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Stability model integration for large scale solar photovoltaic system using Western electricity coordinating council model

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ABSTRACT

Due to the increased demand for renewable energy, the interest in the large-scale solar photovoltaic (LSSPV) power plant has recently grown dramatically. However, when a large amount of electricity is produced from the LSSPV power plant to the grid interconnection, the system commonly experiences instability and thus disrupt the grid system in disturbance issues such as bus fault, line-to-line fault, three-phase fault, and tripping. This sudden disturbance occurrence is tended to interrupt the stability of the system from providing balanced electrical production within the electrical grid. A dynamics response from the simulation is used to study the stability and the behavior of the photovoltaic (PV) plant into the grid interconnection by developing 118 bus system. The observation of critical clearing time (CCT) duration shows that the result from the simulation where the duration takes less than t=15 s for the system to get back to its pre-fault condition in three-phase fault and tripping in a dynamic simulation to shows that the system reaches its stability been observed through the simulation result by using from user-specific models to generic models like those advocated by the Western electricity coordinating council (WECC) in power system simulator for engineering (PSSE) software.

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1. INTRODUCTION

Due to the price of fossil fuels fluctuates rapidly in the last couple of decades and the environmental concern related to the rise in environmental pollution merge the finding in clean energy will counter the problem. As the result most of the country start to accept renewable energy such as solar and wind energy which are among those resources that have been cente4 of attention due environment friendly which can reduce pollution, also reducing utility bill. The United States Department of Energy (DOE) has set a target of 20% renewable energy resources by 2030 [1]. Solar power technology is currently advancing at a breakneck pace around the world, in 2017 the total grid-connected solar power capacity installed was 99.1 GW [2], with the United States, China, Japan, and Germany having the world’s greatest installed power capacity. The Malaysia renewable energy (RE) Act 2011 was published in June 2011 and introduced the feed-in tariff (FIT) program. The sustainable energy development authority (SEDA) is promoting a number of 1.6 percent collection techniques from public power bills [3]. Large-scale solar photovoltaic plant (LSSPV) is a well-known program that Malaysia launched in April 2016 in order to develop solar power technology in terms of power capacity with a deployment objective of 1 G Watt.

There are several types of photovoltaic (PV) plant scale which is the small-scale size generated less than 250 kW, medium-scale PV plant generates 1,000 kW to 100 MW and large-scale solar PV generator project can spread from 100 to 1,000 MW [4], [5]. Due to the substantial penetration of large-scale solar power plants into the grid interconnection, the distribution system will be impacted in terms of power system stability, including system dependability, and the voltage profile will be significantly altered [6]. Nevertheless, the integration can offer grid resilience to system [7]. However, the distribution system's unbalance condition may have an impact on the PV plants integrated therein, which may then have an impact on the PV system's effectiveness. Besides the change of the level irradiance, temperature, and tripping where the high PV penetration also affected the operation of the system which affects the system's stability in both the steady state and the transient due to their unique characteristics that set them apart from conventional generation sources [8].

The high generation of these intermittent energy in the power system will alter power flow patterns, influencing the steady-state and dynamic behaviors of the power system. When tripping or fault occurs, the size of the oscillation of the frequency voltage profile decreases. Nevertheless, as the PV penetration increases, the oscillation may increase further, affecting stability. A random entry of PV plants into the power system without sufficient planning can have a substantial impact on the power flow in the system, resulting in conditional blackouts or generator damage [9]. Furthermore, a considerable volume of solar PV put at the load level will reverse power flow from the load level to the transmission system, and solar PV contributes relatively little to reactive power generation. Solar PV does not add to the system's electrical grid inertia, unlike conventional thermal power plants, because it is asynchronously integrated into the grid through an inverter. As a result, unlike traditional synchronous generators, solar PV cannot aid in the inertia response during frequency regulation [10]. The impacts of solar PV facilities on the electrical system are detailed in [11]–[16]. As a result, assessing the impact of increased solar PV generation on the power system, which is today dominated by conventional generation, is crucial.

