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Synchronous Reference Frame Theory (SRF) Control Strategy for Optimal Operation of Double Stage Three Phase Grid Interface Multifunctional Solar Energy Conversion System

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ABSTRACT

Harmonic distortion, for example, is a major challenge for the electrical system. This is because this type of power quality issue can cause damage to electrical appliances, resulting in a reduced life duration for the electrical appliances; consequently, it is critical to keep the harmonic below 8%. DSTATCOM with Synchronous Reference Frame (SRF) as its control method is introduced to the system to alleviate this power quality issue, such as harmonics. SRF is in charge of generating the reference current to correct for harmonics in the system. After using DSTATCOM, all simulations for all three phases of source current achieved THD < 8%, with all phases achieving THD of 0.23%. These simulations are performed by using MATLAB/Simulink.

1. Introduction

Electrical engineers are largely concerned with resolving power quality issues in power systems, particularly those caused by nonlinear loads. These loads are classified as linear or nonlinear. When linked to the system, linear loads provide a sinusoidal current that matches the voltage frequency. Nonlinear loads, on the other hand, generate a more complex, non-sinusoidal current. Harmonics in the current waveform, which are frequently created by industrial equipment such as rectifiers or ASDs categorised as nonlinear load devices, are a significant concern in power quality. These loads are harmful to both user equipment and the utility. [1].

The altered current harmonic waveform distorts the voltage waveform, resulting in a loss of proportionality between voltage and current. These harmonic currents are fed into the electricity grid through the point of common coupling. They produce additional current harmonics as they

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transit the system's line impedance, resulting in distortion at the PCC. This can lead to overheating and electrical equipment damage [2]–[6].

To overcome this issue, custom power devices have been designed to offer consumers with a stable power source while protecting the utility infrastructure. These devices are classified according to how they are connected: series, shunt, or a combination of both (known as a unified power quality conditioner, or UPQC). The distribution static compensator (DSTATCOM), when coupled in shunt, is very effective at mitigating harmonic currents. [7].

As many countries, particularly modern ones, focus on creating renewable energy sources (RES) such as photovoltaic (PV) systems to replace traditional sources, there are issues in integrating RES into the distribution system, including worries about electricity quality. Custom power devices, such as DSTATCOM, are critical in addressing these issues. [8] [9].It is important to find a proper controller for DSTATCOM as its effectiveness is depending on its controller [10]–[12].

SRF is proved to be a suitable controller for this research as it able to extract fundamental current components [13], reducing Total Harmonic Distortion (THD) in source current [14], and compensating reactive power [15].

This project centres on the design of a shunt active power filter for a 3-Phase-3-Wire system using MATLAB/SIMULINK. It employs the SRF as the control algorithm for the DSTATCOM to ensure the optimal functioning of the single-stage three-phase grid-interfaced multifunctional solar energy conversion system (SECS). The primary goal is to eliminate harmonics, particularly under non-linear loads, in accordance with the IEEE Standard 519:2014. This standard stipulates that the THD value should be kept below 8%.

2. Methodology

2.1 System Configuration

Figure 1 depicts the system configuration, which includes a nonlinear load, a three-phase grid, a Variable Speed Controller (VSC), and a two-stage solar photovoltaic (PV) array. Interface inductors (Lf) are used to dampen current fluctuations. Additionally, resistors (Rf) and a capacitor (Cf) are used to reduce switching ripples at the Point of Common Coupling (PCC). The system consists of two stages linked by a common DC-link capacitor (CDC). The VSC is housed in the second stage, while a DC-DC boost converter is housed in the first. A tiny capacitor connects the first stage's input to the solar PV array. The load, AC distribution network, and second stage are all integrated at the PCC. The first stage harvests peak power from the solar PV array (PPV), which is then distributed in the second stage to both the nonlinear load and the AC distribution network. It corrects power quality issues for the utility by adjusting the load's demand for harmonic current. Switching ripples caused by the VSC switching mechanism have an impact on grid currents and PCC voltages. These waves are then filtered by an interface inductor and a ripple filter, in that order [16].

