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Output Voltage Variations of Grid-Tied Solar Inverter due to Changes in Connected Domestic Load and Their Mitigation

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***Abstract*— Renewable energy has gained much importance lately and solar energy is such an option being widely deployed, specifically in the distributed generation scale. The integration of distributed energy into any traditional power system brings with it, unlike centralized generation, some unique issues apart from the known consumer benefits. By using a simple but novel lumped-element simulation of a distribution feeder circuit comprising of domestic loads, this paper describes the effects of the solar injection of one of these houses – which possesses a grid-interactive roof-top solar PV system – on the network. The issue of voltage rise at the point of common coupling (PCC) is observed, as evidently mentioned in various literatures. However, a method is also proposed in this paper to mitigate the same. This method involves varying the equivalent impedance of the domestic loads, and various alternatives for the same are proposed. With the advent of smart inverters, distributed control and smart appliances, this paper seeks to address the logical future concerns of electricity utility providers, prior to a high-penetration grid integration of rooftop solar. Several such strategies are discussed in the conclusion and future scope to address those concerns.**

***Keywords*— Load Sharing, Grid-Tied Solar Inverter, Distributed Generation , Roof-Top Solar, Voltage variations at PCC.**

I. INTRODUCTION

The demand for energy is continuously increasing. The present electricity generation capacity of India is 254.49 GW as of end September 2014 *[1]* out of which 87.55% is generated by conventional resources (coal, oil and nuclear) and 12.45% is from renewable resource (solar, wind, bio-gas). Generation of electricity using conventional resources has been proven to harmfully affect the environment, with global warming induced climate change as its major problem. Thus there has been a need to switch to renewable energy resources, as they are free from such emissions. Renewable energy resources can either be large-scale centralized power plants or can be tapped in the form of distributed energy resources (DER). For many years large scale renewable energy generation was the only possible method of grid integration, due to the intermittent and uncontrollable nature of any renewable resource viz. solar, wind or tidal; alongside other imperfections in simulating distribution network without sufficient research incentive. However due to recent developments in the sizing, installation and control of solar – wind hybrid stations and deployment of small-scale battery bank enabled micro grid, distributed energy resources (DER) are beginning to play a vital role in the restructured power sector [2]. Advantages of DER are improvement in power quality, reduction of T&D losses, increase in reliability and security of the existing power system [3-6]. But DER like other power sources is not without its share of disadvantages or hurdles either. Technical obstacles like unintentional voltage rise at the point of common coupling (PCC), over-loading of distribution feeder, and repeated yet prolonged tap changing of OLTC-enabled distribution transformers are widespread in the literature, and these have to be surmounted if the global aim to have emissions free generation is to be met. The focus of our paper is to study the effect of distributed solar photovoltaic generation (roof-top solar, to be precise) on an existing and typical distribution network (the radial feeder sort). The effect to be studied is voltage rise and fall at the PCC when the connected load changes in value, and to propose methods to mitigate the same. The proposed model, exact system of study and the simulation work is explained in the consequent paragraphs. The entire simulation is done in MATLAB/Simulink environment.

II. PROPOSED SYSTEM

A grid interactive roof top solar system is modeled via an array of solar cells (using its circuit equivalent form) connected via a DC boost chopper and a single phase inverter (IGBT H-bridge configuration and sine PWM triggered) to the mains connection point of a domestic household as shown in Fig. 1. In Fig. 1 ‘AC’ denotes the feeder transformer represented as a practical voltage source. ‘External load/Grid’ represents the lumped loads of both downstream and upstream loads as seen from this house. A condensed block diagram is shown in Fig. 2.

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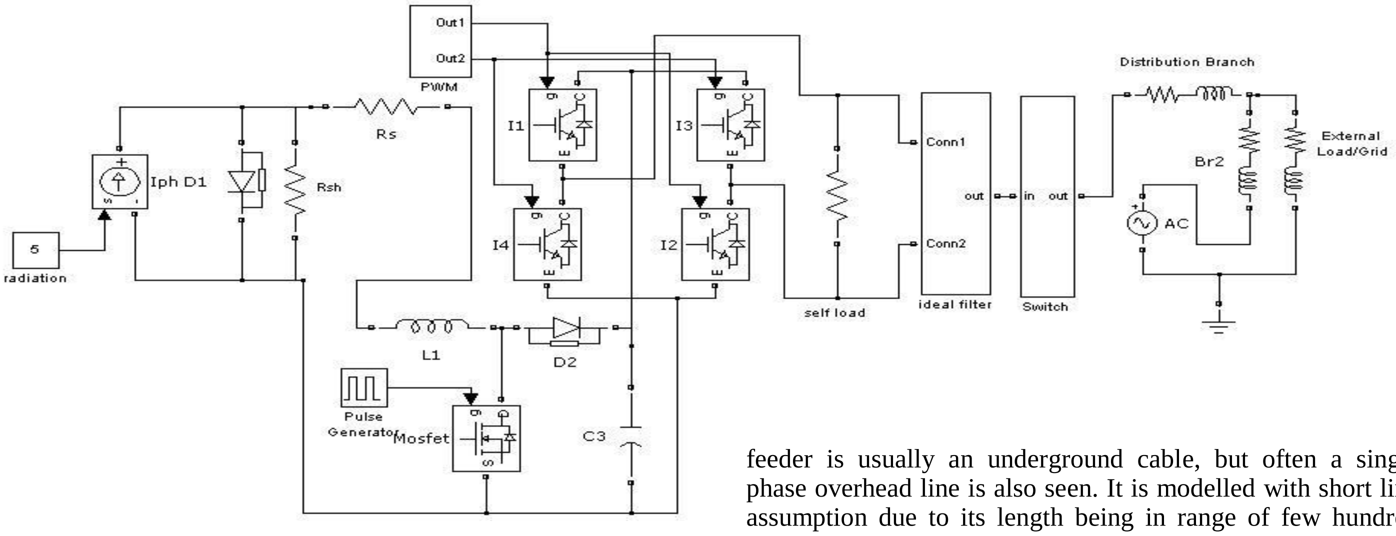

