Wind Power Plant Modeling for the Conditions of Grid-Connected Mode: Integration

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***Abstract*— The load demand to the power grid, as well as the interest in clean and low-cost energy resources, lead to the high integration of wind power plants into the power system grid. There are grid code standards that are set for the design and integration of these wind power plants. These codes often look at the design operation of the wind power plant in islanded mode, where possible analysis of the most sensitive power system quantities such as voltage, frequency, reactive power, etcetera is done. Therefore, attention needs to be paid to the application of these codes to keep the design and integration of wind power plants well standardized as much as possible. The purpose of this research is to review and discuss the literature and theory about the design of the wind turbine generators, model the wind power plant, and integrate it into the power system grid while adhering to the grid code requirements.**

Keywords*— *Integration, Point of Common Coupling (PoCC), Renewable Power Plant (RPP), South African Renewable Grid Code Standards (SAREGCS), Wind Power Plant (WPP), Wind Turbine, Wind Turbine Generator Unit (WTGU), Wind Turbine Power Coefficient (Cp).

I. Introduction

Voltage stability is the ability for a power system to maintain its standard node voltages to an acceptable continuous operating range, even after it has been subjected to disturbances. The power system voltage is said to be unstable if one or more busbar voltages fall out of the acceptable continuous operating range.

A larger amount of reactive power consumption from a substation may cause a voltage decrease and results in voltage instability [1]. The overall system voltage collapse is the result of the reactive power or voltage control limit of the generator, load characteristics, reactive power compensation device characteristics, and the action of the power transformer underload tap changers.

Voltage control and stability challenges were once primarily associated with weak systems and long transmission lines, but now are also associated with heavily stressed systems. Several historical events for voltage collapse examples are recorded in Table I [2].

Various methods have been used for overcoming the voltage stability challenges, namely, application of reactive power compensating devices, control of network voltage and generator reactive power output, coordination of protection or control devices, control of power transformer tap changers, under-voltage load shedding schemes [2], [3].

However, the load-shedding schemes are a last resort. The main objective of the power system is to keep the continuous supply of power to the end-users.

TABLE I. Historical Voltage Collapse Events

Parameter	Values
New York Pool disturbances	22 September 1970
Florida system disturbances	28 December 1982
French system disturbances	19 December 1987
	12 January 1987
Northern Belgium system disturbances	04 August 1982
Swedish system disturbance	27 December 1983
Japanese system disturbance	23 July 1987

In this research, the integration of a large-scale wind power plant (WPP) is done at the transmission level and this reduces power outages to end-users.

II. Overview of Voltage Stability Analysis

Voltage collapse is the condition in power systems, where the voltage can no longer recover after it has been fallen below or above the accepted operating range due to power system disturbances like faults and sudden increases or drops in load demand [4].

The voltage stability analysis of a power system network involves the examination of two aspects, namely, proximity to voltage instability and the mechanism of voltage instability.

Proximity to voltage instability: This aspect is based on the investigation of how close the system is to voltage instability. Physical quantities such as load level, active power flow through the critical interface, and reactive power reserve are used to measure the distance to instability. Planning and operating decisions depend on the appropriate measures of the given situations of the system. Possible contingencies such as line outages, loss of generating unit, or a reactive power source, system overloading, etcetera are considered [2].

Mechanism of voltage instability: Here, the reasons for voltage instability occurrence, the vulnerable areas, and the most effective measures to improve voltage stability are examined. For this aspect, time-domain simulations are included with appropriate modeling where the events that are leading to instability are captured in chronological order.

These simulations are time-consuming and do not provide sensitive information and a degree of stability.

The system dynamics behind the voltage stability are usually slow and therefore, can be effectively analyzed by static methods that examine the viability of the point of equilibrium presented by specific power system operating conditions. The analysis by using the static methods allows examination of a wide range of system conditions and provides much insight into the cause of the problem and the identification of the major contributing factors. Dynamic analysis is useful for a detailed study of specific voltage collapse situations, protection and controls coordination, and the testing of remedial measures. Dynamic simulations also examine whether and how the steady-state equilibrium point will be reached [2].

A. Modeling requirements

The simplest representation of plant components should be used, consistent with the accuracy of the available information. There is no need to use complex items to model a system when the load and other data (for instance transmission line data) are known, up to a limited accuracy. Power system components like long transmission lines should only be used where it is necessary, and this applies to synchronous generator models. For example, system stability studies require the use of sophisticated synchronous machines and special transformer models. Usually, the network size and its complexity provide more than sufficient academic motivation without unnecessary enhancement of the components. Often in high voltage networks, resistance may be neglected with little loss of accuracy and a huge saving in computation time [5].

Planning studies are performed normally for minimum and maximum load conditions. Under minimum load conditions, the possibility of high voltages is examined, and under maximum load conditions, the possibility of low voltages and instability are examined. In every large power system network, the study of collecting data is as important as finding the solution to the problem pertinent to the network. The accurate the data, the simpler the problems that need to be solved and how to solve them. Therefore, calculations must be carried out on a systematic basis, and the nodal voltage method is often convenient. Load flow studies deal with the investigation of certain parameters in the power system networks. The following are the features investigated during the load flow studies:

- Busbar or node voltages.
- The flow of real power (P) and reactive power (Q) in the branches of the network.
- The effect of rearranging circuits and incorporating new circuits on system loading.
- The effect of temporary loss of generation and transmission circuits on system loading (mainly for security studies).
- The effects of injecting in-phase and quadrature boost voltages on system loading.
- Optimum system running conditions and load distribution.
- Minimizing system losses.
- Optimum rating and tap range of transformers.
- Improvements from the change of conductor size and system voltage.

