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Performance Analysis of DSTATCOM with High Solar PV Penetration for Distribution System

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Abstract: The scope of grid-connected photovoltaic (PV) power system installations has grown increased rapidly. According to Ministry of New and Renewable Energy (MNRE) reports thesolar capacity of India is increased 370 % in the last 3 years from around 2.6 GW more than 12.2 GW. Large penetration of PV in a microgrid connected distribution system impacts the weak utility distribution system by creating various powerquality (PQ) problems such as voltage sag or swell, unbalance, harmonics and DC current injection etc. These power quality (PQ) issues and they are broadly classified as current related PQ issues and voltage related PQ issues. When number of solar PVs are connected at the end of long and lightly loaded distribution system, there occur inconstancy inPV generation, so there will be a large voltage variation. A multiple functions of DSTATCOM is thus achieved by operating the device so as to mitigate the current and voltagerelated PQ issues. Thus a multi-functional control strategy allow DSTATCOM to compensate voltage and current relatedPQ problems. This project presents a hybrid DSTATCOM which can be used in highly PV penetrated distribution systemto control the voltage and current related PQ issues. The topology uses a suitably designed foreign inductor, connectedbetween the grid and load.

Keywords: PQ, Penetration, Solar PV, D-STATCOM,etc.

I. INTRODUCTION

Renewable energy use is good option because it provides clean and green energy, with little or no CO_2 emission. Renewable energy is generated from renewable energy sources such as Solar emission, Wind, Tides, geothermal etc. The major renewable energy technologies are Hydropower, wind power generation, biomass and ocean energy. This energy is used in Power Generation, Rural electrification (off-grid) and as transport fuels. Compared to fossil fuels Renewable energy has many advantages. Firstly, the Renewable energy obtained from natural sources so it is sustainable and it will not emit CO_2 gas. [3]

So renewable energies tackle the greenh ouse effect and also provides sustainable energy. To achieve the renewable energytarget, more funds will be provided in research and development of renewable energy. After their installation they generate electricity from the solar irradiation without emitting greenhouse gases. T h e lifetime of PV solar system is around 25 years, which can produce power more than their manufacturing cost. Also they can be installed in places with no other use, such as roofs and deserts, or they can produce electricity for remote locations, where there is no electricity network. The latter type of installations is known as off-grid facilities and sometimes they are the most economical alternative to provide electricity in isolated areas. [4][3]

However, most of the PV power generation comes from grid- connected installations, where the power is fed in the electricity network. Energy resources and their utilization is aprominent issue all over the world. As the conventional naturalresources of energy are exhaustible in nature and also there is exponential rise in demand for the power, the man is forced toexplore the new sources of energy. The solar energy is available abundant in nature. Also it is free of cost. Hence, there lies a challenge to extract this energy effectively and efficiently. Major advantages of solar cells over conventional methods of power system are: -

(i) Solar cells convert the solar radiation directly intoelectricity using photovoltaic effect without goingthrough a thermal process.

(ii) Solar cells are reliable, modular, durable and generally maintenance free and therefore suitablefor isolated and remote places.

(iii) Solar cells are quiet and have an expected life time of 20 or more years.

(iv) Solar cells can be located at the place of use and hence no distribution network is required.

olar energy is one of the important source of renewable energy. The sun radiates large amount of energy which is enough to satisfy the need of whole world. Solar energy is used for providing heating, cooling, light and for electricity. One of the important technologies is Photovoltaic (PV), by photoelectric effect the sunlight is directly converted into electricity.[7]

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PV generation has following main advantages:

- It is green and clean. The production of PV energy does not produces greenhouse gases hence it is safe. It is free from pollution, since manufacturer of PV are committed to minimize pollution during production.
- PV energy is reliable, since power generation using PV has no moving parts hence it has less maintenance. When PV is used as distributed energy source it reduces the cost of transmission lines and improve grid reliability.
- It has longer life than other renewable sources.

However there are few problems when using PV energy:

- PV energy is dependent on weather condition. During cloudy weather its efficiency becomes less.
- It is not available at night. Hence PV energy generation is intermittent and variable.
- The cost of large scale PV system installation is high compared to conventional energy systems for same energy production.

Grid Integration of PV system

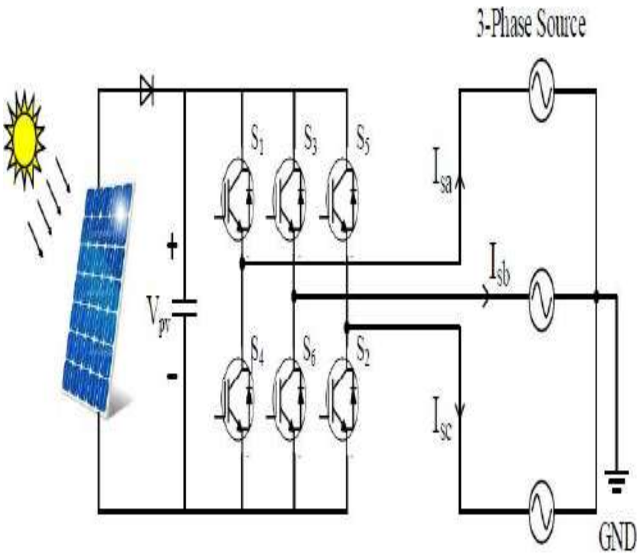

Fig. 1 Schematic diagram of grid integrated solar system

The power obtained from the PV system is in the form of dc quantity. So to integrate the solar energy into the conventional grid an inverter is needed to convert the dc voltage to ac. For integration, it is important to match the frequency and phase of output ac voltage with the grid voltage. Also it is necessary that the voltage obtained across the inverter should be of higher magnitude than the grid so that the power can flow from PV source to grid. A schematic diagram of grid integrated PV system is shown in Fig. 1. Though the integration of solar energy into the conventional grid system increases the reliability of the distribution system, unfortunately it adds to the power quality issues present in the system due to power electronic based loads.[1-4]

II. PV FED D-STATCOM

Photovoltaic fed distributed static compensator (PV- DSTATCOM) is an effective approach for integrating solar energy into the grid with additional power quality improvement features like harmonic mitigation, reactive power compensation and load balancing. The power quality conditioning performance in terms of total harmonic distortion and superior power factor of supply current is appreciably influenced by the passive components associated with the solar voltage source inverter. That means an AC passive interface filter is used to interconnect the inverter and photovoltaic (PV) panels to the grid. The PV panels and solar inverter with power quality conditioning capabilities are when interfaced to the grid through a first order L-type passive filter is labelled as L-type PV-DSTATCOM. The primary objective of the interface filter is to reduce the switching harmonic distortion of the injected current as much as possible to prevent the switching harmonics from propagating into power supply without affecting the flow of harmonics to be compensated.[7][8]

