# LOAD FLOW MODELLING FOR NET METERING APPLICATION IN A COMMERCIAL NETWORK

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# LOAD FLOW MODELLING FOR NET METERING APPLICATION IN A COMMERCIAL NETWORK

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**DECLARATION**

I declare that this thesis entitled "LOAD FLOW MODELLING FOR NET METERING APPLICATION IN A COMMERCIAL NETWORK is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 

Name : YUSUF BIN ABDULLAH

Date : 5 JULY 2021

**APPROVAL**

I hereby declare that I have checked this thesis entitled "LOAD FLOW FOR NET METERING APPLICATION IN A COMMERCIAL NETWORK" and in my opinion, this thesis fulfills the partial requirement to be awarded the degree of Bachelor of Electrical Engineering with Honours.

Signature : 

Supervisor Name : KYAIRUL AZMI BIN BAHARIN

Date : 5 JULY 2021

**DEDICATIONS**

To my beloved mother and father, Zaleha Binti Abdullah and Abdullah Bin Radimin.

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## ABSTRACT

This study was conducted to examine the load flow modelling for net metering application using CIGRE benchmark. This system is programmed using the software PyCharm and coding based on Pandapower open source. Net metering is an initiative of the government to reduce electrical bills. CIGRE, founded in Paris, France in 1921, is a global society dedicated to the collaborative creation and exchange of power system expertise. Thousands of professionals including some of the world's finest specialists, are part of the community. CIGRE community provide different technical viewpoints and experience from all around the world. In this project, the benchmarking system by CIGRE is used to simulate the low-voltage network (commercial). Net metering is applied in the system where the solar photovoltaic panels (PV) are installed at the bus of the network. Different connection of solar panel in the bus system and suitable percentage solar penetration that may results in different magnitude of phase voltage, reactive power and active power with complex coding of Pandapower. The simulation of the network is to develop and simulate the load flow of a commercial network using Pandapower, an open-source tool, study the impact of GCPV systems on a commercial network's voltage profile and impact of GCPV systems in a commercial network under the Net Energy Metering intiative. The percentage of solar penetration varies for different cases. The changes of each magnitude are shown in the results and the capabillities of net metering application based on CIGRE benchmark also show clear result. Moreover, the software Python is used to ease the calculation method for load flow such as Newton-Rhapson.

## *ABSTRAK*

Kajian ini dilakukan untuk mengkaji pemodelan aliran beban untuk aplikasi meteran bersih menggunakan penanda aras CIGRE. Sistem ini diprogramkan menggunakan perisian PyCharm dan pengkodan berdasarkan sumber terbuka Pandapower. Pengukuran bersih adalah inisiatif kerajaan untuk mengurangkan bil elektrik. CIGRE, yang ditubuhkan di Paris, Perancis pada tahun 1921, adalah sebuah masyarakat global yang berdedikasi untuk membuat kolaborasi dan pertukaran kepakaran sistem kuasa. Ribuan profesional termasuk beberapa pakar terbaik di dunia, adalah sebahagian daripada komuniti. Komuniti CIGRE memberikan sudut pandang dan pengalaman teknikal yang berbeza dari seluruh dunia. Dalam projek ini, sistem penanda aras oleh CIGRE digunakan untuk mensimulasikan rangkaian voltan rendah (komersial). Meteran bersih diterapkan dalam sistem di mana panel fotovoltaik solar (PV) dipasang di bus rangkaian. Sambungan panel suria yang berbeza dalam sistem bas dan peratusan penembusan solar yang sesuai yang boleh menghasilkan magnitud voltan fasa, daya reaktif dan daya aktif yang berbeza dengan pengkodan Pandapower yang kompleks. Simulasi rangkaian adalah untuk mengembangkan dan mensimulasikan aliran beban jaringan komersial menggunakan Pandapower, alat sumber terbuka, mempelajari dampak sistem GCPV pada profil voltan jaringan komersial dan kesan sistem GCPV dalam jaringan komersial di bawah Jaringan Intiatif Meteran Tenaga. Peratusan penembusan solar berbeza untuk kes yang berbeza. Perubahan setiap magnitud ditunjukkan dalam hasil dan kemampuan aplikasi pemeteran bersih berdasarkan penanda aras CIGRE juga menunjukkan hasil yang jelas. Lebih-lebih lagi, perisian Python digunakan untuk memudahkan kaedah pengiraan aliran beban seperti Newton-Rhapson..

