily available to do work.

Forms of Energy

Energy exists in several forms such as heat, kinetic or mechanical energy, light, potential energy, and electrical energy.

- **Heat** - Heat or thermal energy is energy from the movement of atoms or molecules. It may be considered as energy relating to temperature.
- **Kinetic Energy** - Kinetic energy is the energy of motion. A swinging pendulum has kinetic energy.
- **Potential Energy** - This is energy due to an object's position. For example, a ball sitting on a table has potential energy with respect to the floor because gravity acts upon it.
- **Mechanical Energy** - Mechanical energy is the sum of the kinetic and potential energy of a body.

- **Light** - Photons are a form of energy.
- **Electrical Energy** - This is energy from the movement of charged particles, such as protons, electrons, or ions.
- **Magnetic Energy** - This form of energy results from a magnetic field.
- **Chemical Energy** - Chemical energy is released or absorbed by chemical reactions. It is produced by breaking or forming chemical bonds between atoms and molecules.
- **Nuclear Energy** - This is energy from interactions with the protons and neutrons of an atom. Typically, this relates to the strong force. Examples are energy released by fission and fusion.

Other forms of energy may include geothermal energy and the classification of energy as renewable or non-renewable.

There may be overlap between forms of energy and an object invariably possesses more than one type at a time. For example, a swinging pendulum has both kinetic and potential energy, thermal energy, and (depending on its composition) may have electrical and magnetic energy.

1.4 Solar Cell

Solar cell, also called photovoltaic cell**,** any device that directly converts the energy of light into electrical energy through the photovoltaic effect. The overwhelming majority of solar cells are fabricated from silicon—with increasing efficiency and lowering cost as the materials range from amorphous (nanocrystalline) to polycrystalline to crystalline (single crystal) silicon forms. Unlike batteries or fuel cells, solar cells do not utilize chemical reactions or require fuel to produce electric power, and, unlike electric generators, they do not have any moving parts.

Solar cells can be arranged into large groupings called arrays. These arrays, composed of many thousands of individual cells, can function as central electric power stations, converting sunlight into electrical energy for distribution to industrial, commercial, and residential users. Solar cells in much smaller configurations, commonly referred to as solar cell panels or simply solar panels, have been installed by homeowners on their rooftops to replace or augment their conventional electric supply. Solar cell panels also are used to provide electric power in many remote terrestrial locations where conventional electric power sources are either unavailable or prohibitively expensive to install. Because they have no moving parts that could need maintenance or fuels that would require replenishment, solar cells provide power for most space installations, from communications and weather satellites to space stations. (Solar power is insufficient for space probes sent to the outer planets of the solar system or into interstellar space, however, because of the diffusion of radiant energy with distance from the Sun.) Solar cells have also been used in consumer products, such as electronic toys, handheld calculators, and portable radios. Solar cells used in devices of this kind may utilize artificial light (e.g., from incandescent and fluorescent lamps) as well as sunlight [2].

1.5 Solar Module

Also called solar panels, a solar module is a single photovoltaic panel that is an assembly of connected solar cells. The solar cells absorb sunlight as a source of energy to generate electricity. An array of modules are used to supply power to buildings.

When we are going to connect the renewable energy with grid there is a transient and there is fluctuation of power so, more harmonics arises. So, we will discuss various aspect of power system like voltage, frequency, current, power factor which changes when we will go to connect to grid. From the studies of various research papers and methodologies from different journals we have to set aim and objective. Though it aspect is discussed in the Chapter 2 in details [4].

1.6 Objective

I. With the change in load, various parameter of power system i.e frequency, harmonics, voltage, power factor changes – we must do broad study about all of these.

II. For the change in the parameters like frequency, harmonics, voltage, power factor what will be the effect on the connected inverter.

III. How can we reduce or mitigate the effect of changes of power system parameter so that inverter can run smoothly.

I) a) Frequency: When the load changes frequency of the grid also changes. When the load is increased it requires more active power from the generation point, if the demand of active power is not or we can say it cannot be achieved, frequency of the system goes down. If load is decreased, this will attract less active power to the load side and therefore frequency of the grid will increase.

b) Harmonics: Harmonics in the grid depends on the nature of the load. If load is highly non-linear harmonics in the grid will be very high. Likewise, if load is mostly linear harmonics in the grid will be less. In practical load is non-linear in nature. So, we can say that there will be harmonics in the grid. We must reduce the harmonics in the grid so that power quality can be improved [6].

c) Voltage: When load is increased, voltage is down and load is decreased, voltage is up. Change in voltage from no load to full load is called voltage regulation. Voltage regulation may be positive, negative or zero. In case of capacitive load it may be zero even negative, in case of inductive load, it is positive.

d) Power factor: In an electric power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred.

1.7 Synopsis of the present work

Present author worked on some relevant areas of Renewable Grid Integration with MATLAB SIMULINK. Present author most focus area will be grid integration and reduction of harmonics in supplied power to the consumer. In present day, use of electronic appliances is gradually increased. They all can bear up to certain level of harmonics which is also mentioned in their respective specification otherwise their life span will gradually decrease due to harmonics. Now most of the DISCOMs are not following the suggested harmonics regulations. Mostly to convert DC to AC, inverter is used for Renewable Energy Grid Integration. Present author's focus will be to integrate different renewable sources with grid and reduction of harmonics will be done. To implement this concept of Signal Processing is required. According to my respected guide if we can use some rotating machine instead of inverter the harmonics can be reduced in great manner. Though respected professors and research scholars are working on it.

If we can reduce harmonics in the supplied power, we can improve the quality of power to the supply side of the consumers [7].

Another aspect is we have to keep in mind that cost must not increase when we will improve the power quality. Cost-effectiveness is also a great factor for which we must think about cost-effective technology [8].

1.8 Conclusion

In the conclusion we can say that we have learnt what is power, what is energy. We learnt about solar cells, solar modules etc. In the objective part with change in load how various parameters like voltage, current, power factor, frequency changes we have discussed it in detail. In the synopsis part It is discussed in detail what would be done throughout the thesis work. Focused area is renewable energy grid integration using MATLAB Simulink.

Chapter 2: REVIEW OF PREVIOUS WORK

2.1 Introduction

In this chapter we will discuss in detail about harmonics of the grid. What will be the effect of harmonics on grid. How will we mitigate the effect of these harmonics, we will discuss all of these in detail. Different paper of the different authors will be discussed in this chapter.

2.2 Literature Review

People from all over the world going towards renewable energy sources due to their various advantages over conventional energy system have led to their wide adoption around the world. Also, in the recent years' technical advances in power electronic converters and electronic materials have led to significant reduction in the cost of REGs such as solar and wind. Majority of developed countries have set energy targets for RE generation. India is targeting around 175 GW of power generation from renewable sources by the year 2022 with a contribution of 100 GW from solar and 60 GW from wind. In the early days of adoption of RE integration with the grid was not an issue and RE could be easily connected or disconnected from the grid. But with the increase in RE penetration grid integration is an issue as it would affects grid stability. This paper discusses the problem that arises when integrating RE to the grid and how it can be overcome by suggesting solutions [12].