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In this section, the focus has been given for the design and switching control of L-type PV-DSTATCOM. In actual systems the load is connected at the end of feeder. If the load is unbalanced, then the point of common coupling (PCC) voltage will be unbalanced. In addition, the PCC voltage will be distorted by both the harmonics generated by a non-linearity in the load and by the switching frequency harmonics generated by the PV-DSTATCOM. Furthermore, there will be reactive power, switching and resistive losses in the PV- DSTATCOM circuit. Taking these factors into consideration, we must choose the switching control algorithm such that irrespective of any disturbance the algorithm shall perform satisfactorily. The new trend is to integrate solar energy into distribution system. For taking care of the power quality issuesof a grid integrated PV system, two voltage source inverters are required. Out of which one will be solely responsible for integration and the other will take care of power quality.[11]

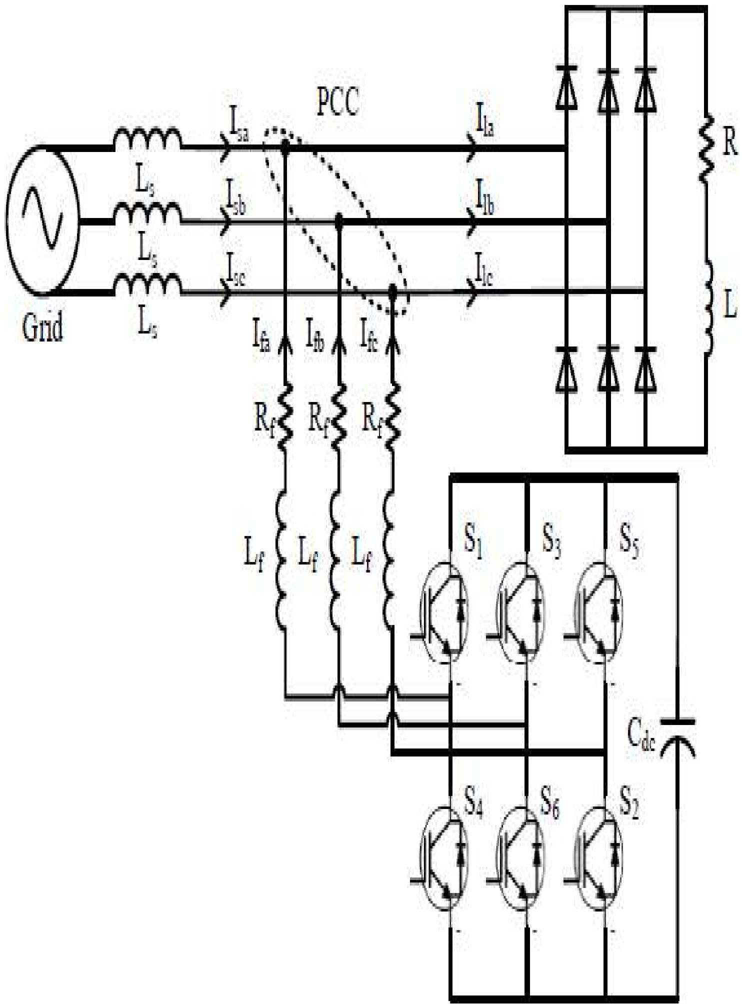

Fig.-2 Schematic diagram of DSTATCOM applied todistribution system

This configuration will make the system more unstable, costlyand inefficient as inverter technology is not so developed as rectifier technology. So a conscious effort has been made to reduce the number of inverter in the system. Hence, the systemtopology is restructured with a single inverter through which the photovoltaic source is integrated to distribution system and simultaneously with a proper inverter control technology the same inverter is used as DSTATCOM to monitor the power quality issues. These devices are popularly named as PV- DSTATCOM.

Photovoltaic Fed Distributed Static Compensator

The schematic diagram of a photovoltaic fed DSTATCOM (PV-DSTATCOM) is shown in Fig.3. The PV-DSTATCOM comprises of solar array, dc/dc boost converter, a voltage source solar inverter and grid interfacing passive ac filter. The solar PV systems are integrated to gird through the VSI and passive ac interfacing filter. The dc voltage generated by a PVarray varies widely and low in magnitude. So the dc/dc boost converter is used to generate a regulated higher dc voltage fordesired converter input voltage.

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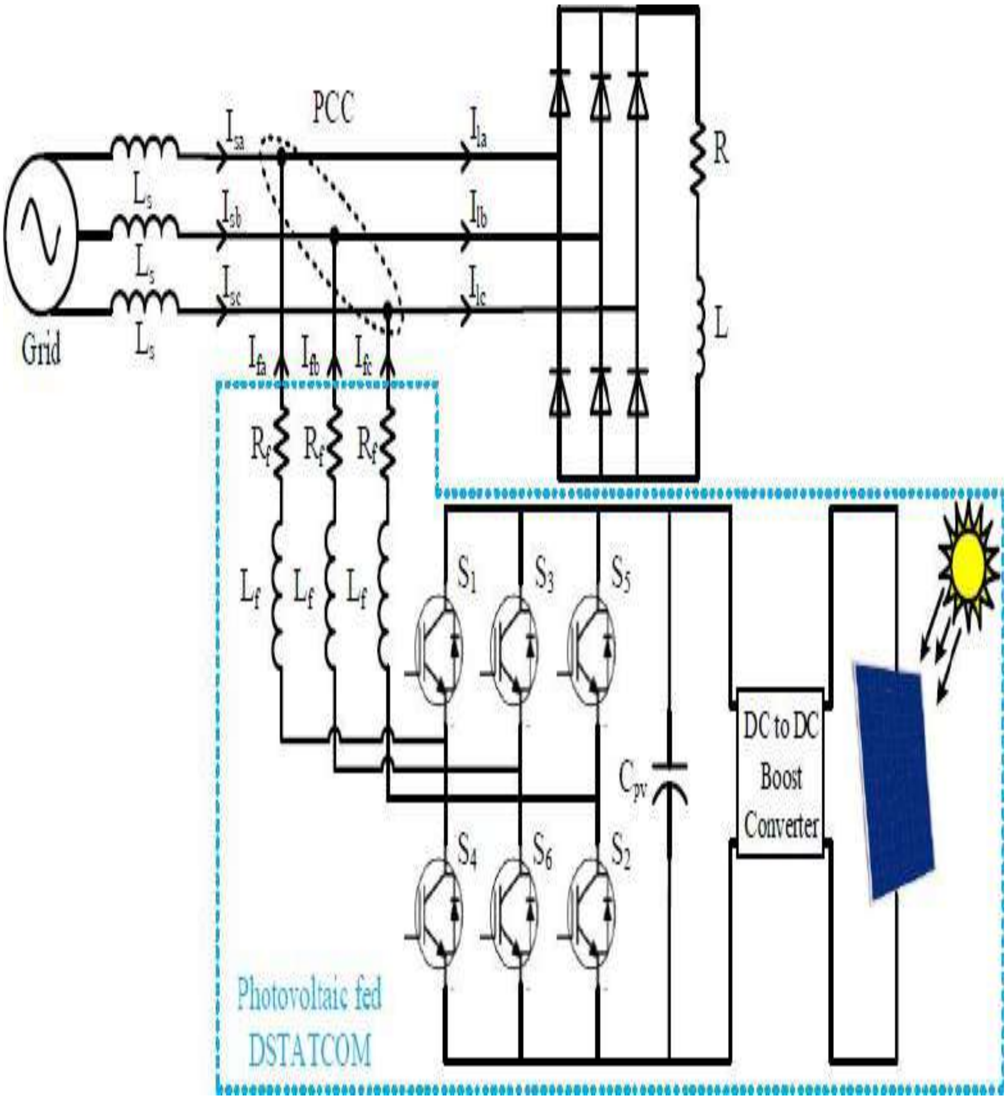

