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INTEGRATED MODEL OF SOLAR PV INTERCONNECTION USING PSSE SOFTWARE

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Abstract:

Due to increase demand of renewable energy, the interest on the solar power plant has recently grown dramatically. However, when a huge generation of power was generating from the solar power plant to the grid interconnection, the system tends to create a stability problem since the generation is depend on varying of solar irradiance. A huge sudden drop of the irradiance will tend to interrupt the stability of the system. When there is large solar power is used it might be interrupting the stability of the PV plant. When there is system increase in penetration to the system the system may be loss its stability which can interrupt the system operation that cause by large penetration trough the PV system. This paper presents the development PV model from scratch until dynamic stability assessment in the PSSE software in order to study the stability of the generation of PV plant to the grid interconnection by developing 30 bus system in the software.

Keywords:

Stability, PSSE, Renewable Energy, PV Plant, Modelling

Introduction

Due to fluctuation of fossil fuel price and one of the cause of the environments pollution and greenhouse gas emission, as a result renewable energy has been chose such as wind and solar generation due to environment friendly, which will lead to reducing the utility bill, maintenance costs and environment friendly plus, the solar feed in tariffs are applicable, making solar

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farming easier than before. Nowadays, renewable energy sources become importance in power system and expected more than 20% of penetration in the future. Currently, solar power technology is developing very fast in the world, with a total installed grid-tied solar power capacity of 99.1 GW in 2017(Phap & Le, 2019), in which United State, China, Germany and Japan where the largest installed power capacity in the world. Since June 2011, Malaysia Renewable Energy (RE) Act 2011 was gazette with introduce Feed-in Tariff (FIT) scheme. A number of 1.6% collection scheme from public electricity bill as RE projects development supporting scheme, which encouraged by Sustainable Energy Development Authority (SEDA)(Tan et al., 2018). Many programs have been held in Malaysia which the large-scale solar photovoltaic plant (LSSPV) is one of the popular programs introduced by the public since April 2016 with a 1GW deployment goal.

There several PV scale type which is small scale which is generate 250Kw, medium scale generate 250kw to 1000kw, large scale generate 1000kw to 100Mw and very large scale which is up to 100Mw.Due to the high penetration of large scale solar power plan will effect many aspect to the distribution system which is power system stability as well as system reliability and also markedly change the voltage profile (Y. K. Wu et al., 2016) (Youssef et al., 2015) need to be well understood. Other expect that need to take is about the solar irradiance, temperature and tripping also can affect the operation of the power system(Bhatt & Affljulla, 2017).If the irradiance drops from 100% to 30% will cause trouble to the stability of the system, same goes to the temperature if the temperature of the panel increase it will reduce the efficiency of the panel, output current increases exponentially while its voltage output is decreased linearly will affect the stability of the system. Due to cloud that cover the solar farm cause voltage dip which will affect the stability due to high PV penetration. For the tripping or fault will cause drop in magnitude of the oscillation of frequency voltage profile when penetration, the oscillation may further increase with higher PV penetration and effect the stability in order to ensure short-term voltage stability even with a large installed PV volume, it is important to research the impact of dynamic behaviour of PV systems. and build counter-measures to control voltage instability phenomena such as by considering the importance of using (LVRT) to the system that will improve the stability of the PV grid system and many more ways. The effects of solar PV plants on the power grid are examined in this article(Remon et al. 2017)

To build the PV plant many aspects must be considered due to maintain the stability of the system and also to extract maximum power that will generated to the grid, if the is no precaution when develop the PV power plant may be result to less power can be produce or damage the grid system due to the PV power plant. Only a few PV plan in Malaysia and it has achieved in very large scale, in the future expect to develop very large scale of PV power plan which can contribute more than 1000Mw and currently Malaysia already installed almost 500MW solar power plant, the ministry of kettha target to develop about 2000MW solar power plant in the future in .This system study in the proposal will discussed to develop PV model by using PSSE software by develop bus system as a benchmark to develop solar power plant to study the integration of large scale PV plant into the traditional power system, where the simulation for the stability assessment consist of steady state analysis and dynamic analysis will be done.

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Literature Review

Power System Stability

Power system stability is the 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, which allows the restoration of forces between the elements of the system to be equal to or greater than the upsetting forces, in order to maintain a state of equilibrium of the power system(Prakash & Singh, 2016).In simple term is the ability of the electric machine or power system will regain its normal condition or previous condition is called steady state stability when been subjected to disturbance such as fault, tripping , loss of production and short circuit which will disrupt the balance of power and the change of the power flow. Power is generated by synchronous generator that operate synchronous with the rest of the system, when the generator is synchronized with the bus at the same frequency, voltage and phase sequence. Power system stability is categorized into steady state, transient and dynamic stability. If the system unstable it will result to increase angular separation of generator rotor or progressive decrease in bus voltage. An unstable system can lead to outage and shut down of the power system.

