Assessment of Different Topological Integration of Solar Power Plants in Medium Voltage Distribution Networks

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Declaration

We, student of M.S. Renewable Energy Technology, Institute of Energy, University of Dhaka bearing Exam Roll: 504 and 510, would like to declare here that this thesis on "**Assessment of Different Topological Integration of Solar Power Plants in Medium Voltage Distribution Networks**" has been authentically prepared by us.

Exam Roll No. 504	Exam Roll No. 510
Session: 2014-2015	Session: 2014-2015
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Certificate

This is to certify that the M.S. thesis report on "**Assessment of Different Topological Integration of Solar Power Technologies in Medium Voltage Distribution Networks**" submitted for the partial fulfillment of the M.S. degree in Renewable Energy Technology from the University of Dhaka, has been carried out by the student bearing Exam Roll: 504 and 510, under my supervision. To the best of my knowledge and as per his declaration, the whole work and the complete thesis report has been prepared by the student and has not been submitted to anywhere else.

The thesis report can be considered for evaluation.

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All praise and thanks to almighty Allah who is our creator, sustainer, nourisher, protector and curer. May His choicest of blessings and salutations be upon our beloved prophet Muhammad *sallallhu alaihi wa sallam*, his family members, his companions, and all those who follow his path with utmost sincerity until the Day of Judgment.

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Abstract

Storage of fossil fuels is limited. Burning of fossil fuels for electricity generation, transportation, heating, cooking, industrial production and other purposes cause emission of gases and other particles, which are harmful for environment. Emission of green hose gases causes global temperature increase. Sunlight is abundantly available than fossil fuels. Photovoltaic (PV) power plants are better than fossil fuel based plants in terms of environmental impact. To make and photovoltaic based plant efficient and cheaper it is important to integrate these systems into distribution systems properly. In this paper, an analysis of placement of photovoltaic system in different uses of medium voltage (MV) a distribution system has been done. Loadability, voltage levels, maximum power input has been analyzed. A comparative study has been carried out about fractioning effect of photovoltaic generator in distribution system. Results and analysis show that change in loadability due to placement and fraction of solar plant in different buses. Maximum input level of photovoltaic system varies with placement among different buses. Interaction among photovoltaic system, induction machine, dc machine and synchronous machine has been also carried out. Results found from this analysis show that interaction among photovoltaic system, induction machine, dc machine and synchronous machine were different in terms of loadability and voltage level. Fractioning of machines has also different impact on bus voltage level and loadability of system. Change in bus voltage level is occurred due to placement of photovoltaic system at different buses. Effect of integration of photovoltaic system into extra buses extended from different buses and effect of distribution of generation unit and fractioning were analyzed. Result has been found that change in loadability occurred due to fractioning and distributing of photovoltaic system on different types of design topology of system.

Index Terms— Continuation power flow (CPF), photovoltaic (PV), distributed generation (DG), maximum loading parameter (λ), power transfer capacity, Static synchronous compensator (STATCOM), voltage collapse, voltage stability.

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Chapter 1

Introduction

1.1 Introduction

Fossil fuels are harmful for environment. Burning of fossil fuels is one of the main causes of global warming. Combustion of fossil fuel causes emission of greenhouse gases. Production of air pollutants such as nitrogen oxides, sulfur dioxide, volatile organic compounds and heavy metals are caused by burning of fossil fuels. The cost of fossil fuels is fluctuates often. Limited reserves of fossil fuels are being used rapidly. Renewable energy sources are generally less polluting than fossil fuels. Renewable energy resources are generally available than fossil fuels. But installment cost of renewable based electricity generation technologies are generally higher than fossil fuel based electricity generation plants. Efficiency, plant area, capacity factor, operating cost, water consumption, impact on environment and cost per kilowatt are the factors which should be considered before installation of electricity generation plant. Some of renewable energy sources' output varies with daytime and season like solar photovoltaic (PV), solar thermal etc. Some sources are not available in all countries like geothermal. Solar is generally more available renewable resources throughout the earth surface.

1.2 Literature Survey

A feasibility study of using PV systems as an alternate source of electricity generation in Bangladesh had done by analyzing the stability of electrical power system with the penetration of photovoltaic based generation. System-loading margin had been studied without and with PV based generator. The contribution of PV based generator on solving under voltage problem and improving bus voltage had been studied. Solution of overloading problem of power transformers with solar PV generator was described [1]. A study had been done about optimal placement and sizing method to improve the voltage stability margin in a distribution system using distributed generation. In that study simulation showed that placing and sizing DG (distributed generation) units was affected by the operating condition of the DG (distributed generation) units (unity power factor or between 0.95 lead or lag), and when the DG (distributed generation) units operate at unity power factor, they were recommended to be placed in the most sensitive voltage buses in order to improve the voltage stability margin with a condition of not violating the system voltage and current limits [2]. A study was done about site selection for plugin hybrid vehicle (PHEV) charging station based on voltage sensitivity of commercial distribution system. The analysis was done in a 16-bus system in power factory simulation software. Voltage sensitivity factor was used to find an optimal place for the PHEV charging station [3].

1.3 Voltage Characteristics of PV

Photovoltaic can be used as a current source and voltage source. PV has no inertia force. it is connected to power system using inverter and it is possible to maintain PV output constantly by the inverter control in the case the amount of insolation does not change. Therefore, the voltage characteristic of PV should be modeled as "constant power characteristic". On the other hand, in the case that inverter capacity is not sufficient; voltage characteristic of PV output becomes "constant current characteristic" because the PV output is not maintained due to the upper limit of current constraint. [4]

1.4 Topology of Photovoltaic System Connected with Grid

Generally grid connected photovoltaic system is connected with grid via inverter because most of the buses are AC bus. However, there are other topologies for grid connection.
Different topologies of grid tied PV are shown below.

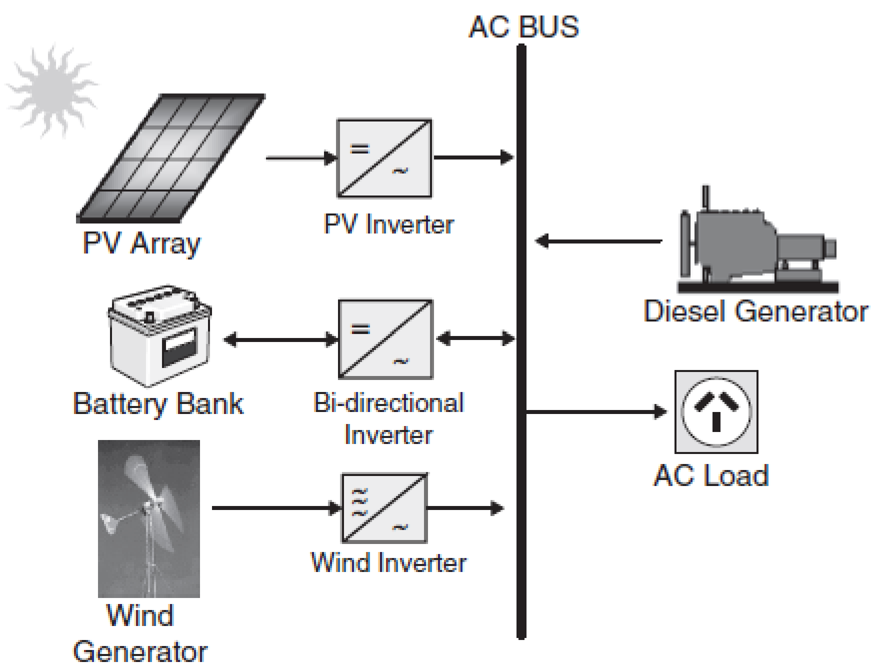

Figure 1.1 Parallel PV–diesel hybrid energy system: AC coupling [5]

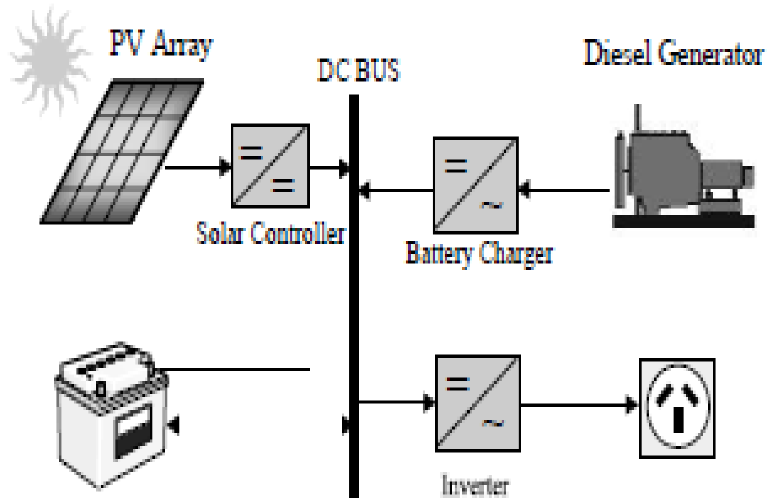

Figure 1.2 Series PV –diesel hybrid energy system [5]

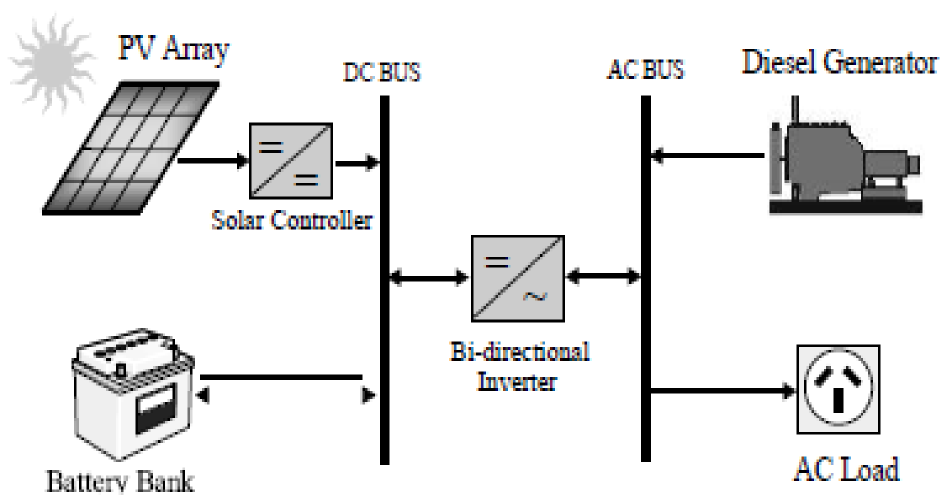

Figure 1.3 Parallel PV –diesel hybrid energy system [5]

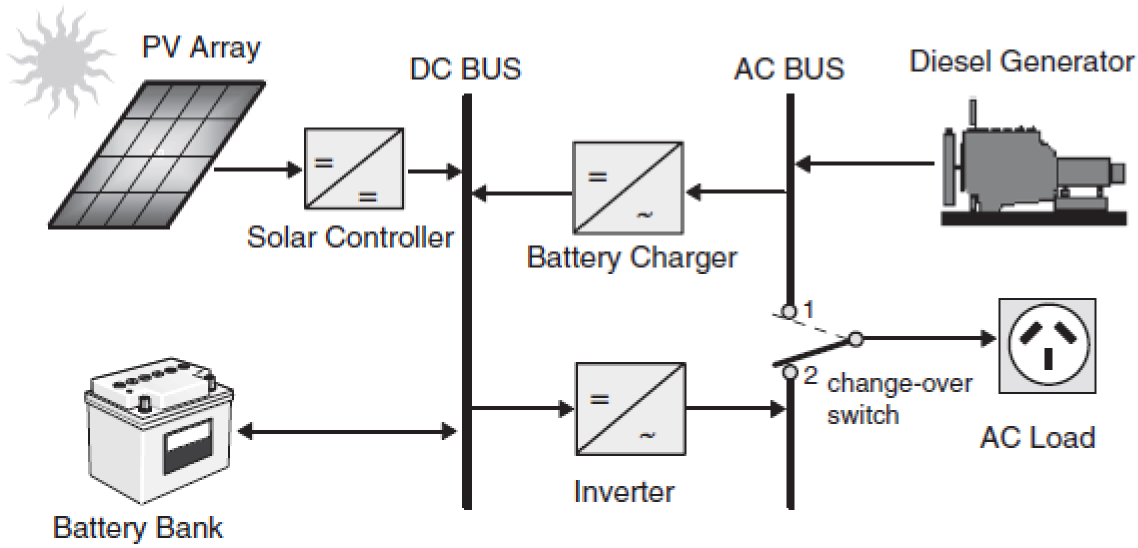

Figure 1.4 Switched PV –diesel hybrid energy system [5]

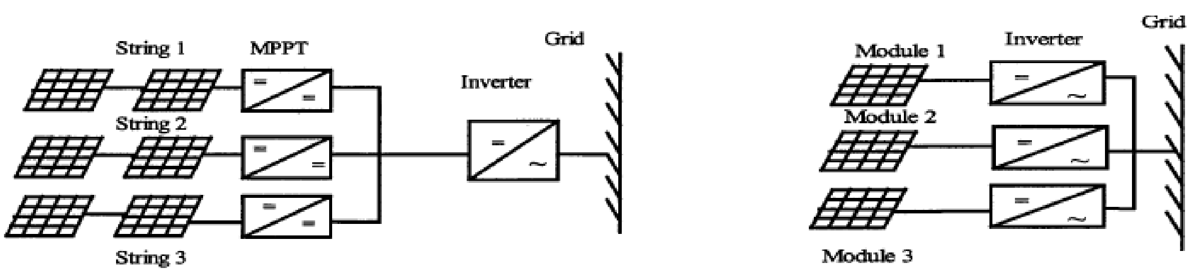

Figure 1.5 Multiple string DC –DC converter and module integrated inverter [5]

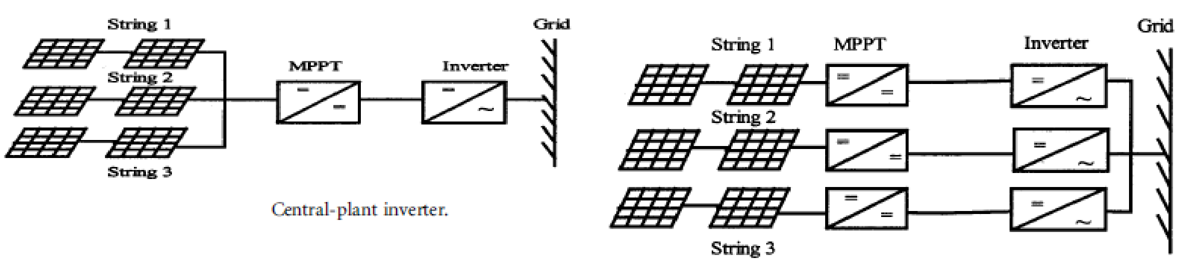

Figure 1.6 Multiple string inverters [5]

1.5 Objectives of this work

Storage of fossil fuels is limited. Burning of fossil fuels causes emission of carbon dioxide, nitrogen oxide, sulfur dioxide, hydrogen sulfite etc. These are very harmful for environment. So it is important to harness energy by better method for electricity generation, irrigation, transportation, industrial use etc. Solar energy technologies are better than fossil fuel based technology in terms of environmental impact. Some of non-fossil based energy resources have negative impact on environment like biomass, nuclear etc. Installation and maintenance of nuclear plant is risky. Disposal of nuclear waste is more risky and have bad effect on environment. Installation of hydroelectric dam has some bad effect like changing water flow, blocking fish passage of fish, affecting ecosystems. Solar energy technology has some advantage over this type of technology. Solar energy is commonly available energy source. It is the fastest growing renewable energy technology. It is important to improve the system efficiency of a solar technology integrated grid. In this thesis work using a sample distribution test system analysis of different modes of solar integration system had been analyzed.

The objectives of this work are as follows:

- Modeling of solar integrated medium voltage system
- Examining the impact of solar PV integration on IEEE 14-bus system.
- Analyzing the variation of load ability for placement and fraction of PV plant in IEEE 14-bus system condition
- Finding the maximum limit of PV integration for each buses for IEEE 14-bus system
- Examining the interaction between PV and induction motor, synchronous motor, dc motor and also determining the change in voltage level due to sizing of motors
- Determining the change in voltage level due to placement of PV at different buses
- Evaluating the change in load ability due to integrate PV in different extra buses

Chapter 2

Solar Power Generation: Photovoltaic Systems

2.1 Introduction

Solar energy is the energy that comes from the sun as radiant light and heat. It is easily available energy resource. Solar heating, day lighting, solar photovoltaic (PV), solar thermal electricity, solar architecture, solar furnace etc. are the different types of solar technology. Uses of solar energy for electricity generation may be a substitute of fossil fuels. Depending on the way of collection, conversion, and distribution the solar technologies are characterized as either passive solar or active solar. The examples of active solar techniques are use of photovoltaic panels, solar furnace and solar thermal collectors to harness energy. Orienting a building to the sun, designing space for natural air circulation are the examples of passive solar technologies. Solar power is defined as the conversion of sunlight into electricity using either PV or concentrated solar power (CSP).

2.2 Classification of Solar Power Generation Systems

Solar power generation technologies are mainly of two types. These are –
1. Solar photovoltaic power systems
2. Concentrated solar power or solar thermal power system

2.2.1 Photovoltaic power systems

A photovoltaic cell or solar cell is a device that converts light energy into electrical energy. Photovoltaic is defined as a method of generating electrical power by converting solar radiation into direct current electricity. In this method semiconductors are used which exhibits the photovoltaic effect. Some materials, which exhibit property of photoelectric effect release electrons when they absorb light. Electricity production can be done by capturing this free electron. Solids, liquids and gases emit electrons when they absorb energy from light. This process is called photoelectric effect. When a material surface absorbs sunlight or other light the electrons in the valence band of the material absorbs energy. These are excited and tend to jump to the conduction band. The photon that comes from the light source can free an electron from atomic bond of an atom if its energy is equal or higher than the band gap of the cell material. These free electrons move throughout the crystal. The covalent bond which has one fewer electron than normal condition is called hole. The hole in a material’s crystal causes movement of bonded electrons of other nearly located atoms to the hole. In this process another hole forms behind. In this way the electrons can transport through the lattice. There are two main modes for charge carrier separation in a solar cell: Drift of carriers, driven by an electric field established across the device. Diffusion of carriers occurs due to their random thermal motion, until they are captured by the electrical fields existing at the edges of the active region.

In thick solar cells there is no electric field in the active region, so the dominant mode of charge carrier separation is diffusion. In these cells the diffusion length of minority carriers (the length that photo-generated carriers can travel before they recombine) must be large compared to the cell thickness. In thin film cells (such as amorphous silicon), the diffusion length of minority carriers is usually very short due to the existence of defects, and the dominant charge separation is therefore drift, driven by the electrostatic field of the junction, which extends to the whole thickness of the cell. Once the minority carrier enters the drift region, it is 'swept' across the junction and does not return. This sweeping is an irreversible process since the carrier typically relaxes to a lower energy state before it has a chance to be elastically scattered back to its starting point. Silicon is widely used as solar cell. Large amount of p-n junctions are made from silicon. In fabrication a layer of n-type silicon are made direct contact with a layer of p-type silicon. In practice, p-n junctions of silicon solar cells are not made in this way, but rather by diffusing an n-type doping into one side of a p-type wafer (or vice versa). If a piece of p-type silicon is placed in intimate contact with a piece of n-type silicon, then a diffusion of electrons occurs from the region of high electron concentration (the n-type side of the junction) into the region of low electron concentration (p-type side of the junction). When the electrons diffuse across the p-n junction, they recombine with holes on the p-type side. The diffusion of carriers does not happen indefinitely, however, because charges build up on either side of the junction and create an electric field. The electric field creates a diode that promotes charge flow, known as drift current that opposes and eventually balances out the diffusion of electrons and holes. This region where electrons and holes have diffused across the junction is called the depletion region because it no longer contains any mobile charge carriers. It is also known as the space charge region.

For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current – that is, electricity. This electricity can then be used to power a load, such as a light or a tool. Figure2.1 shows the external arrangements of a photovoltaic module.

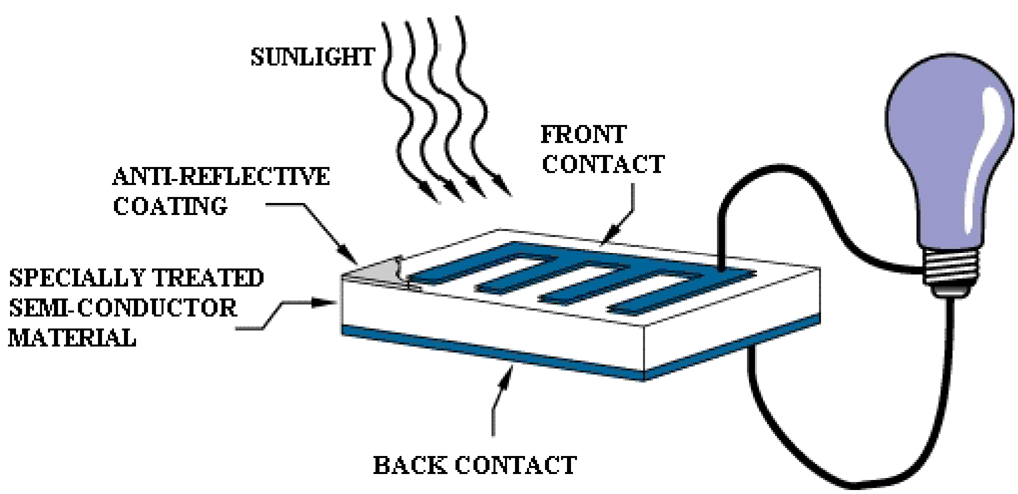

Figure 2.1 External arrangements of a photovoltaic module [6]

A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module [6].

