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M.Sc. in Electronics and Computer Engineering

Doğan Can UĞUR

HASAN KALYONCU UNIVERSITY

GRADUATE SCHOOL OF

NATURAL AND APPLIED SCIENCES

STABILITY CONSIDERATIONS OF CONNECTING A LARGE-SCALE PHOTOVOLTAIC PLANT TO THE PUBLIC GRID

M. Sc. THESIS

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Supervisor

Asst. Prof. Dr. Bilal Eid

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	GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES INSTITUTE M.Sc. ACCEPTANCE AND APPROVAL FORM

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I hereby declare that all information in this document has 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 material and results that are not original to this work.

Doğan Can UĞUR

ABSTRACT

STABILITY CONSIDERATIONS OF CONNECTING THE A LARGE-SCALE PHOTOVOLTAIC PLANT TO THE PUBLIC GRID

UĞUR, DOĞAN CAN

M.Sc. in Electronics and Computer Engineering.

Supervisor: Dr. Bilal Eid

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In these years, due to global warming, energy security and environmental problems, interest in renewable-energy sources, which are environmentally friendly energy production, has increased worldwide. Accordingly, it attracts great interest in modern energy systems in the installation of large scale photovoltaic power plants (LSPVPP) connected to transmission lines. In addition to the rising trend, the control and operation problems encountered during the integration of large scale photovoltaic energy systems into the grid are increasing. A detailed analysis and regulations with limitations are needed to deal with these problems.In this article, a detailed examination of the problems encountered during the connection of LSPVPP to the network will be made. Network regulations created by the countries will be examined. The restrictions to be examined in these regulations will be observed limitations of the grid code used in Turkey. Regarding the problems encountered during the connection of these facilities to the transmission lines; fault ride through requirement (FRT) , voltage and frequency, active-power and frequency control , voltage control and reactive power limitations specified in Turkey in the first network with the correct design and simulations including regulation will be observed.The evaluations to be made; Suggestions will be made for the establishment of stable facilities with correct design and design and meeting the requirements of the grid regulation. Matlab / Simulink will be used to validate the assessments to be made.

Key Words: LSPVPP, stability, grid regulation, integration, limitations

ÖZET

BÜYÜK ÖLÇEKLİ PV TESİSİNİN KAMU ŞEBEKESİNE BAĞLANMASINDAKİ KARARLILIĞI HAKKINDAKİ DEĞERLENDİRMELER

UĞUR, DOĞAN CAN

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Son yıllarda küresel ısınma, enerji güvenliği ve çevresel sorunlar nedeniyle doğa dostu enerji üretimi olan yenilenebilir enerji kaynaklarına dünya çapında ilgi artmaktadır. Buna bağlı olarak, iletim hatlarına bağlı büyük ölçekli fotovoltaik enerji santrallerinin (LSPVPP) kurulumumda modern enerji sistemleri içerisinde büyük ilgi görmektedir. Yükselen trendin yanı sıra büyük ölçekli fotovoltaik enerji sistemlerinin şebekeye entegrasyonu sırasında karşılaşılan kontrol ve işletme sorunları artmaktadır. Bu sorunlarla başa çıkabilmek için detaylı bir analize ve sınırlamaları içeren yönetmeliklere ihtiyaç vardır.

Bu makalede LSPVPP'nin şebekeye bağlanması sırasında karşılaşılacak olan sorunların detaylı bir incelemesi yapılacaktır. Ülkeler tarafından oluşturulan şebeke yönetmelikleri incelecektir. Bu yönetmelikteki sınırlamalar incelenecek olup Türkiye de kullanılan şebeke yönetmeliğinin sınırlamaları gözlemlenecektir. Bu tesislerin iletim hatlarına bağlantısı sırasında karşılaşılacak olan sorunlara ilişkin; fault ride through requirement (FRT), gerilim ve frekans, aktif güç ve frekans kontrolü, voltaj ve reaktif güç kontrolü başta olmak üzere doğru tasarım ve simülasyonlar ile Türkiye de ki şebeke yönetmeliğinde belirlenen sınırlamalar gözlemlenecektir.

Söz konusu yapılacak olan değerlendirmeler; doğru tasarım ve dizayn ile şebeke yönetmeliği gereksinimlerinin karşılanmasıyla istikrarlı tesislerin kurulumunda önerilerde bulunulacaktır. Yapılacak olan değerlendirmeleri doğrulamak için Matlab / Simulink kullanılacaktır.

Anahtar Kelimeler: LSPVPP, kararlılık, şebeke yönetmeliği, entegrasyon, sınırlamalar

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LIST OF ABBREVIATIONS

PV	: Photovoltaic
SVC	: Static Var Compensator
OLTC	: On Load Tap Changer
DG	: Distribution Grid
MG	: Microgrid
AC	: Alternating Current
DC	: Direct Current
MPPT	: Maximum Power Point Tracking
CBs	: Capacitor Banks
MW	: Mega Watt
VA	: Volt Amper
VAr	: Volt Amper Reactive
MPP	: Maximum Power Point

CHAPTER I
INTRODUCTION

1.1 PV System Topology

The direct conversion to solar energy into electricity is generally achieved by using photovoltaic cells that benefit from the (PV) photovoltaic effect. The photovoltaic effect depends on the interaction with the photons to more or equal energy in belt spacing to photovoltaic material. Some to lost caused by limitation in the belt interval are prevented by the cascaded semiconductors in different generation intervals (Goswami DY 2004).

PV cells operate with an efficiency varying between about 5-25% and a power generation capacity of 1-2 w. This situation changes depending on structure of solar cell and the material used (Song, D, 2012). There are different solar cell materials according to efficiency of photovoltaic panel. Basic-types are crystallined and polycrystalline (mSi) silicon.

The increased consumption of electrical energy per capita, together with the high dependence on large generation centers and the interest in preserving the environment by reducing carbon emissions and global warming, are factors that have motivated the investigation of new applied technologies. to distributed generation, transport and energy consumption.

Thus, in recent years, Distributed Generation (DG) has become a trend in developed countries to enter and compete in the energy market, with renewable and alternative resources being its main sources of energy.

However, since the DG presents several technological challenges and is characterized by having small and fluctuating power outputs due to its dependence on environmental conditions (solar photovoltaic and wind energy), it has been restricted within the energy market.

For this reason, in recent years the concept of Virtual Power Plant (VPP for its acronym in English, Virtual Power Plant) has been proposed as a solution to the limitations that the DG has, so that different distributed generators are integrated in a coordinated way. , energy storage systems, communication systems and controlled loads, in such a way that the entire system behaves as if it were a single conventional power plant PI, and that it delivers the reactive and active power required from load.

Energy Management System constitutes the main link of a VPP, because it is in charge of coordinating the flow of energy between its components, thus solving the individual deficiencies that may exist in each generation subsystem. .

Efficiency in energy generation and flow is closely linked to the different static energy conversion topologies and the control strategies used in VPP. Therefore, it is necessary to determine the appropriate static energy conversion topologies for each generation unit, as well as its respective technique and control strategy, so that the energy use of the VPP is maximum and its performance is robust to the different operating scenarios. Thus, the PI-PI cascade control, compose of externals voltage loops and internal current loop, has been implemented in the literature showing satisfactory results. PI controllers are the most widely used technique in the regulation of voltage and current due for they high efficiency, cheap costs and low complexity. However, use to Sliding-Mode Control (SMC) for static power converters has been implemented in recent years. The SMC is characterized by great stability, high robustness to variations in system parameters and to external disturbances, excellent dynamic response and in steady state, and easy implementation. For these reasons, this research project proposes the use of a PI-SMC cascade control for the DC-DC and DC-AC converters of a VPP so that the system has adequate energy use and is will be to supply power reactive and active energy required by load.

1.2 Grid-Connected PV System

Photovoltaic systems connected to electricity grid(SFCR) constitute one of the applications of photovoltaic solar energy that have received more attention in recent years, given its high potential for use in urbanized areas close to the network electrical. These systems are composed of a photovoltaic generator that is located connected to the conventional electrical grid through an inverter, producing a energy exchange between it and the photovoltaic system, characteristic of this type of installations. Thus, the system injects energy into the network when its production exceeds local consumption, and draws energy from it otherwise. The fundamental difference between an autonomous photovoltaic system and those connected to the grid, consists of the absence, in the latter case, of the accumulation subsystem, formed by the battery and charge regulation. Furthermore, the inverter, in grid-connected systems, must be in phase with the mains voltage.

As has been commented so far, there are two types of energy applications solar photovoltaic: isolated systems and those connected to the grid. Even knowing the variety of possibilities offered by the first type of facilities, it is It is important to consider networked systems as they can offer differentiation in places (e.g. Europe) where electrification levels are reaching a level
saturation. The advantage of this photovoltaic technology is in the possibility of creating an installation to starting from a large number of decentralized systems, distributed at points of consumption, compared to installation in large areas, thereby eliminating losses by transport. The applications of photovoltaic installations connected to network: photovoltaic energy installations for bioclimatic buildings, in buildings for subsequent supply to the electricity grid, for the creation of power plants and to reinforce end of line.

1.3 Background

Energy is that, ıt is one of the building blocks to life and need for energy in the world wil be increasing everyday. Today, electrical energy needs are met from energy types such as chemical, nuclear, gravity, wave and renewable energy.
Electrical energy is mostly obtained from chemical or fossil fuels (coal, gasoline, etc.). The existence of these resources in nature is the result of many years. Today, the consumption to fossil fuel is increasing with developing technology, increase into industrial production, increasing living standards and increasing world population.

Therefore, the energy consumed is constantly increasing. For this reason, it is known that it causes a decrease in fuel reserves due to increasing fossil fuel consumption, and adverse effects on the environment, health risks and global climate changes problems due for consumption of fossil fuel (N.L. Panwara, S.C. Kaushikb, and Surendra Kothari, 2011). Along with this, the developing energy crisis is emerging throughout the world. According to the (IEA) International Energy Agency, it is thought that this energy need in the world will increasing by 55% until 2030. Also, fossil fuels will be 84% will increases (Goldthau, A., 2008). Therefore, considering the decreasing fossil-based energy resource reserves day by day, global warming problems, air pollution from vehicles also greenhouse gas emission, importance of alternative energy resources is increasing.

Today, renewable energy generation sources make up the increasing share of electricity. The shared of the renewable energy sources are expect to increased significantly in these years (80% in 2100) (Fridleifsson IB, 2001). Global renewable energy scenario until 2040 will be shown into Table 1.1

Table 1. 1 Global renewable energy scenario to 2040 (Kralova I, and Sjöblom J, 2010).

	2001	2010	2020	2030	2040
Total consumption (million-tons oil equivalnet	10.038	10.549	11.425	12.352	12,310
Biomass	1080	1313	1791	2483	3271
Large Hydro	22.7	266	309	341	358
Photovoltaic	0.1	2	-24		
Small hydro	9.5	19	49	106	189
Wind	4.7	44	266	542	688
Solar thermal	4.1	15	66	244	480
Geothermal	43.2	86	186	333	493
Solar termal electricity	0.1	0.4	3	16	68
(tidal/wave/ocean) Marine	0.05	0,1	0,4	3	20
Total RES	9	1,745.5	2,9644	4289	6351
Renewable energy source concribution	53	16,6	236	34,7	47,7
				221	784

All values in MW

Energy sources; are divided into 3 categories as renewable energy, fossil fuels, and nuclear energy source (Demirbas A, 2000). Renewable energy is sources that generate energy repeatedly and are also called alternative energy sources; such as wind energy, solar energy, biomass energy (Rathore NS, and Panwar NL, 2007).

Solar energy is called the radiant energy that occurs as a result of fusion events occurring in the sun. The sun emite energy at the rate of the 3.8 ×1023 kW, to which about 1.8 ×1014 kW is cut by earth (Thirugnanasambandam M,Iniyan S, and Goic, 2010). Thus, almost half to the sunlight reaches the earth by passing through our atmosphere layer covering the earth's surface. With the increase of the temperature on the earth, the continuation of the living life becomes possible. While solar energy is around 1370 W / m2 outside the atmosphere, the energy reaching the earth is in the range of 0 to 1100 W / m2. In the context, it can said that even small part of amount of energy reaching earth is much more than amount of energy consumed. This literature shows that after 1970s, efforts to generate electrical energy from solar energy have increased. Solar energy systems, also known as photovoltaic (PV) systems, which are environmentally friendly technologies, have decreased in terms of costs with the advancement of technology and have become a new energy source, a renewable energy source (Yegm. Yenilenebilir Enerji. 2018).

Photovoltaic gardens are groupings of individual photovoltaic installations, belonging to different holders, located on a land or plot that brings together some optimal conditions to produce photovoltaic energy Photovoltaic orchards offer several advantages such as:

- The increase in the profitability of the project by reducing costs in infrastructure,

maintenance, cleaning, surveillance and administrative management.

- Photovoltaic generators can be purchased at lower prices due to the volume of

purchase units.

- The few negative environmental effects are concentrated in areas with low environmental value.
- New jobs are created around the installation areas.
- Allows investment in photovoltaic installations by anyone, even without having a suitable own land.

The common elements in an orchard are photovoltaic panels, which can be fixed or with rotating rotors to followed the movements of the sun, allowing an increase in radiation capture capacity. Most manufacturers of solar panels guarantee 80% energy production during the first 25 years of life. The electricity generated by photovoltaic panels is direct current and must be converted into alternating current, for its discharge to the grid, through the use of an inverter. Regarding the economic profitability offered by solar gardens, it should be taken into account This will depend on the amount of kWh injected into the grid, a related concept directly with the solar radiation that the installation receives and collects, in a certain place. Generally, the approximate profitability ranges between 10 and 12% per year, and is guaranteed because the source of energy, the sun, is inexhaustible.

