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RESEARCH ARTICLE

# Study and analysis of the stochastic harmonic distortion caused by multiple converters in the power system (micro-grid)

**Vaishali P. Kuralkar[1], Prabodh Khampariya[2], Shashikant M. Bakre[3]**

## Abstract

The major focus of the conversation in this investigation is on the impact that voltage-source converter harmonics have on the power quality Power Quality (PQ) of a microgrid. The degree of harmonic distortion that is generated by several Voltage Source Converters (VSCs) may drastically change when there are uncertainties present, and its behavior might be difficult to anticipate as a result of these changes. These uncertainties might result from the design parameters' selection or system parameters' modification. Because of this, it is necessary to make use of statistical methods to measure the degrees of VSC harmonic distortion when there are uncertainties present. A practical microgrid lab consisting of three VSCs was also used to experimentally evaluate the Univariate Dimension Reduction (UDR's) performance. The Monte Carlo Simulation (MCS) method served as a standard for judging the accuracy of the expected UDR outcomes. In every instance, the anticipated outcomes of the UDR were attained with significant time savings in comparison to the approach taken by the MCS, and the results of the UDR demonstrated a good match with the strategy taken by the MCS.

**Keywords:** Microgrid, Monte Carlo Simulation, Power Quality, Univariate Dimension Reduction, Voltage Source Converters.

## Introduction

The notion of a microgrid involves the incorporation of Renewable Energy Systems (RES) into the Electrical Power System (EPS) as a method for the production of clean energy, the fulfillment of the energy requirements of consumers, and the preservation of the dwindling supplies of fossil fuels. In order to accomplish the necessary level of control and conversion of power, these RES are typically connected to the grid by means of power electronic converters (such as Voltage Source Converters). This allows for the necessary level of flexibility. Voltage Source Converters (VSCs), on the other hand, are responsible for the generation of harmonics in both current and voltage. These harmonics have a detrimental effect on a microgrid's Power Quality (PQ) and can potentially damage or render equipment inoperable.

New ideas, such as smart grids and microgrids, have emerged as a result of developments in cutting-edge technology and the growing incorporation of renewable and sustainable energy generation systems into the electrical grid. These ideas propose incorporating RES, which include wind turbines and photovoltaics, into the EPS to provide clean electricity, satisfy the need for energy, and protect the dwindling fossil fuel supplies.

Power electronic converters are typically used to accomplish the appropriate level of control and conversion of power within RES. These converters are also used to connect the RES with the grid. In recent years, power converters such as VSCs have attracted increasing interest and been put to greater use as a result of the improved controllability and rapid switching reactions offered by these devices. However, at their terminals, the converters generate current and voltage harmonics, and these disturbances are then passed on to the remainder of the grid. These harmonics have the potential to cause many other electrical and electronic devices to malfunction, become damaged, or experience interference. Some examples include harming or blowing out EPS components as a result of erroneous signals, which can cause fuses and circuit breakers to trip.

[1]Department of Electrical Engineering, School of Engineering, SSSUTMS, Sehore, M.P., India

[2]Department of Electrical Engineering, School of Engineering, SSSUTMS, Sehore, M.P., India

[3]Department of Electrical Engineering, AISSMS IOIT, Pune, India

***Corresponding Author:** Vaishali P. Kuralkar, SSSUTMS, Sehore, M.P, India E-Mail: vaishali.kuralkar@gmail.com

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Harmonics are responsible for stray flux losses and the overheating of transformer windings, both of which cause copper and iron losses in transformers. While harmonics at high frequencies cause electromagnetic interference that can impair telecommunication lines and smart metres, which can result in inaccurate readings and measurements, low-frequency harmonics do not have this effect.

When there are variations in particular aspects like the operating circumstances (output power) or system parameters, the likelihood of an EPS experiencing considerable increases in harmonics and the difficulty of accurately predicting those increases both increases significantly (grid voltage background distortion). In addition, because harmonics do not add up in the same way that other quantities do, it is difficult to estimate the overall impact that harmonics have on the Power Quality (PQ) of an EPS in a scenario in which a large number of VSCs are connected to the system. Because of this, as well as the fact that harmonics are intrinsically random, it is necessary to use statistical methods to anticipate the level of cumulative harmonic distortion caused by power converters in an EPS.