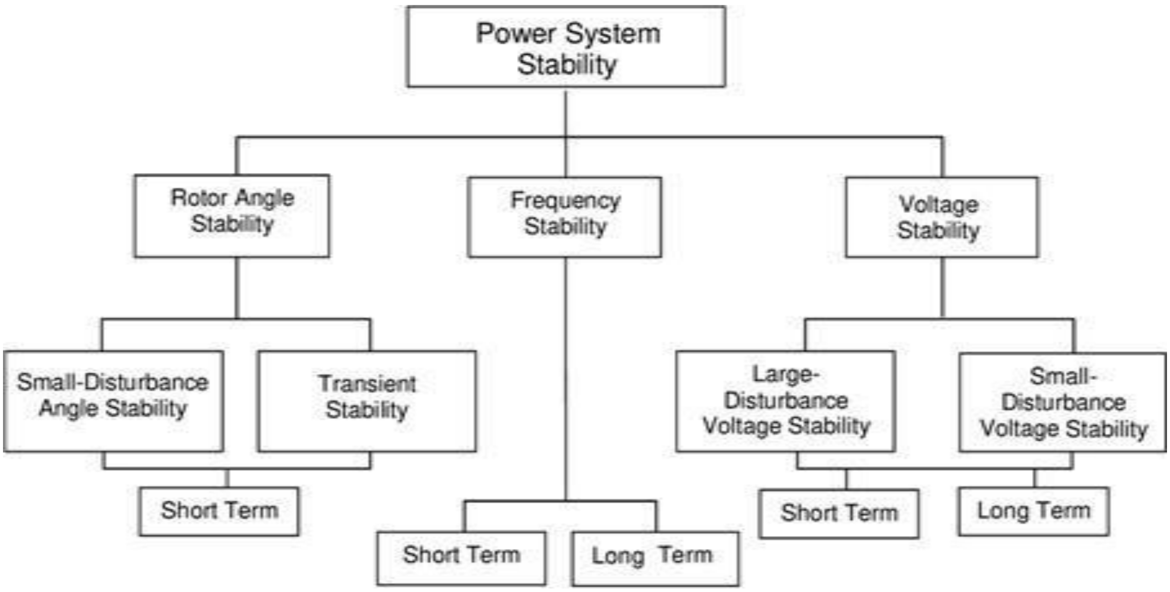

Figure 1: Classification of Power System Stability

PSSE Software

Since its introduction in 1976, the Power System Simulator for Engineering tool has become the most comprehensive, technically advanced, and widely used commercial program of its type. It is widely recognized as the most fully featured, time-tested and best performing commercial program available. PSSE is an integrated, interactive program for simulating, analysing, and optimizing power system performance. It provides the user with the most advanced and proven methods in many technical areas, including:

- Optimal Power Flow
- Power Flow
- Balanced or Unbalanced Fault Analysis

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- Dynamic Simulation
- Extended Term Dynamic Simulation
- Open Access and Pricing
- Transfer Limit Analysis
- Network Reduction

Power flow module is widely recognized as one of the most fully featured, time-tested and best performing commercial programs available for power systems analysis. Over 30 years of commercial use and user-suggested enhancements have made the PSS/E Power Flow base package comprehensively superior in analytical depth, modelling and user convenience and flexibility. This study will focus on the power flow and the way it behaves in normal conditions. At first it is necessary to be educated about the power plant, substation and its main elements such as buses, branches, generators, and transformers. Buses connect components (machines, loads, etc.) in the circuit to one another; it often referred as node in circuit analysis and includes the buses name, number, voltage in kV. Branches represent transmission lines and loads are the elements which consume power; loads in AC systems consume real and reactive power. While machine generate power and provide it for the system. These are the important components used to analyse the power flow study.

Grid Connected to PV System

Grid connected to PV system is where the generation of energy from sunlight through solar PV system which connected to the utility grid. The grid connected to PV system consist of solar panel, solar inverters, a power condition unit and grid connection equipment. Grid connected to PV system easier to install as they do not require battery system, for standalone PV power system operate with integrated battery solution where this system consist of battery itself.

Solar Photovoltaic

Solar photovoltaic is a technology where the sunlight is converted to direct current by help of semiconductor .When the panel is exposed to the irradiation electron are freed and form an electric current .A solar module ca be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential .PV cell that has been mounted and connected together is called PV module, multiple module which is mount to each other will form an array that can be adjust to generated the amount of power required .Unlike solar thermal technology, this PV technologies depend on the sunlight where when there is no sunlight no output power will be produce .Estimates show that there is 10,000x more solar energy coming to the Earth’s surface than global annual fossil fuel demand .Each module is rated by its DC output power under standard test condition(STC), typically rated from 100 to 320watts.PV cell is made up from various semiconductor material, the most common and famous that has been use in a long time is silicon which is about 90% of the world use silicon as PV technologies(IPCC, 2011), but several material has been tested and used to increase the efficiency of the sunlight such as mono-crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium .The efficiency of the solar PV technologies varies, between 6-18% at the moment

Steady State Stability

Steady state study defined as the capability of electric power system to maintain its condition when been interrupt by disturbance or to reach its very near to its initial condition when the

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disturbance is still present(Circuit Globe 2020), in the simple term it is important to ensure the stability of the system when being subjected by the disturbance .The power system remain its initial condition when been interrupt by small disturbance ,such as gradual in variation load(Study and Power 2020).Steady state stability is useful when come to putting into operation new element, planning and developing the power system, or concentrated on restricting the bus voltage to their nominal value. Due to high PV penetration can cause variation in bus voltage and magnitude to the transmission line. The main objective to performed in the system is to calculated the load flow of the transmission line, power frequency variation or voltage amplitude and phase angle. The study of the power system analysis must be analysed in order to determine the selection of the steady state limit, where the power system analysis included the determination of the stability limit and qualitative estimation of transient, checking of the power system in specific steady state.

Transient Stability

Transient stability involve when there is large disturbance has been subjected to the system where ability of the system to return its normal condition such as fault on the system , sudden outage or large load remove .Transient stability use in power system in order to identify the system stability when been subjected by major disturbance where the ability of the synchronous generator to return its normal condition and maintain its synchronous(Mohamad et al. 2011).The objective of the transient stability is where to observe whether the load angle return to its steady state after the disturbance has been cleared. The cause that can lead the effect of the transient are increase of the system voltage, uses of high-speed excitation system, use of high-speed breaker and reduction in system transfer reactance. The differences of transient stability and dynamic stability, where the dynamic stability is where ability of the power system to maintain its stability under continuous small disturbance, where the small disturbance occur due to random fluctuation in load.

Effect of Tripping Solar PV

In order to investigate the behaviour of the PV system, the effect of tripping the PV plant system can be observe by using PSSE software .In (Y.-K. Wu et al., 2013) (Emmanuel et al. 2012) the author investigate the PV system by tripping the PV system using different type of the penetration level to investigate the system stability where tripping the large PV plant in different penetration level that will affect the frequency of the system .The system will be stripped out in certain time to for the system back to normal condition and the frequency of the system will be observe from the graph that has been obtained in the PSSE software. In previous study in paper (Alquthami et al., 2010)"Study of Photovoltaic Integration Impact on System Stability Using Custom Model of PV Array Integrated with PSSE" the study has been done where for the 20% of penetration level, the frequency of the system goes down to 59.55 Hz which is below of the accepted frequency which is for the acceptable frequency of the system for the case was 59.7 Hz, where the frequency that has been obtained reach the UFLS which UFLS of the bus need to take action for the system to be back it's normal condition. For the bus frequency every time the PV generator is being trip the frequency will oscillate before back to its normal condition, therefore the higher the penetration level of the system the higher the magnitude of the oscillation.