Fig. 3 Schematic diagram of a dual stage PV-DSTATCOM

In a conventional grid connected system, the solar inverter takes care of the power injection from PV source to grid. When solar insolation is available, the solar power is generated and feed to load or grid as per requirement. But when solar insolation is not available or not sufficient for generation of solar power the solar inverter remains idle. Hence the solar inverter operates during day time and remains idle for the rest of period thereby reducing the efficiency of the system.

Therefore, the active filtering operations are added to the solar inverter through proper inverter control. The grid connected PV systems capable of power quality improvement of the system with paralleled solar inverter known as PV-DSTATCOM. The PV-DSTATCOM can provide load harmonics compensation, power factor correction, reactive power compensation, load balancing and simultaneously inject active power from the PV source to grid or/and load.[13][12]

L-type PV-DSTATCOM Structure

To illustrate the functioning of L-type PV-DSTATCOM, a three phase, three wire (3p3w) photovoltaic fed distribution system is shown in Fig. 4. Here a three phase balanced supply (Vsa,,Vsc) is connected across a three phase diode bridge rectifier with ohmic-inductive load. The load is such that the load currents (Ila,,Ilc) may not be balanced and contain harmonics and dc offset.

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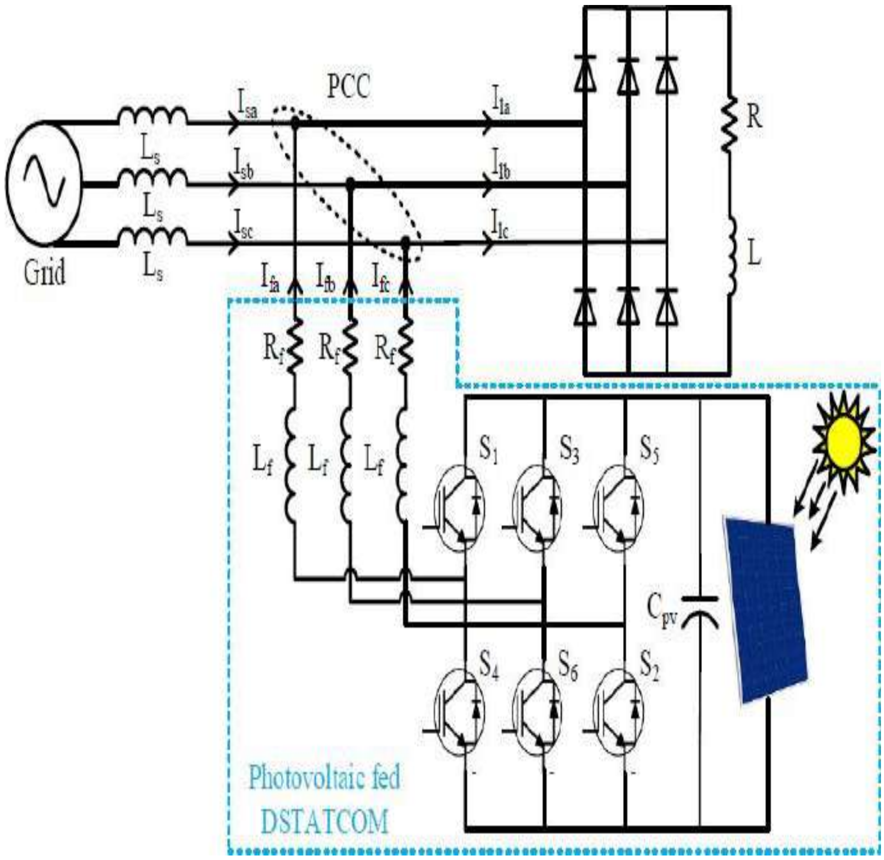

Fig.4: Schematics of L-type PV-DSTATCOM

In addition, the power factor of the load may be poor. The photovoltaic system is integrated to the three phase grid through a voltage source inverter and an L-type (Lf) passive filter whose internal resistance is Rf. The injected compensator current is represented by Ifa, Ifb, Ifc. All the voltages and currents that are indicated in this figure are instantaneous quantities. The point of common coupling is encircled in Fig. 4. The purpose of the PV-DSTATCOM is toinject currents in such a way that the source currents (Isa, Isb, Isc) are harmonic free balanced sinusoids and their phase angle with respect to the source voltages has a desired value. Along with this, during the availability of solar radiation, the photovoltaic system will inject active power to the load.[10]

Instantaneous Reactive Power Theory

The instantaneous reactive power (IRP) theory is also known asp-q theory. The instantaneous reactive power theory is **based on set of instantaneous power defined in the time domain**. As IRP theory is considered as a power theory one could expectthat it does provide a clear interpretation of power phenomena in electrical system. The power properties of a three phase threewire systems with purely sinusoidal voltage and current i.e. even if without any harmonic distortions are determined by three independent features of the system:

- Permanent energy transmission and associated active power (P)
- Presence of reactive element in load andassociated reactive power (Q)
- Load imbalance that causes supply current asymmetry and associated unbalanced power(D)
- Moreover, according to Akagi and Nabae who developed IRP theory, its development was a response to “the demand to instantaneously compensate the reactive power”. So no need ofworry about unbalanced power.