This research proposes a bespoke large PV plant model that may be used to investigate grid stability. The developed model consists of a 118-bus system by using power system simulator for engineering (PSSE) software as a baseline for developing solar power plants and researching the integration of large-scale photovoltaic plants into the traditional electricity grid. Where the developed system has gone through stability assessment which consists of steady-state analysis and dynamic analysis in order to study the behavior of the system when the disturbance has been applied. The system consists of different types of PV generation in order to test the theory where the different levels of the generation affect the stability of the system and the magnitude of the oscillation.

2. RESEARCH METHOD

This research project entails creating and testing the stability of grid-connected solar PV in standard PV systems. The research was carried out in PSSE software, where the bus system was constructed and studied to find the system's greatest likelihood of stability when connected to solar PV. The dynamic stability has been performed, the PV size has been constructed in the PPSE software and the stability assessment has been tested on the PV model. In the PSSE power flow instance, large scale solar (LSS) is simulated as a regulated bus with bus type code 2-generator bus [17], exactly like other conventional generators. In steady state analysis, the attributes of LSS generators are comparable to those of conventional generators, in that they are capable of delivering reactive and active power within limitations on the minimum and maximum reactive and active power. The highest conceivable PV power that could be put into the system has been identified through this research, where the possible output of the PV plant is about 250 MW were considered in this study which consists of four PV generator that has been installed in the 118-bus system that generated from 100 to 250 MW. After the system has been constructed, a dynamic simulation will be performed to monitor the behavior of the PV generator as a result of the power generated by the PV generator in order to determine the system's stability.

2.1. PV generator model

The conventional generator is different from the PV generator, where the PV generating units show stochastic behavior under various settings without inertia, and the dynamic behavior of its sort of generators is subjected to the feature and control approaches used for their converter sections, unlike conventional synchronous generators [18]. Besides designing conventional generators, the PSSE program is used to design and develop renewable generators such as wind and PV generator models for simulation. The Western electricity coordinating council (WECC's) renewable generator attempts to capture the fundamental characteristics of solar plants with central control at the transmission grid's point of connection (PCC) [19]. The first generic model for PV plants was based on a previously developed generic model for wind generation, namely the WECC initial model, which is based on the WT4 complete converter wind model [20]. By selecting a proper value to perform dynamic simulation the most important dynamic basic machine model such as generator controller (REGC_A), electrical control model (REEC_B), and plant control (REPC_A) must be considered such as the block diagram shown in Figure 1. These module does not include plant protection or an inverter where the existing generator model can act as and be used to describe the protective setting for time-delayed voltage and frequency.

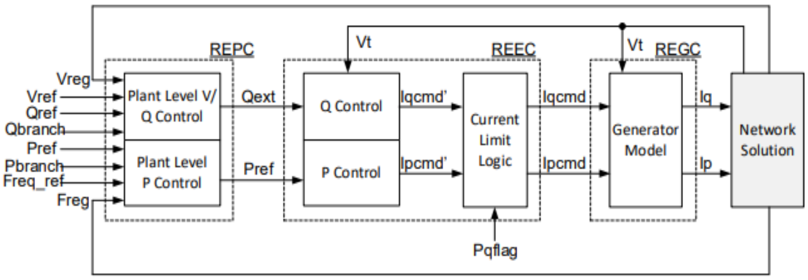

Figure 1. Block diagram of PV system WECC model [20]

