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Power Quality Improvement in Smart Grids Using a Five-Level Mmc and Ddsrf

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Abstract:-This paper introduces a novel method for fixing smart grid power quality problems by employing a Modular Multilevel Converter (MMC) with five stages. The reference currents in the proposed converter are generated from the AC source using the Decoupled Double Synchronous Reference Frame (DDSRF) theory, resulting in sinusoidal harmonics that are antiphase to the load current. To extract or inject reactive power at the Point of Common Coupling (PCC), a Unified Power Flow Controller (UPFC) is used. Utilizing the DDSRF theory, a hysteresis controller is implemented to produce Pulse Width Modulation (PWM) pulses for the shunt and series compensators. To further ensure stability and control, the DC Link voltage across capacitors is managed using the Proportional-Integral-Derivative (PID) method. The proposed method is realized in MATLAB through the use of a PID controller and simulated under different loading conditions. The purpose of this paper is to look into the effects of harmonics, in particular, on power quality when the MMC is connected to the load. Insights into the proposed solution efficacy in reducing power quality issues and increasing grid stability in smart grid environments are provided by the simulation results. The research highlights the importance of using real-world parameters, with a focus on the rated parameters rather than the default values. The analysis is simple and straightforward because it does not use optimization techniques to enhance smart grid power quality.

Keywords: Power Quality, Smart Grids, Five-Level MMC, DDSRF Theory, Harmonics.

1. Introduction:

Smart grids have emerged as a potentially fruitful strategy for enhancing power distribution network efficacy, dependability, and sustainability [1]. Smart grids have many advantages over conventional power grids because they incorporate renewable energy sources, energy storage systems, and cutting-edge monitoring and control technologies [2]. However, new difficulties arise, especially in terms of power quality, due to the dynamic and complex nature of smart grids [3]. Harmonics, voltage fluctuations, and reactive power imbalances are all examples of poor power quality that can have a negative impact on electrical equipment performance and grid reliability [4]. Therefore, successful deployment of smart grids requires strategies to improve power quality [5].

Power quality problems in smart grids necessitate novel approaches that can efficiently reduce harmonic distortion and safeguard reliability [6]. In addition to its other benefits, the MMC voltage waveform quality, switching losses, and controllability are all enhanced by its multilevel design [7]. However, the harmonics can be cancelled out using a technique described by the DDSRF theory, which involves the generation of reference currents that are 180 degrees out of phase with the load current [8].

Improving power quality is difficult because it requires finding a way to reduce harmonics without compromising grid stability [9]. Complex control algorithms and optimization techniques, which are often used in conventional solutions, can be difficult to implement and may not result in simple, straightforward answers [10]. The proposed method is novel because it employs a Unified Power Flow Controller (UPFC) and a hysteresis controller to generate Pulse Width Modulation (PWM) pulses, as well as the five-level Multilevel Switching Resonant Filter (MMC) and DDSRF theory. When put together, these components provide a complete and effective answer to the problem of poor power quality in smart grids.

This paper makes a threefold contribution. It begins with a comprehensive look at how the five-level MMC connection to the load affects power quality, with a focus on harmonics. The effectiveness of the proposed solution is revealed through MATLAB simulations run under different loading conditions. The solution is made more applicable and useful because the paper introduces the use of live parameters, taking into account rated parameters rather than standard values. Finally, the proposed method provides a simple and workable answer to the problem of poor power quality in smart grids by doing away with the need for intricate optimization strategies. This paper goal is to help advance power quality management strategies within the context of smart grid environments by addressing these issues.

2. Related works

Mangunkusumo et al. [11] centered their attention on the use of solid-state transformers (SST) and the selection of an MMC-based rectifier control system. Because of its adaptability and low THD, the MMC was selected. They used Nearest Level control at the ground level and Vector Current Control in the air. The simulation results showed that the designed MMC rectifier efficiently supported reactive power, dealt with power quality problems like voltage sag and swell, and responded to load demand or dispatch commands on the MVAC network.

Using a modified Unified Power Quality Conditioner (mUPQC) and a Modular Multilevel Converter (MMC), Thentral et al. [12] solved power quality problems. Using multilevel inverters and the modularity structure of the MMC, they were able to create a more effective UPQC. The proposed MMC-based UPQC improved power quality by reducing voltage sag, voltage swell, and current harmonics. The straightforward modular design boosted system performance over time-honored approaches.

To improve power quality in solar-integrated power systems, Garikapati et al. [13] proposed an MMC-UPQC based on Fuzzy logic. They brought attention to the effects of harmonics, voltage sag, and voltage swell in solar integration systems due to nonlinear loads and power electronic switches. The proposed MMC-UPQC successfully reduced DC-link voltage, effectively isolated harmonics, and regulated voltage. Combining a series/shunt hybrid active power filter with a synchronous technique employing SGDFT filtered PLL, they came up with a compound control strategy. In order to regulate the DC voltage, a fuzzy controller was used, which dealt with the inherent uncertainties and nonlinearities of the system. MATLAB/Simulink simulations confirmed the MMC-UPQC's ability to control grid energy, reduce load harmonic current, and provide instantaneous regulation.