Statistical methods, such as the Monte Carlo Simulation (MCS), have become increasingly widespread as a standard strategy for forecasting the level of harmonic distortion produced by power converters. However, in order to produce an accurate prediction, tens of thousands of simulations are required, which reduces the practicability of employing such a method for systems that contain a great deal of VSCs. This body of work focuses on investigating how variable speed drives (VSDs) of RES affect the power quality of microgrids. In order to evaluate and anticipate the effect that these parameters will have on the PQ of the microgrid, it explores a variety of factors that have the potential to dramatically enhance or decrease the level of harmonic distortion created by VSCs. Considering the drawbacks of the MCS, this research work aims to develop an effective and time-saving method that can be used to predict the PQ in the design, operation, and/or management of the microgrid when certain parameters are only known within a given constraint. This method will be able to be used in situations where the MCS has a drawback. This technique will give a measure of the VSC's harmonic distortion levels by evaluating whether or not they are within the required harmonic limits as indicated by harmonic regulatory standards. Regulatory harmonic standards state the appropriate harmonic limits.

### *Literature Survey*

The following are the papers that were chosen for the investigation:

Ahmed, E. M., *et al.* (2019) "proposed a multifunctional distributed maximum power point (MPPT) controller for grid integration of PV systems. The suggested distributed MPPT controller is based on using a four-leg three-level T-type multilevel inverter, described in detail below. Among the many functions the proposed inverter performs are distributed MPPT, neutral current correction for unbalanced loads, giving reactive power to the grid, and grid integration, among others. Furthermore, the suggested inverter is capable of overcoming the stochastic behavior of both PV productions with partial shade difficulties and its operation with unbalanced loads. Furthermore, the new suggested controller injects sinusoidal output currents into the grid with lower Total Harmonic Distortion (THD) levels than the previous controller. Various operational scenarios for PV production and load demand are studied using the case study that has been thoroughly tested. The findings and the tabulated performance comparisons have shown that the suggested multifunctional PV-generating system outperforms the competition. The findings demonstrate that the suggested controller can effectively extract distributed MPPT for all PV modules under all of the investigated circumstances. Additionally, the removal of the neutral current caused by imbalanced loads in the system increases the overall energy efficiency of the system."

Ala, G., *et al.* (2019) "conducted an experimental investigation into how much harmonic content is present in the voltages produced by a three-phase, five-stage cascaded H-Bridge Multilevel inverter controlled by an FPGA-based control board. They have also attempted to evaluate the performance of the FPGA by implementing the most common modulation techniques and comparing simulation and experimental results. To build the control algorithms, the VHDL programming language has been used. The output voltage waveforms, which were created by applying the major PWM approaches to the inverter, are compared in terms of the THD percent. Analyzed, compared, and explained are the outcomes of simulation and experimentation, respectively."

Al-duaij, E. O. S. (2015) "introduced the harmonics in the power system by explaining the meanings of the harmonics, causes, and sources. Then there are the impacts of harmonics on the electrical power supply. The harmonics were computed and examined by the team. They investigated the impact of harmonics on the electrical power supply. They also demonstrated how to reduce harmonics from the power system in the fourth part of their presentation. Aiming to understand and search for the sources and consequences of harmonics in the public electric supply system, they conducted a library search and conducted experiments to accomplish their goal. The results of their inquiry were published in a peer-reviewed journal."

Alhafadhi, L., *et al.* (2020) "presented a new method for reducing the THD of photovoltaic (PV) systems by using an adaptive filter based on a predictive model. Instead of reducing the produced THD at each stage of the PV system, a one-step process is implemented at the end stage. The adaptive filter's connection structure is comparable to active and passive filters. The option to alter the filtering coefficients sets it apart from others. To test the validity of the suggested technique, it is applied to a single-phase standalone PV system using LMS, NLMS, and leaky LMS algorithms. Using all of the described techniques, the suggested approach may greatly minimize THD in the current signal of the PV system. The most efficient THD reduction is achieved with tiny step sizes and lengthy filters. NLMS minimizes THD the greatest, whereas LMS achieves the peak current the quickest."

