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Modeling and Simulation of Smart Grid System For Urban Electricity Distribution Network

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--*ABSTRACT*---

This research reviews and analyzes the impact of the application of smart grid systems on electrical systems compared with conventional networks in the form of models and simulations. The software used for electrical simulation is ETAP Power Station. The first stage of the simulation was by making Pontianak Single Line Diagram Modeling on three types of distribution networks namely High Voltage (150 KV), Medium Voltage (20 KV) and Low Voltage (380 V). The next step was to adjust the network equipment data and type of generator with the case studies reviewed. The second phase of the simulation was to interconnect the grid with a smart grid distributed generator in the form of a renewable energy generator. The simulation model was then analyzed by load flow analysis, short-circuit analysis, harmonic analysis and transient stability analysis. The results of the analysis indicated that there is no Over Voltage or Under Voltage on each Bus before and after the Distributed Smart Grid generator was connected. A reduction in power supply on the SESCO Swing Bus occurred because renewable energy helped in supplying power. In addition, there was an increase in the short-circuit current value of 76.163 KA to 76.371 KA in the Medium Voltage Bus due to the contribution of harmonic currents. The increase in value is classified as minor so that short-circuit current interference can be ignored. Furthermore, the contribution of harmonic component currents can be seen in the Medium Voltage Bus order 5, 7, 11, 13, 17, 19, 23 and 25. The largest harmonic component is order 11 and 13 with a magnitude of 0.17%. This value was very light, so it did not affect the form of the Bus Voltage Waveform. In transient stability analysis observed on the Medium Voltage Bus with a distributed generator interconnecting to the grid for 60 seconds, from 2 to 11 seconds, the system spiked. This shows the potential for a voltage imbalance. But because the voltage angle did not reach 90°, the transient stability in the system remained positive.

Keywords— *conventional grid, single line diagram, distributed generator, smart grid, bus*

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I. INTRODUCTION

Economic growth in Pontianak City continues and this must be supported by a sustainability of reliable electricity supply. With an average peak load of 300 MW and 400 MW of power available, there is still a surplus of 100 MW in the Equator Electricity Network Distribution System. There should be no more problems in the distribution of the electricity network in West Kalimantan, especially Pontianak. The conditions that occur are mainly temporary interruption of electricity, which is due to the electrical network system supplied by PT. PLN. [1].

The existing condition of electricity in Pontianak City is currently sourced from Diesel Power Plants (PLTD), Gas Power Plants (PLTG) and SESCO where all activities are managed by the government through PT. PLN. Each of these generators has been synchronized to supply the needs of PT. PLN and is connected to the interconnection network from each substation in the Pontianak City area through a conventional grid centralization system. [2].

However, this condition still leads to many adverse impacts on electricity distribution in Pontianak, such as many new areas that have not been reached by the electricity network. Moreover, it can also cause shrinkage of electricity, unstable electricity voltage and power outages for some areas. [1].

As we know, the smart grid is an electricity network based on digital technology that is used to supply electricity to consumers via two-way digital communication. This system allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce energy consumption and cost, and maximize the transparency and reliability of the energy supply chain. The smart grid was introduced with the aim of overcoming the weaknesses of conventional electrical grids by using smart net meters.

Implementation of new technologies of smart grid method can be applied to electrical systems in major cities in Indonesia. The sample is the electrical system in Pontianak City, which requires varied loads: from households, commercial sectors, and industrial sectors. There is an increase in the burden on the commercial and industrial sectors, the need for high reliability of the electric power system and the freedom to choose the type of electricity services. This shows, theoretically, that the application of a smart grid system in the form of simulation design and research analysis is needed to find solutions to the emerging problems. [3].

The simulation design and analysis of the research can be computerized using the Electrical Transient Analyzer Program (ETAP) Power Station application. ETAP Power Station allows a simulation design with a single line, or one-line, diagram. This program can be used to obtain calculations and analysis of electric power systems in large configurations. In addition, ETAP Power Station can also be used to simulate power flow in large systems with a large number of buses. [4].

The existence of a simulation design in the form of this program is intended to provide an overview of the electricity of Pontianak City in general and to review the impact of the implementation of the smart grid system in the electricity network in Pontianak City. The Distributed generator or grid-connected solar photovoltaic (PV) power poses a unique set of benefits and challenges. In this simulation the distributed solar applications consist of two kind PV systems (25 kilowatts [kW]) generate electricity for on-site consumption and interconnect with medium-voltage transformers on the electric utility system.

II. POWER FLOW CALCULATION AND SYSTEM MODELLING

A. Power Flow Calculation

Calculation of power flow is very important to be carried out in an electric power system. In calculating the power flow, it is necessary to know the parameters on each bus, such as: [5]

- **Real power** has P symbol in MW unit.
- **Reactive power** has a symbol Q in MVAR units.
- **The magnitude of the voltage** has a V symbol in a kV unit.
- **The voltage phase angle** has a δ symbol in a radian unit.