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| PV | - | Photovoltaic |
| TNB | - | Tenaga Nasional Berhad |
| NEM | - | Net Metering |
| IEE | - | Institute of Electrical and Electronic Engineers |
| SEDA | - | Sustainable Energy Development Authority Malaysia |
| UTeM | - | Universiti Teknikal Malaysia Melaka |
| FKE | - | Fakulti Kejuruteraan Elektrik |
| kWh | - | Kilowatt per hour |
| FYP | - | Final Year Project |
| NR | - | Newton Raphson |
| RPF | - | Reverse power flow |
| CIGRE | - | Council on Large Electric Systems |
| GCPV | - | Grid-Connected Photovoltaics System |

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

In this era of modernization, electrical energy is very important as this energy is the main source for train to operate, traffic lights giving signals to driver, and provide lights to user. However, the usage of electricity must be paid according to their bills provided by Tenaga Nasional Berhad (TNB). TNB is Peninsular Malaysia's largest electricity provider company which supplies electricity to customers in every state in Malaysia. Malaysia's Sustainable Energy Development Authority (SEDA) is a national government agency set up under the 2011 Sustainable Energy Development Authority Act [Act 726]. SEDA's key function is to oversee and administer the operation of the feed-in tariff scheme mandated by the Renewable Energy Act 2011 [Act 725], and YB Tuan Lukanisman Awang Sauni is the current Chairman of the Authority.



Net metering (NEM) is one of their initiatives to use renewable energy to produce electricity. This principle is applied by the use of solar photovoltaic panels to turn solar energy into electricity. The current billing method is using the one-directional meter where electricity used is sent directly to the grid. However, NEM is a billing method using bi-directional meter where the electricity produce can be consume by the user and the excess energy (kWh) are exported to the grid and will be offset (or also called one-on-one offset) from the present bill provided by TNB. NEM will help consumer to cut the cost of electrical bills and consumer must be a registered TNB customer to apply the NEM. Figure 1.0 shows the basic flow of energy from the solar energy and converted into electrical energy. In terms of weather and climate changes, Malaysia is an Asian state which located in the north of the equator which experiences hot, humid and rain throughout the year and can

achieve to almost 40 degree of Celsius during sunny days. The weather in Malaysia is suitable to use the technology of solar panels and can bring a lot of advantages to the user of net metering system. Figure 1.1 shows the flow of basic net metering system.

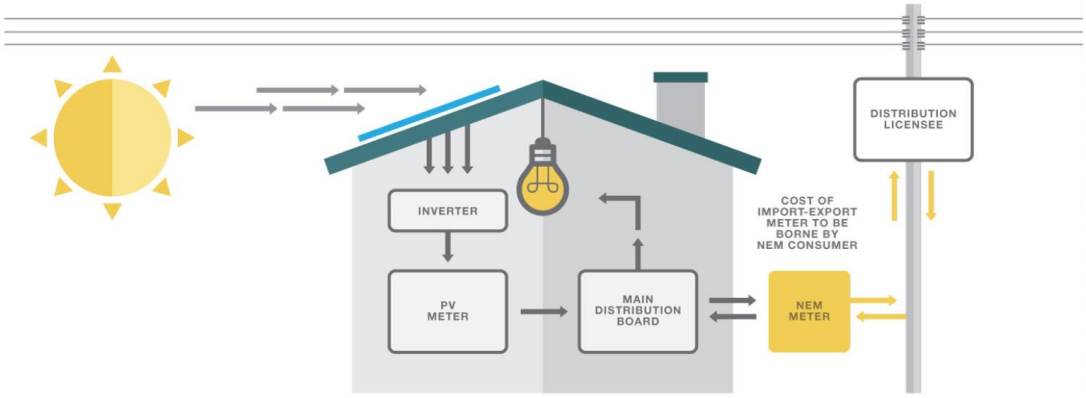


Figure 1.1 Net metering system flow

## 1.2 Problem Statement

This would provide ample electricity for rising consumers, as well as to minimize the environmental footprint, to reach the pace of electrical power generation. The new power grid systems should be flexible and all solar panels should be adequately connected to ensure that net metering is used to optimize performance. Different connection of solar panel in the bus system will results in different magnitude of phase voltage, reactive power and active power.