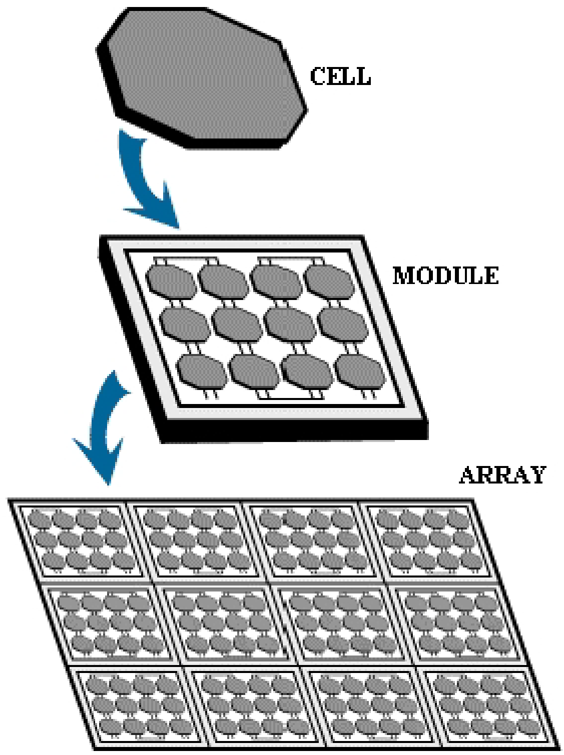

Figure 2.2 Arrangement of solar cell, module and array [6]

The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array. Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can power lights, motors, and other loads. The modules in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current.

2.2.2 Concentrated solar power or solar thermal

In these systems, the thermal energy comes from the sun is used to drive heat engines and these engines are coupled with generator. Thus electricity is generated. Sunlight is concentrated using mirrors or lenses and focused to a heat receiver of heat engines. The descriptions of these technologies are described on Chapter 3.

2.3 Types of Solar Panel Mounting System

These modules are assembled into arrays to set into some kind of mounting systems. Some kind of mounting systems area:

a. roof mounted
b. mounted as a shade structure
c. building integrated
d. roof jack mounting system

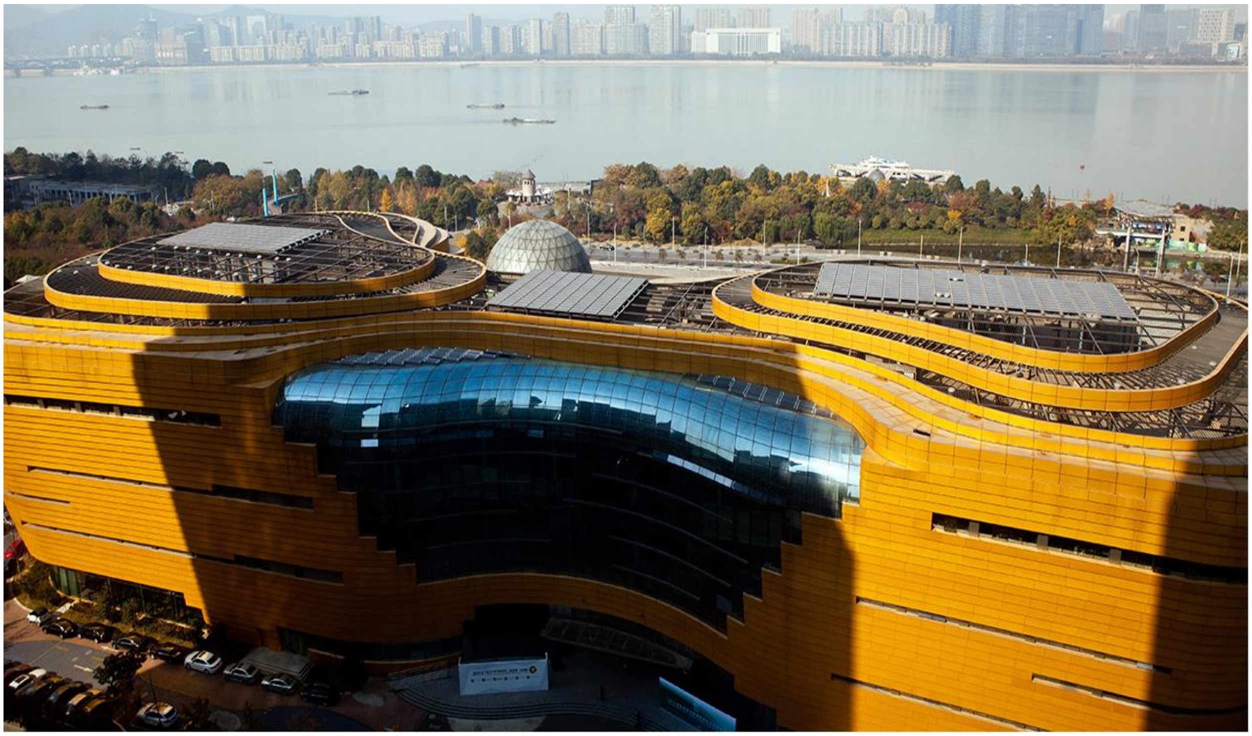

Figure 2.3 Roof mounted [7]

Figure 2.4 Building integrated [8]

Figure 2.5 Tracker mounted photovoltaic [9]

2.4 Solar Tracker

Solar tracker is a device that orients photovoltaic panels, reflectors, lenses or other optical devices towards the sun. Tracking system may be useful to increase the efficiency of both photovoltaic system and solar thermal system. In flat-panel photovoltaic (PV) applications, trackers are used to minimize the angle of incidence between the incoming sunlight and a photovoltaic panel. This increases the amount of energy produced from a fixed amount of installed power generating capacity.

In concentrated photovoltaic (CPV) and concentrated solar thermal (CSP) applications, trackers are used to enable the optical components in the CPV and CSP systems. The optics in concentrated solar applications accepts the direct component of sunlight light and therefore must be oriented appropriately to collect energy. Tracking systems are found in all concentrator applications because such systems do no produce energy unless pointed at the sun.

Different types of solar collector are-

- Non-concentrating flat-panels, usually photovoltaic or hot-water,
- Concentrating systems, of various of types.

Solar collector mounting systems may be fixed (manually aligned) or tracking. Tracking systems may be configured as:

- Fixed collector / moving mirror
- Moving collector

Fixed Mount

Domestic and small-scale commercial photovoltaic and hot-water panels are usually fixed, often flush-mounted on an appropriately facing pitched roof. Advantages of fixed mount systems (i.e. factors tending to indicate against trackers) include the following:

- Mechanical simplicity, and hence, lower installation and maintenance costs.
- Wind-loading: it is easier and cheaper to provision a sturdy mount; all mounts other than fixed flush-mounted panels must be carefully designed having regarded to wind loading due to greater exposure.
- Indirect light: approximately 10% of the incident solar radiation is diffusing light, available at any angle of misalignment with the sun.
- Tolerance to misalignment: effective collection area for a flat-panel is relatively insensitive to quite high levels of misalignment with the sun – see table and diagram at accuracy requirements
section below – for example even a 25° misalignment reduces the direct solar energy collected by less than 10%.

Fixed mounts are usually used in conjunction with non-concentrating systems; however an important class of non-tracking concentrating collectors, of particular value in the 3rd world, is portable solar cookers. These utilize relatively low levels of concentration, typically around
2 to 8 Suns and are manually aligned.

Floating Ground Mount

Solar trackers can be built using a “floating” foundation, which sits on top of the ground without the need for invasive concrete foundations. Instead of placing the tracker on concrete foundations, the tracker is placed on a gravel pan that can be filled with a variety of materials, such as sand or gravel, to secure the tracker to the ground. These “floating” trackers can sustain the same wind load as a traditional fixed mounted tracker. The use of floating trackers increases the number of potential sites for commercial solar projects since they can be placed on top of capped landfills or in areas where excavated foundations are not feasible.

Even though a fixed flat-panel can be set to collect a high proportion of available noon-time energy, significant power is also available in the early mornings and late afternoons when the misalignment with a fixed panel becomes excessive to collect a reasonable proportion of the available energy. For example, even when the Sun is only 10° above the horizon the available energy can be around half the noon-time energy levels (or even greater depending on latitude, season, and atmospheric conditions). Thus the primary benefit of a tracking system is to collect solar energy for the longest period of the day, and with the most accurate alignment as the Sun's position shifts with the seasons. In addition, the greater the level of concentration employed, the more important accurate tracking becomes, because the proportion of energy derived from direct radiation is higher, and the region where that concentrated energy is focused becomes smaller.

Fixed Collector/ Moving Mirror

Many collectors cannot be moved, for example high-temperature collectors where the energy is recovered as hot liquid or gas (e.g. steam). Other examples include direct heating and lighting of buildings and fixed in-built solar cookers, such as Scheffler reflectors. In such cases it is necessary to employ a moving mirror so that, regardless of where the Sun is positioned in the sky, the Sun's rays are redirected onto the collector. Due to the complicated motion of the Sun across the sky, and the level of precision required to correctly aim the Sun's rays onto the target, a heliostat mirror generally employs a dual axis tracking system, with at least one axis mechanized. In different applications, mirrors may be flat or concave.

Moving Collector

Trackers can be grouped into classes by the number and orientation of the tracker's axes. Compared to a fixed amount, a single axis tracker increases annual output by approximately 30% and a dual axis tracker an additional 6%. Photovoltaic trackers can be classified into two types: standard photovoltaic (PV) trackers and concentrated photovoltaic (CPV) trackers. Each of these tracker types can be further categorized by the number and orientation of their axes, their actuation architecture and drive type, their intended applications, their vertical supports and foundation.

Single Axis Tracker

Single axis trackers have one degree of freedom that acts as an axis of rotation. The axis of rotation of single axis trackers is typically aligned along a true North meridian. It is possible to align them in any cardinal direction with advanced tracking algorithms. Figure 2.5 (a) shows the single axis horizontal tracker. There are several common implementations of single axis trackers. These include horizontal single axis trackers (HSAT), vertical single axis trackers (VSAT), tilted single axis trackers (TSAT) and polar aligned single axis trackers (PSAT). The orientation of the module with respect to the tracker axis is important when modeling performance.

Figure 2.6 Single axis horizontal tracker [10]

Figure 2.7 Point focus parabolic dish [11]

2.5 Classifications of Solar Cells

There are several types of solar cells. These are listed below-

Cadmium Telluride Photovoltaic:

Cadmium telluride (CdTe) photovoltaic describes a photovoltaic (PV) technology that is based on the use of cadmium telluride thin film, a semiconductor layer designed to absorb and convert sunlight into electricity. Cadmium telluride PV is the only thin film photovoltaic technology to surpass crystalline silicon PV in cheapness for a significant portion of the PV market, namely in multi-kilowatt systems. Best cell efficiency has plateaued at 16.5% since 2001. A subtle issue with CdTe and with all thin films in relation to greater efficiency PV module technologies is the potential impact of commodity inflation. Lower efficiency modules incur a higher balance of system commodity cost per unit output; as a result such inflation can have a greater percentage impact on system cost. This is another reason that continued efficiency improvements are important.

Figure 2.8 Cadmium Telluride Photovoltaic [12]

Copper Indium Gallium Selenide Solar Cells

Copper indium gallium selenide ($CuIn_{1-x}Ga_xSe_2$ or CIGS) is a direct band gap semiconductor useful for the manufacture of solar cells. The CIGS absorber is deposited on a glass or plastic backing, along with electrodes on the front and back to collect current. Because the material has a high absorption coefficient and strongly absorbs sunlight, a much thinner film is required than of other semiconductor materials. Devices made with CIGS belong to the thin-film category of photovoltaic. CIGS is mainly used in the form of polycrystalline thin films. The best efficiency achieved as of December 2005 was 19.5%. A team at the National Renewable Energy Laboratory achieved 19.9% new world record efficiency by modifying the CIGS surface and making it looks like CIS.

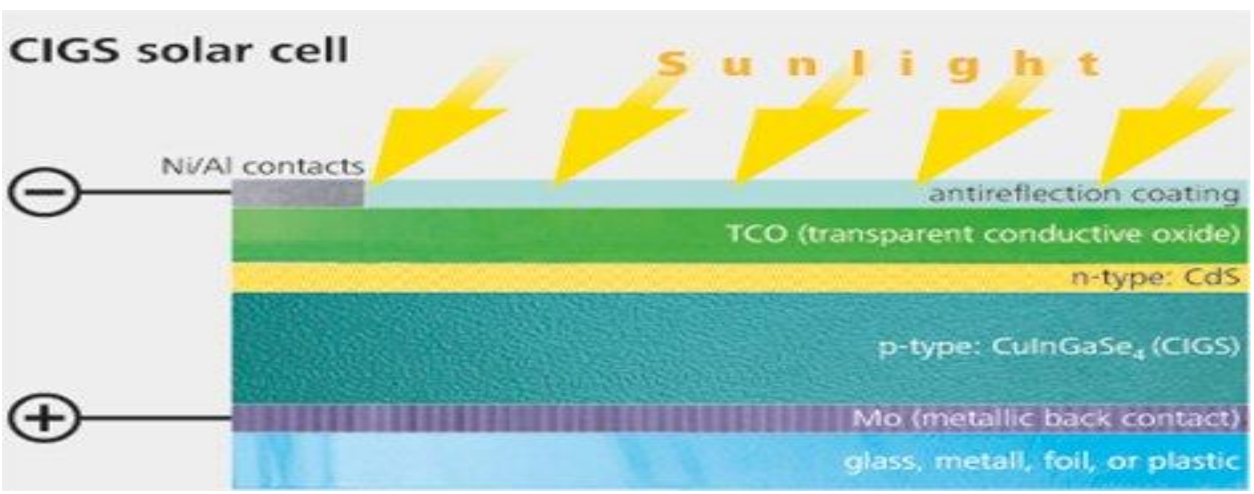

Figure 2.9 Copper indium gallium selenide solar cells [13]

Dye-sensitized Solar Cell

A dye-sensitized solar cell (DSSC, DSC or DYSC) is a low-cost solar cell belonging to the group of thin film solar cells. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a photoelectron chemical system. The modern version of a dye solar cell, also known as the Grätzel cell, was originally co-invented in 1988 by Brian O'Regan and Michael Grätzel at UC Berkeley and this work was later developed by the aforementioned scientists at the École Polytechnique Fédérale de Lausanne until the publication of the first high efficiency DSSC in 1991. Michael Grätzel has been awarded the 2010 Millennium Technology Prize for this invention. Several important measures are used to characterize solar cells. The most obvious is the total amount of electrical power produced for a given amount of solar power shining on the cell. Expressed as a percentage, this is known as the solar conversion efficiency.

Gallium Arsenide Germanium Solar Cell

Germanium is a chemical element with symbol **Ge** and atomic number 32. It is a lustrous, hard, grayish-white metalloid in the carbon group, chemically similar to its group neighbor's tin and silicon. Purified germanium is a semiconductor, with an appearance most similar to elemental silicon. Like silicon, germanium naturally reacts and forms complexes with oxygen in nature. Unlike silicon, it is too reactive to be found naturally on Earth in the free (native) state.

Because very few minerals contain it in high concentration, germanium was discovered comparatively late in the history of chemistry. Germanium ranks near fiftieth in relative abundance of the elements in the Earth's crust. In 1869, Dmitri Mendeleev predicted its existence and some of its properties based on its position on his periodic table and called the element ekasilicon. Nearly two decades later, in 1886, Clemens Winkler found the new element along with silver and sulfur, in a rare mineral called argyrodite. Although the new element somewhat resembled arsenic and antimony in appearance, its combining ratios in the new element's compounds agreed with Mendeleev's predictions for a relative of silicon. Winkler named the element after his country, Germany. Today, germanium is mined primarily from sphalerite (the primary ore of zinc), though germanium is also recovered commercially from silver, lead, and copper ores.

Hybrid Solar Cells

Hybrid solar cells combine advantages of both organic and inorganic semiconductor. Hybrid photovoltaics have organic materials that consist of conjugated polymers that absorb light as the donor and transport holes. Inorganic materials in hybrid cells are used as the acceptor and electron transporter in the structure. The hybrid photovoltaic devices have a potential for not only low-cost by roll-to-roll processing but also for scalable solar power conversion.

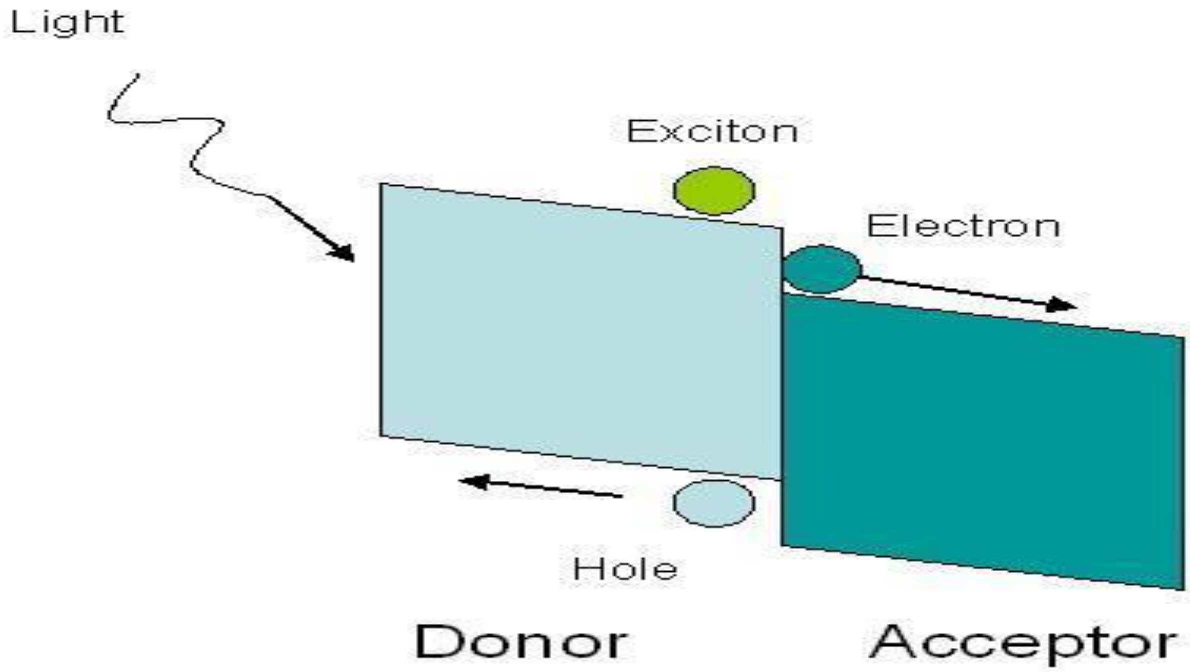

Figure 2.10 Mechanism in Hybrid Solar Cell [14]

Mono-crystalline Silicon Solar Sell

Mono-crystalline silicon or single-crystal Si, or mono-Si is the base material of the electronic industry. It consists of silicon in which the crystal lattice of the entire solid is continuous, unbroken (with no grain boundaries) to its edges. It can be prepared intrinsic, i.e. made of exceedingly pure silicon alone, or doped, containing very small quantities of other elements added to change in a controlled manner its semiconducting properties. Most silicon mono-crystals are grown by the Czochralski process, in the shape of cylinders up to 2 m long and 45 cm in diameter (figure on the right), which, cut in thin slices, give the wafers onto which the microcircuits will be fabricated. Single-crystal silicon is perhaps the most important technological material of the last decades (the "silicon era"), because its availability at an affordable cost has been essential for the development of the electronic devices on which the present day electronic and informatics revolution is based. Mono-crystalline is opposed to amorphous silicon, in which the atomic order is limited to short range order only. In between the two extremes there is polycrystalline silicon, which is made up of small crystals, known as crystallites.

Multi-junction Photovoltaic Cells

Multi-junction solar cells or tandem cells are solar cells containing several p-n junctions. Each junction is tuned to a different wavelength of light, reducing one of the largest inherent sources of losses, and thereby increasing efficiency. Traditional single-junction cells have a maximum theoretical efficiency of 34%, a theoretical "infinite-junction" cell would improve this to 87% under highly concentrated sunlight.
Currently, the best lab examples of traditional silicon solar cells have efficiencies around 25%, while lab examples of multi-junction cells have demonstrated performance over 43%.Commercial examples of

tandem cells are widely available at 30% under one-sun illumination, and improve to around 40% under concentrated sunlight. However, this efficiency is gained at the cost of increased complexity and manufacturing price. To date, their higher price and lower price-to-performance ratio have limited their use to special roles, notably in aerospace where their high power-to-weight ratio is desirable. In terrestrial applications these solar cells are used in concentrated photovoltaics (CPV) with operating plants all over the world.