Author presents a review on grid Integration and power quality issues associated with the integration of renewable energy systems in to grid and Role of power electronic devices and Flexible AC Transmission Systems related to these Issues. In this paper, recent trends in power electronics for the integration of wind and photovoltaic (PV) power generators are presented. Discussions about common and future trends in renewable energy systems based on reliability and maturity of each technology are presented. Classification of various Power Quality Issues used by different researchers has been done and put for reference. Application of various techniques as applied to mitigate the different Power Quality problems is also presented for consideration. Power Electronics interface not only plays a very important role in efficient integration of Wind and Solar energy system but also to its effects on the power-system operation especially where the renewable energy source constitutes a significant part of the total system capacity. However, there are various issues related to grid integration of RES keeping in the view of aforesaid trends it becomes necessary to investigate the possible solutions for these issues [13].

Nowadays, the call for energy has substantially extended due to which fossil fuels are consumed at an excessive charge. If the existing situation continues, younger generation is probably disadvantaged of their use of energy. To prevent customers from lagging of energy and to meet their needs, hybrid system is a precise solution. Solar and wind energy are to be had abundantly in huge quantity and can be considered as reliable source of energy generation. Wind/ solar hybrid RES is integrated to grid using grid interface inverter which incorporates power electronic switches which induce harmonics in the grid thus reducing the quality of power in the load side [14].

The energy is the very important parameter for survival or today's growth we can transfer the energy from one form to other. The mainly wind and solar energies are the most available among other renewable energy sources in all over the world. In the present years, because of the rapid advances of power electronic systems the production of electricity from wind and photovoltaic energy sources have increased significantly. In this paper, the performance of the wind/PV hybrid system is studied under different grid perturbation conditions. Based on the benchmark solid oxide fuel cell (SOFC) dynamic model for power system studies and the analysis of the SOFC operating conditions, the nonlinear programming (NLP) optimization method was used to determine the maximum electrical efficiency of the grid connected SOFC subject to the constraints of fuel utilization factor, stack temperature and output active power. The optimal operating conditions of the grid connected SOFC were obtained by solving the NLP problem considering the power consumed by the air compressor. With the optimal operating conditions of the SOFC for the maximum efficiency operation obtained at different active power output levels, a hierarchical load tracking control scheme for the grid connected SOFC was proposed to realize the maximum electrical efficiency operation with the stack temperature bounded [16].

Wind power, solar power and waterpower are technologies that can be used as the main sources of renewable energy so that the target of decarbonisation in the energy sector can be achieved. However, when compared with conventional power plants, they have a significant difference. The share of renewable energy has made a difference and posed various challenges, especially in the power generation system. The reliability of the power system can achieve the decarbonization target, but this objective often collides with several challenges and failures, such that they make achievement of the target very vulnerable, even so, the challenges and technological solutions are still very rarely discussed in the literature. This study carried out specific investigations on various technological solutions and challenges, especially in the power system domain. The results of the review of the solution matrix and the interrelated technological challenges are the most important parts to be developed in the future. Developing a matrix with various renewable technology solutions can help solve RE challenges. The potential of the developed technological solutions is expected to be able to help and prioritize them especially cost-effective energy. In addition, technology solutions that are identified in groups can help reduce certain challenges. The categories developed in this study are used to assist in determining the specific needs and increasing transparency of the renewable energy integration process in the future [17].

A primary goal of a grid integration study is to address stakeholder concerns that a power system can operate reliably and cost-effectively under high-RE scenarios. While grid integration studies can include RE resources such as hydropower, biomass, and geothermal, they typically focus on the impacts and integration solutions associated with variable RE resources, particularly wind and solar. These resources pose distinct operational challenges for power systems due to their variability (i.e., their change in output over various timescales due to the underlying fluctuation in resource) and uncertainty (i.e., the inability to perfectly predict resource availability and generator output). Although all power systems are designed and operated to efficiently manage variability and uncertainty in electricity demand and resource availability, significant levels of variable RE amplify this inherent variability and uncertainty and may require changes to system operations or physical infrastructure [18].

Economic growth and rising per capita energy consumption, coupled with conducive policy, regulatory framework, fiscal incentive has accelerated development of renewable energy (RE) generation in the country in past few decades. Presently, in renewable generation portfolio, wind constitutes major share and penetration of solar generation is also increasing, However, it is characterized by intermittency & variability. Increasing renewable penetration presents numerous challenges to the system planner as well as grid operator [19].

Identifies of challenges in grid integration of large-scale renewable as well as suggests suitable measures to address them. Need for requirement of other control infrastructure like establishment of Renewable Energy Management Centres (REMC) equipped with advanced forecasting tools as well as Real time measurement/monitoring schemes through WAMS applications, dynamic reactive compensation, energy storage to provide balancing services etc. It also highlights potential of renewable generation in deserts and transmissions plan that serve as a road map up to year 2050 [20].

In the United States and elsewhere, renewable energy (RE) generation supplies an increasingly large percentage of annual demand, including nine U.S. states where wind comprised over 10% of in-state generation in 2013. This white paper summarizes the challenges to integrating increasing amounts of variable RE, identifies emerging practices in power system planning and operation that can facilitate grid integration, and proposes a unifying concept—economic carrying capacity—that can provide a framework for evaluating actions to accommodate higher penetrations of RE. [22].

There is growing recognition that while technical challenges to variable RE integration are real, they can generally, be addressed via a variety of solutions that vary in implementation cost. As a result, limits to RE penetration are primarily economic, driven by factors that include transmission and the flexibility of the power grid to balance supply and demand. This limit can be expressed as economic carrying capacity, or the point at which variable RE is no longer economically competitive or desirable to the system or society. Power systems already have some degree of operational flexibility, an ability to respond to change in demand and supply, as they must accommodate variable and uncertain load. Power system operators have thus, been able to accommodate increased variable RE largely without substantial new investment in system flexibility, such as new storage, demand response, or generation dedicated to addressing RE variability and uncertainty. To achieve higher penetration levels, multiple grid integration studies in the United States have evaluated scenarios where an economic carrying capacity of at least 30% is achieved via transmission expansion and largely understood changes to system operations. Studies have also demonstrated that carrying capacity is not fixed and can be improved through technical and institutional changes. This creates the possibility to achieve even higher penetration levels through strategic investments in both demand- and supply-side sources of flexibility [22].

Countries around the world are establishing ambitious goals to scale up the contribution of renewable energy (RE) toward meeting national energy demand. Because RE resources such as wind and solar generally, increase variability and uncertainty associated with power system operations, reaching high penetrations of these resources on the grid requires an evolution in power system planning and operation. To plan for this evolution, power system stakeholders can undertake a grid integration study. A grid integration study is a comprehensive examination of the challenges and potential solutions associated with integrating significant variable RE generation in the electricity grid. The purpose of this guidebook is to introduce power system policymakers, regulators, operators, and supporting organizations to RE grid integration studies [25].

Widespread application of power electronics in Indus-trial and residential loads has increased the harmonics of the gird significantly. The grid harmonics have destructive impacts on the gird components including distribution transformers. Studying the impacts of current harmonics on distribution transformers is crucial for grid design and maintenance. Therefore, this paper studies the effect of gird harmonics on eddy current loss, other stray losses, hottest spot temperature, and lifetime of distribution transformers. The current harmonics of six 100KVA transformers at a provincial power distribution centre are measured in a oneweek test period and the impacts of grid harmonics on the investigated transformer are thoroughly discussed [26].

