Voltage Stability of Grid Integration for Distributed Energy Resources

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Abstract— **To minimize the gap between supply and demand of electrical power for enhancing the reliability, stability and quality of power in 21st century then there is need to upgrade convention power grid of 20th century to Smart Grid (SG) technology which comprises with information communication technology. Distributed Generation (DG) is one the best solution to minimize the gap because it is connected in distribution network which has negligible transmission loss and boost the power quality. This paper focuses on the different types of DG which is integrated to the existing grid. In this paper, three types of DG systems are considered i.e. solar energy, wind energy and fuel cell are integrated to the infinite bus using Matlab Simulation to verify the integrated system lie in stable region.**

Keywords— Distributed Generation; Fuel Cell; Hybrid system; Renewable Resources; SG; Solar Generation; Wind

I. INTRODUCTION

Electric power and electronic communications are one of the main technologies that changed rapid development of civilization in the 20th century. The study shows that the world's electricity demand will be triple by 2050. This estimation underlines the present electrical power system and to increase robustness in thought and economy of design. To determine what may be gain from new technology for a review of 20th century existing power grid. Need to transform existing power grid for more consumer friendly and economical. The demand of customer is mainly energy quality, availability at the same time it should be on lesser price. In principle, the Smart Grid (SG) is an up gradation of 20th century existing power grids. It provides more optimal way to for routing the power to respond for a wide range situation. It also provides more security by the introduction of communication technology with encryptions and remote access of asset which strengthen it. The definition and description of the SG are not necessarily unique, as its vision to the stakeholders and the technological complexities can be different [1]. For example, the Ontario SG Forum has defined the SG as follows.

"It is a modern electric system which is upgrade of 20th century grid. It comprises of information and communications technology, sensors, automation and computers for betterment of flexibility, grid security, reliability, power efficiency, and safety of the electricity system. It provides an option to consumer to choose and control their electricity uses and respond to electricity bill changes by adjusting their time of consumption. A SG accommodates electric vehicle charging by providing diverse, dispersed and new energy source. It facilitates integrated and connected operation of different source with grid. In a nutshell, it connects all electrical elements and parameter of the electrical system production, transmission, distribution and consumption binds together to control and improve complete system operation for the profit of consumers, distributors and the environment" [2].

In general it can be defined as "A SG is an electrical power grid with automation, communication and IT signal systems that can handle power flows from unit of generation to point of end users consumption (even down to the appliances level) and monitor the power flow or manage the load to equate generation in real time or near real time" [3].

Now days the electrical power transmission and distribution system normally operated at multiple voltage level. Voltage is one of the most important parameter for the control of power system when connected to DG. The connection of DG in distribution system has created a challenge for distribution network operator to change their usual passive approach to an active system. The conventional distribution networks are designed based on the assumption of unidirectional power flow with the increasing connection DG. The network has become more dynamic with bidirectional power flow. It is known as active distribution network. An active distribution network is defined as distribution network with system in place to control a combination of distributed energy resource comprising of generator and storage.

A key component to further deployment of DG and SG technologies and projects is to understand their technical and economic impacts to networks, customers and society in general. A better understanding of these topics will provide tools to decision-makers about the viability, drivers, and objectives of implementing such projects.

II. SYSTEM DESCRIPTION AND MODELING

In order to evaluate the impact of distributed generation on SG's steady state voltage profile and system stability or dynamic behaviour, which is essential to establish an appropriate applied model, an experimental setup is required. The research considers a small and simple system configuration with easier control and design of power system network as shown in Figure 1 and corresponding voltage

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waveform at bus 1 and bus 3 can observed in Figure 2 and Figure 3 respectively. In Figure 1, a power system network has shown in which power is transmitted from generation to distribution where the generation unit is far away from utility and consumer. This network represents the conventional method of power flow which is suitable in 20th century where use of electricity is limited; as the time passed the invention of a number of devices, gazettes, machines, etc. increased and demand of electrical energy sharply increased so the alternate method to increase availability of power is adopted i.e. Distributed generation which is generated in distribution network nearby consumers and transmission loss is negligible shown in Figure 4.

