Comparison of PQ, PQR, and SRF Methods for Reference Current Extraction in Active Power Filtering Systems

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Abstract. This paper is aiming to compare three most used techniques in generating reference currents for active power filters: the traditional pq theory, its extension pqr, and the SRF (Synchronous Reference Frame) approach. In electrical grid it is mostly observed a voltage distortions and a harmonic distortions that can be reduced by those methods and determine its efficacity. The evaluation is implemented via MATLAB/Simulink simulations founded on a two-level inverter model, investigated under several representative operating conditions, extending from ideal balanced voltages to highly distorted and unbalanced cases. We evaluated each approach based on three principal indicators: total harmonic distortion (THD), the injected current waveform quality, and the active and reactive power exchange stability. We conclude from simulation that the SRF method achieved the best overall performance results by maintaining a stable operation and low harmonic content in all tested scenarios, that motivates to apply it in future medium-voltage systems using modular multilevel converters (MMCs).

1 Introduction

The modern electrical networks consider the power quality as a crucial factor that has to be maintained in a good level. Particularly with Nonlinear loads that has been rapidly expanding, such as electronic power converters for example adjustable speed drives and rectifiers, the use of these converters is leading to higher levels of current harmonics and voltage distortion. Which can affect badly the equipment life, decrease energy efficiency, and the stability of the grid[1], [2]. Therefore, the enhancement of the energy quality become a major concern for both researchers and industry field. Active power filters (APFs) have gained recognition in the recent applications multi-level modular converters (MMCs) for their superior voltage scalability, lower harmonic distortion, and enhanced fault tolerance considered one of the best compensation techniques out there, that is well-known for its flexibility and efficiency. They're usually applied using two-level voltage source inverters (VSI) for low and medium voltage applications[3], [4].

The extracting of reference currents used in compensation, various control algorithms have been explored in this research area. Several hybrid or adaptive strategies, by associating pq or SRF theories with intelligent control techniques (e.g., fuzzy logic or neural networks), that have improved dynamic performance, particularly under non-stationary or unbalanced

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operating conditions[5], [6]. the implementation of these advanced algorithms has become increasingly feasible with the availability of real-time digital platforms such as DSPs and FPGAs.

In this the present study, we suggest a unified comparison of three reference current extraction methods pq, pqr, and SRF under identical simulation and operating conditions. This work aims to identify which approach reaches the most stable and efficient compensation across different grid conditions. The results are expected to guide future implementations in medium-voltage active filtering systems based on MMC architectures.

Original Contribution of This Work

In this paper, three main technics have been presented, that can extract reference currents PQ, PQR, and SRF. We implemented, tested and compared all three under identical simulation and operating conditions to make a rigorous comparison. Earlier other studies focused and examined those technics separately, unlike our study that applies an evaluation framework based on several standards: the quality of the current waveform, the total harmonic distortion (THD), and the stability of active and reactive power. We evaluated these aspects based on four representative scenarios: balanced operation, unbalanced supply, harmonic distortion, and fifth-order harmonic injection. A practical conclusions can be determined by the results given, that can help select the most reliable reference current generation approach for medium-voltage active power filters using modular multilevel converter (MMC) technology for the researchers and engineers.

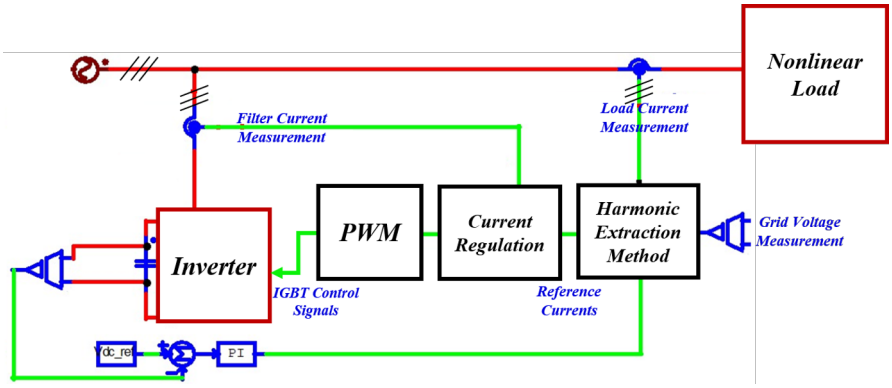

Figure 1. Block diagram of the studied system: three phase grid, nonlinear load, active power filter (APF), reference current extraction module, and PWM based control loop.