Fig 1. The circuit diagram of proposed system in Simulink.

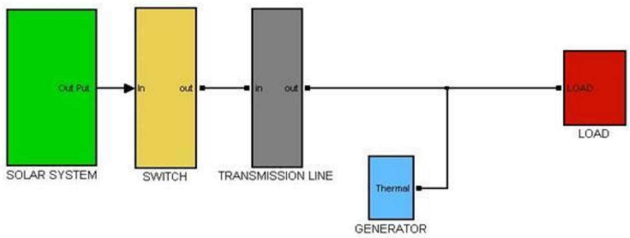

Fig.2 Block diagram of system under study in Simulink

III. DESCRIPTION OF THE SYSTEM CIRCUIT.

Domestic appliances connected to the mains of the house with the roof-top solar are referred to as the self load of the system, because they lie internal to the household premises. Also this self-load is believed to be within the control of the house-hold system, either manually or via some automatic control. This self load is also assumed to be always on-line (albeit as will be explained later, in varying magnitudes), and it is fed on a load sharing basis, by both the solar inverter and the mains supply. The quantum of load sharing will vary depending on the cases considered. The cases of power sharing considered here include firstly a case where both the solar generation and the mains supply are ON, and secondly a case of complete loss of solar generation due to a prolonged cloud cover. In the second case the self-load is as a result met entirely by the mains supply. The value of the self load considered itself depends on the kind of appliances in use, and their method of operation; but we have bothered with only a steady state value. Many of the simpler daily use devices are usually of the resistive kind, with mildly inductive power factors. This has been safely assumed to be true in our simulation cases as well, so a simple series RL model is followed.

The mains connections of households are connected to a distribution transformer via a distribution feeder cable, wich connects all the nearby houses in a radial topology. The end of the feeder where there is supply of power from the grid is known as the point of common coupling or PCC, as this is where many other feeders too converge, and go on to electrify a large area served by one such distribution transformer. This feeder is usually an underground cable, but often a single phase overhead line is also seen. It is modelled with short line assumption due to its length being in range of few hundred metres at the most. The feeder source is modelled as a practical voltage source with series impedance that reflects its maximum current capacity. This can be gauged by the practicalities of any system, where current limits are decided during the planning stage, and accordingly cable and transformers are sized. Now at the PCC node, the remaining households within the same radial feeder (both upstream and downstream) as well as other feeders emanating from this PCC, along with their respective downstream loads are lumped together into one equivalent series R-L branch, and denoted as the external load or grid-side load. This lumping is for simplification and is without any loss of generality. The lumping of both the upstream and downstream loads into one load, parallel to the PCC end is quite involved, and not discussed in detail here, but we can safely assume that it is feasible and useful to do so for purposes of quick analysis and point-of-view simulations. This external load is assumed to remain static for all cases, throughout the simulation.

IV. DESCRIPTION OF THE SYSTEM SIMULATION.

The simulation is performed in Simulink and consists of two cases. The first case demonstrates the system being fed by both the solar inverter and the mains supply, and it lasts for the first 50% of the runtime. A switch in the simulation is timed to disconnect the solar PV source at the 50% runtime instant. Thereafter in the second case, only the mains supply from the grid feeds the system, and this case lasts for the remaining 50% of the runtime. This switching simulates a condition when solar PV fails to generate adequate power, and the inverter is forced to shut down. This case can occur either due to permanent cloud shading or during twilight hours. The main measurement from the simulation is the voltage across PCC or at the feeder source-end. This is valid because the objective is to study the impact of distributed solar generation on the existing LV distribution network in terms of variation in voltage at the PCC. Other measurements are the external load current and active and reactive power consumed by the external load. The ideal filter removes all but the fundamental frequency, and since this is not a harmonic analysis, we are not bothered about the same either.