There are some other forms of investigations in power system engineering, such as circuit analysis and load or power flow analysis. In the circuit analysis, the parameters of the impedance, voltage, and current sources are specified, all nodal voltages and branch currents can just be calculated using the simple expression where the relationship between the voltage and current is linear. In the load or power flow analysis, loads and sources are defined in terms of powers, not in impedances or ideal voltage or current generators. All power system network branches, transformers, and overhead or underground cables are defined in terms of impedance, where the relationship between power, voltage, and impedances is non-linear [5]. This requires appropriate methods to be used when these circuits are to be used.

The power flow in complex power system networks is determined by the power system components, whose characteristics of operation differ. Stability studies require a strong analysis of power flow within the power system network before the resumption of any other investigations.

B. Static and dynamic voltage stability analysis

Voltage stability is divided into two types, static and dynamic voltage stability. The static voltage stability requires the analysis through the use of algebraic equations, while the dynamic requires the modeling of the precise replica of the voltage instability [6]. Simulation-based models are essential for dynamic voltage stability analysis. Therefore, appropriate power system network models must be used, with simulation cases and various contingencies for predicting the voltage collapse point to accomplish the statistical analysis of the system voltage stability problems.

The determination of how close the system is to voltage instability condition is determined by increasing the system load in a predefined manner which represents the stress of the system based on the historical and forecast data. However, it is also important to consider the load pattern that results in the smallest stability margin [2].

III. PREVENTION OF VOLTAGE COLLAPSE

There are design and operating measures that can be taken for the prevention of voltage collapse in power systems as shown in Table II [2], [5], [6].

TABLE II. POWER SYSTEM VOLTAGE COLLAPSE PREVENTION MEASURES

System design measures	**System operating measures**
Reactive power compensating device application	Stability margin
Network voltage and generator reactive power control	Spinning reserves
Protection or control schemes coordination	Operator’s action
Transformer tap-changer control	
Under-voltage load shedding schemes	

Reactive power compensation by capacitors is done up to a certain limit, this means that, when the voltage sags occur in the system, only a small amount of reactive power will be produced by the capacitor bank. This is one of the reasons why an additional or alternative source is opted for in this paper, which is the wind power plant (WPP) source.

The WPP is coupled locally at the point of voltage collapse. It supplies both the active and the reactive power to the system and therefore guarantees a great improvement in terms of load demand fulfilments.

IV. POWER SYSTEM NETWORK USED FOR THE STUDY

The simplest representation of plant components should be used, consistent with the accuracy of the available information. There is no need to use complex items to model a system when the load and other data (for instance transmission line data) are known, up to limited accuracy. Power system components like long transmission lines and synchronous generator models should only be used where it is necessary. For example, system stability studies require the use of sophisticated synchronous machines and special transformer models. Usually, the network size and its complexity provide more than sufficient academic motivation without unnecessary enhancement of the components. In high voltage networks, resistance is neglected most often with little loss of accuracy and this makes a huge saving in computation time [5].

To perform a suitable simulation study with more accuracy, it is advisable to choose the system with all the necessary parameters. This study looks at the voltage stability and will extend to the protection study. The Nine-Bus System shown in Fig. 1 is more than enough for this study and is therefore selected.

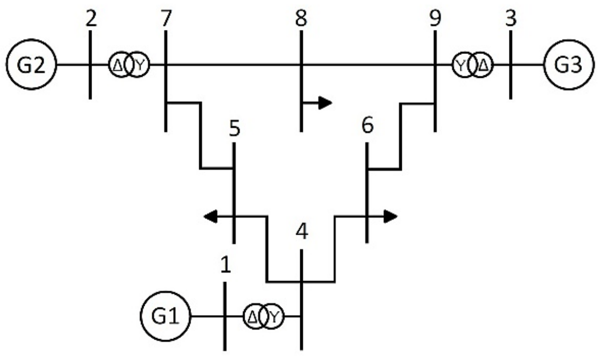

Fig. 1. The IEEE Nine-Bus System adopted from RTDS literature

Power system networks are complex systems to model. Modeling studies require special attention when arranging system components. For instance, in analysis, monitoring, etcetera, components need to be arranged accurately, not just for a scholar's interest, but also for a reader to be able to see and relate. For this reason, the IEEE Nine-Bus System used in this study is re remodeled and its components are re-arranged.

During system modification, bus bars had to be re-arranged, where all the buses modeled within the generating stations are renamed G1Bus, G2Bus, and G3Bus, respectively. While others were renamed Bus1 to Bus6. The modified resultant IEEE Nine-Bus System is as shown in Fig. 2. The system frequency of 60 Hz is found on the data of the network, however, changed to 50 Hz.

