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FINAL YEAR PROJECT REPORT

DEVELOPMENT OF MICROGRID BASED PV-RESTORATION INCORPORATING DEMAND RESPONSE

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SUPERVISOR ENDORSEMENT

“ I hereby declare that I have read through this report entitle “Development of Microgrid Based PV-Restoration Incorporating Demand Response” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”

Signature : …………………………………

Supervisor name : DR. GAN CHIN KIM

Date : …………………………………

" I hereby declare that this report entitle "Development of Microgrid Based PV-Restoration Incorporating Demand Response" is the result of my own research except as cited in the reference. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree"

Signature	:	…………………………………
Name	:	HAKIIMUDDIN BIN SHAARI
Date	:	…………………………………

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ABSTRACT

Today’s electrical grid was designed to operate as a vertical structure consisting of generation, transmission, and distribution with the supported of controls devices to maintain system reliability, stability, and efficiency. However, system operator are now facing new challenges including the penetration of renewable energy resources in the legacy system, rapid technological change, and different types of market players and end users. Technical challenges associated with the operation and controls of microgrid are immense. The microgrid need to optimize their performance during grid connected mode and island mode operation. Interruption of the main grid supply will cause the microgrid disconnect itself and microgrid will loss power. By making the microgrid operates in stand-alone operation, the microgrid need to isolate from the main grid and need a reference voltage to restore and deliver power among the microgrid. Ensuring stable operation during network disturbance, maintaining stability and power quality in the islanding mode of operation requires the development of sophisticated control strategies for microgrid inverter in order to provide stable frequency and voltage in the presence of arbitrarily varying loads. This project focuses on the protection for restoration of PV-connected microgrid incorporating demand response during grid supply interruption. The project aim to restore the power generate by PV system by using grid-tie inverter and pure sine wave inverter aided by battery storage. This project is done to develop a control strategy for restoration of PV-connected microgrid with load control algorithm. The control strategy was designed to be installed on the residential system that comprise of microgrid system with a PV source. The method of load control management was applied to obtain the voltage stability during islanded mode operation. The load control scheme is depend on the current generate by PV. According to the result from conducted experiment, the load control algorithm was operate to stabilize the microgrid voltage by controlled the load demand depend on the PV generation.

ABSTRAK

Grid elektrik hari ini telah direka bentuk untuk beroperasi secara menegak yang terdiri daripada penjanaan, penghantaran, dan pengagihan dan disokong dengan kawalan dan alat-alat untuk mengekalkan kebolehgunaan sistem, kestabilan, dan kecekapan. Walau bagaimanapun, pengendali sistem kini menghadapi cabaran baru termasuk penggunaan sumber tenaga boleh diperbaharui dalam sistem legasi, perubahan teknologi yang pesat , dan jenis pembekal dan pengguna akhir. Cabaran teknikal yang berkaitan dengan operasi dan kawalan microgrid adalah besar . Microgrid perlu mengoptimumkan prestasi mereka semasa mod bersambung dengan grid dan mod pulau. Gangguan bekalan grid utama akan menyebabkan microgrid terputus hubungan dengan grid dan microgrid akan hilang kuasa. Dengan membuat microgrid beroperasi bersendirian, microgrid perlu diasingkan dari grid utama dan memerlukan voltan rujukan untuk memulihkan dan menyampaikan kuasa di dalam microgrid. Pembangunan strategi kawalan yang canggih untuk micrgrid inverter semasa gangguan berlaku adalah diperlukan untuk mengekalkan kestabilan dan kualiti kuasa seterusnya menstabilkan frekuensi dan voltan dengan kehadiran beban yang berubah-ubah. Projek ini memberi tumpuan kepada perlindungan untuk pemulihan PV yang disambung ke microgrid bersama respon kawalan beban semasa gangguan bekalan grid. Projek ini bertujuan untuk mengembalikan kuasa oleh sistem PV dengan menggunakan grid-tie inverter dan inverter bergelombang sinus dibantu oleh penyimpanan bateri. Projek ini dijalankan adalah untuk membina strategi kawalan untuk pemulihan PV yang disambung ke microgrid dengan algoritma kawalan beban . Strategi kawalan telah direka untuk dipasang pada sistem kediaman yang terdiri daripada sistem microgrid dengan sumber PV. Kaedah pengurusan kawalan beban telah digunakan untuk mendapatkan kestabilan voltan semasa operasi mod pulau. Teknik kawalan beban adalah bergantung kepada bekalan yang dijana oleh PV. Menurut keputusan eksperimen yang dijalankan, algoritma kawalan beban telah berfungsi untuk menstabilkan voltan microgrid dengan mengawal beban yang bergantung kepada generasi PV.