Based on known parameters, the rail / bus in an electric power system is classified into 3 types:

- **Swing rail (swing bus or slack bus)**

This rail is used as a reference where known parameters are voltage magnitude (| V |) and voltage phase angle (δ). The swing rail is required on the system because P and Q for each rail cannot be determined first. Generally, in the calculation of the power flow there is only one swing rail.

- **Load rail (P-Q bus)**

Parameters known in load rails are active power (P) and reactive power (Q). The active force and load reactive power are known from the estimated load, while the active power and reactive power of the generator (if any) have been determined. The pure load rail has a value of PG = 0 and QG = 0.

- **Control rail (P-V bus)**

The known parameters are active power (P) and voltage magnitude (|V|). P is determined and |V| maintained constant with reactive power injection. On this rail, the active force and reactive power load are known from the estimated load.

B. Newton-Raphson Method

Power flow equation is a non-linear algebraic equation, so it does not have an exact solution. The equation can be solved by the iteration method of several numerical methods. Convergence prices in the iteration process are determined by the precision index between 0.01 to 0.00001 or according to what is desired. The number of iterations is determined by the amount of the precision desired. The more precision desired the more iterations should be equated.

The Newton-Raphson method is basically an expanded and enhanced Gauss-Seidel method. Power flow calculations with the Newton-Raphson method are considered more effective for large system networks. [6] The Newton-Raphson method relies heavily on the initial value of the rail / bus voltage. Careful selection of initial rail / bus values is highly recommended. If the Newton-Raphson method fails to complete a long radial system or a system with a long transmission line, the fast-decoupled method can be used. The Newton-Raphson method formulates and completes the following power flow iterations:

$$\begin{pmatrix}\Delta P\\ \Delta Q\end{pmatrix}\begin{pmatrix}J_1 & J_2\\ J_3 & J_4\end{pmatrix}=\begin{pmatrix}\Delta\delta\\ \Delta V\end{pmatrix} \qquad (1)$$

Description:

- **ΔP** = real power deviation vectors between predetermined values and the calculated value on rails.
- **ΔQ** = reactive power divider vectors between predetermined values and calculated values on rails.
- **ΔV** = voltage vectors
- **Δδ** = tension angle of rail

- **J1 - J4** = Jacobian matrix

C. Simulation Modelling

The power flow on the grid which is the object of research is described in three buses with three different voltage levels, namely high voltage (HV) 150 KV, medium voltage (MV) 20 KV, and low voltage (LV) 380 V. SESCO Power Grid is connected with 150 KV Bus and operates as a Swing Bus, so that the load power shortages that the Generator cannot provide will be charged to the SESCO Power Grid. The Simulation Modeling is divided into two models, including:

- **Simulation with existing conditions on the grid.**

In this simulation, the power flow in the grid is passed through the Bus at a voltage to all loads with a large grid of input power (MVA) determined based on the actual conditions. Power suppliers use existing power plants on the system and Swing Bus by SESCO Power Grid. The transmission and generation channels on each Bus are properly distributed. The grid is assumed to be an interconnection system where the amount of power demand by the load can always be given and has a constant frequency of 50 Hz.

- **Simulation with the condition of distributed smart grid generator connected.**

This simulation is in accordance with the concept of smart grid connected to the existing grid. There is a power flow at 150 kV, 20 kV and 380 V, where the SESCO Power Grid is the main power source for the 150 kV network. Tests on each Bus were analyzed on a built single line diagram. The standard used is the ANSI standard with a 50 Hz system frequency.

D. Analysis of Simulation Models

Electricity analysis carried out in this study uses ETAP analysis features:

- Load Flow Analysis

Load flow analysis is an analysis of active power flow (P) and reactive power (Q) of a generating system (the sending side) through a transmission flow to the load (receiving side). Ideally, the power delivered will be the same as the power received at the load. But in reality, the power delivered on the sender's side is not the equal as the power received at the load side. This power flow analysis aims (1) to determine the characteristics of the power flow in the form of the influence of variations in transmission loads and losses on the power flow, and (2) to know the voltage drop (drop voltage) on the load side.

- Short Circuit Analysis

Short Circuit (Short Circuit) is an event where a voltage or conductor runs on an unintended media (resistor / load) so that the current flow is abnormal (very large). This is usually called short circuit current.
The existence of a short circuit causes more current, which is generally far greater than the rated current of the equipment, and a voltage drop in the electric power system; if the interference is not immediately eliminated, it can damage the equipment in the system. The amount of short circuit current that occurs is strongly influenced by the number of power plants entering the system, the location of the fault and the type of interference.

