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Performance Analysis of DSTATCOM Using Hysteresis Controller and Conventional PI Controller

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ABSTRACT
DSTATCOM is widely employed to mitigate harmonics generated due to non-linear loading or due to integration of Distributed Generation (DG). Nonlinear load as well as DG are designed using Semiconductor Based Power Electronic Devices (SBPED). SBPED are high switching devices, hence they inherently inject the harmonics into the sinusoidal voltage-current waveforms. DSTATCOM is a three phase inverter followed by filter unit at AC side and a DC battery at DC side. It is connected in parallel with a nonlinear load and acts as a current source which compensate for Non-Linear Current (NLC)and provide reactive power. The way DSTATCOM mitigate harmonics is primarily depend upon the control strategy implemented to trigger the gate pulses of the DSTACOM inverter. There are numerous control available in literature. The widely adopted are parks' transformation based PI controller and clark' transformation based hysteresis controller. In this work comparative analysis of both the control strategies is presented in order to mitigate NLC so as to obtain sinusoidal load and source voltage with sinusoidal source current.
Keywords - DSTATCOM, Semiconductor Based Power Electronic Devices (SBPED), Non-Linear Current (NLC), Parks' transformation, Clark' transformation.

I. INTRODUCTION

Due to increase nonlinear loads in domestic and industrial application, distribution system faces sever problem of power quality. power quality (PQ) problems such as harmonics, imbalance in line voltage-current and flicker are frequently occurring in the system with high non-linearity. On the other hand, increased load involving sensitive digital gadgets and complex process controllers involves a pure sinusoidal supply voltage for its proper operation. The increased Non-Linear Current (NLC) may damage or disturb the performance of these sensitive devices. Hence some compensation is needed for meeting PQ [1-3] standards.

Conventionally capacitor banks were employed as passive compensation. But their deployment may cause problems related with series resonance and capacitor switching. Too large reactive power and voltage-current harmonics induces capacitor failures. Hence stability of the system may be affected. To overcome this controlled compensation like Distribution-FACTS (D-FACTS) controller are employed [4-6]. Although, the concept of FACTS was originally developed for transmission network. But due to the extensive used of microprocessor, computers, and power electronic systems has resulted in PQ issues involving transient disturbances in voltage magnitude, waveform and frequency in distribution system. Hence concept of D-FACTS has been extended since last 10 years for improvement of PQ in distribution systems operating at low or medium voltages. In the early days, the power quality referred primarily to the continuity of power supply at acceptable voltage and frequency [7]. Hingorani [8] was the first to proposed- FACTS controllers for improving PQ. He termed them as Custom Power Devices (CPD). These are based on VSC. The nonlinear loads not only cause PQ problems but are also very sensitive to the voltage deviations. Hence, he introduced broad three categories of D-FACTS;

1. Shunt connected DSTATCOM,

2. Series connected DVR,

3. Series and shunt both connected UPQC.

The UPQC is similar to UPFC while DVR is similar to SSSC. A DSTATCOM is utilized to eliminate the harmonics from the source currents and also balance them in addition to providing reactive power compensation. The way DSTATCOM mitigate harmonics is primarily depend upon the control strategy implemented to trigger the gate pulses of the DSTACOM inverter. There is numerous control available in literature. Instantaneous reactive power (IRP) theory [9], synchronous frame (SRF) theory [10] modified P-Q theory, parks' transformation- based PI controller and clark' transformation based hysteresis controller. In this work comparative analysis of PI controller and hysteresis controller strategies is presented in order to mitigate NLC so as to obtain sinusoidal load and source voltage with sinusoidal source current.

II. DSTATCOM

The goal of DSTATCOM is to eliminate load current harmonics. DSTATCOM is a PED designed using three-phase Voltage Source Inverter (VSI), connected parallel to the source [11,12]. The structure of DSTATCOM is shown in figure 1.

