

Enhancing Power Quality in Transmission Lines with VSC-Based DSTATCOM: A Simulation Study

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Abstract - Maintaining excellent power quality is an absolute must for contemporary electrical systems due to the proliferation of sensitive devices and non-linear loads. This paper presents the results of simulation research that used MATLAB Simulink and a distribution static compensator based on voltage source converters (DSTATCOM) in transmission lines to enhance power quality in distribution networks. The impacts of voltage fluctuations, methods for reducing voltage sag and swell with and without DSTATCOM, and harmonic content analysis are all part of the scope of this research.

The purpose of this study is to simulate the VSC-based DSTATCOM and determine how well it reduces Total Harmonic Distortion (THD) and mitigates non-linear load effects. In electrical situations that are continuously changing, a VSC-based DSTATCOM with passive components is a fantastic approach to maintain power supply consistent. The results show that the suggested solution boosts system dependability and improves power quality.

Key Words: D-STATCOM, Power Quality, Voltage sag & swell, *Voltage source converter, Total Harmonic Distortion (THD), fault analysis, Harmonic Filtering, Non-Linear Loads*

1.INTRODUCTION

Smart cities today run on equipment that grows pickier by the year about how clean its incoming electricity needs to be. As the demand for stable, high-quality power keeps climbing, folding in technologies that can hold the supply steady stops being optional — especially once disturbances, load swings, sags, or swells start threatening that stability [1]. Meanwhile, renewable sources — solar PV leading the pack — keep getting adopted faster across modern grids. Keeping pace with that growth has pushed the development of more capable, more efficient power converters, which lift PV system performance while also helping bring installation costs down.

The complication is that solar generation rides on the weather, so wherever a PV system connects to the grid can see frequent voltage swings, with knock-on effects hitting both power quality and grid stability [2]. The Hybrid Active Power Filter with Photovoltaics (HAPF-PV) this work centers on is built around exactly

that pairing — renewable generation woven into the grid alongside active filtering, forming one unified power-quality solution. It brings a PV system delivering clean solar energy together with an HAPF that handles the harmonics, reactive power, and voltage disturbances that would otherwise chip away at power quality [3].

Inside the HAPF, the Shunt Active Power Filter (SAPF) takes on current harmonics, while sags and swells fall to the Series Active Power Filter (SE-APF) [4]. Between them, the SAPF and SeAPF cut down current harmonics and correct sag/swell-type voltage disturbances, resulting in power that is notably cleaner and more stable at the point of common coupling (PCC) [5]. The PV array and the remainder of the system are connected by a boost converter, raising panel voltage to a level the grid-tied inverter stage can handle efficiently. Incremental-Conductance (IC) based MPP-Tracking (MPPT) is what keeps the panels operating near their best output as weather conditions change [6]-[7]. For the inverter stage, the Cascaded H-Bridge (CHB) topology won out over the conventional Neutral-Point-Clamped (NPC) inverter, since it brings several practical advantages to this particular application [8]:

CHB inverters produce noticeably lower Total Harmonic Distortion (THD) than NPC designs do, which translates directly into cleaner power reaching the grid in this system [9] — making CHB the stronger pick for grid-side harmonic compensation and voltage support within a hybrid active power filter. Beyond the THD gains, CHB inverters also produce a more stable output waveform and mesh more naturally with renewable generation [10]. Taken together, the proposed HAPF-PV system strengthens both the quality and reliability of the connected grid — pairing active filtering with PV generation lifts overall grid performance in a way that neither piece could manage alone [11]. Injecting or absorbing reactive power effectively allows the DSTATCOM to stabilise the voltage and immediately decrease power quality issues. The DSTATCOM is able to react and compensate in real time to changes in the grid because of this block's significant involvement in the feedback control loop.