Grid-tied inverters, used in renewable energy sources, are exposed to distortions emitted by various sources including the reference signal, external power grid, and DC-link along with harmonics created by the pulse width modulation unit. However, the effect of these sources on grid-tied inverter output, especially near the resonant frequency of the inverter's filter, is unknown. In this study, a comprehensive harmonic model of the grid-tied inverter is presented by considering all three types of external sources. The proposed model can be utilised for low and high-frequency harmonic emission of grid-connected inverters. A new analytical expression is introduced as an indicator of the maximum possible individual grid current harmonic in the case of harmonic injection of multiple external sources. The impact of series damping resistor on harmonic rejection ability of the inverter is analysed at the range of frequencies around resonance. The simulation and experimental results fulfil the proposed harmonic model of the inverter [28].

In a power system there are different types of conventional and non-conventional energy resources. The conventional type of energy resources are coal, oil, petroleum and natural gases, fuel wood, thermal power plant, nuclear energy. The non-conventional energy resources are solar, wind, biomass, geo-thermal, ocean-current, tidal energy. All power plants are connected to national or regional grid. Individual State grids were interconnected to form five regional grids covering mainland India. The grids were the Northern, Eastern, Western, North-eastern and Southern Grids. Suppose solar PV system are generating electricity and suppose solar pump relates to it. Let, we assume, the electricity generated is sufficient to run the pump in the daytime. Now, at night as sun is not present, there is no electricity. If the solar pump must run at night, the excess power must be taken from the grid to run the pump unless and unless and until we store the excess energy in battery at daytime. Likewise, all the renewable energy sources and conventional power plants like thermal power plants are connected to grid and battery storage systems [30].

This paper presents the Harmonics in a power system caused by highly non-linear devices degrades its performance controlling and reducing such harmonics have been a major concern of power engineers for many years. This paper discusses the problem of harmonics pollution in electric networks and control methods. it proposes how the wave form of voltage/current is distorted and harmonics are injected to the system due to non-linear loads such as Variable Speed Drive, Arcing Devices, UPS, Personal Computer, Printers, Fluorescent Lamp, Cell Phone battery charger [32].

2.3 Impact of Harmonics on Grid

How Harmonics Impacts on Grid:

The non-linearity of the industrial and residential loads is increasing rapidly as a result of widespread applications of power electronics. The grid harmonics have destructive impacts on distribution transformers. Considering the initial costs of transformers, and the grid connectivity issues that may arise during their replacements, it is important to protect transformers from lifetime reduction. Therefore, studying the effect of current harmonics on the lifetime of distribution transformers is crucial for grid design and maintenance [32].

The main effects of voltage and current harmonics in a power system are usually:

- The potential amplification of some harmonics due to parallel or series resonance
- Reduced performance of energy generation, transport and usage systems
- The premature ageing of insulation on grid components, leading to energy reduction
- Poor functioning of the system or any of its components

Increasing concern on pollution and global warming has prompted Photovoltaic (PV) system as one of the potential renewable and clean energy in power system generation. Power quality issue such as Total Harmonic Distortion (THD) has become an increasingly serious concern as more PV is integrated into the grid system. This encourages an extensive study to identify the challenge in power system network. Power electronic devices used in power converters create power quality problem such as harmonic distortion. PV system performance in terms of power quality strictly depended on the use of the inverters, solar irradiance and temperature that may affect the power generated, voltage and current profile [26].

The effect of solar irradiance level on clear day condition is studied to investigate the effect of these phenomenon on the PV system total harmonic distortion performance. To accomplish this, a PV test model has been developed to investigate the crucial effect of PV generation in terms of voltage and current profile and its harmonic distortion behaviours. Previous investigation shows that PV system output power is proportional to the solar radiation variations. for example, the PV power output can have a sudden drop of up to 25% causes by the passing cloud as discussed in table no. 2.1.

Table No. 2.1, Harmonic voltage distortion limit for non-linear load at the point of common coupling (PCC) (adapted from IEEE 519–1992)

Harmonic Voltage Distortion in % at PCC			
	2.3 – 69 kV	69-161 kV	>161 kV
Maximum for Individual Harmonic	3.0	1.5	1.0
Total Harmonic Distortion (THD)	5.0	2.5	1.5

PCC is known as the point of PV system that is integrated to the main grid. It is recommended that the background voltage distortion of the system to be lower than 2.5% before a distributed resource such as PV is connected to the system as discussed in table no. 2.2 and 2.3.

Table No. 2.2, The maximum amount of injected current into the grids is monitored based on IEEE 1547 & IEC 61727 standards

Issues	IEC 61727		IEEE 1547	
Nominal Power	10kW		30kW	
Harmonic Currents Limits	Harmonics (nth)	THD (%)	Harmonics (nth)	THD (%)
	3-9	4	3-9	4
	11-15	2	11-15	2
	17-21	1.5	17-21	1.5
	23-33	0.6	23-33	0.6
			>35	0.3
Maximum Current THD	5%		5%	

Table No. 2.3, Maximum harmonic current distortion in % of load demand current (adapted from IEEE STD 519–1992 table 10.3)

ID	Maximum Harmonic Current Distortion in % Load Demand Current Voltages 0.12-69 kV Based on IEEE Std 519 1992						
	I_{sc}/I_L	Harmonic Order (Odd Harmonics)					THD
		<11	11<h<17	17<h<23	23<h<35	35<h	
A1	<20*	4	2	1.5	0.6	0.3	5
A2	20<50	7	3.5	2.5	1	0.5	8
A3	50<100	10	4.5	4	1.5	0.7	12
A4	100<1000	12	5.5	5	2	1	15
A5	>1000	15	7	6	2.5	1.4	20

Even harmonics are limited to 25% odd the odd harmonic limits above.
*All power generation equipment is limited to these values of Current distortion, regardless of actual I_{sc}/I_L.
Where: I_{sc} = Maximum short-circuit current at PCC
and I_L = Maximum load demand current (fundamental frequency) at PCC.

2.4 Conclusion

In this chapter we discussed about what is grid integration study, how grid integration works in detail. Most of the paper discussed about grid integration study but very less paper discusses about harmonics reduction technique. So, I discuss about how harmonics effects on grid. What is its effect on transformer, generator – we have discussed it. We discussed about power quality [8] issue. If there is more harmonics in the power which is delivered to the people, there will be hampered on customer side's electronics instrument. So, it is better if harmonics is less in output power of any generation system. So, many cases power electronics devices are used to reduce harmonics.

Chapter 3: THEORIES ON GRID HARMONICS

3.1 Introduction

In this chapter we will discussed about the theories that how we will mitigate harmonics distortion on grid. We will discuss how to nullify harmonics from transformer. For that reason, which harmonics will be removed from which side either primary side or secondary side. We will discuss how reactors will help us to mitigate harmonics. There are different types of inductors like only AC reactor and both AC and DC reactor. We will use these reactors and find corresponding total harmonics distortion or THD. [7] We will discuss about filtering concept. Active filters and passive filters will be discussed.

3.2 Harmonics' Nullification Theory

How to nullify the harmonics in the grid?

we must make an overview of methods to reduce or cancel harmonics in installations side or systems where harmonics already present, by adding additional hardware. we will focus the problem from another point of view to avoid harmonic generation from the very beginning by means of active front ends [26].

Transformer:

Transformers could nullify certain load harmonics. They can discriminate some harmonics to circulate upstream rather than to eliminate them from the system. It is the positive side of transformers.