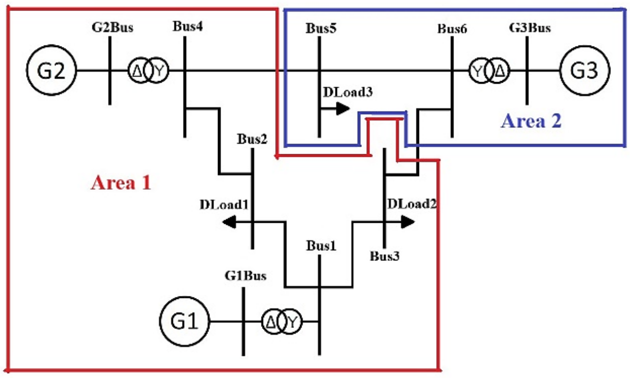

Fig. 2. The modified and rearranged IEEE Nine-Bus System Area 1 modeled in Subsystem 1 (Rack1). Area 2 in Subsystem 2 (Rack2)

RSCAD allows the user to model the power system network and extract the initial load flow results. This option provides the initial steady-state load flow calculations.

For the power system network model used in this paper, the initial load flow results in terms of busbar voltages, active power, reactive power, and apparent power are shown in Table III.

Under normal system operating conditions, the active power and the reactive power absorbed during the transmission must be equal to the difference between the generated and consumed active and reactive power.

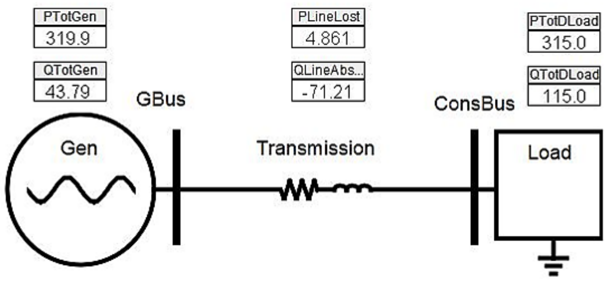

Fig. 3. Power coefficient (Cp) parameter settings of the wind turbine

After the IEEE Nine-Bus System was modeled, all the generated, lost or absorbed, and consumed active and reactive powers were summed up using the RSCAD summing junction components, and the simplified two-busbar system shown in Fig. 3 was achieved.

TABLE III. RSCAD DRAFT LOAD FLOW INITIAL RESULTS

Bus	Bus type	Voltage (PU)	P_G (MW)	Q_G (MVAr)	P_L (MW)	Q_L (MVAr)
Gen1	Slack	$1.04\angle 0°$	71.78	36.28	-	-
Gen2	PV	$1.03\angle 8.36°$	163	11.23	-	-
Gen3	PV	$1.025\angle 4.02°$	85	-3.72	-	-

Bus	Bus type	Voltage (PU)	P_G (MW)	Q_G (MVAr)	P_L (MW)	Q_L (MVAr)
Bus1	PQ	1.02∠27.76°	-	-	-	-
Bus2	PQ	0.99∠26.32°	-	-	125.0	50.0
Bus3	PQ	1.01∠26.57°	-	-	90.0	30.0
Bus4	PQ	1.02∠32.79°	-	-	-	-
Bus5	PQ	1.01∠30.29°	-	-	100.0	35.0
Bus6	PQ	1.03∠31.31°	-	-	-	-

P_G and Q_G represents the true and reactive power generated during the draft load flow in megawatts (MW) and megavars (MVars), and P_L and Q_L represents the true and reactive power demanded by the loads during the draft load flow in megawatts (MW) and megavars (MVars)

In Fig. 3, PTotGen is the total generated active power, QTotGen is the total generated reactive power, PLineLost is the total lost active power due to transmission, QLineAbsorbed is the total absorbed reactive power due to transmission, PTotDLoad is the total consumed active power by loads, and QTotDload is the total consumed reactive power by loads.

The readings shown in the figure are based on the RSCAD normal load flow simulation on runtime and this proves the stability of the system since the lost and absorbed power is made by the difference of the generated and consumed power.

V. Contingency simulation in terms of load demand increase

A contingency study is performed in this section, to investigate the effect of the load demand increase on the busbar voltages. To perform the load demand increase in RSCAD, the load scheduler component is used for the logic to perform this function as described in the section below, and later, the system overloading contingency simulation is presented.

An assumption is made for this study, that the power factor is always constant for all the loads. This means that the relationship between active and reactive power is linear. Therefore, the value of the active power changes simultaneously with the value of reactive power. RSCAD power system dynamic loads can be tuned externally using the control logic, where P and Q setting inputs are fully made available for the external logic for tuning. Fig. 4 shows the dynamic load control logic.

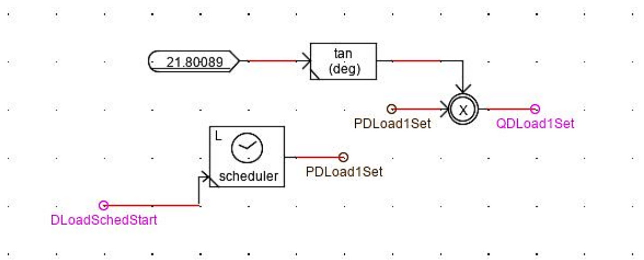

Fig. 4. RSCAD dynamic load control logic for automatic power scheduling

In the figure, *PDLoad1Set* and *QDLoad1Set* are signal names to control DLoad1. The *DLoadSchedStart* signal is the name for controlling the state (*ON/OFF*) of the scheduler component and is an output from a binary switch. The components labeled "scheduler" play the role of increasing the load demand by multiplying the given multiplier with the initial values of power. Settings for this component are by default at the initial rated power of the dynamic loads. The "tan(deg)" component is the multiplier of the active power input signal to the dynamic load. The output signal *QDload1Set* is the reactive power to the load based on the simultaneous increase between the variables P and Q, to keep the power factor of the load constant. The power demand will remain in the initial state until the load scheduler switch is put on the on position on the runtime.