Figure 1 shows the overall architecture of the proposed system. A nonlinear load that introduces harmonic distortions into the grid is supplied by the three-phase source. The active power filter (APF) injects compensating currents. It derives these from a reference generation algorithm. This algorithm is based on measured load currents and supply voltages. A current control loop and PWM modulation ensure accurate current tracking. A fair comparison of the PQ, PQR and SRF methods can be made under identical operating conditions thanks to this modular configuration.

2 Original PQ Method

2.1 Principle of the PQ Method

The *pq* theory introduced in first time by Akagi and colleagues in the 1980s [7]. Their study is based on the concept of instantaneous power in the stationary reference frame. Due to its simple implementation, this technic has long been used in active power filtering, particularly in balanced three phase systems. It enables the decomposition of instantaneous power into active and reactive components, which facilitates the extraction of compensation currents. However, the classical *pq* method exhibits limitations under distorted or unbalanced conditions. It does not address zero sequence components and struggles to maintain power factor stability[8], [9], [10]. To better understand its practical performance in disturbed environments, this study investigates its behavior beyond the nominal case.

2.2 Practical Implementation of the PQ Method

The control scheme based on the *pq* theory involves the following steps:

- **Phase 1:** Transformation of three phase voltages and currents (**abc**) into the $\alpha\beta$ frame using Clarke's transformation.
- **Phase 2:** Computation of the instantaneous active power p and reactive power q from the transformed voltage and current components.
- **Phase 3:** Extraction of the average component $\overline{p}$ of the active power using a low pass filter (LPF), then computation of the oscillating part $\tilde{p} = p - \overline{p}$.
- **Phase 4:** Construction of the compensation vector $[\tilde{p} \quad q]^T$, representing the power components to be compensated.
- **Phase 5:** Inversion of the power equations to determine the reference currents in the $\alpha\beta$ frame.
- **Phase 6:** Inverse transformation from $\alpha\beta$ back to abc to obtain the reference currents i^*_{abc}, which are injected into the grid via the inverter.

2.3 Clarke Transformation

The Clarke transformation (also referred to as the Concordia transformation) maps three-phase quantities (a, b, c) into the two-axis stationary (α, β) frame:

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{1}$$

2.4 Computation of Instantaneous Powers

The instantaneous active power p and reactive power q are computed as:

$$\begin{cases} p = V_\alpha I_\alpha + V_\beta I_\beta \\ q = V_\alpha I_\beta - V_\beta I_\alpha \end{cases} \tag{2}$$

Or, equivalently, in matrix form:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \tag{3}$$

2.5 Harmonic Decomposition of Power

The total instantaneous power can be separated into average and oscillating components:

$$\begin{cases} p = \overline{p} + \tilde{p} \\ q = \overline{q} + \tilde{q} \end{cases} \tag{4}$$

Here, $\overline{p}$ and $\overline{q}$ represent the mean (fundamental) components of active and reactive power, while $\tilde{p}$ and $\tilde{q}$ contain the oscillating contributions associated with harmonics and non linearities.

The compensation strategy in the pq method is based on the principle that the source should only supply the average active power $\overline{p}$. The active power filter is responsible for providing the oscillating component $\tilde{p}$, as well as the total reactive power q. This requires temporary energy exchange between the filter and the network, typically handled by a storage element, such as a DC link capacitor, to buffer energy during dynamic conditions.

2.6 Reference Currents Calculation

The reference currents in the $\alpha\beta$ frame are obtained through inverse transformation of the power equations:

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ q \end{bmatrix} \tag{5}$$

Finally, the three phase reference currents are recovered via the inverse Clarke transformation:

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \tag{6}$$

3 PQR Method

3.1 Principle of the PQR Theory

The *PQR* theory is an extension of the instantaneous power theory *p-q*, specifically developed to address power quality issues in three phase four wire systems, particularly under unbalanced or distorted conditions. Introduced in 1999, it overcomes the limitations of classical definitions of apparent and reactive power, which become inaccurate in the presence of harmonics or asymmetries.