The IRP theory can be implemented in all reference frames but generally used in α-β coordinates due to the ease of calculation. The α-β reference frame is a static reference sameas a-b-c coordinate reference frame but converted to two phase from three phase. So the calculation in this frame is easier. Thecontrol block diagram for IRPT scheme has been shown in Fig.5.[9][8][10]

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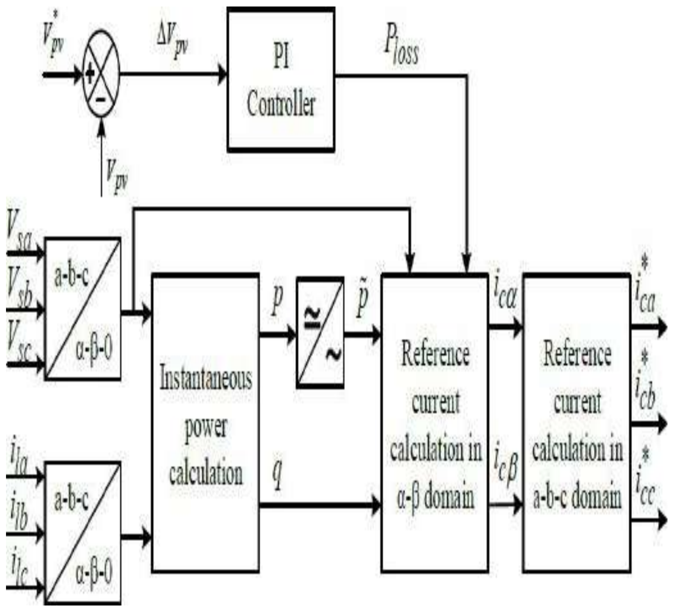

Fig. 5 Control block diagram for generation of referencecurrent using IRPT scheme

III. PROPOSED WORK

Traditional Distribution Network

Traditionally, power-quality issues have been addressed by the use basic devices such as passive filters, and more advanced filtering technologies, such as a static synchronous compensator, active power filter (APF), dynamic voltage regulator, and unified power quality conditioner (UPQC). Passive filters have been traditionally used to improve the power quality of the electrical network. However, they have several issues such as resonance, fixed filter frequency, and difficulty in tuning. Researchers have proposed the active power filter (APF) which is developed to remedy the shortcomings of the passive filter has made it possible to mitigate various power quality problems such as harmonic and reactive power compensation, voltage imbalance, and voltage flicker.

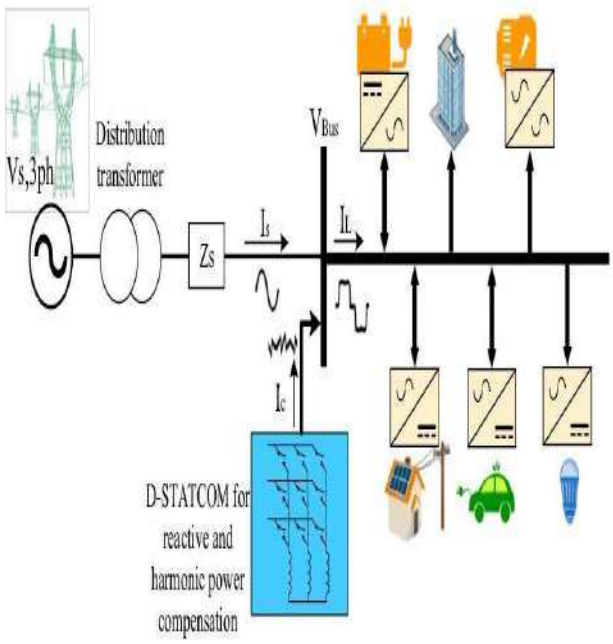

Fig-6 One-line diagram of a distribution network

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In this project, the use of a capacitor-less distribution static synchronous compensator (D-STATCOM) for harmonic and reactive power compensation in a distribution network is investigated. The proposed topology is based on a matrix converter (MC) which is controlled using finite control set model predictive control (FCSMPC). This arrangement enables the use of inductive energy storage instead of electrolytic capacitors so that the compensator can meet the expectations of long service life as the existing distribution transformers. The compensator can be deployed and dispatched within the distribution feeder system, as needed, to compensate locally atthe source of the problem.

System configuration

The D-STATCOM is a power electronic based reactive power compensation device that is shunt-connected at a particular busin the electrical distribution system. The main building block inthe proposed capacitor-less configuration is the three-phase matrix converter. Nine bi-directional switches, three-phase input filter and output chokes connected to the output side of the converter. Fig. 6 shows a simplified diagram of the proposed capacitor-less DSTATCOM configuration connectedat the terminal bus in the distribution network. Upstream, toward the substation, is modelled as three-phase source with series impedance (Zs). Downstream is modelled as two blocks, the first block is the harmonics generator block, this block is prosumer (producer-consumer) and it will generate harmonic currents to represent the aggregate behaviour of photovoltaic system with three-phase inverter and other harmonics producing loads such as personal computers, television sets, energy efficient lamps (fluorescent and LED).
Similarly, the second load is the linear loads that are lumped into equivalent R-L load as shown in Fig. 7. The proposed D- STATCOM is shunt connected and injects current (Ic) to compensate for the downstream operation such that current drawn from the upstream source (Is) is sinusoidal and in phase with the voltage. Fig.7 shows additional details of the system and the proposed capacitor-less DSTATCOM. The D- STATCOM in the figure consists of MC unit connected to the output chokes and controller unit consists of the referencecurrent generator and the MPC.