- Delta-Star transformer: triplen harmonics in the secondary are not able to circulate in the primary of the distribution system since they are confined in the Neutral of the star connection.
- Zig-zag transformer: can also be used to trap triplen harmonics, by placing them close to the distorting loads, and avoiding its propagation upstream.
- Delta-Star-Delta transformer: placing two similar non-linear loads on each of the transformer secondaries (one Delta, the other Star), will have the effect of cancel harmonics 5th and 7th in the Delta primary.

Reactors (In case of AC line or DC link)

- Harmonics pollution of non-linear load can be eliminated by adding a series inductor (reactor), either to the AC line, to the DC link circuit, or both, with the ability of filtering upstream harmonic current, and decoupling the line voltage distortion from that at the non-linear load side. Either of these added elements can limit also current peaks.
- But this reactor has the drawbacks like voltage drops. We have to remember that it is designed for certain working point. It has high THD.

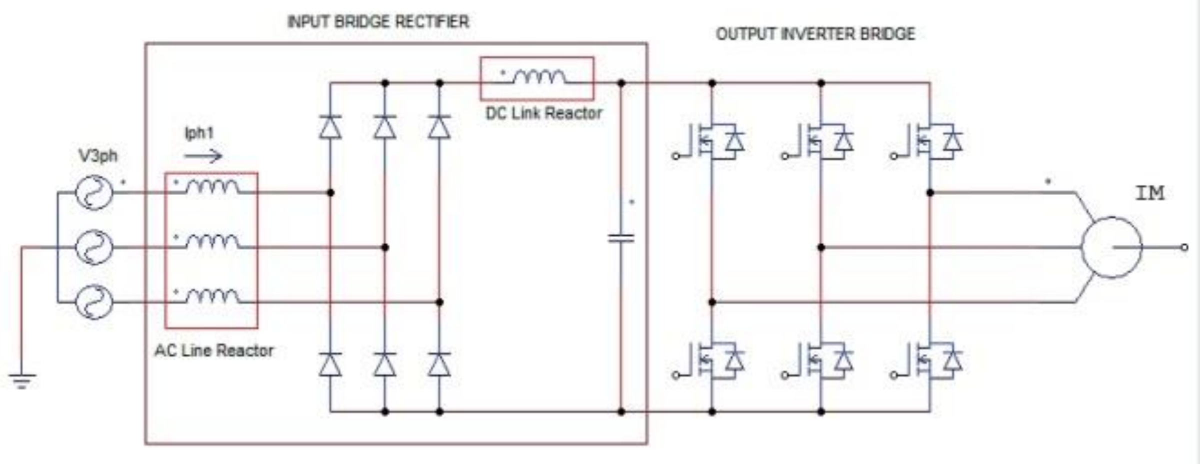

Fig. 3.1, Variable frequency drive motor with the dc link to eliminate harmonics

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In the fig. 3.1, the supply AC line reactors are shown. It is connected with diode configurations with it the DC link reactor is connected to avoid harmonics. A capacitor is connected to the variable frequency inverter. With the variable frequency inverter load is connected.

We see the configuration of variable frequency drive motor with the dc link. Now we see how THDs are changing with no reactor, with only AC reactor, with both AC and DC reactor.

- With no reactor THD is very high around 138%
- With only AC reactor THD is somehow less around 48%
- With both AC and DC reactor THD is very much less around 34%.

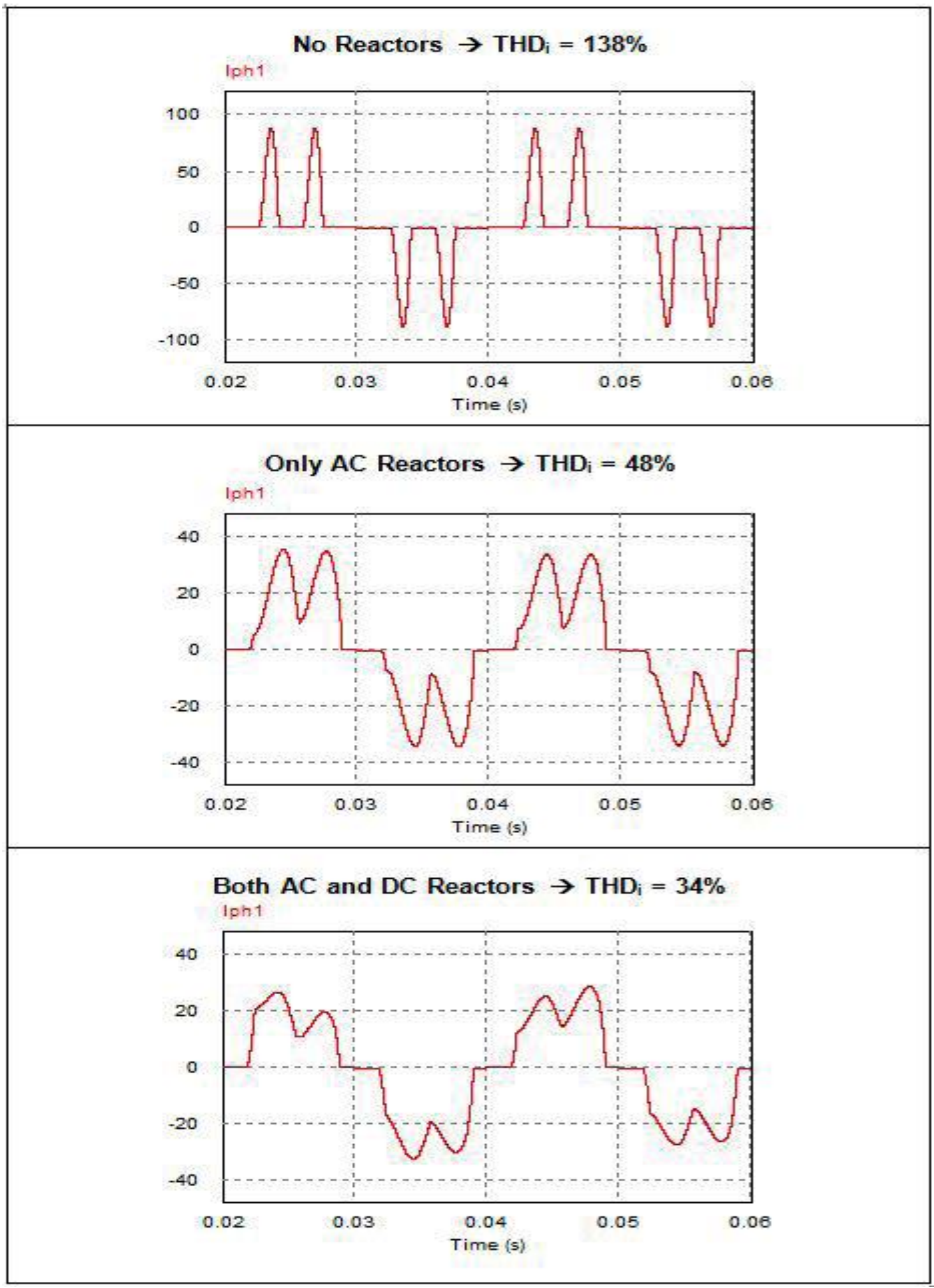


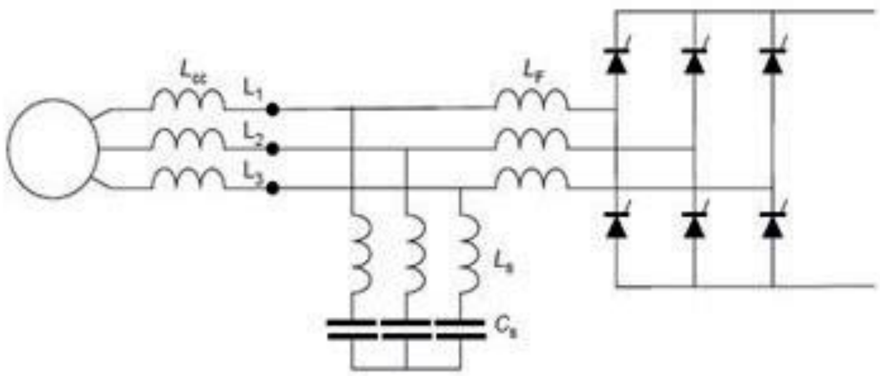
Fig. 3.2, THD with no reactor, with AC reactor, with both AC & DC reactors. (**REF.** JN004A01 **ED.** AUGUST 2015 - HARMONICS: CAUSES, EFFECTS AND MINIMIZATION - **SALICRU WHITE PAPERS)**