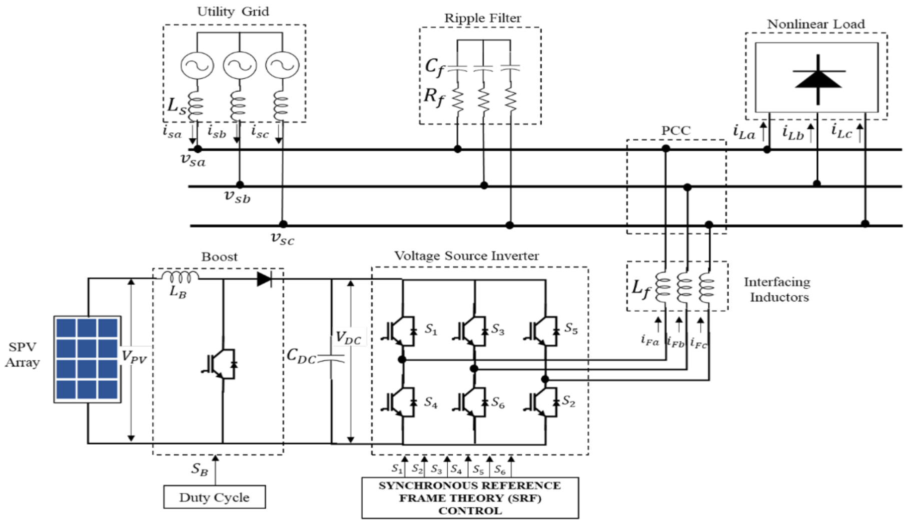

Fig. 1. System Configuration

2.2 DSTATCOM System Configuration
2.2.1 DC bus voltage

In a DSTATCOM, the voltage of the Point of Common Coupling (PCC) has a major impact on the DC bus voltage (Vdc), which is necessary for efficient Pulse Width Modulation (PWM) regulation of the Voltage Source Converter (VSC). For proper operation, the Vdc must precisely exceed the amplitude of the AC mains voltage. The DC bus voltage calculation for a three-phase Voltage Source Converter (VSC) is explicitly described in Eq. (1).

$$V_{dc} = \frac{2\sqrt{2}\ V_{LL}}{\sqrt{3}(m)} \tag{1}$$

Where *m* is the modulation index and is considered as 1, while V is the AC line output voltage of DSTATCOM which is 415V. The value of V_{dc} is obtained as 677V using Eq. (1) and was picked as 700V.

2.2.2 DC bus capacitor

The value of DC bus capacitor is dependent on the instantaneous energy available to DSTATCOM and on second harmonic or ripple voltage in the DC bus voltage. For a three-phase V_{SC}, the DC bus capacitor is defined as Eq. (2).

$$C_{dc} = \frac{I_o}{2\omega\Delta Vdc_{rip}} \tag{2}$$

Where I_o is the capacitor current, ω is the angular frequency and V_{dcrip} is the ripple in capacitor voltage. Considering I_o is 138.88A, ω is 100π and V_{dcrip} is 18V, using Eq. (2), the value obtained for C_{dc} is 12279µF. Hence, the chosen capacitor value is 13000 µF.

2.2.3 AC Inductors

The value of the AC inductance depends on the ripple current, I_{crpp} and switching frequency, f_s. AC inductor will remove the current ripple produced. The value of AC inductor, L_f is defined as Eq. (3).

$$L_f = \frac{mV_{dc}}{4 \times a \times f_s \times I_{crpp}} \tag{3}$$

Where *m* is the modulation index and is considered as 1, switching frequency, f_s is 1.8kHz, DC bus voltage, V_{dc} is 700V, over load factor, *a* is equal to 1.2 and I_{crpp} is 20.83A. Using Eq. (3), the value obtained for AC inductor, L_f is 4mH.

