International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** VII **Month of publication:** July 2021

DOI: https://doi.org/10.22214/ijraset.2021.37219

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VII July 2021- Available at www.ijraset.com

Comparison of SRF and IRPT Algorithm for Mitigation of Voltage Sag and Voltage Swell using NPC based D-STATCOM

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Abstract: This study describes a systematic model of Distribution STATCOM (D-STATCOM) to reduce voltage sag, and swell using Instantaneous reactive power theory also called Power Quality theory (IRPT or PQ) and Synchronous reference frame theory (SRF) using NPC three level inverter. Power quality is an event that manifests as an abnormal frequency, current and voltage resulting in the failure of end-use equipment. The main issues addressed here are voltage sag and swell. Custom power devices are utilised to overcome this problem. The Distribution STATCOM (D-STATCOM) is one of these devices, and it is the most efficient and effective modern specialized power device utilised in distribution system network. The simulation of D-STATCOM is done using MATLAB/Simulink and voltage sag and swell are mitigated.
Keywords: Voltage sag, Voltage swell, D-STATCOM, NPC, PLL.

I. INTRODUCTION

Power quality has become a significant problem for academics as a result of the widespread usage of power electronics-based current technology devices in the power system network. All automated equipment is to blame for low quality electricity since it pulls reactive power into the distribution system and injects harmonics. Electronic components such as electronic drives and programmable logic controllers are becoming increasingly important in modern industrial equipment. [7] As electronic equipment becomes increasingly sensitive to interruptions, it becomes less tolerant of power quality concerns such as harmonics, voltage swell, and voltage sag. Voltage dips are characterized as one of the most serious disruptions to industrial equipment. When reactive power is injected at the load point of a common coupling, voltage support can be provided at the load. D-STATCOM injects a current into the system to correct voltage swell and sag. Voltage sag and swell can be minimised by connecting D-STATCOM in parallel with the power supply at the load side.

D-STATCOM is a shunt kind of compensator that employs several control methods. D-STATCOM phase shift control method will help to reduce voltage sag and swell.[8] The D-STATCOM will be used to enhance voltage profiles in this project. The functionality of D-STATCOM for Phase shift control scheme is established using simulation models in MATLAB/SIMULINK for capacitive and inductive loads.

The first section of paper contains brief description of D-STATCOM, second section contain block diagram of proposed strategy. The next part of paper contains control strategy which contains SRF and IRPT theory. The last part of paper contains the MATLAB simulation and results.

II. METHODOLOGY

In this project basically D-STATCOM which is also called as Static synchronous compensator is used for mitigation of voltage swell and sag which may occur in our distribution system. There problems are made to occur in our simulation by using inductive nature of load. This type of load causes the voltage sag to occur at the distribution end of our power system. Similarly for the voltage swell to occur we have connected capacitive nature load in our system.

For solving these power quality issues in our power system here a controller is designed using two control strategies. First is the Instantaneous reactive power theory (IRPT) which is also called as power quality theory (PQ) and second is the synchronous reference frame theory (SRF). By using these theories D-STATCOM is designed for mitigation of power quality issues in our power system network.

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III. D-STATCOM

The schematic diagram of D-STATCOM, which has three modes of operation, is shown in Fig. 1. STATCOM is linked to the voltage bus Vbus through a coupling reactor. In capacitive mode, the D-STATCOM voltage Vsc is higher than the bus voltage Vbus, therefore the STATCOM injects reactive power into the grid where this device is connected in our power system network. The device functions in inductive mode when the STATCOM voltage is lower than the bus voltage, absorbing reactive power from the grid. In floating mode, the bus voltage Vbus and the device voltage Vsc are the identical, and no power is exchanged between the grid and the device. STATCOM is a voltage source inverter (VSI) based device. In this project the STATCOM is designed using a three level NPC inverter.