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CHAPTER 1

INTRODUCTION

1.1. Motivation

Environment concern like greenhouse effect and pollutant are driving the need for increase interest in more deployment of renewable energy resources. In addition, the low voltage distribution systems need to be expanded horizontally. One proposed solution that may provide remedies for these issues is penetration of distributed energy resources into the next generation of electricity grid. This proposed solution promising the environmental friendly and efficient electricity generation and distribution. As a result, microgrids provide a unique opportunity for integrating the renewable resources into the distribution system [1].

Microgrids comprise low voltage distribution system with a group of interconnected load and distributed energy resources which can operate in both grids connected or island mode [2]. Microgrid are small-scale version of centralized electricity system where smaller scale distributed generator and renewable energy resources like wind turbines, solar panel and energy storage; provide power closer to the point. Microgrids are expected to provide environmental and economic benefits for end-customers, utilities and society. Microgrids need the capability to improve power quality, network efficiency, reliability and economic in order to reduces the environmental effect [3].

In typical microgrid, the microsources may be rotating generator or Distributed Energy Resources (DER) interfaced by power electronic inverter. The installed DERs may be biomass, fuel cells, geothermal, solar or wind turbine. Microgrid systems operate at low voltage distribution and consist of several distributed energy resources. The microgrid structure consists of Distributed Generation (DG); energy reserves from battery

(Distributed Storage/DS) and loads. One of the promising renewable energy sources is photovoltaic (PV). The interesting in PV-based sources is due to their many advantages such as ease of installation, less maintenance and long lifetime [4].

The microgrid-connected PV-sources comprise of PV module, inverter, storage and load. The PV module is use to convert the solar energy into DC electricity. The inverter is use to convert the DC supply from PV module or storage into AC supply. The system is either interconnected to main grid or operated in islanded mode. The difference between grid-connected and islanded mode is the operation of inverter. There are two types of inverter that typically used which is stand-alone and grid-tie inverter [5].

A microgrid can be operating in two modes which are grid-connected mode and island mode. In grid-connected mode, the microgrid is connected to the main grid. The power management system of grid-connected is stable because it sharing a power from the main grid. When the microgrid is connected to the microgrid, its excess power is supplied to the main grid and in the event that the demand surpasses the power being generated at a certain time, the extra power is provided by the main grid.

Under grid-connected mode, the frequency and voltage magnitude of the microgrid must be synchronizing with the main grid. For island mode operation, the distributed energy resources which connect to the DC/AC inverter must controlled in the load-following mode. The power management of island mode is different from the grid-connected mode. The operational in island mode must fulfilled two most important requirement which is good power balance between generation and consumption, and a proper control of the main parameter of the microgrid such as voltage magnitude and frequency [6].

The most important of these are the protection system which are installed to clear fault and limit any damage to the distributed equipment. In order to design a protection for any system, knowledge about the system is required before it can be developed. In order to obtain the optimum protection system, the protection arrangement for any power system must follow to the basic principle which is reliability, speed, selectivity and cost [7]. The disturbances can be found in the system during fault condition such as during a change of operation mode – going from grid-connected to islanded mode. The most common disorder is transients, voltage sags and swells, over-voltage and under-voltage as well as under-current and over-current fault. To overcome these protection issues in microgrid, various protection schemes are discuss [8]. The technique for PV restoration under island mode operation will increase the performance of microgrid during grid loss condition. The uses of demand response algorithm give an advantage for microgrid to deliver the optimal energy generate by PV to the load.

1.2. Problem Statement

Today's electric grid was designed to operate as a vertical structure consisting of generation, transmission, and distribution and supported with controls and devices to maintain reliability, stability, and efficiency. However, system operator are now facing new challenges including the penetration of renewable energy resources in the legacy system, rapid technological change, and different types of market players and end users. The next iteration, the microgrid, will be equipped with communication support scheme and real-time measurement techniques to enhance resiliency and forecasting as well as to protect against internal and external threats.