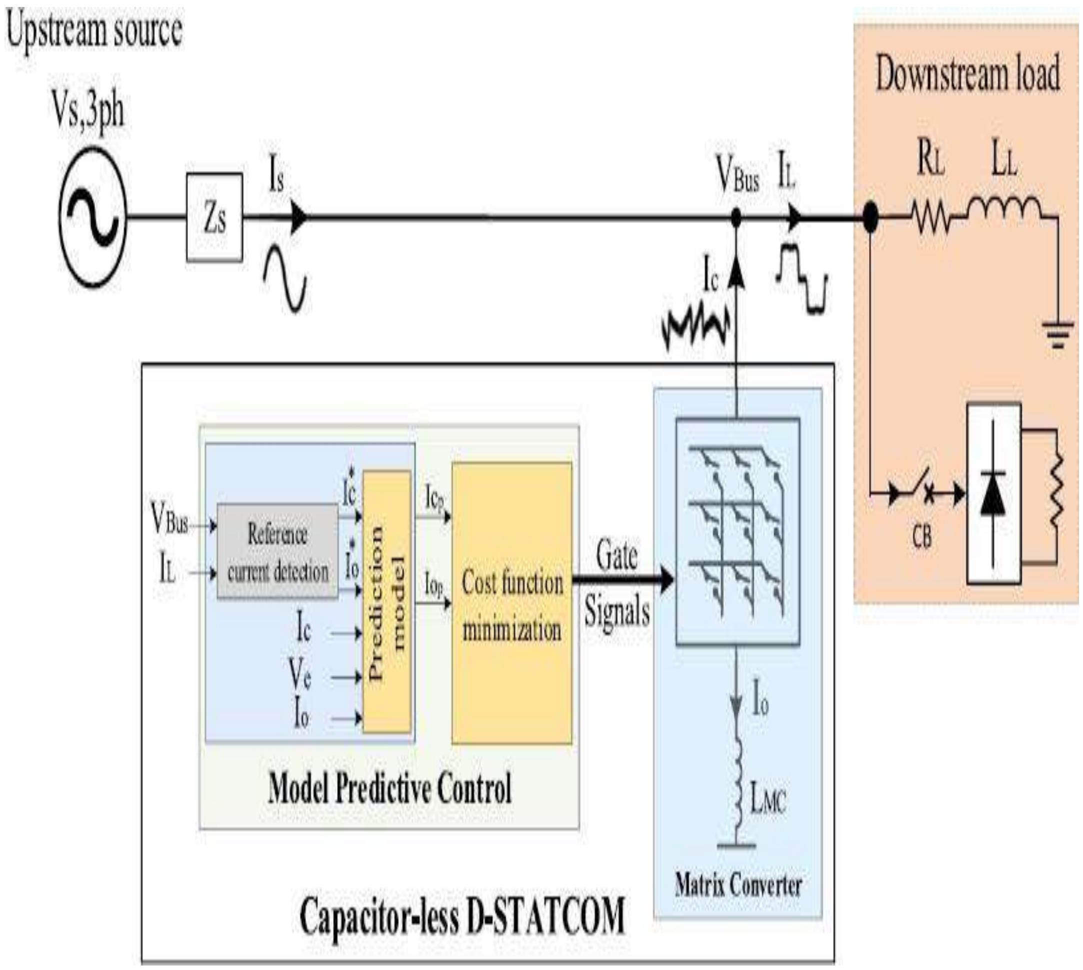

Fig. 7 Capacitor-less D-STATCOM based matrix converter

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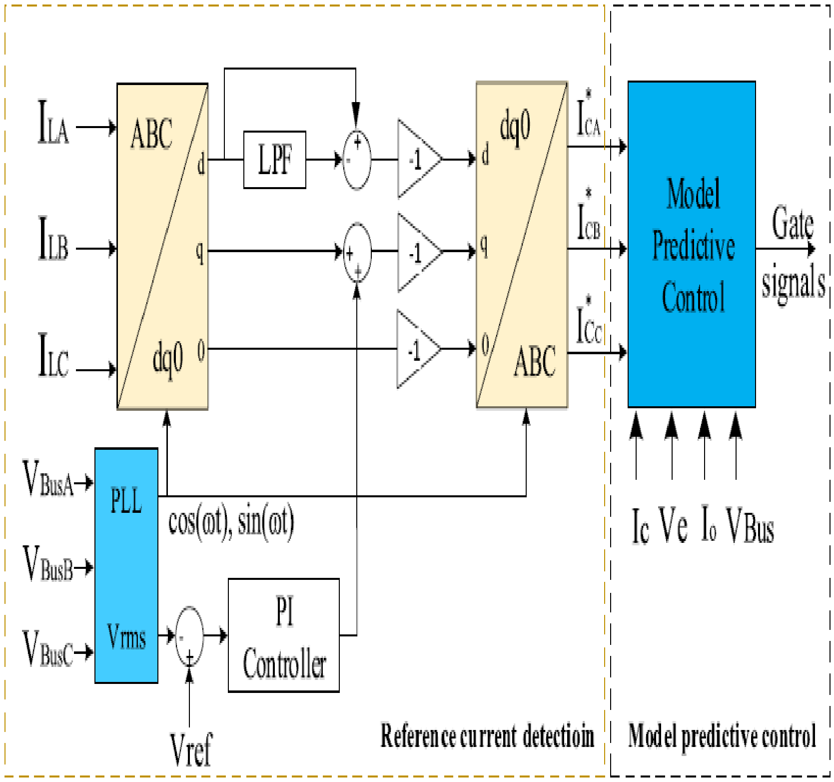

Fig.8 Reference current detection based on synchronousreference frame (SRF)SIMULATION AND RESULTS