3.3 Filtering Concept

Shunt filter short-circuits harmonics current as close to the source of distortion. This helps the current to be out of the supply system. It is very common type of filter applied because it is economic in nature. It improves load power factor, and it eliminates harmonics current.

3.4 Passive Filter

Passive filter consists of inductor and capacitors sometimes a damping resistor is used for damping. It can filter low order harmonics like 5^{th}, 7^{th}, 11^{th} so on.



$$\textit{Resonance Frequency} \equiv 5^{th}\ \textit{Harmonic}$$

$$f_r = \frac{1}{2\pi\sqrt{L_S C_S}}$$

Fig.3.3, Passive Filter

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Passive filters have migration functionality at certain working points at a given load which is away from the point. Though lower the level of load, THD is not minimised. Moreover, they can reduce power factor if no additional circuit is added to compensate that (additional parallel inductor). If there is a possibility of resonance, there is a chance of change of change in source impedance as shown in the fig 3.3.

3.5 Active Filter

Active harmonic filters are power electronic equipment to cancel (or reduce) current harmonic pollution of an installation. The working principle consists in measuring the current harmonics of the load and generate in real-time the same harmonics but in phase opposition, in such way that the addition of both currents seen from the electrical installation contains nearly no harmonics, but only the fundamental f1. This yields to THD lowering, at levels typically below 5%. They also have the capability of reducing reactive power of the load, i.e., increasing power factor to nearly 1.

Due to its design and working principle, the distortion minimization is achieved for all load (within active filter capacity), and they are not affected by resonances nor line impedances.

So, compared to passive filters, they offer several advantages: can compensate several harmonics at the same time, correct also very high order harmonics, increase the power factor of the installation, offer more flexibility (not dependant on the load or source impedance).

On the other hand, they are a more complex and expensive equipment.
Note that the rating (kVA) of A.H.F. must be chosen not for the total rating of the installation (total power demand of the load), but for the Distorting Power that must be compensated.

(Example: an installation with a total power demand of S=60kVA, but with only 20kVA of them corresponding to distortion power D, would need an A.H.F. of around 25-30 kVA rated power).

For reasons given above and considering the robust and low cost of Passive Filters to compensate strong presence of a given harmonic, the Hybrid Filters (combination of Passive and Active), could be a good choice in certain cases.

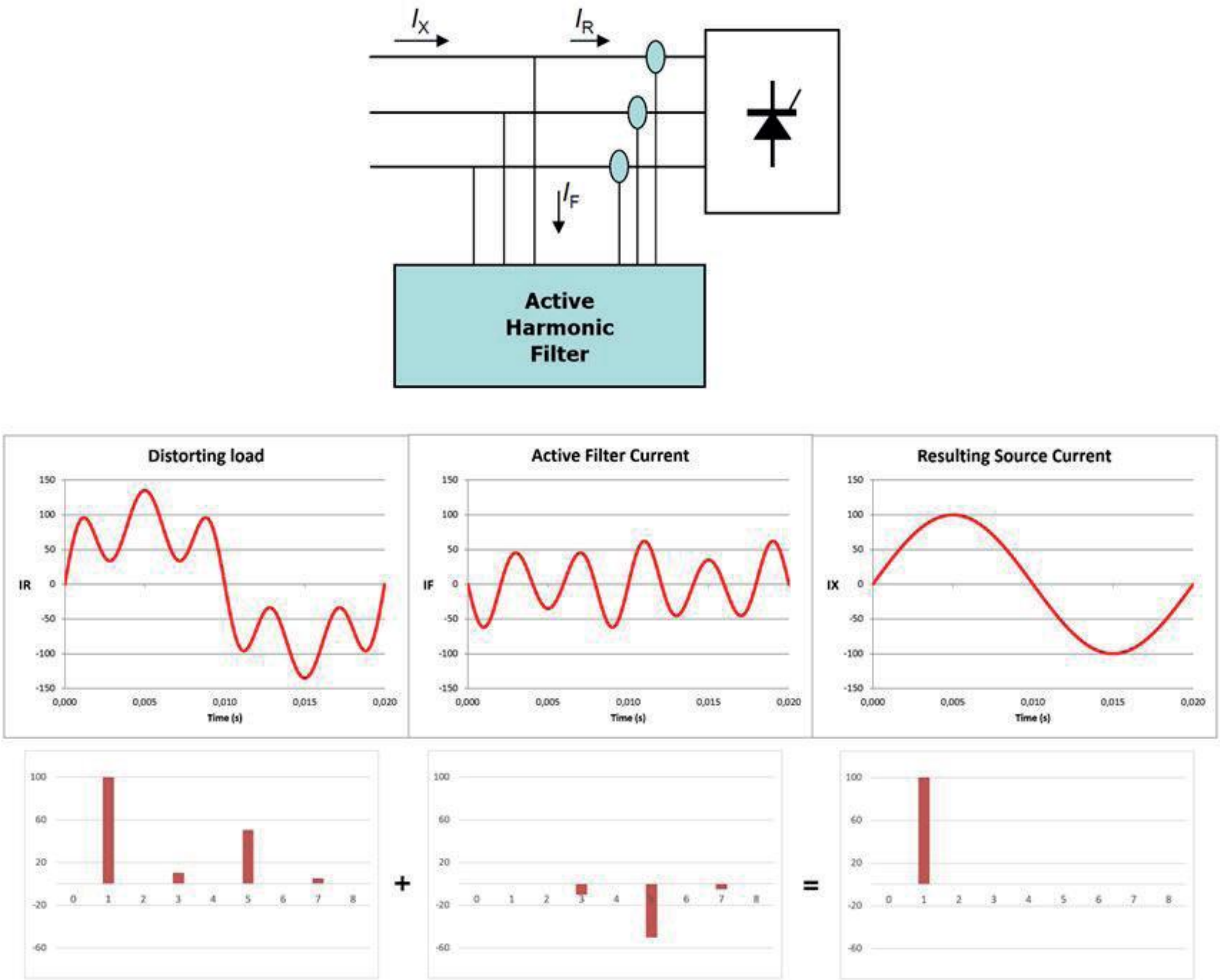

Fig. 3.4, Active filters.
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Active filter disposition, and its corrective behaviour over a non-linear load: the AHF (Active Harmonics Filter) generates the compensation current IF, that once is added to the distorted current of the load IR, composes a "clean" source current IX with a very low THD. Harmonic spectrum for each current is shown at the bottom, and the result of the equation IX=IR+IF as discussed in fig no. 3.4.