Awais, M., *et al*. (2016) "proposed a novel problem formulation as a constrained optimization problem in this regard and applied it to balanced three-phase systems. According to them, THD reduction for single-phase CMLIs would result in a solution that differed from that of a three-phase system due to the presence of triple-n harmonics, which are not taken into consideration in balanced three-phase systems. This study extends the previously provided innovative problem formulation for minimizing THD in CMLIs to single-phase systems, which was originally suggested in multiphase systems. It is shown by the computational findings that THD minimization for single-phase systems leads to a greater number of solutions (switching angles) and a larger value of THD when compared to three-phase systems. Circuit simulations are used to verify the accuracy of the computational findings."

Bajaj, M., *et al.* (2020) "provided an overview of power quality problems that have arisen as a consequence of the increased use of grid-integrated renewable energy systems, followed by a mini-review of the state-of-the-art solutions that have been published in the literature to relieve those concerns. In addition, the potential for future research into mitigating measures is discussed in detail."

Basit, M. A., *et al.* (2020) "presented a comprehensive review of renewable energy sources. The implementation of ESSs in renewable energy systems and the development phase of these systems has been explored. The importance of ESSs in extending the lifespan, improving efficiency, and increasing the energy density of power systems that use renewable energy sources has been examined. Furthermore, numerous strategies for resolving crucial challenges in photovoltaic (PV) systems have been given, such as poor efficiency, harmonics, and inertia reduction. For the first time, this research explores the influence of FACTS technology on renewable energy-based power systems employing multitype flexible AC transmission system (FACTS) controllers, in contrast to the majority of the current review studies. The OpenCL library has created three simulation models in MATLAB/Simulink. Based on the findings, FACTS devices contribute to the stability of RES's integrated power system by increasing its efficiency. Their work is believed to have the potential to benefit researchers from both the industry and academia to gain a better understanding of the challenges and solution techniques for renewable energy-based power systems, as well as future research dimensions in this area, through collaboration."

Basta, B., & Morsi, W. G. (2021) "assessed the harmonic emission from fast-charging stations at both the low-order and high-order harmonics. The implementation of ESSs in renewable energy systems and the development phase of these systems has been explored. The importance of ESSs in extending the lifespan, improving efficiency, and increasing the energy density of power systems that use renewable energy sources has been examined. Furthermore, numerous strategies for resolving crucial challenges in photovoltaic (PV) systems have been given, such as poor efficiency, harmonics, and inertia reduction. For the first time, this research explores the influence of FACTS technology on renewable energy-based power systems employing multitype flexible AC transmission system (FACTS) controllers, in contrast to the majority of the current review studies. The OpenCL library has created three simulation models in MATLAB/Simulink. Based on the findings, FACTS devices contribute to the stability of RES's integrated power system by increasing its efficiency. Their work is believed to have the potential to benefit researchers from both the industry and academia to gain a better understanding of the challenges and solution techniques for renewable energy-based power systems, as well as future research dimensions in this area, through collaboration."

Belega, D., & Petri, D. (2021) "proposed the estimation of the frequency, amplitude, and phase of sine-waves affected by either wideband noise or by both noise and harmonic distortion, respectively. Simple methods for real-time applications. To their knowledge, the novel Corrected Interpolated Discrete Fourier transform (IpDFTc) method estimates signal parameters first by compensating the influence of spectral interference from the basic picture component and harmonics on the traditional IpDFT parameter estimates. Then a linear sine-fit approach is used to improve the estimators' noise resilience, which is harmed by the use of signal windowing to decrease spectral leakage. The Hann window is used in the study because it has the best noise resilience and reduces long-range spectral leakage. Both suggested approaches virtually reach the Cramér-Rao Lower Bounds for unbiased estimators when at least 1.5 sine-wave cycles are detected. This allows windowing to successfully correct interfering tones on IpDFTc estimates. Both approaches' performances are evaluated using computer simulations and experiments."

Biswas, P. P., *et al*. (2017) "proposed an approach based on a differential evolution (DE) algorithm called L-SHADE to optimize Hybrid active power filter (HAPF) parameters. SHADE is the effective history-based parameter adaption strategy used in DE for a restricted multimodal nonlinear objective function. L-SHADE enhances SHADE's performance by lowering population size across generations. The paper covers two popular HAPF topologies for parameter estimation. Finally, harmonic pollution (HP) is reduced in a system with nonlinear sources and nonlinear loads using a single goal function combining VTHD and ITHD. An industrial facility is studied in detail. Previous research compared the L-SHADE algorithm's output to other well-known evolutionary algorithms."