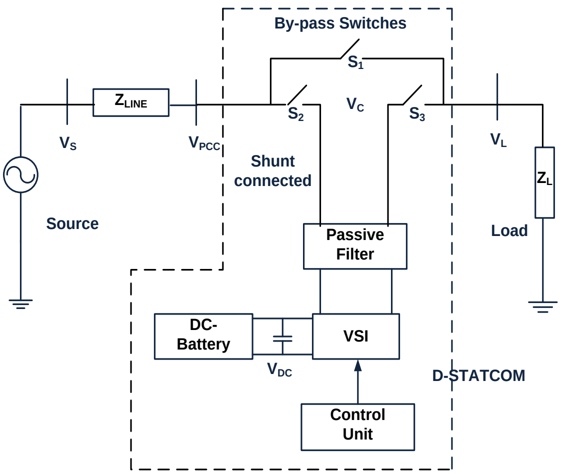

Fig. 1 Single line diagram of DSTATCOM

IV. SIMULATION MODEL

The schematic of DSTATCOM comprised of three-phase VSI followed by filter unit. The triggering of VSI is coordinated by control unit. DC side of DSTATCOM is charged by DC battery and AC side is connected in parallel with a nonlinear load, acting as a current source [13]. It results in a current alignment and providing reactive power. DSTATCOM injects current to the common coupling point to compensate for the current load's undesirable components. This principle applies to any kind of load being considered harmonious. The advantage of this is that it can carry only a small amount of the active current supplied to compensate for losses in the system in addition to the compensation current. Examples of shunt active power filter in current control mode are called DSTATCOM [14].

III. CONTROL OF DSTATCOM

In a high power VSI with high frequency switches, the switch is turned on and off only once in a cycle to minimize switching losses. The magnitude of the injected voltage can be controlled by Pulse Width Modulation (PWM). There are many variations in PWM. PWM converters requires several switching in a cycle. In a STATCOM with an energy source on the DC side, both the phase angle and magnitude of the injected voltage by the VSI is controlled in order to control the power and reactive power output [15].
In this work in order to generate reference current and to control gate pulse comparative analysis of PI controller and hysteresis controller is presented.

Conventional PI Controller

The reference current is generated using Synchronous Reference Frame (SRF). In the configuration of the SRF technique, as shown in the Figure. 2. Conventional SRF methods can be used to extract harmonics present at source or current voltages. At present, the distortion is first transferred to the two-phase DC components for compensation in line with the current. After that, the number of stationary frames transferred to the rotating frame corresponds to the cosine and sine function using Phase-Locked Loop (PLL). he sine and cosine functions help to maintain synchronization with the source voltage and current. The conventional SRF algorithm is also known as the d-q method and is based on the abc to d-q-0 transformation. In this work, a proportional-integral controller is used to eliminate the DC component's steady-state error and maintain the constant dc-side voltage. The dc capacitor voltage is sensed and compared with the reference voltage to calculate the fault voltage. Following the PI controller, the output is dripped from the direct axis (d axis) of the tuned component to remove the steady-state error.

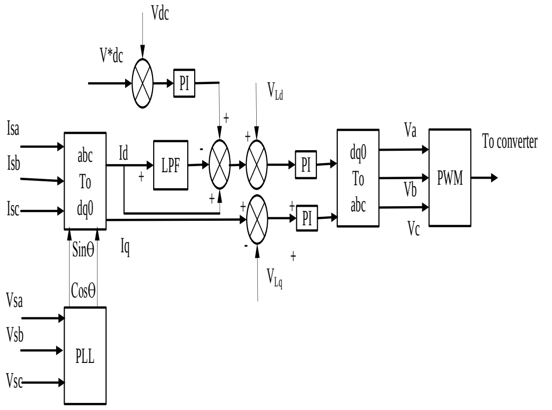

Fig. 2 Control of DSTATCOM using PI controller in SRF

Hysteresis Controller

The hysteresis controller can be made with either a current- or a voltage loop. The benefits of hysteresis controllers are primarily the linear modulation caused by the sawtooth-shaped carrier with ideally straight slopes. The control design for hysteresis controller is presented in figure 3. Hysteresis controller is designed using Clark' transformation, which convert three phase reference source current Iabc-into equivalent αβ0 coordinate. A PLL is used to synchronize the reference source voltage to obtain desired output. The hysteresis controller result in sum and difference products of the reference signal and the power supply variation, which meets high suppression of THD.