Technical challenges associated with the operation and controls of microgrid are immense. Ensuring stable operation during network disturbance, maintaining stability and power quality in the islanding mode of operation requires the development of sophisticated control strategies for microgrid inverter in order to provide stable frequency and voltage in the presence of arbitrarily varying loads.

The main problem is once the network disturbance, how to make the microgrid disconnect itself from the main grid and operate in islanded mode using PV source without battery storage. As the battery is too expensive and short lifespan, this project develops the protection scheme for PV-connected microgrid without battery as storage.

This project used a grid-tie inverter as a conversion to convert DC voltage from PV module to AC voltage supply. To operate this grid-tie inverter, it needs a reference in frequency and voltage. The use of Pure Sine Wave (PSW) inverter is to provide a reference to the grid-tie inverter. This project can prevent the wastage of energy during the high irradiation of sun that can handle some critical load. Therefore, to make the microgrid more efficient and safe, the development of PV restoration and protection scheme for PV-connected microgrid is needed to overcome this problem.

1.3. Objectives

The main project objective is to propose strategies for development of protection scheme for PV-connected microgrid. To achieve this goal, the aims of the research project were identified as:

1. Develop a control strategy for restoration of PV-connected microgrid during grid loss condition.
2. Develop load control algorithm to maintain supply and demand.

1.4. Scope

This project focuses on designing a PV restoration under off grid condition for PV-connected microgrid. The execution of this project includes the development of friendly interface. The protection scheme is designed to be installed on low voltage distribution system that comprise of microgrid system with a PV source.

The main function of this protection scheme is to isolate the microgrid from the main grid due to the grid failure. Then the microgrid will operate in islanded mode and give power supply to the critical load. The PSW inverter with battery storage is used to give a reference in voltage and frequency to the grid-tie inverter that connected from the PV module and will powered the critical load.

This protection scheme should disconnect the microgrid itself from the main grid due to occurrence of abnormal condition and to be shifted to islanded mode. In order to prevent the reverse power flow to the PSW inverter, a load control algorithm is used to protect the PSW inverter from reverse current. This protection scheme is very useful to critical appliances that need a power without a long interruption. This protection scheme also prevents the wastage of power that supplied from PV module especially when the PV captures high irradiation of solar energy that will produce high power to handle the critical load. Figure 1.1 shows the hourly PV generation profile.

Based on Figure 1.1, the PV starts to produce electricity at 9.00 a.m. Then, PV will increase the generation of electricity. The maximum irradiance occurs at 12.00 p.m. to 2.00 p.m. After this period, the irradiance will decrease until 6.00 p.m. However, the peak demand of PV are depends on weather [9].

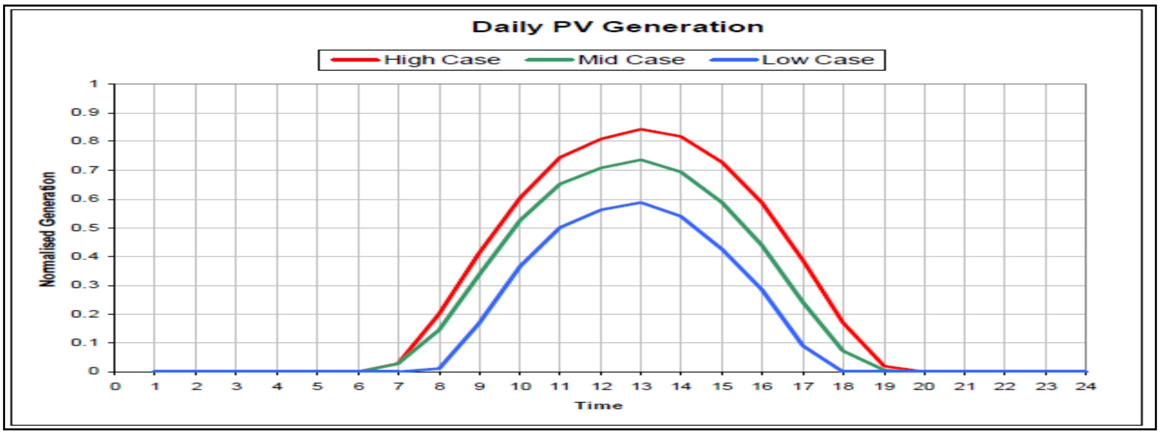

Figure 1.1: PV generation curve

This proposed project gives many benefits to consumer especially which consume high energy during the PV capture high irradiation of solar energy. The target audience to propose this project is the commercial building. The commercial building is referring to office building, government building, industrial building, retail, shopping mall and etc. During this period, their energy consumption is high because of lighting, cooling system and other appliances. Figure 1.2 shows the pattern average of daily energy consumption for office building [10].