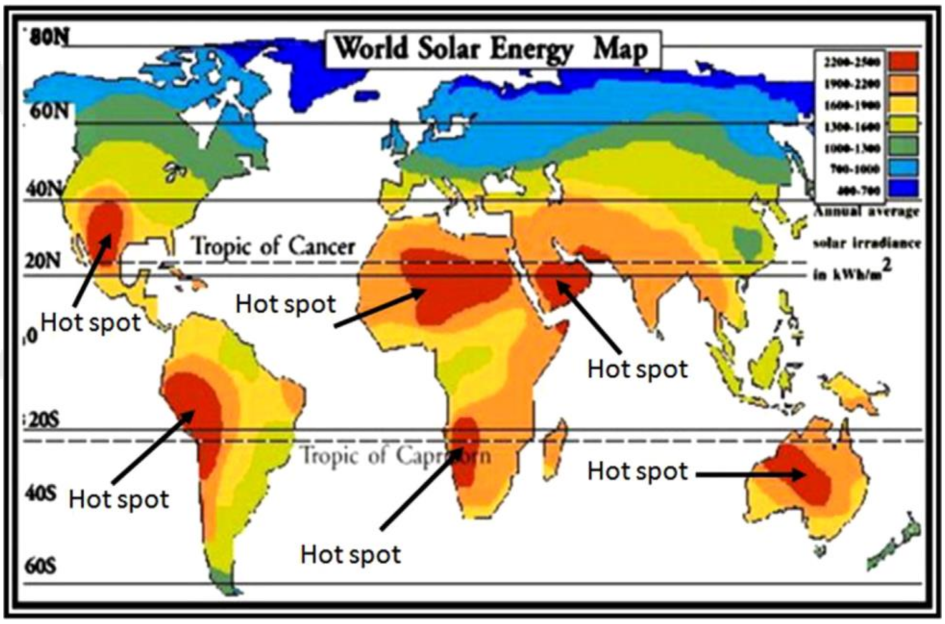

Figure 1. 1 World solar energy map (Desertec Foundation,(Online)).

Turkey, in terms of nominal energy potential is better off than many countries in the world. Efficient use of photovoltaic (PV) systems is directly effective with sunshine duration. According to the data obtained from the EIA Turkey's total annual sunshine duration of 2,640hours (total daily 7.2hours), the average annual solar radiation of 1,311kWh / m² / year (daily total of 3.6 kWh / m²) has proved to be. Solar energy potential is calculate as 380 billion kWh/year. Turkey's solar energy potential atlas shown in Figure 1.2. (Kamil B. Varınca ve M.Talha Gönüllü, 2006).

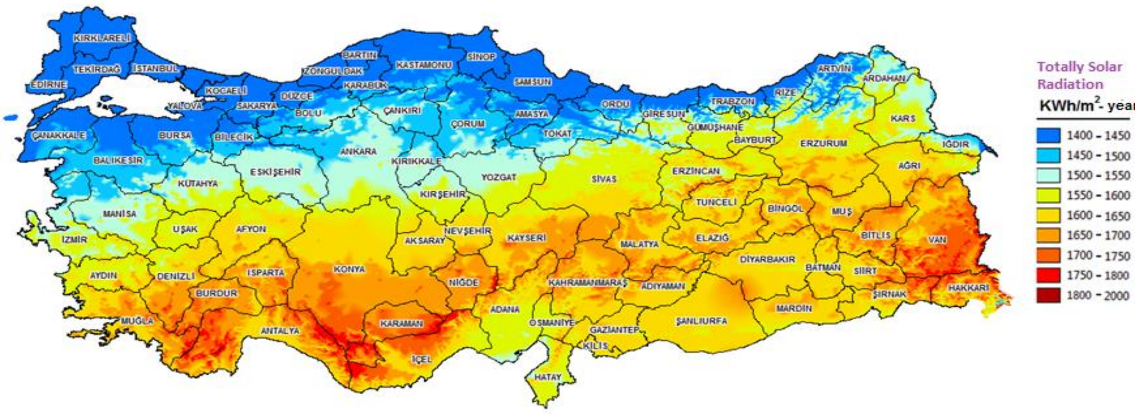

Figure 1. 2 The totally solar radiation of Turkey (Kamil B. Varınca ve M. Talha Gönüllü, 2006).

There is two different methods to solar power generations, solar photovoltaic. Solar thermal concentration. Photovoltaic energy that a mature and viable option to power generation by International Renewable Energy Agency (IRENA) working document,2012). Solar Photovoltaic (PV) power plants convert sunlight directly into electricity without any rotating machinery. Usually, the individual capacities of the photovoltaic module is between 100W and 320W (Omran W, 2010). Large-Scale-Photovoltaic-Power-Plant (LSPVPP) is required obtain MW power range from the PV system. This is possible by connecting thousands of PV modules to each other. For this reason, an important land area is needed for the placement of LSPVPPs.

With the development of solar cell production and converter technology, PV energy generation systems are emerging as increasing renewable energy source. With increasing interest into PV systems, the PV system can cause various aspects of power systems to be changed. It can affect the stability of systems. This study examines network regulations for the integration of LSPVPPs. In addition, it summarizes this research finding on technicals solution to overcome challenges of stability of the electrical system associated with the integration of LSPVPP in the transmission and distribution system.

1.4 Problem Statement

With the increase in energy need, energy interruptions may occur. The reason for this can be explained by economic and / or physical reasons such as loss of power when transported energy over long distances, insufficient production despite increasing energy needs, and unbalanced power distribution. Therefore, more detailed analysis is required to ensure network security (Moslehi, K. and R. Kumar, 2006).

The quality of the energy produced, transmitted and distributed at designated points made available to the consumer is important. Stability of the amplitude and frequency of the voltage at the determined points and the stability of the wave shape are the most important power quality factors that increase the energy quality. For this reason, amplitude variation, imbalance, wave distortion and frequency instability of the voltage show that the quality of energy in power transmission systems is insufficient. The definition of power quality by users may differ. In general, it can be expressed as "malfunction or incorrect operation of electrical devices due to changes in current, voltage or frequency values". The literature shows that there are many studies aimed at improving the quality of power (Kusko, A. and M.T. Thompson, 2007).

Photovoltaic solar cells are so named since they are composed of materials semiconductors that are capable of converting the electromagnetic energy contained in light coming from the sun and converting it into electrical energy. This phenomenon is called photovoltaic given the potential difference that gives rise to an electric current (Taretto, 2018).

In Table 1.2 you can see a simplified version of the basic principle of operation of a photovoltaic cell, which could be described as follows: light from sun reaches surface of the PV modules. It is there that photons (elementary particles responsible for the electromagnetic phenomenon) are absorbed by the semiconductor material causing the excitation of the electrons and allowing what is known as the pair to form electron-hole. Since electrons and holes tend to recombine to re-release the photon energy, if they wishes for harness the energy store in an electron hole pair to To do work into external circuits, electrons and holes will be separated by insertion of other materials that allow only the passage of electrons towards one end and only the passage of holes towards the other. Finally, the electrical charges were extract from the photovoltaic cell by electric contact so that ıt can be perform works on external circuits. Energy chemistry of electron-hole pair is converted into electrical energy, so that after electron has pass through the circuits, recombine with the holes (Smets, Jäger, Isabella, Van Swaaij, & Zeman, 2016).

Table 1. 2 General comparison among photovoltaic and conventional power plants (Rakibuzzaman Shah, N.Mithulananthan, R.C.Bansal, and V.K. Ramachandaramurthy, 2014).

Conventional generator	Charecteristics	PV
No	Fluctation	High
Low to moderate	Cost for large- scale	High
Moderate	Maintenance cost	Minimal
Large inertia	Inertia	No inertia
High	Capacity factor	Very low
High	Annual growth in electric power sector	Very High

In this article, technical concerns regarding the integration of LSPVPPs and strategy and recommendations for the development of those systems will be evaluated with public networks.

1.5 Research Objectives

Purpose of the study is to contribute to connection of LSPVPP to the network. Network regulations and limits of countries will be examined in the study. This will determine the most appropriate boundaries reviewed and network regulations for Turkey. As a result, it will simulate the system by making the most accurate modeling, it will make evaluations on ensuring the stability of the system by overcoming the technical concerns during the connection to the public grid, and will make recommendations in its methodology.

1.6 Scope of Work

In this study, grid-connected PV system has been designed and variable local loads have been studied. PV system configurations, local load distortion, partial shading conditions and their effects on distribution networks under the influence of distance were investigated. Active and reactive powers given / received from the sources were examined. Matlab / Simulink was used as a simulation program.

1.7 Methodology

The method of this study began by examining previous studies in detail. The proposed PV system concept of LSPVPP with FC sources, local loads, inverters and grid has be modeled and simulated by using Matlab / Simulink.

Using of solar energy depends on temperature and irradiation. Due to the shadowing effect caused by clouds, PV production is intermittent. For this reason, voltage and frequency cause problems such as instability of active and reactive power. This article focuses on the key parameters that propose solutions to mitigate the difficulties encountered in achieving stability in the current transmission grid power system network in connecting LSPVPP to the national power grid. Therefore, optimized configurations for LSPVPP integrations into the bus to the transmission network will constitute the novelty of this article. Matlab / Simulink is used to verify the system. Many situations such as load change, dynamic DC reference voltage, feeder line removal (cut) and voltage regulator have been studied. Depending on these situations, the max power point (MPPT) to the system was determined, and most accurate model was created. Active power, reactive power and effective (RMS) voltage value were measured and analyzed. In addition, a comparison of the obtained findings between different configurations was made. Evaluations have been made about these difficulties.

1.8 Thesis Outline

This structure of this thesis consists of following parts;

In Chapter 2, the literature summaries are given, and what studies have been done for the connection of LSPVPP systems to the transmission line are explained until today. It also summarizes the control strategy work used and technical difficulties encountered.

With the thesis methodology given in Chapter 3, the internationally applied network regulation restrictions for the integration of LSPVPP into the network were explained.

In Chapter 4, simulations, discussion are given in this chapter and results. Necessary evaluations have been made on the technical difficulties mentioned in the previous sections and the study has been completed with suggestion.

CHAPTER II
LITERATURE REVIEW

2.1 Introduction

Photovoltaic phenomenon was discovered and then studied for the first time in 1839 by the physicistFrench Alexandre-Edmond Becquerel. After forty-four years, in 1883, the inventor

American Charles Fritts was able to manufacture the first photovoltaic device based on a jointgold-selenium. The result was very poor, reaching only a conversion efficiency of 1%. It was not until the second half of 20th century that SFV (SFV) industry began its development andexpansion with the objective of energizing satellites placed in Earth orbit. The decade of 1970, began to develop photovoltaic modules for terrestrial applications. Nowadays is one of the pillars of energy transition in second decade of 21st century for search to replace fossil-based energy sources in order to combat climate change as a Once the park is installed, it doesn't produce greenhouse gases like as carbon dioxide. carbon (CO_2) (Smets, Jäger, Isabella, Van Swaaij, & Zeman, 2016) (Zhang, Li, Li, & Wang, 2012). As an introduction, the components of a SFV system and its principle will be briefly reviewed. basic operation (transformation of light from the sun into electrical energy). Basically, an SFV system is made up of the following components:

- Photovoltaic module
- Investor
- Support / monitoring system

The SFV generation parks also have the equipment associated with any system electrical systems, such as connection systems, protections, grounding, transformers, among others. (Gregorini, Kühn, & Zúccolo, 2018)

For insteance, generation of electrical energy from renewable resources. For example solar energy, is presented as convenient alternative to the use of fossil resources in conventional generation systems. At present, the technology to take advantage of solar energy through photovoltaic conversion has a high degree of development, which has allowed its costs to be comparable with those of conventional technologies in many countries. (Sher and Addoweesh, 2012). The use of photovoltaic (PV) modules for converting solar energy to electrical energyis much widespread worldwide and has been the subject of study for decades. A PV module generates direct current (DC) energy which can be used directly by DC loads or it can be transformed to supply alternating current (AC) loads. A set of electrically interconnected PV modules (PV generator) together with the additional conversion and interconnection equipment constitute a PV system, which are divided into two main topologies: Autonomous Photovoltaic Systems (SFA) and Photovoltaic Systems Connected to the electricity Grid (SFCR). SFAs require an energy storage medium, such as battery banks, for later use. On the other hand, SFCRs dispense with such storage systems since all energy generate by photovoltaic modules is inject into the electrical grid at which they are connected. Thus, in the SFCRs the cost of both maintenance and additional equipment is lower, increasing the reliability of the system (Ikkurti and Saha, 2015). The ability of the SFCRs to inject energy at any point in the network constitutes them as distributed generation (DG) systems. Two GD scenarios are observed, on the one hand in PV generation plants, with large areas covered by modules, and on the other hand, small power generation systems, which can be installed in urban environments, and even architecturally coupled to existing structures or buildings (Cossoli et al., 2014). Regardless of the power of the SFCR, they all have a common component: a DC-AC converter or also called an inverter, which is responsible for transfering of the energy between generator and electrical grid. In current market there are a diversity of inverters, of different powers and topologies, but all of them fulfill two main functions. They must first convert the d.c. generated by the modules in a.c. compatible with the electrical network to be injected. Second, because the power delivered by the PV generator depends on factors such as PV cell temperature and solar radiation, such inverters must be able to polarize the generators at their maximum power point. To do this, they implement max power point tracking algorithms (Maximun Power Point Tracking, MPPT) (Ikkurti and Saha, 2015). The main objective is that, of this work is to introduce study of inverters as a review of the existing bibliography, in particular micro-inverters for grid connection. For which, in the first place a general classification of the SFCR will be presented, with its different topologies, benefits and points against. Next, the review of main topologies reported for power stage at the micro-inverters in particular will be presented, presenting their main characteristics. The work is concluded by summarizing the presented topologies and making a comparison between them, so that the designer has a starting point when selecting the most suitable topology.