3.6 Conclusion

We have discussed different concepts and theories for harmonics elimination in the chapter. We have discussed harmonics nullification technique in case of transformer. The concept of active filter and passive filter have been discussed.

Chapter 4: PROCESS, METHODS, RESULTS AND DISCUSSION

4.1 MATLAB Model

Mis a programming platform designed specifically for engineers and scientists to analyse and design systems and products that transform our world. The heart of MATLAB is the MATLAB language, a matrix-based language allowing the most natural expression of computational mathematics.

4.2 What MATLAB Does?

- Analyse Data
- Develop Algorithm
- Create model and application

4.3 Process and Methods

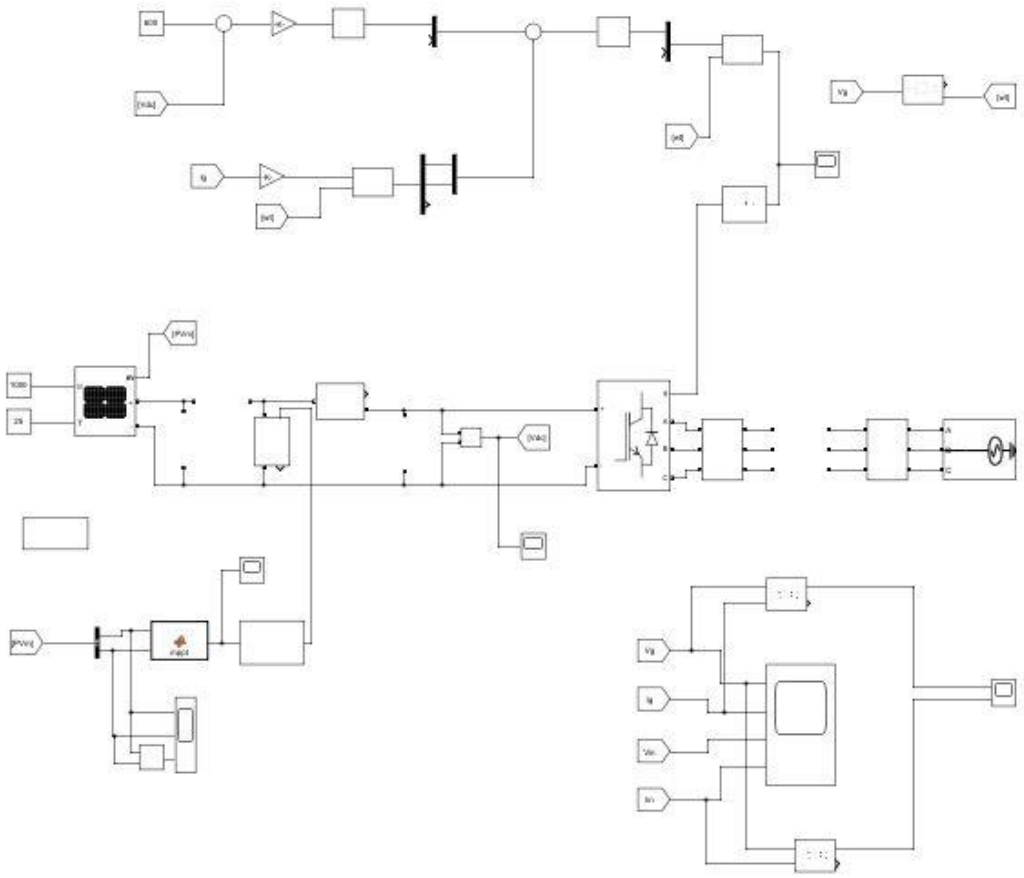

Fig. 4.1, 3MW renewable energy grid integration model.

In fig no. 4.1, 3MW renewable energy grid integration system is shown.

At first we set irradiance 1000 W/m2, and set temperature 25 degree Celsius. We connected it to inverter from where we can get 3 phase grid current and grid voltage. In the above of the solar panel in this model we set a PID controller so that the voltage across the inverter input be constant. We have taken different scope to see the pattern of input output voltage current etc. So, now comes to the advantage of this model. We can put input of solar panel varying the irradiance and temperature and we can see the output. From this simulation data we can get an idea about in which region our output will be high and we can do as many experiment as possible before we go to the real infrastructure creation. To set up a plant we really need this simulation data.

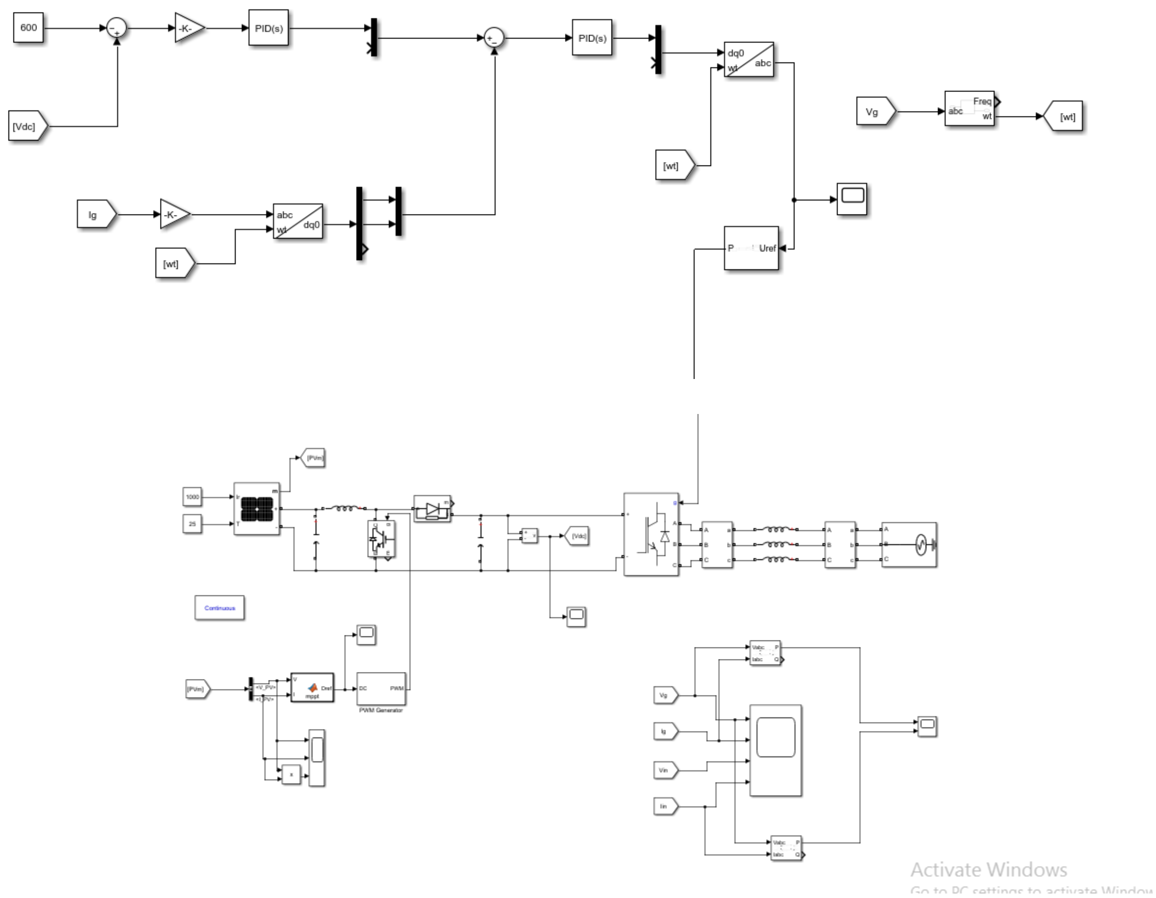

Fig.4.2 3MW grid integration model in elaborated form.