Busatto, T., *et al.* (2020) "addressed the difference between the results from the commonly-used model and the actual harmonic distortion measured in a low-voltage installation. A variety of indices are presented to measure the nonlinear interaction between the two variables. It is possible to quantify the amount to which the generally used model can also predict harmonic voltages and currents in a contemporary low-voltage system using these indices. Experimental evidence for the suggested model and subsequent mathematical analysis is provided by measurements taken from various combinations of PV inverters and LED bulbs utilizing various technologies. The findings demonstrate that deviation depends on the technology utilized, the network impedance, and the source voltage waveform. Other discoveries include the fact that nonlinear interaction occurs mostly at low harmonic orders and that effects are more noticeable at the phase angle of the harmonics. These observations are examined about possible reasons for them."

Chen, F., *et al.* (2019) "built a complete charger (station) model to explore the effects of the number of chargers, the power of the charger, and the initial SOC state on the harmonics. Then, to reduce harmonics, APF is implemented. The control approach makes use of a hybrid control strategy that includes both PI control and repeated control elements. The results of the simulations confirm the usefulness of the strategy that has been presented. The harmonic pollution caused by electric car charging stations is growing more and more significant as the number of electric vehicles on the road continues to grow. The ability to evaluate and manage the harmonics created during the charging process of electric cars is very important for safety reasons."

Elkholy, M. M., *et al.* (2018) "addressed the applications of passive filters in grid-connected and isolated hybrid renewable microgrids are addressed. Single-tuned filters are used to maintain overall demand distortions within the maximum permissible limits. Both the total cost and THD of suggested passive filters define the modified bi-objectives to be reduced concurrently within certain operational inequality limitations. A MOGOA (multi-objective grasshopper optimization algorithm) is used here. The best Pareto solutions are chosen carefully using the TOPSIS (similarity to ideal solution) method. Before and after installing passive filters, harmonic analysis is used to check crucial frequencies. Their work examines the impact of harmonics on motor and wind generator torque. The system power factor is also enhanced. Various grid operating scenarios are explored, including the uncertainty of renewable energy sources. The induction motor and wind turbine generator torque ripples are reduced. Compared to the results of the well-structured multi-objective genetic algorithm, the MOGOA cropped filter cost and THD results are extremely competitive and compelling."

Etesami, M. H., *et al.* (2018) "compared prominent stochastic methods adopted for SHE and modified SHE (MSHE) pulse width modulation techniques. The issue is characterized as they search for local optima in the operating parameters of cascaded H-bride converters. Specifically, the study looks at important indices of low-order harmonic components and weighted overall harmonic distortion. For SHE and MSHE, a floating fundamental component is included to gain a greater rate of flexibility for optimization procedures, which is beneficial. Finally, an enhanced modulation strategy is given to handle the voltage ripples on the dc-link circuit. To demonstrate the idea, simulation and experimental findings are provided."

Fang, J., *et al.* (2020) "proposed an impedance estimation method well suited to grid-forming converters. The approach is comprised of four operating modes, all of which are effective in voltage and power control applications, respectively. In the instance of voltage control, the amplitude perturbation or phase angle information of the voltage is used to regulate the voltage. Following that, the grid inductance and resistance are calculated based on the power measurement. In the power control instance, on the other hand, the active or reactive power information is used to predict the grid impedance. The suggested technique is simple to apply and free of harmonic distortion, safety concerns, and dependency on control settings. Furthermore, the approach is non-intrusive in the vast majority of circumstances. Using a unique Kalman filtering approach is also recommended to give additional incentives. Finally, the results of simulations and experiments demonstrate that the suggested strategy is both successful and straightforward."

"Due to these considerations, my study will concentrate on a realistic microgrid that is built on tried and tested technology in the interface VSC architecture, its switching strategy, and control approaches, with a particular emphasis on developing a model that ensures excellent PQ in the microgrid. Based on the predictions made about the harmonic distortion level of the converters used in a microgrid and the influence of different elements that affect the produced harmonics, an investigation and study into the power quality of a microgrid will be carried out. This will provide researchers and design engineers with a tool to examine the power quality of a microgrid and build/operate an EPS under specified limits to guarantee high power quality." (Vaishali P. Kuralkar1*, 2022)

### *Proposed Methodology*

"The following section provides a high-level overview of the key stages involved in using the Univariate Dimension Reduction (UDR) approach to estimate the harmonic distortion levels at a microgrid's Point of Common Coupling:

Step i): Identify all random variable functions in the system (for example, power and impedance) and calculate their possible distribution functions.

