"A review on Impact of Solar Panels on Power Quality of Distribution Networks and Transformers"

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Abstract - *This paper presents an investigation on the impact of solar panels (SPs) on the power quality of distribution networks and transformers. Both solar farms and residential rooftop SP are modeled with the distribution network according to Canadian Utility data. Total harmonic distortion of voltages and currents on both sides of the distribution transformer are monitored under different operation conditions. A laboratory setup employing a single-phase inverter and three-phase transformer is used to test system performance in the presence of phase unbalance and harmonics. Core and winding temperatures are measured under various loads. Simulation and experimentation results show that the performance of distribution networks and transformers under the impact of SPs is within standard limits. SOLAR photovoltaic (PV) energy is one of the most rapidly developing renewable sources. Solar cells are made of semiconductor materials which convert light energy of the sun into dc electricity. Therefore, the usage of inverters with solar panels (SP) becomes inevitable before solar power can be used by local loads or transmitted into the grid. SPs are normally installed in distribution networks, rather than the generation or transmission levels of power systems. Both small rooftop SP installations and large solar farms create voltage harmonics and inject current harmonics into the distribution network by the associated inverters. On the other hand, distribution transformer.*

Key Words*: Power Quality, Solar Energy, Harmonics, Inverter, *Distribution networks, distribution transformers, harmonics, solar panels (SPs).

1. INTRODUCTION.

Government promotion of renewable energy sources has led to several large scale solar power plants in India. India receives solar energy in the region of 5 to 7 kWh/m2 for 300 to 330 days in a year. This energy is sufficient to set up 20 MW solar power plants per square kilometre land area. With about 300 clear, sunny days in a year, India's theoretical solar power reception, on only its land area, is about 5 Petawatt-hours per year (PWh/yr) (i.e. 5 trillion kWh/yr. or about 600 TW). The daily average solar energy incident over India varies from 4 to 7 kWh/m2 with about 1500–2000 sunshine hours per year (depending upon location), which is far more than current total energy consumption. For example, assuming the efficiency of PV modules were as low as 10%, this would still be a thousand times greater than the domestic electricity demand(in India) projected for 2015. The amount of solar energy produced in India is less than 1% of the total energy demand. The grid-interactive solar power as of December 2010 was merely 10 MW.

Government-funded solar energy in India only accounted for approximately 6.4 MW-yr of power as of 2005. However, as of October 2009, India is currently ranked number one along with the United States in terms of installed solar power generation capacity. Renewable distributed generation units, if properly controlled and designed can improve the power flow management on the grid and reduce the probability of grid faults, so increasing the power quality of the energy supply. It's important to evaluate also the possible drawbacks of the increasing number of renewable energy sources on the power-supply stability and quality, both in grid connected and stand-alone configurations, in order to prevent possible. Problems with a proper design and management of this generation. formers are subject to second-quadrant operation (i.e., when the active power flow is reversed) under light load conditions when SP operate at or close to full capacity. Although power system harmonics are known to be consequences of nonlinear loads, accurate measurement of voltage and current harmonics is quite tricky [1]. Tracking down harmonic sources is also challenging as well as effective filtering and mitigation techniques [2]. A few publications in the literature have considered the effects of SP on distribution networks. Impact of the SP at the Sydney Olympic Village on accommodating network is addressed in [3], where voltage and current total harmonic distortion (THD) remain within standard limits even if all SP operate simultaneously. In a weak network supplied by SP, the replacement of incandescent lamps by compact fluorescent lamps, for energy saving, increases voltage THD [4]. The initial THD of 3.14% can reach 10.15%, 22.2%, and 34% if 30%, 60%, and 90% of the lighting load is replaced, respectively. In [5], the effects of SP on power grids of two small Greek islands are studied and compared with the case of Diesel generator supplies. Although voltage THD with SP operation is higher than the Diesel generator case, yet, it remains under standard limits. With the combination of linear and nonlinear loads on a transformer, an expansion of the standard K-factor evaluates the composite harmonic current [6]. Rad et *al.* [7] Problems with a proper design and management of this generation unit harmonic measurements on six distribution transformers along with other performance indices. Harmonic effect on winding eddy current loss is found much more significant than other stray loss. A laboratory setup is proposed to measure losses of high switching frequency converter transformers, and compare with those computed through finite elements [8]. In [9], voltage and current harmonics caused by various nonlinear lighting loads are presented, and de-rating of the distribution transformer is accordingly proposed. A calculation routine of the reduced per unit load, at which distribution transformers maintain full lifetime under current harmonics, is presented in [10]. Harmonics generated by different nonlinear loads are measured in the laboratory, and their impact on transformer losses, temperature rise, and loss of life is studied [11]. The finite element method is used to calculate the hottest spot tem- perature through field strength solution at different parts of the transformer [12]. The change in the temperature rise because of harmonics is used to estimate the lifetime expectancy and propose a new loading profile to keep lifetime unaffected.

