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Analysis of PV Cell-based DG involving Improved Power Quality Converter for voltage control

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Abstract: ***The research investigated the impact on the power system with an extensive penetration of photovoltaic (PV) generation. A model of PV generation suitable for studying its interactions with the power system was developed. The dynamic response of a PV generation system to rapid changes in irradiance was investigated. An aggregated model of grid-connected PV generation was built, and it was used for simulating the integration of PV generation on a large-scale. Voltage control technique was investigated by simulation. Distributed Generation (DG) units are connected to the grid increasing nowadays for several reasons. Most DG units are relatively small and connected to the distribution network. A large part of the DG units connected to the grid via power electronic converters. The main task of the converters is to convert the power that is available from the prime source to the correct voltage and frequency of the grid. The general objective of this paper is to investigate how the power electronic converters can support the grid and solve power quality problems. An IEEE-5 bus system considered for this work to validate the power electronic converter using MATLAB/ Simulink.***

Keywords: Distributed Generation, PV Cell, IEEE – 5 bus system, Voltage control, Zeta converter, power Quality**.**

1. Introduction

The Over the last years an increasing number of Distributed Generation (DG) units are connected to the grid. This development is driven by governmental policy to reduce greenhouse gas emissions and conserve fossil fuels, as agreed in the Kyoto protocol, by economic developments such as the liberalization and deregulation of the electricity markets, and by technical developments. Most DG units are relatively small and connected to the distribution network (DN). A large percentage of the sources are connected to the grid via power electronic converters. The introduction of DG results in a different operation of the electrical power system. The conventional power system is characterized by a power flow from a relatively small number of large power plants to a large number of dispersed end-users. Electrical networks transport the electrical energy using a hierarchical structure of transmission and distribution networks. In a limited number of control centers the system is continuously monitored and controlled [1-2]. The changes due to the introduction of DG are mainly caused by the differences in location and operation principle between the DG units and the conventional generators and loads. The most important differences are:

1) The DG units are mostly connected to the DN; this introduces generators in the DN, which historically only contained loads [3-4].

2) A large percentage of the DG units are connected to the grid via power electronic converters, which have a behaviour that is fundamentally different from the behaviour of the conventional synchronous machine based generators [5-6].

3) Several types of DG unit are based on renewable energy sources like sun and wind, which are uncontrollable and have a recurring character [7-8].

4) Most DG units behave as ‘negative loads’ and do not participate in the conventional control of the network [9].

The introduction of DG causes several problems. The four problems that will be investigated in this thesis are described in this section. They are all caused by the differences in location and operation principle between DG units and the conventional generators and loads, outlined in the previous section. First three problems with a local impact are considered. The fourth issue has a global impact, meaning that the system as a whole is affected [10]. This article focuses voltage control of DG with power electronics converters application.

The objective of voltage control is to maintain the RMS value of the voltage within specified limits, independent of the generation and consumption [11-12]. Conventional voltage control in the high-voltage transmission network is mainly performed by the large power plants. In Distribution Networks (DN) voltage control is done by tap changers on distribution transformers. This control is relatively slow and compensates for the current depending voltage drop along the line, based on the assumption that only loads are connected to the network. The introduction of DG units in the DN will change the power flow in a part of the network. Also, some DG units have a primary energy source that fluctuates [9], especially those that are based on renewable energies such as the wind and the sun.

As a result, the DG unit power may fluctuate. The changes in magnitude and direction of the power will result in changing voltages, due to the current depending voltage drop along the line, which has a relatively high impedance in the low-voltage and medium-voltage grid [9], [13]. The voltage fluctuations can range from slow (hours) to fast (milliseconds). It may become difficult to keep the voltage within the specified limits and to meet requirements regarding flicker [3], [14].

2. PV Generation as A Source of Renewable Energy

One technology to generate electricity in a renewable way is to use solar cells to convert the energy delivered by the solar irradiance into electricity. PV energy generation is the current subject of much commercial and academic interest. Recent work indicates that in the medium to longer term PV generation may become commercially so attractive that there will be large-scale implementation in many parts of the developed world. The integration of a large number of embedded PV generators will have far reaching consequences not only on the distribution networks but also on the national transmission and generation system. If the PV generators are built on the roof and sides of buildings, most of them will be located in urban areas and will be electrically close to loads. On the other hand, these PV generating units may be liable to common mode failures that might cause the sudden or rapid disconnection of a large proportion of operating PV capacity.