Unlike the conventional *p-q* theory, which primarily applies to balanced systems without a neutral conductor, the *p-q-r* formulation introduces a third component, *r*, associated with the zero sequence (homopolar) component. This allows the theory to account for and compensate the neutral current, even when supply voltages are non sinusoidal [8], [9], [1].

The instantaneous powers in this formulation include:

- p: Instantaneous active power, composed of a mean and oscillatory part,
- q: Instantaneous reactive power, linked to energy exchange without net consumption,
- r: Homopolar component, representing the power associated with the zero-sequence mode in the neutral wire.

3.2 Practical Implementation

The control structure based on the PQR theory involves the following steps:

- **Phase 1:** Transformation from the three-phase **abc** frame to the stationary $\alpha\beta 0$ frame,
- **Phase 2:** Computation of the current components I_p, I_q, and I_r,
- **Phase 3:** Low-pass filtering of the active component to extract $\overline{I_p}$,
- **Phase 4:** Generation of the reference currents,
- **Phase 5:** Inverse transformation from $\alpha\beta 0$ to the **abc** frame.

3.3 Computation of Stationary Frame Quantities

The voltage and current magnitudes in the $\alpha\beta 0$ frame are given by:

$$\left|\mathbf{v}_{\alpha\beta}\right| = v_{\alpha\beta} = \sqrt{v_\alpha^2 + v_\beta^2} \tag{7}$$

$$\cos\theta_1 = \frac{v_\alpha}{v_{\alpha\beta}}, \quad \sin\theta_1 = \frac{v_\beta}{v_{\alpha\beta}} \tag{8}$$

$$\left|\mathbf{v}_{\alpha\beta 0}\right| = v_{\alpha\beta 0} = \sqrt{v_\alpha^2 + v_\beta^2 + v_0^2} \tag{9}$$

$$\cos\theta_2 = \frac{v_{\alpha\beta}}{v_{\alpha\beta 0}}, \quad \sin\theta_2 = \frac{v_0}{v_{\alpha\beta 0}} \tag{10}$$

where $v_{\alpha\beta} = \sqrt{V_\alpha^2 + V_\beta^2}$, and $v_{\alpha\beta 0} = \sqrt{V_\alpha^2 + V_\beta^2 + V_0^2}$.

The PQR frame is aligned such that the voltage vector satisfies:

- $V_p = v_{\alpha\beta 0}$ (aligned with the active axis),
- $V_q = 0$ (orthogonal to the reactive axis),
- $V_r = 0$ (orthogonal to the homopolar axis).

3.4 Direct Transformation: $\alpha\beta 0 \rightarrow PQR$

The transformation of current components from the $\alpha\beta 0$ frame to the PQR frame is expressed as:

$$\begin{bmatrix} I_p \\ I_q \\ I_r \end{bmatrix} = \begin{bmatrix} \frac{V_\alpha}{v_{\alpha\beta 0}} & \frac{V_\beta}{v_{\alpha\beta 0}} & \frac{V_0}{v_{\alpha\beta 0}} \\ -\frac{V_\beta}{v_{\alpha\beta}} & \frac{V_\alpha}{v_{\alpha\beta}} & 0 \\ -\frac{V_0 V_\alpha}{v_{\alpha\beta} v_{\alpha\beta 0}} & -\frac{V_0 V_\beta}{v_{\alpha\beta} v_{\alpha\beta 0}} & \frac{v_{\alpha\beta}}{v_{\alpha\beta 0}} \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \\ I_0 \end{bmatrix} \tag{11}$$