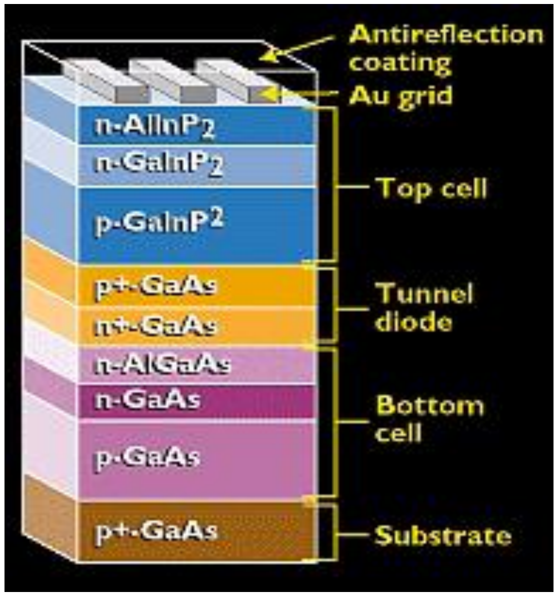

Figure 2.11 Internal structure of Multi-junction Photovoltaic Cell [15]

Nano-crystal Solar Cells

Nano-crystal solar cells are solar cells based on a substrate with a coating of Nano-crystals. The Nano-crystals are typically based on silicon, CdTe or CIGS and the substrates are generally silicon or various organic conductors. Quantum dot solar cells are a variant of this approach, but take advantage of quantum mechanical effects to extract further performance. Dye-sensitized solar cells are another related approach, but in this case the nano-structuring is part of the substrate. Previous fabrication methods relied on expensive molecular beam epitaxial processes, but colloidal synthesis allows for cheaper manufacture. A thin film of nano-crystals is obtained by a process known as “spin-coating”. This involves placing an amount of the quantum dot solution onto a flat substrate, which is then rotated very quickly. The solution spreads out uniformly, and the substrate is spun until the required thickness is achieved. Quantum dot based photovoltaic cells based around dye-sensitized colloidal TiO_2 films were investigated in 1991 and were found to exhibit promising efficiency of converting incident light energy to electrical energy, and to be incredibly encouraging due to the low cost of materials used. A single-nano-crystal (channel) architecture in which an array of single particles between the electrodes, each separated by ~1 exciton diffusion length, was proposed to improve the device efficiency (figure below) and research on this type of solar cell is being conducted by groups at Stanford, Berkeley and the University of Tokyo. Although research is still in its infancy, in the future nano-crystal photovoltaics may offer advantages such as flexibility (quantum dot-polymer composite photovoltaics) lower costs, clean power generation and an efficiency of 65%, compared to around 27% for first-generation photovoltaics.

Organic Solar Cell

An organic solar cell or plastic solar cell is a type of polymer solar cell that uses organic electronics, a branch of electronics that deals with conductive organic polymers or small organic molecules, for light absorption and charge transport to produce electricity from sunlight by the photovoltaic effect. The plastic used in organic solar cells has low production costs in high volumes. Combined with the flexibility of organic molecules, organic solar cells are potentially cost-effective for photovoltaic applications. Molecular engineering (e.g. changing the length and functional group of polymers) can change the energy gap, which allows chemical change in these materials. The optical absorption coefficient of organic molecules is high, so a large amount of light can be absorbed with a small amount of materials. The main disadvantages associated with organic photovoltaic cells are low efficiency, low stability and low strength compared to inorganic photovoltaic cells.

2.6 Advantages of Photovoltaics:

a. Small scale installation is possible**.**
b. Grid tied small scale installation is possible.
c. Low carbon emission than fossil fuel based plant.
d. Maintenance is easier than fossil fuel based plant.
e. Can be installed at roof, light post, roof of vehicles.
f. Generally no working fluid is required.

2.7 Advantages of Photovoltaic with compared to CSP:

a. Generally no water consumption.
b. No rotating part; static generator.
c. Start giving output earlier than solar thermal at the early morning.
d. More capacity factor.
e. Photovoltaic system does not need flat land and can be installed in slope area.
f. Photovoltaic plants can be constructed in shorter time than CSP plant.
g. PVs are more suitable for off grid operation.
h. Quiet in operation.

2.8 Disadvantage of Photovoltaic:

a. Output affected by dust and snow.
b. High temperature causes reduction in output.
c. Lack of low cost storage.
d. Losses of inverter.
e. Degradation with times.
f. Purification of silicon is expensive.

2.9 Photovoltaic Power Stations

This table includes the list of photovoltaic based electricity generation plant installed in different countries.

Table2.1 World's largest photovoltaic power stations (50 MW or larger) [16]

PV Plant	Country	Year	Capacity (MW_p)	Notes
Longyangxia Dam Solar Park	China	2014	850	320 MW Phase I Completed in December 2013, 530 MW phase II in 2015
Solar Star Star I & Star II	United States	2015	579	579 MW_{AC} (747.3 MW_p) connected to the grid on June 19, 2015.Consists of Solar Star I (318 MW_{AC} or 397.8 MW_{DC}) and Solar Star II: 279 MW_{AC} or 349.5 MW_{DC}
Topaz Solar Farm	United States	2014	550	Gradually commissioned since February 2013, reached final capacity 550 MW in November 2014
Desert Sunlight Solar Farm	United States	2015	550	Phase I with 300 MW completed in 2013. Construction of phase II to final capacity of 550 MW completed in January 2015
Huanghe Hydropower Golmud Solar Park	China	2014	500	Phase I completed in October 2011, followed by Phase II and III. 60 MW phase IV under construction. Within a group of 1,000 MW of co-located plants
Copper Mountain Solar Facility	United States	2015	458	Phase 1 completed in December 2010. Phase 2 completed in January 2013. Phase 3 completed in early 2015. Construction of 94 MW phase 4 scheduled to commence in 2015 and be completed by year-end 2016.
Kamuthi Solar Power Project	India	2016	360	Collection of 5 plants, expected to be 648 MW on completion
Charanka	India	2012	345	Collection of 23 co-located power

Solar Park				plants, of which the largest is 51 MW
Cestas Solar Farm	France	2015	300	Completed in October 2015

2.10 Advantages of Grid Connected Photovoltaic

• A grid-connected photovoltaic power system will reduce the power bill as it is possible to sell Surplus electricity produced to the local electricity supplier.

• Grid-connected PV systems are comparatively easier to install as they do not require a battery system

• Grid interconnection of photovoltaic (PV) power generation systems has the advantage of effective utilization of generated power because there are no storage losses involved.

• A photovoltaic power system is carbon negative over its lifespan, as any energy produced over and above that to build the panel initially offsets the need for burning fossil fuels. Even though the sun doesn't always shine, any installation gives a reasonably predictable average reduction in carbon consumption.

2.11 Summary

Photovoltaic panels have less negative impact on environment with compared to fossil fuel based plants. Cost of solar panel is high. But it is suitable for off grid or isolated grid use. Solar panel should be kept neat and clean. Otherwise output will be reduced. Control mechanism, shading effects, solar irradiation, land type of location, weather of location should be considered before set up a photovoltaic plant.

Chapter 3

Voltage Level Stability

3.1 Introduction

Voltage stability is an important part of power system stability. Voltage instability is caused due to lack of reactive power support to the line. Definition of voltage stability had given by IEEE power system engineering committee in the following way:

“Voltage stability is the ability of a system (Grid Line) to maintain voltage so that when load admittance increased, load power will increase and voltages are controllable. Load shedding is one of the problem that caused by voltage level stability [17].”

3.2 Power System Stability

The definition of power system stability is given by IEEE\CIGER task force “Power system stability is an ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact” [18]. There are three major modes of stability. These are

1. Rotor angle stability
2. Frequency stability
3. Voltage stability

Generally voltage collapses is the process by which the sequence of events accompanying voltage instability leads to a low unacceptable voltage profile in a significant part of the power system [19].

3.2.1 Basic phenomenon behind voltage stability

- Voltage level decreases with loading.
- No increase of voltage with addition of a new generation unit if the system reaches to its maximum transfer limit.
- High reactive loading causes reduction of voltage in that area.
- Load quality has an effect on voltage change.
- Transfer capacity is reduced due to reactive loading.

3.2.2 Classification of voltage level stability

According to the IEEE classification, voltage stability classified into two major parts. These are-

1. Large disturbance voltage stability
2. Small disturbance voltage stability

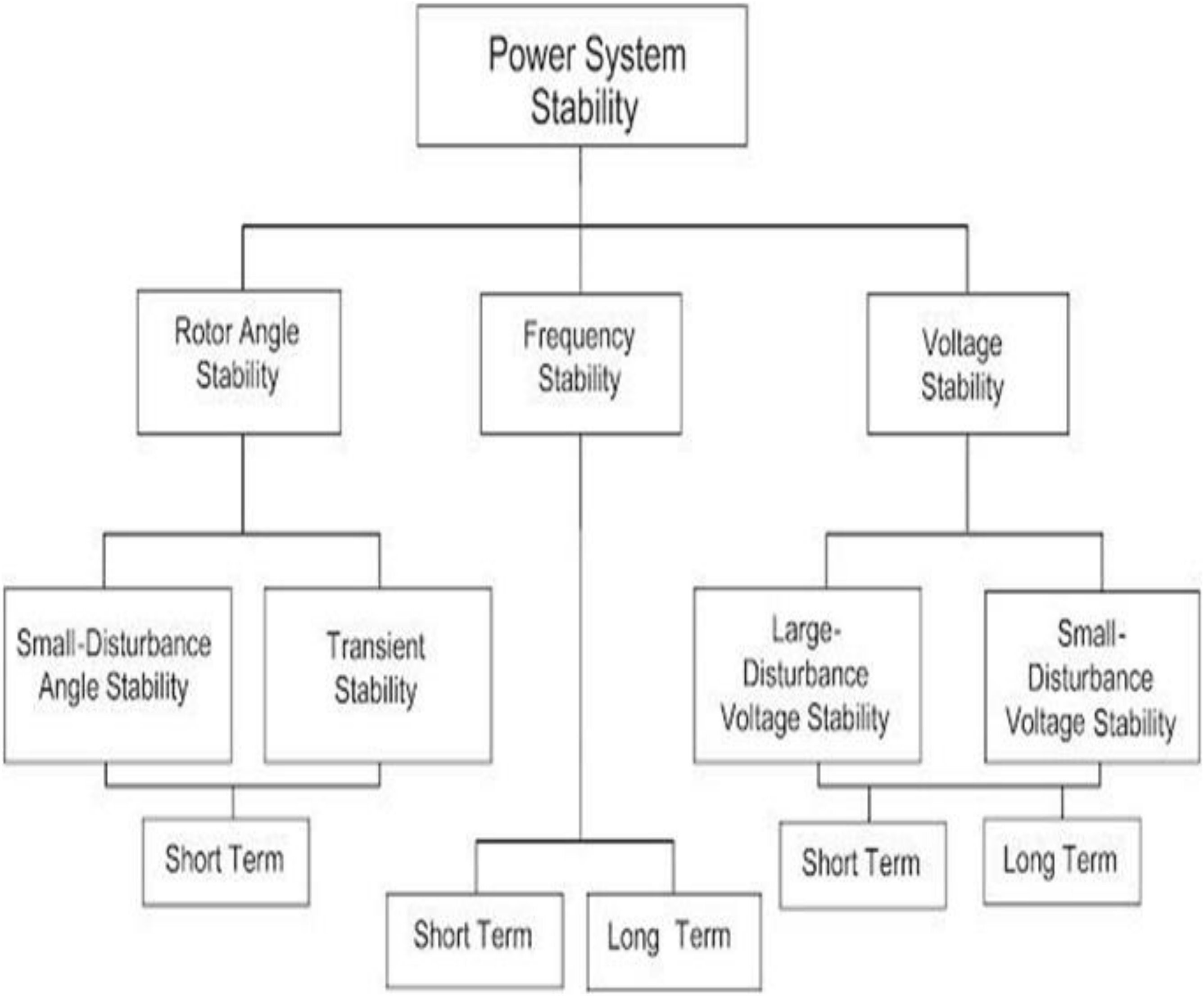

Figure 3.1 IEEE classification of Power system stability [20]

3.2.3 Classification of voltage level stability time frame

There are two types of voltage level stability time frame. These are –

1. Short – Term time frame
2. Long- Term time frame

Short-Term Timeframe

Short-term timeframe involves the time taken between the onset of a system disturbance to just prior to the activation of the automatic LTC. Rotor angle instability and voltage instability can occur within this timeframe [20]. The following fast acting, automatically controlled power system equipment may be considered in assessing system performance within this timeframe [19]:

- Synchronous Condensers
- Automatic switched shunt capacitors
- Induction motor dynamics
- Static VAR Compensators
- Flexible AC Transmission System (FACTS) devices
- Excitation system dynamics
- Voltage-dependent load

Long-Term Timeframe

Long-term timeframe refers to the time after OELs engage and includes manual operator-initiated action. During this timeframe, longer-term dynamics come into play such as governor action and load-voltage and/or load-frequency characteristics in addition to operator-initiated manual system adjustments [21].

3.2.4 Analyzing the P-V curve

It is important to study the P-V curve for analyzing the voltage level stability of a power distribution system. Greater the output power from photovoltaic or solar thermal greater the load ability of a specific grid system. A sample P-V curve given below-

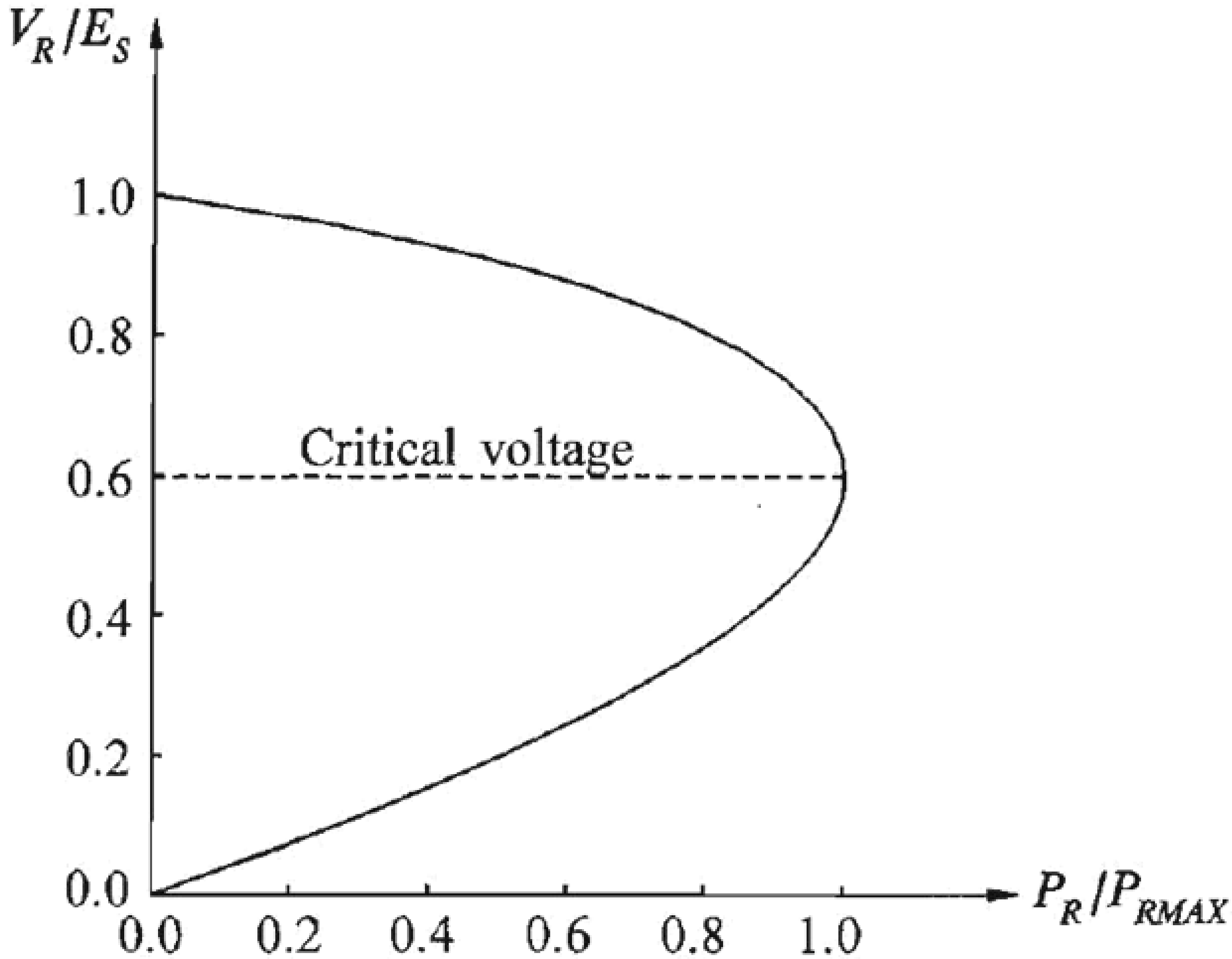

Figure 3.2 Sample P-V [22]

Load quality has an effect on loadability. The part below the critical voltage in the curve cannot be found from practical system operation. This part is mathematical expression. In this condition collapse of voltage occurs in a grid. In case higher load demand, control of power by varying load would be unstable. With a constant impedance static load characteristic, the system stabilizes at power and voltage level lower than the desired values. On the other hand, with a constant power load characteristic, the system becomes unstable trough collapse of the load voltage. With other characteristics, the voltage is determined by the composite characteristic of the transmission line and load. If the load is supplied by transformers with automatic under load tap-changing, the tap-changer action will try to raise the load voltage [22].

4.3 Continuation power flow (CPF)

This is a method to find out some voltage stability conditions of a grid system. It is also used to find out the load margin. At several load quality and load level, the effect in voltage level is observed. Thus an area is found from voltage vs. load curve where the voltage of a system is collapses [23].

4.4 Summary

It is important to analysis the voltage level stability to avoid collapse of a grid system. Load quality, generator type are factors of voltage level stability. Analysis of P-V curve is important to find out loadability. Steady state voltage level is required at consumer side because almost all domestic loads are made for operating within a specific voltage range.

Chapter 4

Simulation and Result Analysis

4.1 Introduction

As mentioned before efficiency, plant area, capacity factor, operating cost, water consumption, impact on environment and cost per kilowatt-hour are the factors which should be considered before installation of electricity generation plants.

As a part of this thesis, using simulation tools the following important features have been analyzed.

- Modeling of solar integrated medium voltage system
- Examining the impact of solar PV integration on IEEE 14-bus system
- Analyzing the variation of load ability for placement and fractioning of PV plant in IEEE 14-bus system
- Finding the maximum limit of PV integration for each bus for IEEE 14-bus system
- Examining the interaction between PV and induction motors, synchronous motors, DC motors and also determining the change in voltage level due to sizing of motors
- Determining the change in voltage level due to placement of PV at different buses
- Evaluating the change in load ability due to integrate PV in different extra buses

4.2 Test System and Tools

For the analysis of above mentioned effects PSAT (Power System Analysis Toolbox) and Power Factory simulation software have been used.
From PSAT a test system was chosen named d_014.mdl bus system which is derived from IEEE 14-bus system. IEEE 14-bus system is not available in power factory simulation software so for voltage stability analysis a 16-bus test system used in power factory simulations.
The schematic diagram of the 14-bus PSAT generalized test model is given below.

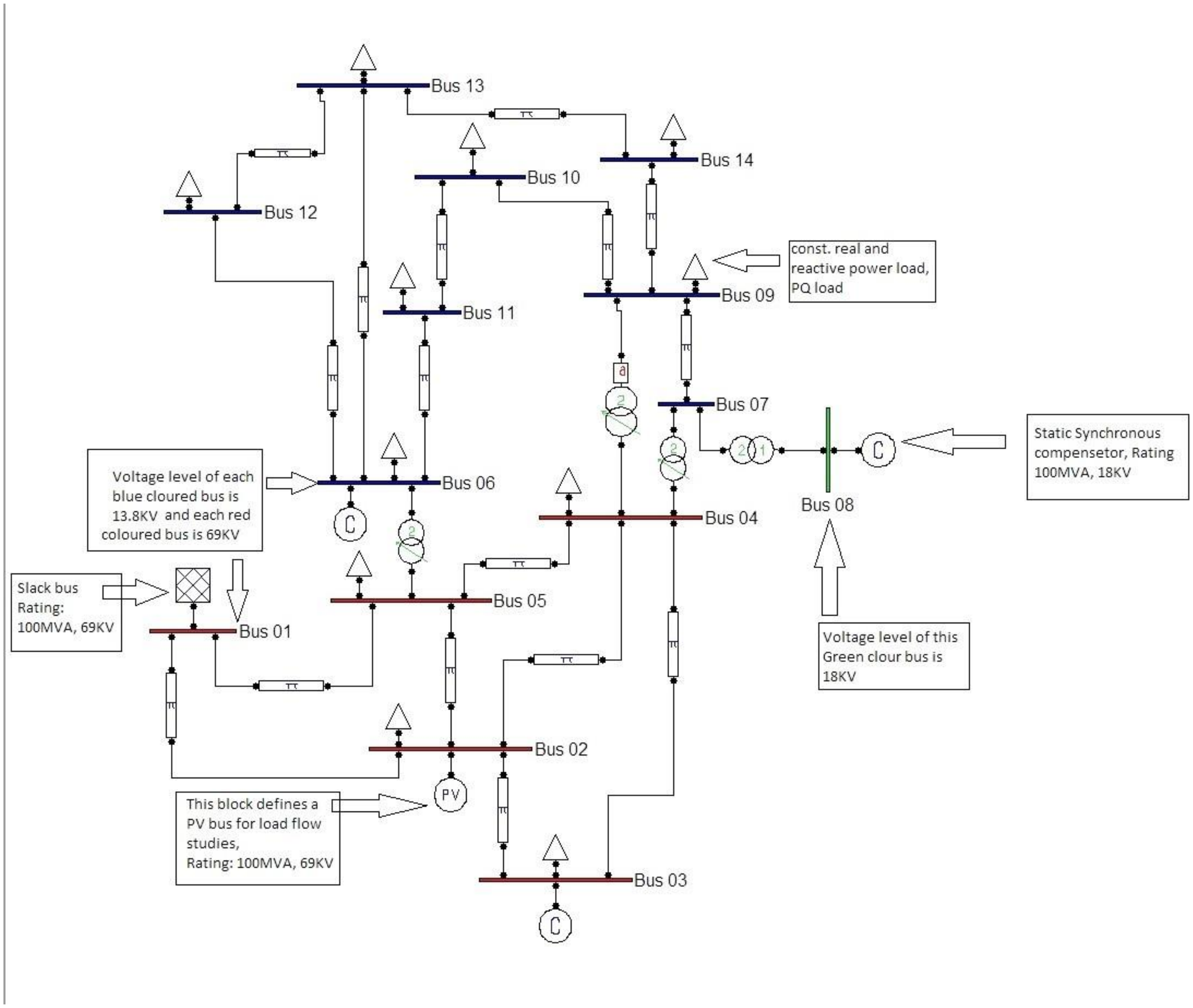

Figure 4.1 IEEE 14-bus PSAT generalized test model [24]

4.2.1 General description of IEEE 14-bus system

Generalized IEEE 14-bus system consists of 14-buses including the slack bus. The rating of these buses varies from 69 KV to 13.8KV. Bus 1 to bus 5 is garish in color because this color signifies high voltage and power rating of 69 KV and 100MVA where rest of the buses (except bus-8) is blue in color signifying comparatively medium voltage of 13.8 KV. Bus number-8 is unique because it is the only bus of rating 18KV the color this buses is typically green. There are other components like transmission lines and step-up or step-down transformers connecting and establishing a network of fourteen buses. Apart from these, there are two static synchronous compensators, one is in bus-8 another is in bus-6.