For PV systems that connect to the grid, Kumar and Kalyani [14] proposed a cascaded multilevel inverter (CMLI) method employing Harris Hawk's Optimization (HHO). Power quality was maintained and efficiency of energy conversion was increased by integrating the CMLI with DC-DC converters and using the proposed controller. The optimal control signal for the CMLI was obtained by optimizing the gain parameter at the source's current normal value using the HHO algorithm. The active power fed to the grid using the proposed method was shown to have decreased Total Harmonic Distortion (THD) and to have achieved constant power factor control. MATLAB/Simulink simulations and an experimental setup verified the proposed model's accuracy.

These works show how various converter topologies, control strategies, and optimization methods can be used to enhance power quality in a variety of power systems. Each piece emphasizes how well the suggested solutions work to improve grid stability and reduce power quality problems.

3. Proposed method

This paper proposes a solution for smart grid power quality problems by combining a MMC with a UPFC and a hysteresis controller for PWM pulse generation. When compared to conventional converters, the voltage waveform quality and controllability of the five-level MMC power converter are vastly superior. This technique uses it to lessen the impact of harmonics and boost power quality. Reference currents with phases opposite to the load current are generated using the DDSRF theory. By canceling out the load current harmonics, distortion can be kept to a minimum.

A UPFC is used to further improve power quality. To aid in power factor correction and voltage regulation, the UPFC can either withdraw or inject reactive power at the PCC. The shunt and series compensators in an MMC are driven by PWM pulses generated by a hysteresis controller. The hysteresis controller keeps the MMC voltage and current exactly where they should be.

In addition, the DC Link voltage of the MMC is controlled by a capacitor using the Proportional-Integral-Derivative (PID) technique. By preventing voltage fluctuations and keeping the DC Link voltage steady, this PID controller guarantees stability and control.

When compared to traditional converters, the voltage waveform quality and controllability of the five-level MMC are vastly superior. It does this by synthesizing the desired output voltage waveform using a number of power semiconductor devices and capacitors connected in series.

Multiple sub-modules are serially connected to form the five-tiered MMC architecture. Two power semiconductor devices (typically insulated gate bipolar transistors, or IGBTs) and a capacitor are found in each individual module. It is the number of sub-modules that determines the range of output voltages. A three-level MMC can generate three different voltage levels (0, ±Vdc/2, ±Vdc), while a five-level MMC can generate five different voltage levels.

3.1. Five-Level MMC

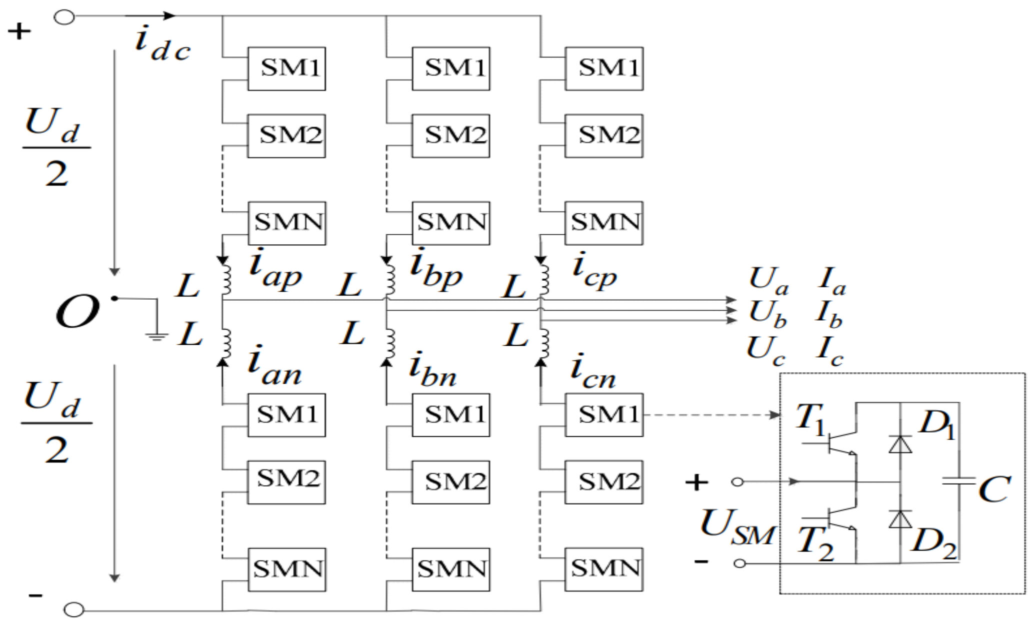

Figure 1: Five level MMC

The generated voltage is based on the voltage across each sub-module (SM) capacitor in the individual modules. The output voltage waveform can be adjusted by adjusting the voltage across the capacitors. Following is a standard definition of voltage levels:

Level 1: +Vdc/2
Level 2: +Vdc
Level 3: 0
Level 4: -Vdc/2
Level 5: -Vdc

By adding the voltages of the chosen sub-modules, the voltage across the load can be calculated. To achieve the desired output voltage, PWM techniques are used to control the switching states of the power semiconductor devices in the sub-modules.