2.3 Synchronous Reference Frame Theory (SRF)

Figure 2 shows the control structure's SRF block diagram. The SRF approach is based on the conversion of current into a d-q frame that rotates synchronously [17]. An extraction procedure is preceded by a transformation technique that transforms distorted current into two-phase stationary coordinates. This transformation method makes use of the α-β transformation and is referred to as the 3-phase to 2-phase Clark's transformation [18]. The sine and cosine functions are then used to feed the values from this transformation into the rotating frame via the Phase Locked Loop (PLL) circuit. The functions are essential for preserving the synchronisation of the supply voltage and current. After this, the three-phase a-b-c stationary coordinate system—where the reference signals are initially located—is transformed into the rotating coordinate system, or 0-d-q, using the reference frame transformation method [19] [20].

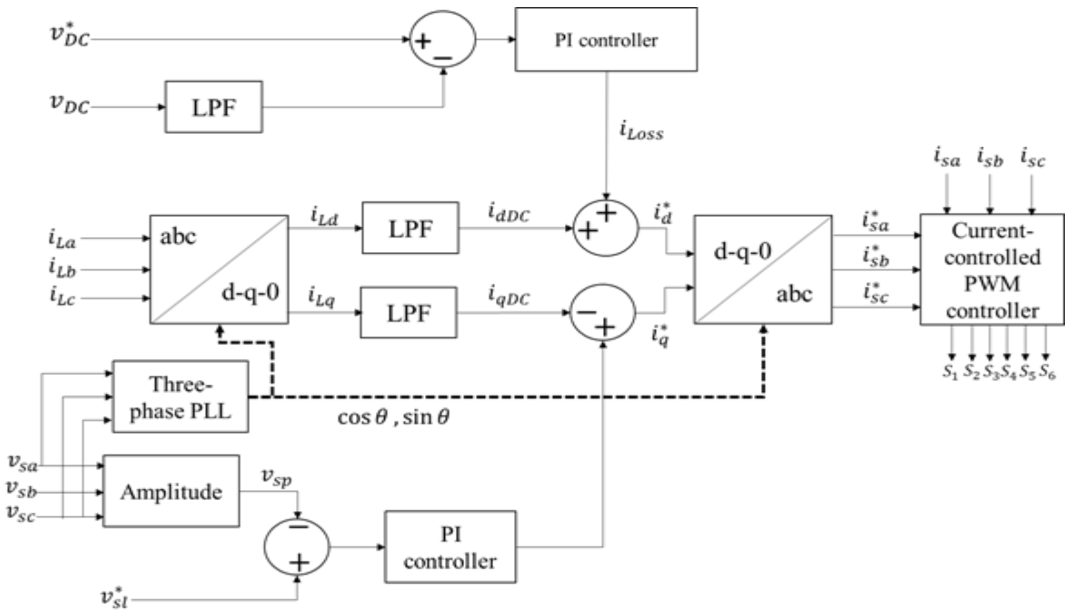

Fig. 2. SRF block diagram of control structure [16]

2.4 Design of GCPV

To design a solar PV panel, we need to calculate its series and parallel array using Eq. (4) and (5) respectively. The values of the parameters of PV module are listed in Table 1. The series and parallel PV array used after the calculations have been done is 13 series and 2 parallel panels with rated power 10784.83W.

$$N_{s\_oc\_max} = round\ down \left[\frac{V_{max\_inv\_abs} \times k_3}{V_{oc\_max}}\right] \tag{4}$$

$$N_{p\_max} = round\ down \left[\frac{I_{\mathrm{dc\_max\_inv}} \times k_7}{I_{\mathrm{sc\_string\_stc}}} \right] \tag{5}$$

Table 1
The value of the parameter of PV module type Q. Peak Duo-G5 315-335

Parameter	Value
I_{MPP}	5.69A
V_{MPP}	72.9V
V_{OC}	85.3V
I_{SC}	6.09A
Max.Power	414.801W

2.5 Circuit Design

Figure 3 show the system configuration of the nonlinear load connected with the DSTATCOM using the SRF strategy control that is design in the MATLAB/SIMULINK. DSTATCOM is connecting in parallel to the nonlinear loads.