3.5 Inverse Transformation: $PQR \rightarrow \alpha\beta 0$

Reference currents in the $\alpha\beta 0$ frame are recovered using:

$$\begin{bmatrix} I_{\alpha,ref} \\ I_{\beta,ref} \\ I_{0,ref} \end{bmatrix} = \begin{bmatrix} \frac{V_\alpha}{v_{\alpha\beta 0}} & -\frac{V_\beta}{v_{\alpha\beta}} & -\frac{V_0 V_\alpha}{v_{\alpha\beta} v_{\alpha\beta 0}} \\ \frac{V_\beta}{v_{\alpha\beta 0}} & \frac{V_\alpha}{v_{\alpha\beta}} & -\frac{V_0 V_\beta}{v_{\alpha\beta} v_{\alpha\beta 0}} \\ \frac{V_0}{v_{\alpha\beta 0}} & 0 & \frac{v_{\alpha\beta}}{v_{\alpha\beta 0}} \end{bmatrix} \begin{bmatrix} I_{p,ref} \\ I_{q,ref} \\ I_{r,ref} \end{bmatrix} \tag{12}$$

3.6 Inverse Clarke Transformation: $\alpha\beta 0 \rightarrow abc$

Finally, the reference currents are converted back to the three phase system as:

$$\begin{bmatrix} I_{a,ref} \\ I_{b,ref} \\ I_{c,ref} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} I_{\alpha,ref} \\ I_{\beta,ref} \\ I_{0,ref} \end{bmatrix} \tag{13}$$

4 SRF Method

4.1 Principle of the SRF Theory

(Harmonic distortions and system imbalances can be reduced by converting three-phase time domain (**abc**) into a rotating reference frame *dq0* using the synchronous reference frame (SRF).

The reconstruction of highly effective compensation currents in the original three-phase system is only possible by filtering the DC components in the dq0 frame, according to this method. The SRF method operates in a rotating frame synchronised with the fundamental frequency of the grid, a synchronisation realised through a phase-locked loop (PLL), which keeps track of the instantaneous phase angle of the supply voltage, indicated as θ; this differs from the PQR formulation, which stays in a stationary reference frame, and therefore the PLL is essential in maintaining correct transformations and ensuring the dynamic stability of the entire compensation process[11],[12],[13],[14].

4.2 Practical Implementation

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The Implementation of the SRF method in the control scheme has six steps:

- **First step:** The load current must be converted from the **abc** frame to the **dq0** frame, and to do this, the Park transformation must be applied using sine and cosine values derived from the supply voltage.
- **Second step:** Use low-pass filters (LPFs) to filter the resulting i_d and i_q currents to isolate the fundamental components
- **Third step:** The DC bus voltage is regulated using a PI controller that adjusts the i_d^{ref}.
- **Fourth step:** In most cases, without reactive power compensation, the reference currents i_d^{ref} and i_q^{ref} are generated (with $i_q^{ref} = 0$).
- **Fifth step:** Perform the inverse Park transformation to obtain the reference currents in the **abc** frame; To obtain the reference currents in the **abc** frame, perform the inverse Park transformation.
- **Last step:** The calculated reference currents should be injected into the power system using a voltage source converter (VSC).

4.3 Computation of dq0 Components

The Park transformation converts three-phase quantities from the stationary frame (**abc**) to the rotating reference frame (**dq0**) as follows:

$$i_d = \frac{2}{3}\left(i_a \cos\theta + i_b \cos\left(\theta - \frac{2\pi}{3}\right) + i_c \cos\left(\theta + \frac{2\pi}{3}\right)\right) \tag{14}$$

$$i_q = \frac{2}{3}\left(i_a \sin\theta + i_b \sin\left(\theta - \frac{2\pi}{3}\right) + i_c \sin\left(\theta + \frac{2\pi}{3}\right)\right) \tag{15}$$

$$i_0 = \frac{1}{3}(i_a + i_b + i_c) \tag{16}$$

The angle $\theta = \omega t$ must be synchronized with the grid voltage through a phase locked loop (PLL) to ensure proper separation between fundamental and harmonic components.