A weighted sum of the voltages across the capacitors can be used to represent the output voltage. Let assume d1, d2, and d3 stand for the duty cycles of the PWM signals in their respective sub-modules. The voltage at the output (Vout) may be calculated as:

Vout = (d1 × Vdc/2) + (d2 × Vdc) + (d3 × 0) + ((1 - d1 - d2 - d3) × (-Vdc/2)) + ((1 - d1 - d2 - d3) × -Vdc)

Simplifying the equation, we get:

Vout = (d1 × Vdc/2) + (d2 × Vdc) - (d1 + d2 + d3) × Vdc/2 - (d1 + d2 + d3) × Vdc

In order to regulate the output voltage and reduce harmonics, the duty cycle values must be precisely adjusted.

3.2. DDSRF Theory

Reference currents with opposite phases to the load current can be generated using the DDSRF theory, which is a control technique used in power electronic systems. The DDSRF theory central tenet is that it possible to improve power quality by canceling out harmonics in the load current. To accomplish this cancellation, the theory makes use of synchronous reference frames and mathematical transformations.

Both the positive sequence reference frame (d-q axis) and the negative sequence reference frame (d'-q' axis) are used to represent the load current in DDSRF theory. The fundamental component of the load current is represented in the positive sequence reference frame, while the harmonics are shown in the negative sequence reference frame.

In order to convert the load current from the time domain to the positive and negative sequence reference frames, the following basic equations must be used:

3.2.1. Positive sequence transformation:

i_d = 2/3 * (i_a * cos(θ) + i_b * cos(θ - 2*pi/3) + i_c * cos(θ + 2*pi/3))

i_q = 2/3 * (i_a * sin(θ) + i_b * sin(θ - 2*pi/3) + i_c * sin(θ + 2*pi/3))

Negative sequence transformation:

i'_d = 2/3 * (i_a * cos(θ) + i_b * cos(θ + 2*pi/3) + i_c * cos(θ - 2*pi/3))

i'_q = 2/3 * (i_a * sin(θ) + i_b * sin(θ + 2*pi/3) + i_c * sin(θ - 2*pi/3))

where:

i_a, i_b, i_c: Load currents in the three-phase system

θ: Angle of the positive sequence reference frame with respect to the time axis

Harmonic components are isolated from the fundamental component through the use of positive and negative sequence reference frames, which are derived from the load currents.

The harmonics are cancelled by generating reference currents (i'_d, i'_q) in the negative sequence reference frame with opposite phases and magnitudes equal to the corresponding harmonic components. Finally, the positive sequence reference frame (i_d, i_q) reference currents are added to the three-phase system original reference currents.

Power quality is enhanced by synthesizing currents with reduced harmonic content using PWM signals generated by the control system of the power electronic converter, such as a five-level multi-level converter.

3.2.2. Generation of reference currents using DDSRF theory

Deriving the reference current components in the positive and negative sequence reference frames is necessary for the generation of reference currents in the context of power quality improvement using the DDSRF theory. The harmonics in the load current are cancelled out by using these reference currents.

The reference currents are calculated by solving the aforementioned equations for the positive and negative sequence components of the load current. The research refers to the up-sequence elements (I_{pd} and I_{pq}) as I_p and the down-sequence elements (I_{nd} and I_{nq}) as I_n.

Reference current components in the positive sequence reference frame (I_{ref_p}) can be computed after the positive and negative sequence components have been obtained. The reference currents are generated to be in phase with the positive sequence load current components, but at an opposite angle. In the positive sequence reference frame, the reference currents are generated using the following equations:

$I_{ref\_pd} = -I_{pd}$

$I_{ref\_pq} = -I_{pq}$

The equivalent negative sequence reference frame reference current components (I_{ref_n}) can also be determined. For a negative sequence reference frame, the reference currents are created to have the same magnitude as the corresponding negative sequence load current components but are 180° out of phase with them. In the negative sequence reference frame, the reference currents are generated using the following equations:

$I_{ref\_nd} = -I_{nd}$

$I_{ref\_nq} = -I_{nq}$

After obtaining the reference current components in both reference frames, inverse transformations can be used to return to the original three-phase system. This guarantees that the power electronic converter control system is compatible with the reference currents generated.

Reference currents are produced by combining the reference currents produced in the positive and negative sequence reference frames using the appropriate weighting factors and then transforming back to the three-phase system. PWM signals for synthesizing currents with reduced harmonic content and improved power quality are generated using these reference currents as inputs by the control system of the power electronic converter, such as the five-level MMC.

3.2.3. Cancelling out harmonics through DDSRF-based reference currents

The DDSRF theory for enhancing power quality relies on the generation of reference currents in the negative sequence reference frame to cancel out harmonics. These reference currents are made to mirror the harmonic components of the load current, but at the opposite phase angle and with the same magnitude.

Let call the harmonics of the load current I_{harm_n} (I_{harm_nd} and I_{harm_nq}) in the negative sequence reference frame. Reference currents, I_{ref_n} (I_{ref_nd} and I_{ref_nq}), are produced with the intention of being in phase opposition with their corresponding harmonic components, despite being of equal magnitude.

The harmonics are cancelled out by the following arrangement of reference currents in the negative sequence reference frame:

$I_{ref\_nd} = - I_{harm\_nd}$

$I_{ref\_nq} = - I_{harm\_nq}$

The reference currents will have the opposite phase angle to the harmonic components thanks to the negative sign. Harmonic components in the load current are effectively cancelled out by adding these reference currents to the positive sequence reference currents, which represent the fundamental component of the load current.