2.1 PV cell characteristic

The equivalent circuit shown in Figure 1 and described by Equation 1 represents a PV cell:

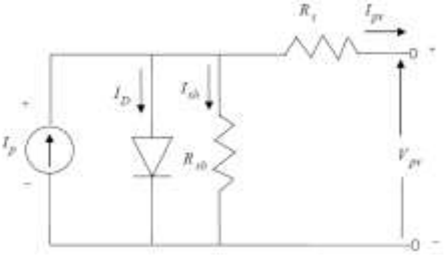

Figure 1: PV cell equivalent circuit

$$I_{pv} = I_p - I_D - I_{sh}$$
$$= I_p - I_o\left[e^{\frac{q(V_{pv}+R_s I_{pv})}{NkT}} - 1\right] - \frac{V_{pv} + R_s I_{pv}}{R_{sh}} \qquad (1)$$

where

I_p = Photocurrent [A]
V_{pv} = Terminal voltage of the cell [V]
I_D = Diode current [A]
I_o = Saturation current [A]
I_{sh} = Shunt current [A]
N = Ideality factor
q = Electron charge [C]
k = Boltzmann’s constant
T = Junction temperature [K]
R_s = Series resistance [Ω]
R_{sh} = Shunt resistance [Ω]

A sun power 305-WHT panel is modelled for the proposed system, which consists of 96 cells, and have the capacity of 100kW at 1000 W/m2, 25°C. Below Figure 2 shows the different V-I and P-V characteristics of the proposed PV panel (sun power SPR-305-WHT) at various temperature conditions. From the figure it is observed that the solar panel shows the maximum power point of 100kW with an irradiance of 1kW/m2 and 25°C temperature, at 200 W/m2 irradiance with 25°C temperature have the maximum power of 22kW and 82kW of maximum power at 1000W/m2 with 75°C.

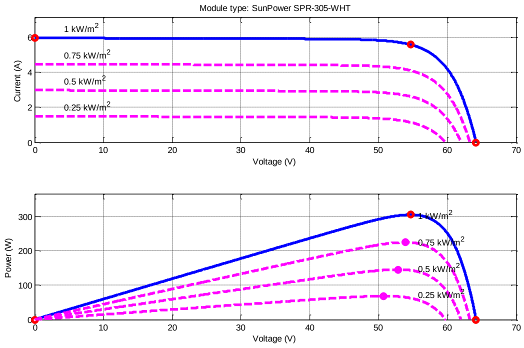

Figure 2: V-I and P-V characteristics of sun power SPR-305-WHT module

3. Power electronics interface

Power electronic converters play an increasingly important role in modern electrical engineering. They are an essential part of the integration of DG units into the grid. The voltage generated by most DG units cannot be connected to the grid directly. The power electronic interfaces are necessary to match both the voltage level and frequency of the DG unit and the grid [1]. This system consists of a zeta converter as a power quality improved in association with voltage source inverter.

3.1 Zeta converter

Different types of AC-DC converters have been introduced to fulfil the demanded power conversion such as Sepic, Cuk converters, etc. From the available converters, the zeta converters (Buck-Boost type) is incorporated in the proposed work. The zeta converter has advantages such as, safety, flexibility, isolation and output adjustment. Zeta converters usually have high transfer voltage gain and also produce high insulation on both sides. The gain of the Zeta converters always depends on the transformer’s turn ratio N, which can be thousand times. The zeta converter is a transformer based converter with a low-pass filter. Its output voltage ripple value is small [15-16]. The circuit diagram of zeta converter is shown in Figure 3., and Simulated output voltage and input responses of the zeta converter power quality improvement is shown in Figure 4.

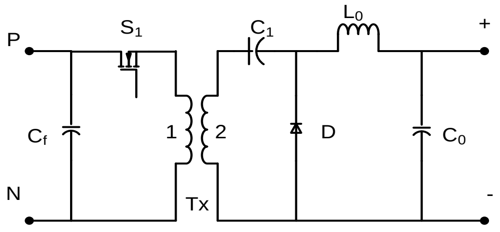

Figure 3: Circuit diagram of zeta converter

The output voltage is given by,

$$V_o = \frac{k}{1-k} N V_{in} \qquad (2)$$

Where N is the turn ratio of transformer, and k is the conduction duty cycle k= ton/T.