2.1.1. Renewable energy generator converter model (REGC)

This module depicts the generator that interferes with the grid system by processing reactive and real current commands as well as reactive and real current injection outputs into the grid module. This model features a high bandwidth current regulator that injects real and reactive inverter components into the external network solution in response to reactive and real current instructions [20]. A set of six or more specific time and frequency protective components were used to trip the generation represented by the model, with each element having a separate user-settable pickup and time delay. FRQDCA/FRQTPA and VTGDCA/VTGTPA were external models that provided the capability of tripling the generation represented by the PSSE model. The present injection model is the same as the one proposed by the WECC renewable energy modeling task force (WECC REMTF) for the type 4 and type 3 generic wind turbine types [21]. The current injection logic limits reactive current injection during high voltage transient operation to prevent contributing to the voltage rise [19]. For low voltage transient operation, the active current injection logic simulates the inverter phase lock loop (PLL) control's response to voltage sags induced by faults, along with the active current injection when the voltage returns to normal levels. The model input parameter is fixed in order to operate properly according to the datasheet.

2.1.2. Renewable energy electrical controls model (REEC)

This module is utilized to provide the inverter with electrical control. This study model utilized the REEC B model, which was simplified from REEC A and is specified for solar photovoltaics. REEC does not offer many advantages or extra modeling capabilities [22]. It sends real and reactive current commands to the REGC module using the REPC module's reactive and active power references as well as feedback from the terminal voltage and generator power output [23]. For local active power, the active power subsystem offers real and reactive current instructions to the REGC module and gives an active current command to the current injection module, as well as terminal voltage and generator power output feedback. Current limiting will apply to the reactive current command, with a user-selectable priority between active and reactive current. Between the maximum and minimum inverter limitations, active power regulation maintains a reference value, which can include ramp-down and ramp-up limits. The initial power flow solution or the plant control is used to determine the active power reference.

2.1.3. Renewable energy plant controller (REPC)

This module represents the plant controller to the system it is an optional model used when reactive and active power is needed in the system, where it processes reactive and voltage power output to emulate volt/Var control of the plant level and it also processes active power output and frequency to imitate the active power control. This model supplies REEC modules with reactive and active power. The model input parameter should be considered fixed according to the datasheet specification to complete the model's characteristics. The voltage at the connection point or another point in the grid that was compensated by the current was controlled using reactive power control. Active power regulation, which includes primary frequency response based on a proportional regulator with dead band and ramp-up and down limits, regulates the active power provided by the plant in a branch. This model is only available for grid codes that use an aggregated inverter model to represent PV plants.

2.2. Dynamic performance assessment

The PV dynamic model will be simulated to evaluate the performance of a PV system that is connected to the grid via a power converter. The wind machine is used as solar PV generator because both PV and wind models use similar technology to inject power into the grid. The PV generator has been installed at bus 11, 30, 71, and 100, where each of the PV generators generated different level which is 50, 100, 150, and 200 MW of power to the grid system. The PV generator will be injected by the disturbance which acts as when a tree falls on a power line, the line’s protective system disconnects it automatically and a resulting outage or sudden fault occur at the transmission line. The goal of the dynamic stability simulation of the modeled power system in the PSSE program is to analyze the system’s stability when a disturbance is applied, which is tripping and subject three-phase fault to the PV generator, and to observe the critical clearing time (CCT) when the system when return to normal condition by calculating the midway between the fault time when the system becomes unstable and the time before that [24]. The stability of a power system may be determined by examining its output such as frequency, voltage, power, active power, reactive power, and angle oscillated back to its normal condition before the fault has been subjected to the PV generator. The level of the PV generation also increases the probability for the system becoming unstable and also leads to a higher magnitude of oscillation [25] and takes a longer time for the system back to its condition before being subjected by disturbance.

The generator type for the PV generator utilized is seen in Figure 2, where REGCAU1 for the generator, REECAU1 for electrical, and REPCAU1 for the auxiliary control type of the PV generator model (PVGU) which in other aspects, it is nearly identical to the PVGU model. It has a high bandwidth current regulator that, in response to reactive and real current commands from the electrical controller model, injects reactive and real inverter current into the external network during the network solution. Unfortunately for the REGC generator, the irradiance cannot be varied, unlike PVGU, in the solved power flow situation on the generic WECC models by default assume a fixed reference generator output. Currently, large-scale system studies do not yet have any provisions for including the modeling of irradiance variability.