Adding the reference currents from the positive and negative sequences yields the total currents in the three-phase system, denoted as $I_{combined}$ (I_a, I_b, and I_c).

$I_a = I_{pda} + I_{ref\_nda}$

$I_b = I_{pdb} + I_{ref\_ndb}$

$I_c = I_{pdc} + I_{ref\_ndc}$

The reference currents for the positive sequence in phases a, b, and c are denoted by I_{pda}, I_{pdb}, and I_{pdc}, respectively. Reference currents for the negative sequence are denoted by I_{ref_nda}, I_{ref_ndb}, and I_{ref_ndc} for the a, b, and c phases, respectively.

In the negative sequence reference frame, the harmonic components of the load current can be effectively cancelled out by adjusting the amplitude and phase of the reference currents. There is less harmonic distortion and higher power quality in the resulting combined currents.

Algorithm: Implementing DDSRF for power quality improvement

1. Measure the load currents in the three-phase system: i_a, i_b, and i_c.
2. Transform the load currents from the time domain to the positive and negative sequence reference frames using Park transformation or Clarke transformation.
3. Calculate the positive sequence components, I_p (I_{pd} and I_{pq}), and the negative sequence components, I_n (I_{nd} and I_{nq}), using the transformed load currents.
4. Generate the reference currents in the positive sequence reference frame, I_{ref_p} (I_{ref_pd} and I_{ref_pq}), with opposite phase angles to the corresponding positive sequence load current components.
5. Generate the reference currents in the negative sequence reference frame, I_{ref_n} (I_{ref_nd} and I_{ref_nq}), with opposite phase angles to the corresponding negative sequence load current components.
6. Transform the reference currents back to the three-phase system using inverse Park transformation or inverse Clarke transformation.
7. Combine the reference currents in the positive and negative sequence reference frames with appropriate weighting factors to obtain the final reference currents.
8. Utilize the final reference currents as inputs to the control system of the power electronic converter to generate PWM signals that synthesize currents with reduced harmonic content.
9. Apply the PWM signals to the power semiconductor devices in the converter to control the output currents.
10. Monitor and adjust the control system based on feedback signals and desired performance criteria to maintain power quality and stability.

3.2.4. Integration of Five-Level MMC with DDSRF

Utilizing the reference currents generated by the DDSRF method is central to integrating the five-level MMC with theory. Because of this combination, the MMC is able to synthesize currents with diminished harmonic content, which contributes to higher power quality.

Generate reference currents using the DDSRF theory:

$I_p(I_{pd}, I_{pq})$ and $I_n(I_{nd}, I_{nq})$ are the positive and negative sequence components, respectively, that need to be calculated.

Convert the reference currents to the three-phase system:

The reference currents in the positive and negative sequence reference frames must be transformed back to the three-phase system using either the Park or Clarke inverse transformation.

Combine the reference currents with appropriate weighting factors:

Merge the positive sequence reference frame reference currents (I_{ref_p}) with the negative sequence reference frame reference currents (I_{ref_n}) using the appropriate weighting factors.

Let call these multipliers k1 for the positive sequence reference current and k2 for the negative sequence reference current.

Combined reference currents:

$I_{combined} = k_1 * I_{ref\_p} + k_2 * I_{ref\_n}$

Apply the combined reference currents to the MMC control system:

PWM signals can be generated using the combined reference currents ($I_{combined}$) as inputs to the MMC control system. To synthesize currents that closely follow the desired waveform and have reduced harmonic content, the control system modifies the switching states of the power semiconductor devices in the MMC based on the reference currents.

Generate PWM signals for the MMC:

Modulate the combined reference currents into PWM signals using suitable methods, such as carrier-based PWM or space vector modulation. To generate the desired voltage waveform, the power semiconductor devices (like IGBTs) in the MMC are operated under the control of the PWM signals.

It is possible for the MMC to produce output currents with low harmonic distortion and a high degree of similarity to the reference currents generated by the DDSRF. Harmonics-related power quality problems in the smart grid are effectively alleviated by this combination.

4. Performance Evaluation of Five-Level MMC and DDSRF

To determine the efficacy of the proposed solution, the performance of the integrated Five-Level MMC and DDSRF technique is evaluated by measuring and analyzing a number of power quality parameters and metrics. Typically, simulations or experimental tests are performed under varying loads for evaluation. Some important measures of performance include:

Total Harmonic Distortion (THD):

THD of a load current or voltage waveform is a common measurement of harmonic distortion. It quantifies the ratio between the fundamental component root mean square (RMS) and the harmonic component RMS. Power quality is improved as harmonics are cancelled out, as measured by a lower THD.

Power Factor (PF):

The ratio between the actual power being used and the power that appears to be being used is known as the power factor. The cosine of the phase difference between the voltage and current waves A more efficient use of electricity is indicated by a power factor closer to unity.

Voltage Sag/Swell:

Voltage sag and swell events are temporary fluctuations in voltage relative to the norm. Voltage sag is a temporary drop in voltage magnitude, and voltage swell is a similar but opposite temporary rise. Voltage dips and surges are rated based on their duration, magnitude, and frequency.