2.2 Effect of Solar-Variation

According to Tadeo (2000), due to high solar radiation, plants suffer stress when the chlorophylls of the photosystem antennas, which are found in the thylakoid membranes of the chloroplasts, absorb more light energy than can be used in the process. of photosynthesis. This light stress initially leads to photoinhibitions to photosynthes that prevents oxidative damages to photosynthetic apparatus by generation to reactive oxygen species (ROS; reactive oxygen species) in photosystem I (PSI) and II (PSII) (Tadeo and Gómez-Cadenas, 2008). In addition, high radiation, high temperatures and water stress increase the photorespiration of the plant, which affects its productivity due to the considerable consumption of carbohydrates, fixed in photosynthesis (Gómez de Enciso, 2012). The light saturation point (expressed in the density of the photon flux; DFF) is characteristic for each plant species and is the point at which the plant experiences the highest photosynthetic efficiency (Tadeo and Gómez-Cadenas, 2008). However, in the case of a constant DFF, light stress can also occur when the photosynthetic rate decreases due to situations such as drought, salinity, extreme temperatures or nutritional deficiency (Tadeo and Gómez-Cadenas, 2008). Photooxidation occurs when photosynthetic pigments are destroyed by high radiation, especially by the loss of functionality of the LHCII proteins (light-harvesting complex proteins) that promote the release of chlorophylls, linked to these proteins, and their destruction by chlorophylase (Tadeo and Gómez-Cadenas, 2008). Consequently, green tissues decrease their chlorophyll concentration, presenting a yellowish discoloration to whitish. Species and varieties react differently to light stress that depends on the growth conditions and intensity and duration of solar radiation to which the plant or organ is exposed, which, in extreme cases, can cause its death (Kays, 1997). In tomatoes, direct solar radiation can cause overheating of the fruits, with temperatures higher than 10 ° C than those shaded, which, in turn, results in lycopene degradation (Helyes et al., 2007). Also Pék et al. (2011) found in tomatoes, exposed to full sun and with higher epidermis temperatures, changes in the concentration of antioxidants with a decrease in the lycopene content but with an increase in the levels of polyphenols and ascorbic acid, compared to fruits completely shaded. Light stress also occurs when a plant is moved in shady conditions to full sunlight (Rajendran et al., 2009), especially due to the higher proportion of UV light in the spectrum, which is called transplant shock. In broccoli, the high and prolonged radiation, in susceptible varieties, can cause yellowing and opening of the flower (H. Pinzón, personal communication, 2012), undesirable characteristics in quality vegetables. Prolonged high solar radiation causes the so-called sun blow, or burns on a large number of fruits and vegetables, effects that are aggravated if they are accompanied by a dry period (Dussi, 2007), frequent during the El Niño phenomenon. High temperatures during times of high solar radiation affect the normal structure and function of the membranes, increasing respiration and denaturation of enzymes, when the temperature passes a certain limit (Yuri et al., 1996; Ferguson et al., 1998). In addition, strong radiation can generate the cracking of fruits, due to its additional affect in increae temperatures in layers of insolated cells (Fischer and Orduz-Rodríguez, 2012). The destruction of pigments can manifest itself, in some cases, as a darkening of the affected tissue. Also the plant, in general, shows wilting and desiccation due to increased perspiration in the affected tissues (Kays, 1997) and necrosis of the leaves and shoots. Burns may occur on the stem, with deep injuries. The changes that the skin of the fruit undergoes during the growth and maturation period in the plant affect the susceptibility of this organ, being the fruits that were developed in the shade or with little light more susceptible to the sun blow than those that grew under radiation

2.3 Power System Challenges

At the last “Energy Week” that took place in Buenos Aires, officials from 21 energy ministries in the region discussed the energy challenges that our region will face in the coming years. The agenda of the debates was marked by the 21.8 million Latin Americans who still do not have access to electricity. Although this number has dropped since OLADE's last measurement (which placed it at 25 million without access to energy in 2014) there is still a significant gap to close. The governments of our countries have limited resources to face the great challenges involved in increasing the electrical inclusion of their population. But there is room to generate efficiencies in the use of the resources we have, particularly in the field of governance and adequate regulation, and thus maximize the impact of our efforts. That is why it seems appropriate to comment on some of the challenges that the energy sector will face in 2018.First, the region has to prepare to address the uncertainty that technological, environmental and social changes are causing in the energy sector. The speed of these changes makes us question both the regulation and the governance of an industry whose dynamics have historically been stable and which is now impacted by multiple factors. The use of information technologies (networks / meters / smart platforms / dashboards) are central in this new context and are changing the way in which the sector relates to its customers, in terms of user knowledge and the transparency that they provide. they demand today. Digitization is also making it possible to create support tools so that systems are able to respond and adapt quickly in the presence of unexpected and extreme events, such as those caused by natural disasters. But digitization brings attention to cybersecurity. That is to say, the need for more and more exhaustive and efficient attention to avoid alterations to the systems and possible hacks and to guarantee that when there are losses in a system, the restoration of the service is as fast as possible. Technological change in the energy sector makes it necessary and urgent for governance structures to be more flexible with the capacity to adapt to a new corporate energy model. This new corporate model will include new agents due to increased market area, or greater consumer participation, therefore, it must be more flexible. Second, although more than 50% of the region's electricity generation is based on renewables and progress is being made in energy efficiency programs, energy demand is expected to continue growing. That is why affordability and sustainability will be major challenges for the future of the sector. To face this challenge, the IDB presented the study "The Future Network" which represents a very important input for the discussion on the de-carbonization of the electricity sector in Latin America, quantifying the costs and benefits of an integrated Latin American network for reach the goal of 80% renewable energy in the region's electricity matrix by 2030.The third challenge is the interdependence between different industries. Energy and telecommunications will continue to interact strongly and we will see a greater impact of energy in the water and transport sectors due to increased urbanization. For example, transport consumes a quarter of the energy (approx 27%) that is produced in the world. The growing interdependence of industries means that potential problems that can be verified in one sector impact another with a domino effect. This requires us to have an increasingly integrated vision of infrastructure (in its planning, regulation and policies) and also in terms of investment costs. These and other Energy issues will be discussed at the III Business Summit of the Americas, which will take place in Lima, Peru, on April 12 and 13. The Summit will be attended by heads of state and the main CEOs of the region. Economic growth, trade, and public-private investment will be promoted in order to promote sustainable, transparent and inclusive development in Latin America and the Caribbean. The good news is that Latin America is once again in everyone's eye, not only because of football, but also because of the record lowest prices worldwide for wind energy (in Mexico) and solar (in Chile). The revolution has reached our lands, but we will need to develop common vision in tomake the best use to all its benefits. In these new debates, the IDB will continue to be side by side with the countries of Latin America and the Caribbean, sponsoring the constructive dialogue so necessary to improve lives.

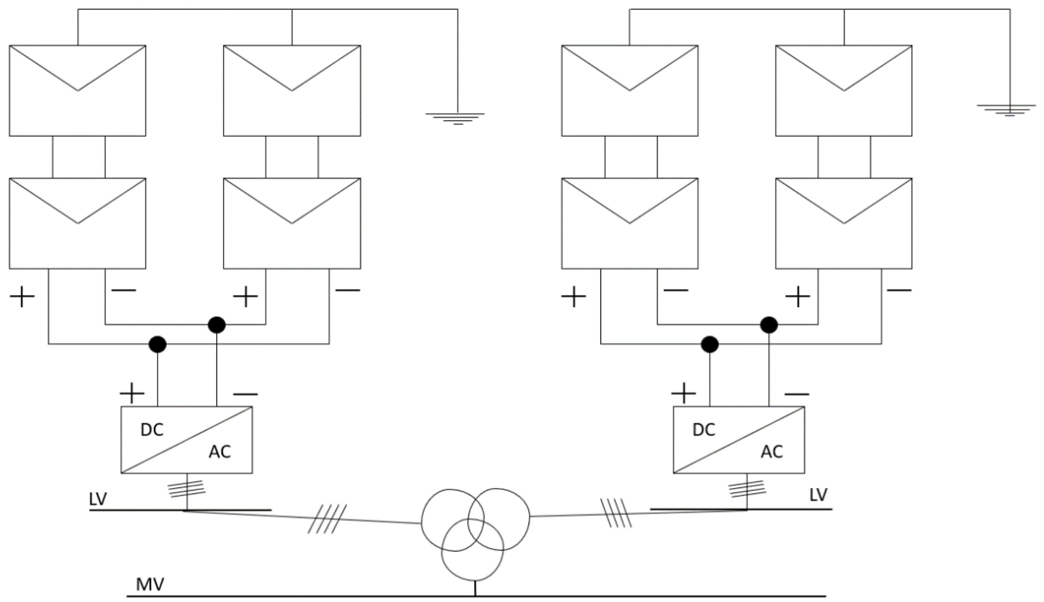

Figure 2. 1 PV unit for central configuration.

Figure 2.1 presence two seperated solar plant which is connected to grid. In order for the energy to at the best level in terms of quality, the frequency and amplitude values of the voltage at a specified point of the network must be approximately constant and the wave shape (sine form) must be preserved. As it is known, amplitude variation of the voltage, unbalanced voltage values or fluctuations, differences in frequency and interruptions are the causes of power poor quality. Since the output power in PV systems constantly changes depending on the weather conditions, there are imbalances in the grid due to the PV system depending on the time. For this reason, harmonic effects that can be caused by photovoltaic systems in network bring some doubts and it becomes important to investigate, determine and eliminate these harmonic distortions. PV systems produce direct current and there is alternating current in the grid. Therefore, PV systems are connecting to the grid with inverter. All semiconductor devices use to during connection to this network are harmonic generating devices (Du, Y., et al.,2013). In recent years, researches on power quality of photovoltaic plants have intensified in the literature (Hernández, J., et al., 2011). These studies are mentioned in the subsection.

2.4 Load Flow Analysis

An electrical power system containselements capable of generating, transforming, transmit and distribute electrical energy, this energy must be delivered to thefinal consumer with standards of quality, reliability and cost accessible. Due to growthing of world populations as well as demand for electrical power, the systems electric power have grown to achieve complex designs of functioning as are systems radial, ring systems and systems that form a complex network, so in the resolution of power flows in the electrical distribution must be analyzed as a set of connected nodes each other by means of lines and transformers that have a general power supply source electricity, from this network you get relevant information of the conditions system operation and reliability electric power such as: phase angle and magnitude of voltage at every nodes, the real and reactive powers circulating in each element of the system in addition to the total losses of this.

2.4.1 Voltage Stability

The growth of photovoltaic generation distributed in low voltage electrical networks in residential areas have raised concerns about the stability and quality of the power in future electrical distribution networks, this brings new opportunities in controller designs in order to to improved performance of microgrid. The problem is complex due to the variability of the loads and generation that depend on many factors: customs, consumption patterns, weather conditions, the connection point of the photovoltaic inverters, between Many others. This work shows that stability can be maintained of the microgrid adjusting the gain of control systems of the photovoltaic generator. These articles is organized as follows that: The second sections presents brief description of microgrid to be analyzed and the energy scenario used to Throughout this work, the third section presents the models of the photovoltaic generator and the microgrid, thus as their equivalent models which will be used more ahead for your review. The fourth section presents the analysis of the stability of the microgrid and how to adjust the control system of the photovoltaic generator, according to the network impedance seen from the connection point, with the in order to maintain stabilities of microgrid. In the fifth section shows the result of this simulation with the in order to corroborate detailed analysis into the previous section and finally in section six the conclusions are presented obtained from this work. The numerical simulations presented later are carry out using Matlab. Also, corroborate results of presented simulation was carried out simulations of the circuit with this simulation software of EMTP electrical networks.

2.4.2 Rotor Angle Stability

The important deficiency of PV due to the variable power generation is that there is no splint when necessary. PV systems with static welding elements cannot be included in the power angle swing. For this reason, LSPVPs are difficult to adapt to the equivalent splint of the grid system due this the intermittent power outputs. The integrations of LSPVP into the grid had also change the original grid power flows and transmissions power. Also, during troubleshooting, the system will show different support characteristics than the conventional generator (Viet NH, and Yokoyama A., 2010).

Oftenly it will cause oscillation imbalance in the low frequency ranges due to lack of sufficient-damping torques. Synchronous generator has a rotational mass that was directly proportionals to frequency and thus controls change of load, but PV generations do not have such a feature. Therefore, the generation system must have inertia in case of suddenly changing frequency. The inertia is called the rotor-angle. In (R. Shah, N. Mithulananthan, and R.C. Bansal, 2013), the study was conducted to the determine the rotor angle stabilisied on the New England, New York systems with this effect of PV and synchronous generators. In this analysis, it has been shown that highly effective PV systems have negative effects on this power system. It is connected to reduce these problems caused by the lack of inertia, it is necessary to use additional devices. As a result of the two studies described above; This effect has been tried to be reduced by using different devices such as battery, ultra capacitors and shunt capacitor. In the results obtained, considering different devices as well as different parameters revealed more effective results (R. Shah, N. Mithulananthan, and R.C. Bansal, 2012).

Result of the issues mentioned above, one of the instability problems encountered during the integration of LSPVPs into power systems is rotor angle instability. This is a problem that can not be ignored. Power angle stability; power network topology, grid operation mode, photovoltaic system capacities, locations, and control strategies of the PV system. The research in (Tan YT, and Kirschen DS., 2007) explains that the stability of rotor angle during integrations can have positive also negative effects, but it is necessary to determine whether these effects are beneficial or not by using simulations. If the operation of the PV system in failure is not sufficient, this causes the system to be disconnected from the network. The effect of LSPVPP on stability on the off-grid system will be more and more intense when there is integration of central LSPVPP connected to the grid. Given this situation, it is important to assess the risk of LSPVPP being off-grid (Ming Ding, Zhicheng Xu, Weisheng Wang, Xiuli Wang, Yunting Song, and Dezhi Chen, 2016).

It is known that a large number of PV installations connected to the grid change the standard in power flow and the weak dynamic support of PV systems, yet pushing the limits of the transmission channel system. To understand the effects on the rotor angle stability of power systems with LSPVPP, a real simulation is needed. In the current situation, PV reduction and dynamic reactive power compensation configurations are applied to increase the stability and security of the grid (Ming Ding, Zhicheng Xu, Weisheng Wang, Xiuli Wang, Yunting Song, and Dezhi Chen, 2016). PV regulation parameters have been found to have a great influence on damping of the local modes of the systems. However, it has been found that incorrect setting of PV control parameters can also impair the damping of local modes (Golshani A, Bathaee SMT, and Moghaddas-Tafreshi SM., 2012).