Three Phase Fault

In power system three phase fault where the fault occurs one or more phase and ground or occur in between phase. In power system when the fault occur it will interrupt the system

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stability to operate. In this study the fault analysis will be done in order to identify the overflow of current in bus by the solar power generation, the analysis will be done by using PSSE software where the three-phase fault analysis will be done during steady state condition and the ability of the system to be its initial condition will be observed. Due to higher PV penetration level the system shows a different behaviour then the system with no PV when fault been applied(Kawabe and Tanaka 2015) .The generator that closest to the fault tend to having higher frequency oscillation following fault been cleared, same goes to voltage where the voltage oscillated down below 0.6pu until the fault has been cleared the system back to its normal condition, where the farthest generator from the fault that has been applied tend to having less oscillation than the near generator. In paper "Impact of Increase Penetration of Photovoltaic Generation on Power System" simulate three phase faults in the PSSE bus modelled to find out the behaviour of the PV system where the author finds out the that the frequency and voltage oscillation in the system with PV generation are well damp than the case with no PV where its poorly damp.

System Implementation

PSSE Assessment

This research study involves of developing and perform stability assessment on grid connected solar PV to Malaysia standard PV grid. The study will be performed in PSSE software where the bus system will be developed and be investigated to determine the largest possibility of the system when connected to solar PV to maintaining its stability. In this study the steady state analysis and dynamic stability will be performed, the PV size will be developed in the PPSE software and the stability assessment will be test on the PV model that has been developed. In this study is to identify the maximum possible PV power that could be injected to the system, the possible output of the PV plant is about more than 250M watt were considered in this study. In the PSSE software where the renewable generator will be developed which is PV generator bus will be connected to the bus system that has been modelled. After the system has been developed the dynamic stability will be done in order to observe the behaviour of the PV generator due to the power generate by the PV generator.

PSSE Bus System Parameter

The PSSE PV model system for the first step is to determine how many buses that the user want to use, in this study has used about 30 bus for the PV model, the base KV of each bus has been determined which is 132KV and 33KV which is standard base KV has been used in the grid system if there's any branch that's connecting different KV buses, the bus need to place transformer between the interconnection of the bus. Voltage limit must be insert between 0.95 to 1.05 which is to prevent from the bus having under voltage. Or the type of bus there is non-gen bus and gen bus, which is the non-gen bus is for the bus where the bus did not connect to any generator while generator bus where the bus is connected to the generator.

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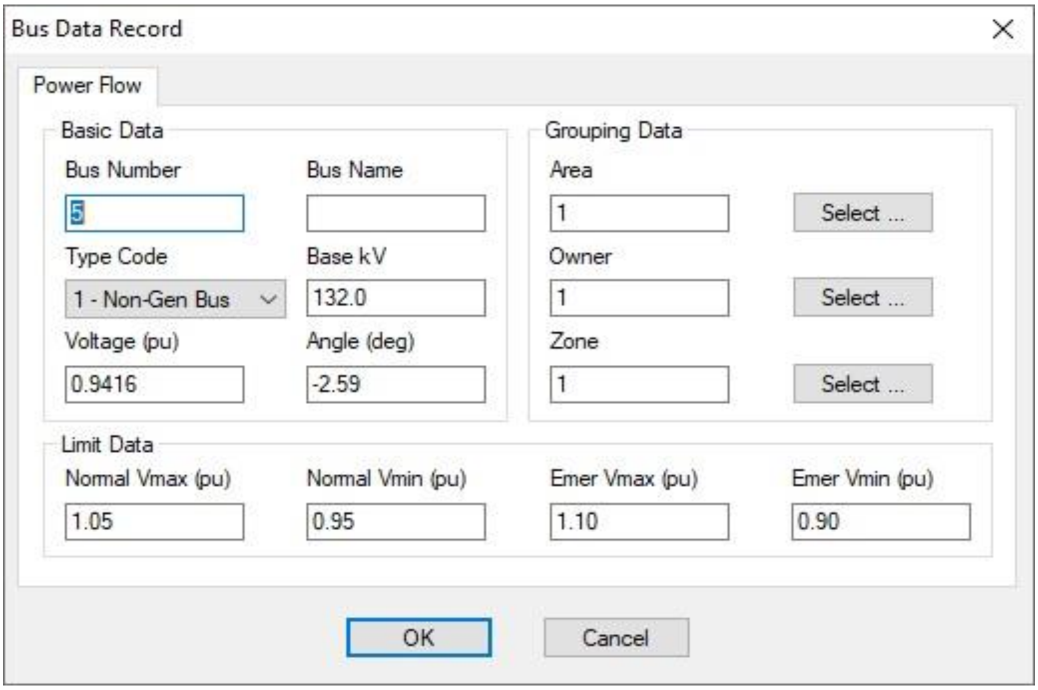

Figure 2: Bus Data Record

For the load the load can be placed at the bus based on user requirement, since load will not get affected in dynamic significantly. Load will be presenting factories, residential area in the simulation just makes sure the load is not placed in solar farm plant, or near to any conventional plant, just make sure it is connected to transmission line in order to get stable output in the end of the study. The active and reactive load can be determined according to the user to represent the factories of residential area.