4.4 Filtering and Reference Current Generation

The i_d and i_q components contain both DC (fundamental) and AC (harmonic) terms. The DC components are extracted using low pass filters:

$$\overline{i_d} = \text{LPF}(i_d), \quad \overline{i_q} = \text{LPF}(i_q) \tag{17}$$

The PI controller regulates the i_d^{ref} value to maintain the desired DC bus voltage V_{dc}^{ref} [15]:

$$i_d^{ref} = \overline{i_d} + K_p e(t) + K_i \int e(t)dt \tag{18}$$

where the voltage error $e(t)$ is defined as:

$$e(t) = V_{dc}^{ref} - V_{dc} \tag{19}$$

In most cases, the reactive power is not compensated, and thus:

$$i_q^{ref} = 0 \tag{20}$$

4.5 Inverse Transformation: dq0 to abc

Finally, the reference currents are obtained in the time domain as:

$$i_a^{ref} = i_d^{ref} \cos\theta + i_q^{ref} \sin\theta + i_0^{ref} \tag{21}$$

$$i_b^{ref} = i_d^{ref} \cos\left(\theta - \frac{2\pi}{3}\right) + i_q^{ref} \sin\left(\theta - \frac{2\pi}{3}\right) + i_0^{ref} \tag{22}$$

$$i_c^{ref} = i_d^{ref} \cos\left(\theta + \frac{2\pi}{3}\right) + i_q^{ref} \sin\left(\theta + \frac{2\pi}{3}\right) + i_0^{ref} \tag{23}$$

These reference currents are injected into the grid by the converter to cancel harmonics and improve overall power quality.

5 Comparative Methodology

This study evaluates three methods for reference current generation:

- The conventional **PQ** method
- The extended **PQR** method with zero sequence component
- The **SRF** method (Synchronous Reference Frame)

The selected test scenarios replicate typical disturbances found in industrial power systems: balanced sinusoidal conditions (Case 1), voltage unbalance (Case 2), distortion caused by multiple harmonics (Case 3), and the injection of a 5^{th} order harmonic component into an otherwise balanced system (Case 4). These cases were intended to evaluate the performance of each control algorithm under practical, nonideal conditions [16]. Once steady-state operation is achieved, injected currents are analyzed over two fundamental cycles. The assessment focuses on three main criteria the waveform quality of the compensated currents, the Total Harmonic Distortion (THD) in accordance with IEEE Standard 519 [17], and the stability of active, reactive, and apparent power components.

The simulation scenarios are detailed as follows:

- Case (1): Balanced sinusoidal voltages (from $t = 0.4$ s to $t = 3$ s)
- Case (2): Unbalanced voltages (from $t = 3$ s to $t = 6$ s)
- Case (3): Voltages containing multiple harmonics (from $t = 6$ s to $t = 9$ s)
- Case (4): Balanced voltages with a 5^{th}-order harmonic (from $t = 9$ s to $t = 12$ s)

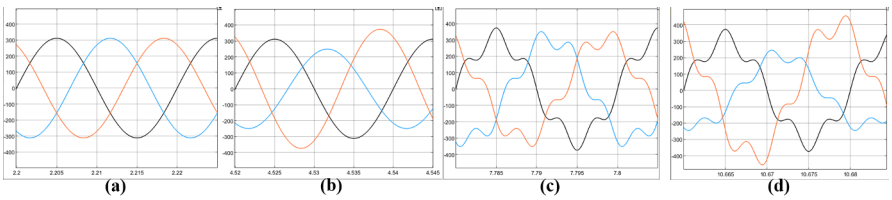

Figure 2. Three-phase voltage waveforms for the four test conditions (1) balanced sinusoidal, (2) unbalanced, (3) harmonic distortion, and (4) fifth-order harmonic injection.

Figure 2 shows the time-domain behavior of the applied voltages for each simulated case. In Case 1, the supply was perfectly sinusoidal and balanced. Case 2 presents a clear voltage imbalance, whereas Case 3 introduces strong harmonic distortion. In Case 4, a specific fifth-order harmonic was superimposed on an otherwise balanced voltage. Together, these four conditions provide a comprehensive framework for evaluating the response of each reference current extraction method to different grid disturbances.

6 Simulation Results

6.1 System Specifications

The simulation environment is configured to emulate a medium voltage active filtering application. The parameters used are summarized in Table 1:

Table 1. System parameters for active power filtering simulation.