2.4.3 Frequency Stability

For correct operation and operation of an electrical system is necessary to maintain a state of balance between generation and load (including losses) throughout the weather. If there is an event and the load, therefore increases torque electromagnetic of generators, these begin to slow down, and the frequency. However, there are small power imbalances that affect this equilibrium constantly, either by variations in load or by disturbances in the system, such as generator disconnection due to failure. To prevent these imbalances or disturbances end in a bad equipment operational performance and the collapse of the system, there are responses or controls or regulations frequency. The frequency response is divided into three control phases, not including the inertial response they possess naturally synchronous machines already that these act in the first 3 to 5 seconds. The three control phases are known as: primary response of frequency (RPF), secondary response frequency (RSF); and, answer tertiary frequency (RTF) as shown shown in Figure 3. Each acts in different time windows. The RPF acts between 3 and 30 seconds, the RSF operates between 30 seconds and 2 minutes and RTF operates after 10 minutes. Each frequency response has actions different, the RPF controls the speed of rotation of the shaft of each generator, the RSF acts in the control of the frequency and interact power with areas contiguous and the RTF operates in the place of an extensive electrical system, seeking optimally distribute the loads ensure sufficient energy reserves.

2.5 Summary

In this section, a detailed investigation of the difficulties encountered during the integration of LSPVPP, which is the key words of our study, into Energy transmission networks has been made. The studies in literature for voltage problems and solution methods, reactive power problem, rotor angle stability due to lack of inertia, frequency problem and solutions are summarized. This studies have also been made on issues such as voltage regulation, high power sharing providing minimum power losses, hence low harmonic distortion among the difficulties associated with the operation of micro grids. Voltage problems are more powerful and sudden in networks with other energy sources and PV systems. This situation increases the importance of network management.

CHAPTER III
GRID CODE COMPASION AND REQUIREMENTS

3.1 Grid Code of Operation

Talking about Network Code, nowadays it is very recurrent in the electrical environment and other areas; however, it is still not entirely clear. They have told us that we must comply with it so as not to be sanctioned by the Energy Regulatory Commission (CRE) and pay fines for thousands of pesos, but you have asked yourself: What is the Network Code? and Why should I comply? The Grid Code is the main instrument in terms of reliability issued by the Energy Regulatory Commission (CRE); It corresponds to the general administrative provisions that establish criteria of efficiency, quality and, reliability, continuity, security and sustainability of the National Electric Systems (SEN). It is applicable and mandatory for medium and high voltage load centers, in addition to any industry or commerce under the conditions mentioned and that is connected to the SEN. These are the studies and analysis of parameters that are applied to an electrical system to verify that the results are within the operating standards and, in this way, to have the certainty that our SEN can operate in stable conditions to supply energy. electricity to users and supply their electricity consumption needs.

3.2 (FRT) Fault ride through requirements

Broadly speaking, these are the technical requirements that must be met in the Network Code:

- Tension
- Frequency
- Short circuit
- power factor
- coordination of protections
- control
- exchange of information
- power quality (flicker, harmonic current distortion and current unbalance)

Through these technical requirements, the SEN will regulate itself in various activities such as interconnection to power plants, connection of load centers and, planning and operation of National Distribution Network and the General Distribution Network. It is worth mentioning that the monitoring of compliance with the Network Code is the obligation of the Energy Regulatory Commission, for which it may carry out the verification and inspection acts that it determines necessary through the public servants it has attached or through the units of inspection. In conclusion, after the Energy Reform, what we want to achieve is that all users and suppliers that are connected to the SEN have good quality electrical energy. On many occasions we do not see beyond our own electrical installation, that is, we do not realize that behind all this we have a great infrastructure that is in charge of supplying electricity to each user in the country and that needs to correspond to it. way to have an efficient generation, distribution and commercialization of electrical energy. Definitely, the objective of Grid Code to safeguard the correct operation of the SEN in terms of power quality. In order to give continuity, security and sustainability to National Distribution Networks and the General Distribution Network.

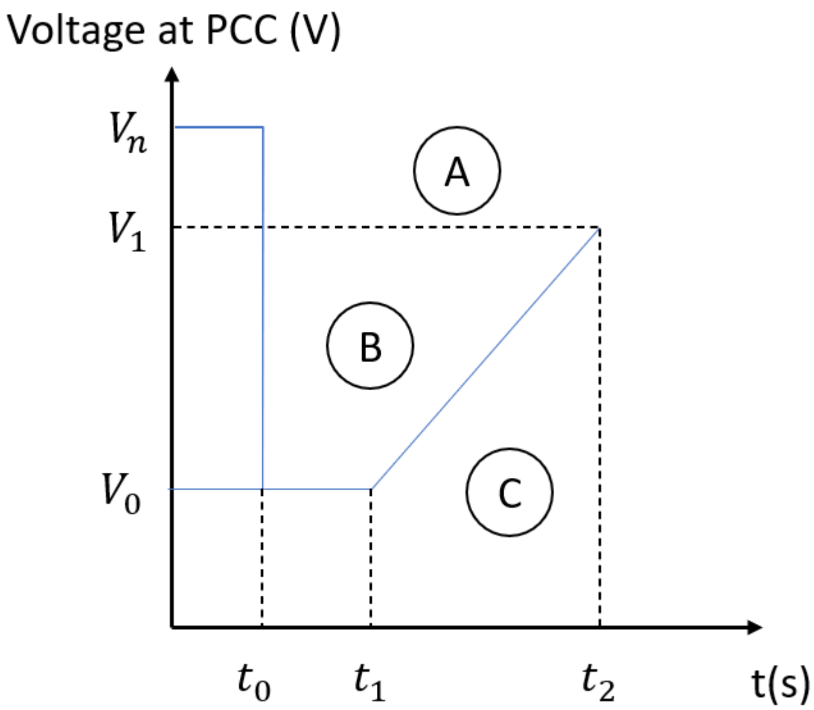

Figure 3. 1 (FRT) General curve for fault ride through requirements.

In this figure presence typicall curves for FRT. In Table 3.1, voltage limits and durations of some countries are shown and Figure 3.1 shows the voltage profiles for low voltage requirement to each network regulation (Rahmann C, and Castillo A., 2014).

Table 3. 1 Requirements in international grid codes for FRT.

Grid Code	During fault		After fault	
	$V_0(pu)$	$t_1(S)$	$V_1(pu)$	$t_2(pu)$
Germany	0	0,15	0,9	1,5
Romania	0,15	0,625	0,9	3
US-Puerto Rico	0	0,600	0,85	3
China	0	0,15	0,9	2
South Africa	0	0,15	0,85	2

For example, in the grid regulation issued in Malaysia in 2016, for symmetric or asymmetric failure cases; The photovoltaic power plant must remain connected into the transmission lines at least 150ms as show in this Figure 3.2. Then this failure, 1.5 seconds. In it, the transmission line must reach 90% of nominal voltage (Grid code for peninsular Malaysia, 2016).

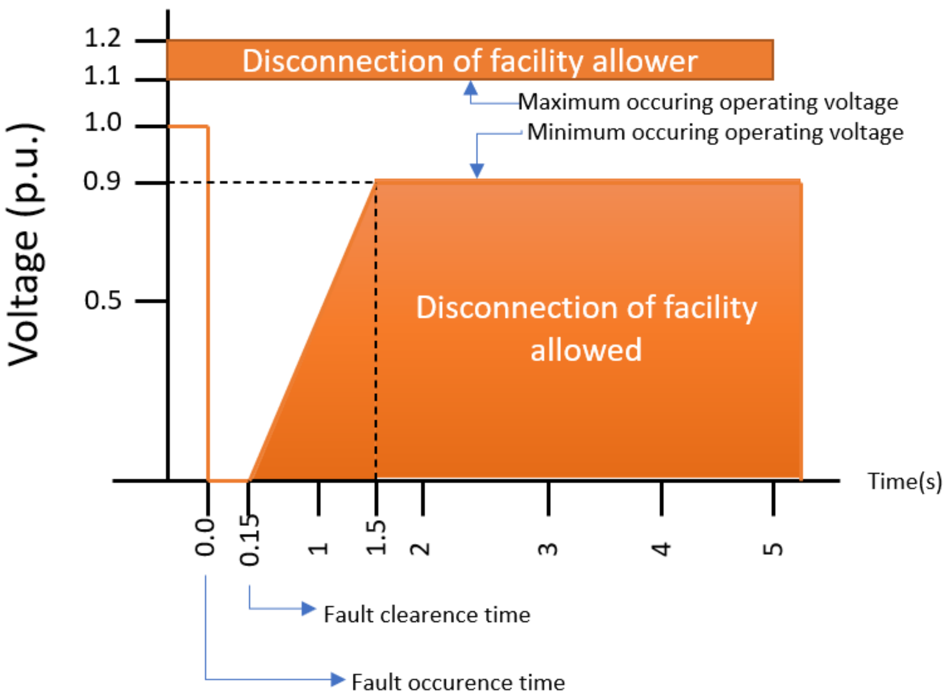

Figure 3. 2 Fault ride through requirement to Malasia (Grid codes for peninsular Malaysia, 2016).

In Turkey, a grid code to meet network requirements in these plants through growing licensed solar power plants has been established. In the said regulation, grid connection criteria of photovoltaic generation facilities based on solar energy have been determined. All power plant connect to distribution or transmissions level must remain connect to network into case to a fault in network and the grid voltage stays in areas 1 and 2 in Figure 3.3. In addition, after this fault is cleared, if this network voltage exceeds 0.9 pu. It should reach the maximum active-power values this can produced to increasing at 20% and 5% of nominal-active power per to second, respectively, for zones 1 and 2. In terms of reactive power, the inverters within the photovoltaic plants should reach maximum reactive-power value (inductive or capacitive) within 60 ms with ten percentage error margin and provide this support for 1.5 seconds.

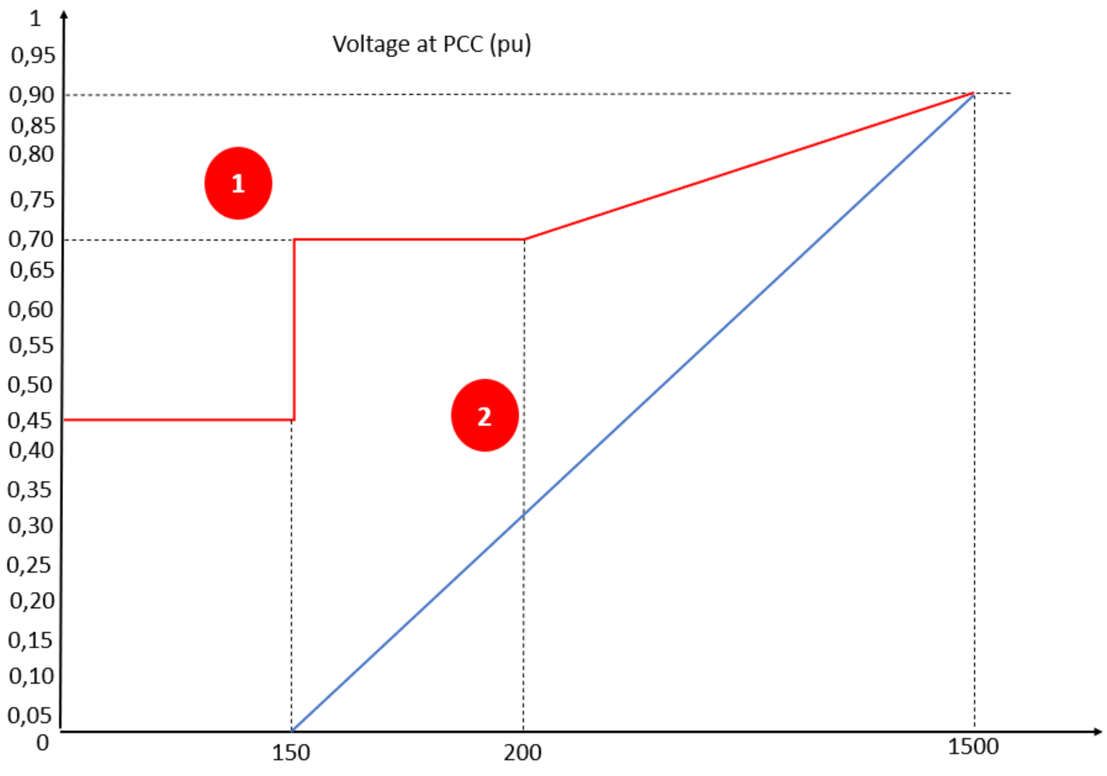

Figure 3. 3 Mains voltage change in case of failure.

The PV plant must also remain connected when overvoltage occurs, these are high voltage transition requirements (HVRT). Figure 3.4 shows the requirements determined by the South Africa and Peurto Rico grid regulation. According to the

Peurto Rico grid regulation, PVPPs must be able to withstand 1.4 pu overvoltage for 0.15 s (Rahmann C, and Castillo A., 2014).