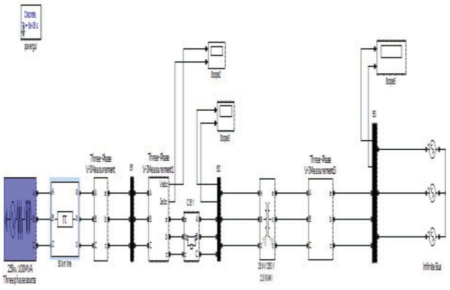

Figure 1: Power System network

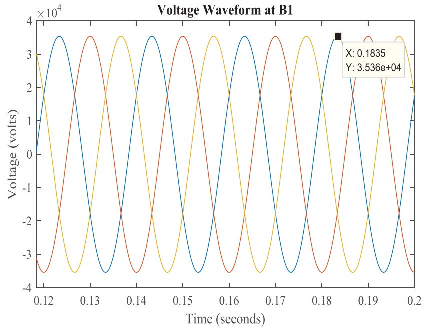

Figure 2: Voltage Waveform at bus 1

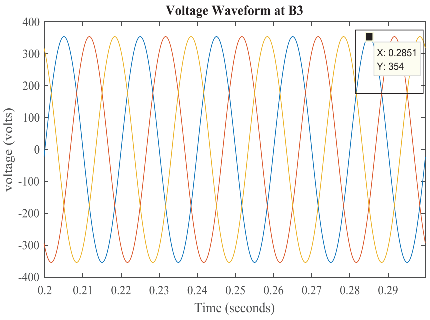

Figure 3: Voltage waveform at bus 3.

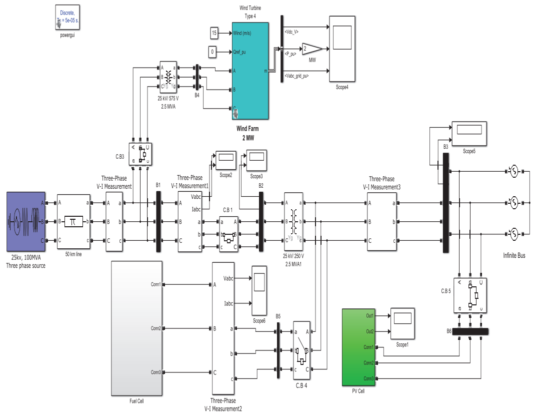

Figure 4: Power system network with DG connected

The parameters of power system network used in this simulation of Figure 1 are listed in Table 1.

Table 1: Parameters of power system network

Parameters	Values
Three phase AC voltage source	25 KV
Frequency	50 Hz
Line Distance	50 Km
Line Resistance	0.1153 Ω/Km
Line Inductance	1.05 mH/Km
Line Capacitance	11.33 nF/Km
Infinite Bus Voltage	250 V
Infinite Bus Frequency	50 Hz

III. INTEGRATION OF DIFFERENT DG SOURCES

There are three different types of DG sources integrated in power system network of Figure 1 and Shown in Figure 4,

- 2 MW Wind Turbine Generator (WTG)
- 50 KW fuel cell
- 250 W solar Photovoltaic (PV) cell [6-9]

The system is studied and analyzed under different cases.

Case I: Integration of Wind Turbine Generator:

Wind turbine power generation is rapidly becoming the preferred renewable source of electric energy. This research presents the modeling and simulation of a wind turbine energy conversion system connected to the power grid.