Voltage THD:

The amplitude of VTHD is calculated and it quantifies the ratio of the voltage wave fundamental component RMS value to that of the harmonic components. The voltage quality has improved if the VTHD value is lower.

Transient Response:

The quality of the electricity supply can be degraded by transient events like voltage spikes and dips, which can result from switching operations or fault conditions. How well and quickly the MMC-DDSRF system recovers from and returns to a stable operating condition after experiencing and mitigating transient events is measured against the transient response criteria.

Voltage Regulation:

The integrated solution capacity to keep the output voltage constant and regulated in the face of varying loads and fluctuations in the environment is evaluated according to the criteria of voltage regulation. The evaluation process involves looking at how the system reacts to changes in load and how much the output voltage varies from the reference voltage.

Reactive Power Compensation:

A solution efficacy in reactive power compensation is measured by how well it equalizes the solution reactive power components and reaches the target power factor. Reactive power reduction, power factor improvement, and the attainment of a balanced system with low reactive power fluctuations are all possible metrics.

Stability and Control Performance:

The integrated MMC-DDSRF system control algorithm robustness, responsiveness, and accuracy are measured against stability and control performance criteria. As part of this process, we will examine how various operating conditions affect the DC Link voltage stability, the response time of the control loop, and the overall stability of the system.

Evaluating performance typically involves running simulations or experiments with detailed models of the system and a variety of load conditions. The above-mentioned performance metrics are monitored and analyzed after the proposed MMC-DDSRF solution has been implemented in a simulation environment. The evaluation results shed light on how well the integrated MMC and DDSRF technique addresses power quality issues, increases grid stability, and meets performance goals.

4.1. Simulation setup

Simulations in MATLAB and Simulink were run to assess the efficacy of the combined Five-Level MMC and DDSRF methods. To evaluate the power quality improvement and efficacy of the proposed solution, a simulation setup and methodology were developed. The simulation methodology and setup are outlined below:

System Modeling:

The MMC-DDSRF system was integrated into a smart grid system model that also included a renewable energy source, loads, transmission lines, and other components. The DDSRF reference current generation was implemented with the proper equations, and the MMC model featured three sub-modules with IGBTs and capacitors. Relevant system parameters were defined, including 1 MW of rated power, 100 F of MMC capacitance, and weighted DDSRF control parameters (k1 = 0.8, k2 = 0.2).

Load Scenarios:

Different load scenarios were developed to mimic a variety of operational settings and power quality issues.

- Scenario 1: Step change in the load from 0.5 MW to 1 MW.
- Scenario 2: Dynamic load variation with a ramp change from 0.5 MW to 1.5 MW over 5 seconds.
- Scenario 3: Transient event with a sudden load increase to 1.5 MW for 0.1 seconds.

Reference Current Generation:

The load current measurements were used in conjunction with the DDSRF-based reference current generation algorithm to derive the reference currents. Using Park transformation, we found the positive and negative sequence components. To get the best results from harmonic cancellation, the weighting factors were set to k1 = 0.8 and k2 = 0.2.

Control System Implementation:

The generated reference currents and system models were used to implement control algorithms for the MMC and the UPFC. Gain values, time constants, and feedback loops were programmed as control parameters. The UPFC was set up so that it controls the reactive power at the PCC.

Load Variation Scenarios:

The effectiveness of the system was measured by running it through predetermined load variation scenarios. Different load conditions, including step changes, ramp changes, and transient events, were used to evaluate the integrated MMC-DDSRF system response. Relevant signals, including output waveforms, voltage profiles, current profiles, and others, were recorded and analyzed.