4.4 Results and Discussion

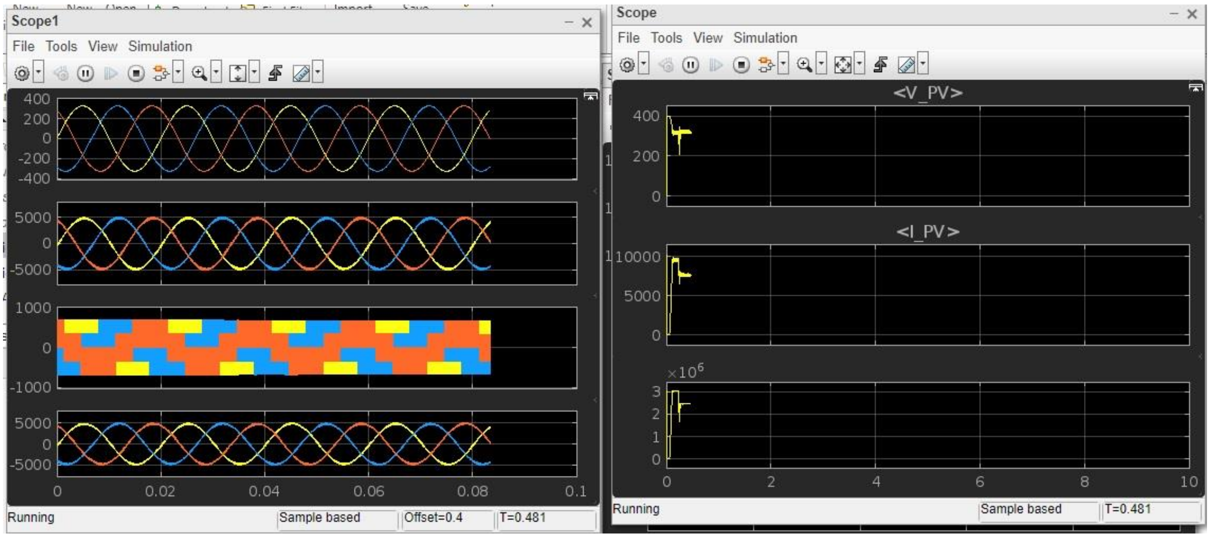

Fig. 4.3, Input Current, voltage, power in the right side and output voltage, current of the grid and inverter current and inverter voltage in the left side.

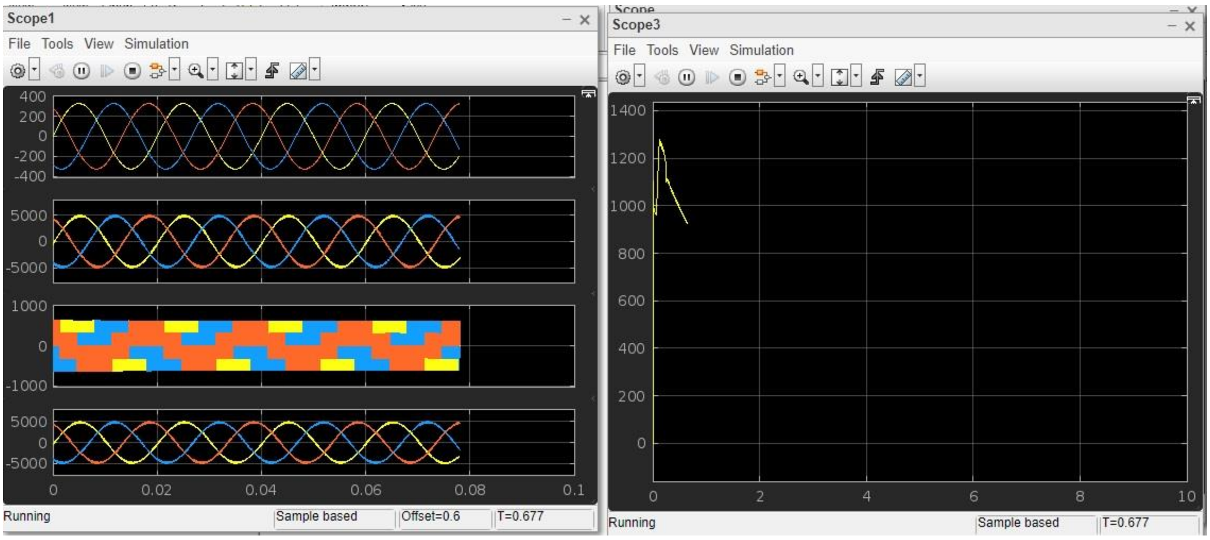

Fig. 4.4, Output voltage, current of the grid and inverter current and inverter voltage in the left side and capacitor voltage in the right side.

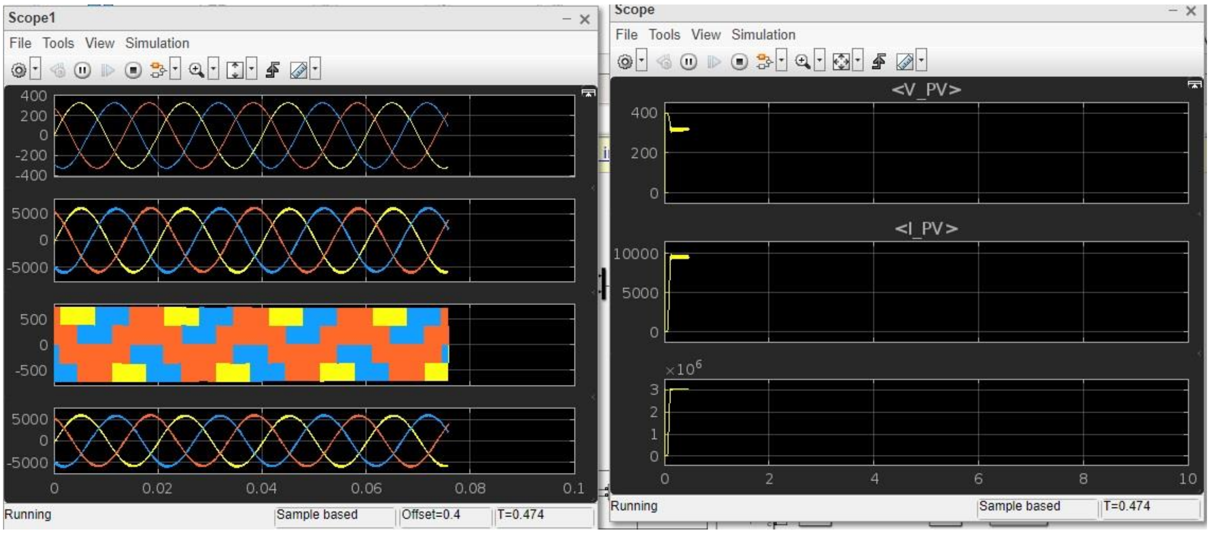

Fig. 4.5, Input Current, voltage, power in the right side and output voltage, current of the grid and inverter current and inverter voltage in the left side.