In this section, the load increase is implemented before and after the wind power plant is integrated and the results are recorded.

A. System overloading contingency in standalone power grid

The decision has been taken in this study, that the load is instantly increased by 5 MW in each load after every 0.1 seconds until the voltage collapse point is reached. The voltage is monitored for both the least significant and most significant busbars. The least significant busbars are those that do not have loads connected to them, and the most significant are those with loads.

1) Bus1 to Bus6 per unit voltage monitoring

When the instant load increase is simulated, the voltage sags were experienced in the system, especially in the loaded busbars. The results shown in the consecutive figures (Fig. 5 to Fig. 10) show the per unit voltage waveforms under this event.

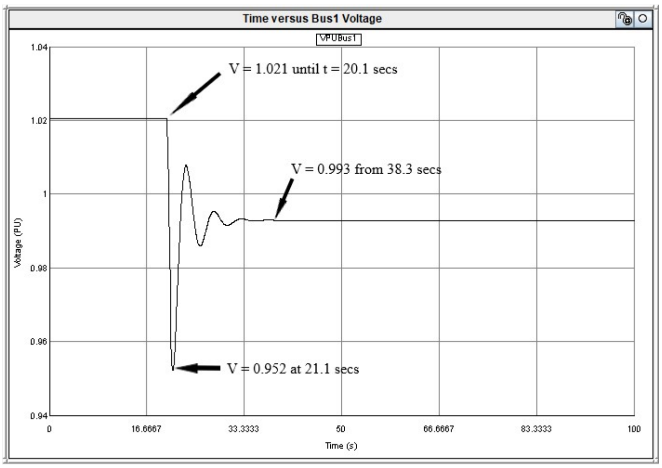

Fig. 5. Bus1 per-unit voltage waveform

Bus1: In Fig. 5, the initial voltage is 1.021 PU and this is when the initial loading is 315 MW. An instant load increase began at 20.1 seconds and a voltage decrease was experienced in Bus 1. At 21.1 seconds, the busbar voltage was at 0.952 PU for a very short period and suddenly recovered for 0.993 PU at 38.3 seconds. According to the specified continuous operating range of the node voltages, these values are still accepted. Based on these observations, Bus1 is healthy.

Bus2: In Figure 6, the initial voltage is 0.993 PU until 20.1 seconds. An instant increase in load demand begins until 20.1 seconds. It shows that the busbar voltage went below the minimum operating range of 0.95 PU starting from 20.5 seconds until 21.1 seconds. The voltage tries to recover between 21.1 seconds and 42.1 seconds but it does not get back to the accepted continuous range, therefore is unstable.

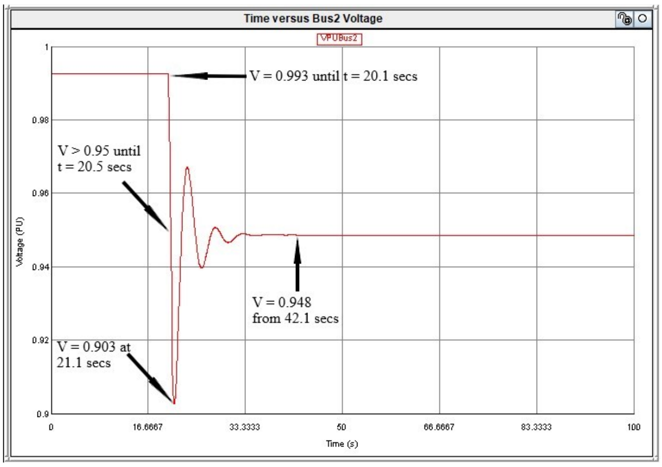

Fig. 6. Bus2 per-unit voltage waveform

Bus3: In Fig. 7, the initial voltage is 1.006 PU. The voltage is at the accepted range until the time of 20.7 seconds elapses. After this time, it is when the busbar voltage begins to collapse. When the duration of the event expires at 21.1 seconds, the voltage goes back to stability after 50.4 seconds.

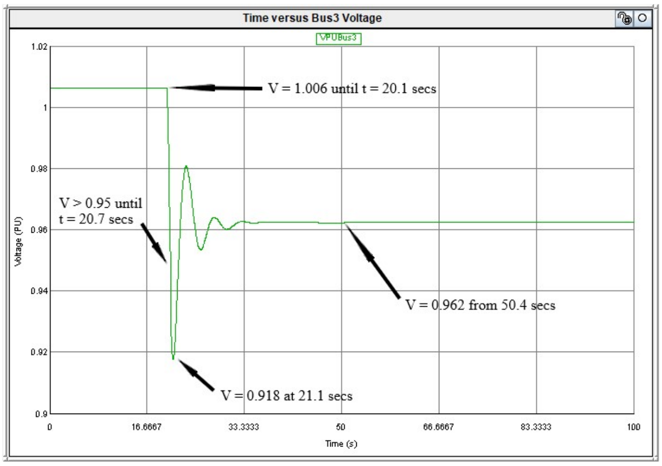

Fig. 7. Bus3 per-unit voltage waveform

Bus4: In Fig. 8, the initial value of the voltage was 1.023 per unit. When an instant increase in load demand began, a decrease in busbar voltage was experienced. The minimum operating range of 0.95 per unit was experienced before 20.8 seconds. It was found that the voltage has reached the instability level of 0.938 per unit at 21.1 seconds. The voltage recovery was experienced after the event.