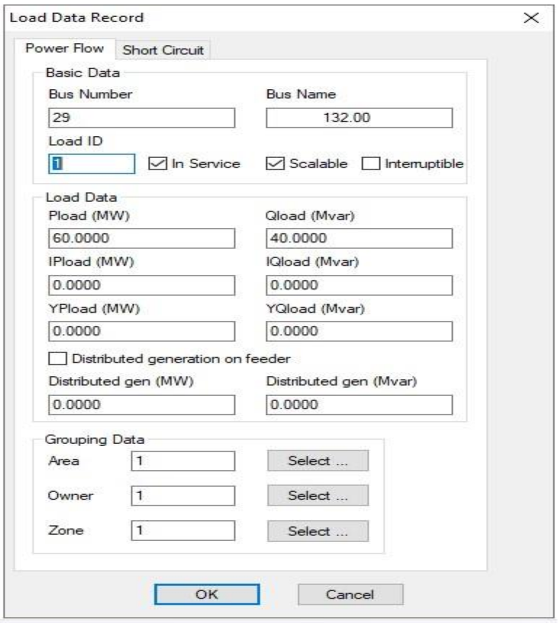

Figure 3: Load Data Record

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For the generator parameter the user can set the Pgen which is the generation of the generator will be generate power to supply to the bus system for this study each of the generator has been set different of Pgen which is above 250M watt watt and also the Pmax can be set which is the limit where the power PV generator can be produce, in the transient stability process the Pgen can be gradually increase in order to get possible output that can the PV generator can produce. Or the study there is 4 generator that has been set up which is 2 conventional generator and 2 PV generator where the wind data control mode is different where for the conventional generator is used not a wind machine while the PV generator been set to no.2+, -Q limit based on WPF which act as renewable generator.

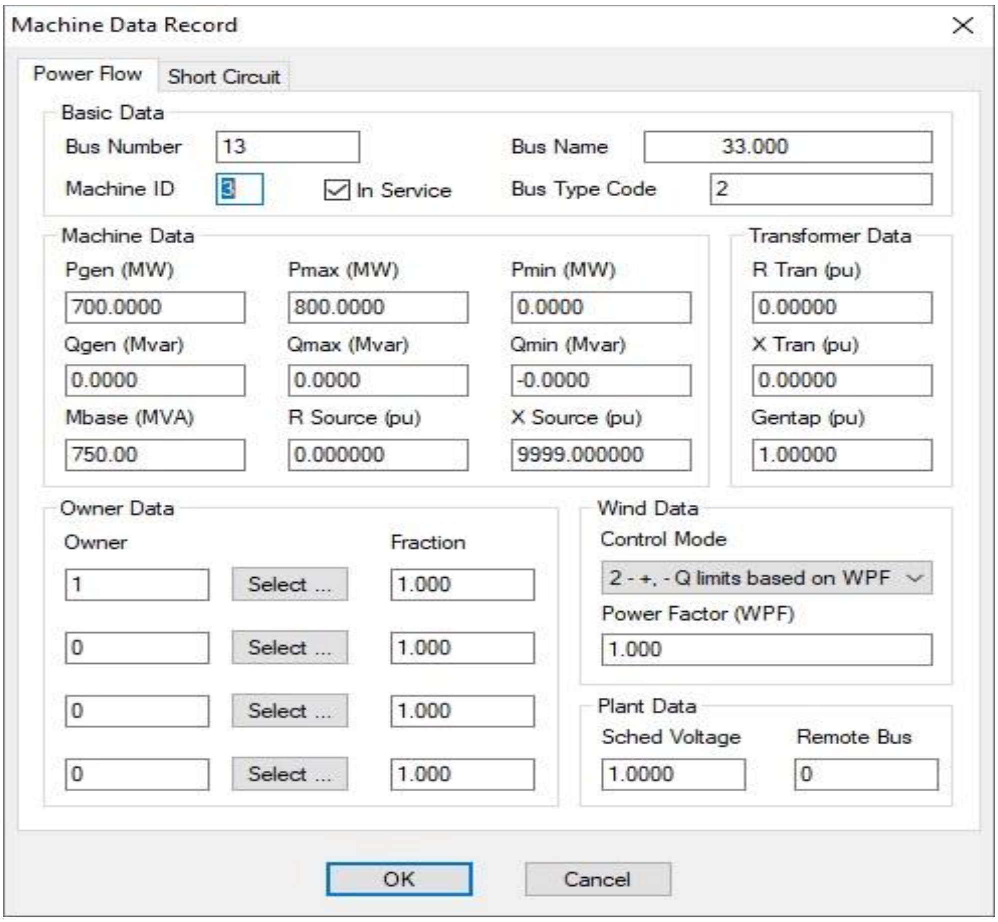

Figure 4: Machine Data Record

Steady State Performance Analysis

A steady state analysis is carried out on the same system describe before the present of high PV penetration levels. As the level of the PV generation increase more convention generator are displaced account for the generation and load balance within the system. The power Flow study or known as load- flow study is an important tool involving numerical analysis applied to the power system. PSSE software has become crucial part when come to design the power system and to run simulation for the stability of the system, In this section will discuss about PV model that has been develop by using 30 bus, 4 generator and 10 load as shown figure below where the generator for the PV at bus 1 and 13 generate more than 300M watt in the bus system.