Static synchronous compensator: Static synchronous compensator (STATCOM) also called Static synchronous condenser is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. There are however, other uses, the most common use is for voltage stability.

Slack bus: In electrical power systems a slack bus (or swing bus), defined as a (Vδ) bus, is used to balance the active power |P| and reactive power |Q| in a system while performing load flow studies. The slack bus is used to provide for system losses by emitting or absorbing active and/or reactive power to and from the system.

Power for slack bus = Total Power going into the system - Total Power going out of the System + Transmission line losses

The slack bus is the only bus for which the system reference phase angle is defined. From this, the various angular differences can be calculated in the power flow equations. If a slack bus is not specified, then a generator bus with maximum real power |P| acts as the slack bus. A given scheme can involve more than one slack bus.

4.3 Simulation

4.3.1 Modeling of solar integrated medium voltage system

In Matlab Simulink and PSAT library there are two types of solar photovoltaic generator. One is constant PV block and other one is constant real power and reactive power (PQ generator).

In all PV integrated cases and simulations solar photovoltaic generator with constant real power and reactive power (PQ generator) had been used.

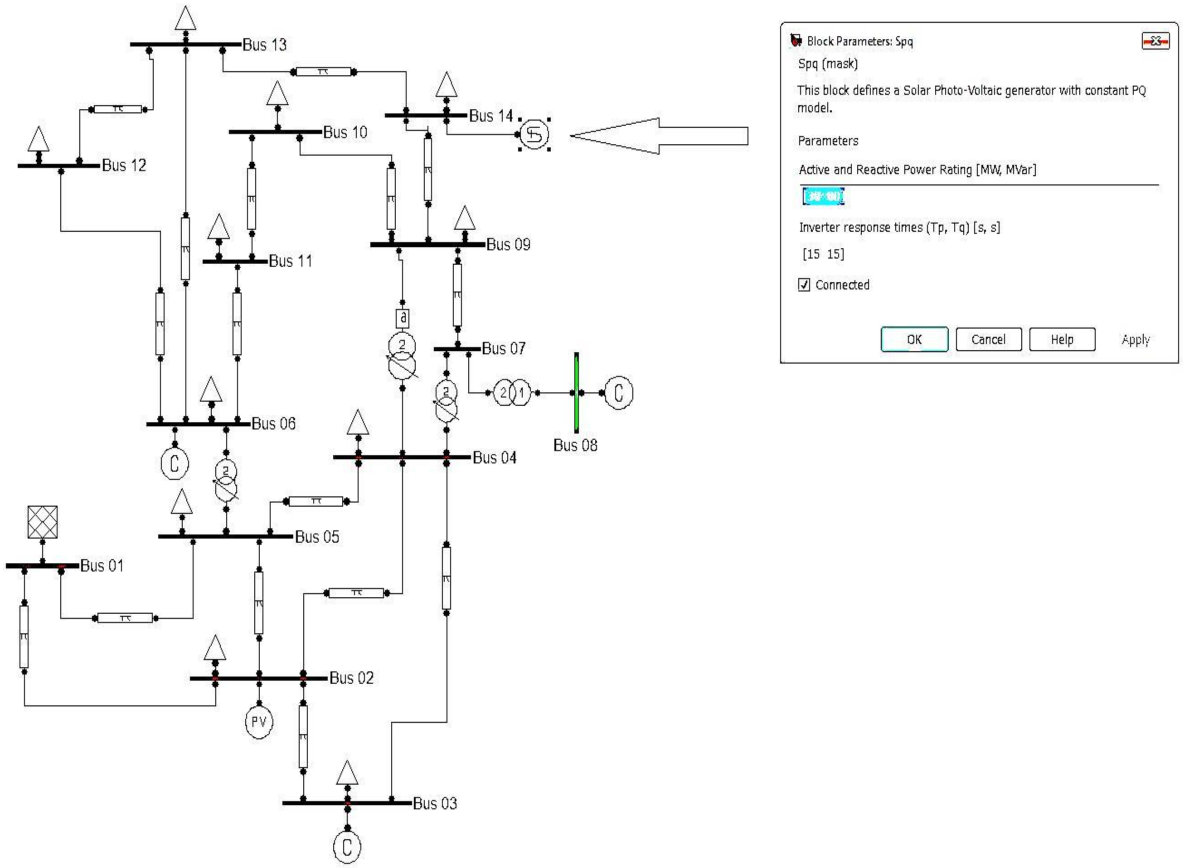

Figure 4.2 PV generator integrated test system

Using PSAT load ability of the whole system was analyzed.

From power factory simulation software the voltage level was examined. The sample of 16-bus test system is given bellow. Power factory software was chosen to study voltage level stability. Change in specific bus voltage can be easily analyzed by using this software. This 16-bus test system was used for analysis of voltage Sensitivity Based Site Selection for PHEV Charging Station in Commercial Distribution System [3].

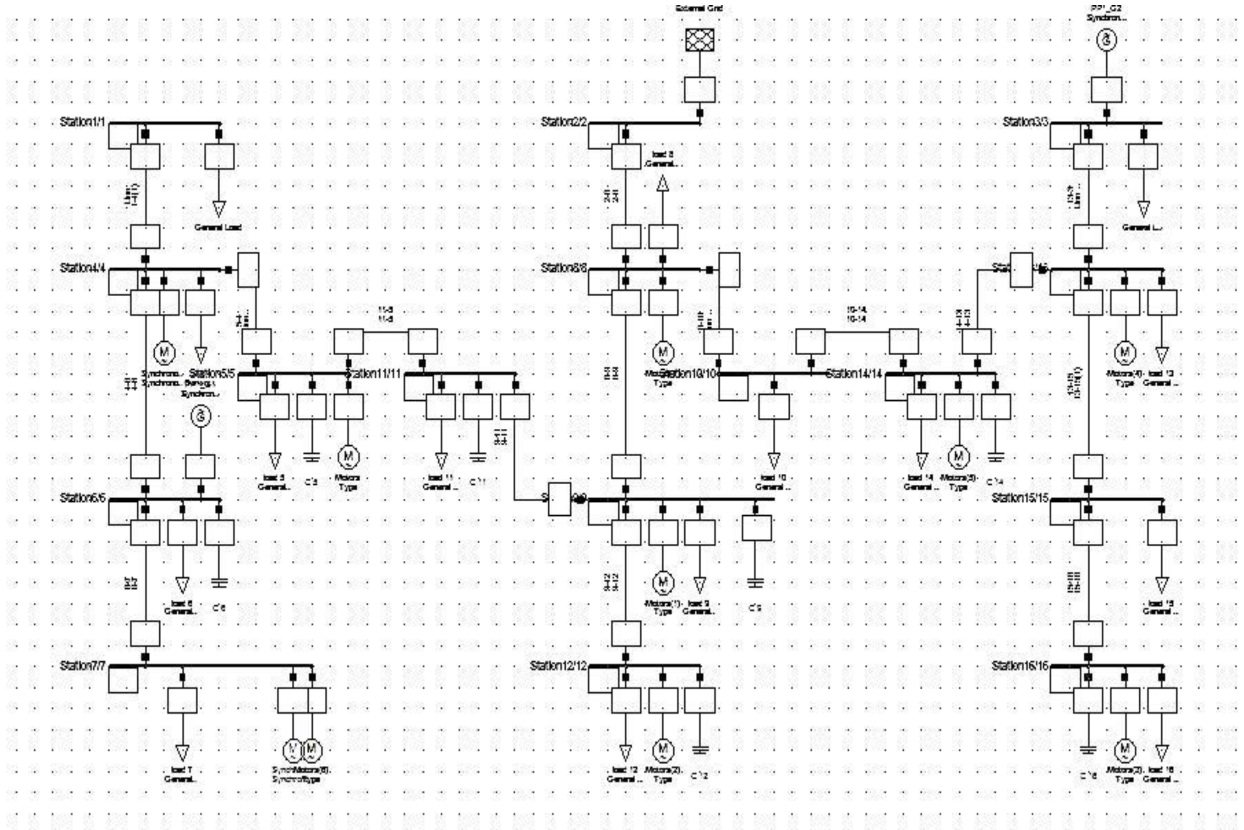

Figure 4.3 Typical 16-bus system in power factory

4.4 Simulation and Results and Analysis

4.4.1 Analyzing the variation of load ability for placement and fractioning of PV plant in IEEE 14-bus system

Load ability of this 14-bus system varies with placement of PV plant at different buses. Load ability also varies with the size of a single plant and number of plants. These effects have been simulated by the software as described below.

Placement effect:

Level of loadability is represented by the value of lamda (λ) in the simulation. The load ability of the default system which is taken from PSAT is λ= 2.8286.

In this analysis, solar PQ generator of rating 30MW active power and 0 MVar reactive power has been placed at one bus at a time from bus number- 2 to bus number- 14. As bus number-1 is slack bus, so no generator is added here.

Variation of ladability due to variation of placement is shown below:

Table 4.1 Variation of Loadability due to placement

Name	Loadability
PQ generator at bus 14	2.9755
PQ generator at bus 10	2.9484
PQ generator at bus 9	2.9453
PQ generator at bus 13	2.9379
PQ generator at bus 11	2.9346
PQ generator at bus 12	2.9291
PQ generator at bus 7	2.9241
PQ generator at bus 4	2.8928
PQ generator at bus 5	2.8801
14 -bus default	2.8286
PQ generator at bus 8	2.5175
PQ generator at bus 3	2.2129
PQ generator at bus 2	2.0344
PQ generator at bus 6	1.8792

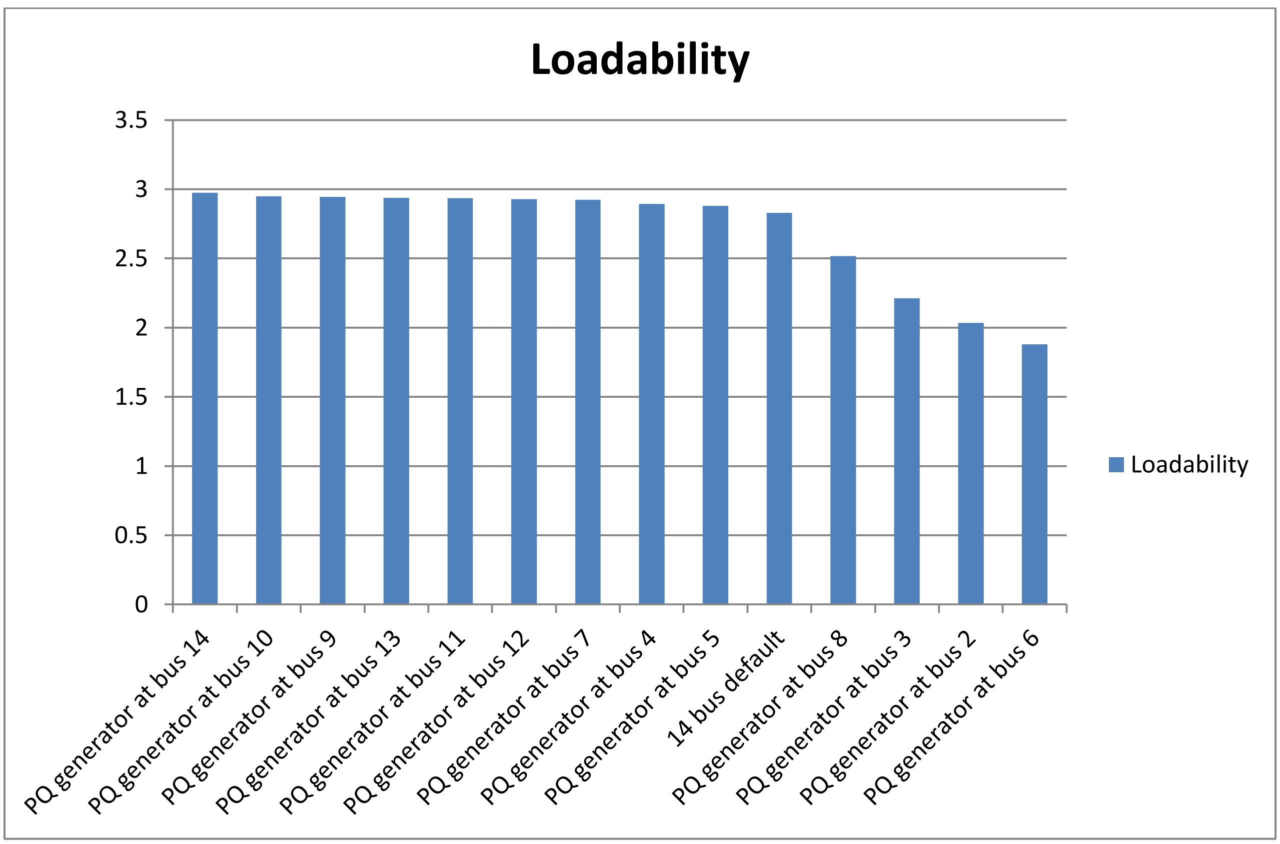

Figure 4.4 Variation of Load ability due to placement of PQ generator

Findings: Load ability increases as a result of integration of solar PQ generator at all the busses, except at bus number 2, 6, 3, and 8 where load ability decreases. It is due to the default constant PV generator at bus 2 and synchronous condenser at bus number 3, 6 and 8. The increase rate at other buses is not same although the same size PQ generator has been placed.

Fractioning effect: In this case, size of single generation plant and number of total generation plant were changed maintaining same total generation capacity. In some cases, multiple generation plants were integrated at same buses and in other cases plants were distributed at different buses. Effect of fractioning and placement is shown below.

Table 4.2 Effect of fractioning at same bus and different bus

size x number of unit	bus 10	bus14	bus 9	bus 5	bus 7	bus 4	bus 11	bus 12	bus 13	Bus 13 14	Bus12 13 14	Bus10 11 12 13 14	Bus8 14
30x1	2.9484	2.9755	2.9453	2.8801	2.9241	2.8928	2.9346	2.9291	2.9379				
15x2	2.9481	2.9752	2.9449	2.8802	2.9243	2.8929	2.9348	2.9293	2.938	2.9607			2.5964
10x3	2.9479	2.975	2.9448	2.8802	2.9244	2.8929	2.9349	2.9294	2.9381		2.952		
6x5	2.9478	2.9749	2.9447	2.8802	2.9244	2.8929	2.935	2.9295	2.9382			2.9499	

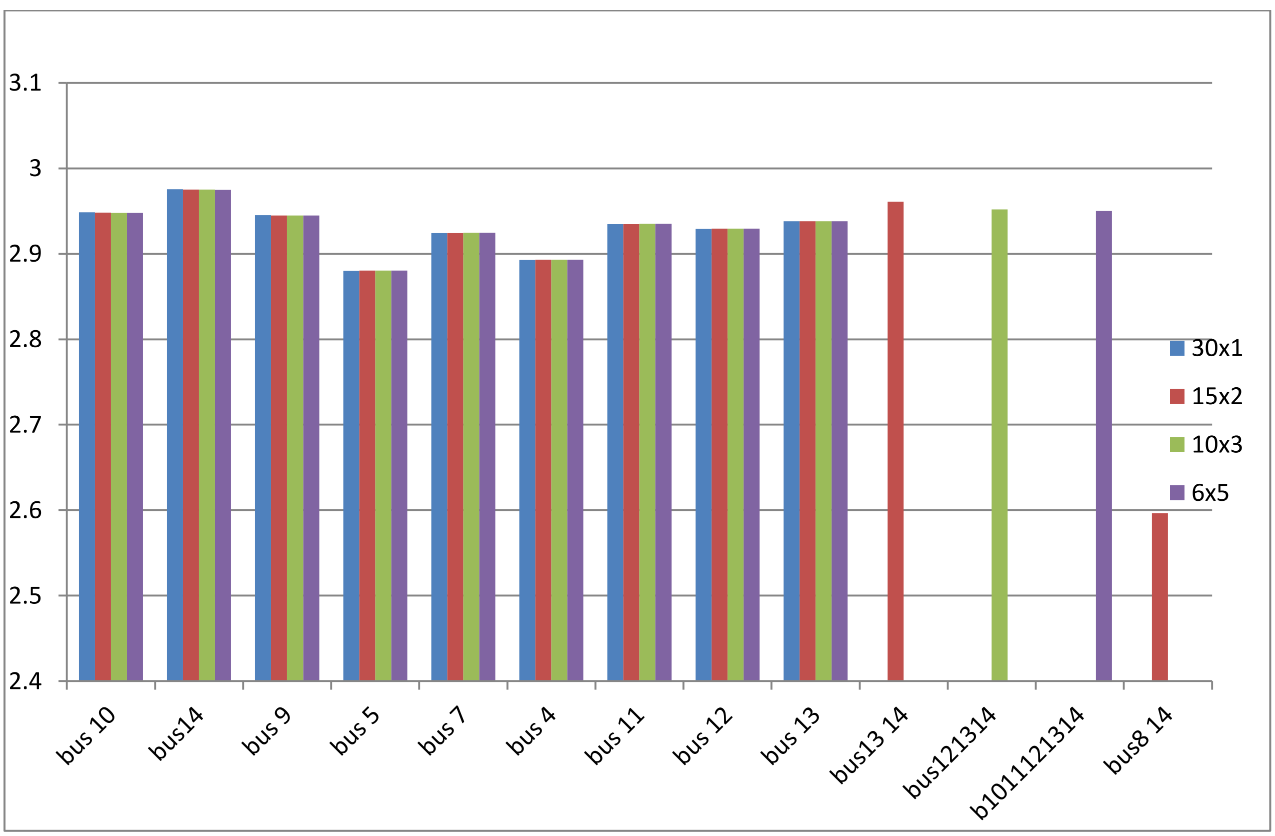

Figure 4.5 Variation due to fractioning and placement

Findings: As we can see from the graph and table, bus -14, bus -10 and bus-9 can have higher loadability than others next to these three buses there is bus-12 and bus-11 down to the chronological order there is bus-14 and bus-7 and further down to the order bus -4 and bus -5 have minimum variation in loadability due to fractioning and placement Generally, where increase of loadability is higher (as shown in Fig. 4.4) due to integration of PV plant, the effect (increase or decrease) of loadability is higher for fractioning there.

The three buses (bus 14, bus 10and bus 9), where loadability is higher as compared to others, if we split the generator on those three buses loadability decreases. Whereas, on the other buses loadability increases, if generation unit is fractioned. In case of distribution at different buses load ability decreases with the increase of plant number by fractioning.

4.4.2 Finding the maximum limit of PV integration for each buses of IEEE 14-bus system

In this case, solar PQ generation unit were integrated at different buses of IEEE 14-bus system in PSAT. Ratings of the solar generation unit were increased until system becomes unstable. In each simulation power factor of PQ generation unit was considered 0.94 which is the minimum value to get better results. The results found from this simulation are given in the following table and graph.