Bus5: In Fig. 9, the initial busbar voltage was at 1.013 PU until 20.1 seconds. After this time when the load continued to increase instantly, the voltage decreased and began to collapse after 20.7 seconds. However, at 4.86 seconds, the voltage went back to stability.

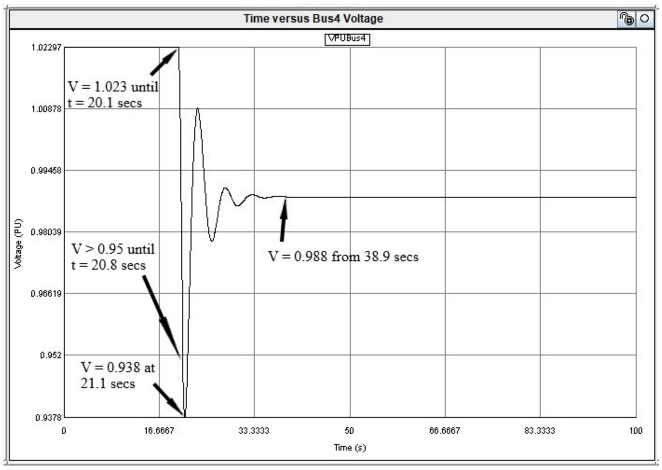

Fig. 8. Bus4 per-unit voltage waveform

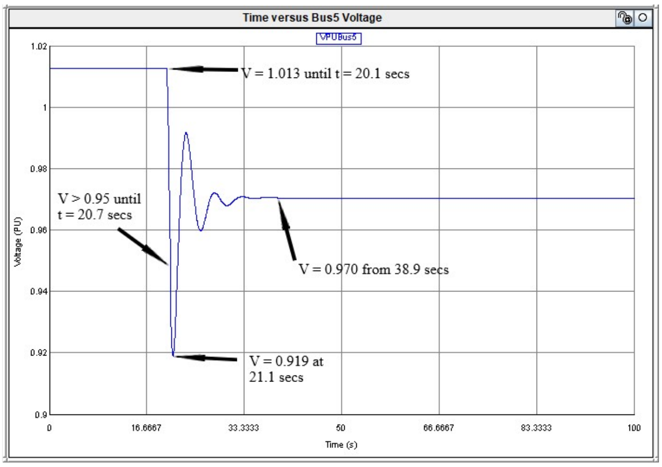

Fig. 9. Bus5 per-unit voltage waveform

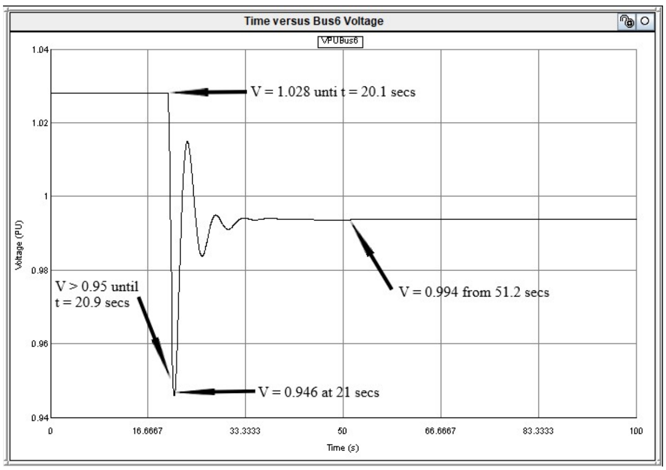

Fig. 10. Bus6 per-unit voltage waveform

Bus6: In Fig. 10, the initial busbar voltage was at 1.028 PU until 20.1 seconds. After this time when the load continued to increase instantly, the voltage decreased and began to collapse after 20.9 seconds. It was found that the voltage was 0.946 PU at 21.1 seconds during the last 15 MW increase in the system. However, at 51.2 seconds, the voltage went back to stability.

The above results show that voltage instability is experienced in Bus2. For this reason, only Bus2 active, reactive, and apparent power plots are discussed in the following section.

2) Active, reactive, and apparent power monitoring at Bus2

The observations were made on the power demand value at the point where the voltage at Bus2 was 0.95 PU. It can be seen in Fig. 11 that the active power (P) demand at that instance (20.5 seconds) was 145 MW. Beyond this value, the busbar voltage began to fall below the accepted continuous operating range and never recovered. In this case, the active power demand by the load is the same as the active power at the busbar.