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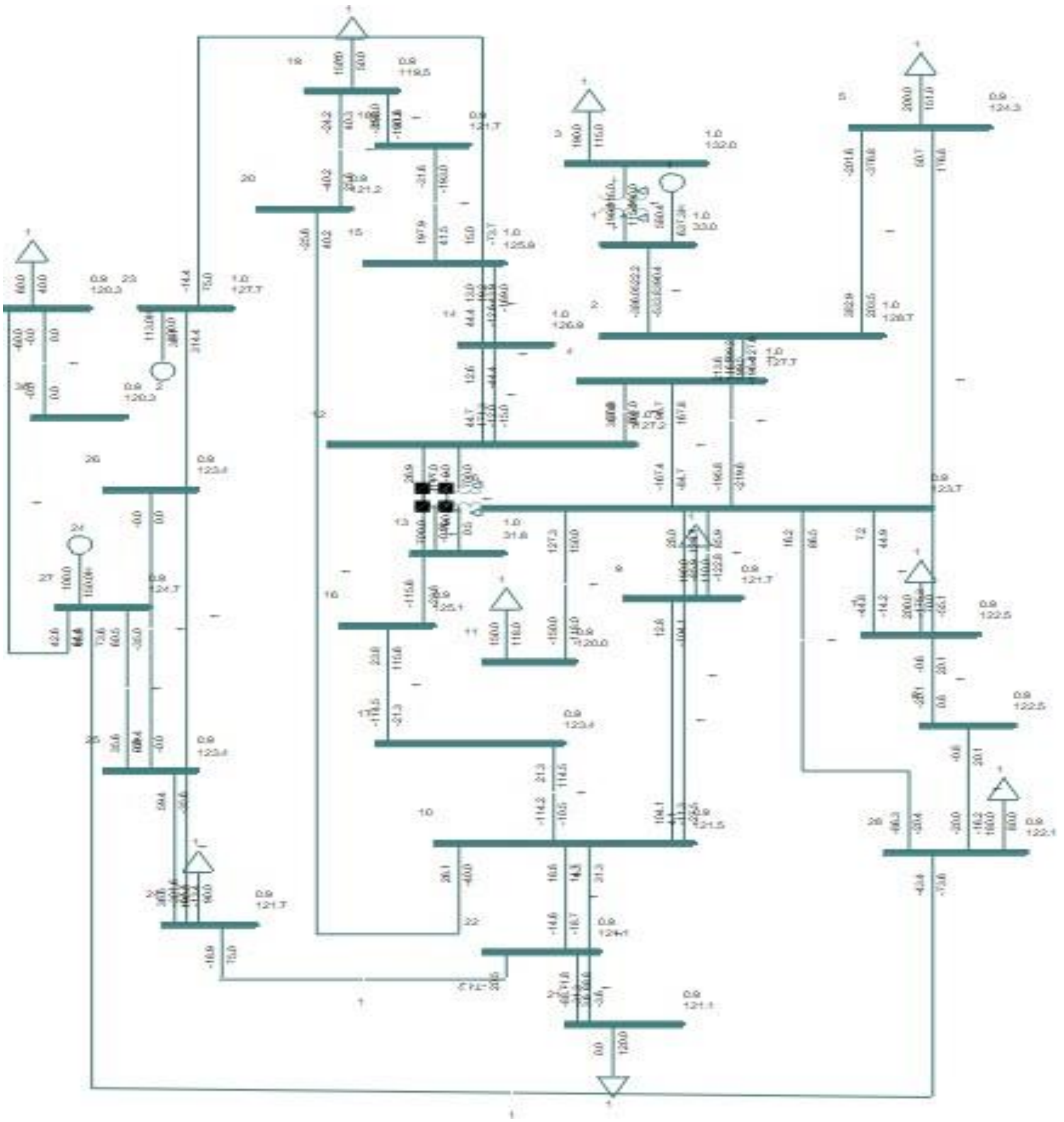

Figure 5: 30 Bus Modelled In PSSE

The parameter of the at the load, bus and generator such active, reactive, base KV , vmin and vmax has been set up. The solar PV plant has been developed to inject power to the 132KV grid. There is some data needed to be key in into the PSSE software such as the interconnection solar PV bus and step up transformer to be used to step up the output voltage from 33KV until reach to 132KV. The renewable energy modelling in PSSE is different from models with conventional generators, the solar bus is connected to the swing bus as the latter acts as a reference bus for the solar bus and has a phase angle of zero degree. A simple model of solar renewable energy modelling with a load bus is shown in figure below. From the modeled PV power system, the solar PV plant is modelled as direct current source injected to the grid. For the solar PV plan has been modelled as wind machine where for the control mode has been chosen and been set to no.2+,-Q limit based on WPF which act as renewable generator, where for the conventional generator has been set to no.0 not a wind machine .In the system there is

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2 renewable generator has been installed at bus1 and bus 13 , where the 2 conventional generator has been installed that has been installed at bus 27 and bus 23.

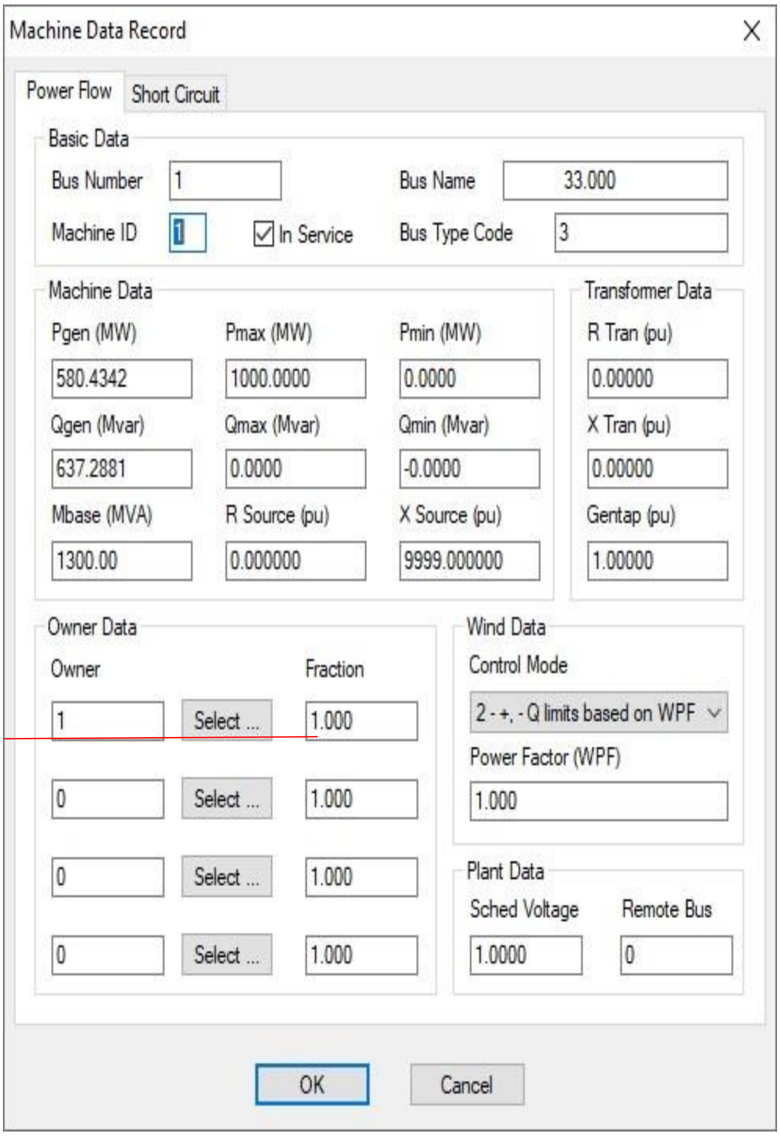

Figure 6: PV Generator Installed in The PV Model

In order to start the simulation for steady state analysis, there are some data which needed to be input in the PSSE software such as interconnection of the solar PV bus and transformer used to step up the output voltage up to 132KV.In this study there some information that is need to be considered which are:

1) The location of the solar PV located near to the substation
2) The solar PV was generated power from 33KV up to 132KV to be injected to the substation

The PV generator was generated power output power of 33KV and has been step up to 132KV in order to connect to the bus where the power is 132KV.The model of the step up from 33KV to 132KV transformer is shown on figure below.