This paper introduces a study on the impact of SP and their associated inverters on the distribution network and transformer. A MATLAB/Simulink model is built for SP and distribution network according to Canadian Utility data; both solar farms and residential rooftop SP are considered. Voltage and current THD are monitored under different conditions. In a laboratory setup, a single-phase grid-tied commercially available inverter for solar power applications is used to feed a three-phase transformer connected to the grid. Losses, efficiency, and voltage and current THD are measured as well as core and winding temperatures. Results show that SP do not have significant harmful impact on distribution networks or transformer, as long as they keep low relative rating with respect to the power carrying capacity of the system.

2. SIMULATION RESULTS:

A) Review on analysis of Solar Farm

A simulation model is built in MATLAB/Simulink for a solar farm on the basis of Canadian Utility data for the system shown in Fig. 1. The transmission system is modeled as 115 kV, 170 MVA, and three-phase source. Two 83 MVA, 115/27.6 kV transformers exist within the distribution system shown as one block in Fig. 1. Bus 1 is the point of common coupling (PCC), where the solar farm is connected to the system at this point. The solar farm includes 17 SP of 500 kW each. One SP is separately connected to a 27.6 kV/265 V, via a dc converter, whereas the associated inverter applies sinusoidal pulse-width modulation (PWM) and has an LCL low-pass filter (Fig. 2).

It is still practically accepted to have such ratings by consid- ering that solar farms do not usually operate at rated capacity all the time owing to changes in environmental conditions. SPs typically give rated output at standard test conditions (1000 W/m^2 solar irradiation and 25 °C cell temperature) which may not be maintained all the time. On the other hand, from the simulation-work viewpoint, the SP impact on distribution transformers becomes more serious as the SP rating increases. Therefore, simulation results would be more conclusive in the present case.

The system shown in Fig. 1 is modeled under balanced and unbalanced conditions with and without capacitors at the PCC when the solar farm operates at rated power. The THD of phase voltages and currents on both sides of the transformer are monitored. In balanced case, system voltages of the transmission system are equal to rated value and shifted from each other by 120°. Three cases of voltage unbalance are considered as shown in Table I. In practice, it is unacceptable to have voltages more than 1.1 pu. However, some phase voltage values in Table I are exaggerated to make sure the impact of voltage unbalance on harmonic distortion is insignificant. The THD of phase voltages and currents at both sides of the transformer are given in Table II. Results imply that phase voltage THD is always less than the standard permissible limit of 5%, except for phase-B secondary voltage under unbalanced case #3. However, current THD is mostly under the standard limit, except for phase-A primary current.

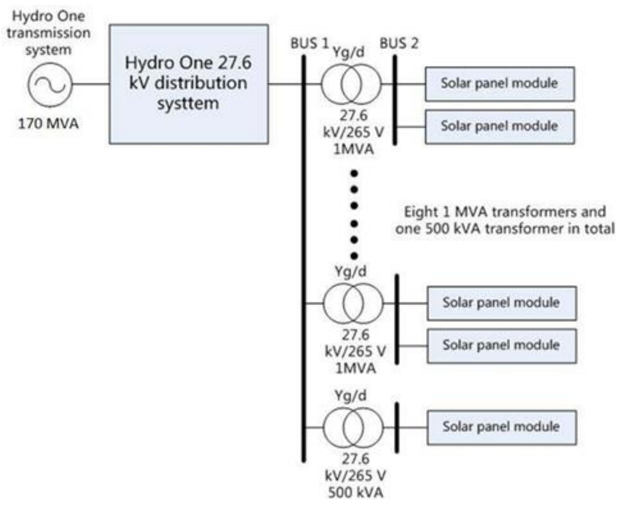

Fig. 1: Solar farm system model.