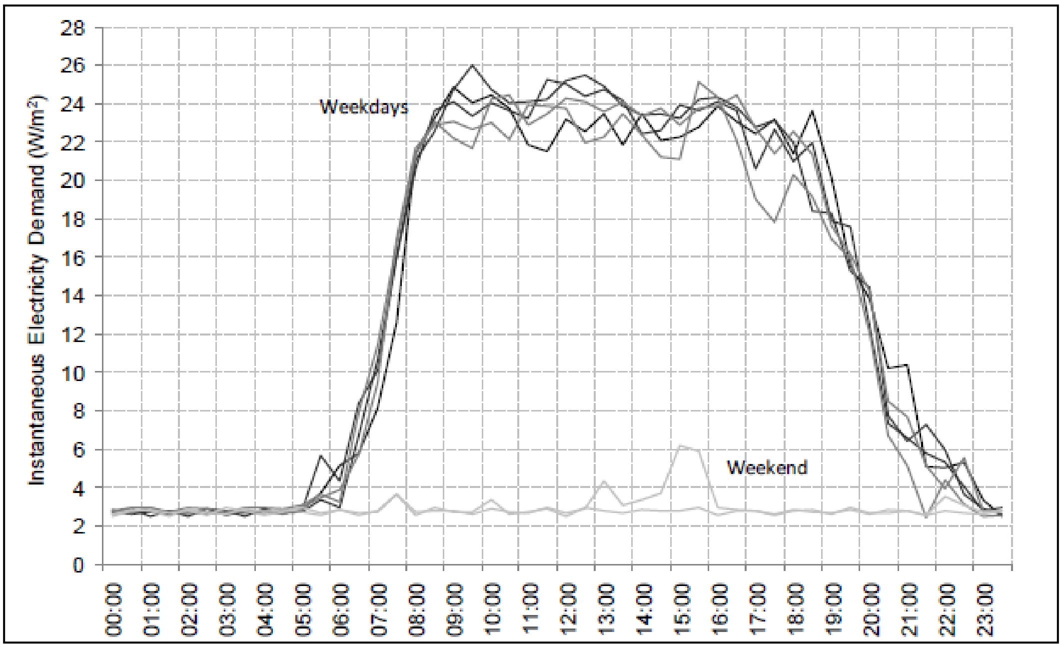

Figure 1.2: Average energy consumption

Figure 1.2 shows analysis of energy consumption for lighting and small power in office building. This daily energy consumption pattern is considered same as any office building [10]. Based on Figure 1.2, it shows the load is start from 7.00 a.m. until 9.00 p.m. The loads start to increase at 8.00 a.m. and reach maximum demand at 10.00 a.m. Then, load will decrease after 6.00 p.m. By comparing Figure 1.1 and Figure 1.2, the patterns are exactly same and can be combined. Therefore, the implementation of PV connected microgrid will give benefits to office building and other commercial building that has same pattern energy consumption.

CHAPTER 2

LITERATURE REVIEW

2.1. Basic Topologies

2.1.1. Microgrid

Microgrid means a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and that connects and disconnects from such grid to enable it to operate in both grid-connected or island mode [11].

A microgrid is a localized grouping of electricity generation, energy storage, and loads that normally operate connected to a traditional centralized grid. This single point of common coupling with the microgrid can be disconnected. The microgrid can then function autonomously. Generation and loads in microgrid are usually interconnected at low voltage. From the point of view of the grid operator, a connected microgrid can be controlled as if it were one entity.

Microgrid generation resources can include fuel cells, wind, solar or other renewable energy resources. Figure 2.1 shows typical microgrid architecture. The microgrid can operate either in grid-connected or island mode. In grid-connected mode, the goal of power management can be achieved by controlling the frequency and voltage profile of the inverter by referring to the main grid frequency and voltage profile. In the islanded mode, the microgrid operates in stand-alone using the DG.