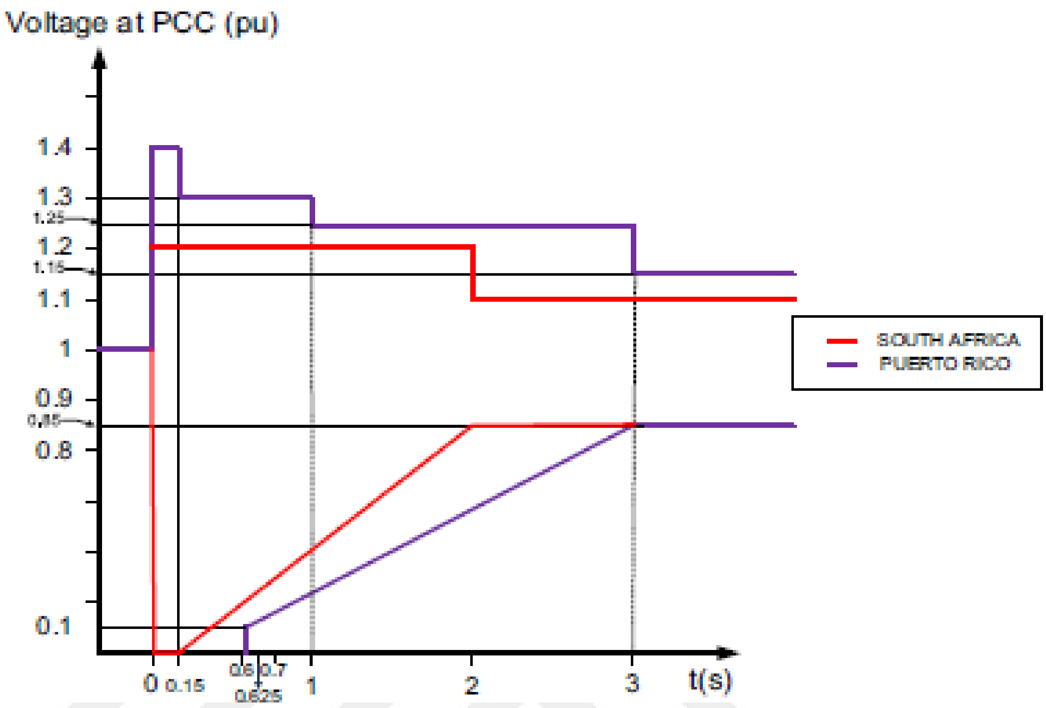

Figure 3. 4 Comparison on the HVRT requirement in internationals with using grid-codes.

Voltage-stability is supported reactive by power support. Regarding reactive-power support, not all grid code has this same requirements. Since it's not easy to adapt on the absorption and injection of reactive power, it is necessary to find effective solutions. The different grid code in addition allow installations of equipments to overcome these requirement as statics requirement compensators(SVCs), (STATCOMs) statics synchronous stabilizers and capacitors bank For this reason, this criterion must be evaluated in the selection of equipment and power plant controller (PPC). In Figure 3.4, since the inverters should it able to provide maximum reactive power support within 60 ms, it should be demonstrated with the analysis to be performed over the dynamic models of the inverter. For this reason, it is a great importance to ask the dynamic models of inverters in equipment procurement processes and to confirm whether the requirements specified here are supplied.

3.3 Voltage and Frequency Limits

The thermal limit of a conductor for overhead lines is the maximum allowed current, considering a maximum temperature through the conductor for established environmental conditions. The calculation of the thermal limit for overhead lines is obtained by heat balance methods. To determine the thermal limit of bare air conductors, it necessary for the consider in analysis the affect of ambient temperature, wind speed and direction, solar emission and height above sea level (IEEE Std. 738-2002). At present, there are both static and dynamic methods to determine the thermal limit, the difference is that in the case of the dynamic ones, some of the variables used in the calculation are obtained through measurements in real time (voltage, arrow, temperature, current in the driver) that are sent to be processed in a control center. Standard voltage limits are shown in Table 3.2.

Table 3. 2 Voltage-limits

	Maximum	**Minimum**
500KV	+ 5%	- 5%
275 and 132KV	+ 5%	- 5%
<132KV	+ 6%	- 6%

An advantage offered by high-temperature conductors is that they can be installed in the same towers as the existing right-of-way, without the need to reinforce them. Regarding the line hardware and accessories, these are replaced depending on the type of high temperature conductor to be used (Cigre, 2007).

As shown in the previous paragraphs, the determination of the thermal limit of conductors depends on a large number of criteria, which are defined in accordance with the design criteria of electricity companies. When considering criteria with very conservative values, the links transmit energy levels lower than the real limit, on the contrary, selecting more restrictive parameters the links could violate their maximum levels of energy transfer. To counteract the restrictions in determining the thermal limit indicated in the previous paragraph and, with this, make the most of the transfer capacity of a link or power line, the methodology in which the thermal limit is obtained dynamically (Kyeon et al., 2001). This is achieved through the measurement of the environmental conditions also parameters of the power lines: current flow, deflection, clearance between conductor and ground. These methods allow to know the capacity of the link in real time, which leads to being able to transmit the maximum level of electrical energy safely. Short-length electrical power lines (Duncan, 1990) are those that could transmit power levels close to their thermal limit. In the case of lines of medium or high length, there are restrictions that prevent them from being operated, within adequate safety margins, with MW transfer values close to their thermal limit. Some restrictions that limit the operation of power lines to power transfer levels lower than the thermal limit are analyzed in the following sections.

Table 3. 3 Frequency limits in international grid codes (Omran W, Kazerani M, and Salama M., 2011).

Grid Code	**Frequanc (Hz)**	**Limits (Hz)**	**Maximum duration**
Romania	50	f>52 47.5<f<52 f<47.5	Instantaneous trip Continuous Instantaneous trip
South Africa	50	f> 52 51<f< 52 49<f< 51 48<f< 49 47<f< 48 f< 47	4s 60s Contiuning
Us (Pierto Rico)	60	f>61.7	60s
		61.6 < f <61.7 60.6 < f <61.6 59.4 < f <60.6 58.4 < f <59.4 57.8 < f <58.4 57 < f < 57.3 f < 57	10s 3 min Contiuning 3 min 30s 7.5s Instantaneous trip
China	50	f >50.2 49.5 <f< 50.2 48 < f< 49.5 f< 48	2 min Contiuning 10 min PV inverter chaceristics
Germany	50	f>51.5 47.7<f<51.5 f<47.5	Instantaneous trip Continuous **Instantaneous trip**

When examining such cases, for Turkey; The response of the power plants in frequency change should be provided within the framework specified in the regulation. As shown in Figure 3.5, the GES decreases its active power by 4% change from 50.3 Hz to 51.5 Hz (this corresponds to a 60% reduction in power at 1.2 Hz change) and if it is above 51.5 Hz, it will reset its active power completely or should be deactivated. PPC manages this operating regime and adjusts the output power of the inverters by calculating the required active power change according to the network frequency.

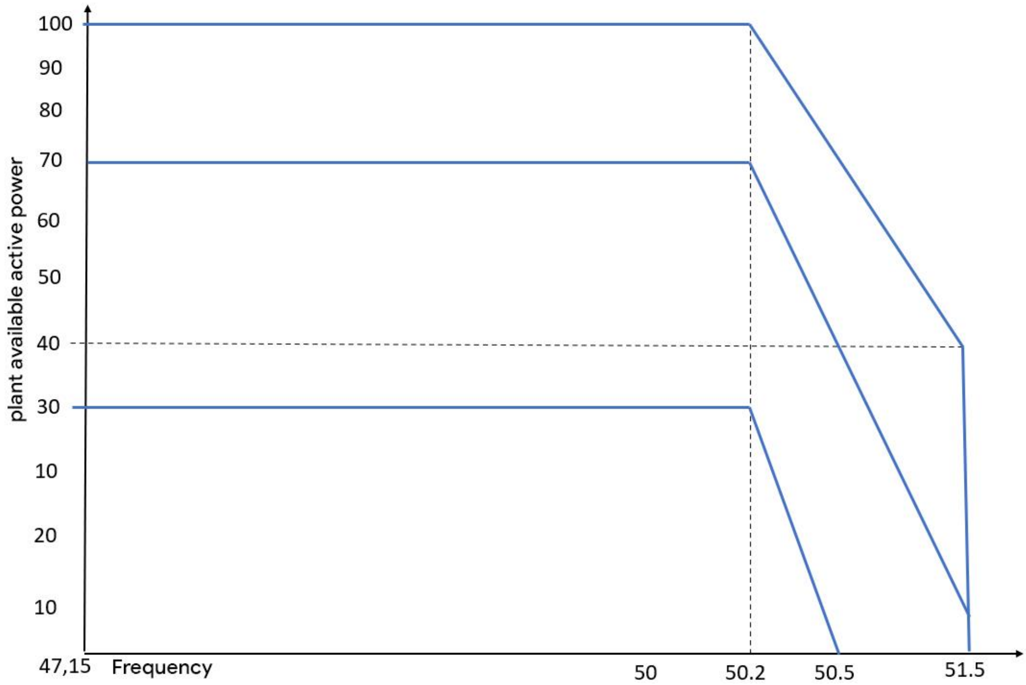

Figure 3. 5 Change of plant power depending on frequency.

Frequency and time limits to be based on the PV plant design and studies in Turkey set out in the grid code is shown in Table 3.4

Table 3. 4 Operating times in frequency range of the PV plant in Turkey.

Frequency Range	Minimum work time
50,5 Hz ≤ f ≤ 51,5 Hz	1hour
49 Hz ≤ f ≤ 50,5 Hz	continuosly
48.5 Hz ≤ f ≤ 49 Hz	1hour
48 Hz ≤ f ≤ 48,5 Hz	20minute
47,5 Hz ≤ f ≤ 48 H<	10minute

3.4 Active-Power Regulation

Operating to the power point existing photovoltaic inverter is in the max active power Varying according the radiation. LSPVPP will always work at maximum power in for each solar radiations. Because of opacity, these electrical systems will treat large and rapid fluctuations in active power.

With these actions, the network affects the energy balance and triggers emergency situations. Active power control must comply with changing energy throughout day and requirement of network regulation. Another constraint entering active power control is the speed limit into power gradient. If we look the network code of South Africa, control the active power is divide into the three main requirements; absolute generation and delta-power gradients generation (Ana Cabrera-Toba, Eduard Bullich-Massagu, Monica Aragés-Peñalba, Oriol Gomis- Bellmunt,2016). The absolute generations are base on this value of active-power must provide LSPVPP. Delta generation determines the active power reserve. In Rico, delta productions are defined to an energy reserving. The gradient limit value power that power generation should increase or decrease the values of active power MW per minute (Omran W, Kazerani M and M. Salama, 2011). LSPVPP must meet any of those requirements despited the change of radiation and, clouds cover. Those requirement are shown into Figure 3.6. An important factor determining this value to decrease or increase the active-power are units to megawatts per minute. In research (Magoro B, and Khoza T., 2012), the power plant should photovoltaic power control at a rate by 15% of the nominal capacity per minutes.

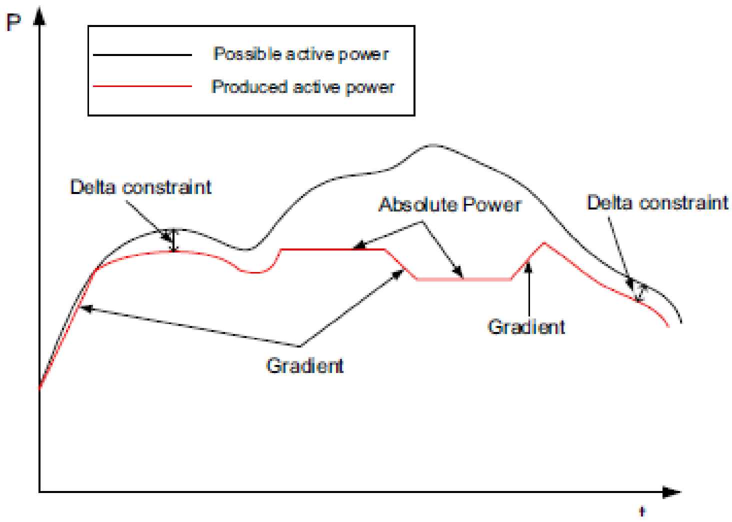

Figure 3. 6 Active power control constraints for PVPPs.

Table 3.5 is summarize that, active power controlled required by various regulations of International Network for the integration of the photovoltaic system. They allow to shorten the active powers to a specified values. Shortly active power it developed from ramp rate limiting with different value depending on the countries (Omran W, M and M. Salama Kazerani, 2011). Network regulations require the least two types of active power controlling. They are power outages alos ramp speed controlling.

Table 3. 5 Active power constraints required by international grid codes.

Grid Code	Curtailment	Reserve	Ramp Rate
Germany	X	-	X
Romania	X	-	-
US (Puerto Rico)	X	X	X
China	X	-	X
South Africa	X	X	X

Active power control are also available in Turkey in these grid codes. Based on demand from distribution company, it should be able to reach the desired value in the range of 20-100% of the active output power with a change rate of 5% (for power plants smaller than 100 MW) and 4% (for power plants larger than 100 MW) per minute. The important point here is that the selected PPC can transmit the command received from the distribution company to all inverters within the PV facility in accordance with the specified slope and the power plant output power can reach the desired value.

3.5 Reactive power regulation

During the high solar radiation of the interconnected photovoltaic, any variation in the voltage limits is this possible. The possible solution is to reduce voltage spike at feeder runs PV-based generating units capable of providing reactive power (H. Abdel-Gawad, and V. K. Sood, 2014). Also, in this event in a voltage drop, inverter must do to withstand sufficient-reactive current and the stabilize grid within certain time periods defined by grid codes. One of the main challenges in connecting a photovoltaic solar power plant to a grid, voltage needs to be controlled. The photovoltaic inverter technology used at the distribution level is not controlled by PQ. With the increasing requirements of LSPVPPs and grid regulation, PV inverters need to control not only active power but also reactive power. The MPPT control used in normal photovoltaic systems does not have full control over the PQ capacity during the day, limiting system performance.

Figure 3.7. shows the curve of the capacity of the photovoltaic generation system. In the figure, the dark line curve represents the nominal operating capacity while the dotted line represents the ability of reactive power with the large inverter. These values also showed the operational properties of the envelope of the constant power factor (Alquthami,T, Ravindra,H, Faruque, M.O, SteurerM and Baldwin, T., 2010).