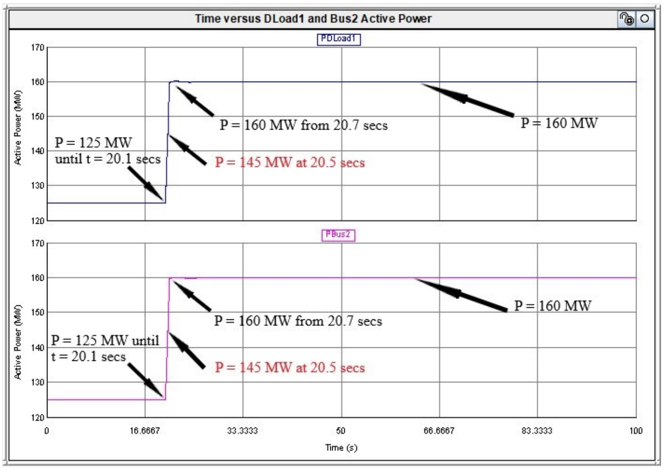

Fig. 11. Active power demand by DLoad1 from Bus2 and active power demanded by Bus2 from the system

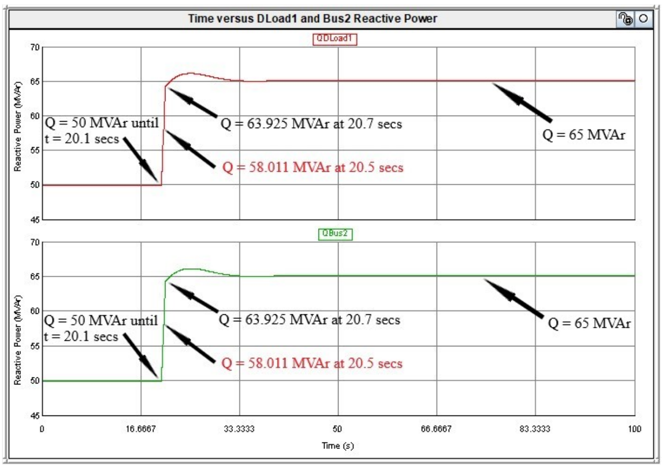

Fig. 12. Reactive power demanded by DLoad1 from Bus2 and active power demanded by Bus2 from the system

As can be seen in Fig. 12, the reactive power demanded by the load and the reactive power demanded by Bus2 from the grid is 58.011 MVAr, and this occurred at 20.5 seconds at the minimum acceptable continuous operating voltage of 0.95 per unit.

The power measured on the busbar is the actual power the substation draws from the system to fulfill the load demand requirements. This discrimination of power monitoring helps in the analysis of power contributed by the system generators when additional power sources are available, whose contribution to the load requirements reduces the dependency of the loads to the system generators. Fig. 11 and Fig. 12 show the Bus2 and DLoad1 active and reactive power demand corresponding values during the event. When the system overloading was implemented, the voltage at Bus2 did not recover.

B. *System overloading contingency in wind power plant integrated power grid*

The system overloading contingency was implemented and some of the quantities during the transition from 315 MW to 420 MW loading were monitored. For this case, results for Bus2 voltage are provided.

1) Bus2 per unit voltage monitoring

While the wind power plant and the grid are connected, the load increase contingency is applied to the system. For this simulation, only the Bus2 voltage results are provided, since it was identified the busbar that did not recover after the load increase disturbance was simulated.

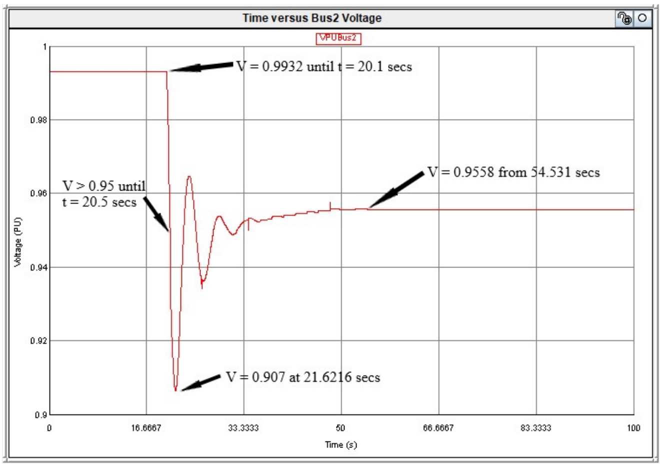

Fig. 13. Bus2 voltage under the instant increase of load

In Fig. 13, the initial voltage is 0.9932 PU and this is when the initial loading is 315 MW (125 MW at Bus2). An instant load increase began at 20.1 seconds and a voltage decrease was experienced in Bus 2. The voltage at this busbar was above 0.95 PU before the time 20.5 seconds. Beyond this time, the voltage dropped and experienced a sudden dip for a short period, noticeable at 21.6216 seconds with the value of 0.907 PU. At a later stage, the voltage tried to stabilize and finally reached a stable condition at 54.531 seconds with a value of 0.9558 PU. From this analysis, it can be seen how effective the wind power plant integration was in the system

2) Active, reactive, and apparent power monitoring at Bus2

The active, reactive, and apparent power demand by the DLoad2 from Bus2, as well as the one demanded by Bus2 from the system due to the load demand, is monitored and recorded.

Fig. 14 shows the active power demand whose corresponding values of reactive power are shown in Fig. 15. These figures show the initial power demanded by the load is shown as well as the power drawn by the busbar from the system generators. Initially, these power are the same. Once the load demand increase has started, the power demanded by the busbar from the system generators suddenly drops due to the power supplied by the wind power plant in contribution to the load demand requirements.