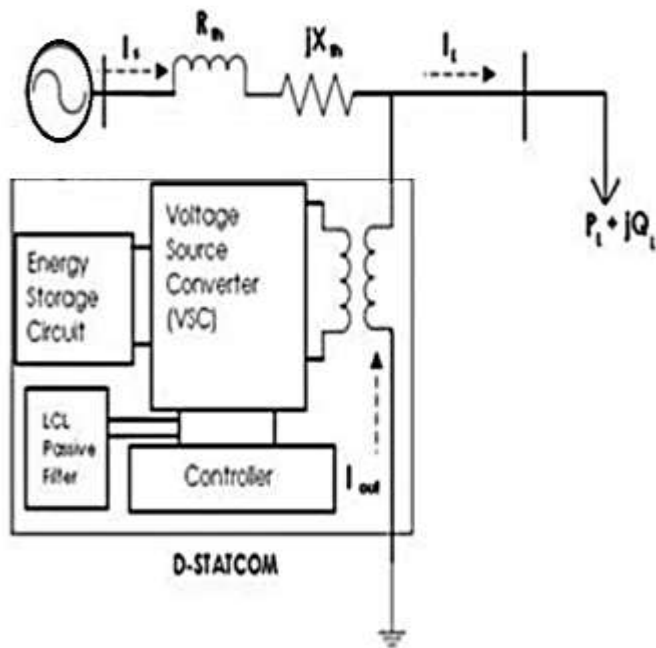


Fig. 1. schematic diagram of DSTATCOM

Figure 1 shows the DSTATCOM is one of the best electronic devices designed to solve these problems. It is a voltage converter VSC based system that provides energy recovery, coordination and power management at the distribution level. By integrating DSTATCOM into a distributed network, the following benefits can be achieved, DSTATCOM can reduce THD caused by nonlinear components, standards and improving the quality of electronic products. Voltage disturbances such as voltage sags and swells can cause operational failures in commercial and industrial applications. DSTATCOM provides stable voltage by dynamically injecting or absorbing reactive power as needed.

DSTATCOM analyzes and reduces multiple faults line-to-line, line-to-ground, three-phase faults, improving the fault and reliability pressure on the system. Through local balancing, DSTATCOM reduces the load on electrical equipment such as transformers and generators, improving overall performance. In this project, DSTATCOM is used to improve the quality of power distribution by comparing the performance in two cases (without DSTATCOM and with DSTATCOM). This approach demonstrates the effectiveness of DSTATCOM in solving important power quality issues, increasing reliability, and improving the performance of modern electronic systems.

2. VSC-Based DSTATCOM

1) Voltage Source Converter

A VSC is a high voltage converter that converts DC voltage to controlled AC output with the ability to adjust amplitude, phase angle, and frequency. VSC can quickly and efficiently inject or absorb power to stabilize the profile during events such as voltage sags and swells.

This has the added ability to control current, which is important for business and commercial operations. This allows the DSTATCOM to eliminate harmonic interference from nonlinear components, VSC provides a stable output, ensuring that the voltage remains within the allowable range even in the presence of disturbances such as faults or unbalances, traditional solutions rely on passive components such as capacitors and inductors, which are not very useful for dynamic applications. They cannot respond instantly to changes in voltage or harmonics, which often results in slow response times and poor power performance. By integrating VSC, the system can quickly adapt to changing conditions and disturbances in non-linear loads.

2) Control Block

The circuit and DSTATCOM make use of the following control blocks: a PLL for synchronisation, voltage and current control blocks for control and harmonic reduction based on SRF or p-q theory, a PI controller for DC link voltage control, and VSC-Switching. The method's foundation is a sinusoidal type PWM approach, which offers both ease of use and responsiveness. Compared to FFS methods, PWM methods provide greater choices for customisation because to the low application of user-defined performance (fundamental frequency switching). Another way to increase converter efficiency without significantly increasing switching losses is to employ high switching frequencies. The RMS value of the terminal voltage and the error signal obtained from the reference voltage constitute the controller input. Instances like these are dealt with by the PI controller. When using PWM signal generators, this will be possible [9, 10]. Among these approaches, you can find VSC control using PWM (SPWM or SVPWM), voltage control using PI, current control using hysteresis, and correlation using SRF/p-q theory.