Bus Number	Bus Name	Id	Mbase (MVA)	Generator	In Service	Type	Electrical
11	132.00	1	100.00	REGCAU1	✓	Wrtn	REECAU1
30	132.00	1	150.00	REGCAU1	✓	Wrtn	REECAU1
71	132.00	1	200.00	REGCAU1	✓	Wrtn	REECAU1
100	132.00	1	300.00	REGCAU1	✓	Wrtn	REECAU1

Auxiliary control	In Service
REPCAU1	✓
REPCAU1	✓
REPCAU1	✓
REPCAU1	✓

Figure 2. WEEC generator selection in dynamic simulation

3. RESULTS AND DISCUSSION

In this study, the modeled 118 bus systems were subjected to tripping and fault during the dynamic simulation and the behavior of the system has been observed whether it is stable where the system is back to its normal condition or not. The system has been subjected with a fault in 0.1 seconds of duration. Even in a short amount of time faults have been applied some of the previous studies show that the system become unstable and did not back to its normal condition. The performed dynamic simulation examines the immediate response after a fault and tripping condition and inspects the CCT. CCT is defined as the maximum duration that a disturbance could occur without causing it to lose its stability, the higher the generation of the PV generator the longer the time and the higher the magnitude the system oscillated until back to its normal condition.

3.1. Three-phase faults

Every PV generator generates a different level of generation starting with 100 Mw to 250 Mw where the bus system consists of four PV generators. A three-phase fault has been applied to each PV bus in order to assess how well the transmission grid can handle the integration of renewable energy sources. The fault is subjected one second after the simulation is initiate, the fault has been applied in 100 ms at t=1.1 s. and the step time gradually increased and the total simulation time only take 8 s. Figures 3(a) and (b) in Appendix illustrate the active power and reactive power response of all PV farm output during the three-phase fault occurrence respectively During the fault occurrence, the active power output oscillates around 2 s and recovers to its same steady state pre-fault value Figure 3(a) same goes to Figure 3(b) where the reactive power has a damp oscillating response for 5.5 s and returns quickly to its normal condition before the fault occurs. From the simulation it shows that there are differences in the magnitude of oscillation, this is because each PV generator generates a different capacity of power where the highest generation of power tends to have higher oscillation magnitude than the least generation of power, and also tends to has longer time for the oscillation and to settle down. Reactive and active power output show the highest PV generation located at bus 100 which generates 250 Mw tend to have the highest oscillation magnitude and takes a longer time to settle down. PV generators tend to have a shorter time than wind turbines to return to the same steady state value before the fault occurred, this proves that the PV generator did not have any rotary mechanism while wind generator rotor speed increases and accelerates during the fault, a bigger negative slip results, which helps to explain these active and reactive power response.

The same result has been observed from the terminal voltage shown in Figure 3(c) in Appendix which shows that the terminal voltage oscillates when subjected by a three-phase fault where the magnitude of the oscillation behavior shows the same as the previously active and reactive output where the higher PV generation tends to have higher magnitude of the oscillation which may influence the system's voltage stability in the absence of an optimal solution to safeguard the system from the undesirable situation. PV generator located at bus 100 which generates 250 Mw drop top zero while other PV generator drop to a low value almost to zero and after the fault clearance the voltage gradually recover to 1 pu which is a condition before the fault occurred in 0.9 seconds of duration. Under the same simulation fault scenario, severe oscillations of frequency are observed and shown in Figure 3(d) in Appendix. The variation in the magnitude of the oscillation may lead to the triggering of a series of load shedding relays where these procedures describe the activities performed by an operator after the load shedding by frequency opened a corresponding set of circuit breakers which loads being disconnected from the power system and when the emergency situation is over the operation restore its power. The nature of frequency response as described above necessitates a major push in the area of protection coordination in order for the system to obtain reliable operation were to gain frequency stability by quickly returning to its normal condition before the fault.