Symbol	Description	Value
f	Grid frequency	50 Hz
T_s	Sampling time	1×10^{-5} s
R_s	Grid resistance	0.1 Ω
L_s	Grid inductance	3 mH
R_{ch}	Load resistance (non-linear)	40 Ω
L_{ch}	Load inductance	10 mH
L_f	Filter inductance	1.2 mH
R_f	Filter resistance	5 mΩ
C_{dc}	DC bus capacitance	2.2 mF
t_{sw}	Filter activation time	0.2 s

6.2 Overall Simulation Scheme

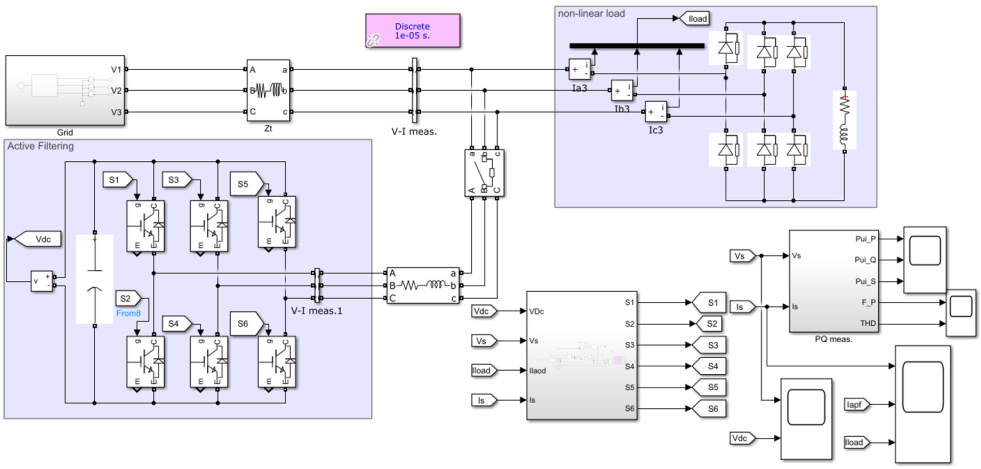

Figure 3. Overall simulation setup in MATLAB/Simulink: three phase supply, non linear loads, MMC based active filter, and reference current generation blocks (PQ, PQR, SRF).

As shown in Figure 3, the simulation system includes a three phase source, non linear load bank, and a two level inverter based active power filter. The system is equipped with a DC link voltage control loop (PI based), ensuring regulated current injection into the grid. The modular structure allows switching between different reference generation methods (PQ, PQR, SRF) under identical testing conditions.

6.3 Results with the PQ Method

As illustrated in Figure 4, the PQ method yields satisfactory compensation under balanced and sinusoidal conditions (Case 1). However, performance degrades significantly under unbalanced (Case 2) or harmonically distorted (Cases 3 and 4) scenarios. The THD remains high (see Table 2), especially when odd order harmonics are present. The power factor fails