Step ii): To reduce the amount of variability, compute sigma and weight points using the Univariate Dimension of UT-reduced Gaussian quadrature.

Step iii): Fill in the blanks with data from a small grid. The system, which includes sigma points and weights as obtained from step ii.

Step iv): Simulation of the microgrid can be used while collecting statistical data for output is recommended.

Step v): Calculate the output variables statistically using the marked output values and UDR weights

(current rate/voltage THD/IHD, THD/IHD Current/ voltage standard deviation, and voltage THD/IHD standard deviation).

Step vi): Mathematical information on output variables is obtained." (Vaishali P. Kuralkar1*, 2022)

### *Experimental Validation*

The performance of the UDR technique in forecasting harmonic distortion levels of numerous voltage source converters (VSCs) in a practical microgrid is tested by means of a number of separate experiments. After generating power values at random using uniform and Gaussian distributions, these values are then fed into the VSCs, and the harmonic distortions that emerge from this process are anticipated.

#### *Aim and Procedure*

This experiment intends to test the efficacy of the UDR technique in predicting the harmonic distortion of VSCs in the presence of uncertainty for a small Electrical Power System. Specifically, the experiment will focus on predicting the distortion caused by ha rmonic currents (EPS).

The experiment requires making random adjustments to a number of parameters (such as power) while adhering to a specific limitation. First, pseudorandom power values were produced on a personal computer, and then these values were fed into the variable speed controllers (VSCs) to simulate the MCS method. The harmonic distortion of the current and voltage that corresponds to each power value is recorded, and then the data obtained are processed to produce the statistical moments that correlate to those distortions.

The generated power mean value, range, and standard deviation of the different VSCs are then utilized to construct the sigma points and accompanying weight for the UDR method. This is done in order to ensure that the approach is accurate. The VSCs have the generated sigma points inputted into them. These sigma points each represent a particular reference power value necessary for implementing the dimension reduction techniques. For every different power value specified, the harmonic

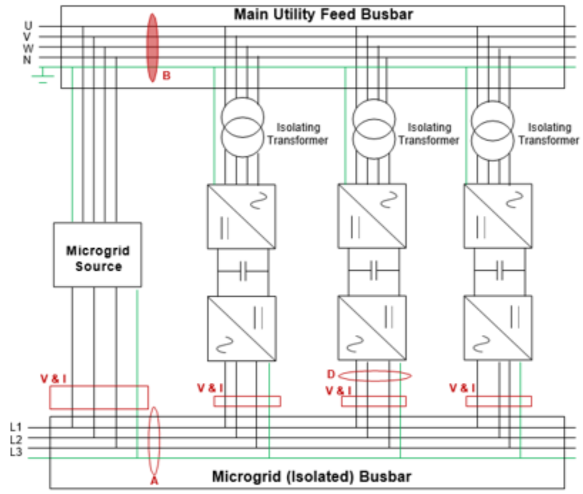


**Figure 1:** Microgrid Lab Set-up

distortion of the current and voltage corresponding to that value is recorded. The calculated weights are then applied to the expected final outcomes, and the recorded harmonic distortions are then scaled accordingly. In conclusion, the results that the UDR anticipated are then examined in light of the MCS method (Table 1).

#### *Schematic Structure of Microgrid Setup*

The layout of the laboratory is depicted in Figure 1, which contains the schematic. The experiment is carried out by utilizing three voltage source converters, a programmable power/voltage supply as the source of the microgrid, a device for monitoring current and voltage, and three isolating transformers.

Parallel connections are made between the three VSCs, which are then supplied with power from the mains by way of a three-phase distribution line and a transformer. The VSCs are isolated from the grid by the use of three transformers at the grid side of the VSC, and the programmable power/ voltage supply is linked to the grid side of the VSC (Microgrid Source).