3.2. Tripping

In this section where the bus that has a PV generator has been installed with a conventional generator, this is because the PV generator will be tripped during the process which is the PV generator at bus 11 and bus 30. The PV generator has been trip at t=1 s and the result has been obtained. Despite the fact that the PV generator's output was reduced to zero owing to the inverter tripping, the conventional generator connected to the bus continued to provide electricity to the system. From Figure 4(a) in Appendix, it can be observed that sudden tripping at a different level of PV generation effect slightly the oscillation of the bus frequency. The PV has been tripped at t=1 s and its shows that the frequency is at zero and stable operation of the system at 50 Hz. The PV plant is tripped at t=1 s for 100 ms and it shows that the frequency deviation before the tripping is zero and so the system operation is at 50 Hz which is in stable condition. After the tripping has been cleared the frequency gradually oscillated to its normal condition and takes less than 15 seconds. Sudden tripping in the system will lead to a severe frequency drop followed by oscillation which will interrupt the stability of the system. The reason for the installation of the PV generator at the conventional generator bus is to reduce the kinetic energy available in the system and also reduce the system inertia which will reduce the oscillation of the frequency. If the frequency is under the acceptable level of frequency operation, the under-frequency load shedding of the bus will play its role by taking the appropriate steps to keep the system operational in such a circumstance.

The tripping of the PV generator resulting an oscillation in the voltage at the bus as shown in Figure 4(b) in Appendix. The impact of student tripping during 100 ms impacts the voltage profile magnitude and the duration of the oscillation which depends on the PV generation level. The higher the generation level the higher the oscillation magnitude and the longer the time taken for the voltage to back so to its normal condition, where PV at bus 30 has higher generation than PV at bus 10, and both take less than 15 seconds before back to its normal condition before tripping been applied.

Figure 4(c) shows the result of output power after the PV generator has been tripped. The result shows that the behavior of the PV generator and the conventional generator where the PV generator drop to zero at t=1 s is because the PV generator has been tripped and the conventional generator oscillated and back to its normal condition in between t=10 s where it shows the system is stable. The conventional generator produces a part of lost PV generation and its total generation increase, some part of the lost PV generation must be delivered to the system in order to maintain the stability of the system. So, the maximum PV integration limit should be optimized in a way that the sudden tripping of a large PV plant does not lead to damage to the system by the conventional generating unit in the system in order to avoid overloading limits of the power system.

4. CONCLUSION

From the research study, the impact of different PV generation into the modeled 118 bus systems with integration of four different buses 11, 30, 71, and 100 using Siemens PSSE software using WECC generator are reported in this paper. It was discovered that when large PV plants generate power to the grid, the system is more sensitive to the stability issue. It was found that a higher PV generator leads to the system becoming unstable operation point if protection is not constructed with sufficient thought. The simulation is carried out by applying fault at the PV generator which is tripping and three-phase fault where the behavior of each PV generator with different PV generation has been observed. The dynamic simulation found that the higher generation of the PV plant will cause a higher disturbance of oscillation that the lower generation, where it also takes a longer time for high PV generation for the system to become stable and back to its condition before the fault been applied in the tripping and three phase fault simulation. The result simulation of reactive power, active power, frequency, and voltage show that the system is back to its actual condition, but it shows the need for protective coordination at the distribution end when frequency decreases and voltage profiles shift as a result of PV integration, raising serious concerns about the power system's stability and dependability. To attain a stable state following a post-fault condition, the dynamic reaction of active power produced by the PV plant is faster than that of a traditional generator, the above result of an integrated PV plant is better suited to feeding unexpected power demand in a smart power system. The simulation results also proved that the higher generation of penetration influence the voltage variation, power flow, dynamic system behavior and short circuit current. Overall, the dynamic simulation result shows that the PV generator that has been tested by tripping and three-phase fault reached its stability with different generation levels up to 100 MW with CCT less than 15 seconds. Besides that, the study found out that the different levels of generation will cause a higher magnitude of oscillation and take a longer time to settle down.