Net Metering policies are significant in enhancing the adoption of solar power. Proving the solar panels using the net metering are bringing an advantage to the user is one of the problems. The suitable percentage solar penetration is one of the problems to be solved which can determine the optimum value of electricity produced. Furthermore, the complexity of power flow to be calculated without using any power tools software.

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## 1.3 Objectives of the Study

As outlined below, this initiative has many goals:

i. To develop and simulate the load flow of a commercial network using Pandapower, an open-source tool.

ii. To study the impacts of GCPV systems in a commercial network's voltage profile.

iii. To study the impacts of GCPV systems in a commercial network's voltage profile under the Net Metering initiative.

## 1.4 Scope of Research

The purpose of this research is to design a network based on the CIGRE benchmark which focuses on the study of power flow while introducing net metering. The scope of this study in the investigation of the power flow in the production of renewable energies has been determined in order to achieve the objectives as follows:

i. The analysis of the power flow expressed in the net metering will require the penetration of renewable energy.



ii. The modeling of electrical power grid system in commercial area (Low Voltage 20/0.4 kV) with new connection of solar panels is based on the CIGRE benchmark.The output behavior of the power flow and reliability of the grid will be analyzed using Pandapower software.

iii. This project will only simulate the design and parameters of a three phase network but not a single phase network

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Net Metering

First of all, the use of solar panels is introduced by the United States of America, where clean energy such as solar and wind power is synchronized with the grid network. [1]. Net metering strategy requires utility consumers to generate power from renewable energy resources in order to fulfill any or all of their normal demand needs and, if generated in excess, then supply energy to the grid [2], [3] . This means the solar energy that is not used in the building will be sent to the grid and the payment for the excess energy is a must and this statement is supported with the statement from an article which is net-metering is a system whereby energy may be transmitted to an electrical grid at the same cost as that prescribed by the delivery providers to whom the user is paid [1].

This paper also agree on the same concept which is net metering is an energy program that encourages utility users to reduce any or more of their consumption of electricity using PV-based self-produced electricity [4], [5]. In Tamil Nadu, India, study has shown that net metering enables power producers to sell surplus electricity to the grid. [6]. In summary, net metering requires consumers to receive grid credit if the PV panels accumulate surplus electrical electricity to be sent back to the grid. The PV panels are arranged in abundance and mounted in a rectangular or square frame and the quantity of panels is installed in compliance with customer specifications.

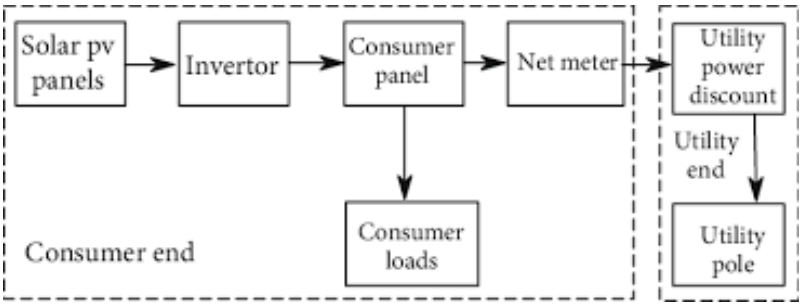


Figure 2.1 Block diagram of the net metering system

### 2.1.1 Gross Energy Metering and Net Energy Metering

Solar Metering is divided into two categories, one of which is Gross Energy Metering, where full PV array power is supplied to the electricity grid, the other is Net Energy Metering, where excess PV array power is supplied to the grid, and where there is a lack of PV array power, power can be taken from the electricity grid [7]. There is, however, a gap in economic value between Malaysia and other countries owing to the discrepancy in the price of the grid and the market price of each country. [7].

A paper concludes the value disparities for each self-consumed and exported energy because other or no consumer benefits are preferable to stop uncontrolled market shifts as the expense of the PV system decreases and the PV sector expands. [8]. This means that net metering system can be applied in a country that can come to an increment to their economic value and also can benefit the users of the net metering system. PV modeling plays a big role for obtaining the optimum value of electricity and this research state that the accurate prediction of the yield of the PV plant and the behavior of the PV plant under different conditions is very important for the size of the PV plant as well as for the optimization of the configuration of the PV plant components [9]. This report will only focus on the study of the net metering instead of gross energy metering.