Table 4.3 Maximum limit of integrated PV for each bus

Bus number	MW	Mvar
Bus 5	1198.5	76.5
Bus 4	1132.7	72.3
Bus 7	526.4	33.6
Bus 9	437.1	27.9
Bus 10	352.5	22.5
Bus 11	329	21
Bus 12	291.4	18.6
Bus 13	258.5	17.5
Bus 14	253.8	16.2

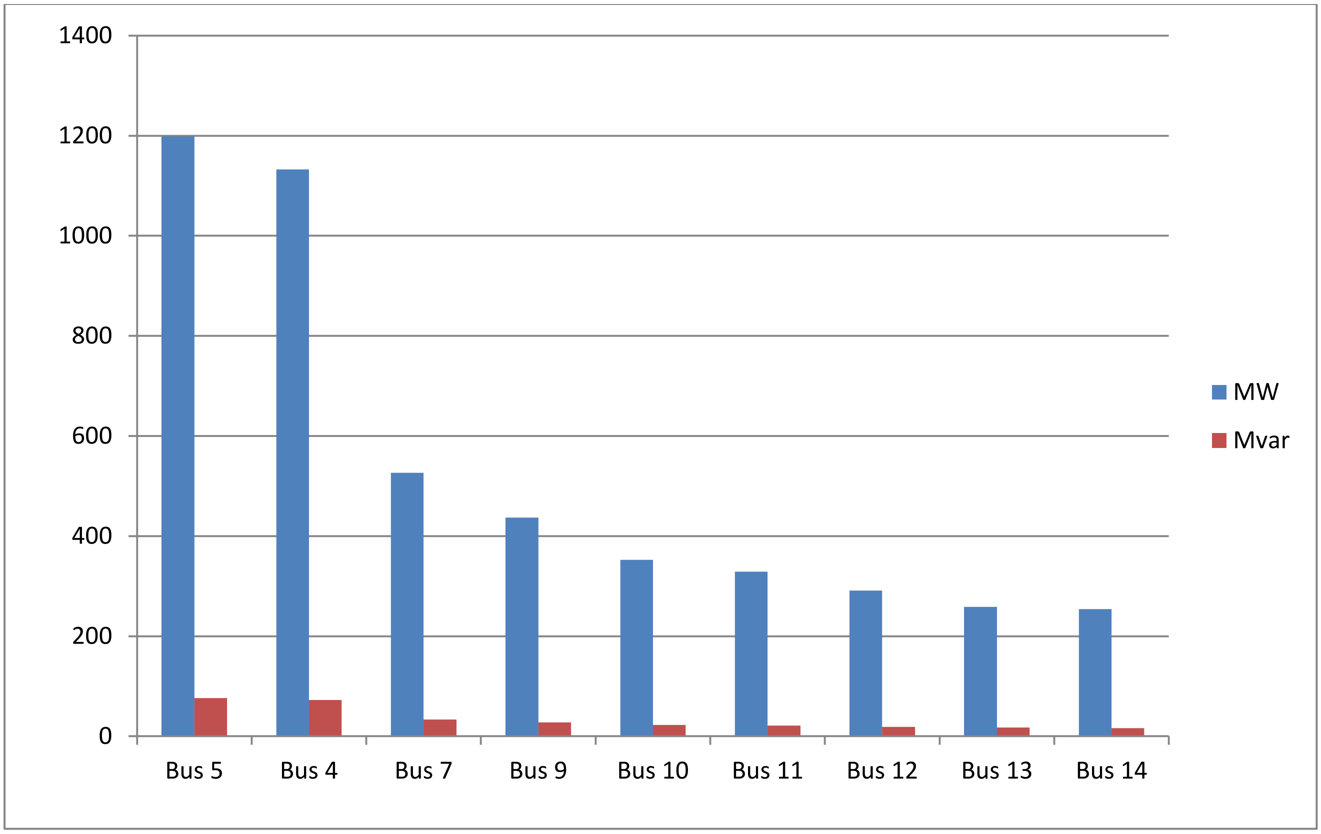

Figure 4.6 Maximum real power and reactive power limit

Observations: Maximum amount of PV power can be integrated to the bus which is closer to the slack bus. As the distance increases from slack bus the integration capacity decreases. Significant change was occurred in maximum limit from bus 4 to bus 7 due to change in bus voltage level from 69 KV to 13.8 KV. The voltage level of slack bus and bus number 2, 3, 4 and 5 is 69 KV where the voltage level of the rest of the buses is 13.8 KV except bus 8 where the voltage level is 18 KV.

4.4.3 Examining the interaction between PV and induction motors, synchronous motors, dc motors

In these simulations, solar PQ generation plant was integrated along with induction motor or synchronous motor or DC motor at different buses. The effect on load ability due to integration of any motor alongside PV generation plant has been analyzed.

Interaction between induction motor and PV generation plant

In this case, induction motor rating was considered to be 3MVA, 11KV and 50Hz and the other parameters were considered to be same as defined for IEEE type-6 induction motor. Solar PV generation unit was also placed and the rating was increased gradually and the effect was monitored.

Table 4.4 Effect on load ability due to integration of induction motor and PV generation plant

Name	Loadability	Differences in Load ability	Shift from default
14-bus default file	2.8286	0	0
INDUCTION_MOTOR_without_PQ Generation	1.8676	-0.961	0.961
INDUCTION_MOTOR_PQ1MWatB14	1.8695	0.0019	0.9591
INDUCTION_MOTOR_PQ2MWatB14	1.8918	0.0223	0.9368
INDUCTION_MOTOR_PQ3MWatB14	1.8938	0.002	0.9348
INDUCTION_MOTOR_PQ4MWatB14	1.875	-0.0188	0.9536
INDUCTION_MOTOR_PQ5MWatB14	1.8768	0.0018	0.9518
INDUCTION_MOTOR_PQ6MWatB14	1.8996	0.0228	0.929

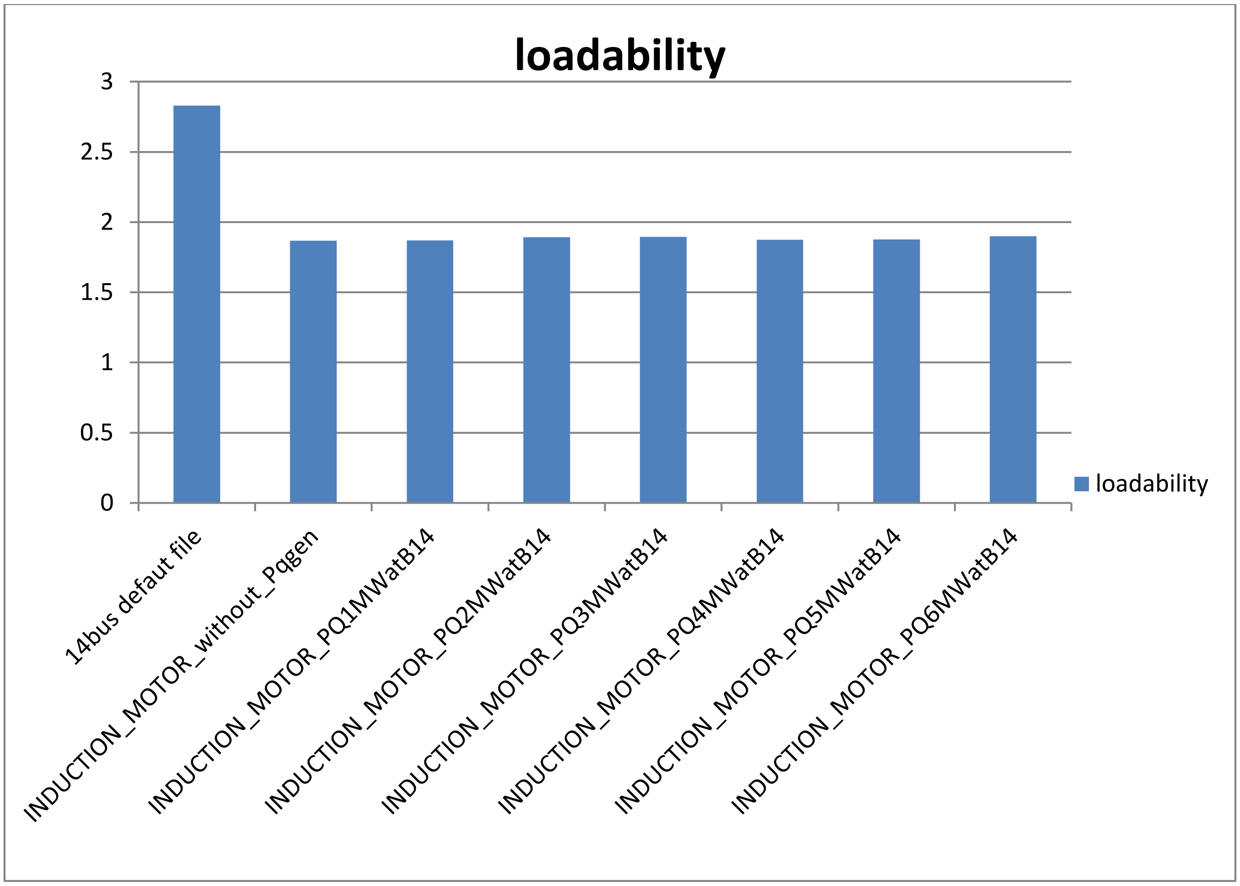

Figure 4.7 Effect on load ability due to integration of induction motor and PV generation plant

Effect of fractioning of induction motor and interaction with solar PQ generation plant

Here, six induction motors of 0.5MVA were integrated with the bus. Rating of PQ generation unit was increased gradually from 1MW to 6MW. The effect is shown below:

Table 4.5 Effect on load ability for induction motor fractioning

Induction Motor 6X0.5MVA	Loadability for fractioning
PQ1MW	1.9355
PQ2MW	1.9396
PQ3MW	1.944
PQ4MW	1.9465
PQ5MW	1.9514
PQ6MW	1.9562

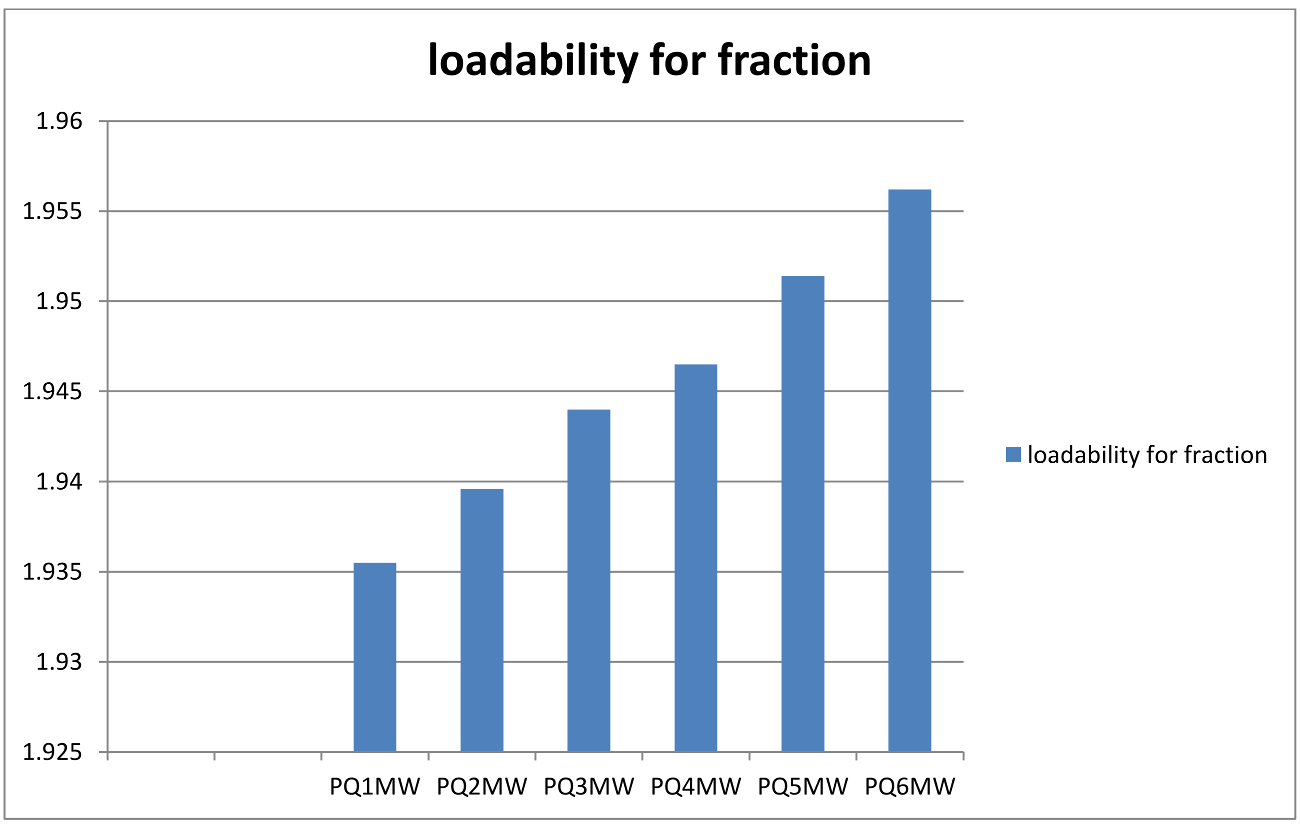

Figure 4.8 Load ability for fractioning

Table 4.6 Comparison between single induction motor and multiple induction motor connected system

Rating of PQ gen	Loadability for single induction motor	Loadability for fractionalized induction motor
without PQ generator	1.8676	1.9254
PQ1MW	1.8695	1.9355
PQ2MW	1.8918	1.9396
PQ3MW	1.8938	1.944
PQ4MW	1.875	1.9465
PQ5MW	1.8768	1.9514
PQ6MW	1.8996	1.9562

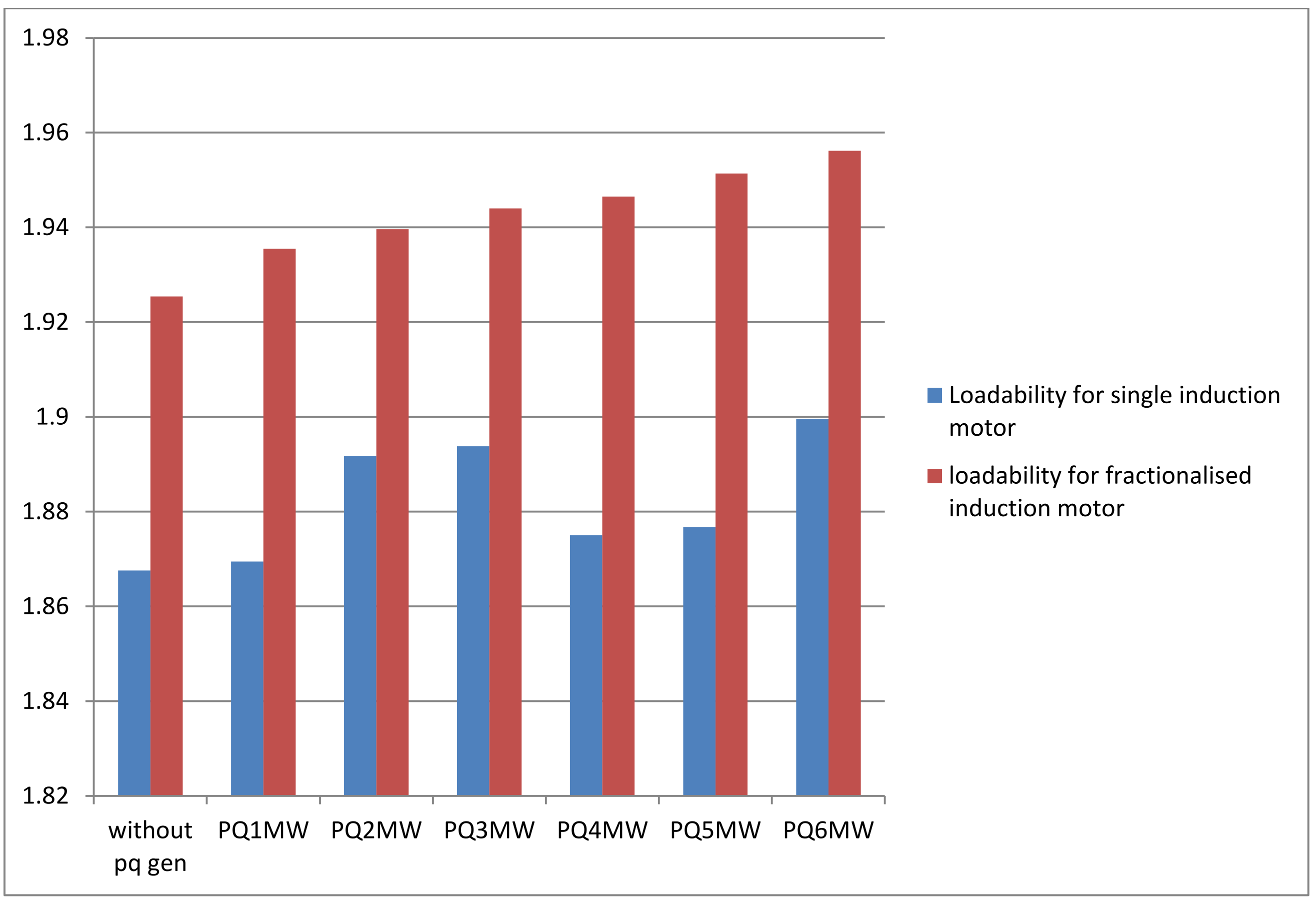

Figure 4.9 Comparison between single induction motor and multiple induction motor connected system

Findings

Load ability is increased if the PQ generator is fractioned. Better stability is found if the induction motor is fractioned.
Load ability increases linearly with increase of the rating of solar PQ generator in the case of fractioned motors. On the other side, load ability increases exponentially up to 3MW of solar PQ generator integration.

Effect of fractioning of induction motor on voltage level of bus and interaction with solar photovoltaic generation plant

In this study, change in voltage of a particular bus was observed. This voltage level study was done in simulation software called Power Factory. Bus 12 and Bus 9 were selected for this study.