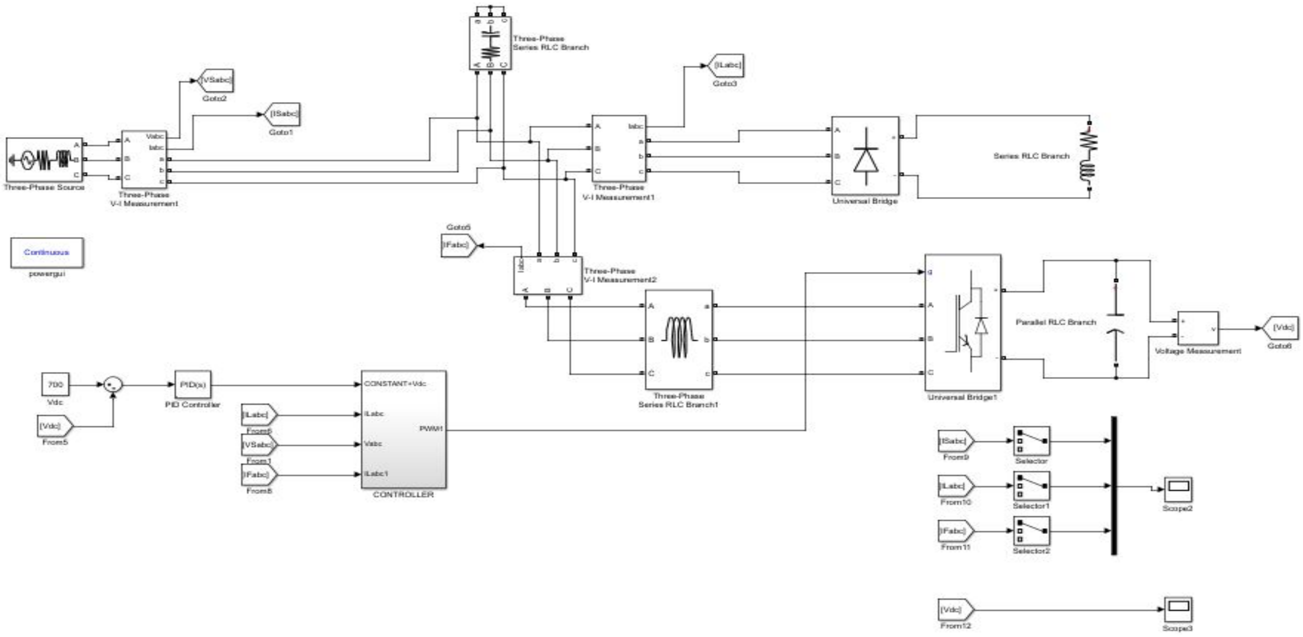

Fig. 3. MATLAB/SIMULINK model for nonlinear load with DSTATCOM

3. Results

3.1 Performance of Three-Phase System under Non-Linear Load without DSTATCOM

Based on its load current and source current, the performance of a three-phase system under non-linear load without DSTATCOM was assessed. To determine how non-linear load affected it, its waveform and THD value were examined. The total harmonic distortion of the source current and the load current are displayed in Figures 4(a) and (b), respectively. The source current THD at PCC is displayed in Figure 4(b), where it is higher than the recommended harmonic distortion value of IEEE STD 519-2022. The system's nonlinear loads are to blame for this. A higher THD is caused by these harmonics, which are multiples of the fundamental frequency.