- Harmonics Analysis

Ideally, voltage and current waveforms that do not contain harmonics are waves that only have one basic frequency (0 Hz frequency for DC voltage and current, and 50/60 Hz frequency for AC voltage and current). The harmonic analysis module can simulate harmonic current and voltage sources, identify harmonic problems, reduce interference when the system is running, design and test filters, and report harmonic voltages and violations of current distortion limits.

- Transient Stability Analysis

Transient stability analysis is used to accurately test the dynamics of electric and transient system dynamics by simulating system disturbances and other specific events.

III. RESULTS AND ANALYSIS

A. Single Line Diagram of Pontianak Power System

Two types of configuration systems were analyzed. First when the Grid is connected by Distributed Generator, second after Grid is connected to Distributed Generator. The analysis simulated using ETAP included Load Flow Analysis, Short Circuit Analysis, Harmonics Analysis and Transient Stability Analysis.

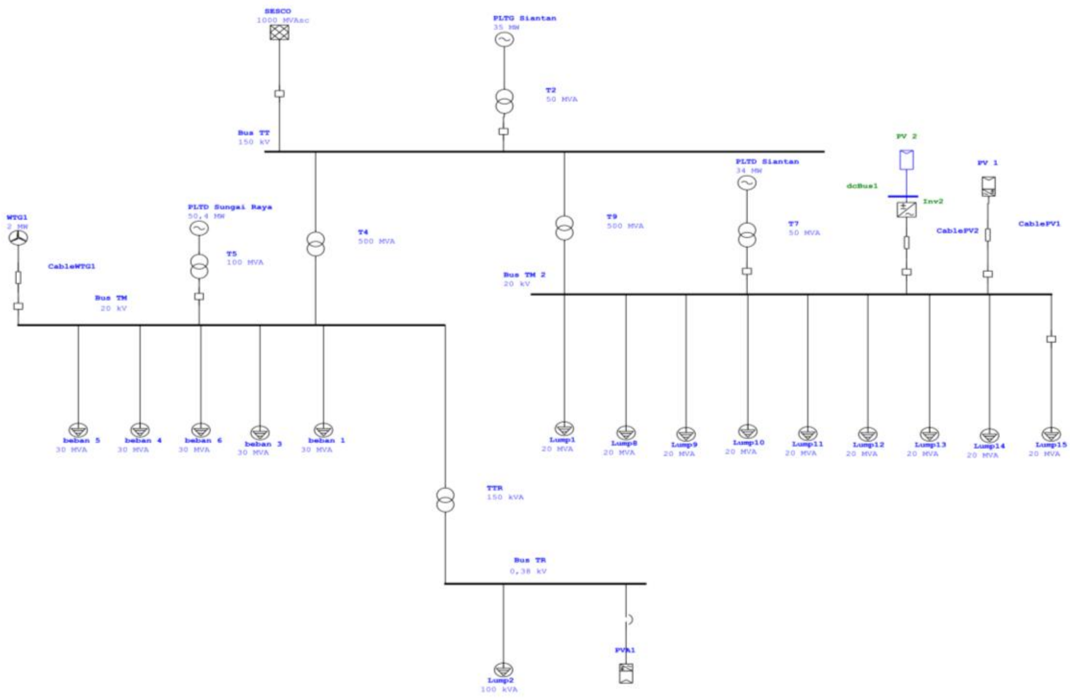

Fig. 1. Single Line diagram of Pontianak power system

The grid electrical system was described in three buses with three different voltage levels, namely high voltage (HV) 150 KV, medium voltage (MV) 20 KV, and low voltage (LV) 380 V. SESCO Power Grid is connected with 150 KV Bus and operates as a Swing Bus, so that the load power shortages that the Generator cannot provide will be charged to the SESCO Power Grid.

B. Single Line Diagram of Pontianak Power System

In conducting analytical testing, power flow in the grid transmission lines and generation as well as the respective Bus was channeled properly. The grid is assumed to be an interconnection system with normal synchronization, where the amount of power demand by the load can always be given and has a constant frequency of 50 Hz. There were two types of configuration including:

- Configuration Before connecting a Distributed Smart Grid Generator

LOAD FLOW REPORT

Bus	Voltage			Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
Bus TM	20.000	98.240	-1.1	0	0	126.610	78.466	Bus TT	-78.765	-66.676	3032.4	76.3	
								Bus12	-47.930	-11.844	1450.8	97.1	
								Bus TR	0.085	0.054	3.0	84.4	
Bus TM 2	20.000	97.744	-1.8	0	0	151.635	93.975	Bus13	-29.545	-10.318	924.3	94.4	
								Bus TT	-122.090	-83.657	4371.0	82.5	
Bus TR	0.380	95.741	-1.8	0	0	0.084	0.052	Bus TM	-0.084	-0.052	156.0	85.0	
* Bus TT	150.000	100.000	0.0	171.097	151.209	0	0	Bus4	-29.947	-7.614	118.9	96.9	
								Bus TM	78.827	69.434	404.3	75.0	
								Bus TM 2	122.217	89.388	582.8	80.7	
Bus4	6.300	102.340	4.2	30.000	10.000	0	0	Bus TT	30.000	10.000	2831.7	94.9	
Bus12	6.300	100.066	2.3	48.000	15.000	0	0	Bus TM	48.000	15.000	4605.6	95.4	
Bus13	6.300	99.800	-0.9	30.000	11.000	0	0	Bus TM 2	30.000	11.000	2934.1	93.9	

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)

\# Indicates a bus with a load mismatch of more than 0.1 MVA

Fig. 2. Results of Load Flow Analysis before connecting a Distributed Smart Grid Generator

Load Flow analysis shows that Over Voltage or Under Voltage does not occur on each Bus. The power load supplied by the SESCO Power Grid is 171 MW.

- Configuration After connecting a Distributed Smart Grid

LOAD FLOW REPORT

Bus	Voltage			Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
Bus TM	20.000	98.217	-1.1	0	0	126.599	78.459	Bus3	-1.800	0.968	60.1	-88.1	
								Bus TT	-76.953	-67.639	3011.3	75.1	
								Bus12	-47.930	-11.842	1451.1	97.1	
								Bus TR	0.084	0.054	2.9	84.0	
Bus TM2	20.000	97.769	-1.6	0	0	151.650	93.984	Bus1	-10.775	0.001	318.1	100.0	
								Bus2	-0.500	-0.375	18.5	80.0	
								Bus13	-29.545	-10.318	924.0	94.4	
								Bus TT	-110.830	-83.291	4093.5	79.9	
Bus TR	0.380	95.741	-1.7	0.001	0.000	0.084	0.052	Bus TM	-0.082	-0.052	154.1	84.6	
*Bus TT	150.000	100.000	0.0	158.007	151.062	0	0	Bus4	-29.947	-7.614	118.9	96.9	
								Bus TM	77.013	70.359	401.5	73.8	
								Bus TM2	110.941	88.317	545.8	78.2	
Bus1	20.000	97.784	-1.6	10.777	0.000	0	0	Bus TM2	10.777	0.000	318.1	100.0	
Bus2	20.000	97.770	-1.6	0.500	0.375	0	0	Bus TM2	0.500	0.375	18.5	80.0	
Bus3	20.000	98.220	-1.1	1.800	-0.969	0	0	Bus TM	1.800	-0.969	60.1	-88.1	
Bus4	6.300	102.340	4.2	30.000	10.000	0	0	Bus TT	30.000	10.000	2831.7	94.9	
Bus12	6.300	100.043	2.4	48.000	15.000	0	0	Bus TM	48.000	15.000	4606.7	95.4	
Bus13	6.300	99.824	-0.7	30.000	11.000	0	0	Bus TM2	30.000	11.000	2933.4	93.9	

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)

\# Indicates a bus with a load mismatch of more than0.1 MVA

Fig. 3. Results of Load Flow Analysis after connecting a Distributed Smart Grid Generator

After Distributed Generator Smart Grid is connected to the Grid, the amount of load power is partially supplied by Distributed Generator Smart Grid (Renewable Energy). The power provided by SESCO declined from the previous 171 MW to 158 MW. The bus voltage condition was also in normal conditions, there is no Over Voltage or Under Voltage condition.

C. Short Circuit Analysis

The existence of a short circuit can cause more current which is generally far greater than the rated current of the equipment, and a decrease in voltage on the electric power system, so if the interference is not immediately given, it can damage the equipment in the electrical system. The Short Circuit Current that will be simulated is when there is a 3 Phase Fault on a Medium Voltage Bus (MV) 2 where the Distributed Smart Grid PV1 and PV2 Generator are connected. To obtain a comparison of the short circuit current in each configuration, it is necessary to test each case. The results of the short circuit analysis can be seen in Figure 4 and Figure 5.