3) Passive Elements

The DC Link Capacitor aids in reactive power compensation, harmonic reduction, and voltage stabilisation by storing and regulating the DC voltage needed by the VSC. By removing the VSC's high-frequency switching harmonics, the AC filter (L & C) guarantees that the grid receives sinusoidally-shaped current injections. Couplers and Series Inductors Links the VSC to the distribution system, which in turn reduces fault current and makes the grid's compensatory current injection more consistent. Through enhancing element values and coordinating with active components, these passive components stabilise voltage, decrease harmonics, and improve distribution system power quality as a whole. Fewer power supplies are required thanks to UPQC-based fuzzy logic's low unit input performance and low source current. Consequently, the DC connection voltage stabilisation

using the suggested fuzzy control approach is highly good [11].

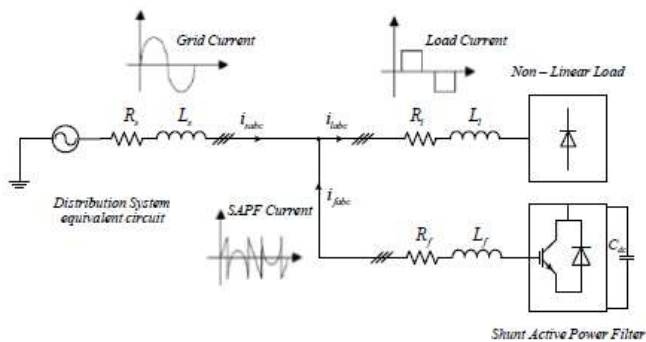


Fig.3 . Shunt active power filter compensation characteristics.

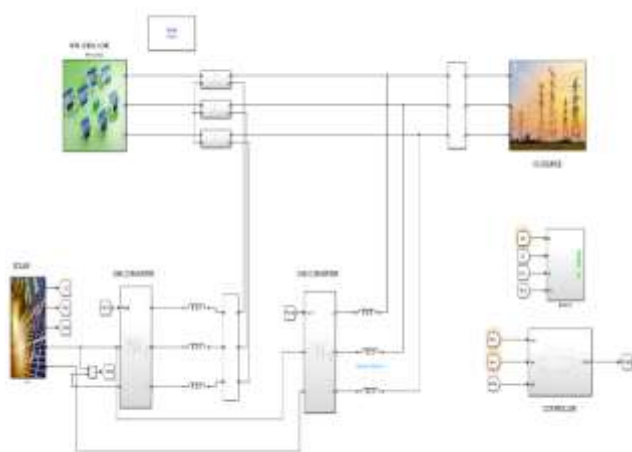


Fig.4. proposed system simulation Diagram

The proposed Hybrid Active Power Filter with solar Photovoltaics (HAPF-PV) takes shape in MATLAB/Simulink. Everything starts at the solar PV array, modelled on the Trina Solar TM-200DA01A module so its DC output stays consistent with whatever environmental conditions the simulation throws at it; Table 1 lists out the parameters behind this model. From there, the array's power feeds a boost converter, which raises panel voltage to a level the rest of the system can work with. An Incremental-Conductance (IC) MPP-Tracking (MPPT) algorithm drives that converter, tracking shifts in the PV array's ΔV voltage and ΔI current and voltage so the operating point stays pinned to maximum power even while solar

3. Proposed Implemented

irradiance (IR) shifts around, generating the duty-cycle (D) pulses the converter relies on to pull the most energy it can out of the panels. From there, the boost converter's

output lands on a DC-link capacitor, which irons out ripple and holds the voltage steady ahead of the DC-to-AC stage. That regulated DC voltage then feeds a Cascaded H-

Bridge (CHB) multilevel inverter, converting it to AC with cleaner waveform quality and lower Total Harmonic Distortion (THD) than a conventional inverter could manage. Two series-connected H-bridge units make up this CHB inverter's multi-level AC output, with each one pulling from its own DC source on the solar side.