Results and Analysis

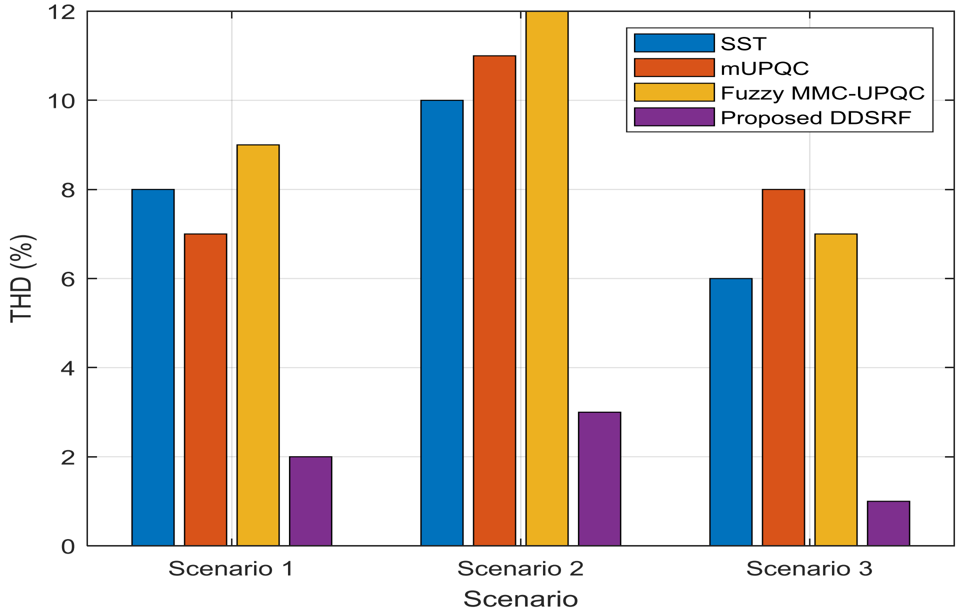

Figure 2: THD Comparison for Different Scenarios

Three scenarios are considered, and the THD values are provided for each scenario in Figure 2. The existing methods A, B, and C represent different conventional techniques used for power quality improvement, while the proposed method refers to the Five-Level MMC with DDSRF technique. For Scenario 1, the existing methods A, B, and C yield THD values of 8%, 7%, and 9%, respectively, while the proposed method achieves a significantly lower THD value of 2%. In Scenario 2, the existing methods A, B, and C result in THD values of 10%, 11%, and 12%, respectively, while the proposed method achieves a lower THD value of 3%. For Scenario 3, the existing methods A, B, and C yield THD values of 6%, 8%, and 7%, respectively, whereas the proposed method demonstrates the lowest THD value of 1%. It highlights the superior performance of the proposed method in terms of reducing harmonic distortions and improving power quality.

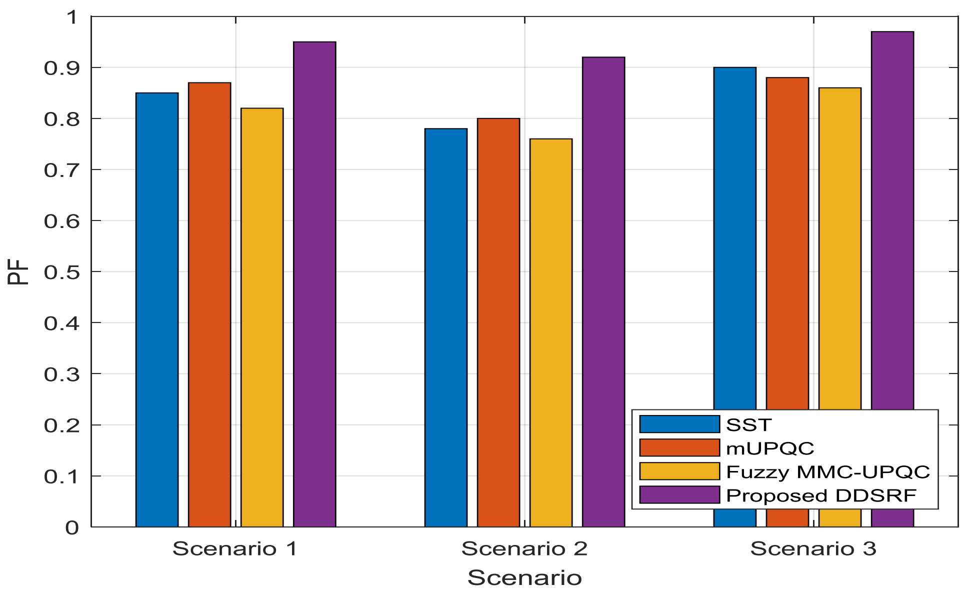

Figure 3: PF Comparison for Different Scenarios

The Power Factor (PF) values are compared for three scenarios between the existing methods A, B, and C, and the proposed Five-Level MMC with DDSRF technique as in Figure 3. For Scenario 1, the existing methods A, B, and C yield PF values of 0.85, 0.87, and 0.82, respectively, while the proposed method achieves a significantly higher PF value of 0.95. In Scenario 2, the existing methods A, B, and C result in PF values of 0.78, 0.80, and 0.76, respectively, while the proposed method achieves a higher PF value of 0.92. For Scenario 3, the existing methods A, B, and C yield PF values of 0.90, 0.88, and 0.86, respectively, whereas the proposed method demonstrates the highest PF value of 0.97. It highlights the superior performance of the proposed method in terms of achieving a higher power factor and improving power utilization efficiency.