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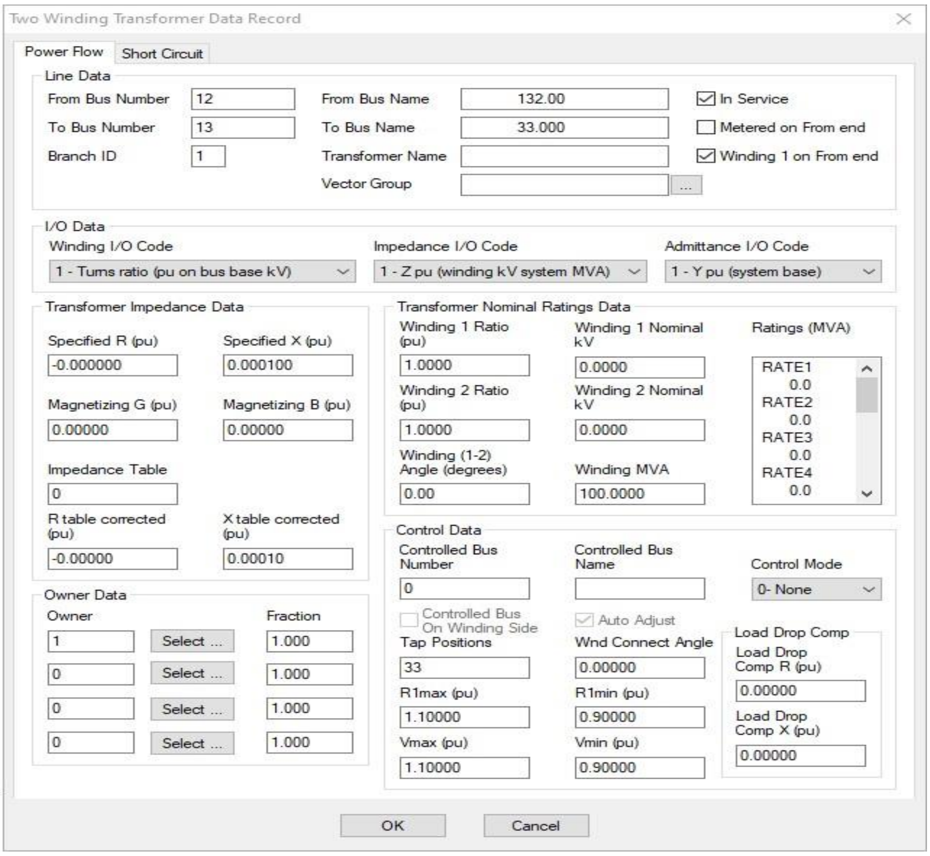

Figure 7: Model of Step-Up Transformer

Dynamic Performance Assessment

The PV dynamic model that has been modelled will be simulate in order to observe the performance of the PV plan that connected to the grid using power converter where the solar PV plan was modelled as a wind machine where both PV and wind model use the same technology where both use similar control and inverter technology use too inject power to the grid, where the solar PV plant was connected at bus 1 and bus 13 of the modelled system .The objective of the transient stability simulation of the modelled power system in the PSSE software where to analyses the stability of the system when being apply disturbance, tripping the PV plant to analyses the time for the system to back to normal condition where this simulation will be perform in the PSSE software in different PV penetration level .Where the disturbance can be category as tree falling on the line resulting automatic disconnection of the line by its protection system or unexpected fault occur at the transmission line .In power system the system can be clarified as stable when the rotational speed of motor and generator, and the substation voltage levels return its normal condition in a nick of time .The fault will be applied to the modelled system in the PSSE software and the clearing time will be analysed for the system will back to its normal condition and also the modelled PV system also will be analyse the effect level of irradiation to the behaviour of PV generator to the grid system.

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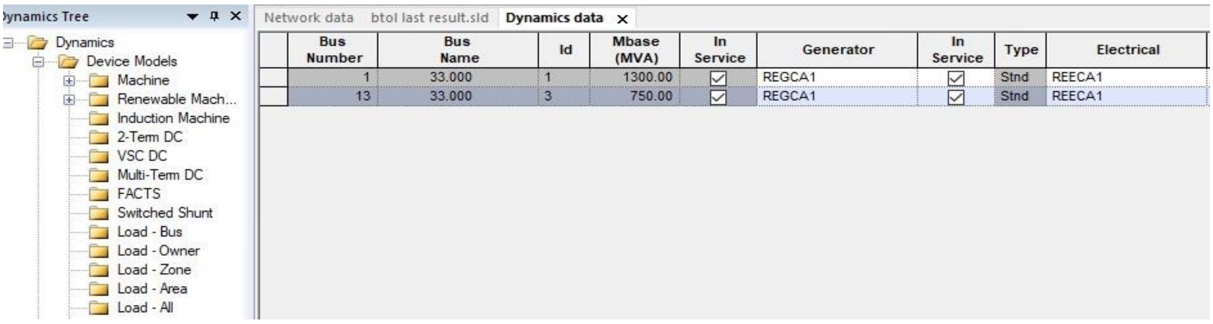

Figure 8: Dynamic Data for PV Generator

Figure above show the generator type for the PV generator which used REGCA type of generator which is almost similar to PVGU model in all respects. It incorporates a high bandwidth current regulator that injects real and reactive components of inverter current into the external network during the network solution in response to real and reactive current commands from electrical controller model.