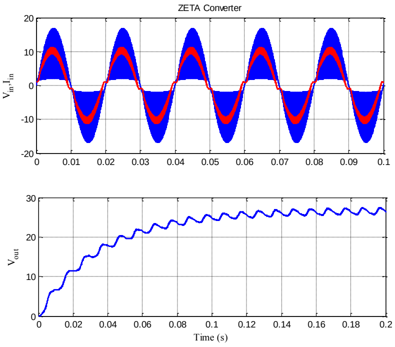

Figure 4: Simulated input and output voltage, current responses of zeta converter with improved power quality

An essential part of a grid connected PV systems is the means of converting the dc output of the PV array to AC power to supply to the utility network. Inverters are used to perform this task.

3.2 Grid

A load of grid connected PV inverters is the utility network. As seen from the inverter, this network looks like an infinite energy sink. The requirements for the grid connected PV system are dictated by the electric utility, and each utility may impose a unique set of requirements. These requirements can be divided into protection, power quality, operation and safety. IEEE- 5 bus, two machine system taken as a system to evaluate the DG performances with a solar panel. Voltage control using DG involving power electronic interface with IEEE 5-bus test system were obtained and discussed in this section. Voltage stability indices are calculated for the IEEE 5 bus system with and without Improved Power Quality Converter (IPQC) and Distributed Generation (DG). Figure 5 shows the IEEE-5 bus system with two generators without IPQC and DG.

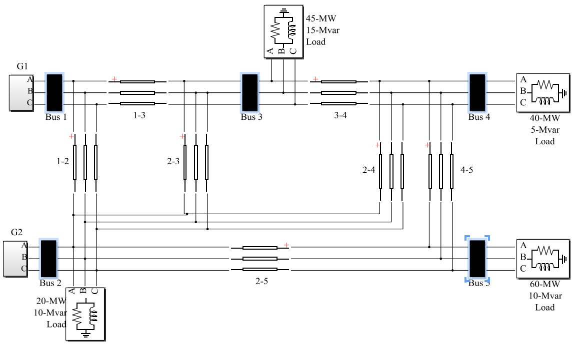

Figure 5: IEEE-5 bus test system

4. Simulation Results

This proposed system consists of a model of an IEEE-5 bus system with two generators for power quality analysis with DG and power electronic interface. Zeta converter chosen as a power quality converter, which boost a maximum output voltage from DE source. PV cell is considered as a DE source of this proposed system. The proposed system performance has been evaluated with and without IPQC with DG for various voltage disturbances. Figure 6 shows the Simulink representation of IEEE- 5 bus system with IPQC and DG. Figures 7-12 show the performance analysis of the 5 bus system for the analysis of PV cell based DG with improved power quality converters.

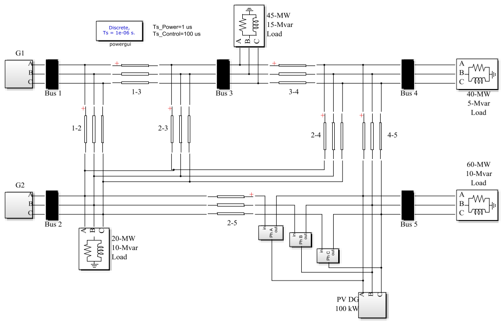

Figure 6: IEEE-5 bus test system with IPQC and DG

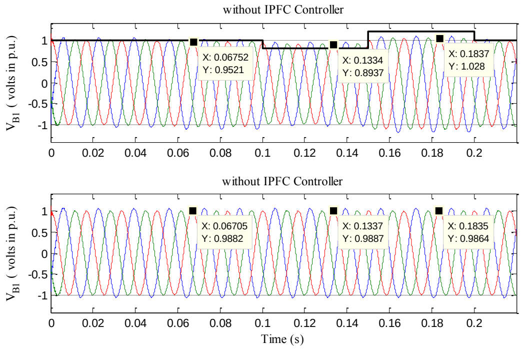

Figure 7: Voltage response of bus1 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2

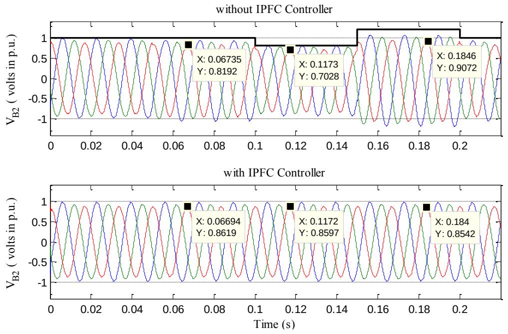

Figure 8: Voltage response of bus2 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2