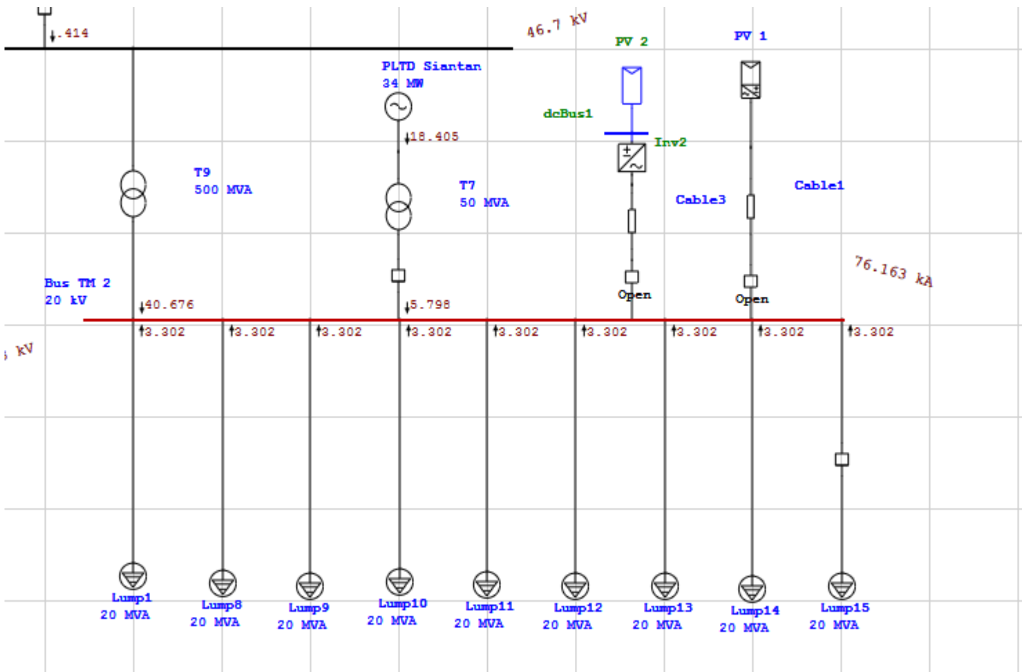

Fig. 4. Results of Short Circuit Analysis after connecting a Distributed Smart Grid Generator

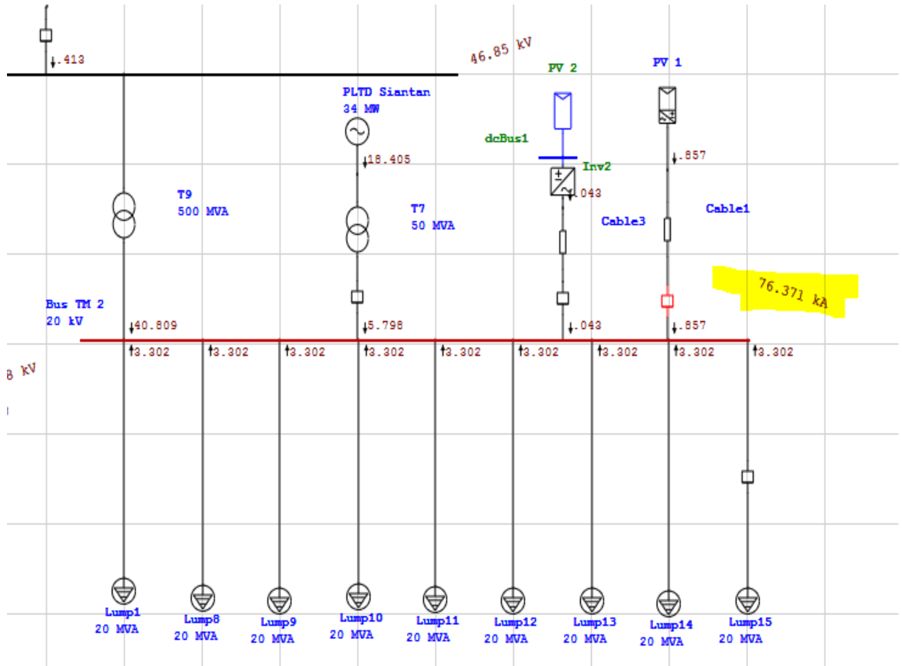

Fig. 5. Results of Short Circuit Analysis after connecting a Distributed Smart Grid Generator

After being connected to the Distributed Generator Smart Grid the value of Short Circuit Current rose from 76,163 KA to 76,371 KA. This short circuit increase occurred because of the harmonic current contribution from the inverter connected to the Distributed Smart Grid generator.