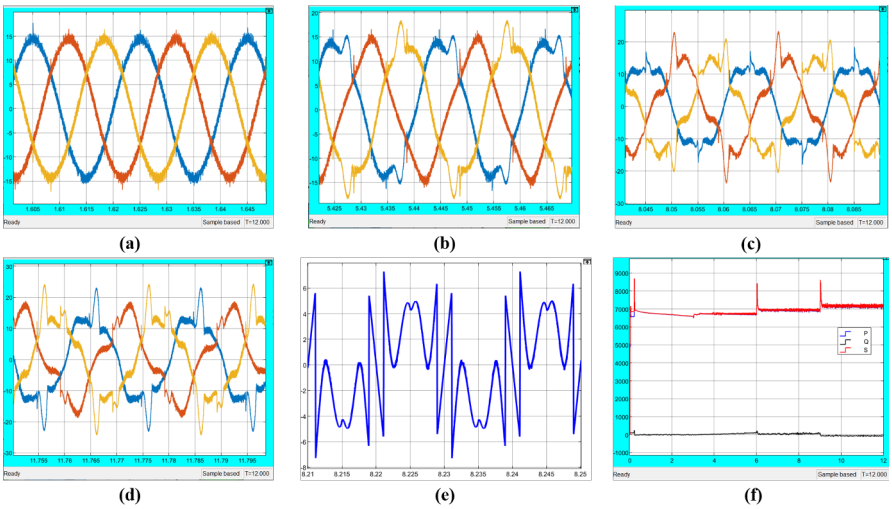

Figure 4. Simulation results for the PQ method (a) Line currents for Case 1, (b) Case 2, (c) Case 3, (d) Case 4, (e) Reference current i_{fa}^{*} in steady state, (f) Active (P), reactive (Q), and apparent (S) powers.

to reach optimal levels, revealing the method's limited ability to suppress non fundamental components under complex operating conditions.

6.4 Results with the PQR Method

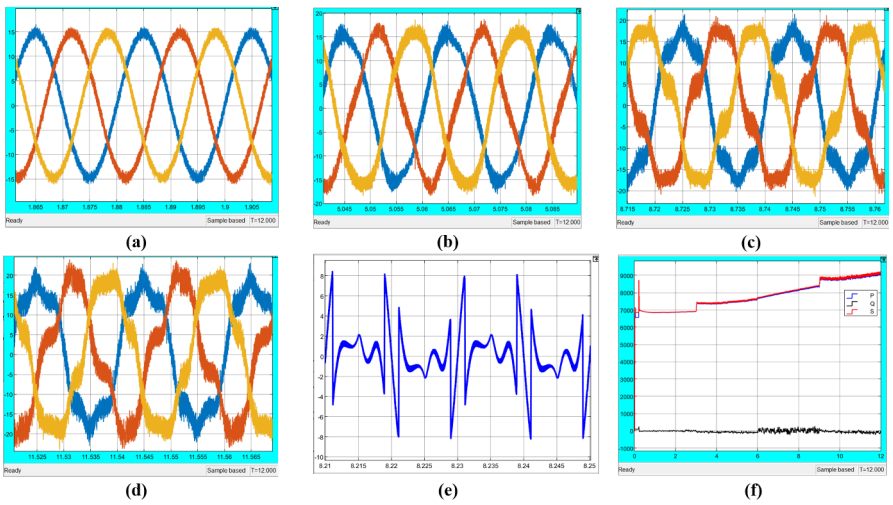

Figure 5. Simulation results for the PQR method (a) Line currents for Case 1, (b) Case 2, (c) Case 3, (d) Case 4, (e) Reference current i_{fa}^{*} in steady state, (f) Active (P), reactive (Q), and apparent (S) powers.

As seen in Figure 5, the PQR method significantly outperforms the PQ method, particularly under unbalanced conditions (Case 2) and in the presence of notable zero sequence

components (Case 3). The THD is markedly reduced, as reflected in Table 2, and the separation of power components improves compensation selectivity. However, the method requires more advanced vector processing, which can increase computational burden. Overall, it is well suited for four wire networks or systems experiencing asymmetries.