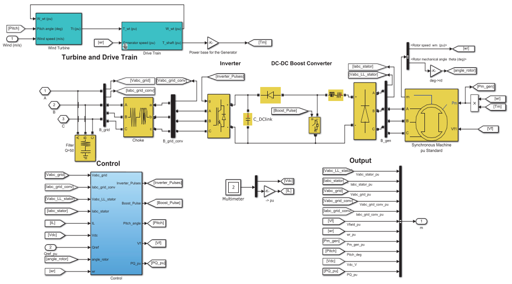

Figure 5: Simulation library model of wind turbine type 4

The wind turbine under consideration is a variable-speed variable-pitch turbine, connected to a speed-multiplying gear box to move a 3-phase wound rotor synchronous generator. The variable frequency energy produced by the generator is converted to the 50 Hz power system energy by a full power AC/DC/AC electronic converter. A detailed library model of wind turbine type 4 shown in the Figure 5.

Table 2: Wind Turbine Synchronous generator parameters

Parameters	**Values**
Nominal Power	2 MW
Nominal Voltage $(V_{L-L})_{rms}$	730 V
Frequency	50 Hz
Reactances $[Xd\ Xd'\ Xd''\ Xq\ Xq''\ Xl]$(p.u.)	1.305, 0.296, 0.252, 0.474, 0.243, 0.18
Time constants $[T_{do}'\ T_{do''}\ T_{q''}]$ (s)	4.49 0.0681 0.0513
Resistance R_s (p.u.)	0.006
Inertia constant	0.62
Friction factor	0.01
No. of poles	2

Table 3: Wind Turbine parameters

Parameters	**Values**
Nominal mechanical output power	2 MW
Wind speed at nominal speed and at C_p max	11 m/s
Initial wind speed	11 m/s

Power curve is shown in Figure 6 in which it is shown that once the maximum rated power is reached, the blade pitch angle is increased to reduce the power coefficient and power. These figures illustrate that in less than one minute, the blade pitch angle is adjusted by the controller in order to set the wind turbine output power to reference value. As the wind speed increases, the turbine extracts more power from the wind. Above 10-15 m/s wind speeds, the output power of the rotor must be controlled to reduce driving forces on the rotor blades as well as the load on the whole wind turbine structure. As shown in the graphs, once the rated power is achieved, the controller accurately increments the blade pitch angle to shed some of the unwanted power and prevent the wind turbine from damage. Figure 7 shown is the waveform of output voltage of wind farm in which it can observe that harmonics appear in graph because of DC-DC Boost converter. The Total Harmonic Distortion (THD) analysis performed in which it comes 2.42 %.

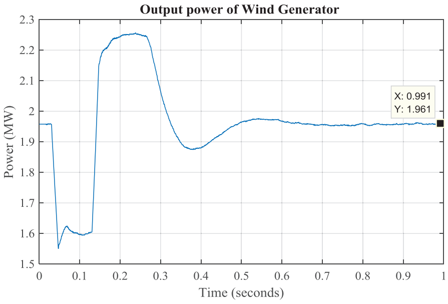

Figure 6: Output power of Wind Generator

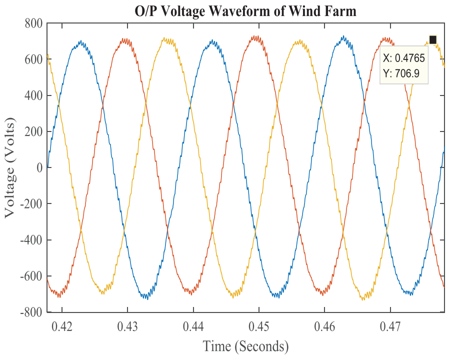

Figure 7: Output Voltage waveform of Wind Farm

Case II: Integration of Fuel cell:

Fuel cells are another rapidly developing generation technology. Fuel cells feature the potential for high efficiency (35–60%), low to zero emissions, quiet operation, and high reliability due to the limited number of moving parts. They produce power electrochemically by passing a hydrogen-rich gas over an anode and air over a cathode, and introducing an electrolyte in between to enable exchange of ions. The effectiveness of this process is strongly dependent upon the electrolyte to create the chemical reactivity needed for ion transport. As a result, fuel cells are classified by the electrolyte type:

- Polymer Electrolyte Fuel Cell (PEFC)
- Alkaline Fuel Cell (AFC)
- Phosphoric Acid Fuel Cell (PAFC)
- Molten carbonate Fuel Cell (MCFC)
- Solid Oxide Fuel Cell (SOFC)

In this research work, SOFC is considered for simulation, in which it is connected to a three-phase at bus 5 through an Insulated Gate Bipolar Transistor (IGBT) inverter. The inverter uses hysteresis switching and controls active power by manipulation of direct-axis current while holding reactive power at 0 VAr. The measurement blocks are rated at 50 kW. Therefore, an active power reference of 1 pu = 50 kW. Figure 8 shows a simulation model of SOFC and it is designed from the work done by [4]. The parameters for this simulation block are listed in Table 4.

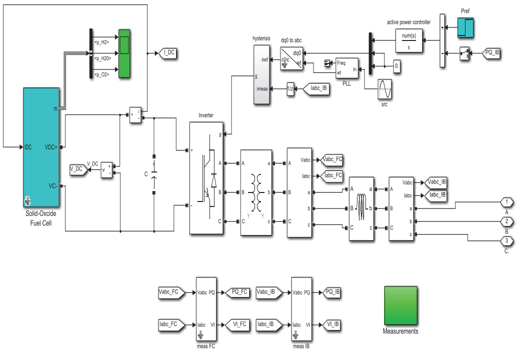

Figure 8: Simulation Model of SOFC

Table 4: Parameters for SOFC simulation

Parameters	Values
Absolute temperature (K)	1273
Initial current (A)	100
Faraday's constant (C/kmol)	96.487e6
Universal gas constant J/(kmol K)	8314
Ideal standard potential (V)	1.18
Number of cells in series	450
Maximum, minimal and optimal fuel utilization	0.9, 0.8, 0.85
Valve molar constant for hydrogen, water and oxygen (kmol/(s atm))	8.43e-4, 2.81e-4, 2.52e-3
Response time for hydrogen, water and oxygen flow (s)	26.1, 78.3, 2.91
Ohmic loss per cell (ohms)	3.2813e-004
Electrical response time (s)	0.8
Fuel processor response time (s)	5
Ratio of hydrogen to oxygen	1.145

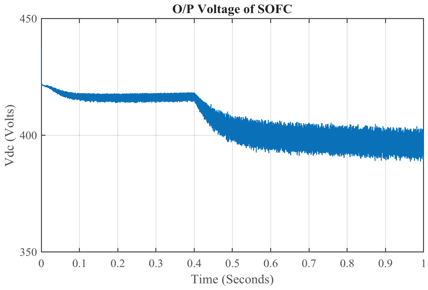

Figure 9: Output Voltage of SOFC

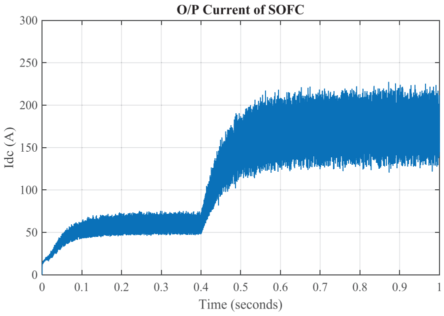

Figure 10: Output current of SOFC

Output voltage and current waveform of SOFC shown in the Figure 9 and Figure 10 respectively which shows that variable DC components. Figure 11 is Power curve of SOFC which is taken from terminal of transformer after DC component converts into AC component using universal bridge.