Isolating transformers are required to be used so that the equipment may be protected and also so that short circuits can be avoided. As a result of the main utility feed functioning as the grid, the VSCs are currently working in the grid-tied mode. The voltage and current measurements were carried out with Labview on a CompactRIO using units from National Instruments (NI) 9227 and NI-9225. Prior to being fed into the measuring blocks, the current was routed through 100:5 CTs. The amount of time it took to complete the practical is detailed down below (Table 2).

## Results And Discussion

### *Case Study 1 – Harmonics of VSCs Predicted in the Presence of Uniform Power Variation*

It was previously demonstrated that changes in output power can alter THD. This investigation aims to make a prediction regarding the net harmonics produced by three

**Table 1:** Microgrid And VSC Laboratory Parameters

| | | |
|---|---|---|
| VSC Parameter | Rated Power, *P* | 12.5 kW |
| | Rated line Voltage | 415V |
| | Rated Current | 32A |
| | VSC Topology | 3_phase 2 Level VSC |
| | VSC Filter Configuration | LCL Filter |
| Microgrid Network | Mains Line Voltage<br>Current | 415V<br>Fuse 20A |
| Microgrid Source (Programmable Power/Voltage Supply) | Rated Power<br>Rated Voltage<br>Rated Current<br>Fuse Rating | 90kW<br>1000V<br>300A<br>125A |
| Statistical Power Variation | Uniform Power Variation | Range = 2.5kW - 10.0kW<br>Mean = 6.25kW |
| | Normal Power Variation | Mean = 3.44kW<br>Std = 2.02 |

VSCs under conditions in which the output power varies in a uniform manner both randomly and independently (range: 2.5–10.0kW).

In order to simulate the methodology utilized by MCS, the VSCs were initially subjected to thousands of arbitrary power input values. After that, the net harmonics are measured and recorded in their entirety. After that, the UDR is utilized to generate the sigma points and weights by making use of the statistical information associated with the distribution, such as the range, mean, and standard deviation. After that, the sigma points that were formed are input into the VSCs, which serve as the power inputs, and the net harmonics are detected at point B. (Figure 1). Following this, the outcomes of both the MCS-type approach and the UDR are statistically examined, and then compared, in order to evaluate how effective, the UDR technique is. The acquired experimental results are presented in Tables 3 and 4 and Figures 2 and 3, respectively.

The MCS and UDR results for the mean value are very similar, as seen in Table 3. Compared to the MCS methodology, the standard deviation values for the VTHD were anticipated to be 57% lower than they were.

The derived statistical moments of the ITHD and VTHD, respectively, employing 3pts UDR are depicted in Figures 2 and 3, respectively.

The results of the laboratory tests may be shown in Table 4,

**Table 2. Approx. Time Utilized by Microgrid to Conduct Practical.**

| | Case 1 | | | Case 2 | |
|---|---|---|---|---|---|
| | **MCS** | **UDR 3pts** | **UDR 5pts** | **MCS** | **UDR 5pts** |
| **Time (s)** | 21600 | 600 | 2700 | 24200 | 2850 |
| **Time Saved (%)** | - | 97 | 88 | - | 88 |

Table 3: Laboratory Results Showing Predicted Moments of ITHD and VTHD using MCS and 3pts UDR

| | $I_{THD}$ | | $V_{THD}$ | |
|---|---|---|---|---|
| | **Mean** | **Std** | **Mean** | **Std** |
| **MCS** | 4.46 | 1.44 | 1.93 | 0.52 |
| **UDR** | 4.84 | 1.11 | 1.94 | 0.22 |
| **Error (%)** | 8.52 | -22.9 | 0.52 | -57.7 |
| **Diff** | 0.38 | -0.33 | 0.01 | -0.30 |

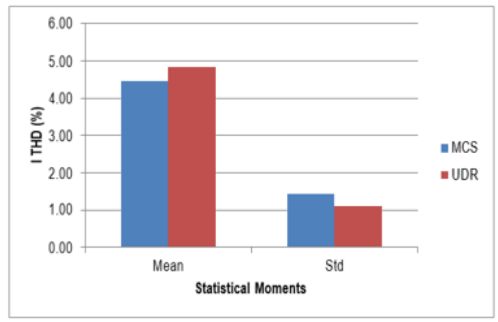


Fig.2: Laboratory Results of ITHD Predicted Statistical Moments (3pts UDR).

which includes the obtained statistical moments of ITHD and VTHD. It is obvious from Table 4 that a more accurate prediction of the mean and standard deviation was obtained using the 3pts UDR because it had fewer mistakes expressed as a percentage.