D. Harmonics Analysis

Harmonics analysis is used to find the n order of the Harmonics component that occurs due to the installation of DC current components on the Grid. In the first configuration (before connecting the Distributed Smart Grid Generator) there was no DC component connected to the network so there was no harmonic current. The harmonics analysis before connecting to the Distributed Smart Grid Generator carried out on the Medium Voltage Bus (MV) 2 is as follows:

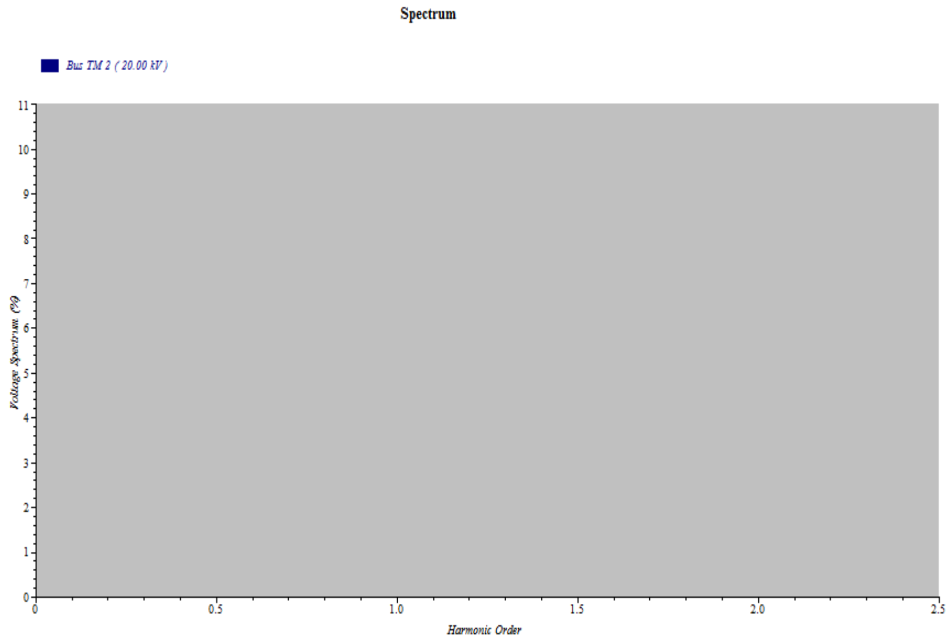

Fig. 6. Results of Harmonics Analysis before connecting a Distributed Smart Grid Generator

It can be explained that the MV2 bus forms a pure sinusoidal voltage, and there is no harmonic component in the harmonic frequency spectrum. Thus, it can be concluded that harmonic current and voltage sources are not identified, harmonic problems are not identified, there is no interference when the system is running, and there is no violation of the current and voltage distortion limits. Electronic components that are used as PhotoVoltaic (PV) 2 Inverter Controllers will cause Harmonic effects on MV2 Bus voltage. The controller used is 12 Pulse Type Current Source.

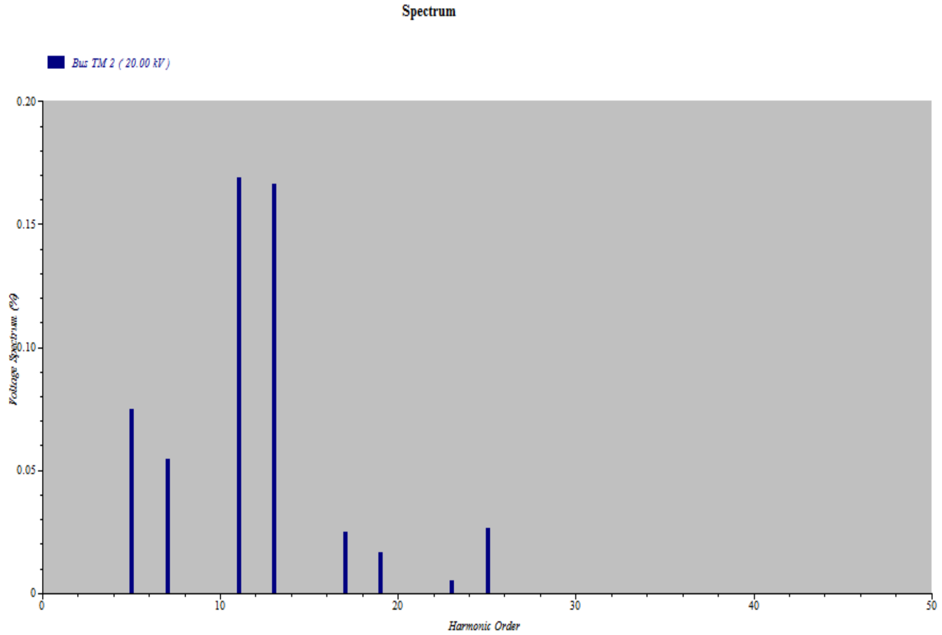

Fig. 7. Orders of Harmonics Analysis after connecting a Distributed Smart Grid Generator on MV2 Bus Voltage