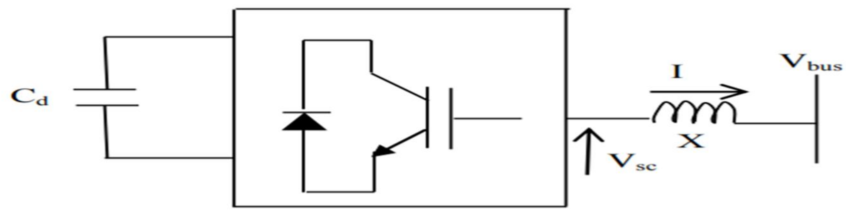

Fig. 1 Schematic of D-STATCOM

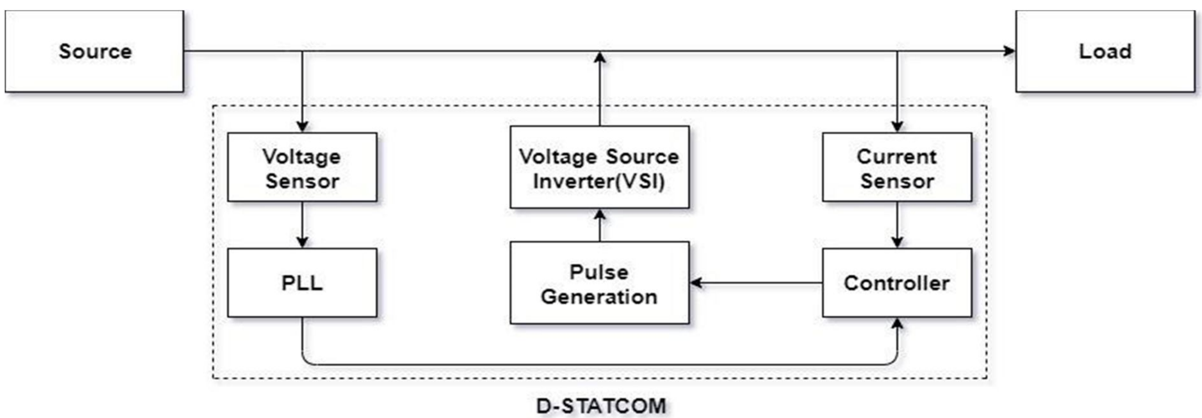

Fig. 2 Block Diagram of proposed strategy

IV. BLOCK DIAGRAM OF PROPOSED STRATEGY

In fig. 2 block diagram of the D-STATCOM for mitigation of sag swell is shown. Here two sensors are used for measuring the source voltage and the load currents. The output of voltage sensor is given to PLL (phase-locked loop) block to calculate the angle ωt for phase synchronization with the grid frequency. The controller block takes the input from PLL block and current sensor block which makes the calculation for mitigation of voltage related problems occurred in the system and then generates signal which is given to pulse generation block. The pulse generation block generates the pulses and gives output to voltage source inverter to inject the current in to the grid.

V. THREE LEVEL NPC INVERTER

Table 1 – Switching states of NPC inverter

Output Voltage	S1	S2	S3	S4
+Vdc/2	1	1	0	0
0	0	1	1	0
-Vdc/2	0	0	1	1

Table 1 shows the switching states of a three level NPC inverter which is compared with the simulation diagram shown in fig. 3. We can see that when switches S1 and S2 are ON we get output voltage +Vdc/2. For 0 volts switches S2 and S3 must be ON. We get voltage -Vdc/2 when S3 and S4 are ON at a same time.