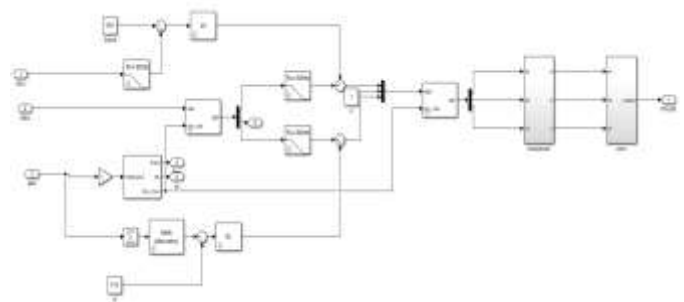


Fig .5 SOSF Controller for HAPF

Figure 5 shows the SAPF leaning on a Second Order Sequence Filter (SOSF) to extract the fundamental component of the load current, which generates the reference signals that the controller turns into pulses — those pulses then drive the CHB inverter to inject compensating current and knock down harmonics right at the grid PCC. That same controller, working alongside the CHB inverter inside the HAPF, also handles DC-link voltage regulation, checking it against a reference and running the error through a PI controller. Three-phase voltages and currents get converted into the dq frame so active and reactive components can be split apart, and those then generate the reference currents; converting back to abc form and comparing against carrier signals produces the PWM pulses. Those pulses drive the inverter to inject compensating currents, cutting harmonics and lifting the power factor. The other half of the hybrid pairing, the Series Active Power Filter (SeAPF), connects in series with the grid supply and takes care of voltage-side quality. It catches sags, swells, or imbalances as the PV system feeds power into the grid, injecting a compensating voltage to keep the load supply steady. Between them, SAPF and SeAPF cover both current and voltage distortion as PV generation gets folded into the grid, which is what delivers solid power quality across the board.

4.Simulation Results

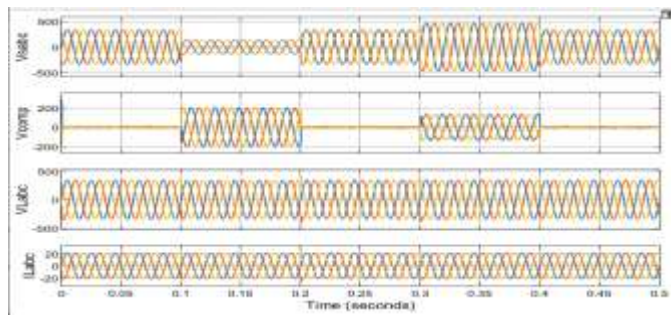


Fig.6. Vsabc,Vcomp,VLabc and ILabc

Figure 6 shows how the HAPF-PV system reacts once grid voltage disturbances — sag and swell — get applied. The source-side voltage (V_{sabc}) at the Point of Common Coupling (PCC) dips visibly between 0.1 s and 0.2 s, then swells between 0.3 s and 0.4 s. Despite those disturbances, the pairing of the PV system with the CHB multilevel inverter holds power quality together — the load voltage (V_{Labc}) sits steady at its preset value the whole time, which is exactly the voltage regulation the system was built to deliver. Both the series compensation voltage (V_{comp}) and the load current (I_{Labc}) back this up, confirming the system rides out the disturbance window without losing stability.

CASE 1: INPUT WAVEFORM WITHOUT DSTATCOM:

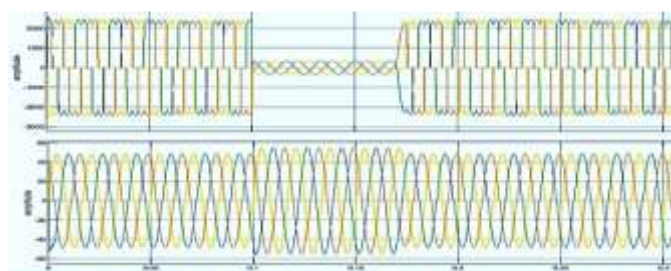


Fig. 7. Voltage (V_a) & Current (I_a)

Figure 7 shows The input waveforms of three-phase 30 kV AC distribution system. The top plot displays the three-phase voltage (V_{abc}) in per-unit (pu), while the bottom shows the corresponding current (I_{abc}) in per-unit. Between 0.05 and 0.15 seconds, a voltage sag occurs. From 0.25 to 0.35 seconds, a voltage swells increases both voltage and current amplitudes. By 0.35 to 0.5 seconds, the system stabilizes, with voltage and current returning to normal levels.