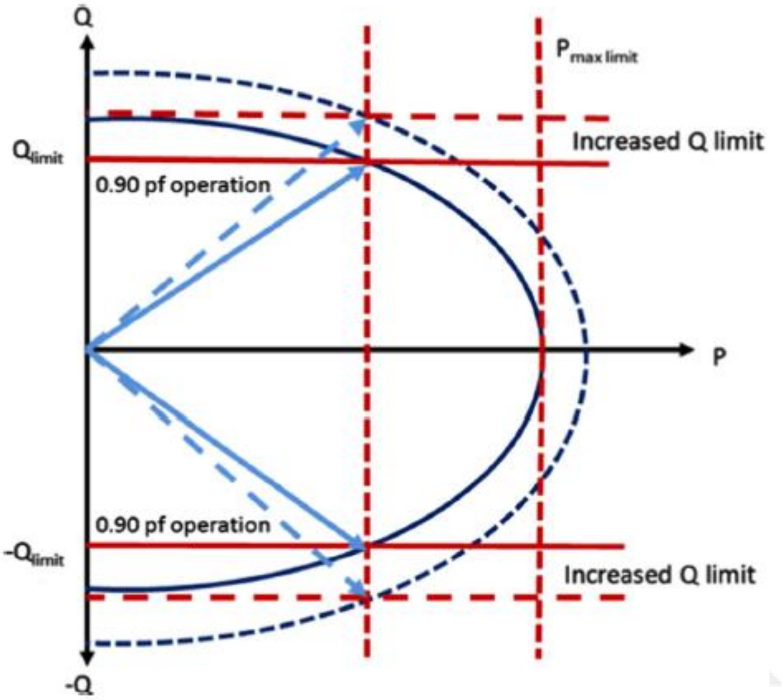

Figure 3. 7 Real and reactive power characteristics of PV (Rakibuzzaman Shah, N. Mithulananthan, R.C. Bansal, V.K. and Ramachandaramurthy, 2015).

Table 3. 6 Power factor/reactive power requirement.

Country of origin / regulatory-body	Power-factor reqirement
Germany	Medium voltage ± 0.95; high voltage + 0.90 / -0.95 ±0.95 Power factor
FERC	+ /- 0.95 Power factor
ERCOT	+ /- 0.95 Power factor for full output, scaled by the ratio of active power for lower output
CAISO	± 0.95 Power factor for real power generation > %20

The weak reactive power support capability of most of existing PV plants can cause overvoltage and voltage-instability (Marionpoulos A,Papandrea F, M. Reza, Norrga

S,Spertino F, and NapoliR., 2011). Voltage spikes and stability issues, along with high-impact distributed PV integration, are one of major problems of distributions network operators. The voltage fluctuation-level is the mostly affected for the distributed photovoltaic allocation, installations capacity, and the correlation between PV output and the local load profile (Alquthami T, Ravindra H, and Faruque MO., 2010). It is the reactive power support that should be provided by the power plant, which generally requires additional hardware investment. PV plants must be able to operate continuously at every point for reactive power values within the limits indicated by dark lines at the transmission or distribution connection point. The important point here is that the plant can give a reactive power corresponding to half of its rated power while providing maximum active power. For the plants connected from this transmission or distribution level, it should be taken into consideration in the selection of DC and inverter power as well as the installed power of step-down / inverter transformers. Thanks to selection to both DC-power also inverters above Altarnete-Current (AC) contract powers in the design of recent power plants (provided that the transformers are selected accordingly), the following curve can be provided with reactive-power supported provided by inverters. However, it is a more economical solution to use reactive-power compensation systems connected at MV level instead of additional inverter investments in order to meet the reactive power originating from step-down transformers and inverter transformers in the power plant, especially in the plants connected from the transmission level. Turkey's grid code examination when the plants of the compatibility analysis while reactive power support the evaluation of the adequacy and the inverter through PPC reactive power required or additional compensation you warranty issue are supplied with systems need to be confirmed.

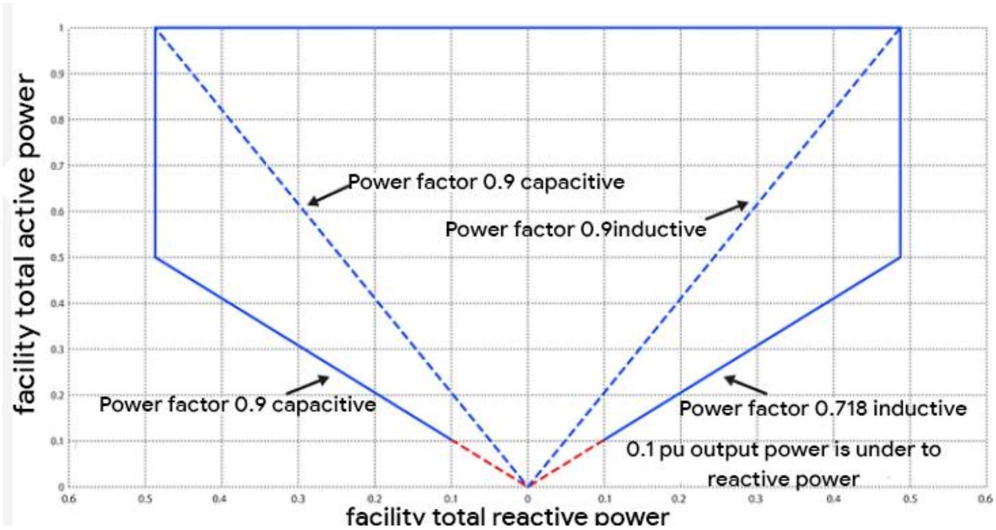

Figure 3. 8 The reactive power curve that PV plants should provide.

In figure 3.8, the reactive-power of the photovoltaic power plant must supply curve shown located in Turkey. In addition to the curve above, the power plants connected from the transmission level should adjust the output reactive power dynamically according to change of this voltage at connection point under normal operating conditions defined between 0.9-1.1 pu values of the connection point voltage.

In literature as "droop" called control In this control, the slope of the curve showing the change of reactive power output against voltage TEİAŞ (electricity transmission company in Turkey) from 2-7% depending upon the demand must be amended. Thus, with the commands given by the PPC, the PV plants automatically react to the voltage changes in the network, contributing to the busbar voltage remaining at the nominal value with reactive power support in the inductive or capacitive direction. In addition, sudden step change this may occured under normal operate conditions should start to respond within 200 ms at the latest, as indicated in the graphic in Figure 3.9, the reactive output-power should be reach 90% of the require balance values within 1 second at the latest and within 2 seconds at the latest adn should also balance.

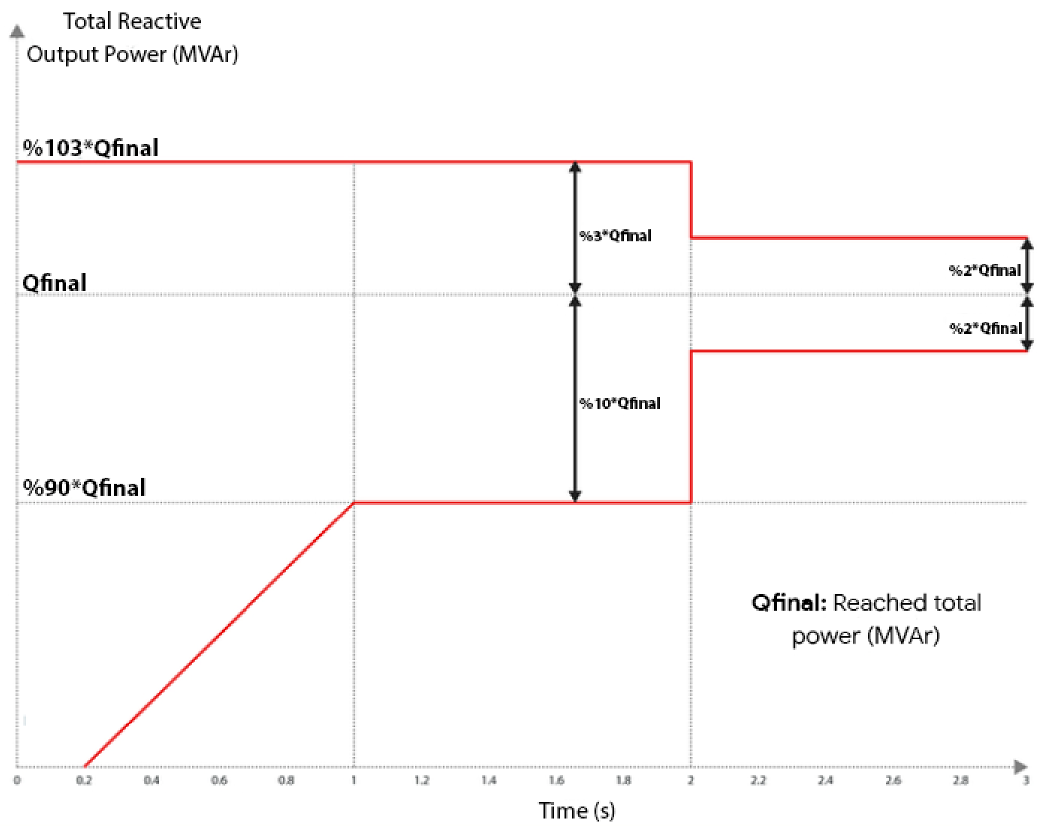

Figure 3. 9 Reactive power change response times.

In summary, the licensed active and reactive output powers connecting to transmission or distributions systems can be controlled into case of failure, frequency oscillation and voltage change, and the power plant controller, namely the PPC, must react and manage inverters and additional compensation systems, if any, within the framework of the conditions specified in the grid regulation. For this reason, before the design and material selection processes in the power plant are completed, the requirements in the grid regulation should be taken into consideration and it is a great importance to verify the system design (rated powers, etc.) and especially the qualifications of the inverters with the analyzes to be carried out. However, if there is not support all the control functions specified in the regulations ppc'n network will be selected and can only inverters must have the ability to manage the additional compensation.

CHAPTER IV
SIMULATION AND CONCLUSION

4.1 Grid Code Simulation Using Matlab/Simulink

This simulation has implemented with using Matlab/Simulink. This simulation consist to some components related to grid and solar system, also IEEE standarts and grid code check. A controlable voltage source is used and voltage and frequency value changes according to the scenario which is uploaded in workspace. When simulation is starts voltage and frequency changes in time. After voltage source grid connection transformer is placed, after the transformer grid and solar plant connection is made, between transformer and pv plant there is static load.

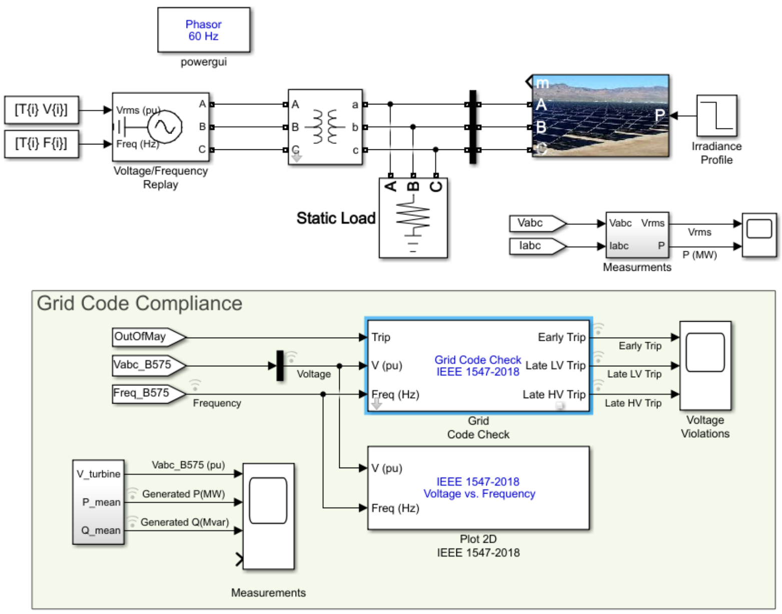

Figure 4.1 Simulation Outline

- The solar power-plant connected to grid with a power to 500 kw was designed using Matlab simulink.
- We will observe whether the voltage and frequency values of the solar energy system are within these limits with the limitations we have created.
- A scenario was created in which the voltage and frequency values were determined. In this scenario, voltage and frequency values varying with time are given to the network.
- Measurements were made from the place where the solar energy system is connecting to grid.
- They were observing whether this voltage and, frequency values varying depending on the time are in accordance with the LVRT and HVRT limits of the IEEE 1547-2018 standard.
- In the grid code compliance, evaluation has been made according to IEEE 1547-2018 standards. Voltage and frequency values are observed. In case of going beyond this standard, the system can be interrupted.

4.2 Grid Code Definitions

We must add graphics to create grid codes in the simulation. Compliance with the network code is one of the requirements for (CUSC) “Connection-and-use-of-system-code” and Network Code details the technical requirements for connection and use of the (NETS). “National-Electricity-Transmission-System”. These codes are in Appendix.

4.3 Simulation Results

After simulation start the system is working according to the workspace scenerio when voltage and frequency change the grid code check system analyze this values according to the IEEE1547 standarts. In figure 4.2 and 4.3 presence IEEE1547 standarts measurements. It has some internal comparision for voltage and frequency values which is measured from common coupling point also voltage and frequency block has inner and outer limits for defining measured values and with this limit the boundries can be seen on scopes.