Fig. 16 shows three sets of graphs. The top and the middle graphs show the wind power plant active and reactive power supplied by the wind power plant. The bottom graph shows the reactive power produced by the wind power plant receiving-end reactive power compensating device. In the top graph, the initial active power is shown at 0. The increase starts after 20.1 seconds, and this is when the load increase begins in the system.

In the middle graph, a small value of the reactive power was experienced, however, not that significant. The major increase begins when the load demand increases in the system. The bottom graphs show no reactive power injection from the reactive power compensator. Later after 20.1 seconds, the switching of the capacitor banks starts and significant values of the reactive power compensation begin. The step-by-step switching of each capacitor bank unit is done after every 2 seconds as noted in the Red zone of the graph.

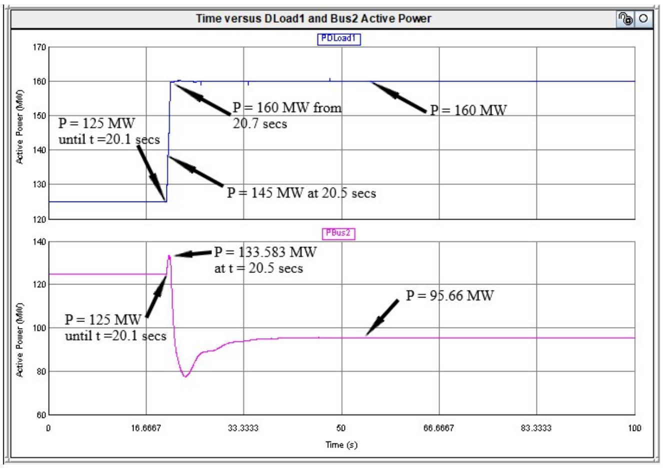

Fig. 14. Active power demand by DLoad1 and active power demanded by Bus2 from the system

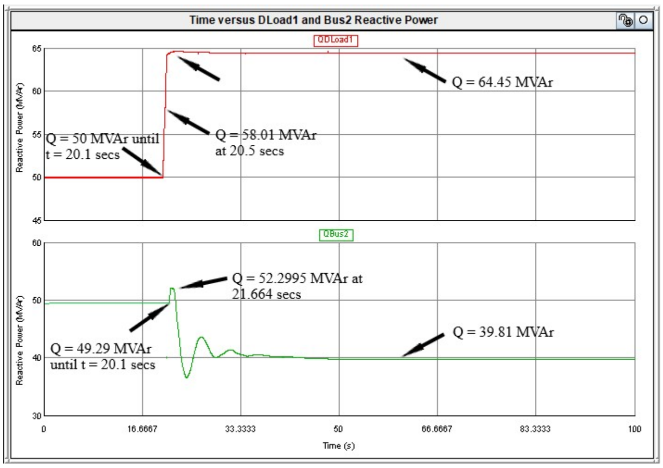

Fig. 15. Reactive power demand by DLoad1 and reactive power demanded by Bus2 from the system

VI. Discussion of Results

The results obtained during load demand increase contingency were done, at first when the wind power plant (WPP) is not integrated into the grid. The results were recorded as shown in Table IV for per-unit voltage, active, reactive, and apparent power viewed from both the load and the busbar. The overall initial load demand in the system was 315 MW (125 MW + 90 MW + 100 MW). These results are analyzed locally at the busbar for a seven-iteration overall load increment of 5 MW after every 0.1 seconds up to 21.1 seconds.

Initially, the load demand of 125 MW was experienced at Bus2 and the voltage was 0.9928 per unit. When the instant increase of load by 5 MW per 0.1 seconds, the voltage at Bus2 fell below 0.95 per unit after the fifth iteration at 20.5 seconds and never recovered up to the seventh iteration where the maximum power demand was 160 MW.

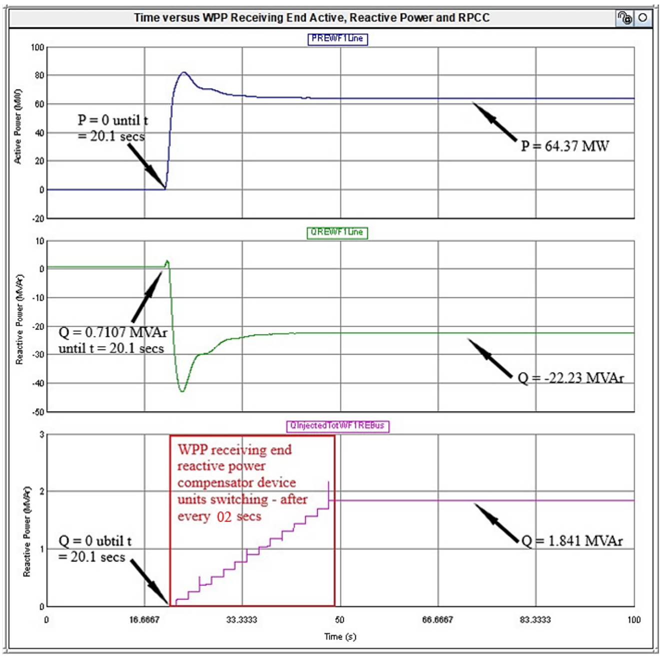

Fig. 16. The wind power plant receiving-end active and reactive power and the reactive power is compensated by the wind power plant reactive power compensator device at 420 MW overall system loading