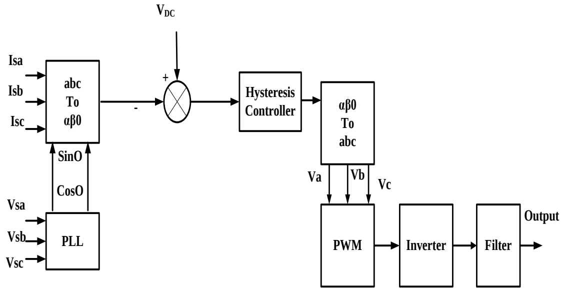

Fig. 3 Control of DSTATCOM using hysteresis controller

The simulation study of the proposed work is carried out in MATLAB simulink software using simulation tool. The matlab simulation model of the designed DSTATCOM is presented in Figure 4. The system has been analysed for two converter control strategies to obtain the PWM for three phase VSI. The converter control topology for PI controller is presented in Figure 5.

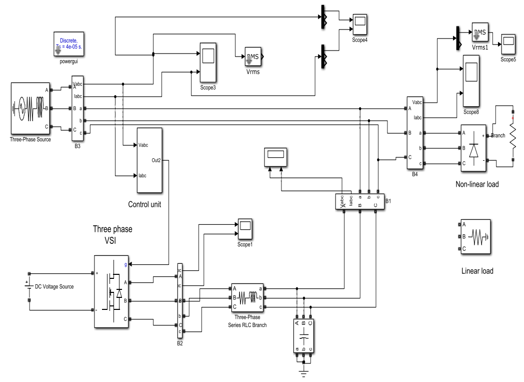

Fig. 4 Simulation model of the DSTATCOM

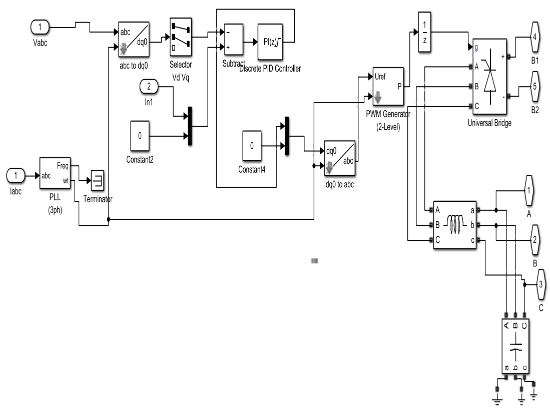

Fig. 5 Simulation model of the DSTATCOM using PI controller

The design parameters for the DSTATCOM with PI controller is presented in Table 1. Firstly, the performance of the system is studied for linear load. Under this condition the voltage and current waveforms are shown in figure 6. Since load is linear hence the voltage and current waveforms for source as well as load side will be same. Also waveforms are completely sinusoidal with negligible THD as shown in figure 7 and figure 8 for voltage and current respectively.

Table 1. Design parameters for DSTATCOM using PI controller

Parameter	**Values selected**
Voltage, RMS (L-L)	415 V
Source impedance	1.58mH
Frequency	50 Hz
V_{DC}	100V
Filter inductance L_f	15mH
Filter resistance R_f	0.1Ω
Filter capacitor C_f	800 uF
Three phase rectifier resistor R_{NLL}	125 Ω
Coupling capacitance	4500 µF
PI gains	0.04, 500
Linear load	10KW
Non-linear load	8KW

The designed system has been analysed for three phase non-linear load. A full wave-rectifier with resistance connected is taken as non-linear load for studying the proposed work. The voltage and current wave forms at load side is presented in figure 9. The harmonics in load voltage is presented in figure 10 and the THD for non-linear load current is presented in figure 11. The nonlinearity of load will distort the source voltage and current. But DSTATCOM supply variable reactive power and regulate the voltage of the bus where it is connected and also it will provide compensation for non-linear load current. The voltage and current wave forms at source side is presented in figure 12 with DSTATCOM connected. The harmonics in source voltage is presented in figure 13 and the THD for source current is presented in figure 14.