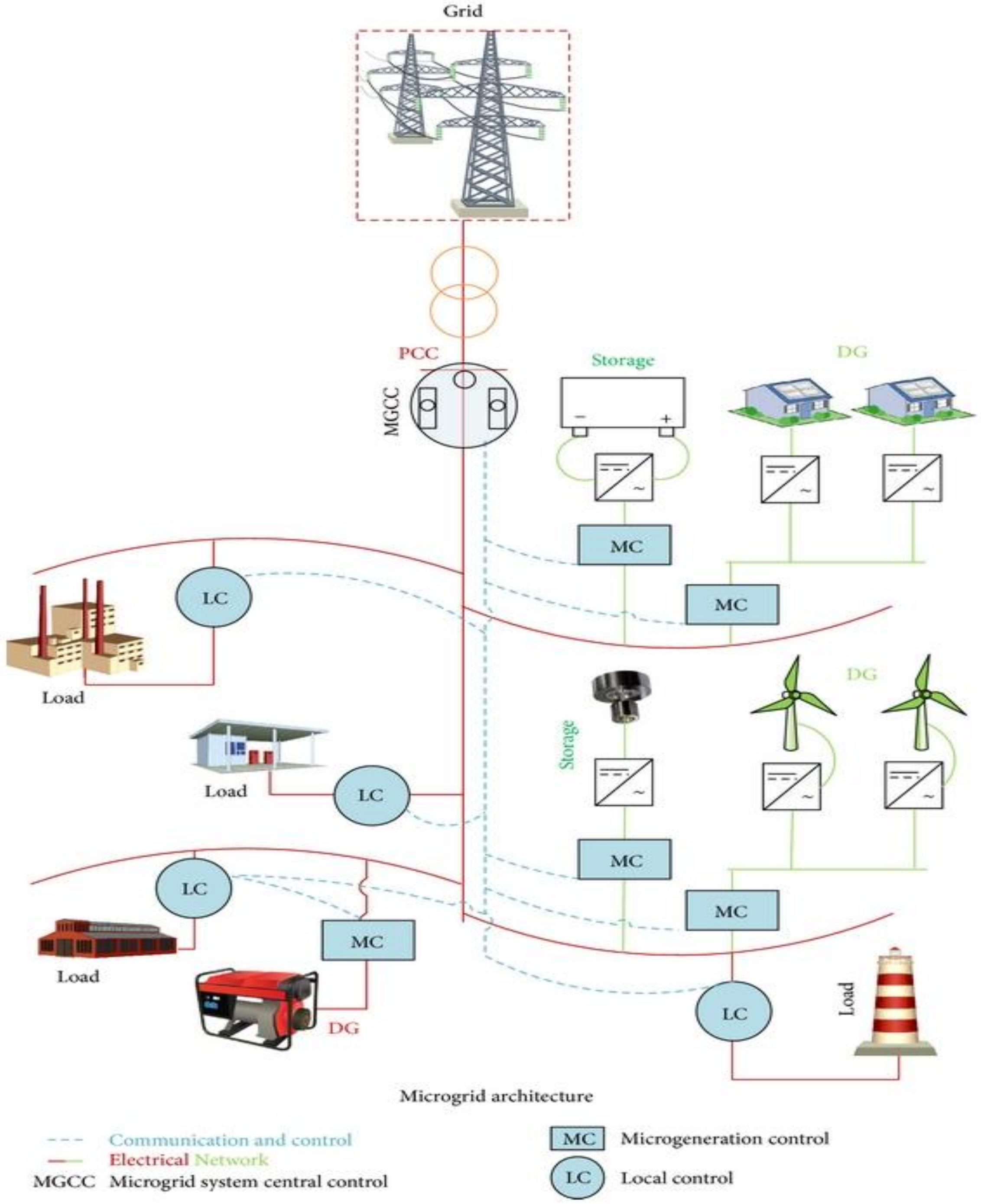

Figure 2.1: A simple microgrid structure

2.1.2. PV Generation

The conversion efficiency of a solar cell is defined as the cell-produced power (W) divided by the input light irradiance (W/m^2) in standard test conditions (STC: 1000 W/m^2 and 25°C) and the surface area of the solar cell (m^2). Thus, conversion efficiency depends on many factors such as irradiance levels and temperature. Manufacture processes usually lead to differences in electrical parameters, even within the same type of cells. In view of the foregoing, only the experimental measurement of the I-V and P-V curves allows to get to know with precision the electrical parameters of a photovoltaic cell, module and array. This measure provides very relevant information for the design, installation, and maintenance of PV systems. The experimental measurement of the I-V characteristic is of great importance, as it can be considered as a quality and performance certificate of every PV generator.