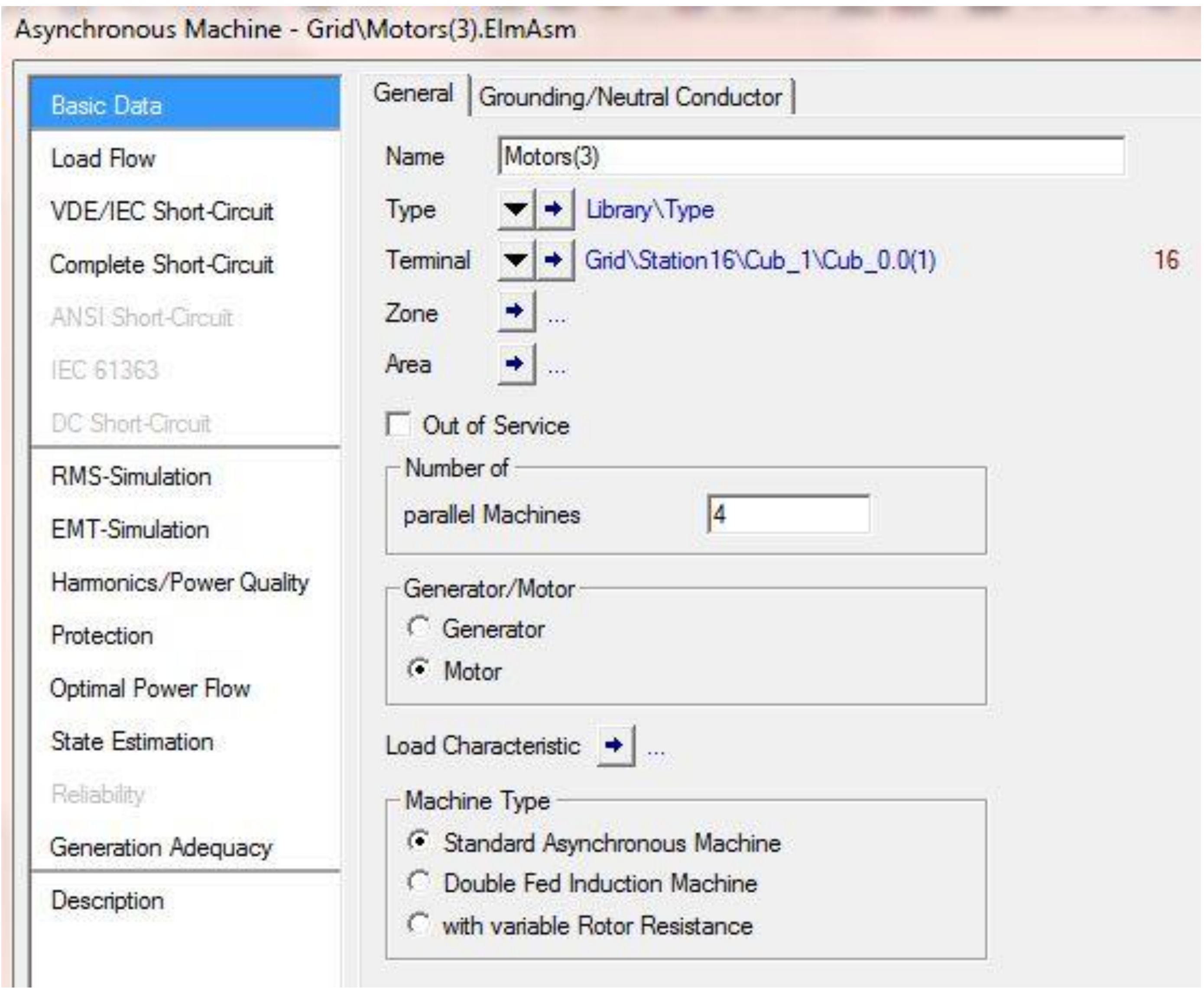

Figure 4.10 Basic data of induction motor

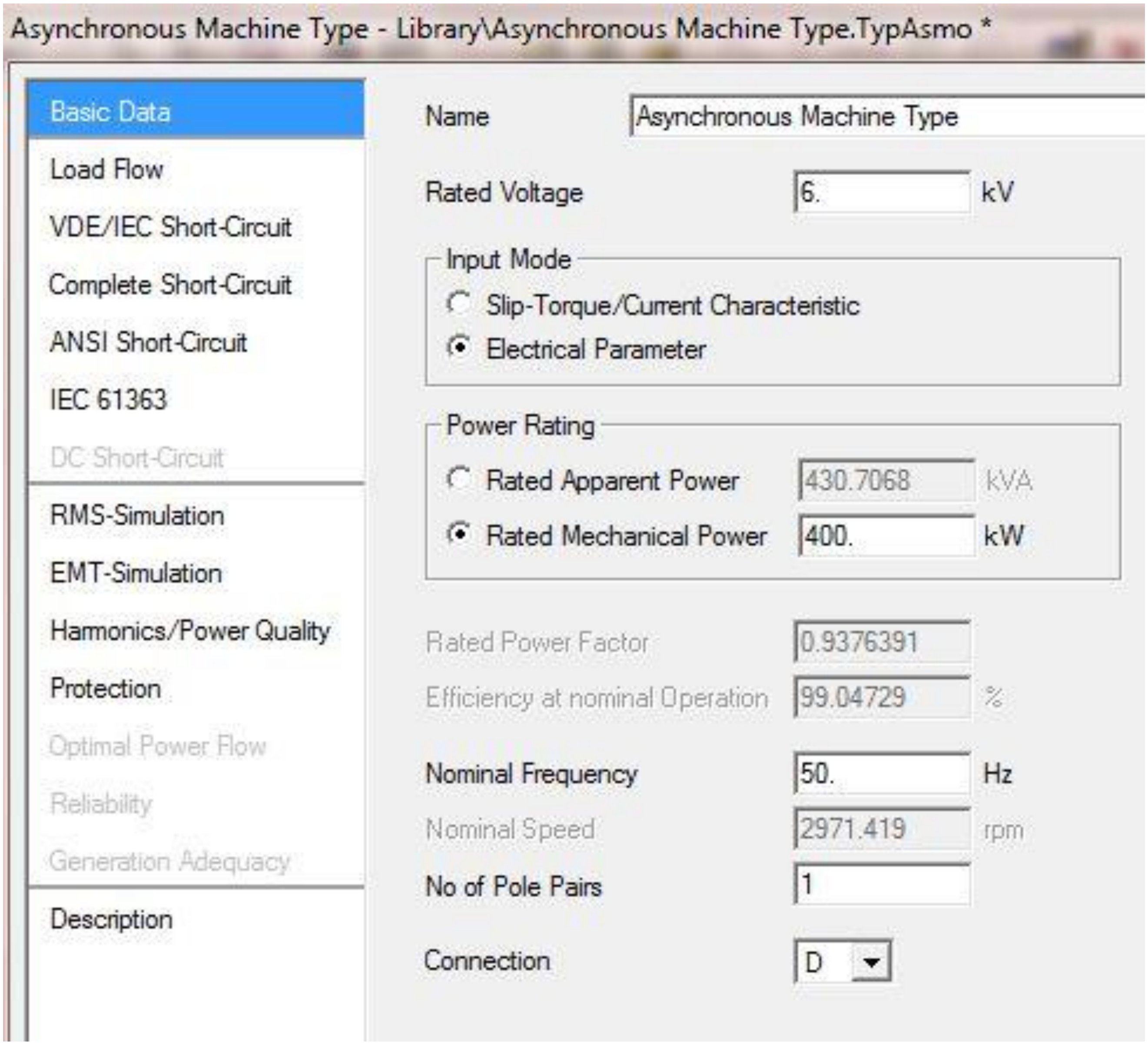

Figure 4.11 Basic data of induction motor

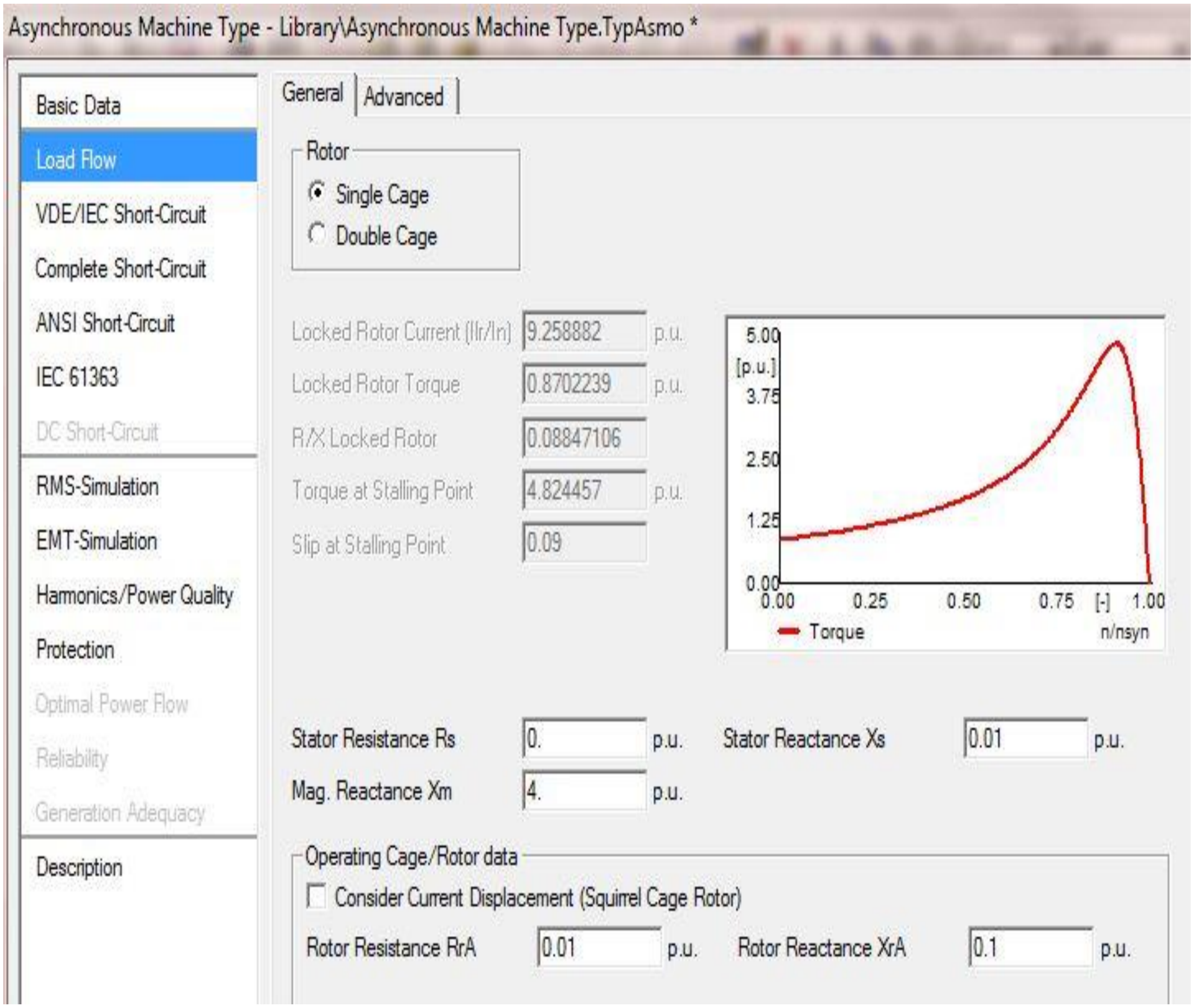

Figure 4.12 Parameters of Induction motor

Table 4.7 Effect of fractioning of Induction motor on voltage level of bus and interaction with solar photovoltaic generation plant

Here, Induction motor of 165KVA was fractioned, active power 150KW, Power factor 0.9 and Photovoltaic rating 1MW with power factor 1.

Induction Motor at Bus12	**bus 12 effects**	**bus 9 effects**	**number of motor**	**PV connection**
bus voltage in KV	22.27	22.15	1	No PV connection
	22.35	22.2	1	PV is connected
	22.27	22.15	3	No PV connection

	22.35	22.2	3	PV is connected
	22.27	22.15	5	No PV connection
	22.35	22.2	5	PV is connected

Observation and findings

Voltage profile improved after integration of photovoltaic plant, no change occurred in voltage level due to fractioning of induction motor.

Interaction between synchronous motor and PV generation plant

In this study, change in voltage of a particular bus was observed due to integration of Synchronous motor, fractioning of Synchronous motor and integration of solar photovoltaic plant on the same buses. This voltage level study was done in simulation software called Power Factory. Bus 12 and Bus 9 were selected for this study.

The parameters of Synchronous motor are shown below:

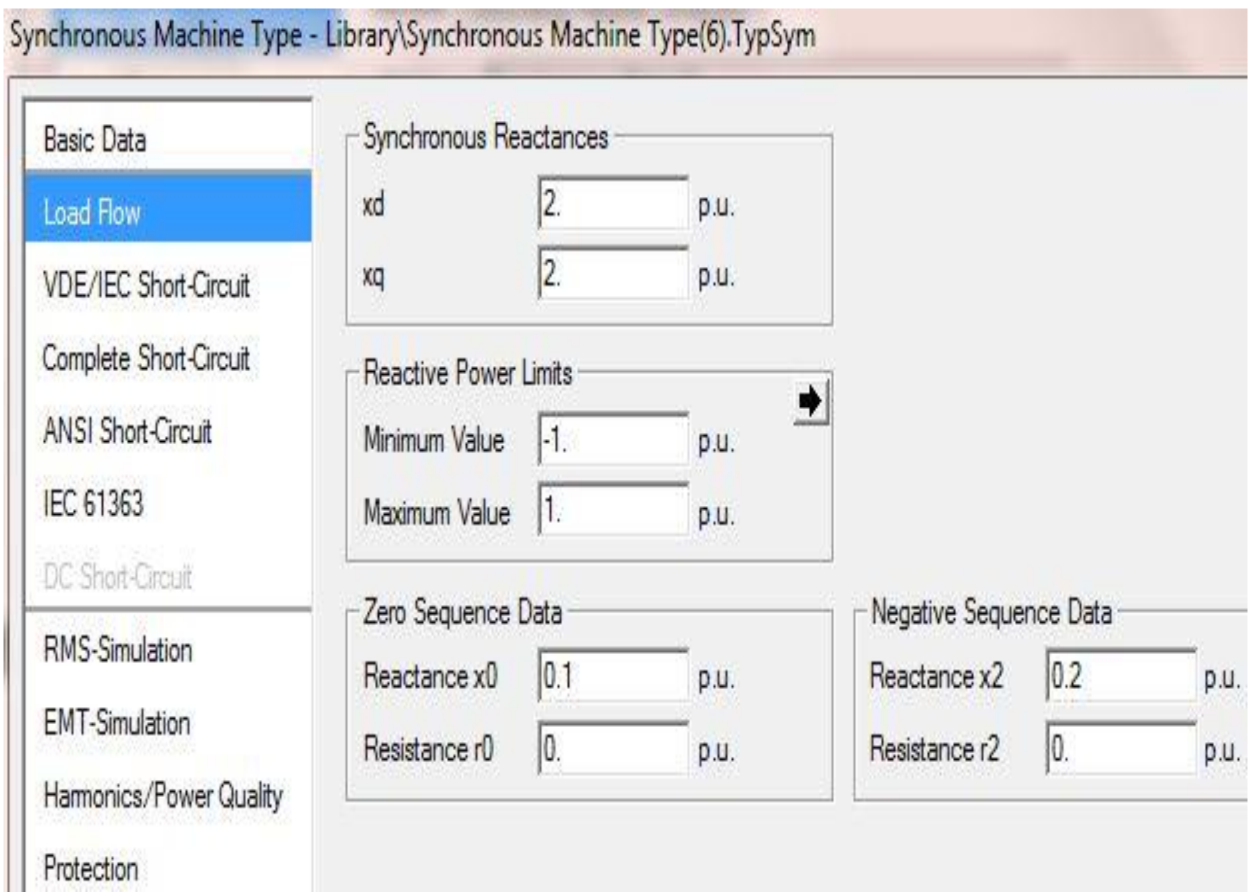

Figure 4.13 Load flow data of synchronous motor

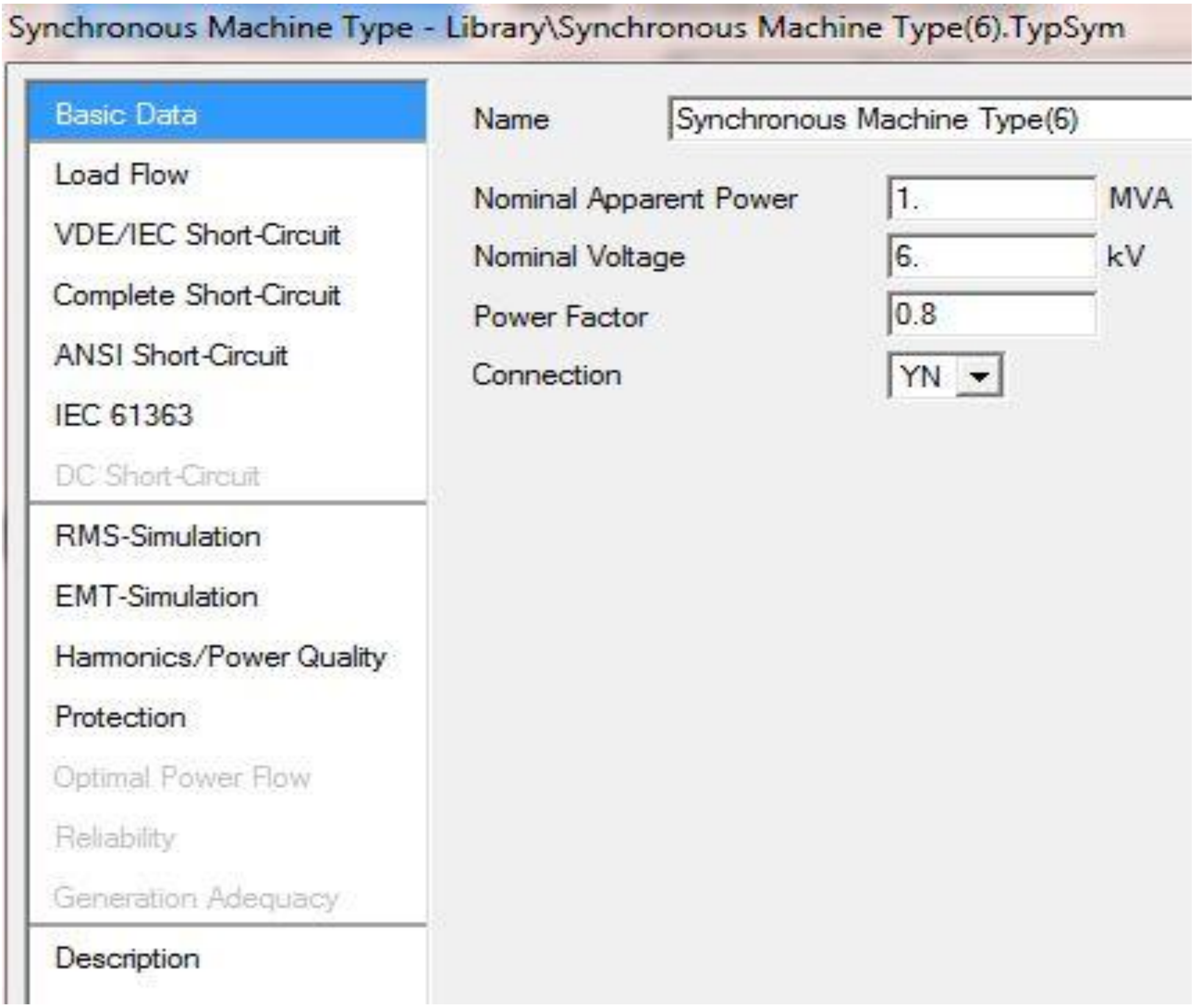

Figure 4.14 Parameters of synchronous motor

Table 4.8 Effect of fractioning of synchronous motor on voltage level of bus and interaction with solar photovoltaic generation plant

Synchronous Motor at Bus12	bus 12 effects	bus 9 effects	number of motor	PV connection
bus voltage in KV	22.27	22.15	1	No PV connection
	22.35	22.2	1	PV is connected
	22.27	22.15	3	No PV connection
	22.35	22.2	3	PV is connected
	22.27	22.15	5	No PV connection
	22.35	22.2	5	PV is connected

Here, bus 12 default voltage is 22.29 KV and bus 9 default voltage is 22.15 KV, all motor and PV are connected at bus 12

Motor Rating is 165KVA, 150KW and Power factor 0.9;
PV Rating is 1MW, Power factor 1

Findings and analysis

As it seems effect of integration of synchronous motor and PV is identical with integration of induction motor. Voltage profile improved after integration of photovoltaic plant, no change occurred in voltage level due to fractioning of synchronous motor.

Interaction between DC motor and PV generation plant:

Here, a new DC bus is added as an external bus where DC motor is integrated. Rating of new DC bus is 11KV. DC motor rating is congruent with previous ratings.

Table 4.9 Effect of fractioning of DC motor on voltage level of bus and interaction with solar photovoltaic generation plant

DC Motor at new DC bus	bus 12 effects	bus 9 effects	number of motor	PV connection
bus voltage KV	19.99	20.6	1	No PV connection
	20.07	20.66	1	PV connected
	19.99	20.6	3	No PV connection
	20.07	20.66	3	PV connected
	19.99	20.6	4	No PV connection
	20.07	20.66	4	PV connected

Findings and analysis: Voltage level decreases as extra DC bus included. No change in voltage level observed due to fractioning.

4.4.4 Determining the change in voltage level due to placement of PV at different buses

This simulation is done in a 16-bus system in power factory simulation software. Here, photovoltaic plant was integrated at bus-7, bus-12 and bus-16. The change in voltage level due to integration of photovoltaic plant at PV plant integrated busses as well as nearby buses was observed using this simulation software.