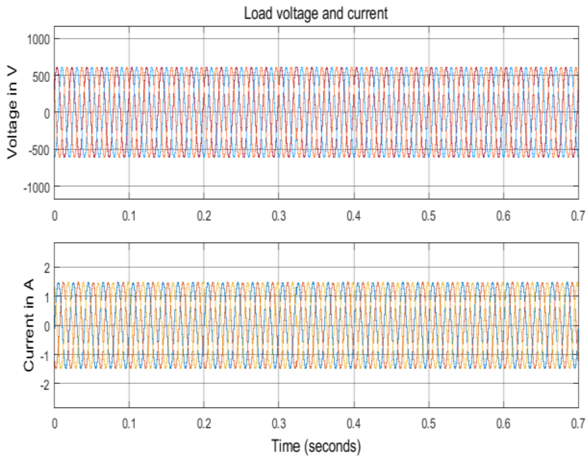

Fig. 6 Voltage and current waveforms for linear loading

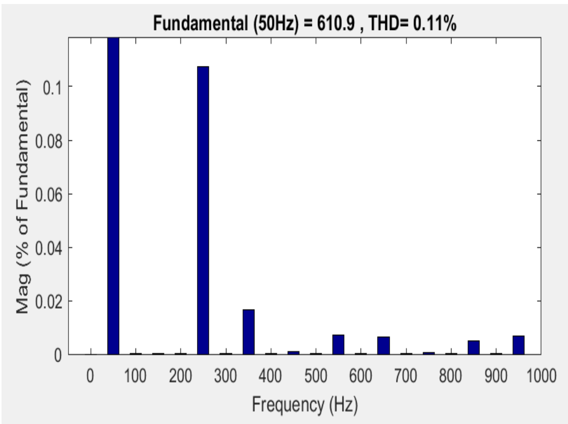

Fig. 7 THD of voltage for linear loading

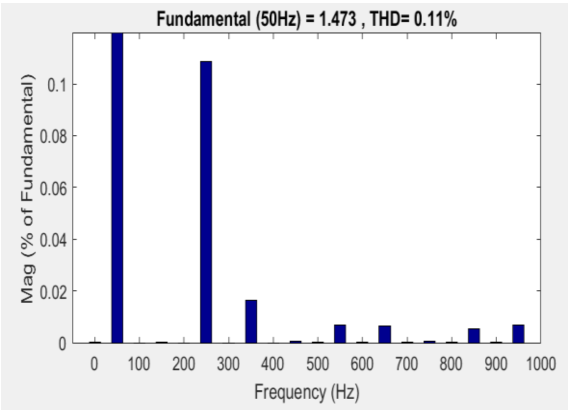

Fig. 8 THD of current for linear loading

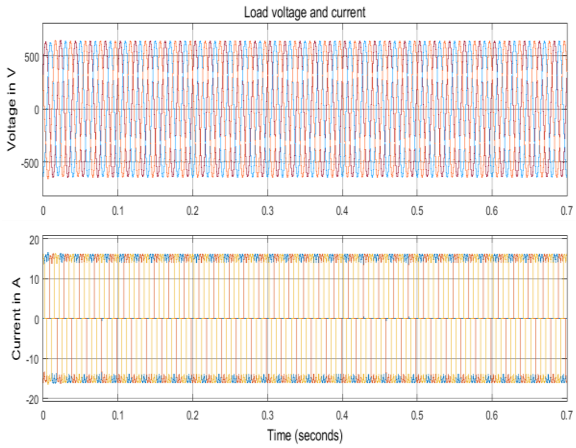

Fig. 9 Load voltage and current waveforms for non-linear loading using PI controller