The results of using the 5 pts UDR are depicted in Figures 4 and 5, which show the obtained mean and standard deviation of ITHD and VTHD, respectively.

### *Case Study 2 - A Gaussian (Normal) Power Variation and Its Effect on the Prediction of VSCs Harmonics*

Case study 2 involves making predictions regarding the net harmonics of the three VSCs in a scenario where the output power fluctuates randomly according to a Gaussian distribution (with a mean value of 3.44 kW and a standard deviation of 2.02e+3). To simulate the method used by MCS, the power of the VSC was made to fluctuate using thousands of random power inputs. This was done in the

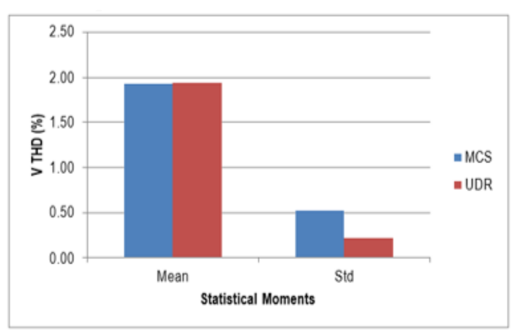


Fig.3: Laboratory Results of VTHD Predicted Statistical Moments (3pts UDR).

Table 4: Laboratory Results Showing Predicted Moments of ITHD and VTHD using MCS and 5pts UDR

| | ITHD | | VTHD | |
|---|---|---|---|---|
| | **Mean** | **Std** | **Mean** | **Std** |
| **MCS** | 4.46 | 1.44 | 1.93 | 0.52 |
| **UDR** | 5.07 | 1.67 | 2.06 | 0.60 |
| **Error (%)** | 13.68 | 15.97 | 6.74 | 15.38 |
| **Diff** | 0.61 | 0.23 | 0.13 | 0.08 |

Table 5: Laboratory Results Showing Predicted Moments of ITHD and VTHD using MCS and 5pts UDR Normal Variation

| | ITHD | | VTHD | |
|---|---|---|---|---|
| | **Mean** | **Std** | **Mean** | **Std** |
| **MCS** | 4.61 | 1.62 | 1.95 | 0.51 |
| **UDR** | 4.72 | 1.19 | 2.25 | 0.54 |
| **Error (%)** | 2.39 | -26.54 | 15.38 | 5.88 |
| **Diff** | 0.11 | -0.43 | 0.30 | 0.03 |

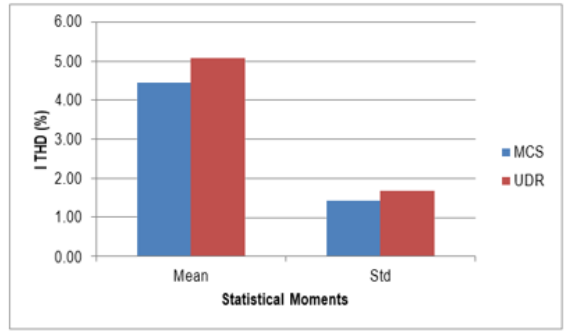


Fig.4: Laboratory Results of ITHD Predicted Statistical Moments (5pts UDR).

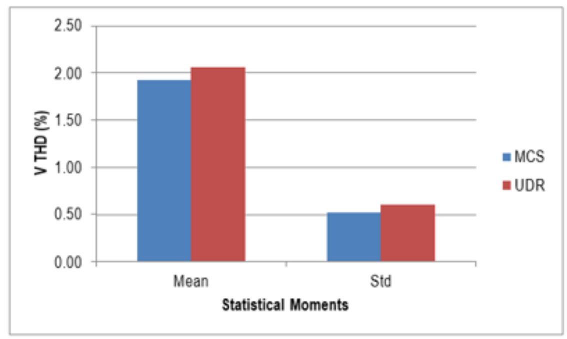


Fig.5: Laboratory Results of VTHD Predicted Statistical Moments (5pts UDR).

same way as case 1. Recording the statistical construction of the distribution and measuring the THD are both steps in the analysis process. After that, the five-pointed UDR sigma points and weights were calculated and inputted so that the performance of the UDR approach could be evaluated using the MCS as a standard.

