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Harmonic Modelling of PV System for the Assessment of Impact on Grid

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Abstract: *With the growing awareness in sustainable environment, more electricity customers are becoming energy conscious. This leads to the increase of installation of grid-connected photovoltaic (PV) panels for small scale electricity generation. The nature of intermittent power generated by PV cells and the interconnection between PV panels and the network through DC-AC converter affect the quality of the electrical supply and these issues are as important as the environmental issues. Various studies observing the impact of (increasing) penetration of PV systems at distribution level and the methods to mitigate this impact have been conducted by many parties, including academia, network operators, even PV inverter manufacturers.*

Theoretically, the overall power quality performance of the system can be managed by assigning limits to customers and ensuring that they do not exceed their apportioned harmonic limits. In practice, it is often difficult to assess the actual harmonic current contribution of an individual customer. This is particularly true when the customer installation incorporates capacitive elements such as power factor correction capacitors or harmonic filters. A combination of measurements and simulations is therefore required to evaluate compliance [9].

Keywords: *PV Grid Integration, Grid Interactive Photovoltaic System, Resonance, Harmonic Domain, Medium-Voltage Distribution Network*

I. Introduction

Power quality issues in electrical power system are gaining more attention lately, especially those stemming from non-linearity of power electronics used in certain grid connected equipment. Switching mechanisms implemented in converter-connected distributed generation units such as photo-voltaic (PV) inverters are responsible for additional harmonics in the network and the output filters used to reduce these harmonics are also responsible for resonance frequencies in the network. Simulation models for PV inverters are essential for understanding the technical issues, developing solutions, and enabling future scenarios with high PV penetration. The model used to represent these inverters depends on the purpose of the study. This thesis presents alternative PV inverter models to be used in harmonic studies and investigates possible models to be used in voltage dip studies. The investigation on inverter behavior during voltage dip, however, suggests that the models are to be developed for harmonic studies only. Following the experiment with voltage dip scenario, the models are verified in simulations and experiments in the laboratory that also observe the behavior of an aggregation of inverters in harmonic study.

The pulse-width modulation (PWM) inverters used within PV plants inject current harmonics into the distribution / transmission network. This may cause harmonic-sensitive equipment to malfunction if the level of harmonic distortion is too high [5]. The malfunctioning of control and protection equipment, overloading of power plant – notably power transformers – and the failure of power factor correction capacitors are well-known effects of power system harmonics [6].

Furthermore, harmonic current and voltage distortion can be exacerbated by the introduction of series and parallel resonances caused by connection of a solar PV plant to the network. If a resonant frequency coincides with a harmonic frequency present in the power system – generated by the PV plant or by an external harmonic source –the current or voltage distortion may be amplified, depending on the nature of the resonant impedance [7].

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Harmonic modelling of power systems can be difficult. Haplin [10] identifies the following key challenges for harmonic modelling of a new installation:

- Data for new equipment and installations are approximate and may change from initial design to as-built plant status.
- Utility systems are large and very complex so simplification and network reduction are required.
- Data for existing equipment may be limited to harmonic measurements at the Point of Common Coupling (PCC). Detailed data from existing customers are often not available.
- Utility network configurations and operating conditions as well as customer equipment operating conditions, configurations and procedures vary widely over time and are difficult to predict.

The ability to determine the harmonic emissions of an individual customer is important to both the utility and the customer. If the utility relies only on its measurement of the global harmonic voltage distortion at designated points in the network, high harmonic emissions from an individual installation may not be detected. This is because the sum of all contributions at the point of measurement may not exceed the utility planning levels even though one or more installation is exceeding its apportionment. The problem may become apparent only after connection of additional customers or after a change in the system configuration. In this case, the management of harmonic distortion will be reactive and customers may be adversely affected until a solution can be found.

The problem of harmonic emissions from utility-scale solar PV plants, and the development of methodologies for assessment of such emissions, is becoming increasingly pertinent as the number and individual generating capacity of plants worldwide is growing rapidly. The issues are especially relevant in the South African context due to the rapid expansion of the solar PV industry and the significant number of large utility-scale generating plants which have recently been connected to the network or are due to be connected within the next few years. The proximity of some of these projects to one another, their remote location, far from major load centres, and the fact that they are often connected to relatively weak HV distribution systems are further factors that may influence the impact that these plants have on the harmonic distortion in the local distribution network.