Table 4.10 The default voltage level of 16-bus test system

bus number	bus voltage in KV
1	22.17
2	23
3	22.93
4	22.17
5	22.07
6	22.33
7	22.3
8	22.37
9	22.01
10	22.41
11	22.04
12	21.87
13	22.55
14	22.45
15	22.43
16	22.39

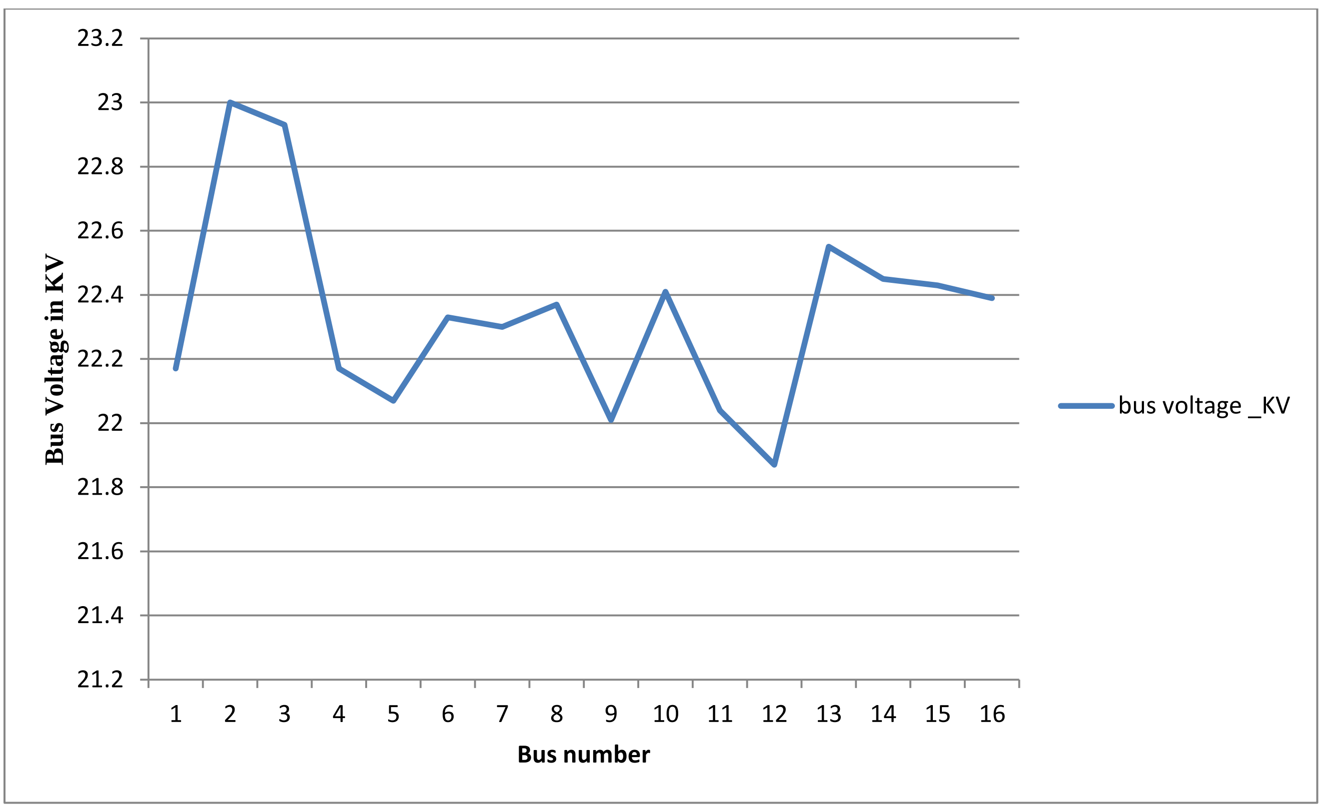

Figure 4.15 voltage status at 16-bus default system

Effect in voltage level for integrating PV plant at bus 12 is shown in the table below. Rating of the PV is 2MW active power and Power factor is 0.9

Table 4.11 Voltage change from default due to PV integration at bus-12

Bus number	Voltage in KV	Change from default
12	22.07	0.2
9	22.15	0.14
8	22.45	0.08

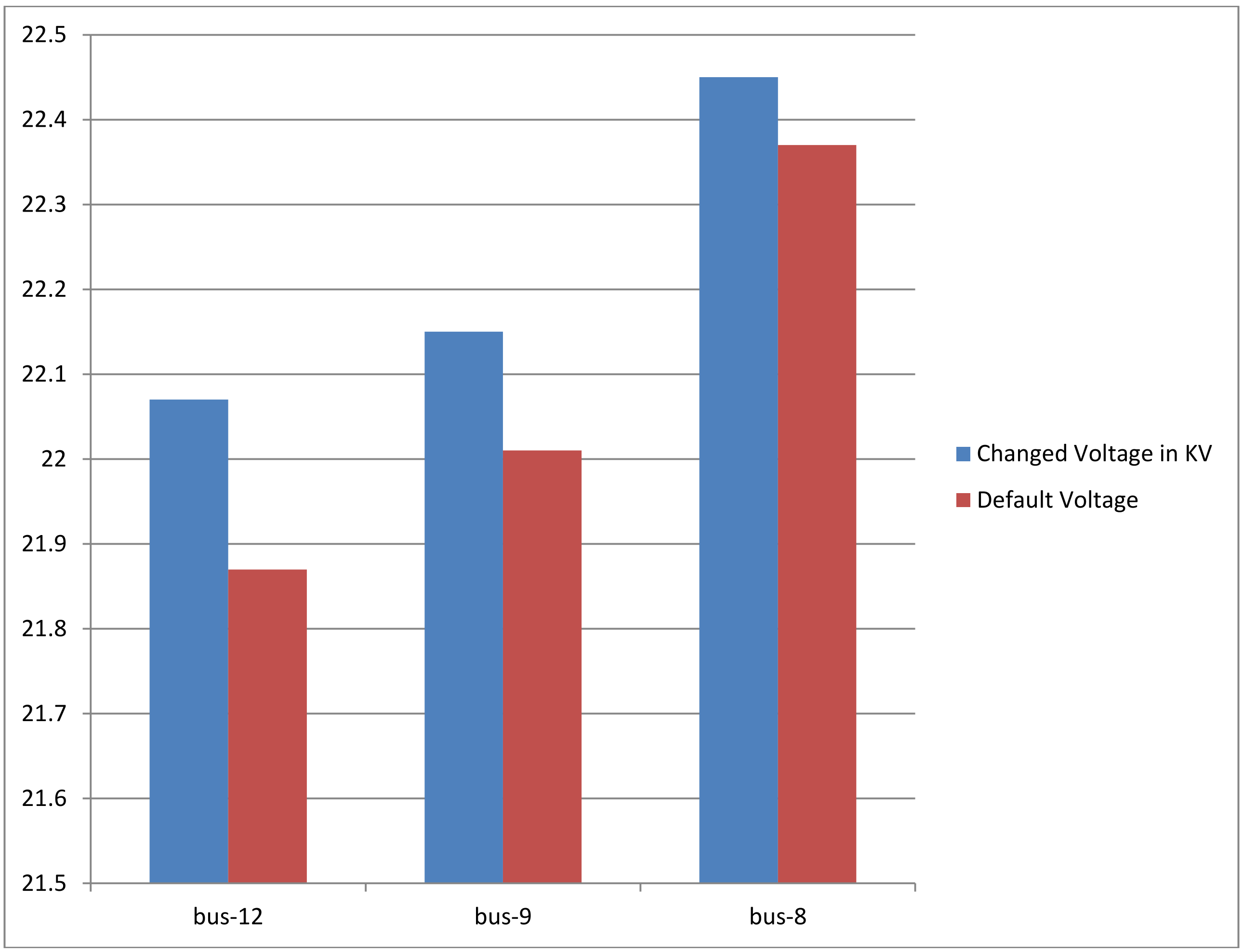

Figure 4.16 Change in voltage level at bus 12, 9 and 8

Effect in voltage level for integrating PV plant at bus 16 is shown in the table below. Rating of the PV is 2MW active power and Power factor is 0.9

Table 4.12 Voltage change from default due to PV integration at bus-16

Bus number	**Voltage in KV**	**Change from default**
16	22.72	0.33
15	22.72	0.29
13	22.79	0.34

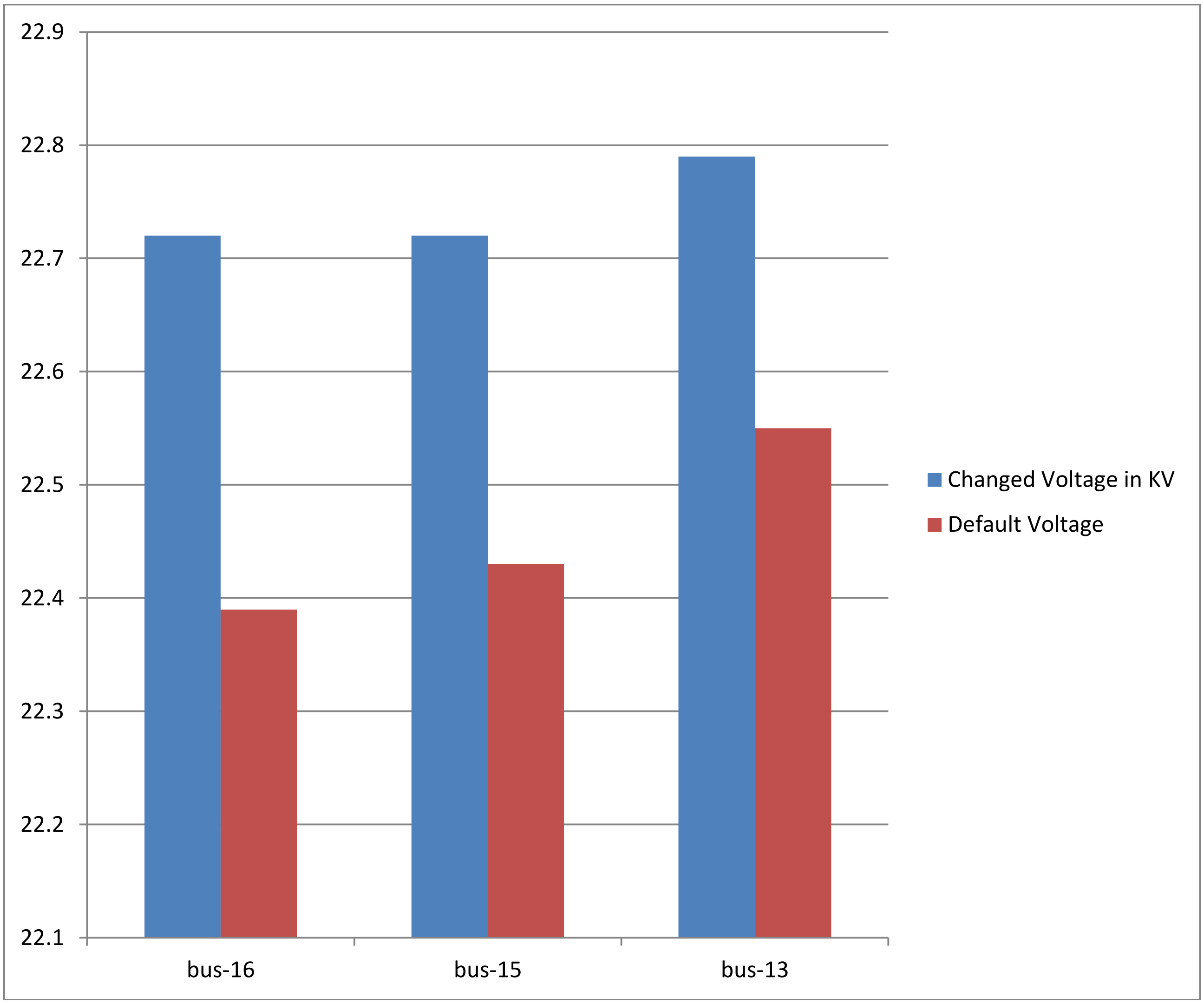

Figure 4.17 Change in voltage level at bus 16, 15 and 13

Effect in voltage level for integrating PV plant at bus 7 is shown in the table below. Rating of the PV is 2MW active power and Power factor is 0.9

Table 4.13 Voltage change from default due to PV integration at bus-7

Bus number	Voltage in KV	Change from default
7	22.67	0.37
6	22.68	0.35
4	22.43	0.26

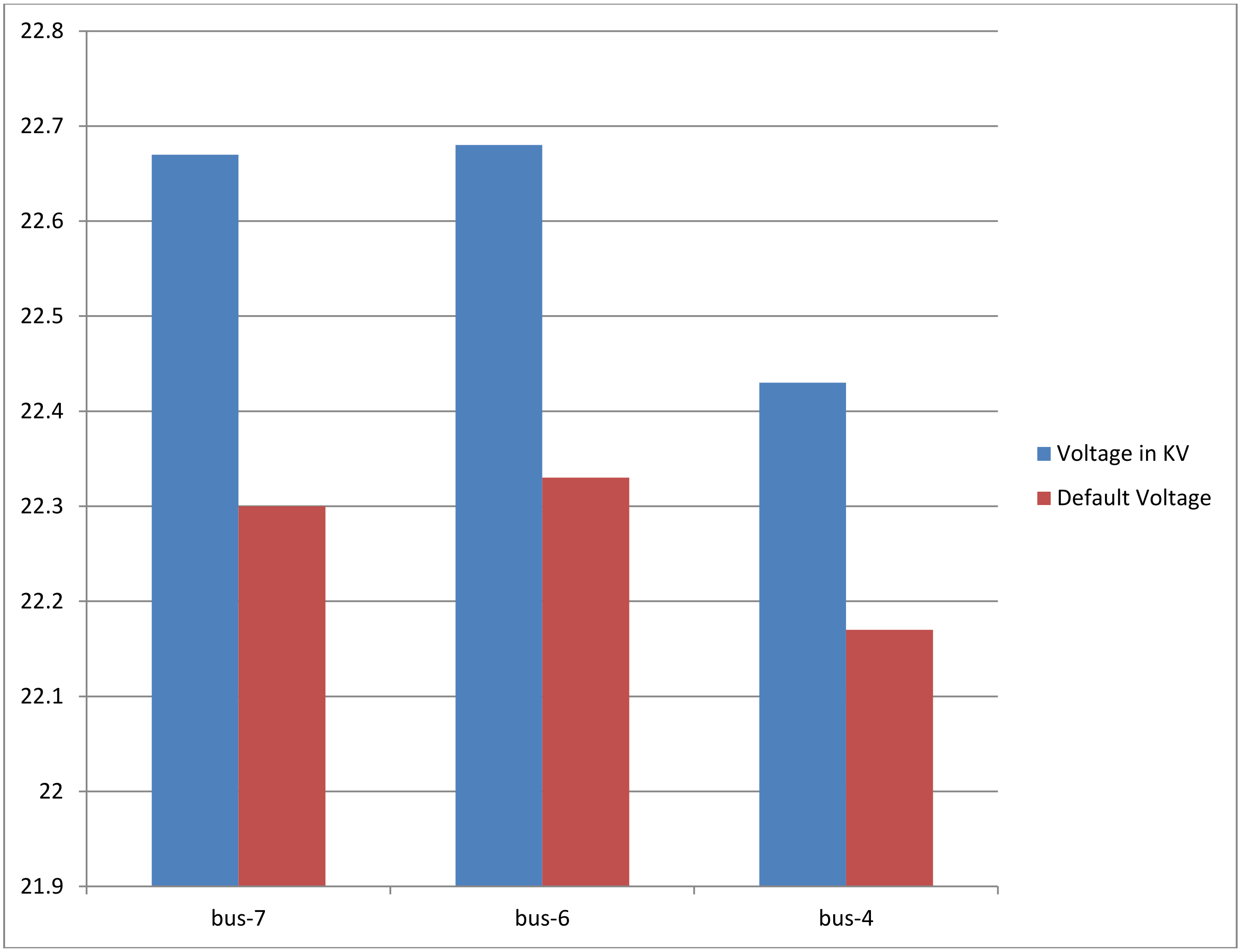

Figure 4.18 Change in voltage level at bus 7, 6 and 4

Change in voltage level at different PV integrated buses at different simulations is shown in following diagram.

Table 4.14 Voltage change from default at PV integrated buses

Bus number	Bus Voltage in KV for 2MW	Bus Voltage in KV for 3MW	Default Voltage
Bus-7	22.67	22.85	22.3
Bus-12	22.07	22.2046	21.87
Bus-16	22.72	22.88	22.39

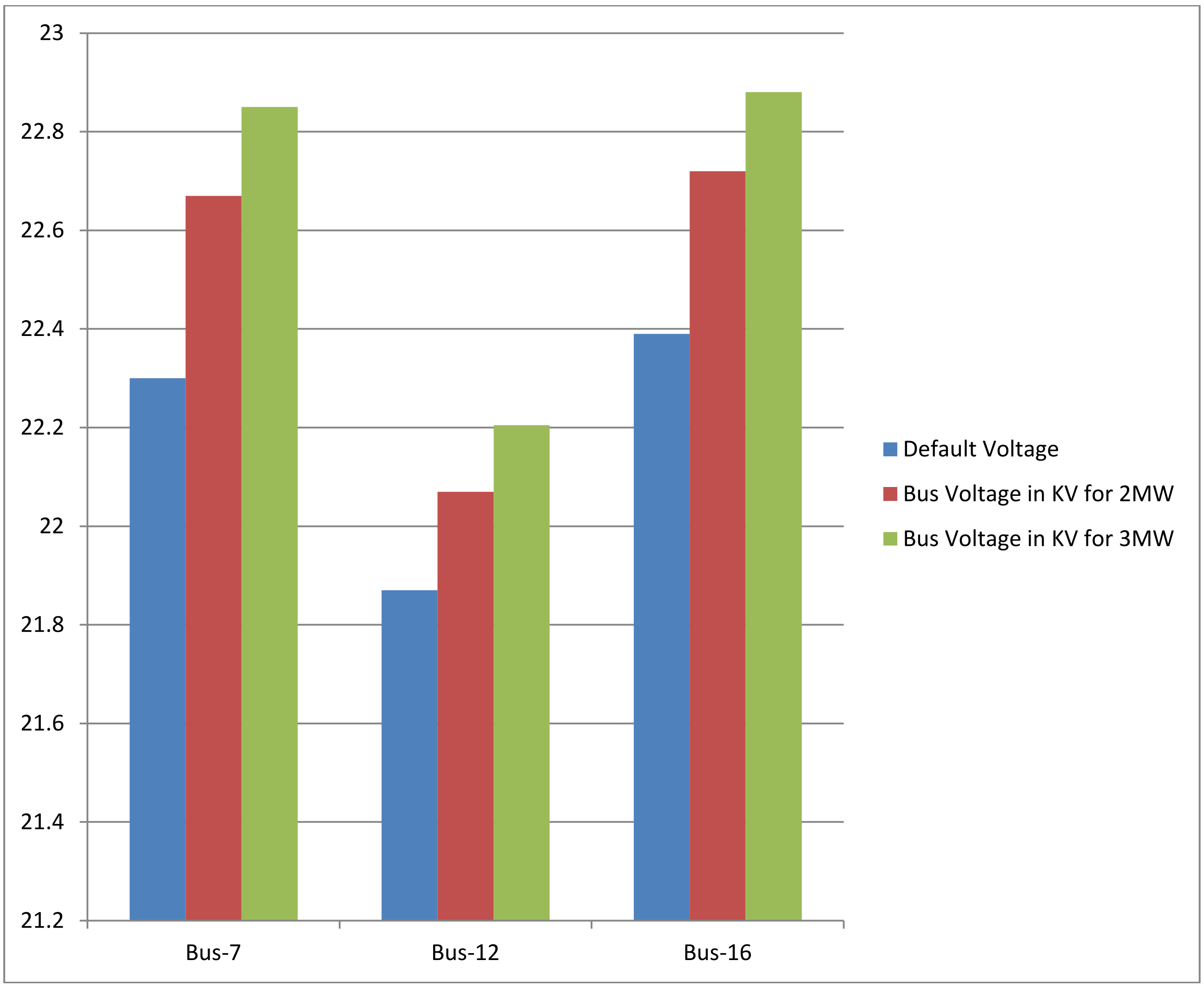

Figure 4.19 Change in voltage level at bus 7, 12 and 16 for 2MW and 3MW PV

On similar way, PV plant rating was increased from 2MW active power to 3MW active power and power factor was kept 0.9

Table 4.15 Percentage increase in voltage level after integration of PV on bus number 7, 12 & 16

Bus number	Percentage increase in voltage level for 2MW active power	Percentage increase in voltage level for 3MW active power
7	1.66%	2.47%
12	0.91%	1.53%
16	1.47%	2.19%

Findings

Here we can say that sensitivity is higher at the furthest branch of the bus from the slack bus. Bus number 7 is the furthest and the transmission distance is also higher in contrast with bus number 16 and bus number 12. For similar reason bus number 12 has least sensitivity.

4.4.5 Evaluating the change in load ability due to integrate PV in different extra buses

In IEEE 14-Bus system, some extra buses have been added and the effect has been analyzed. In first case, an extra bus (bus-15) is extended from bus-14, where 30MW PQ generator was integrated and for further study the PQ generator fractioned into three, ten megawatt unit and five-six megawatt unit.

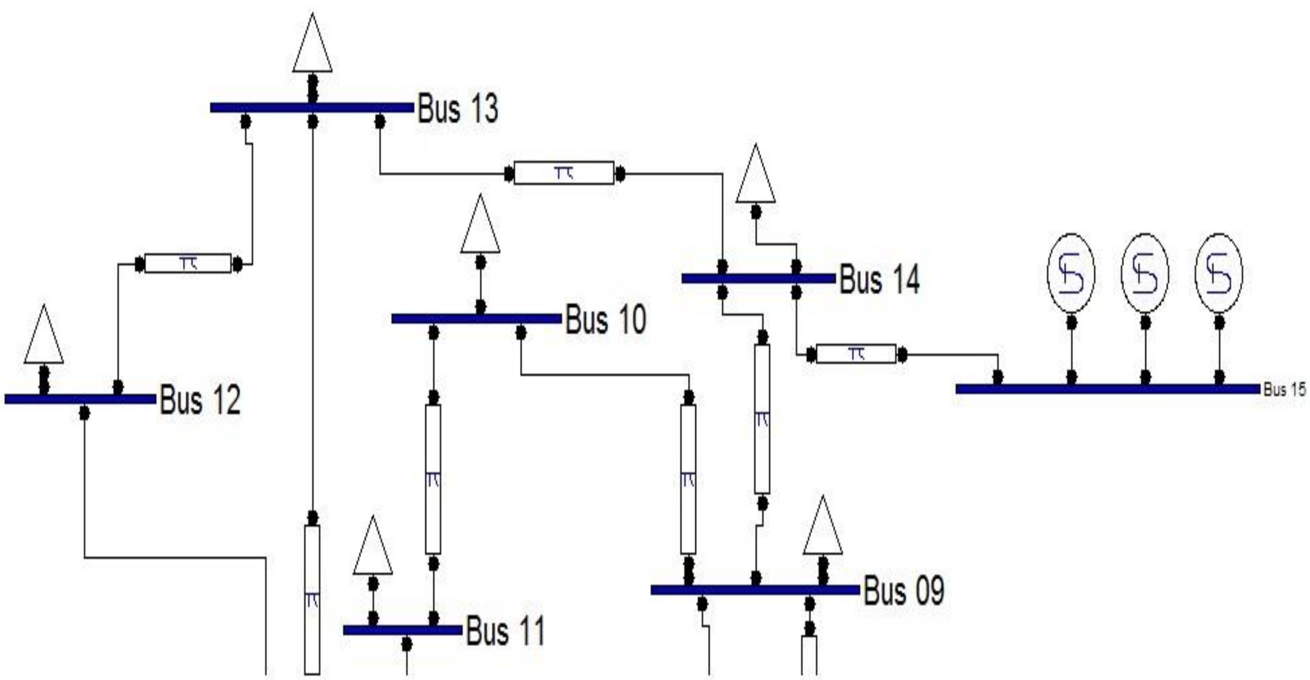

Figure 4.20 Extra bus-15 with IEEE 14-bus system (first case)

In second case, another extra bus (bus-16) was also extended from bus-14. In second case part one, two- ten megawatt PQ generator was placed on bus-15, and one ten megawatt PQ generator was placed on bus -16. In second case part two, two- ten megawatt PQ generator was placed on bus-16, and one ten megawatt PQ generator was placed on bus -15.