OUTPUT WAVEFORM

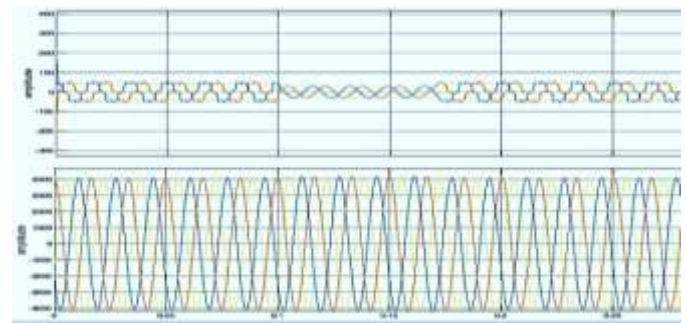


Fig.8. Voltage (V_a) & Current (I_a)

Figure 8 shows the Output waveforms of three-phase 30 kV AC distribution system, from 0 to 0.05 seconds, the waveforms are stable at 400 V. A voltage sag occurs from 0.05 to 0.15 seconds, followed by a swell (overvoltage) from 0.25 to 0.35 seconds. The waveforms return to normal by 0.35 to 0.5 seconds, indicating recovery. The top section displays three sinusoidal waveforms.

CASE 2: INPUT WAVEFORM WITH DSTATCOM:

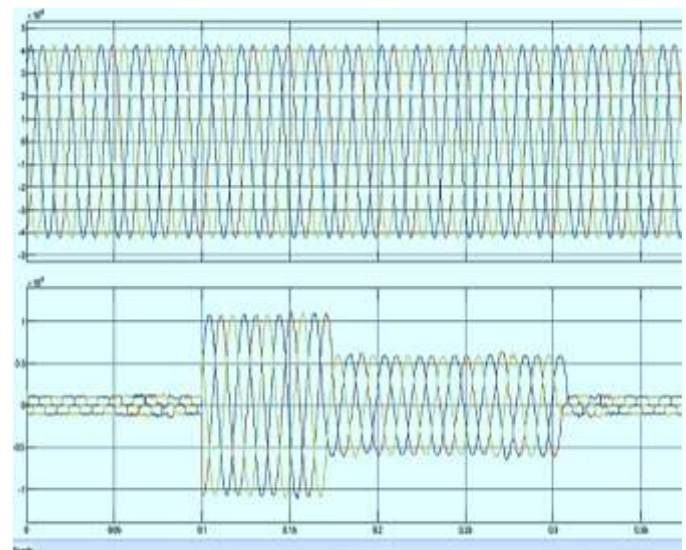


Fig. 9. Voltage (V_a) & Current (I_a)

Figure 9 shows the voltage and current two sets of input waveforms, likely representing different electrical parameters in a power system with DSTATCOM to reduce harmonic mitigation. The top section shows three sinusoidal waveforms, which could represent the three-phase voltages & currents in an AC system of 30kv.