As a result, the document seeks to achieve two objectives in the primary sense of developing an improved PV model (one and three phases) and then repeat the research on the occurrence of MVDN using the proposed model. The suggested harmonic range (HD) technology has been implemented in. The proposed model can be referred to as the HD Norton equivalent circuit model for the VSC-PV system. The HD method is useful to describe the interaction between the photovoltaic system and the network that works under distorted and undistorted conditions. In addition, this model is suitable for proposed studies of harmonic energy flow (HPF) using a technique developed in HD (taking into account the harmonics and between both harmonics).

To carry out a MVDN resonance study, network components such as transformers, loads and capacitors have been extruded as in HD. The standard IEEE 13-bus distribution system was modified and used for simulation. The technical and insightful results are presented and discussed.

II. Pv System Modelling

The photovoltaic system includes a range of photovoltaic modules, power conditioning unit, filter, control circuits, protection devices (for example, isolation keys), connected transformer, etc. VSC is a type of PV in this work although the method is also applicable. Figure 1 and Figure 2 are used to develop circuit equations for single and triple phase photovoltaic systems, respectively. The DC voltage is estimated from PV modules / matrices that act as inputs to the inverter using different formulations. The inverter is designed using the conversion function technique. This method treats the inverter unit as a black packet and, therefore, depends on its operation instead of a circuit-based model. The input (DC voltage) and the output are equated by (1).

$V_{inv}(t) = G(\omega t)V_{dc}$ ………………………………… (1)

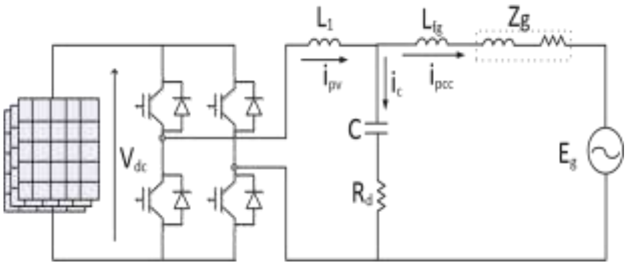

Fig 1: Schematic diagram of single phase PV system

In fact, the expressions of the conversion function are not unique where multiple expressions can be derived for the same conversion process. This modeling approach was published in [16] although no explicit expressions of the conversion functions used were given. The document also assumed a bipolar substitution process that was inferior to the unipolar strategy deployed here. This is because the former generates more harmonics than the latter [17]. The double-Fourier series is also used in [18], but this requires many computer requirements and is difficult to integrate with other models of the photovoltaic system, for example. LCL filters. Therefore, in this document, the method adopted in [19] was used to derive the HD coefficients of the following conversion function of the photovoltaic system in 3 stages.

III. Proposed Model Validation

Not only to invert DC current into a sinusoidal AC current, an inverter must also boost the array's voltage with a further element, if the PV array's voltage is lower than the grid voltage, in order to feed energy to utility grid. The electrical behavior of PV systems connected to a network is determined by its inverter's topology. PV inverters are currently based on single-phase self-commutated voltage-source converters in the 1-5kW power range for individual households. These inverters utilize high-frequency or line-frequency transformers; some are even transformer-less. [2] Figure 4-1 shows the topology of transformer-less single-phase self-commutated inverters; DC source consists of PV panels and a DC-DC converter. [3]

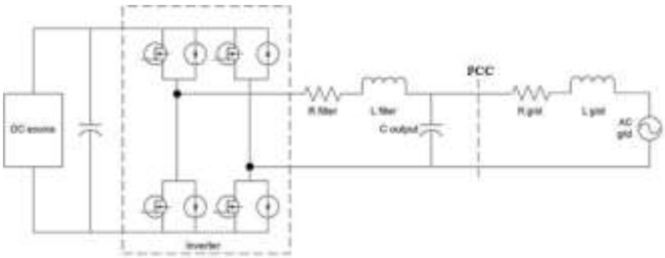

Fig 2: Topology of Transformer-less Single-Phase Self-Commutated Inverters

In addition to the agreements in the results between our proposed model and those already in the literature, our model shows some strength in some aspects. First, the model suggested in this document can accurately capture all unusual and unusual harmonics and thus eliminate the assumption of distinctive harmonics by themselves.