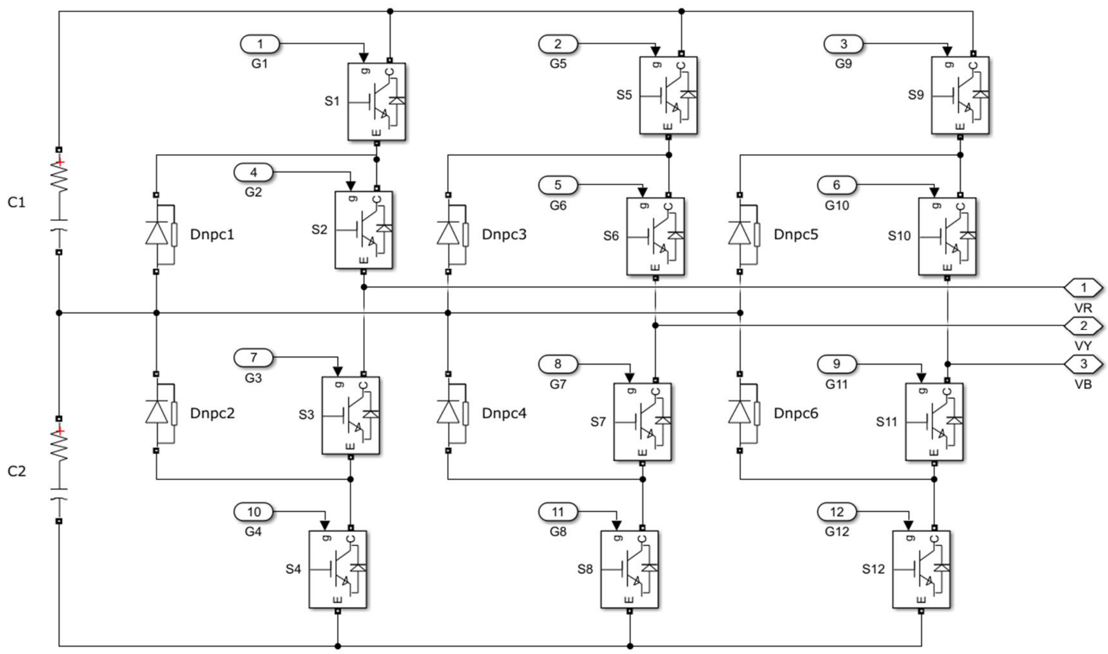

Fig. 3 Circuit Diagram of NPC three level inverter

Fig. 3 shows a three level NPC inverter in which two capacitors are connected as shown. In each leg four IGBT's are connected. Each phase of the inverter contains two clamping diodes as shown in the above figure.

VI. CONTROL STRATEGY

Control strategy [3] is basically the equations which are used for mitigation of problems which occur in our system. In this project as explained in previous topic the STATCOM is designed used two control strategies. We will see the equations related to the control strategy and the controller-

A. Instantaneous reactive power theory (IRPT) or Power Quality Theory (p-q)

In this theory first step is to convert load currents and source voltages using Clarke's transformation by using below matrices as shown

$$\begin{bmatrix} I\alpha \\ I\beta \\ I0 \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}\begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \qquad \begin{bmatrix} V\alpha \\ V\beta \\ V0 \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix}$$

After transformation we get Vα,Vβ,V0 and Iα,Iβ,I0 after using above matrices. Now for p-q theory equations we require Vα,Vβ and Iα,Iβ. The calculation of p and q is calculated using below matrix equations

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v\alpha & v\beta \\ -v\beta & v\alpha \end{bmatrix}\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \qquad \begin{bmatrix} ic\alpha \\ ic\beta \end{bmatrix} = \frac{1}{v\alpha^2+v\beta^2}\begin{bmatrix} v\alpha & -v\beta \\ v\beta & v\alpha \end{bmatrix}\begin{bmatrix} pc \\ qc \end{bmatrix} \qquad \begin{bmatrix} Ia* \\ Ib* \\ Ic* \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} ic\alpha \\ ic\beta \end{bmatrix}$$

As we can see from above matrix p q values we get and after getting we pass p component through filter and again, we take inverse of p q to get icα & icβ i.e., compensating αβ reference currents. After calculating icα & icβ we calculate Ia*,Ib*,Ic* compensating reference current components for generating gate pulses using hysteresis current control technique.