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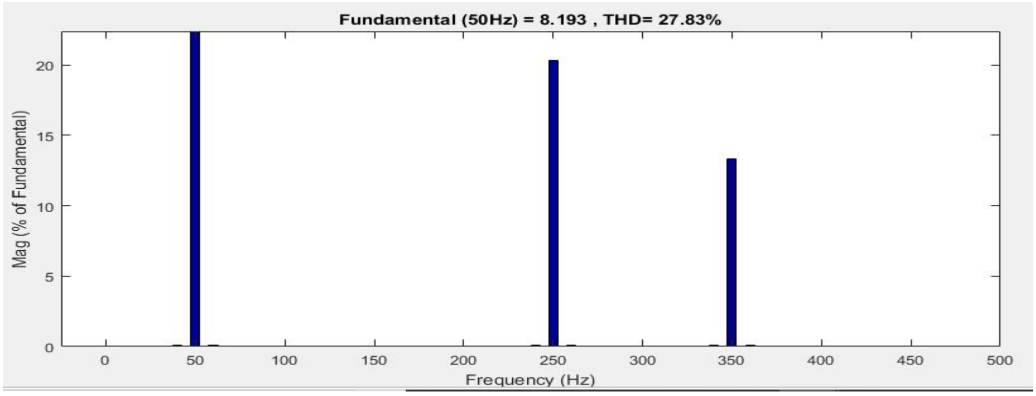
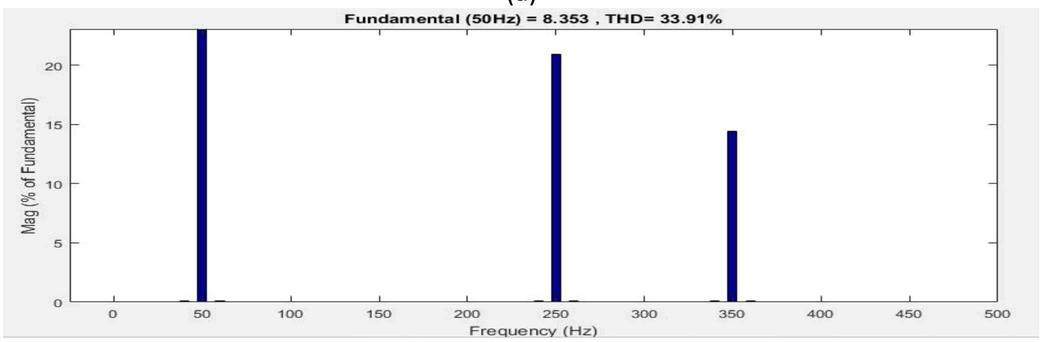


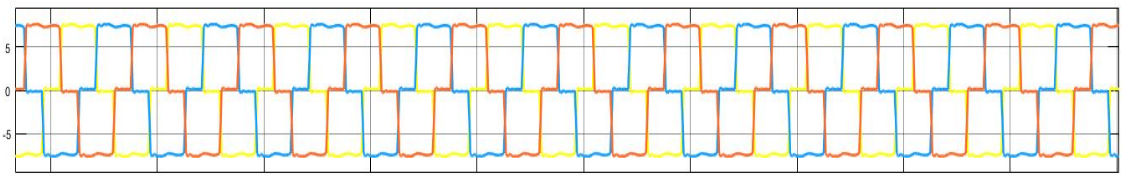
(a)



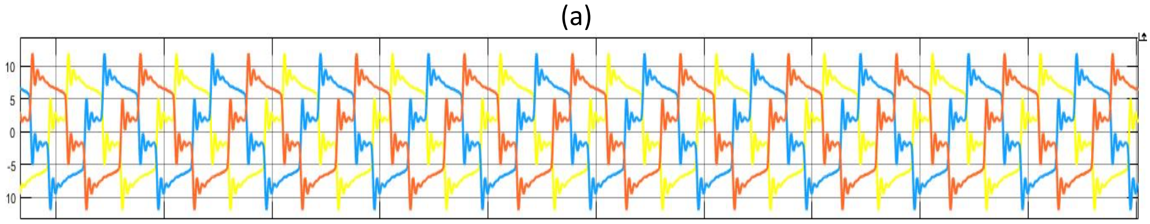
(b)