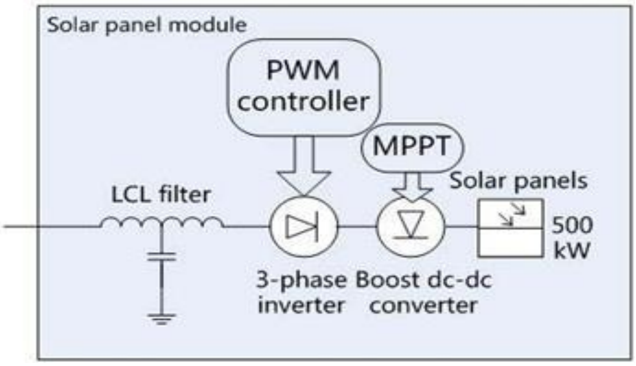

Fig. 2: SP model.

under case #3 of unbalanced operation. None of the individual voltage or current harmonic components exceeds the standard limit of 3% under any case. The only exception is the fifth secondary voltage harmonic on phase-B under unbalanced case #2, which is 3.05%. Results show that waveform distor- tion is more sensitive to unbalance in voltage magnitudes than phases. It should be noted that waveform distortion in cases of unbalance may not be due only to SP. Some phase voltage magnitudes significantly exceed rated value which could cause transformer saturation leading to more distortion. Finally, it could be concluded that voltage and current THD are mostly within acceptable values with SP operation under balanced and unbalanced conditions.

The next procedure to remedy the negative impact on voltage and current waveform distortion is to install shunt capacitors at PCC to help filter out harmonics. Capacitors with different VAR ratings are tried; results of new THD are shown in Table III. It can be noticed that there is no significant changes in THD values for capacitor rating up to 8 MVA. At 10 MVA, voltage THD on both sides and secondary current THD are noticeably reduced. Capacitors at such rating are likely to assist low-pass filters of SP by reducing the cutoff frequency. However, for ratings above 14 MVA, all THD increase again, possibly due to transformer saturation as a result of voltage increase at PCC.

B) Review on analysis of Residential Rooftop SP

Impact of residential rooftop SP on distribution network and transformer is then considered. The difference between residential SP and solar farms is not only the output power, but also the method of integration with the system. Solar farms are usually located far outside residential areas, and are normally connected to the grid at PCC using long feeders. On the contrary, residential SP is located in urban areas, and are connected to the grid at many points inside the distribution network. Three-phase inverters are commonly used with solar farms, and transformers are mostly employed to raise the voltage up to the distribution level. However, because residential SP are usually less than 10 kW in rating, single- phase inverters are used to connect directly to the 240 V feeders.

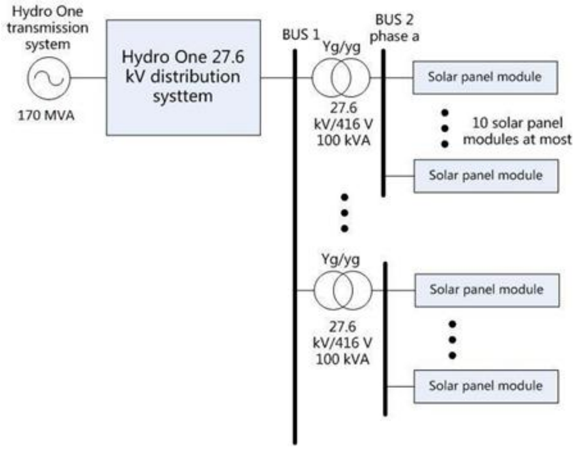

Fig. 3:Residential SP system model

3. CONCLUSIONS

This paper presents a study on the impact of SPs on the power quality of distribution networks and transformers. Solar farms and rooftop residential SPs are independently simulated when incorporated into distribution systems. Results show that voltage and current are mostly within permissible limits under different conditions. An optimum value of capacitors connected at the PCC can help the system reduce voltage and current THD. Results also show that voltage and current distortion increases as the number of SP inverters connected to the system increases. An experimental setup is built in the laboratory to test a three-phase dry-type transformer when fed by a single-phase grid-tied inverter, and connected to the grid. Voltage and current THD, losses and efficiency of the transformer, and core and winding temperatures are all measured under different SP output powers. Results show that all THD values are within standard limits, losses and efficiency increase with loading, and temperature is always well below the rated load value.

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