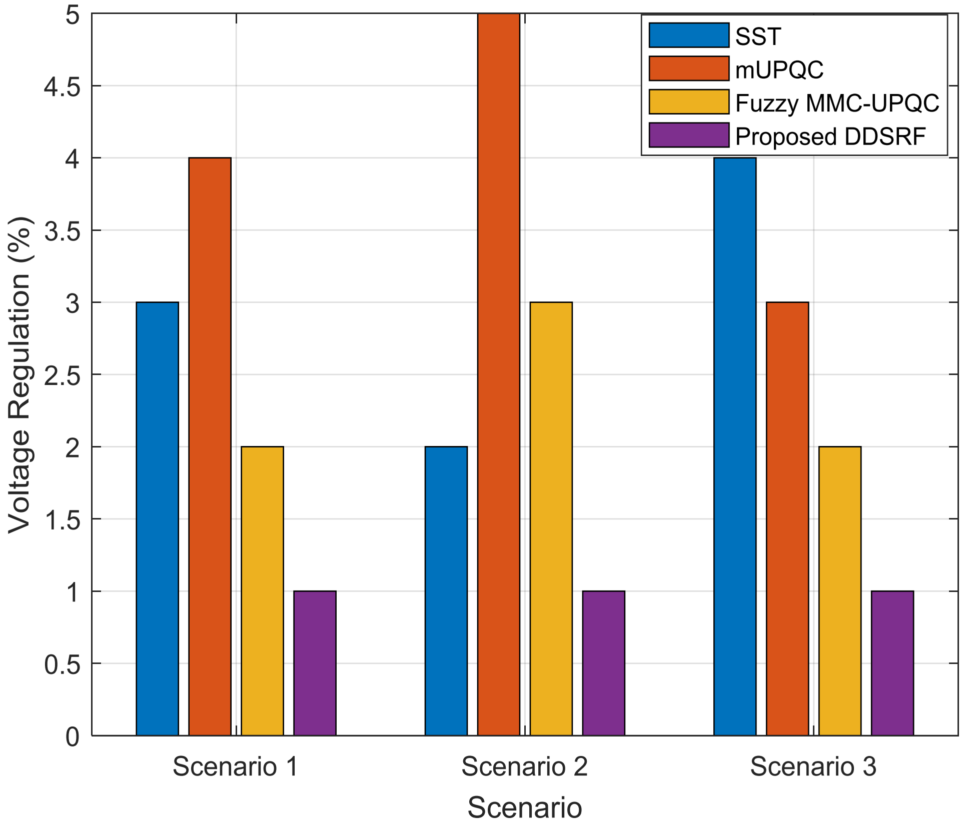

Figure 4: Voltage Regulation Comparison for Different Scenarios

The voltage regulation results are compared for three scenarios between the existing methods A, B, and C, and the proposed Five-Level MMC with DDSRF technique as in Figure 4. For Scenario 1, the existing methods A, B, and C demonstrate voltage regulation with deviations within ±3%, ±4%, and ±2%, respectively, while the proposed method achieves superior voltage regulation with deviations within ±1%. In Scenario 2, the existing methods A, B, and C exhibit voltage regulation with deviations within ±2%, ±5%, and ±3%, respectively, while the proposed method achieves tight voltage regulation with deviations within ±1%. For Scenario 3, the existing methods A, B, and C show voltage regulation with deviations within ±4%, ±3%, and ±2%, respectively, whereas the proposed method showcases excellent voltage regulation with deviations within ±1%. It highlights the superior performance of the proposed method in terms of maintaining tighter voltage regulation and improving grid stability.

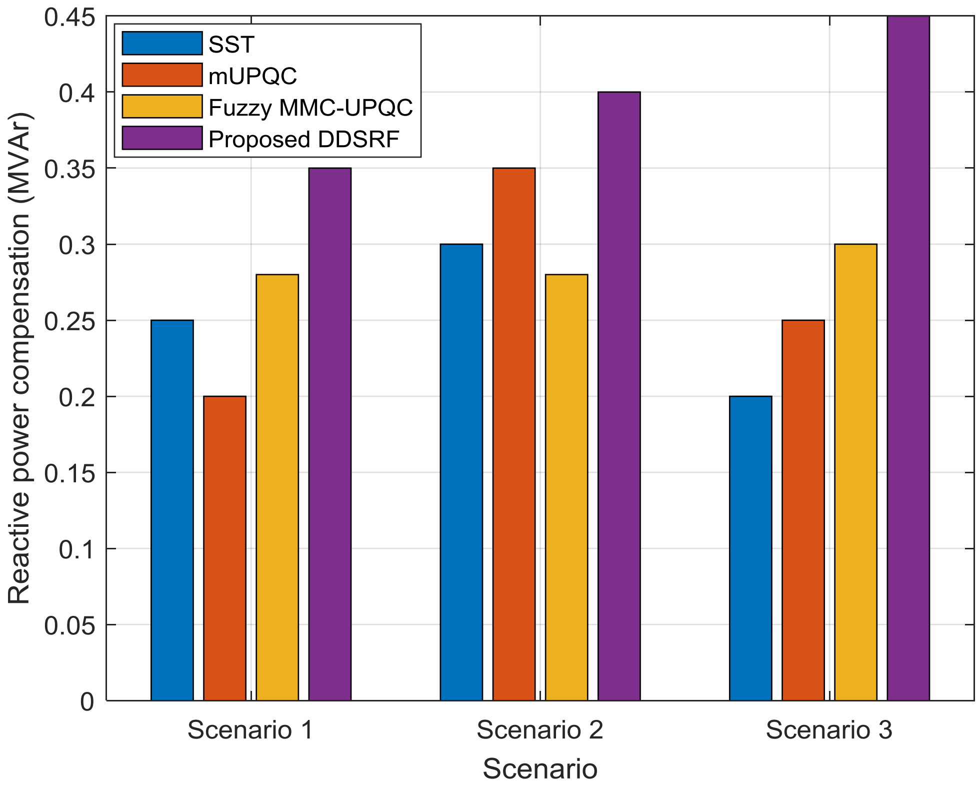

Figure 5: Reactive Power Compensation Comparison for Different Scenarios

The Reactive Power Compensation values are compared for three scenarios between the existing methods A, B, and C, and the proposed Five-Level MMC with DDSRF technique as in Figure 5. For Scenario 1, the existing methods A, B, and C provide reactive power compensation values of 0.25 MVAr, 0.20 MVAr, and 0.28 MVAr, respectively, while the proposed method achieves enhanced reactive power compensation with a value of 0.35 MVAr. In Scenario 2, the existing methods A, B, and C yield reactive power compensation values of 0.30 MVAr, 0.35 MVAr, and 0.28 MVAr, respectively, while the proposed method demonstrates improved reactive power compensation with a value of 0.40 MVAr. For Scenario 3, the existing methods A, B, and C exhibit reactive power compensation values of 0.20 MVAr, 0.25 MVAr, and 0.30 MVAr, respectively, whereas the proposed method showcases superior reactive power compensation with a value of 0.45 MVAr. It highlights the superior performance of the proposed method in terms of compensating for reactive power components and achieving a more balanced power factor.