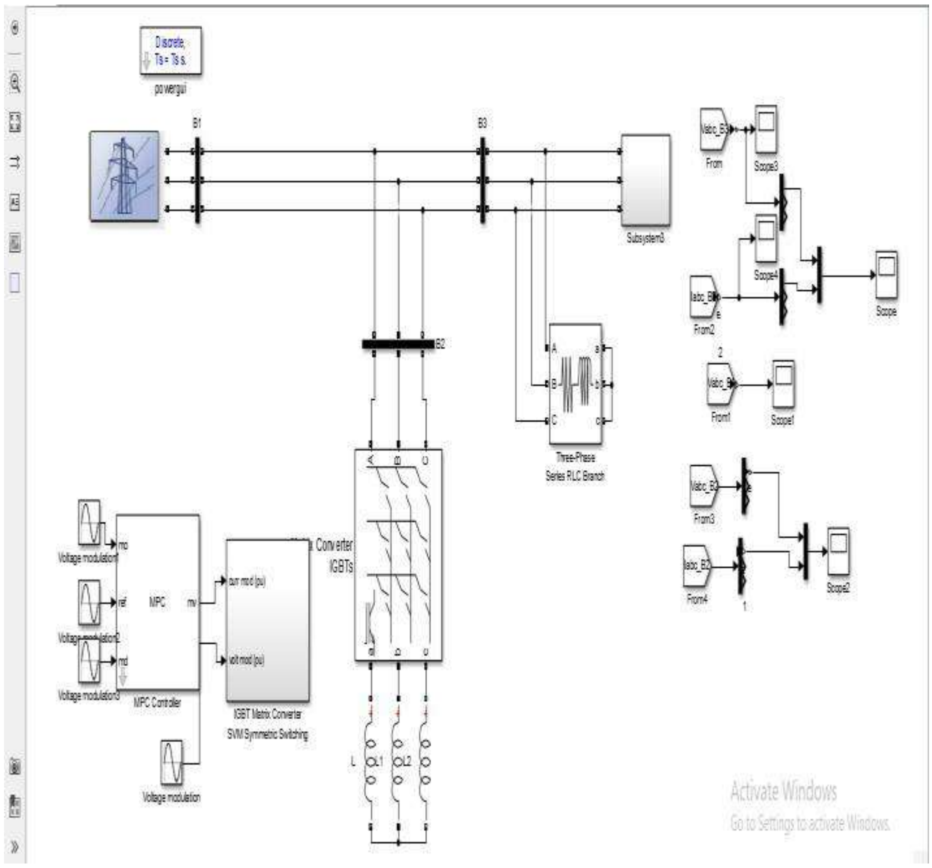

Fig 9- Matlab Simulation of Matrix Converter

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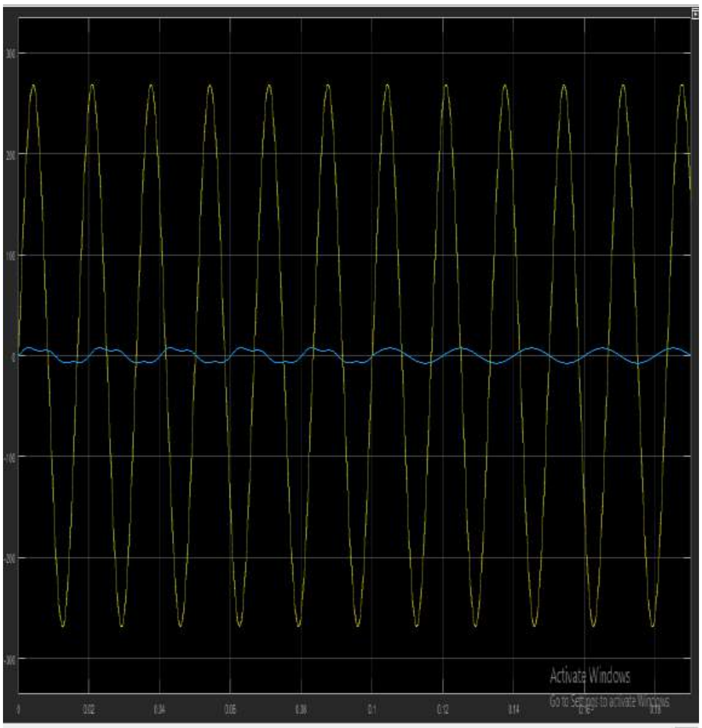

Fig. 10 Simulation results of the source voltage (VBusA) andcurrent (IsA). After the D-STATCOM is enabled the source current is in-phase with the source voltage and distortion free.

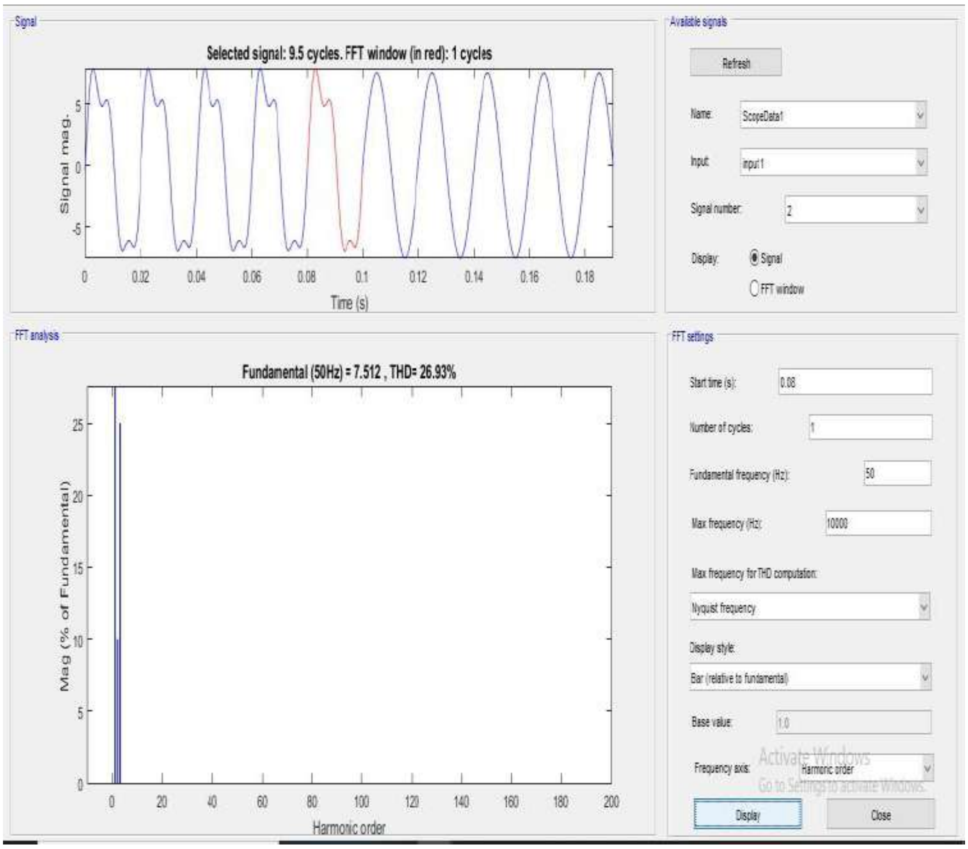

Fig. 11 Simulation results of source current spectral analysis(IsA) before D-STATCOM is connected

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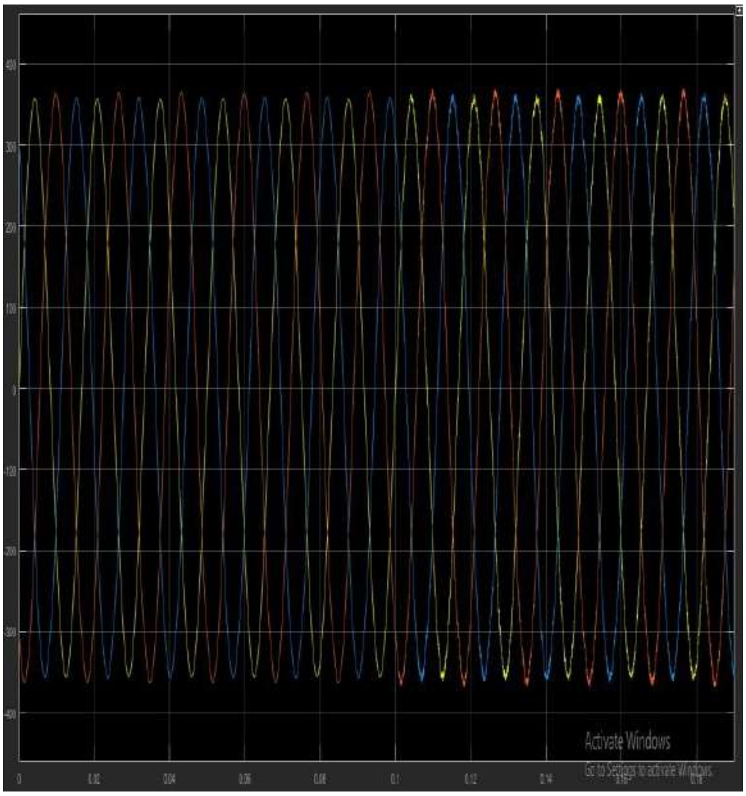

Fig. 12 Simulation results of the three-phase source voltage.