Secondly, the wind power plant (WPP) was integrated and the system overloading contingency was implemented. Some of the quantities during the transition from 315 MW to 420 MW loading were monitored. The results obtained during this contingency were recorded in Table V for per-unit voltage, active, reactive, and apparent power viewed from both the load, DLoad1 and the busbar, Bus 2. The Red rows in the table show the voltage collapse point, and the Blue ones are the recovery point. The overall initial load demand in the system was 315 MW (125 MW + 90 MW + 100 MW). The results were analyzed locally for a seven-iteration overall load increment of 5 MW after every 0.1 seconds up to 21.1 seconds.

Initially, the load demand of 125 MW was experienced at Bus2 and the voltage was 0.9934 per unit. When the instant increase of load by 5 MW per 0.1 seconds, the voltage at Bus2 fell below 0.9526 per unit after the fifth iteration at 20.5 seconds, the voltage became unstable after 21.1 seconds by the value of 0.909 per unit at the maximum power demand was 160 MW. 54.531 seconds later, the effect of the wind power plant has come into place and brought the Bus2 voltage to a massive recovery of 0.9558 per unit. This fulfills the 160 MW (overall of 420 MW) loading for the system.

VII. Conclusions

The literature about voltage stability improvement is reviewed in this paper. IEEE Nine-bus system was selected and modeled, for the investigations of voltage stability challenges. Power flow simulations were done for both steady-state and abnormal conditions. The steady-state power flow simulations were done for the verification of system parameters. The abnormal load simulations were used as fundamental calculations of the voltage collapse point. Above 145 MW to 160 MW load demand, the voltage collapse was declared because it fell out of the range specified for transmission systems. The most vulnerable busbar was Bus2, in Area 1 of the system. For this reason, the additional power source was coupled to this busbar, to contribute with power when the load demand increases so that the system can remain stable even at 160 MW load demand at Bus2. The results show that the wind power plant can improve the voltage in the grid. Also, it shows that the wind power plant can be integrated into the grid while not contributing, and only start contributing with power when the load demand increase.

TABLE IV. BUS2 AND DLOAD1 QUANTITIES UNDER A STEP-BY-STEP LOAD INCREASE IN THE SYSTEM

	Duration (Seconds)	VBus2 (PU)	PBus2 (MW)	QBus2 (MVar)	SBus2 (MVA)	PFBus2
Bus2 measurements	20.1	0.9928	125	50	134.6291	0.9285
	20.2	0.984	130	51.8279	139.9505	0.9289
	20.3	0.974	135	53.7097	145.2919	0.9291
	20.4	0.964	140	56.1290	150.8326	0.9282
	20.5	0.950	145	58.0108	156.1738	0.9285
	21.1	0.905	160	63.9250	172.2970	0.9287
	42.1	0.948	160	63.9250	172.2970	0.9287
Load measurements	**Duration (Seconds)**		**PDL1 (MW)**	**QDL1 (MVar)**	**SDL1 (MVA)**	**PFDL1**
	20.1		125	50	134.6291	0.9284
	20.2		130	51.8279	139.9504	0.9289
	20.3		135	53.7097	145.2919	0.9292
	20.4		140	56.1290	150.8326	0.9282
	20.5		145	58.0108	156.1738	0.9285
	21.1		160	63.9250	172.2970	0.9286
	42.1		160	63.9250	172.2970	0.9286

TABLE V. BUS2 AND DLOAD1 QUANTITIES UNDER A STEP-BY-STEP LOAD INCREASE IN THE SYSTEM WITH WIND POWER PLANT INTEGRATION

	Duration (Seconds)	VBus2 (PU)	PBus2 (MW)	QBus2 (MVar)	SBus2 (MVA)	PFBus2	P-WPP (MW)	Q-WPP (MVar)
Bus2 measurements	20.1	0.9934	125.0000	49.2893	134.3668	0.9287	0.0000	0.7107
	20.2	0.9849	128.4700	51.1173	138.2661	0.9290	1.5300	0.7107
	20.3	0.9748	129.5650	51.5358	139.4382	0.9292	5.4350	2.1739
	20.4	0.9637	130.0000	53.9551	140.7521	0.9236	10.0000	2.1730
	20.5	0.9526	144.9999	54.8588	155.1306	0.9341	0.0000	3.1520
	21.1	0.909	-	-	-	-	-	-
	54.531	0.9558	95.6600	39.8100	103.6000	0.9233	64.3700	24.0710
Load measurements	**Duration (Seconds)**		**PDL1 (MW)**	**QDL1 (MVar)**	**SDL1 (MVA)**	**PFDL1**		
	20.1		125.0000	50.0000	134.6291	0.9285		
	20.2		130.0000	51.8279	139.9505	0.9289		
	20.3		135.0000	53.7097	145.2919	0.9292		
	20.4		140.0000	56.1290	150.8326	0.9282		
	20.5		145.0000	58.0108	156.1738	0.9285		
	21.1		160.0000	64.3011	172.2970	0.9286		
	54.5310		160.0000	64.3011	172.2970	0.9286		

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