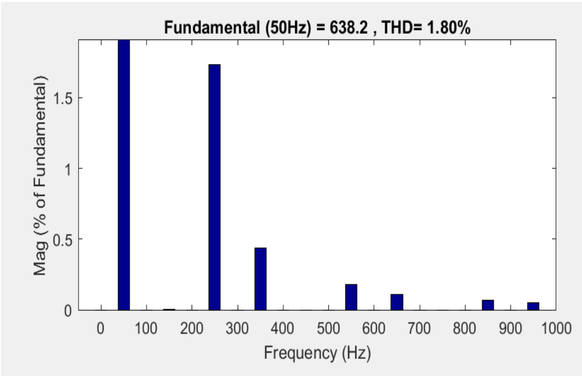

Fig. 10 THD of load voltage for non-linear loading

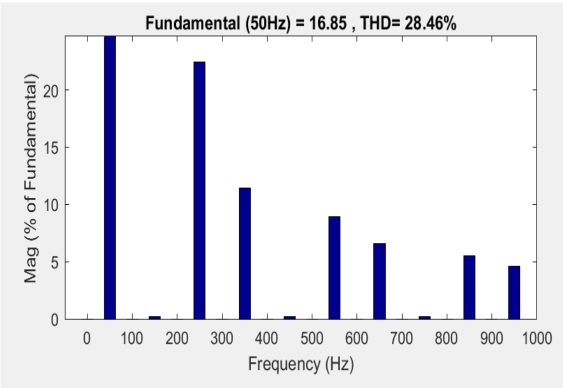

Fig. 11 THD of load current for non-linear loading

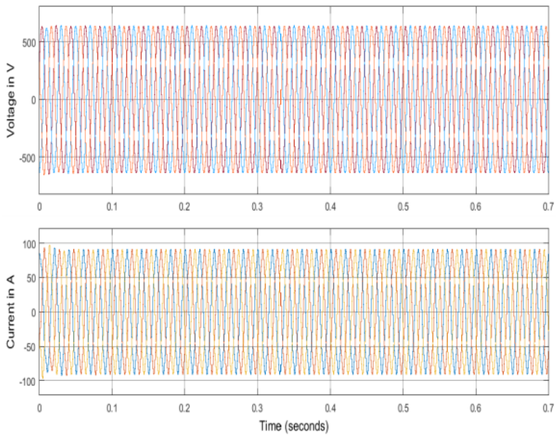

Fig. 12 Source voltage and current waveforms for non-linear loading using Pi controller