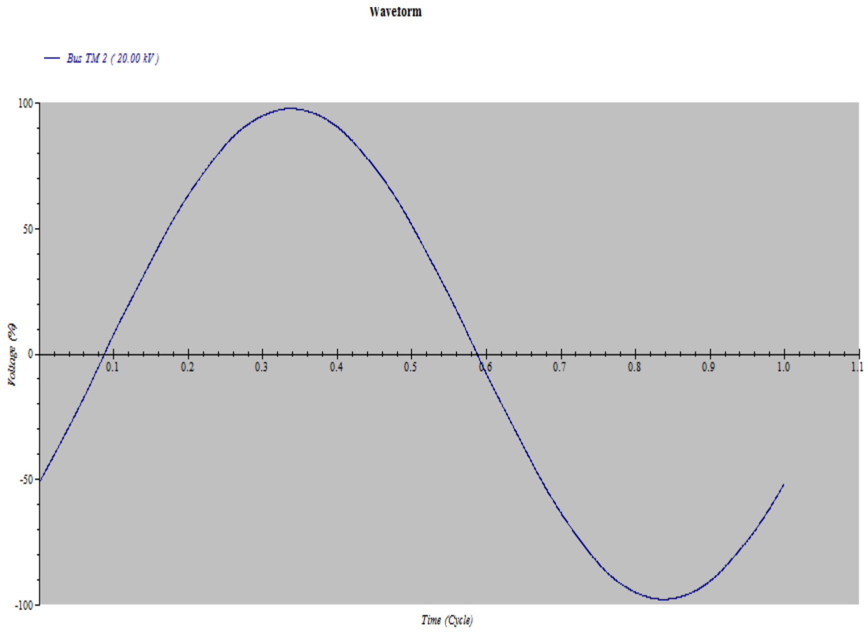

Fig. 8. Results of Harmonics Analysis after connecting a Distributed Smart Grid Generator on MV2 Bus Voltage

Harmonics Analysis shows that there is a Harmonics component on MV2 Bus voltage with orders of 5, 7, 11, 13, 17, 19, 23 and 25. The biggest harmonic component is order 11 and 13 (0.17%). Although there is a harmonic component on TM2 bus voltage, the value is small, so it does not change the shape of the Bus Voltage Waveform.

E. Transient Stability Analysis

Transient stability analysis, simulated when a change occurred whilst Circuit Breaker PhotoVoltaic 1 (CB PV1) and Circuit Breaker Photo Voltaic 2 (CB PV2) are connected to the network in a Grid On Power condition for 60 Seconds, was to see how long the injection shock (spike) occurs when the system with DC Current is connected during Grid On Power. The response of the Bus voltage to the Transient Event is as follows.

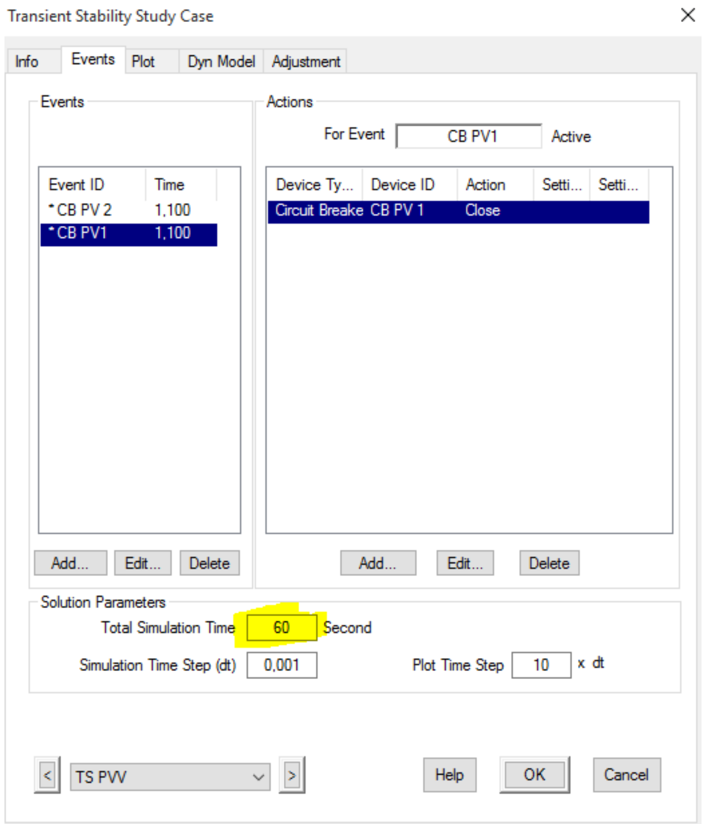

Fig. 9. Transient Stability Analysis on CB PV1 and CB PV2 when connected to Grid On Power for 60 Seconds