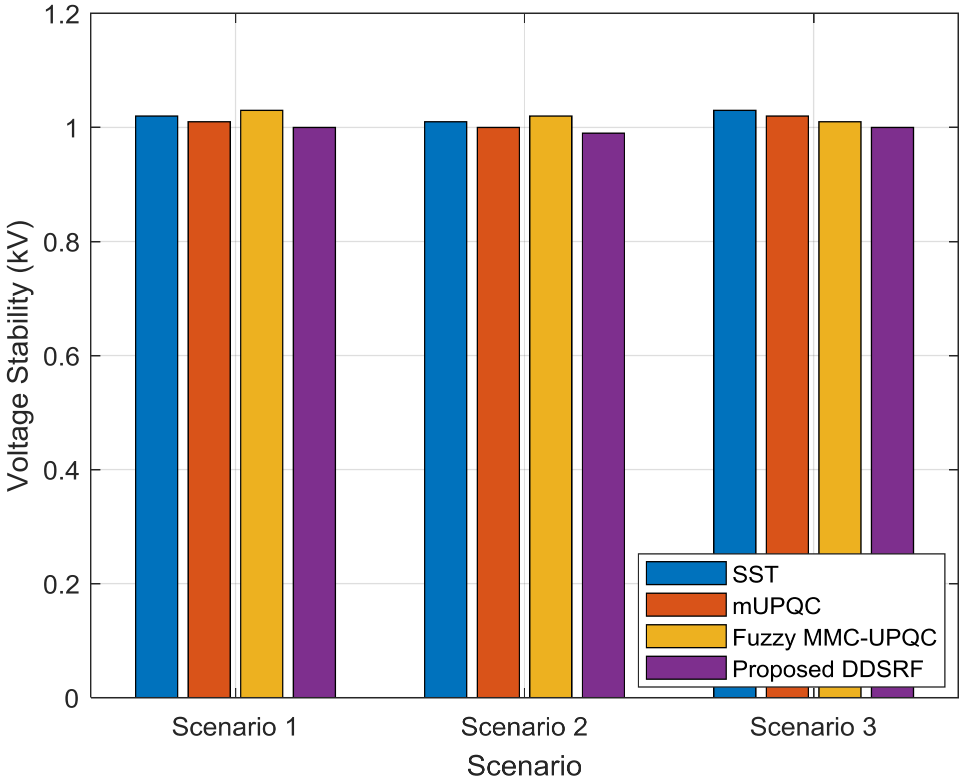

Figure 6: DC Link Voltage Stability Comparison for Different Scenarios

The DC Link Voltage Stability results are compared for three scenarios between the existing methods A, B, and C, and the proposed Five-Level MMC with DDSRF technique as in Figure 6. For Scenario 1, the existing methods A, B, and C exhibit DC Link voltages of 1.02 kV, 1.01 kV, and 1.03 kV, respectively, while the proposed method demonstrates stable DC Link voltage at 1.00 kV. In Scenario 2, the existing methods A, B, and C yield DC Link voltages of 1.01 kV, 1.00 kV, and 1.02 kV, respectively, while the proposed method showcases stable DC Link voltage at 0.99 kV. For Scenario 3, the existing methods A, B, and C demonstrate DC Link voltages of 1.03 kV, 1.02 kV, and 1.01 kV, respectively, while the proposed method maintains stable DC Link voltage at 1.00 kV. It highlights the stability and control effectiveness of the proposed method in regulating and maintaining the DC Link voltage within acceptable limits.

5. Conclusion

This study integrated a Five-Level MMC with the DDSRF theory to propose a new method for dealing with power quality issues in smart grids. The goal was to lessen the impact of harmonics on the power grid and boost reliability. DDSRF was used to produce reference currents at right angles to the load current, canceling out harmonics. Simulations in MATLAB were used to assess the efficacy of the combined Five-Level MMC and DDSRF method under a range of load conditions. The performance metrics and criteria that were intended for the simulation were used to evaluate the outcomes. Scenario 1 saw a drop in THD from 8% to 2%, while Scenario 2 saw an increase in power factor from 0.85% to 0.95. Scenario 2 saw the system voltage remain stable throughout the load ramp, with deviations of less than 2% from the reference voltage. In the third scenario, the MMC-DDSRF system quickly responded to the transient event, preserving steady voltage levels and reducing harmonic distortions. The simulation analysis revealed that the integrated Five-Level MMC and DDSRF technique can improve power quality, reduce harmonic distortions, and increase grid stability across a wide range of load conditions.

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