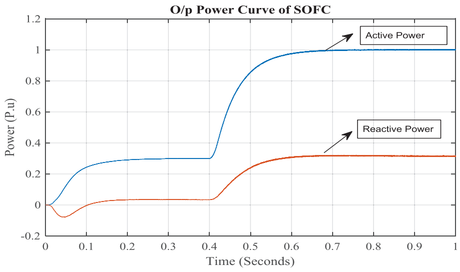

Figure 11: Power Curve of SOFC

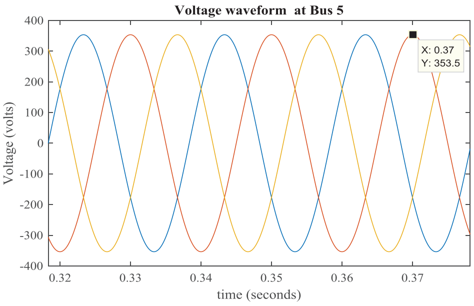

Figure 12: Voltage Waveform at bus 5

Figure 12 is voltage waveform at bus 5 just before integrated in distribution network and it matches one of the criteria to integrate that a voltage should be same of both incoming line and line which is integrated.

Case III: Integration of Solar PV cell:

Solar energy maintains life on the earth and it is an infinite source of clean energy. There is an increasing trend for the use of solar cells in industry and domestic appliances because solar energy is expected to play significant role in future SGs as a distributed renewable source. Optimal and large-scale integration of renewable sources into SG is possible by the aid of computer simulations and hence there is a growing demand for computer modelling and simulation of renewable sources. This study presents a generalized PV system simulation model for Matlab/Simulink simulation environment. The proposed model in Figure 13 is based on a behavioural cell model for modelling solar radiance to electricity conversion and an electrical driver interface for implementing electrical characteristic of power limited systems in power simulations.

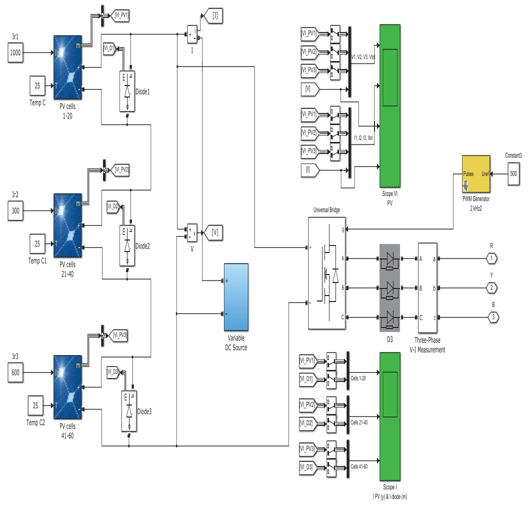

Figure 13: Simulation model of PV Cell

The model is efficient in computational complexity and it is easy to configure for representing wide-range of PV installations. The output characteristics of the PV model with different solar irradiance and cell temperature are nonlinear.

Furthermore, the solar irradiation is unpredictable, which makes the Maximum Power Point (MPP) of the PV module changes continuously. Therefore, a Maximum Power Point Tracker (MPPT) technique is needed to operate the PV module at its MPP.

The PV module is connected to a variable DC voltage source for measuring its *I-V* and *P-V* characteristics. It is modeled as three strings of 20 series-connected cells in parallel with bypass diodes that allow current flow when cells are shaded or damaged. Standard irradiance of 1000 W/m^2 is applied on the first string of 20 cells while partial shading is applied on strings 2 (cells 21-40) and string 3 (cells 41-60), resulting in respective irradiances of 300 W/m^2 and 600 W/m^2.The *I-V* and *P-V* characteristics are plotted in Figure 14. Note that the P-V curve exhibits three maxima. When this PV module is connected to a voltage-sourced converter, this may be challenging for the MPPT algorithm to converge on the highest peak. The MPP (P_m= 104 W) indicated by a red circle on the figure is 34% lower than the expected maximum power (250/3*(1 +0.3 +0.6) = 158 W).