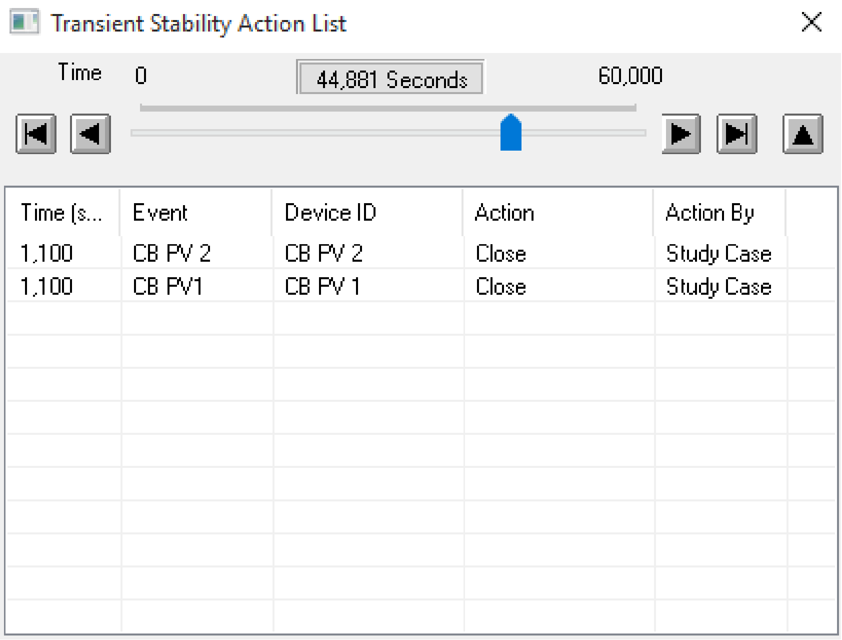

Fig. 10. Action List of Transient Stability Analysis on CB PV1 and CB PV2 when connected to Grid On Power for 60 Seconds

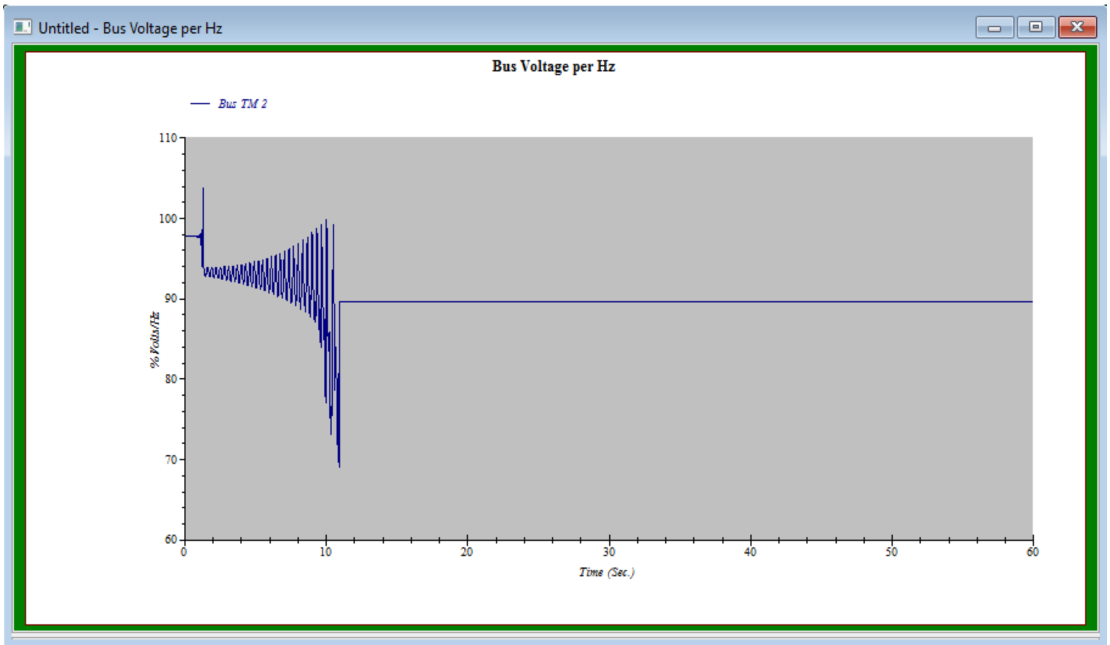

Fig. 11. Voltage on TM2 Bus Transient Stability Analysis on CB PV1 and CB PV2 when connected to Grid On Power for 60 Seconds

The picture above shows the transient process when CB PV 1 and PV2 are connected to the Grid for 60 Seconds. In a longer time span (the 2nd to 11th seconds), there is a spike when the system is installed on Grid On Power. This shows the potential for instability in the system. However, at 12 seconds and so the voltage becomes very stable. The voltage phase angle on the spike that occurred at the beginning of PV1 and PV2 installed on the bus did not reach 90° before then returned to a stable position. Because the voltage angle is still below 90°, transient stability on the network can be categorized as positive.

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