Fig.4. (a) THD of load current, i_L under non-linear load in steady state without DSTATCOM compensation (b) THD of source current i_S under non-linear load in steady state without DSTATCOM compensation

The non-linear load causes the load and source current waveforms to be distorted, as seen in Figure 5. The high overall harmonic content in the circuit as a result of the consumer's non-linear load causes this distorted waveform. Since there is no injection at PCC, the source current will follow the load current's waveform. The distorted waveforms of the source current and load current are depicted in Figures 9(a) and (b), respectively.



(a)

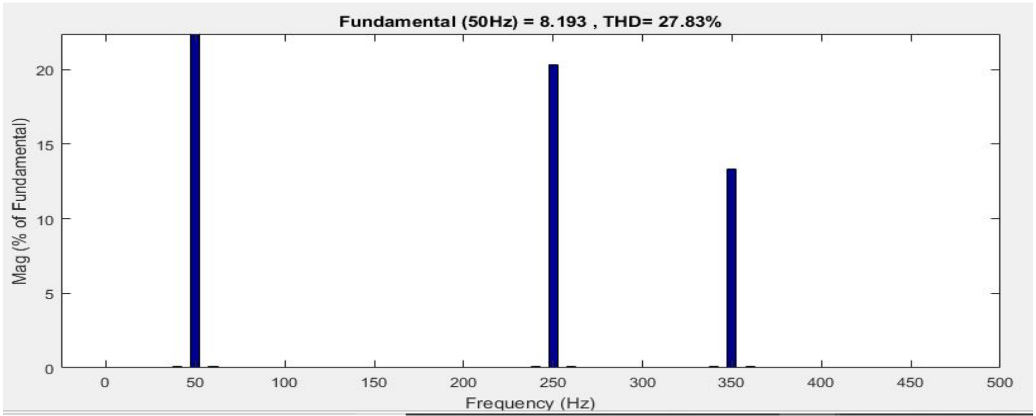


(b)

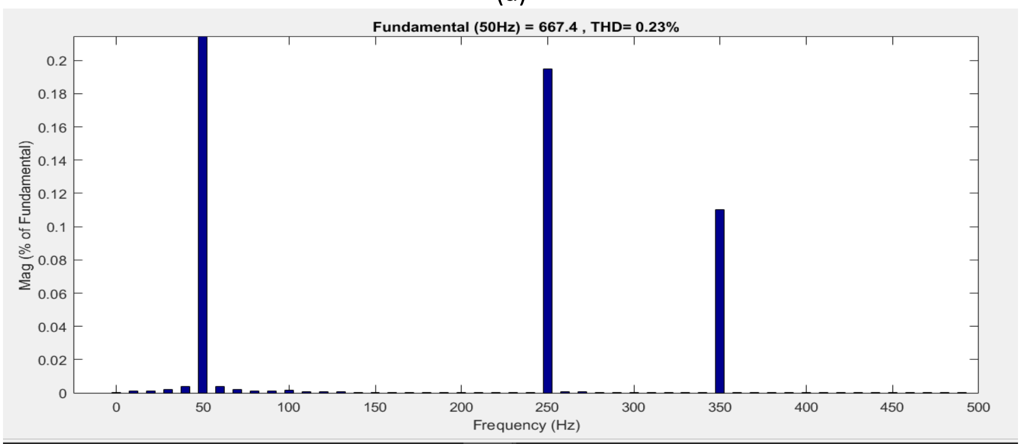
Fig.5. (a) Waveform of load current, i_L under non-linear load without DSTATCOM compensation (b) Waveform of source current, i_S under non-linear load without DSTATCOM compensation

3.2 Performance of Three-Phase System under Non-Linear Load with DSTATCOM Compensation with SRF

To counteract the distribution system's harmonic current distortion, DSTATCOM is introduced to the setup. In order to determine how DSTATCOM compensates for source current and source current THD at PCC, its performance is examined. Figure 6 displays the total harmonic distortion value. After DSTATCOM adjustment, the harmonic for source current decreased from 33.91% to 0.23%, while the THD for load current remained at 27.83%. This is possible because DSTATCOM counterbalances the harmonic currents in the system by introducing compensatory currents. DSTATCOM efficiently reduces harmonic currents at the PCC and enhances overall power quality by injecting compensating currents that are out of phase with the harmonic currents and synchronised with the system voltage.