6.5 Results with the SRF Method

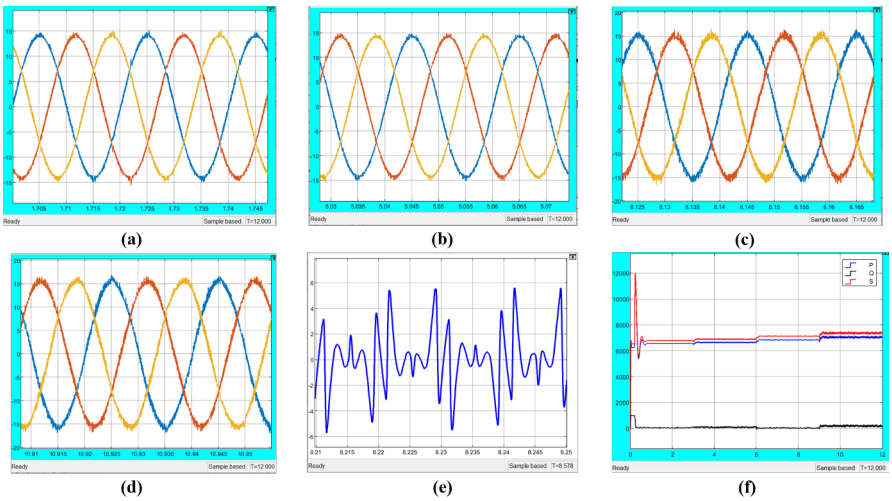

Figure 6. Simulation results for the SRF method (a) Line currents for Case 1, (b) Case 2, (c) Case 3, (d) Case 4, (e) Reference current i^*_{fa} in steady state, (f) Active (P), reactive (Q), and apparent (S) powers.

Figure 6 confirms the superior performance of the SRF method across all tested conditions. Whether facing balanced, unbalanced, or harmonically polluted scenarios, this method generates compensation currents that closely match the ideal fundamental waveform.

The Total Harmonic Distortion (THD), computed as per IEEE 519 [17], drops significantly from an initial 32% before compensation (at $t < 0.4$ s) to below 6% afterward (see Table 2). Additionally, the SRF method ensures excellent stability of the active, reactive, and apparent powers, confirming its robustness and efficiency in harsh power quality environments.

7 Comparative Performance Analysis

To support the qualitative observations, Table 2 provides a quantitative summary of the performance achieved by the three current reference generation methods under each test scenario. The evaluation is based on three key metrics: the waveform quality of the compensated currents, the Total Harmonic Distortion (THD), and the stability of active, reactive, and apparent powers.

This analysis highlights the limitations of the PQ method, which performs adequately only under balanced and undistorted conditions but deteriorates significantly when faced with unbalances or harmonic distortion. The PQR method is especially useful in unbalanced scenarios because it accounts for the zero sequence component. However, this comes at the cost of greater computational complexity.

Table 2. Quantitative comparison of the PQ, PQR, and SRF methods under the tested scenarios

Case	Method	Current Waveform	THD (%)	Power Stability
3*1: Balanced	PQ	Slightly distorted	4.8	Average
	PQR	Nearly sinusoidal	4.5	Good
	SRF	Sinusoidal	2.7	Very good
3*2: Unbalanced	PQ	Severely distorted	11.2	Unstable
	PQR	Moderate	7.9	Average
	SRF	Sinusoidal	2.7	Good
3*3: Harmonic distortion	PQ	Distorted	18.5	Poor
	PQR	Moderately distorted	17.3	Average
	SRF	Slightly distorted	4.4	Good
3*4: 5^{th} order harmonic	PQ	Distorted	23.1	Poor
	PQR	Moderate	17.1	Average
	SRF	Sinusoidal	5.2	Very good

In contrast, the SRF method stands out in all simulated conditions, exhibiting the lowest THD and the highest stability of power flows. Its use of a synchronized rotating reference frame allows it to respond effectively to a variety of grid disturbances.

Based on these results, the SRF approach emerges as the most robust solution and is therefore considered the best candidate for implementation in future medium-voltage active filtering systems using modular multilevel converters (MMC).

8 Conclusion

In this study, we presented a comparaison between three reference current generation technics applied in active power filtering: the classical pq theory, its extended pqr version, and the Synchronous Reference Frame (SRF) method. MATLAB/Simulink is used to implement the three algorithms in under identical conditions and tested through several grid disturbance scenarios. The results present the strengths and limitations of each technic. The pq approach can work better when the supply is perfectly balanced and sinusoidal but the accuracy decreases under distortion or unbalance. The pqr method overcomes this limitation by the zero sequence component, even if it involves more complex processing. However, the SRF method demonstrates the most stable performance to produce almost sinusoidal currents and maintain the stability of power in the most hard conditions. To summarize , based on this comparaison, the SRF technique is the most reliable and effective solution for modern active power filtering by combining the simplicity of implementation with strong robustness that make it suitable for integration into medium-voltage systems based on Modular Multilevel Converters (MMCs). Through real-time control on a hardware test platform, these findings can be tested experimentally in future work in the aim to validate it.

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