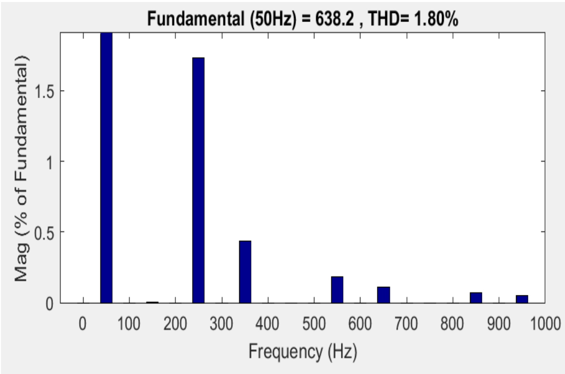

Fig. 13 THD of source voltage for non-linearload

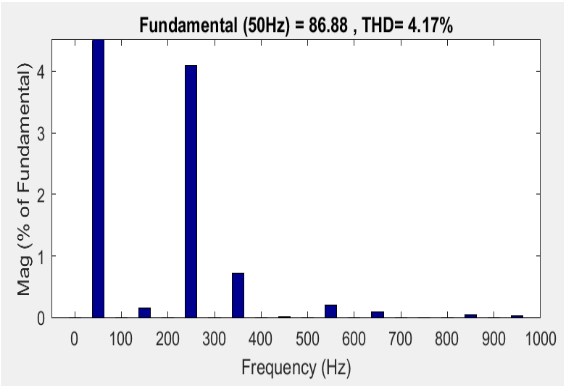

Fig. 14 THD of source current for non-linear loading

The DSTATCOM is again analysed using hysteresis controller. The simulation model for hysteresis controller is give in figure 15. All the parameters are same as in case of PI controller, but filter design is changed a bit. In hysteresis controller the series RL with 1 Ω resistance and 10mH inductor and parallel capacitance with 20 μF is used. The voltage and current wave forms at load side for non-linear load is presented in figure 16. The harmonics in load voltage is presented in figure 17 and the THD for non-linear load current is presented in figure 18. The voltage and current wave forms at source side is presented in figure 19 with DSTATCOM connected. The harmonics in source voltage is presented in figure 20 and the THD for source current is presented in figure 21.

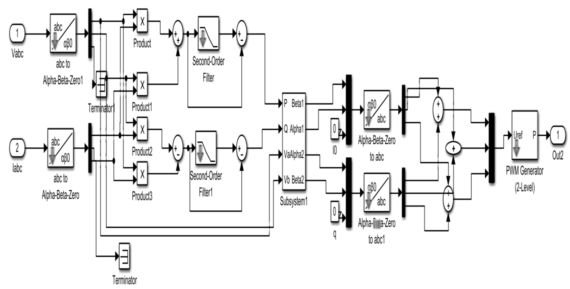

Fig. 15 Simulation model of the DSTATCOM using hysteresis controller

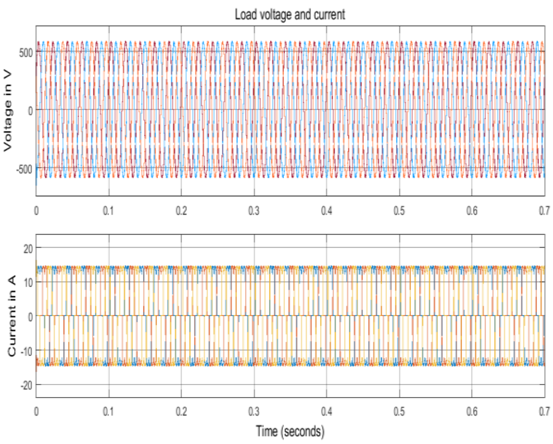

Fig. 16 Source voltage and current waveforms for non-linear loading using hysteresis controller