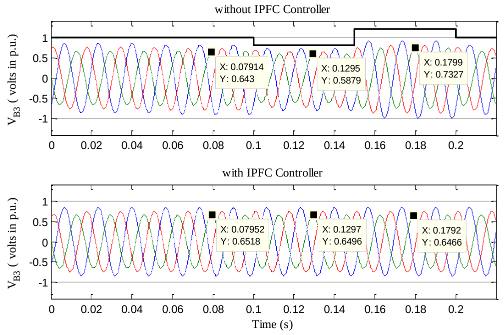

Figure 9: Voltage response of bus3 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2

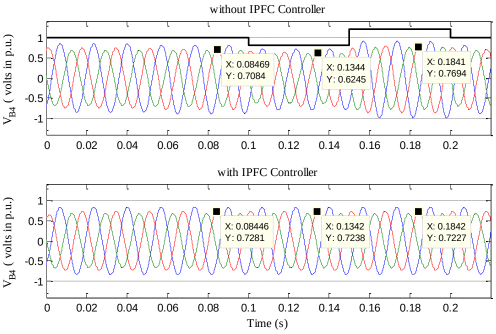

Figure 10: Voltage response of bus4 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2

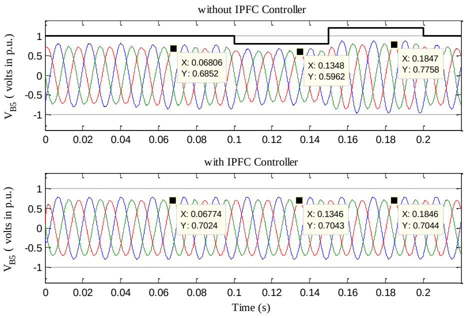

Figure 11: Voltage response of bus5 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2

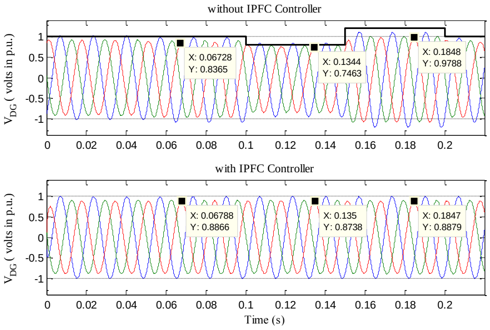

Figure 12: Voltage response of DG connected with IEEE 5 – Bus system without and with IPFC controller with disturbance introduced at bus 2

Voltage disturbance created in bus 2, the voltage fluctuation has been compensated with implementation of zeta based power electronic converters and improved the power quality of this proposed system. Figure 7 shows the voltage response of bus1 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2 with voltage disturbances occurs at t=0-0.1, V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 above V=1 p.u. Figure 8 shows the voltage response of bus2 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2 with voltage disturbances occurs at t=0-0.1 , V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 –above V=1 p.u. Figure 9 shows the voltage response of bus3 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2 with voltage disturbances occurs at t=0-0.1 , V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 –above V=1 p.u. Figure 10 shows the voltage response of bus4 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2 with voltage disturbances occurs at t=0-0.1 , V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 –above V=1 p.u. Figure 11 shows the voltage response of bus5 of 5 bus IEEE system without and with IPFC controller with disturbance introduced at bus 2 with voltage disturbances occurs at t=0-0.1 , V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 –above V=1 p.u. Figure 12: Voltage response of DG connected with IEEE 5 – Bus system without and with IPFC controller with disturbance introduced at bus 2 (t=0-0.1 , V =1 p.u ; t=0.1 – 0.15 , V = 0.8 p.u; t=0.15 – 0.2 , V = 1.2 p.u; t= 0.2 –above V=1 p.u). the overall power quality analysis is tabulated in Table. 1. It is observed that the system produced best power quality with presence of IPQC.

Table 1: Simulated performance evaluation of DG based grid interface with power electronic converters

Bus Number	*Voltage in p.u*	
	Without IPFC	*With IPFC*
1	0.96	0.98
2	0.81	0.86
3	0.64	0.65
4	0.70	0.72
5	0.68	0.70

5. Conclusion

Most distribution network operators require the disconnection of DG units when faults occur in the network. One reason for this requirement is that they fear that DG units disturb the classical protection schemes that are applied. It has been shown in this work that disturbance of protection does not necessarily occur when power electronic interfaced DG units are controlled properly. When DG units stay connected during faults, they can support the grid during a voltage dip. For some larger DG units directly connected to the transmission network, this is often required already. Voltage dips occur for a short period only. Overloading of a converter will mostly be possible for this short time. In combination with a variable inductance a significant reduction in the dip, depth can be achieved. It should be noted, however, that in some cases the variable inductance can reduce the short-circuit current that flows in the network, causing blinding of protection.

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