Simulation diagram of D-STATCOM using instantaneous reactive power theory (IRPT) control strategy is shown in fig. 4. In the below simulation diagram, there is conversion of load current and source voltage using the abc to αβ0 blocks. After that the signals are passed to P Q equation block where P and Q are calculated as per the instantaneous reactive power theory. In signal P loss component of capacitor voltage is added through PI controller and a filter is used. P and Q component signals are then passed to inverse P Q equation block so as to calculate I*alpha and I*beta components.

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After that αβ0 to abc block is used for calculating again Ia*,Ib*,Ic*. These are the reference current; these currents are compared with the STATCOM injected current IF and pulses are generated using the hysteresis current control block. In this way we calculate the pulses required for the mitigation of voltage swell and sag in the distribution end of power system.

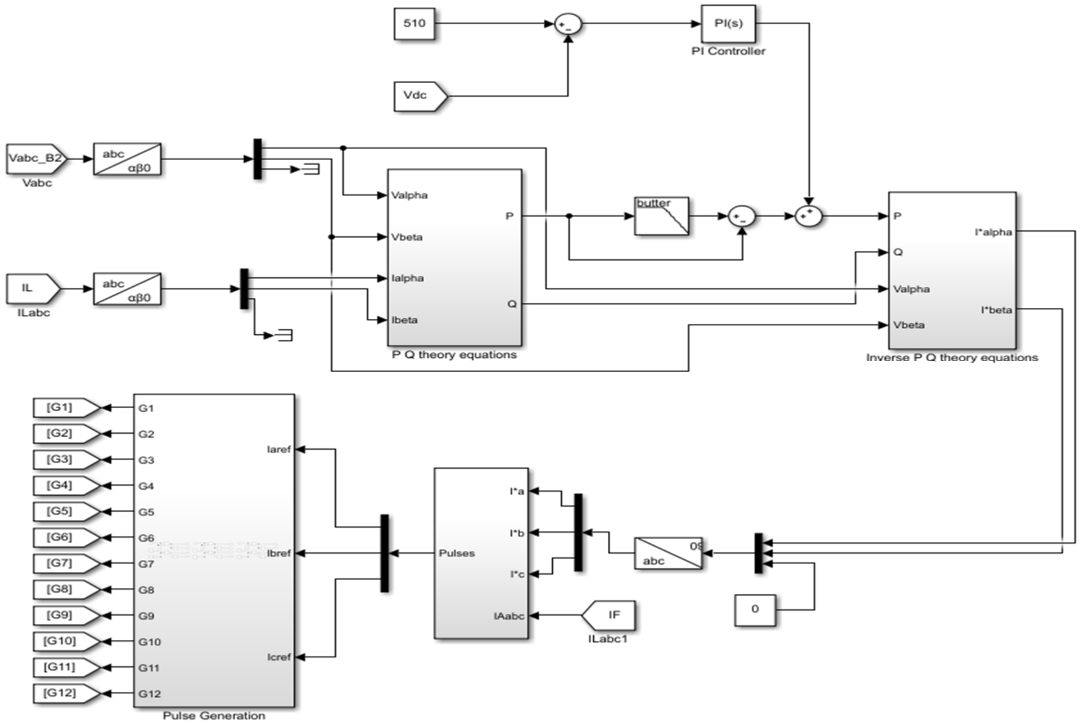

Fig. 4 Control Strategy Simulation of IRPT theory

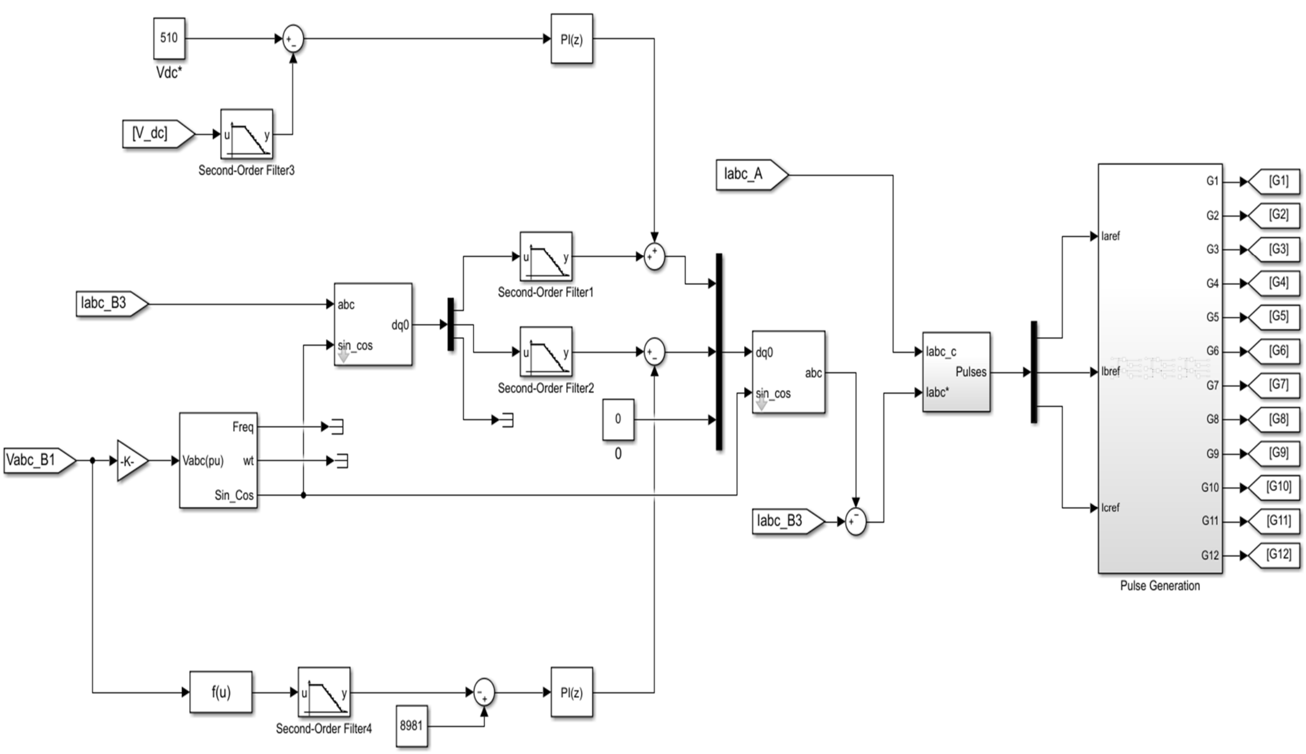

Fig. 5 Control Strategy Simulation of SRF theory

B. Synchronous Reference Frame Theory (SRF)

This control strategy [6] is same as of previous one but in this there is transformation of apha beta components to dq components so that correction for voltage problems can be mitigated. Transformation of three component to alpha beta component is done using Clarke's transformation equations. The equations for transformation of load currents to alpha beta is shown in matrix form below

$$\begin{bmatrix} I\alpha \\ I\beta \\ I0 \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}\begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \qquad \begin{bmatrix} Id \\ Iq \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix}$$

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} Id \\ Iq \end{bmatrix} \qquad \begin{bmatrix} Ia* \\ Ib* \\ Ic* \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} ic\alpha \\ ic\beta \end{bmatrix}$$

From the above equations the first step which we perform is to calculate alpha and beta components of load currents. We need to find those components because we require for Park's transformation equations. After that we calculate Id and Iq component of load current Iα and Iβ. The d component of current is passed thorough filter and loss component of capacitor voltage in added to it. Similarly, from q component reference of source voltages through PI controller is removed. The next step is again transformation of those corrected d and q component of sources currents to three phase components Ia*,Ib*,Ic*. These are calculated from the above matrix equations as shown. Fig. 5 shows the simulation of control strategy of synchronous reference frame theory.