V. RESULTS

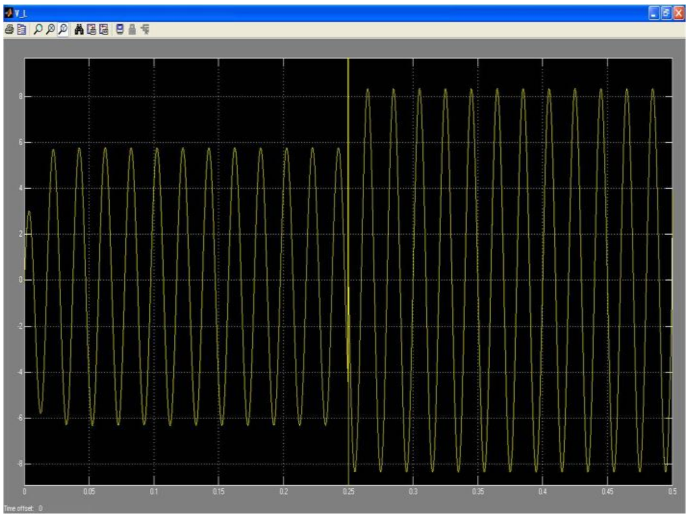

Fig.3: Variation of Voltage at PCC on X-axis vs. Time (sec) on Y-axis for self load equal to 100 ohm.

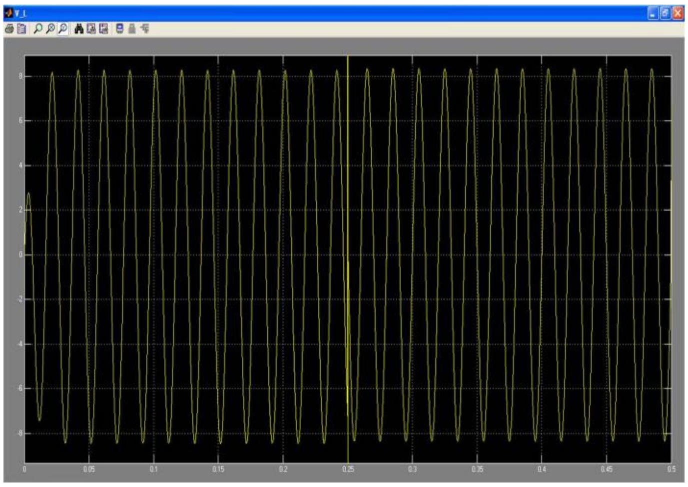

Fig.4: Variation of Voltage at PCC on X-axis vs. Time (sec) on Y-axis for self load equal to 250 ohm.

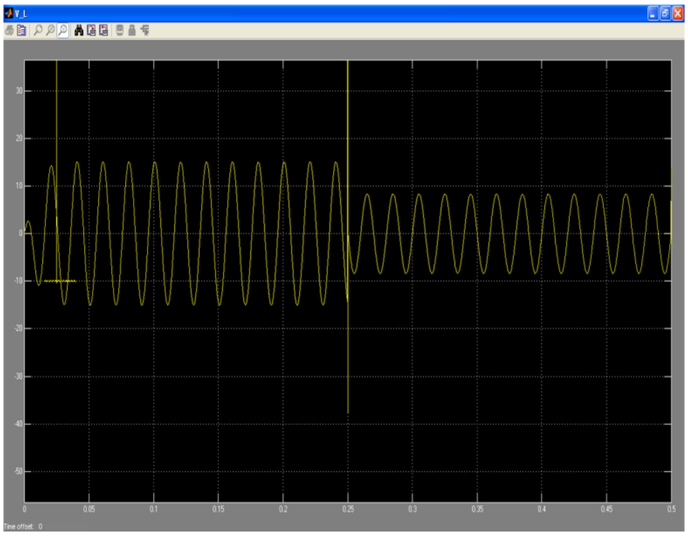

Fig.5: Variation of Voltage at PCC on X-axis vs. Time (sec) on Y-axis for self load equal to 1000 ohm

Table 1. Tabulation of the results for the cases

Sr. No	Variation of voltage at PCC for changes in self Load		
	Self load (ohms)	Voltage before switch (Volts)	Voltage after switch (Volts)
1.	100	5.9	8.2
2.	250	8.2	8.2
3.	1000	15.00	8.2

VI. OBSERVATION AND CONCLUSION

The result figures above clearly show that by simply changing the value of self load we can mitigate any voltage variation at PCC, occurring due to sudden loss of solar generation. The voltage before the switching event indicates the value resulting from generation due to both solar and conventional mains, whereas the PCC voltage after the switch is due to the solar generation alone. We observe that for a particular value of self-load the voltage levels at the PCC stay the same even when the solar PV generation disappears. In other words irrespective of the fact that solar generation takes place or not, the voltage level will remain the same, provided a particular value of self load remains connected. As penetration levels of distributed solar generation increase, such voltage rises will become all the more pronounced, especially during light local load conditions. This method of tuning or varying 'smartly' the appliances equivalent impedance, so as to mitigate such voltage variations, either due to loss of solar generation or sudden variations in external load (not considered in this paper), seems promising, at least in theory.

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