Secondly, the harmonic interpretation between the photovoltaic system and the non-linear component (such as the transducer in the saturated state) or the load (like the asynchronous speed motor) can be fully calculated in our proposed analytical model, unlike the interval approach of phases that separates the interaction. From this point of view, the possible cancellations between the PV harmonics and the network can also be easily captured using our model. Therefore, the assumption about the variation of the phase angle of the harmonic components becomes unnecessary.

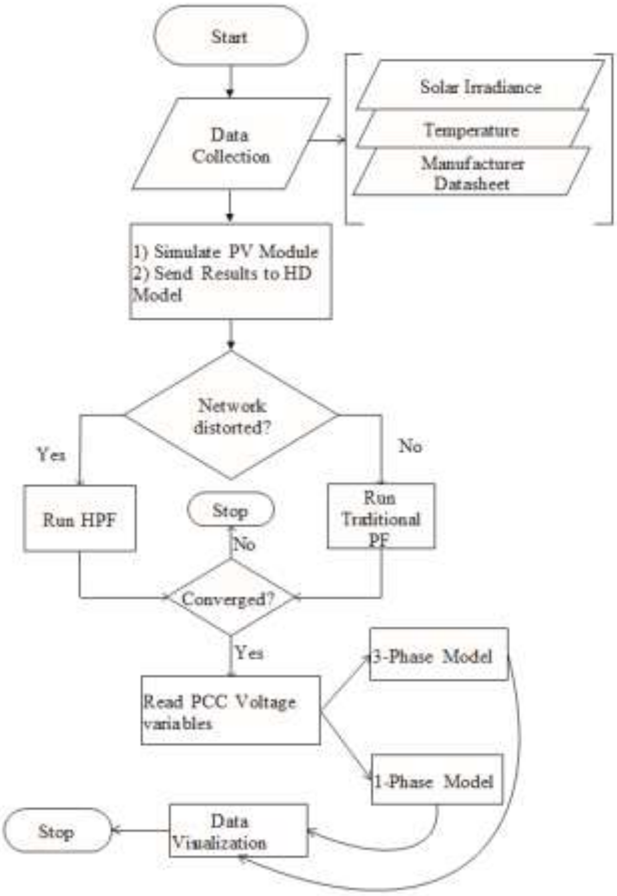

Fig 3: Harmonic Prediction Algorithm Using Proposed Model

The resonance test carried out with the proposed model also confirms the effect of the resistance to inhibition and the negative charge on the inhibition of the resonance affected by the interaction between the LCL inverter filter and the network. This is also consistent with [9].

After validating our model, it is important to clarify that the model proposed in this document is the first HDRF model for the VSC-PV system (for better knowledge of the authors) and has useful applications beyond the resonance probe where it can also be publish in HPF studies developed in HDRF.

The main cause of harmonic generation is non-linear loading. Non-linear loads change their impedance in response to the applied instantaneous voltage. This causes non-sinusoidal current to flow when the applied voltage is zero. In other words, this type of load does not have a constant ratio of current to the voltage during switching. Power electronics used in power converters cause problems with power quality such as harmonic distortion. The performance of photo-voltaic systems with respect to power quality is highly dependent on the use of the inverter, the amount of solar radiation, and the temperature, which can affect the generated power, voltage and current profiles. In this study, we examine the effects of solar radiation on a clear day to investigate the effect of this phenomenon on the overall distortion performance of a photo-voltaic system.

The DC output of the photo-voltaic array should be converted to AC in the power system grid. Under this condition, the inverter needs to convert direct current to alternating current. Switch mode inverters use switching devices such as commutating thyristors that can control the turn-on timing but not the turn off time itself. Shutdown must be performed by reducing the circuit current to zero using additional circuitry or power. On the contrary, the self-excitation inverter is characterized by using a switching element capable of freely controlling the on state and the off state, for example, an IGBT or a MOSFET. The self-excited inverter can freely control the voltage and current waveforms on the AC side, adjust the power factor, and suppress harmonic currents. He is very resistant to network confusion. With the advancement of switching devices, most inverters use distributed power supplies such photo-voltaic power generators which is now self-commutated inverters.