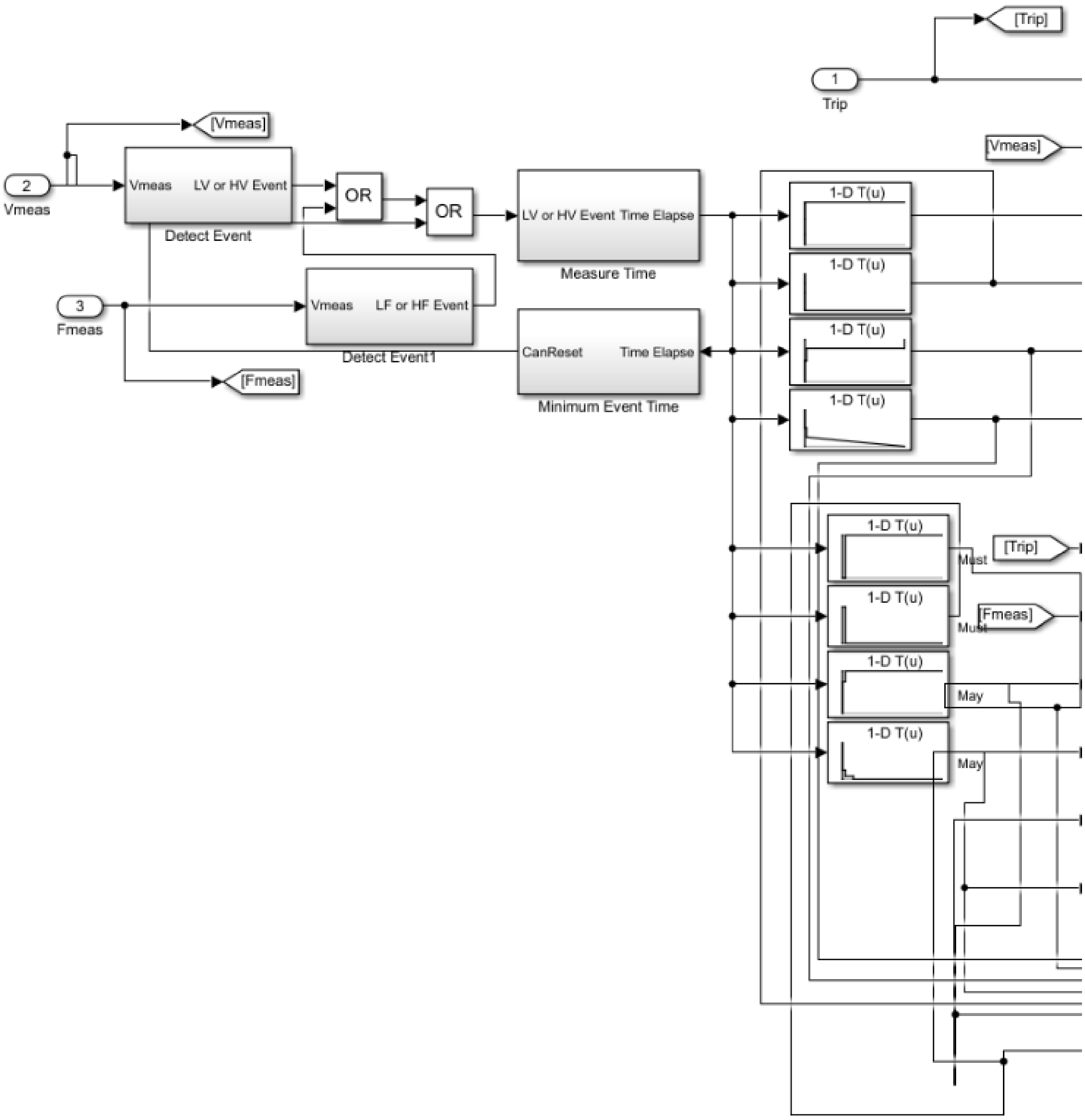

Figure 4.2 IEEE1547 Standarts Measurement-1

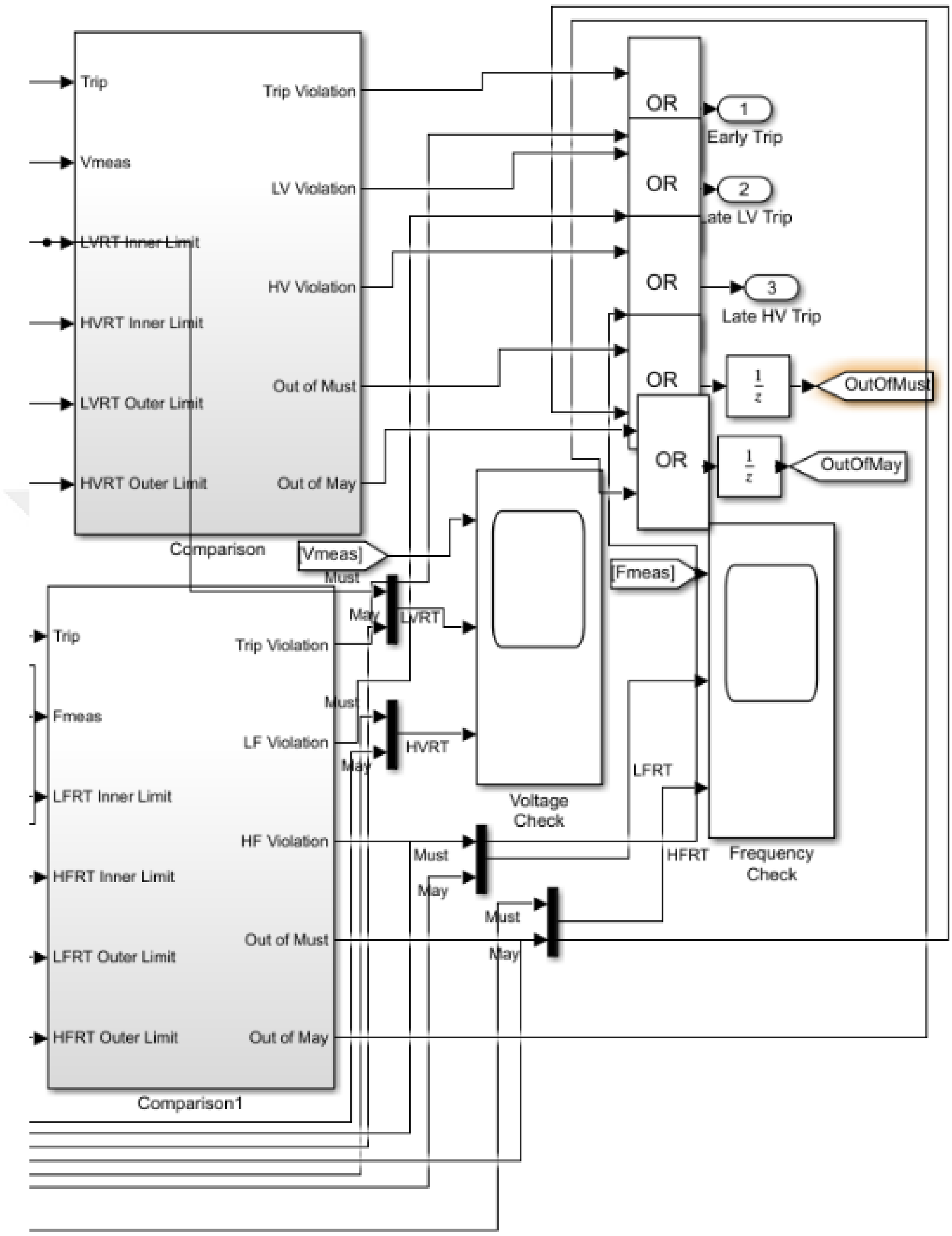

Fıgure 4. 1 IEEE1547 Standarts Measurement-2

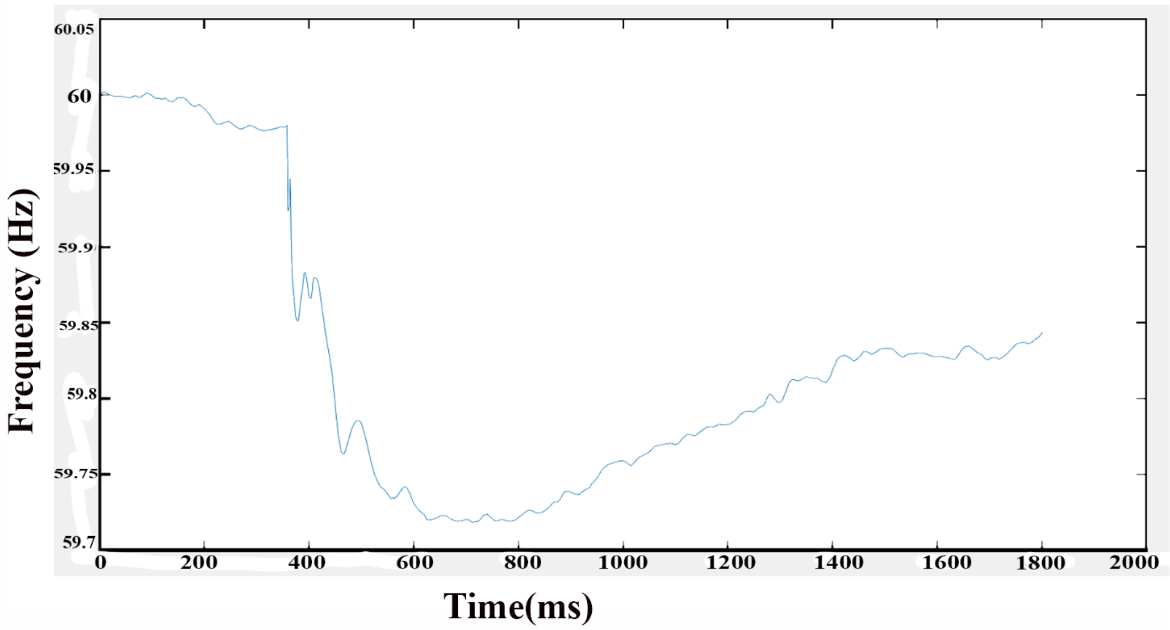

Figure 4.3 Frequency drop at the PCC during the variation of irradiation

Figure 4.4 presence frequency scenerio of simulation. With this scenerio virtual fluctiations implemented on simulation, with this fluctuations IEEE1547 standarts can be examine. The frequency start with 60 Hertz which is North american standart after 200 ms sample it start to decrease dramatically to 58 hertz and after 800 ms sample it start to increase slowly. This points saved in Matlab workspace and it work similtaneously with simulation.

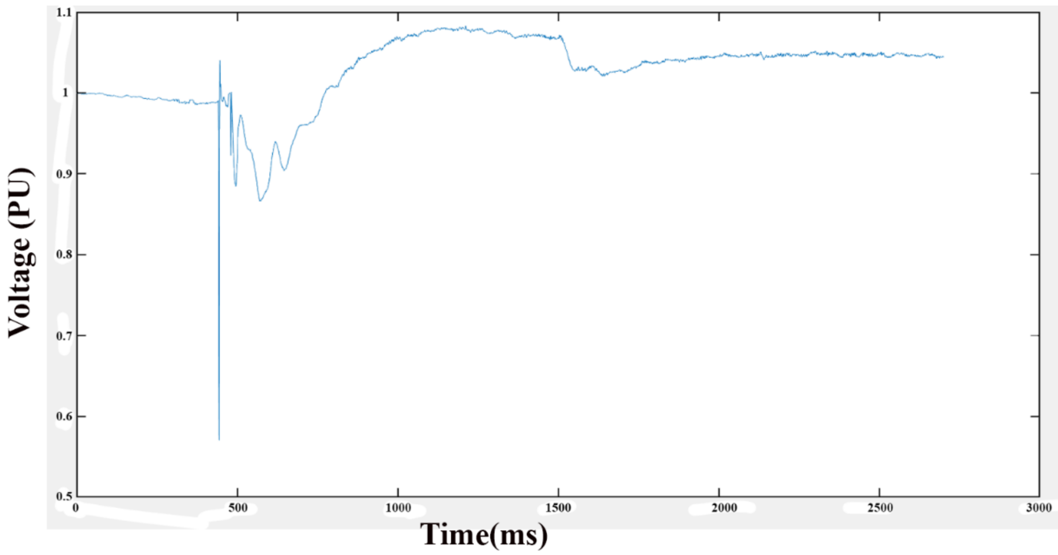

Figure 4.4 Voltage drop at the PCC during the variation of irradiation

This voltage sceniro not in spesific interval. In this scenirio the fluctition start in nearly middle of simulation. The sceniro contain 3000 sample the fluctition start in 5000 and it finish 15000 sample this temple came the sample start and finish with simulation time. Figure 4.5 presence voltage scenerio of simulation. With this scenerio virtual fluctiations implemented on simulation, with this fluctuations IEEE1547 standarts can be examine briefly. The voltage start with 1 PU after 200 sample it start to fluctuate dramatically to 0.9 PU and after 800 sample it start to increase slowly. This points saved in Matlab workspace and it work similtaneously with simulation.

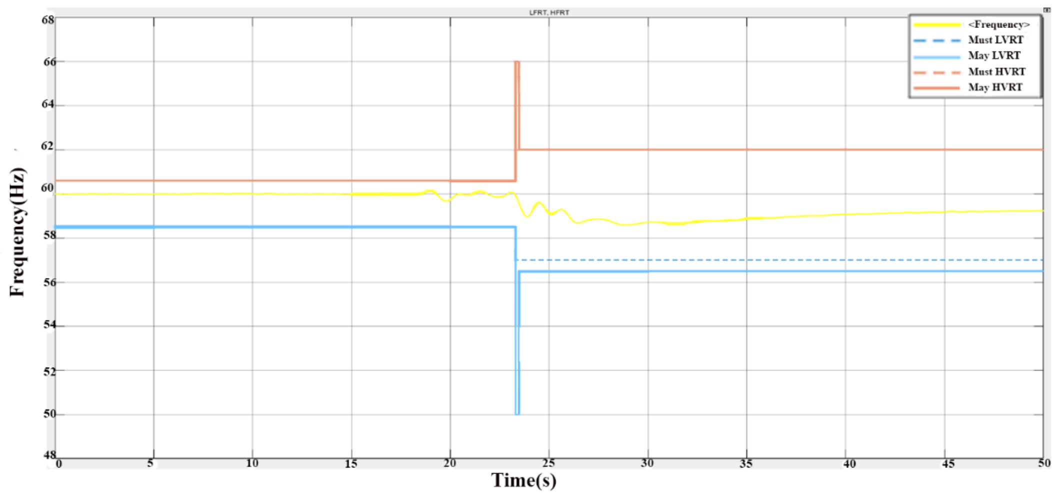

Figure 4.5 Frequency Check For LVRT and HVRT

In this graph there is not specific point to show HVRLT and LVRT. The only thing to understand in this border, it will come from IEEE1537 standart. The figure shows the frequency change in the network depending on time.in the figure 4.6 the frequency graph obtained, it was observed that the frequency values in the network depending on the time are within the standards. It appears that the frequency is in the range of must LVRT and must HVRT. If it is out of these limitations, the system can be interrupted. Red dashed line and normal line is presence upper limit of frequency check which is defined in IEEE1547 standarts before. Blue dashed and normal line presence lower limit of frequency check which is defined in IEEE1547 standarts. This graph shows the frequency measurement change in allowable limit of IEEE1547 standarts.