Result

Three Phase Fault

In transient stability simulation fault has been applied at bus1where at t=1.1 where the PV generator located and the result has been obtain where the motor speed has been recorded where the conventional generator oscillated and back to its normal condition around 5 second while the PV generator did not oscillated where it's did not have rotary machine where the graph show plain reading as shown in figure 9. For the net power in figure 10 both PV generator oscillated in the same time where the PV generator of both PV generator down near to zero until the fault is clear, the power delivered by the solar PV plain attains the pre-fault level followed by clearance of fault, it is significant to notice that the PV output power response is not oscillatory in nature during the post fault period because of the absence of the rotating machine in the PV plant, in general the power response of the PV plant settles down faster than the conventional unit power response. In figure 11 for the frequency both PV generator oscillated and settle down at the same time to its normal condition around 3 second, the variation in the magnitude of these oscillations may lead to triggering of a series of load shedding relay. The above nature of frequency response demand significant trust in the area of protection coordination for the reliability of system operation .For the voltage pu both PV generator oscillated and back to its normal condition where the PV at bus 1 oscillated higher than PV at bus 13 where the PV at bus 1 has higher generation of power than PV at bus 13, the oscillation may further increase with higher PV penetration may affect the voltage stability of the system in the absence of optimum solution to protect the system from such unwanted condition as shown in figure 12.

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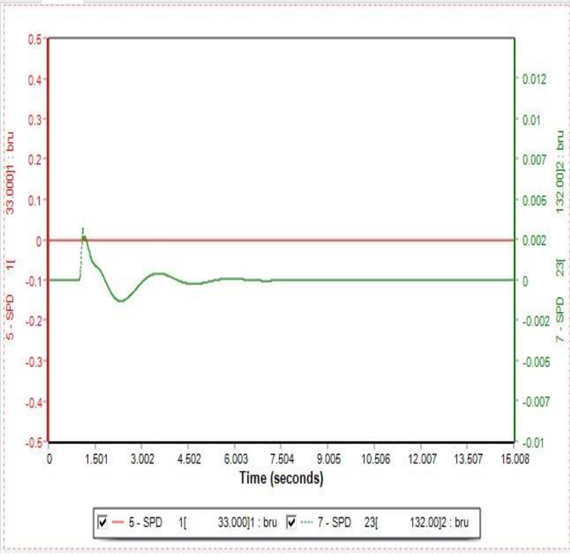

Figure 9: Motor Speed

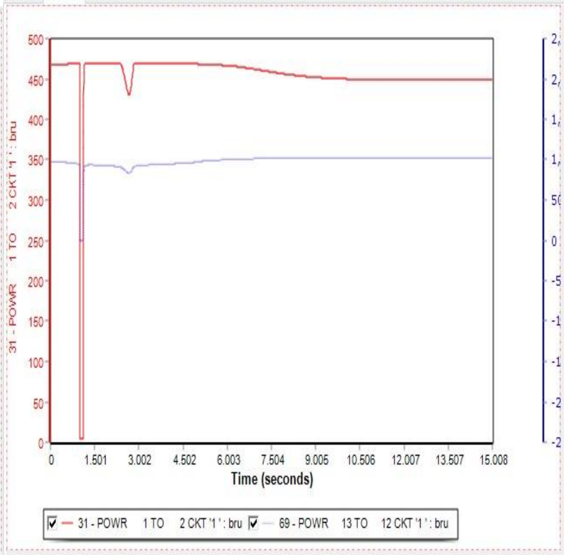

Figure 10: Power

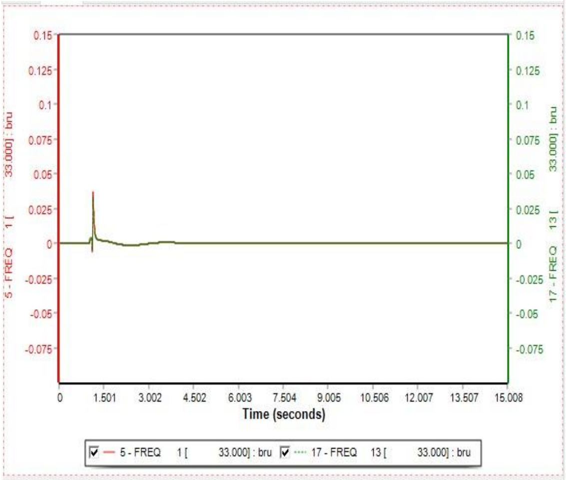

Figure 11: Frequency

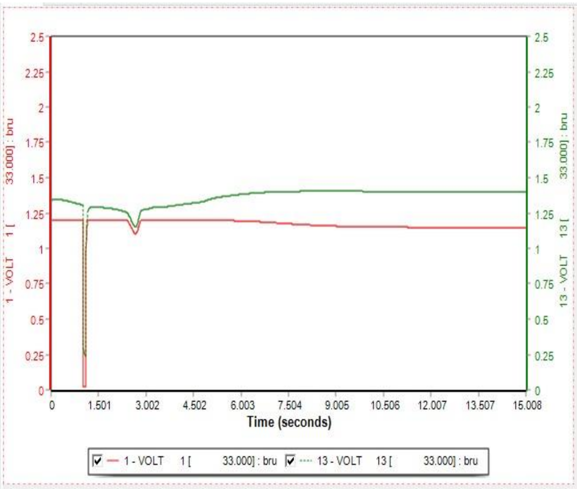

Figure 12: Voltage

Tripping PV Plant

When a large PV plant integrated to a bus with conventional generator is tripped at t=1.1 second the output from the PV plant become zero but the conventional generator connected to the same bus continues supplying power to the system. This tripping has a significant impact on power frequency, power and voltage on the bus .This simulation both PV plant at bus 1 and bus 13 was been stripped out at time 1.1s and the result has been observed .For the motor speed it's the same case with the applied fault where the PV generator at bus 1 did not oscillate where it's did not have rotary machine and its settle down faster than conventional generator while the conventional generator oscillated and back to its normal condition within t= 3 second as shown in figure 13. In figure 14 the power its different from the previous case where the PV generator at bus 13 oscillated higher than PV generator at bus1 where the PV generator at bus 13 oscillate longer than PV generator at bus 1.For the frequency both bus where both PV generator oscillated and back to its stability in 1.5 second after fault has been applied where both oscillated in almost the same oscillation, the PV plant is tripped at t=1.1 s and its revealed from the simulation result that the frequency deviation before tripping the solar PV plant is zero and so the operation is stable at operating at frequency 50Hz as shown where when its

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oscillate below level of under frequency load shading (UFLS), the UFLS of the bus will take action to keep the system stable in such case as shown in figure 15 before tripping the PV plant. For the voltage pu in figure 16 which is same case with the fault case where the PV at bus 1 oscillated higher than PV at bus 13 where the PV at bus 1 has higher generation power than PV at bus 13, where the magnitude and duration of the oscillation increase with the increase level of penetration.