## 2.2 Load Flow Modelling

Load flow or also known as power flow is a method use to analyze electrical power flow in a circuit or a system which contain a series of network, load and power generator. Power flow problem requires the calculation of voltages and the line flow [10]. In addition, the primary details derived from the load flow study has been investigated to include the magnitude and phase angle of the load bus voltage, the reactive power and voltage phase angle of the generator bus, the real and reactive power flow on the transmission line, and the power on the reference bus [11].

Power flow analysis is very important to gain these values from various buses and the new power injection into a system from the generated electricity of solar panel. Calculations are critical for this method because it is nonlinear and repetitive and to overcome this problem, method such as Newton-Raphson and Gauss-Seidel method is essential. However, the photovoltaic grid-connection primarily affects the distribution of power supply, power quality and dynamics of the grid. The efficiency of the solar power generation is spontaneously determined by the intensity of the sunlight. Therefore, the power flow calculation and the simulation did not adequately reflect the variables and results of the current scenario. [12].



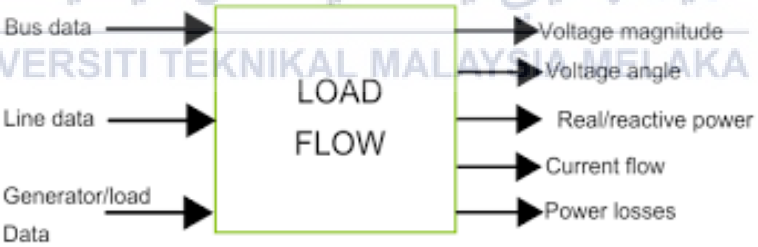


Figure 2.2 The basics flow of power flow analysis.

### 2.2.1 Type of Buses

A bus is a node where a line or a number of lines are joined and may also involve several elements in a power grid, such as loads and generators. Each bus or node is associated with one of four quantities; voltage magnitude, voltage angle of phase, active or true power, and reactive power. Essentially, power system buses are classified into three groups called load bus (P-Q), generator bus (P-V) and slack bus or swing bus. The Load Bus is a bus where there are no associated generators. The generator bus is a bus with at least one generator attached to it, and eventually a slack bus where one randomly picked bus with a generator is an exception. Slack bus does not hold any load that has yet been assumed to be actual, so that losses can be considered during power transmission.

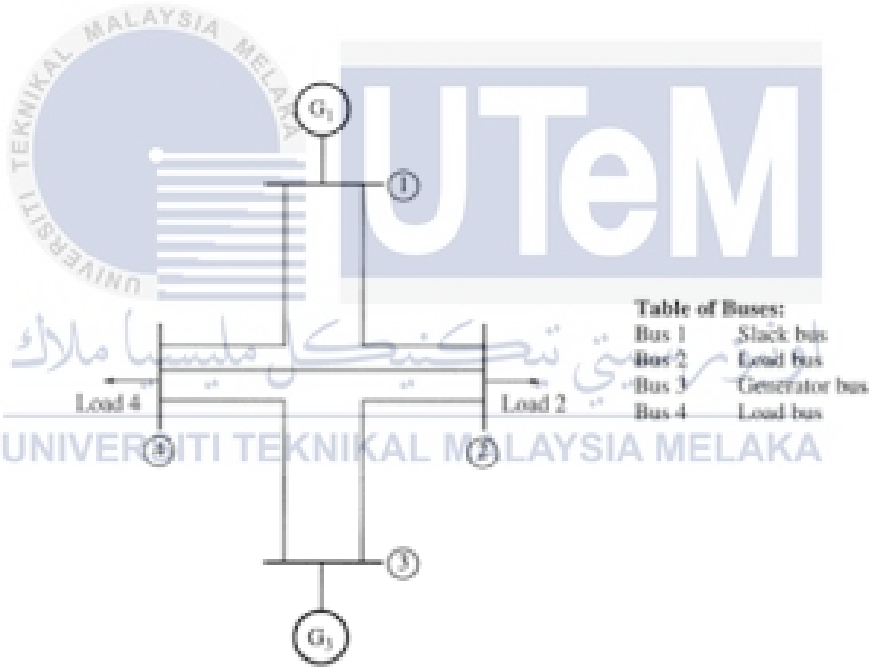




Figure 2.3 Connection of each type of bus.