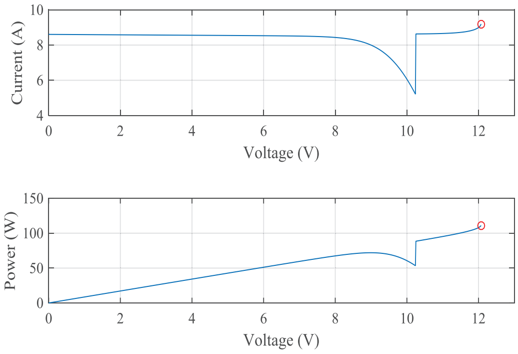

Figure 14: I-V & P-V Characteristics

Case IV: Integration of Solar, Wind and Fuel cell:

Three different types of distributed energy resources integrated in power system network i.e. wind, Fuel and solar to reduce transmission loss and increase efficiency along with more reliable, stable and improved power quality. When all three DG integrated then voltage profile observed at bus 3 shown in Figure 15 whereas without DG voltage waveform is plotted in Figure 3, when compared both voltage profile then one can see there is slightly reduced voltage at bus 3 when DG is connected, it is because of imbalance between active and reactive power. The considered maximum and minimum voltage variation is ±5 per cent from nominal voltage [5].

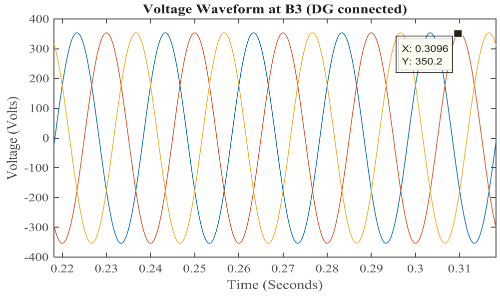

Figure 15: Voltage waveform at Bus 3 when DG is connected

IV. CALCULATION FOR VOLTAGE STABILITY

RMS voltage phase to phase $(V_1)_{\mathrm{rms}}$ without DG is

$$V_{1rms} = \frac{354}{\sqrt{2}} = 250.31 \text{ V}$$

RMS voltage phase to phase $(V_2)_{\mathrm{rms}}$ when DG is connected

$$V_{2rms} = \frac{350.2}{\sqrt{2}} = 247.6 \text{ V}$$

% Difference in voltage V_{2rms} and V_{1rms} is calculated as

$$\%\ \Delta V = \frac{250.31-247.6}{250.31} \times 100 = 1.08\%$$

The % difference in voltage at bus 3 is 1.08% which is acceptable However, large violations of voltages is not evident on all buses. The overall voltage remains within the allowable range.

V. CONCLUSION AND FUTURE WORK

In order to obtain the issue of distributed generation on the SG, four cases were studied on steady state voltage profile The integration of distributed generation on SG does not modify its steady-state voltage behavior. It shows that the steady state voltage deviation is still within limits although voltage oscillation is present. The result also shows the feasibility of integrating distributed generation on SG while its operation is in PV mode. Hence, the bus voltage and frequency of distributed generation is regulated by its own controller. This work incorporated only three distributed generations. Future experimental platforms must consist of different models of distributed generation technologies to provide diverse input. It also looks at the size of distributed generation using real time data. Future work could also be to look at the presence Flexible AC Transmission Systems (FACTS) device like Static VAR Compensator (SVC) controllers on the system as well as its location. Thus, the dynamic performance of the system can be analyzed further. In addition, future work should also investigate the system stability if another SG device is used, for example Static Compensator (STATCOM). With different SVC or STATCOM ratings and controls, the system can become more complex and this obviously has an impact on network strength and stability. Due to insertion of distributed generation with various power electronic converters in SG, future work could look at the system power quality concern, such as harmonic, flickers and voltage sags or dips. Transient stability is of major concern towards SG development. The adoption of a SG scheme allows making the current power system smarter. However, significant research direction is required to look at the application of standards based on the SG concept that will make the grid truly a SG.

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