The mean and standard deviation values for ITHD and VTHD are very similar in the UDR and the MCS, as the comparison in Table 5 demonstrates. The standard deviation of the ITHD was 26 percentage points lower than the UDR had projected.

The findings of the laboratory experiment provide credence to the utilization of the UDR method to accurately predict harmonic distortion in a real-world system in which the configuration and operational characteristics are only known, to a limited extent. The findings of the experiment are sufficient evidence to support this assertion. When it came to the mean values and the majority of the standard deviation values of the ITHD and VTHD, the results acquired via the practical use of the UDR approach offered a satisfactory match with the results achieved through the application of the MCS technique.

This indicates that the UDR technique may be used as a prediction tool to examine the harmonics of a practical VSC system before the commissioning of an EPS as well as while it is operational. This can be done both while the EPS is in operation and before it is. The UDR allows for a reliable

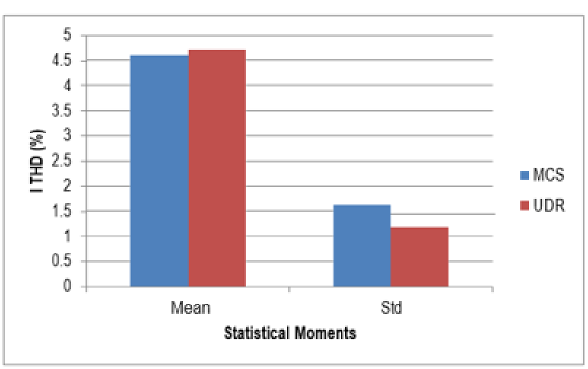


Fig.6: Laboratory Results of ITHD Predicted Statistical Moments (5pts UDR Normal).

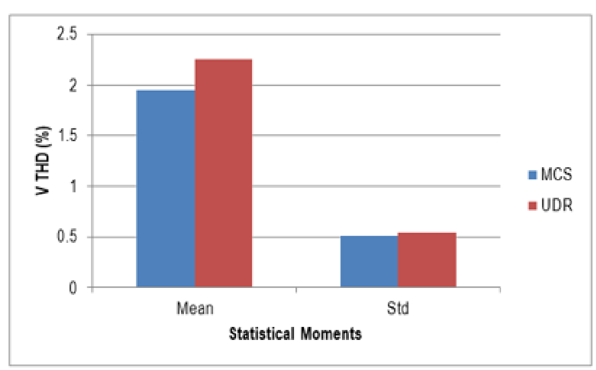


Fig.7: Laboratory Results of VTHD Predicted Statistical Moments (5pts UDR Normal).

statistical measurement of the harmonic distortion level in a VSC-based renewable energy system or microgrid to be completed in a very short amount of time in comparison to previous measurements. This is made possible by the UDR's ability to measure harmonic distortion in real-time. The ability of the UDR to detect harmonics is one of the factors that is considered when determining the overall quality of the power supply in the microgrid.

The computed statistical moments of the ITHD and VTHD, respectively, using 5pts UDR for a Gaussian distributed random variable are displayed in Figures 6 and 7, respectively (power).

## Conclusion

It was shown that design specification parameters such as the converter topology, switching frequency, and amplitude modulation affected the harmonics that were created by the VSC in an EPS. Since this is the primary method of dampening harmonics created by harmonic systems, including VSCs, the kind of filter and the values of the filter parameter can also have a significant impact on the VSC's harmonics. In addition to these factors, the features of the microgrid or EPS or the operating conditions, such as the line impedance of the EPS, the harmonic distortion of the EPS background voltage, or the output power of the VSCs, can have a substantial impact on the harmonics produced by the VSCs.

Some of these factors, particularly those about the VSCs of RES, can only be known within a given set of limitations. The output power of RES such as wind turbines and photovoltaics is reliant on the wind speed profile and solar irradiation, respectively. These two factors are suitable examples to demonstrate this variability. As a result, there is an element of unpredictability within the EPS due to the fact that there are no promises regarding the amount of power that will be generated by RES. Additionally, when a large number of RES VSCs are connected, such as in a microgrid, it becomes impossible to anticipate the cumulative harmonics generated by the VSCs. This is due to the fact that the harmonics generated by individual VSCs do not add up in an arithmetic fashion." [(Vaishali P. Kuralkar1*, 2022)]

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