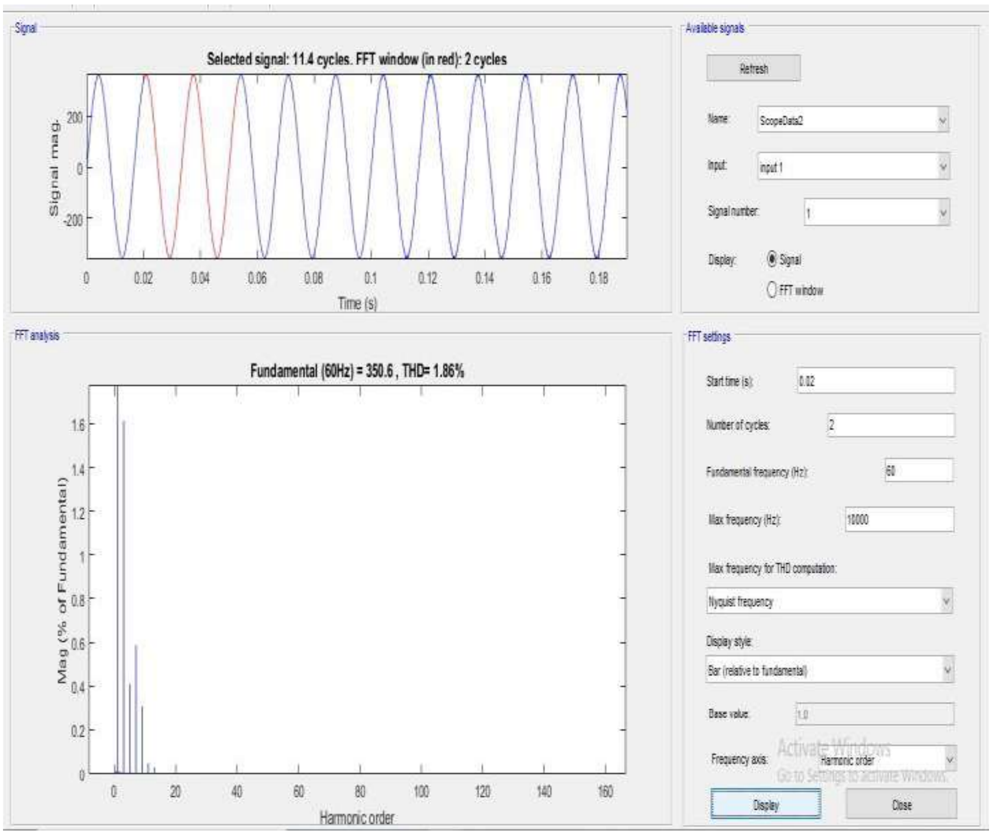

Fig.13 Simulation results of source voltage spectral analysis(VBus-A) before D-STATCOM is connected.

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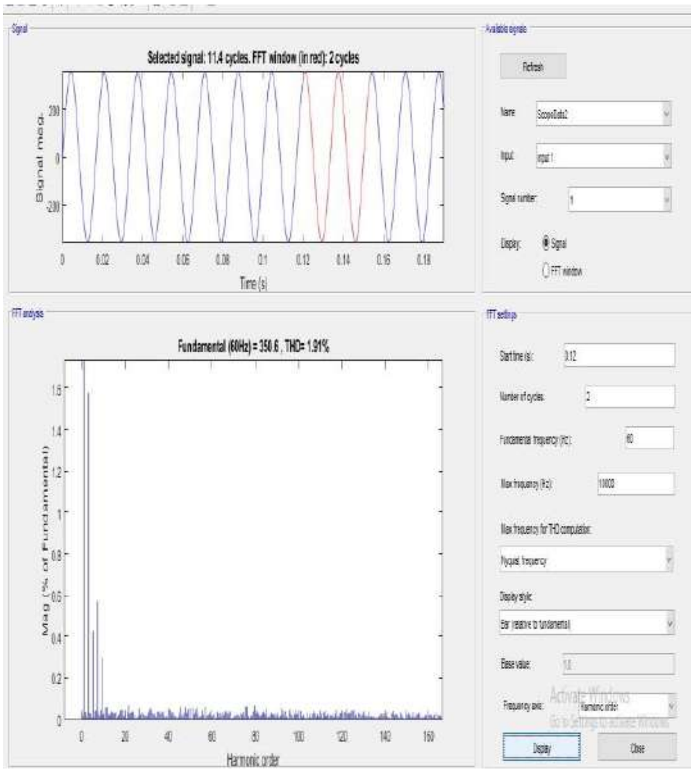

Fig. 14 Simulation results of source voltage spectral analysis(VBus-A) after D-STATCOM is connected

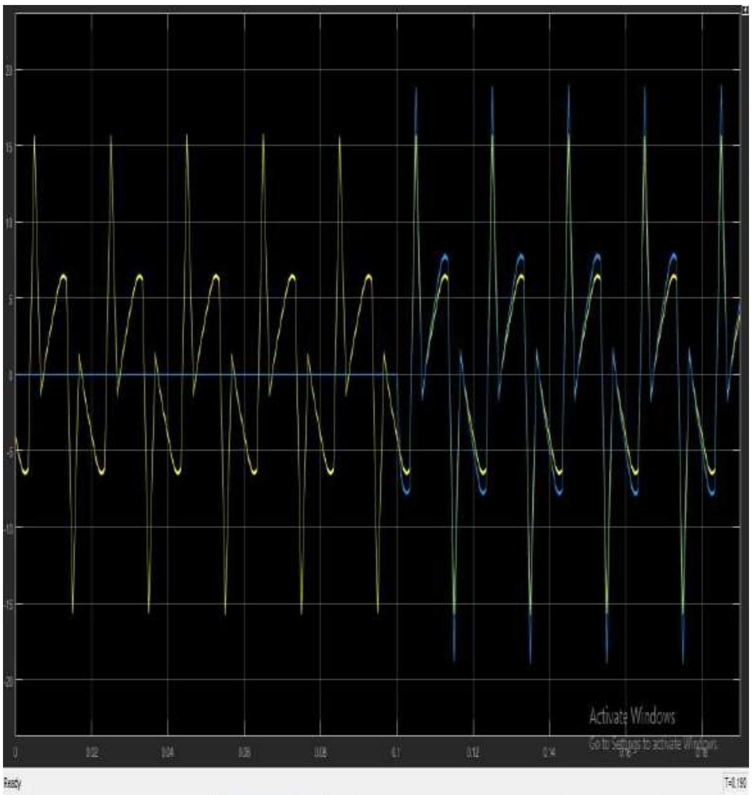

Fig. 15 Simulation results of reference current (IcA_Ref) andthe actual measured current (IcA). After the D-STATCOM Is enabled at t¼0.1, good tracking between D-STATCOM measured and reference current is shown

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Fig 16- Simulation results of the source voltage (VBusA) andcurrent (IsA) with non-linear and linear loads. After the D-STATCOM is enabled the source current is in-phase with thesource voltage and distortion free