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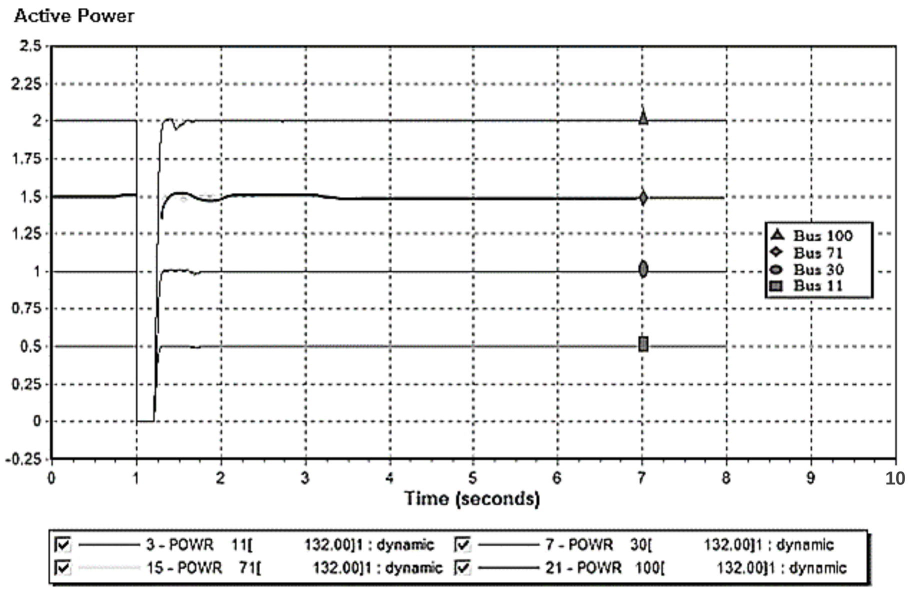
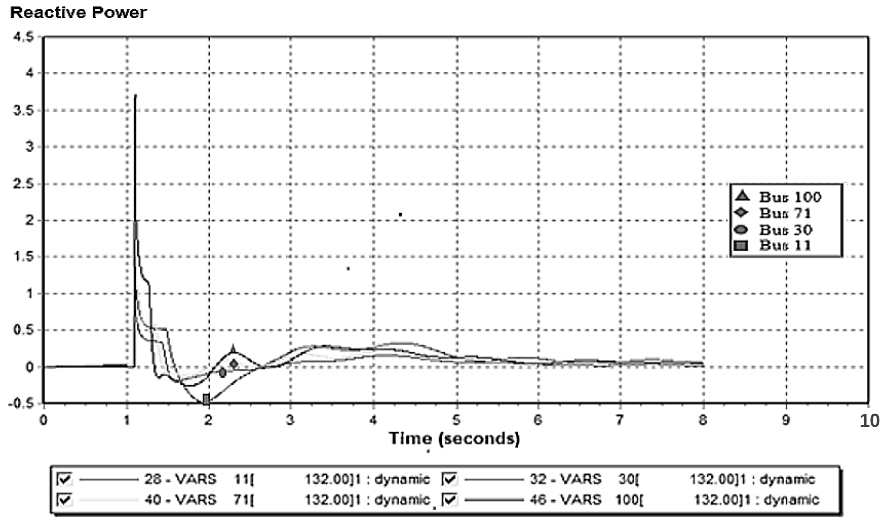
APPENDIX