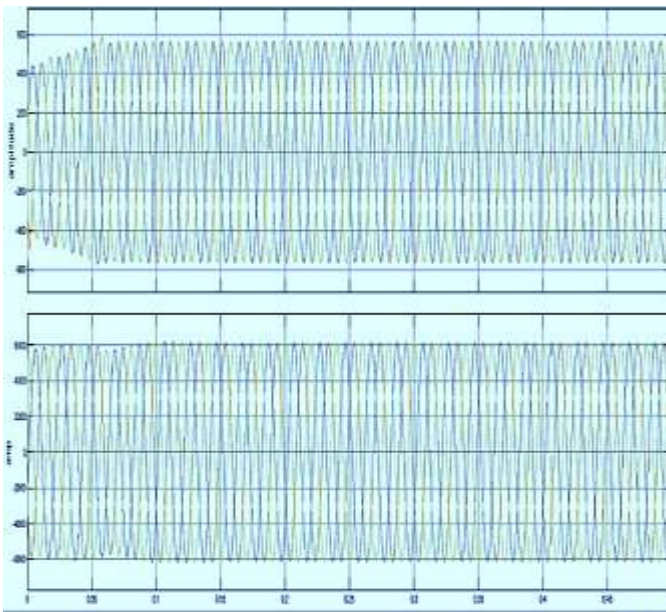


Fig. 10. Voltage (Va) & Current (Ia)

Figure 10 shows the voltage and current two sets of output waveforms, likely representing different electrical parameters

Total Harmonic Distortion:

Without distribution compensator

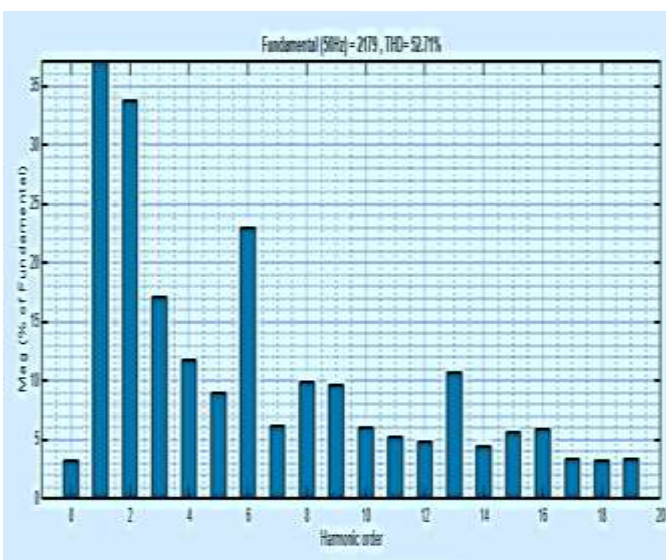


Fig. 22. Voltage (Va) & Current (Ia)

With Distribution Compensator

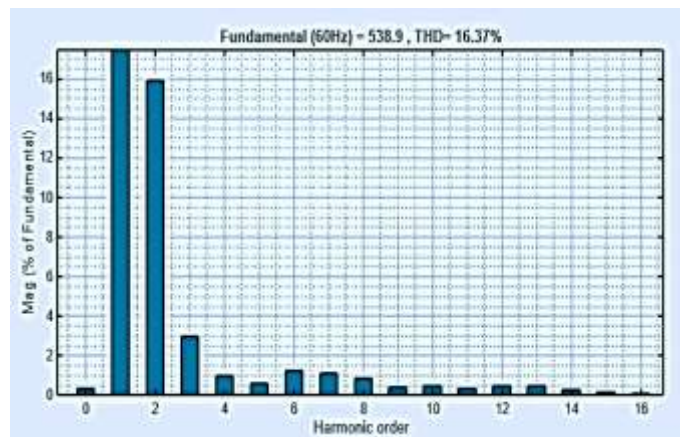


Fig. 23. Voltage (Va) & Current (Ia)

5. CONCLUSIONS

Built around a CHB multilevel inverter and IC-based MPPT control, the HAPF-PV system put forward here proves to be a genuinely solid approach to lifting power quality. The MATLAB/Simulink results bear that out, showing the system weathering voltage sag and swell events while continuing to deliver stable, clean energy even as grid conditions shift underneath it. The SOSF and PI controller working in tandem are what make accurate signal extraction and voltage regulation possible in the first place, and across the board the system brought THD down to 2.10% — a clear step up from what a conventional multilevel inverter manages on its own. Taken together, these results make a strong case that the CHB inverter, paired with its control strategy, meaningfully strengthens both system reliability and waveform quality.

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