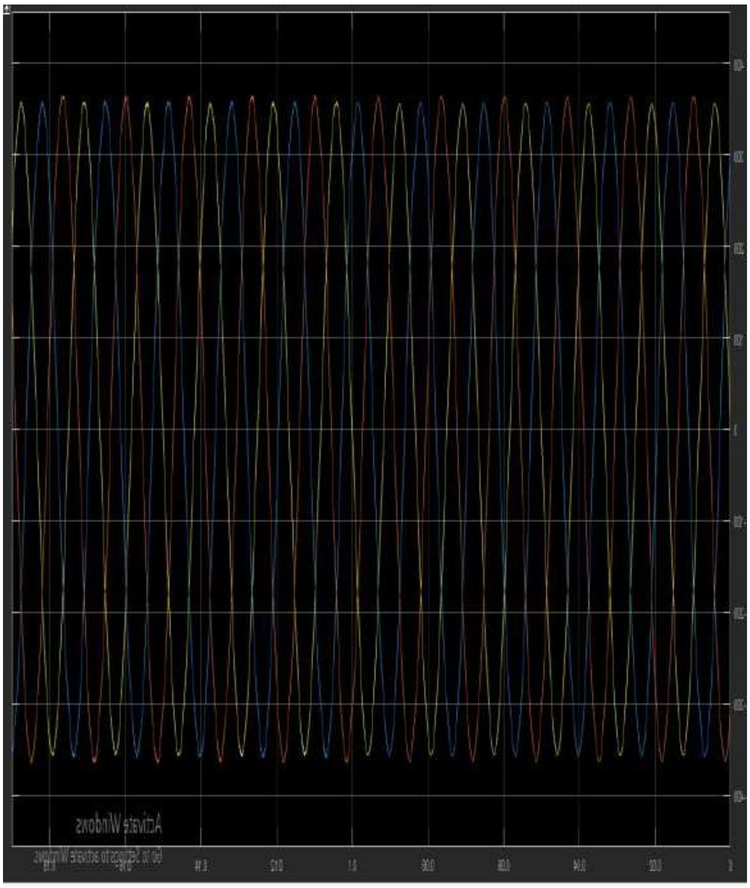

Fig 17- Simulation results of the three-phase source voltage

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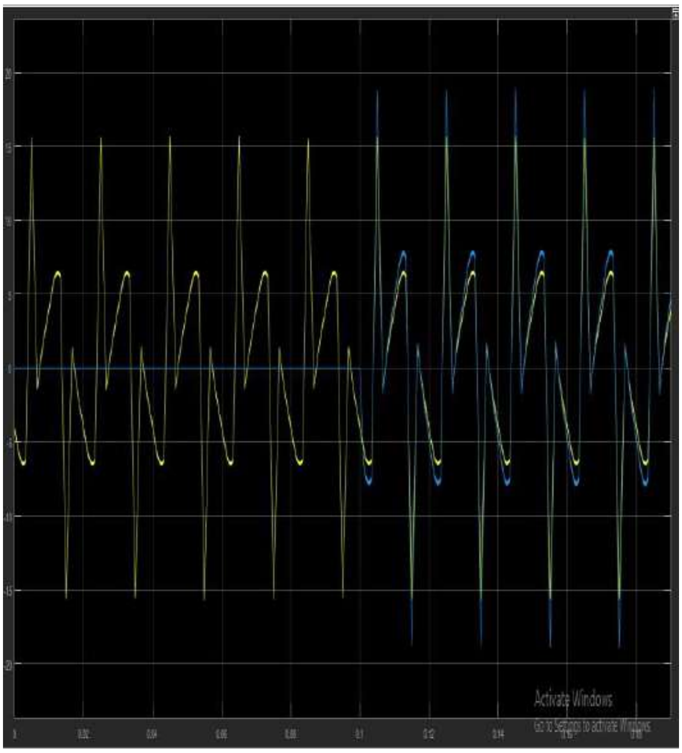

Fig. 18 Simulation results of source current (IcA) during non- linear and inductive load condition. After the D-STATCOM isenabled at t¼0.1, good tracking between D-STATCOM measured and reference current is shown.

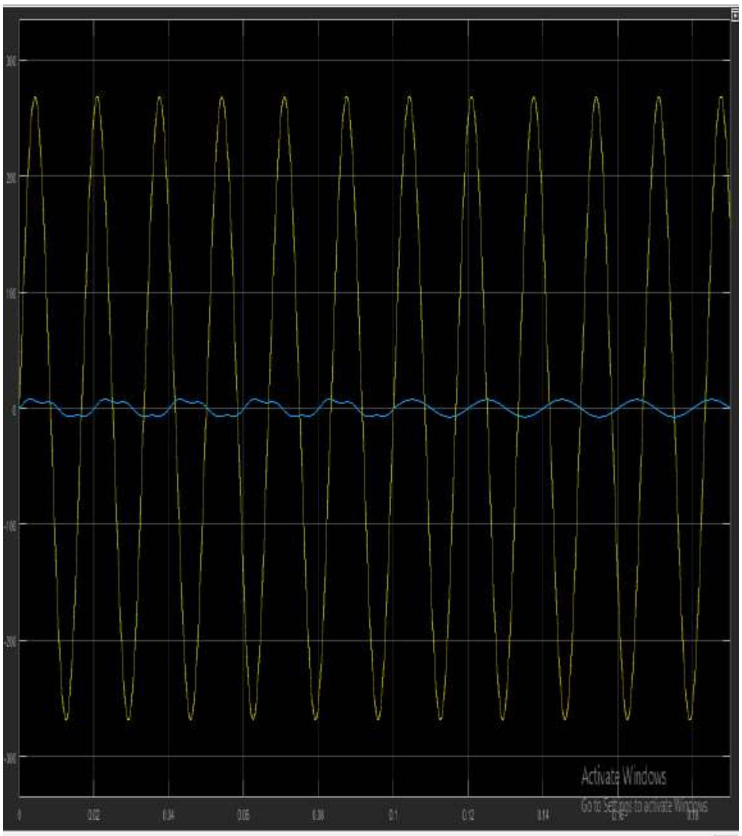

Fig 19- Simulation results of the source voltage (VBusA) andcurrent (IsA) with non-linear and linear loads. After the D-STATCOM is enabled the source current is in-phase with thesource voltage and distortion free

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THD Analysis

Sr. No.	Parameter Name	WithoutD-STATCOM	WithD-STATCOM
1	Case-I Source Side Current	26.88%	2.99%
2	Case-I Source SideVoltage	1.15%	0.2%
3	Case-II Source Side Current	11.10 %	2.10 %
4	Case-II Source SideVoltage	2.65 %	0.63 %
5	Case-III Source Side Current	26.99 %	3.43 %

Table-1- THD Analysis of Proposed system with D-STATCOM Connection

IV. CONCLUSION

This project proposed a capacitor-less D-STATCOM based onMC and controlled using FCS-MPC for harmonic current mitigation and power factor correction, which results due to the use of non-linear loads in the modern electrical distribution network. The instantaneous control of the active and reactive power is accomplished by the SRF method and FCS-MPC. In this manner, the shunt- connected, D-STATCOM, mitigates theharmonic pollution at the source, thus preventing the propagation of undesirable harmonics, which can disrupt the smooth operation of other devices and can lead to overheating issues in lines and substation transformer windings. Simulation results of the different use cases presented in this project show that the proposed capacitor-less D-STATCOM is able to provide the required power factor correction and harmonic mitigation to the non-linear loads connected at the low voltage side of the distribution network.

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