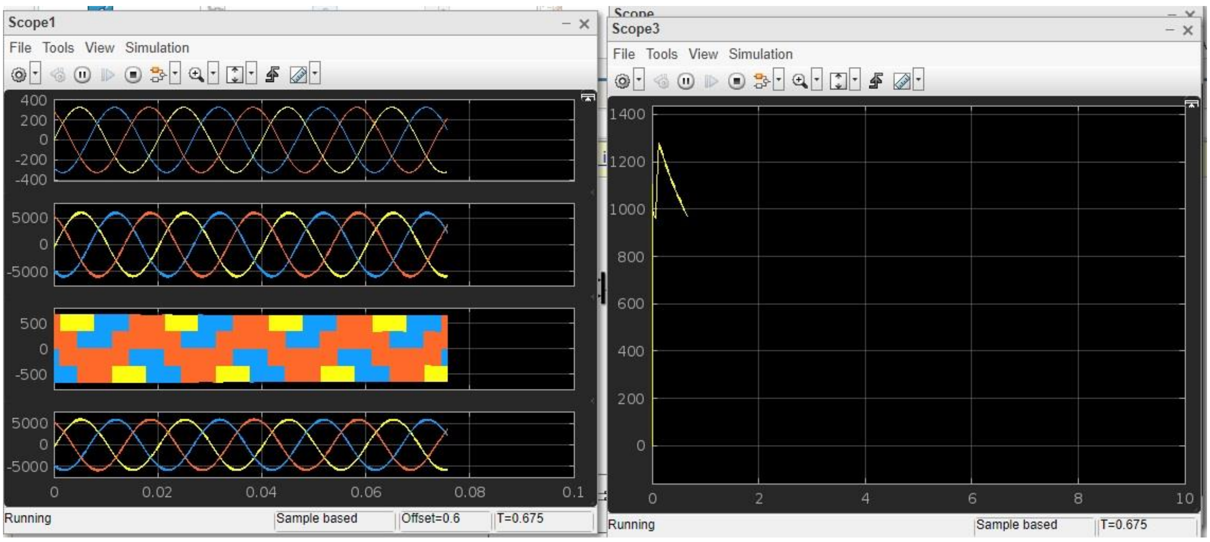

Fig. 4.6, Output voltage, current of the grid and inverter current and inverter voltage in the left side and capacitor voltage in the right side.

In the world, the total sunny day varies in different areas. It has different cause. One of the main causes of this is we have to see tilt of the sunray. We know that if sunrays fall on solar panel vertically, efficiency of that system will be high comparted to others solar panels in which sunrays does not fall on it vertically. A cost benefit analysis will be conducted step by step below.

In this project we have taken 3MW system. Suppose we have set different solar plant in different location like Kolkata, Delhi, Bangalore, Shillong and Mumbai. These areas are in the different points in India. Our motive is to set up plants in those location.

Before setting up any plant we require survey of that place. We can get data from CLIMATE-DATA.ORG [1].

We can find that average temperature in Kolkata is 24 degrees Celsius, in Delhi that is 25 degrees Celsius, in Bangalore that is 23 degrees Celsius, in Shillong it is 18 degrees Celsius and in Mumbai it is 24 degrees Celsius.

Now we can provide the data about the average annual amount of sun hours in different points of the country.

The average annual amount of sun hours in Kolkata 2240 hours, in Delhi 2780 hours, in Bangalore 2365 hours, in Shillong 2122 hours, in Mumbai 2590 hours.

Now our plan is to evaluate the annual average energy in those concerned locations.

Our power output of the system will be

$$P(\text{average}) = (1/2\pi) \int V_m \sin t \; I_m \sin t \; dt \; (0 < t < 2\pi)$$

$$= V_m I_m / 2$$

So Energy output = $V_m * I_m * t/2$ (Where V_m is Maximum voltage of the grid, I_m is Maximum current of the grid, t is the time)

We will use this formula to calculate output energy to a particular city.

For Kolkata we know the average temperature is 24 degrees Celsius. Keeping constant temperature, we vary the irradiance from 1000W/m^2 to 750W/m^2 to 500W/m^2 to 200W/m^2 to 100W/m^2

This process is done for all the cities, and we got the average energy value for an hour. And to get yearly data we multiply it with average yearly sunshine hours.

Let be the average Energy E1 for irradiance 1000W/m^2, E2 for 750W/m^2, E3 for 500W/m^2, E4 for 200W/m^2, E5 for 100W/m^2.

So average energy for an hour E= (E1+E2+E3+E4+E5)/5

So average yearly energy = E* Average yearly total sunshine hours

Table No. 4.1, Citi wise hourly average and yearly average energy

City	Average energy for an hour	Average Yearly Energy
Kolkata	2712MJ	6074.88GJ
Delhi	2832MJ	7872.96GJ
Bangalore	2688MJ	6357.12GJ
Shillong	2448MJ	5194.656GJ
Mumbai	2712MJ	7024.08GJ

So, we can see from the above table no. 4.1 that Delhi has more yearly average energy.

We also observe from the table that Shillong has lowest yearly average energy.

So, if anybody want to set up a plant, he will prefer Delhi because it will provide higher efficiency compared to other cities. Then they will prefer Mumbai because after Delhi it will provide more energy than others remaining.

So, in this way we can do survey before setting up any plant and can watch in which location our output will be high. So, clearly we can see the efficiency of the power plant.

4.5 Conclusion

In this chapter we discussed about the model, results of the output of the system. Kolkata, Delhi, Bangalore, Shillong, Mumbai these five cities are taken for the analysis of the result. It is seen that where total sunshine hours is high, probability of getting higher efficiency of that particular area will be high. As it is analysed in this chapter – Delhi is the most efficient area and Shillong is the less efficient area in India.

Chapter 5: CONCLUSION

5.1 Conclusion

World is changing rapidly, and energy demand is increasing by leaps and bounds. We cannot rely only on conventional technologies because a) harmful gases are disastrous to the environment b) one day fuel like oil, coal etc. will run out. So, now the importance of renewable energy gradually increases. Renewable energy is little bit costly than conventional energy. What engineers have decided is to use both energies simultaneously through grid. That is why grid integration of renewable energy is so much important. For healthy operation of electrical appliances power quality should be improved for which harmonics reduction is necessary. To nullify harmonics active filter and passive filter are used.

A MATLAB model is created to observe the input output performance of the different cities of India based on different climate condition. Taking average temperature and average sunshine hours the input output analysis is done in this thesis. As total sunshine hour is high in Delhi, output is high in Delhi and as total sunshine hour is less in Shillong, output is less in Shillong. So, we can easily observe where efficiency of solar panel will be high.

Before setting up any plant this performance analysis of the model is very much required. Because we can get an idea about performance of the real plant if simulation of the MATLAB model is done. Simulation may not give exact result but will give a clear idea about efficiency of the plant.

5.2 Avenues of The Future Work

There are lots of opportunity to do future work regarding this topic. I have done input output analysis of the concerned renewable energy grid integration model in different cities of India based on different climate condition. In my thesis I discussed about harmonics of the grid, total harmonics distortion and how to mitigate harmonics' effect from the grid. Harmonics' effect on transformer has been discussed and its mitigation technique is also discussed. Active filter and passive filter concept have been discussed but MATLAB simulation on harmonics is not done. Finding total harmonics distortion is also not done. So, there are lot of scope to proceed work in this regard.

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