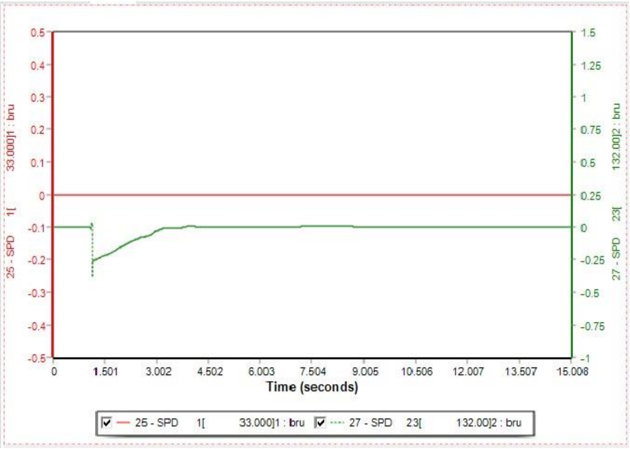

Figure 13: Motor Speed

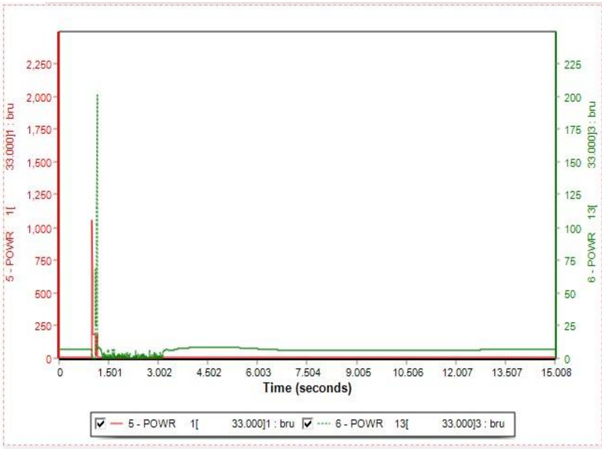

Figure 14: Power

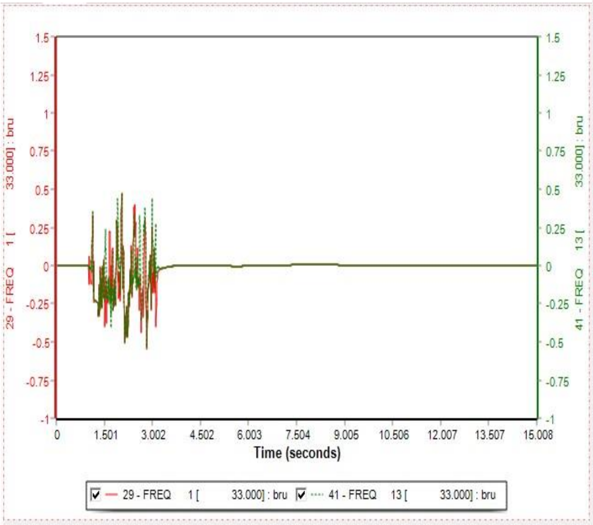

Figure 15: Frequency

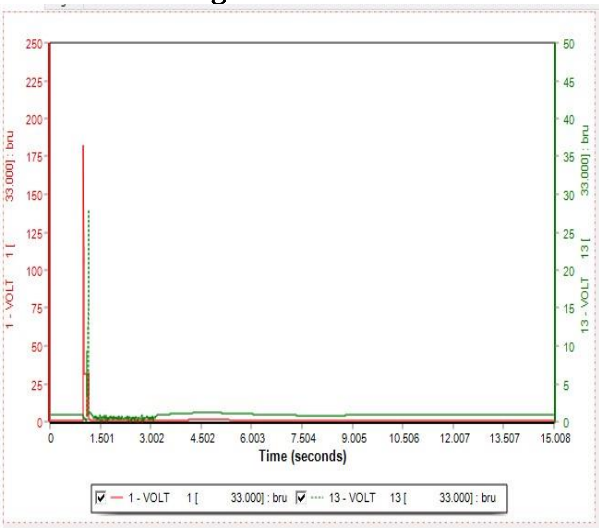

Figure 16: Voltage

Conclusion

This study can give a clear view for PV plant interconnection to the grid where the behavior of the PV plant system can be observed which is different from conventional generator , viewer can identify the effect of the PV penetration to the grid system, where the graph of the oscillation of different parameter can be observe through simulation in PSSE, the simulation are carried out to study the effect of sudden loss of PV plant, three phase fault at solar PV plant connected bus for different PV generation. The simulation result of voltage, power, frequency and motor speed revealed that the need of protection co-ordination at the distribution end as the frequency drops and change in voltage profile followed by PV integration may lead to severe concern for the stability as well as reliability of power system. The dynamic respond of active power delivered by the PV plant is faster than the conventional generator to achieve a

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stable state after post fault. The above behavior of integrated PV plant is more suitable to feed sudden power demand in the smart power system. Overall, from the simulation result its safe to say that the both PV plan stable due to fault and tripping assessment for high PV generation which is both generate more than 300M watt. In the future the study will be held from different of PV penetration level and the generation of the PV generator up to 1000M watt of generation in the future, the study also, will be held in different irradiance level to observe the stability of the PV system and the behavior of the PV system.

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