### 2.2.2 Newton-Rahpson Method

The method of Newton (also known as the method of Newton-Raphson named after Isaac Newton and Joseph Raphson) is a method for sequentially adjudicating superior approximations to the extraction (or zeroes) of a real-value function [13]. Newton-Raphson, or Newton Method, is a powerful technique to solve numeric equations. The NR convergence trait can be reached within a few iterations in the most common networks and the NR process is commonly used in the engineering industry [14] . This technique was able to transcend the scale of the machine memory, which was poor at the time. This paper stated that the NR method is a preferred algorithm for non-linear equations solved on workstations or personal computer systems [15]. In this paper it proves that NR method is better than GS method when tested on five different standard of IEEE bus system and stated that Compared results indicate that the NR is the most accurate approach since it has the least number of iterations and converges faster [16]. There is a downside, however, and this journal claimed that a well-known drawback to this method is that the initial iteration value must be selected sufficiently close to a true solution in order to guarantee its convergence [17].

### 2.2.3 Gauss-Seidel Method



Besides Newton-Raphson and the Fast Decoupled Load Flow method, Gauss Seidel is one of the alternative methods for power system analysis. One of the easiest and most basic iterative approaches of power flow studies since the early days of digital power analysis is the benefits of using the Gauss-Seidel method. Thanks to its simplicity, the GS method can effectively be used for load flow tests in small power systems and for even large systems. A first approximate solution can be obtained using the GS technique, which can then be used as a "initial solution" for the Newton-Raphson process [18].

## 2.3 CIGRE Benchmark

Commercial low voltage load profiles from CIGRE report of are used in this project. This benchmark was created to investigate the impacts of linking renewable and distributed energy resources with electric power networks, as well as to conduct comprehensive evaluations of various resource-side topologies and control techniques [19]. Although the CIGRE Benchmark model is frequently used as a standard test model for research, it is typically essential to enhance in practical projects [20]. The employment of fuses as protection devices has been investigated for the protection of the LV CIGRE network against short circuit faults. Circuit breakers or fuses can be used to safeguard the various components of the CIGRE network (such as the transformer, WTG, lines, bus bars, battery inverters, and PV inverters) [21]. It should be noted that, for the CIGRE distribution network, exceeding the hosting capacity at each bus poses a danger of limitation not only for the bus system but also for the other components [22]. The CIGRE benchmark is being used by the researchers in the study to analyse the probability of constraint occurrence in a distribution network when the hosting capacity of renewable energy sources is not respected.

## 2.4 European Vs North America Low Voltage Network

Distribution network operators (DNOs) operate distribution networks supplying customers the electricity from the grid network (HV) that are normally divided into industrial, commercial, residential and other loads or customer categories, and voltage levels within the power of DNO are low voltages which are 230 V and 400 V and networks with a capacity of 11 kV, 22 kV for medium voltage networks [23]. The structure of North American infrastructure differs substantially from that of Europe, where three-phase LV networks are virtually nonexistent and the system is successfully carried out by three phase's four wire (3-phase and neutral) MV networks [24]. The study also concludes that the major advantage of the North American structure is that the load density supplied by each substation, as well as the capital cost of construction, are lower than in the European network. European systems are bigger and have more clients per transformer than North American versions. Most European transformers are three-phase and have capacities ranging

from 300 to 1000 kVA, making them significantly bigger than the normal 25- or 50-kVA single-phase ones used in North America [25].

## 2.5 Pandapower

In this moment of era, technology has been updating and helping developers overcome complex challenges and develop new concepts to improvise an existing structure that is now obsolete. Power system tools model the interactions between the energy grid and the consumers and generators who use the grid. [26]. Software may be broken into three groups, based on the method of creation: Free Software (FS), Open Source Software (OSS) and Proprietary Software [27]. Python is known as an FS, while Pandapower is an open source platform based on Python, a BSD licensed power system analysis tool developed to automate static and quasi-static analysis and optimize balanced power systems. An article reported that in accordance with IEC 609099, Pandapower provides power flow, optimum power flow, state estimation, topological graph searches, and short circuit calculations [28]. Pandapower helps to model grid system with various loads or other elements such as transmission line and transformer with a proper coding using Python included with Pandapower. Educational purposes are tally with Pandapower because it is an open source and does not require paying for the service.



Pandapower is based on a tabular data structure in which a table containing all parameters for a given element and a result table containing the basic results of the different measurement methods are defined for each type of element [29]. This paper also notes that Pandapower enables the storage of variables of some data type, so that electrical parameters are being stored along with status variables and meta-data, such as names or descriptions. The tables can be easily expanded and customized by adding new columns without losing the functionality of Pandapower. [29].