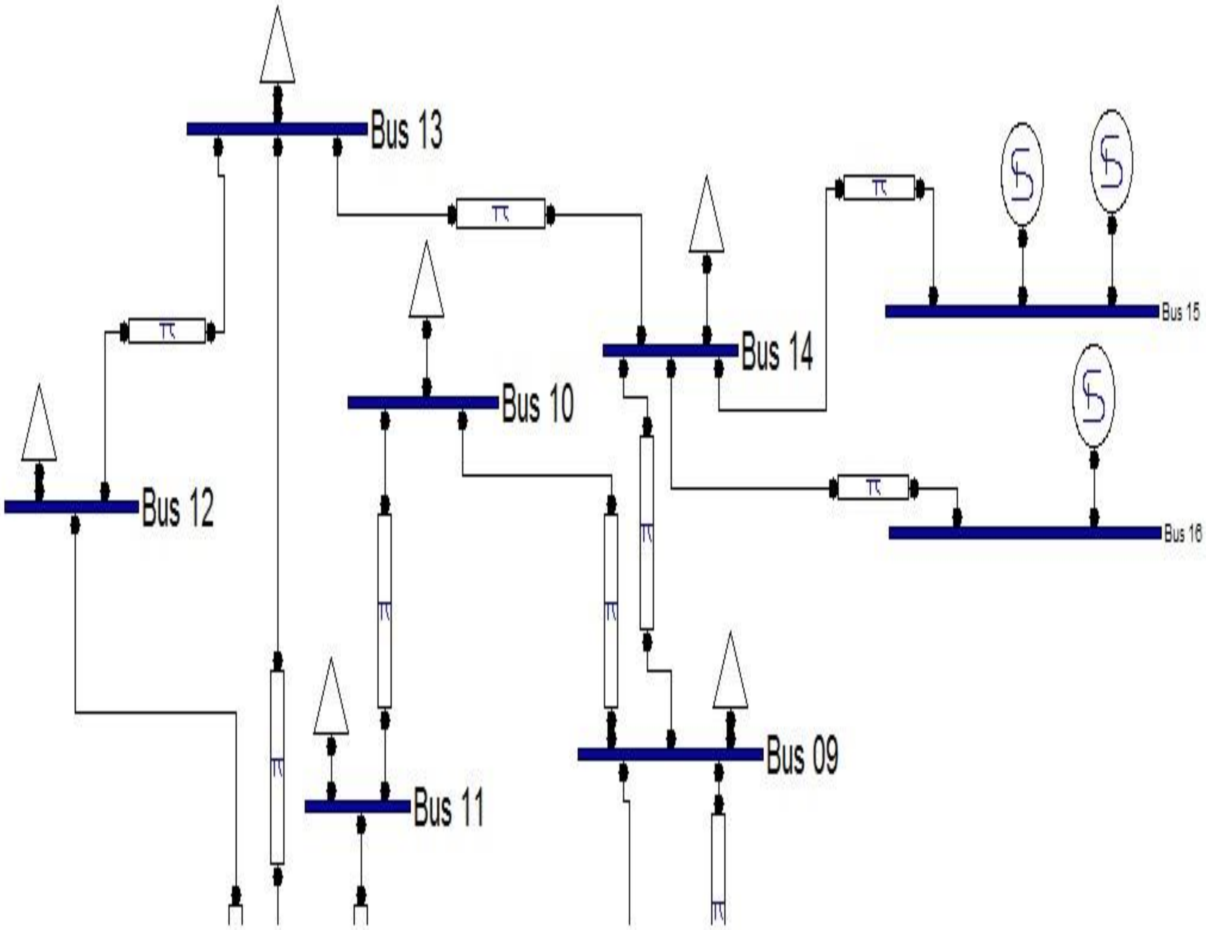

Figure 4.21 Second case part one

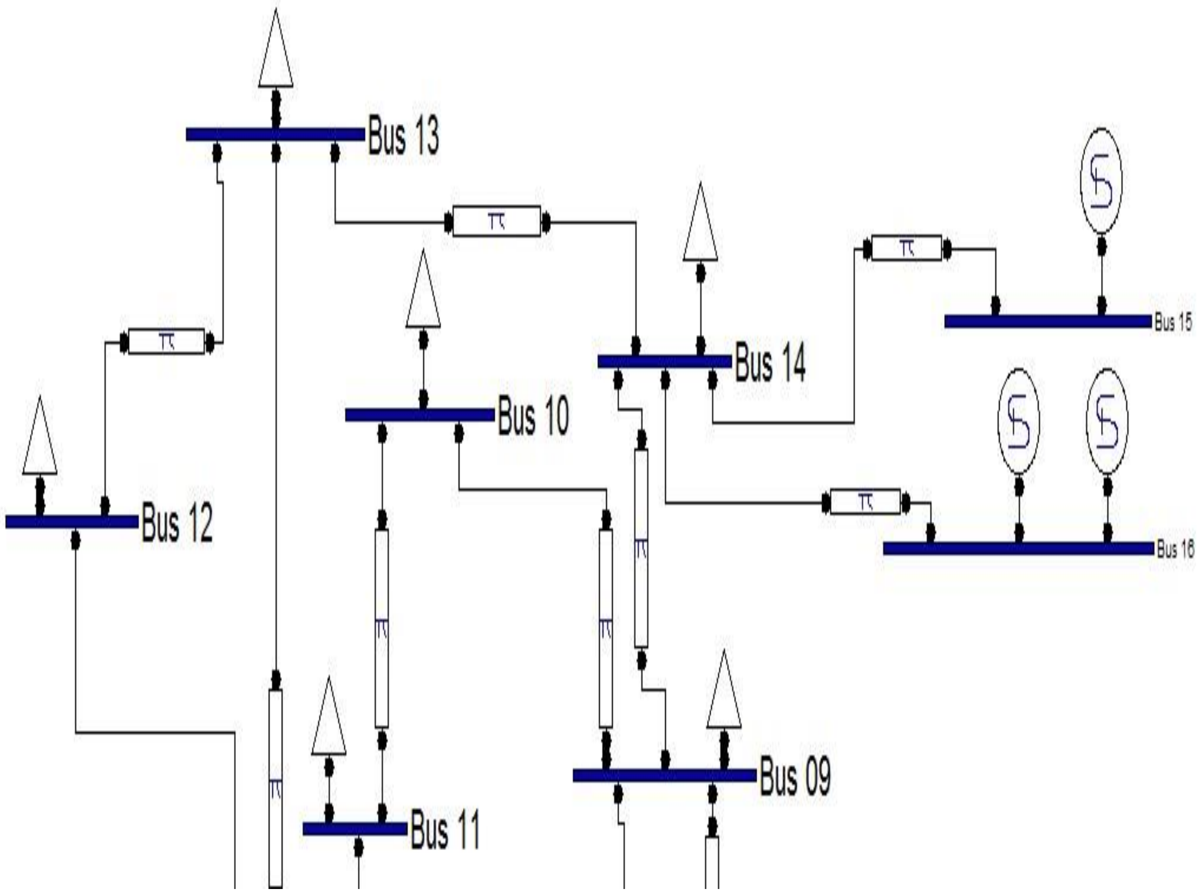

Figure 4.22 Second case part two

Then in third scenario, bus-16 was extended from bus -15. In third case part one, two- ten megawatt PQ generator was placed on bus-15, and one ten megawatt PQ generator was placed on bus-16. In third case part two, two- ten megawatt PQ generator was placed on bus-16, and one ten megawatt PQ generator was placed on bus-15.

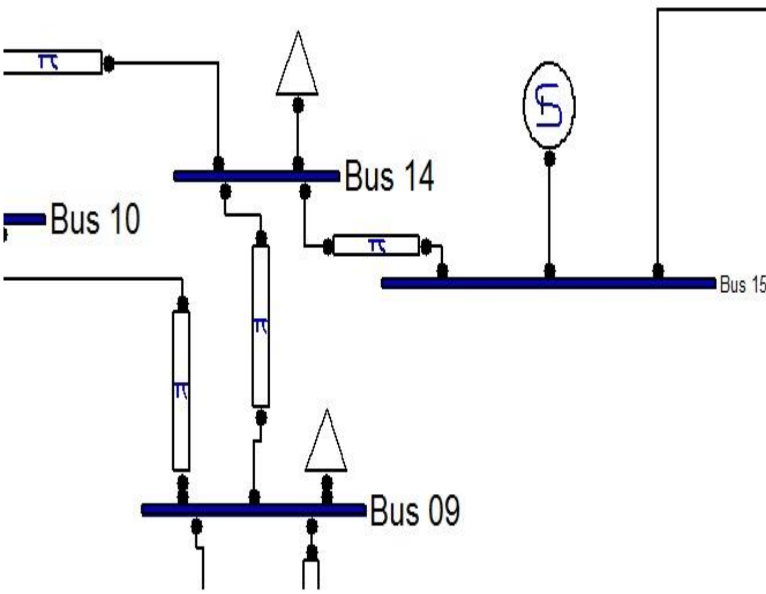

Figure 4.23 Third case part one

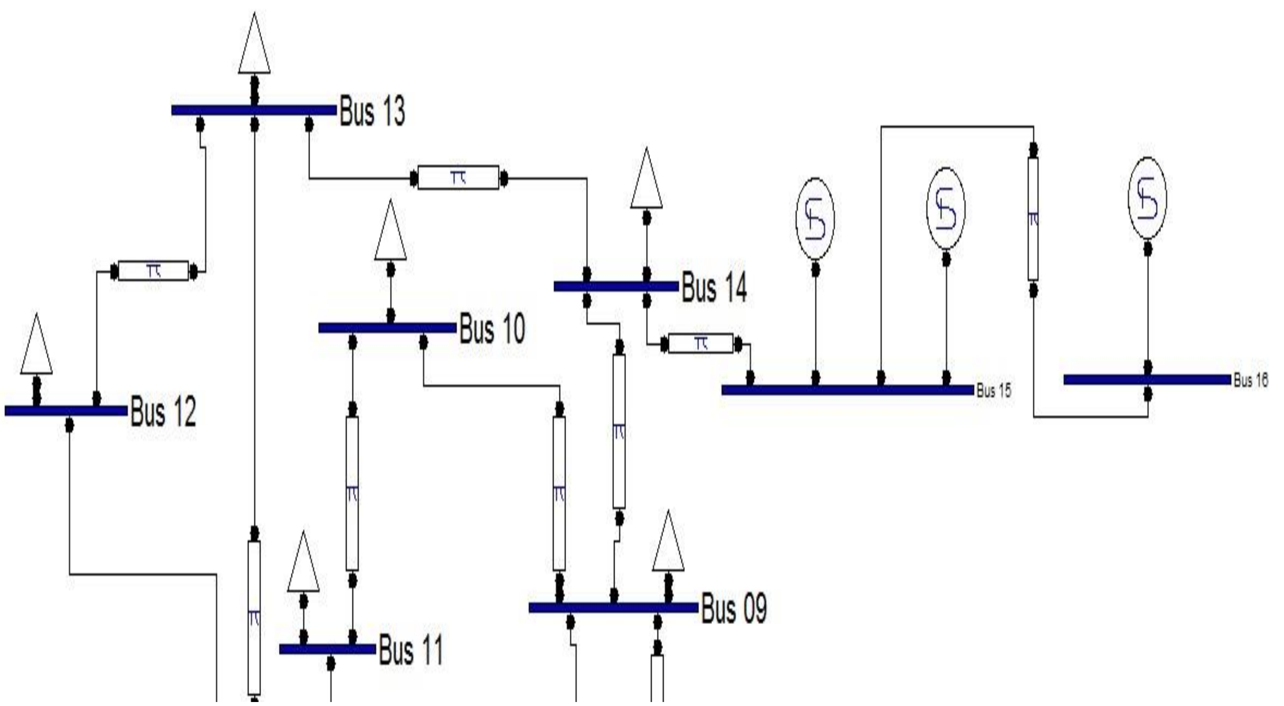

Figure 4.24 Third case part two

In fourth case, part-1 bus-15 was extended from bus-13 where one 30 megawatt PQ generator was connected with the new extra bus-15, and in part-2, three PQ generator of 10 megawatt and in part-3, five PQ generator of 6 megawatt was integrated in the extra bus-15.

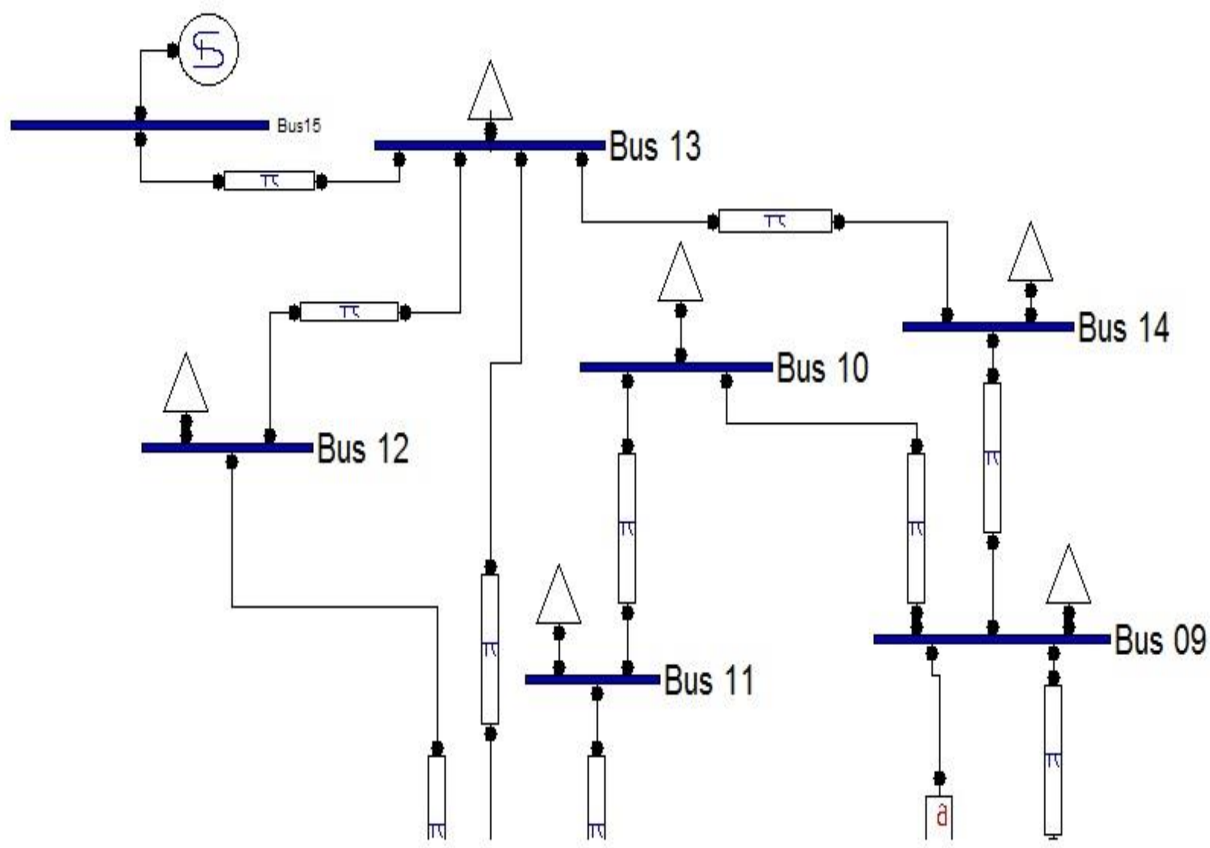

Figure 4.25 External bus-15 drawn from bus-13 (fourth case, part1)

In all of the above mentioned cases transmission line parameters of extra buses were same as transmission line between bus-13 and 14.

Findings The effect on loadability is as follows:

Table 4.16 Loadability of above mentioned cases

Case study	Loadability
case1, part1	2.9567
case1, part2	2.9566
case1, part3	2.9566
case2, part1	2.9631
case2, part2	2.9631
case3P1	2.9467
case3P2	2.953
case4	2.9339

The comparison of fractional effect of PQ generator on bus-14 and extrabus-15 (which is extended from bus-14) is as follows.

Table 4.17 Comparison of loadability between bus-14 and bus-15

Number of Unit × Size	Loadability for Bus-14	Loadability for Bus-15
1×30MW	2.9755	2.9567
3×10MW	2.975	2.9566
5×6MW	2.9749	2.9566

Comment: Loadability decreases for extra bus-15, in contrast with bus-14. Although for both cases loadability is higher than default 14-bus system. Sensitivity is slightly higher in bus-14 for fractioning of PQ generator. 0

Table 4.18 Comparison between extra bus extended from bus-14and bus-13

number of unit x size	bus-14	bus-14to15 case1	bus-13	bus-13to15 case4
1×30MW	2.9755	2.9567	2.9379	2.9339
3×10MW	2.975	2.9566	2.9381	2.9338
5×6MW	2.9749	2.9566	2.9382	2.9338

Comment: As we can see, the bus-14 where loadability is usually higher than other buses, from that bus if an extra bus is extended, loadability of that extended bus is higher than other extra buses extended from other bus, in this case bus-13. In bus-14 loadability decreases with fractioning, in bus 15 extended from bus14 loadability also decreases due to fractioning. In bus-13 loadability increases with fractioning, in bus 15 extended from bus13 loadability also increases due to fractioning.

Table 4.19 Comparison among extra buses extended from bus-14, bus-15, and bus-13

number of unit x size	Bus	extra-bus	Case-Part	Loadability
3×10MW	14	n/a	n/a	2.975
	14	15	case1part2	2.9566
	14	15,16	case2part1	2.9631
	14	15,16	case2part2	2.9631
	14	15 to 16	case3part1	2.9467
	14	15 to 16	case3part2	2.953
	13	15	case4part2	2.9338

Comment: From first two rows it is evident that loadability decreases with extension of extra bus along with integration of PQ generator. From third and fourth row no change in loadability due to interchanging generation size between bus-15 and bus-16 where both the extra buses bus-15 and bus-16 were extended from bus-14. From row two and three it is seen that loadability increases for extending another extra bus, bus-16.

From row four, five and six in observed that loadability decreases for further extension of bus name Bus-16, from bus-15. Loadability increases with increase of PQ generation size at the furthest bus namely bus-16 from slack bus. Loadability for all fractioning cases and extended bus cases for bus-14 is higher than bus-13.

Conclusion: In this chapter, loadability margin, voltage sensitivity was examined with variation of solar generation plant size, number of unit and placement. From all of these simulations and analysis, it is found that loadability and voltage varies with plant size, number of units and placement. It is also found that loadability varies with extra buses. From another simulation it is found that interaction between solar generation plant and different types of motors were not similar.

Chapter 5

Discussion & Conclusion

5.1. Discussion

Modeling of solar photovoltaic integrated medium voltage distribution system has been done using PSAT simulation tools and power factory simulation tools. IEEE-14 Bus test system and a 16-bus system on Powerfactory Simulation Software were modified. To find out the placement and fractioning effect of solar plants the placements of solar photovoltaic plant at different buses have been done. It is found that loadability varies with fractioning and placement of solar plant at different buses. Maximum input rating of solar plant for an individual bus was not same for all buses. Interaction among photovoltaic plant and induction motors, synchronous motors, DC motors were different, in that cases change in loadability and voltage levels were not similar. Voltage sensitivity and loadability were changed for fractioning different types of motor. Change in bus voltage level was occurred due to placement of photovoltaic system at different buses. Impact on voltage level for solar plant integration at the nearby buses of solar plant integrated bus was not similar for different location. From the analysis, it is found that loadability of the system changes due to fractioning and distributing of photovoltaic system on different types of design topology of bus system.

5.2 Conclusion

Renewable energy resources can be a substitute to fossil fuels. Besides installation and operation cost, it is important to give emphasis at the other issues like environmental impact, capacity factor, water consumption, cost, area requirement, maintenance etc. Environmental impact is a big issue. It is not a wise decision to setup nuclear power plant as a substitute to fossil fuel based power plant. In some cases, installation of hydroelectric plant causes flood. It is risky to setup wind turbine at an area where tropical storms hit. Wave and tidal based plant is also risky at this type of area. Cloudy and foggy climate is not suitable for both solar thermal and photovoltaic. Solar thermal plant (except dish sterling) need huge water supply. It is not suitable to setup these types of solar thermal plant at an area where water is unavailable. A desert area far from water source is not a suitable place for setup solar thermal plant. Solar PV has several advantages, it has no noise and vibration and scalable to house hold level. But installation cost of solar PV is higher than conventional fossil fuel fired generation plant. So it is important to integrate solar PV plant at suitable place. Sizing of PV plant is also important for efficient operation. One of the objectives of this thesis work was improvement of solar integrated grid system. For this reason this simulation tasks have been done by analyzing fractional effect and placement effect. This analysis can be used as reference for analysis of existing grid systems in Bangladesh.

5.3 Suggestions for future works:

In this study, all the simulation works were carried out in IEEE 14-Bus system in PSAT (Power System Analysis Toolbox) and a sample 16-Bus system in power factory software. There is a scope to do this work in other standard bus test systems such as the IEEE 30-Bus test system. Similar analysis can be done by changing machine parameters like reactive power rating, power factor, rating of each unit etc. Interaction between solar plant and other different types of loads like ZIP load, constant power factor load, exponentially recovery load, thermostatically controlled Load, jimma's load, mixed load can also be analyzed.

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