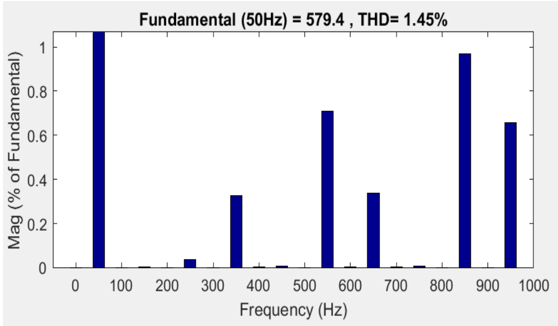

Fig. 17 THD of source voltage for non-linear loading

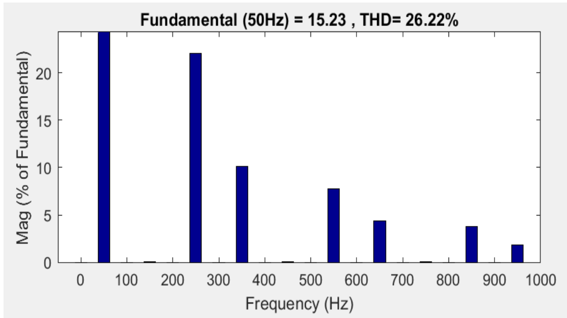

Fig. 18 THD of source current for non-linear loading

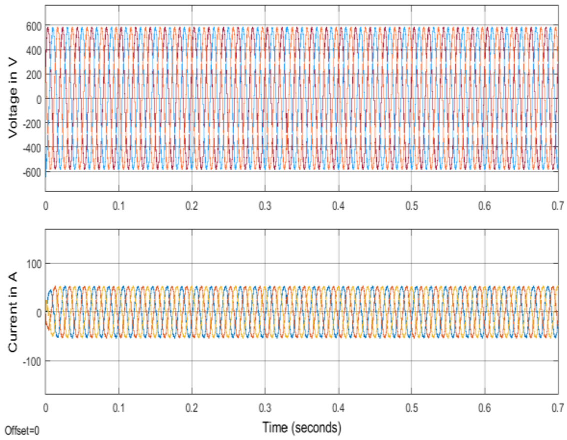

Fig. 19 Source voltage and current waveforms for non-linear loading using hysteresis controller

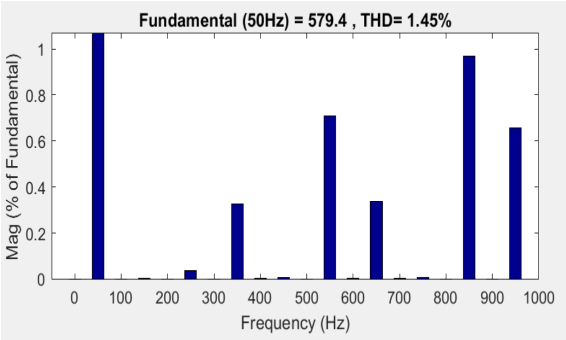

Fig. 20 THD of source voltage for non-linear loading

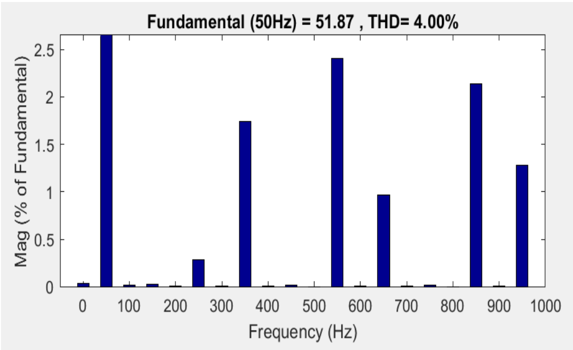

Fig. 21 THD of source current for non-linear loading

V. SIMULATION MODEL FOR SPGS IN STAND-ALONE MODE (SAM)

The work presented in this paper is to mitigate harmonics at source side generated due to non-linear load. A DSTATCOM is designed with PI controller and hysteresis controller. Though harmonic reduction using both the controller is almost same but there is a huge difference in filter size. PI controller uses a large size filter having RC connected in series and C in parallel. On the other hand, hysteresis controller uses a very small filter size with series RL and parallel capacitance. The comparative analysis for both the controller is presented in Table 2 below.

Table 2 Comparative Analysis

Controller	Source voltage THD	Source Current THD	Load current THD	R	L	C
PI Controller	1.8	4.17	28.4	1	--	730μF
Hysteresis controller	1.4	4.0	26.2	1	10mH	20μF

VI. CONCLUSION

This work has been done to compare PI and Hysteresis controller used to design DSTATCOM control to obtain reference current and gate pulses. The performance analysis is done by comparing the power quality of each compensator. It can be seen, though both the controller reduces THD remarkably and are compatible in this context. But the filter size required to design PI controller is large as compared to hysteresis controller. Due to this the source current drawn increase double to that hysteresis controller. Hence this will increase cost as well as system losses. Therefore, from the simulation study it can be concluded that hysteresis controller gives better performance as compared to PI controller. As well as it also reduces the design cost.

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