IV. Matlab Simulation

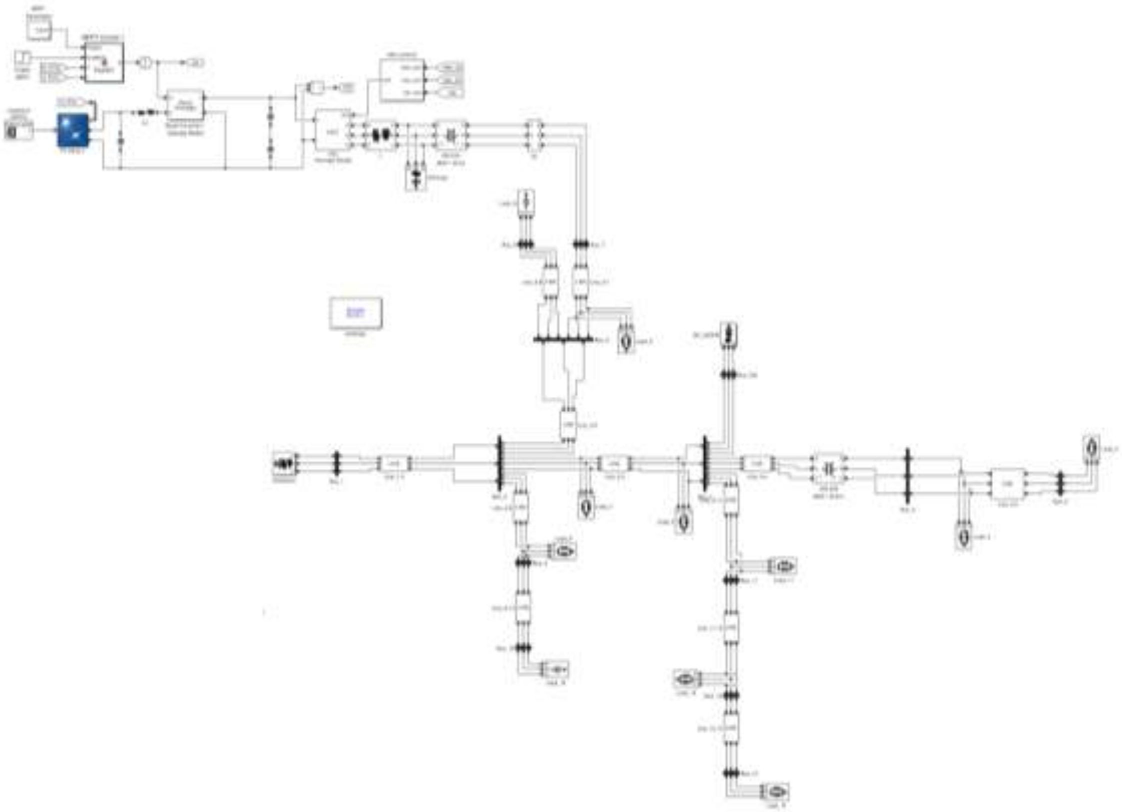

Fig 4: Matlab Simulation Diagram Using Standard IEEE 13-Bus Distribution System

Fig.3 shows Matlab simulation diagram of harmonic modeling of PV system using standard IEEE 13-bus distribution system for the assessment of impact on grid. We observed the simulation results obtained from this model.

V. Conclusion

In this work, we propose a complete HDRF system model for the PV VSC system for interactive single-phase and triple interactive systems. These HD models were used to evaluate and measure the interaction between the performance of the harmonics in the photovoltaic system and the network. The results of the simulation show a consensual interaction between the harmonic currents of the photoelectric system and the background distortions of the network. In addition, an MVDN resonance was investigated in a three-phase photovoltaic system using the previous model. The results confirm that the resonance excitation (both sequences and parallelism) is possible due to the interaction of the systemic impedance with a PV filter capacitor. Although the well-known buffer solution of the chain resistance was able to discourage phase A and C resonances, the parallel resonance of phase B can not be completely avoided. This is not out of line with a different level of negative charges related to different stages. With equal loads, all three phases were wet, indicating that the negative charges on the PCC significantly helped to dampen the resonance.

Therefore, we recommend a detailed evaluation and possibly measure the harmonic performance of the network before and after the PV installation to differentiate between the real harmonic effects caused by the PV integration.

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