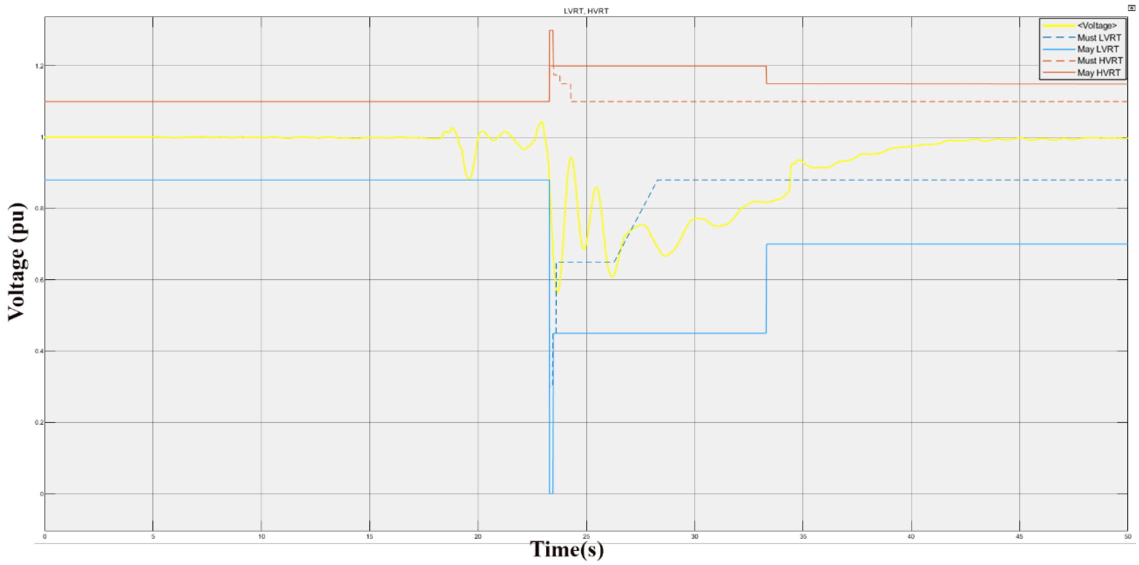

Figure 4.6 Voltage Check For HVRT and LVRT

The figure shows the voltage change in the network depending on time. The figure 4.7 voltage graph obtained; it was observed that the voltage values in the network depending on the time are within the standards. It appears that the voltage is in the range of LVRT and HVRT. If it is out of these limitations, the system can be interrupted. Red dashed line and normal line is presence upper limit of voltage check which is defined in IEEE1547 standarts before. Blue dashed and normal line presence lower limit of voltage check which is defined in IEEE1547 standarts. This graph shows the voltage measurement change in not allowable limit of IEEE1547 standarts it exceeds the borde of blue dashed line in middle of simulation. With this result the controller trip and all system can be shutdown till voltage value will be in nominal standart value. Yellow line presents the measure voltage from system.

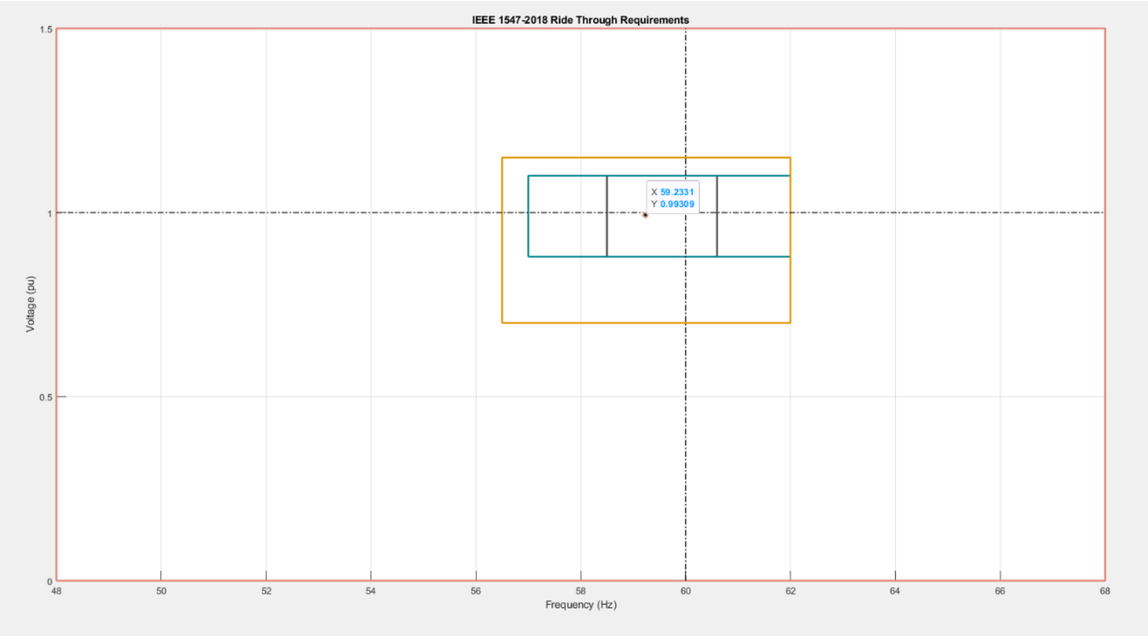

Figure 4. 2 IEEE1547 Ride Through Requirements

Figure 4.8 presence voltage frequency comparision of IEEE1547 standarts. This system has been evaluated according to IEEE 1547-2018 standards. It has been observed that the solar energy system can control the voltage and frequency according to these standards. In case of breakdown, the system can be shut down. In the figure, frequency and voltage values of the system depending on the time are within the determined limits. For the future works when a solar plant planning to establish this work can be used and limit of voltage and frequency values determine with IEEE1547 standarts. This graph presentation starts with simulation. The point in the middle of graph is centered after simulation started its position is changed according to the fluctuations of voltage and frequency

CHAPTER V
CONCLUSION AND FUTURE WORKS

For grid connected photovoltaic systems tracking and monitoring system stability is very crucial nowadays. The decreasing of photovoltaic module prices main reason of establishment of this situation. Accordingly, it attracts great interest in modern energy systems in the installation of large scale photovoltaic power-plants (LSPVPP) connect to transmissions lines. In addition to the rising trend, the control and operation problems encountered during the integration of large scale (PV) photovoltaics energy system in the grid are increasing. A detailed analysis and regulations with limitations are needed to deal with these problems. In this thesis FRT requirement implemented on grid connected PV Array simulation and IEEE1547 Grid code standarts is used to compare some specific scenerios like voltage and frequency fluctuations. Some general conclusion about simulation is given below;

- The controller of system succesfully implemented to see ride through requirement on scopes.
- The PV aray block is succesfully connected to grid and maximum power extract it and (PCC) Point of common-coupling point measured via current and voltage measurement block.
- Generating sine wave from pv array made with matlab algorithms real switching elements is not used in simulation.
- In fault condition controller able to trip system breakers to shutdown all elements.
- When measuring voltage frequency exceed the border of IEEE 1547 standards, the controller and a signal to the circuit breaker for this connect PV array from system.
- Develop more complex controller for fast recovery from fault conditions.

- When a pv plant start to established this simulation can be used as reference for seeing fault through requirements
- Partial shading and irradiance parameters can be add to simulation in future.

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APPENDIX

Common Grid Code Definitions

PRC-024

Voltage Ride Through

PRC024.LVRT.T = (-1 0 0+1e-6 0.15 0.15+1e-6 0.3 0.3+1e-6 2 2+1e-6 3 3+1e-6 600);
PRC024.LVRT.V = (0.9 0.9 0 0 0.45 0.45 0.65 0.65 0.75 0.75 0.9 0.9);
PRC024.HVRT.T = (-1 0 0+1e-6 0.2 0.2+1e-6 0.5 0.5+1e-6 1 1+1e-6 600 600+1e-6);
PRC024.HVRT.V = (1.1 1.1 1.2 1.2 1.175 1.175 1.15 1.15 1.1 1.1 1.1);

Frequency Ride Through

PRC024.WECC.LFRT.T = (-1, 0, 0+1e-6, 0.75-1e-6, 0.75, 7.5-1e-6, 7.5, 30-1e-6, 30, 180-1e-6, 180 10000);
PRC024.WECC.LFRT.F = (59.4, 59.4, 57, 57, 57.3, 57.3, 57.8, 57.8, 58.4, 58.4, 59.4 59.4);
PRC024.WECC.HFRT.T = (-1, 0, 0+1e-6, 30-1e-6, 30, 180-1e-6, 180, 10000);
PRC024.WECC.HFRT.F = (60.6, 60.6, 61.7, 61.7, 61.6, 61.6, 60.6, 60.6);

PRC024.East.LFRT.T = (-1, 0, 0+1e-6, 2-1e-6, 1800, 10000);
PRC024.East.LFRT.F = (59.5, 59.5, 57.8, 57.8, 59.5, 59.5);
PRC024.East.HFRT.T = (-1, 0, 0+1e-6, 2-1e-6, 600, 10000);
PRC024.East.HFRT.F = (60.5, 60.5, 62.2, 62.2, 60.5, 60.5);

PRC024.Quebec.LFRT.T = (-1, 0, 0+1e-6, 0.35-1e-6, 0.35, 2-1e-6, 2, 10-1e-6, 10, 90-1e-6, 90, 660-1e-6, 660 10000);
PRC024.Quebec.LFRT.F = (59.4, 59.4, 55.5, 55.5, 56.5, 56.5, 57, 57, 57.5, 57.5, 58.5, 58.5, 59.4, 59.4);
PRC024.Quebec.HFRT.T = (-1, 0, 0+1e-6, 5-1e-6, 5, 90-1e-6, 90, 660-1e-6, 660, 10000);
PRC024.Quebec.HFRT.F = (60.6, 60.6, 66, 66, 63, 63, 61.5, 61.5, 60.6, 60.6);

ERCOT

Voltage Ride Through

ERCOT.LVRT.T = (-1 0 0+1e-6 0.15 1.75 2 600 600+1e-6);
ERCOT.LVRT.V = (0.95 0.95 0 0 0.9 0.9 0.9 0.95);
ERCOT.HVRT.T = (-1 0 0+1e-6 0.2 0.2+1e-6 0.5 0.5+1e-6 1 1+1e-6 600 600+1e-6);
ERCOT.HVRT.V = (1.1 1.1 1.2 1.2 1.175 1.175 1.15 1.15 1.1 1.1 1.1);

Frequency Ride Through

PRC024.ERCOT.LFRT.T = (-1, 0, 0+1e-6, 2-1e-6, 2, 30-1e-6, 30, 540-1e-6, 540, 10000);
PRC024.ERCOT.LFRT.F = (59.4, 59.4, 57.5, 57.5, 58, 58, 58.4, 58.4, 59.4, 59.4);
PRC024.ERCOT.HFRT.T = (-1, 0, 0+1e-6, 30-1e-6, 30, 540-1e-6, 540, 10000);
PRC024.ERCOT.HFRT.F = (60.6, 60.6, 61.8, 61.8, 61.6, 61.6, 60.6, 60.6);

IEEE 1547-2018

Voltage Ride Through
IEEE1547.mayLVRT.T = (-1 0 0+1e-6 0.16 0.16+1e-6 10 10+1e-6 1000 1000+1e-6);
IEEE1547.mayLVRT.V = (0.88 0.88 0 0 0.45 0.45 0.7 0.7 0.88);
IEEE1547.mayHVRT.T = (-1 0 0+1e-6 0.16 0.16+1e-6 10 10+1e-6 1000);
IEEE1547.mayHVRT.V = (1.1 1.1 1.3 1.3 1.2 1.2 1.15 1.1);
IEEE1547.mustLVRT.T = (-1 0 0+1e-6 0.16 0.16+1e-6 0.32 0.32+1e-6 3 5 1000);
IEEE1547.mustLVRT.V = (0.88 0.88 0.3 0.3 0.45 0.45 0.65 0.65 0.88 0.88);
IEEE1547.mustHVRT.T = (-1 0 0+1e-6 0.2 0.2+1e-6 0.5 0.5+1e-6 1 1+1e-6 600 600+1e-6);
IEEE1547.mustHVRT.V = (1.1 1.1 1.2 1.2 1.175 1.175 1.15 1.15 1.1 1.1 1.1);

Frequency Ride Through
IEEE1547.mayLFRT.T = (-1, 0, 0+1e-6, 0.16-1e-6, 0.16, 300-1e-6, 300, 10000);
IEEE1547.mayLFRT.F = (58.5, 58.5, 50, 50, 56.5, 56.5, 58.5, 58.5);
IEEE1547.mayHFRT.T = (-1, 0, 0+1e-6, 0.16-1e-6, 0.16, 300-1e-6, 300, 1000-1e-6, 1000, 10000);
IEEE1547.mayHFRT.F = (60.6, 60.6, 66, 66, 62, 62, 61, 61, 60.6, 60.6);
IEEE1547.mustLFRT.T = (-1, 0, 0+1e-6, 299-1e-6, 299, 10000);
IEEE1547.mustLFRT.F = (58.5, 58.5, 57, 57, 58.5, 58.5);
IEEE1547.mustHFRT.T = (-1, 0, 0+1e-6, 299-1e-6, 299, 10000);
IEEE1547.mustHFRT.F = (60.6, 60.6, 62, 62, 60.6, 60.6