The main points of the I-V and P-V curve characteristics are the short-circuit current (I_{sc}) or the maximum current at zero voltage, and the open-circuit voltage (V_{oc}) or the maximum voltage at zero current. For each point in the I-V curve, the product of the current and voltage represents the output power for that operating condition. The MPP produced by the generator is reached at a point on the characteristic where the product I-V is maximum. Hence, P_{mp}=I_{sc} x V_{oc}. Figure 2.2 shows the relation of I-V curve and P-V curve.

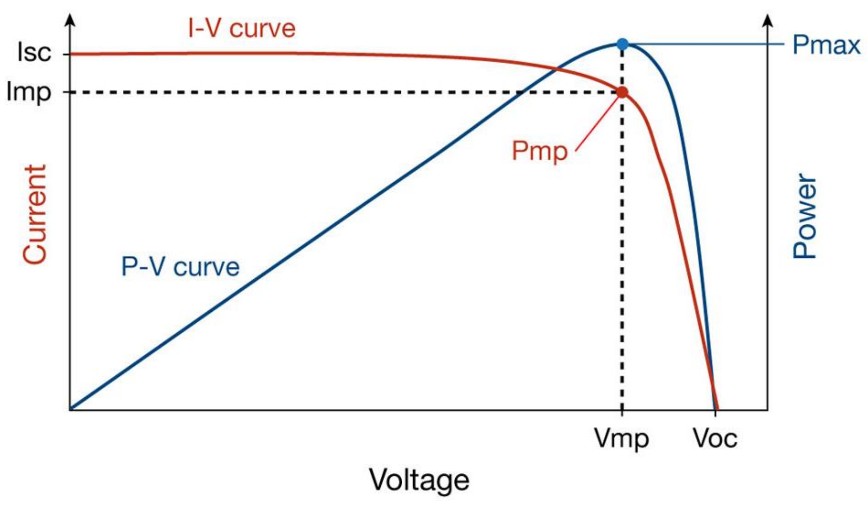

Figure 2.2: Normal I-V curve and P-V curve

2.1.3. Load Flow Studies in a Simple Radial System

Every distribution network operator has an obligation to supply its customers at a voltage within specified limits. This requirement often determines the design and capital cost of the distribution circuits and so, over the years, techniques have been developed to make the maximum use of distribution circuits to supply customers within the required voltages.

The connection of distributed generator will change the power flows in the distribution network hence the voltage profile. In grid connected mode, the voltage received by all customers will be regulated under specified limits. During minimum load, the voltage will increased below the maximum allowed. The most onerous case is likely to be when the customer load on the network is at minimum and the output of the distributed generator must flow back to the source.

For lightly loaded distribution network the approximate voltage rise (ΔV) caused by a generator exporting real and reactive power is given by Equation (1):

$$\Delta V = \frac{PR + XQ}{V} \tag{1}$$

Where:-

P = Active Power output of the generator

Q = Reactive power output of the generator

R = Resistance of the circuit

X = Inductive reactance of the circuit

V = Nominal voltage of the circuit

2.2. Review of Previous Related Works

A microgrid is formed when an electrical region capable of autonomous operation is islanded from the remainder of the grid. Formation of a microgrid due to an islanding process can be due to disturbances, such as a fault and its subsequent switching incidents or due to pre-plan switching events. Current utility practices do not permit autonomous microgrid operation. This requirement is imposed to address safety concerns and to comply with the existing control constraints of distribution system.

2.2.1. Protection Issues in Microgrid

For the protection issues, P.Anil Kumar, J.Shankar and Y. Nagaraju were discussed the protection issues in the International Journal of Applied Control, Electrical and Electronics Engineering (IJACEEE). The title of this paper is “Protection Issues in Microgrid”. This paper discuss on the various protection scheme depends on the various protection issues. In microgrid application, the traditional power system protection strategies cannot be used. The integration of DG in microgrid system poses several technical problems in the operation of system protection. There is a various protection issues arises such as change in fault current level of network, possibility of sympathetic tripping, reduction in reach of distance relays, loss of relay coordination and unintentional islanding [12]. This paper also present the key of protection issues in microgrid which are:

i. Modification in fault current level
ii. Device discrimination
iii. Reduction in reach of impedance relays
iv. Reverse power flow
v. Sympathetic tripping
vi. Islanding
vii. Single phase connection
viii. Selectivity.