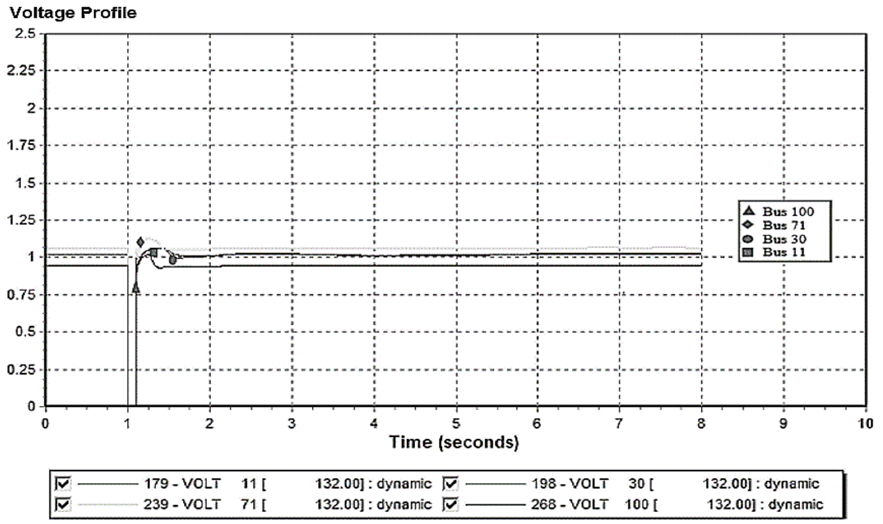


(a)

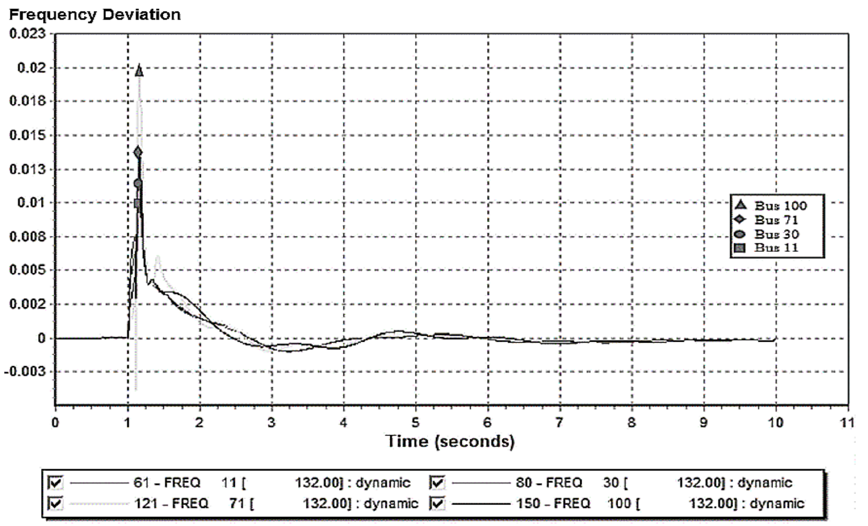
Figure 3. Three-phase fault occurrence for (a) active power output (*continue*)



(b)

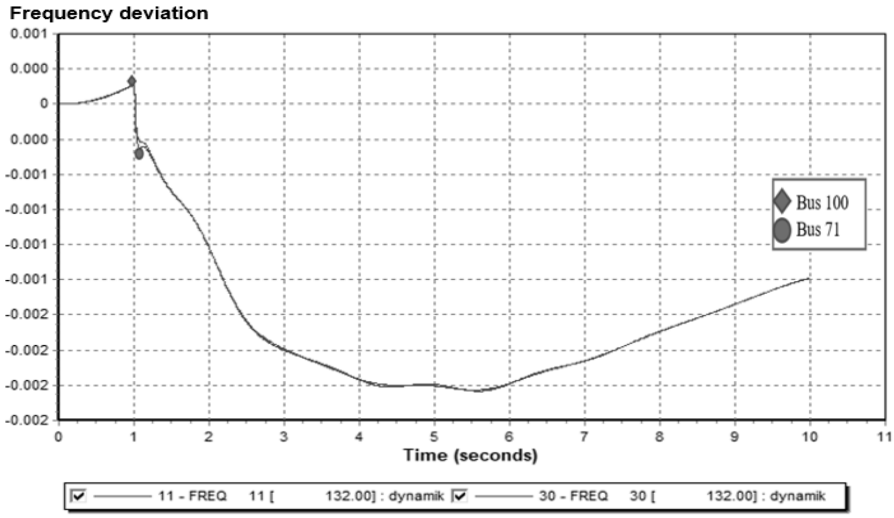


(c)