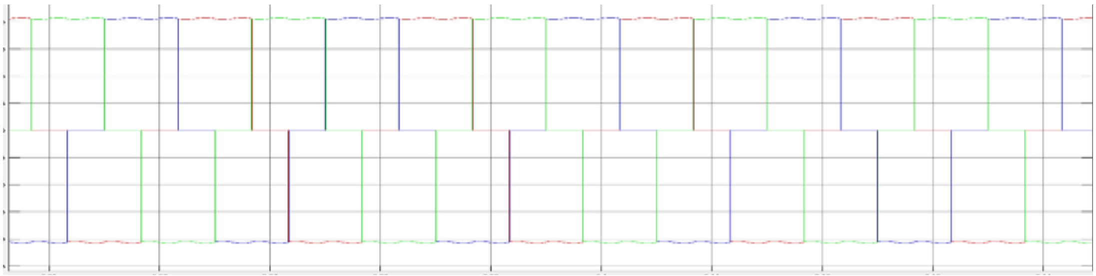
(a)



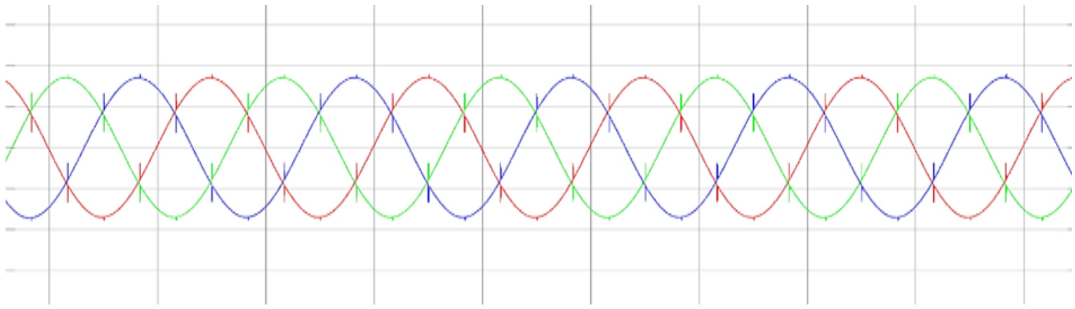
(b)

Fig.6. (a) THD of load current, i_L under non-linear load with DSTATCOM compensation
(b) THD of source current i_S under non-linear load with DSTATCOM compensation

Figure7 (a) and (b) shows the output waveform of the system after DSTATCOM compensation using SRF. The DSTATCOM has successfully compensated the source current as it achieved the desired sinusoidal waveform. This is because the THD has been reduced below the limit of harmonic current distortion.



(a)



(b)

Fig.7. (a) Waveform of load current, i_L under non-linear load with DSTATCOM compensation (b) Waveform of source current, i_S under non-linear load with DSTATCOM compensation

4. Conclusions

In conclusion, problems with power quality, such as harmonic distortion, pose a serious risk to the electrical system. This is due to the fact that certain power quality problems can harm electrical appliances, resulting in a shorter lifespan; for this reason, it is critical to resolve these problems. Since DSTATCOM can correct for problems linked to harmonic distortion, it can alleviate these harmonic concerns when used with the proper control algorithm. The THD for source current was initially at 33.91% before adding DSTATCOM, but after adding DSTATCOM, its THD dropped to 0.23%, proving the reliability of the device.

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