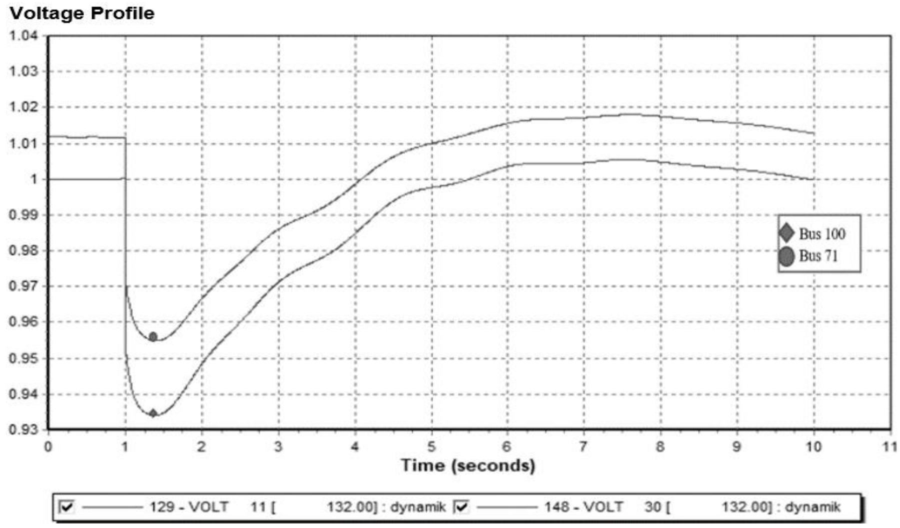


(d)

Figure 3. Three-phase fault occurrence for (a) active power output, (b) reactive power output, (c) voltage profile output, and (d) frequency deviation output



(a)



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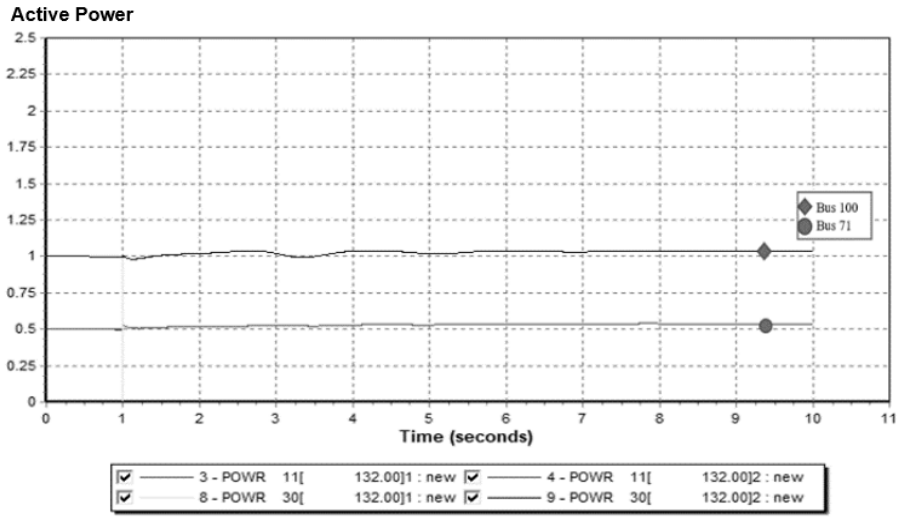

(c)

Figure 4. Tripping occurrence in (a) frequency deviation output, (b) voltage profile output, and (c) active power output

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