VII. MATLAB SIMULATION OF D-STATCOM AND RESULTS

In this project the simulation of D-STATCOM is performed using the two control strategies, first is the synchronous reference frame theory and second is the instantaneous reactive power theory. Fig. 6 shows the simulation of STATCOM in which source voltage of 11kV is stepped down using step down transformer to 415v. In synchronous reference frame two PI controller are required, one is for adding the loss component of capacitor to d component of load current and second is required to add reference of source voltage to q component of load current. In the simulation the voltage sag and swell are made to occur by using a circuit breaker. Initially a RL load of certain rating is connected in the circuit at the distribution end. For voltage sag an inductive load is connected to the load end with the help of circuit breaker as shown in fig. Similarly, for the well to occur a capacitor bank is connected at the load end in the system with the help of circuit breaker.

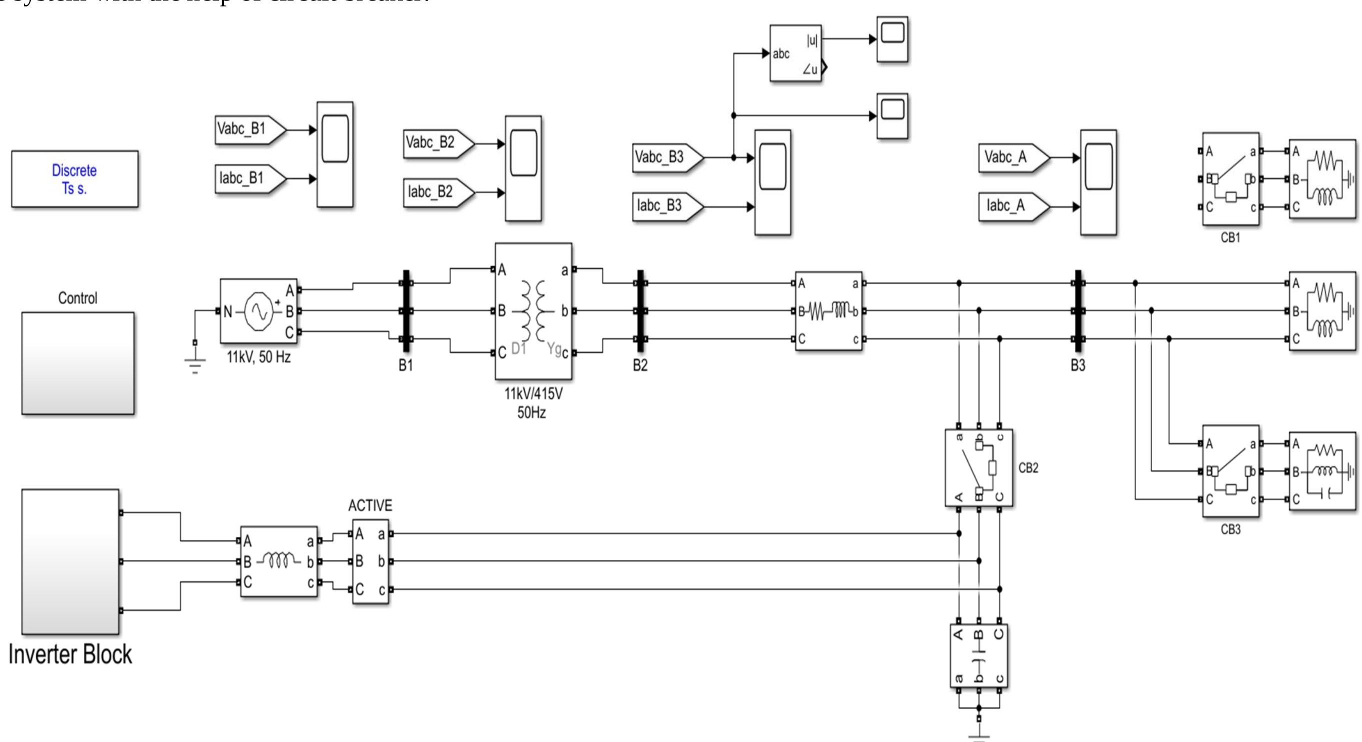

Fig. 6 Simulation diagram of D-STATCOM

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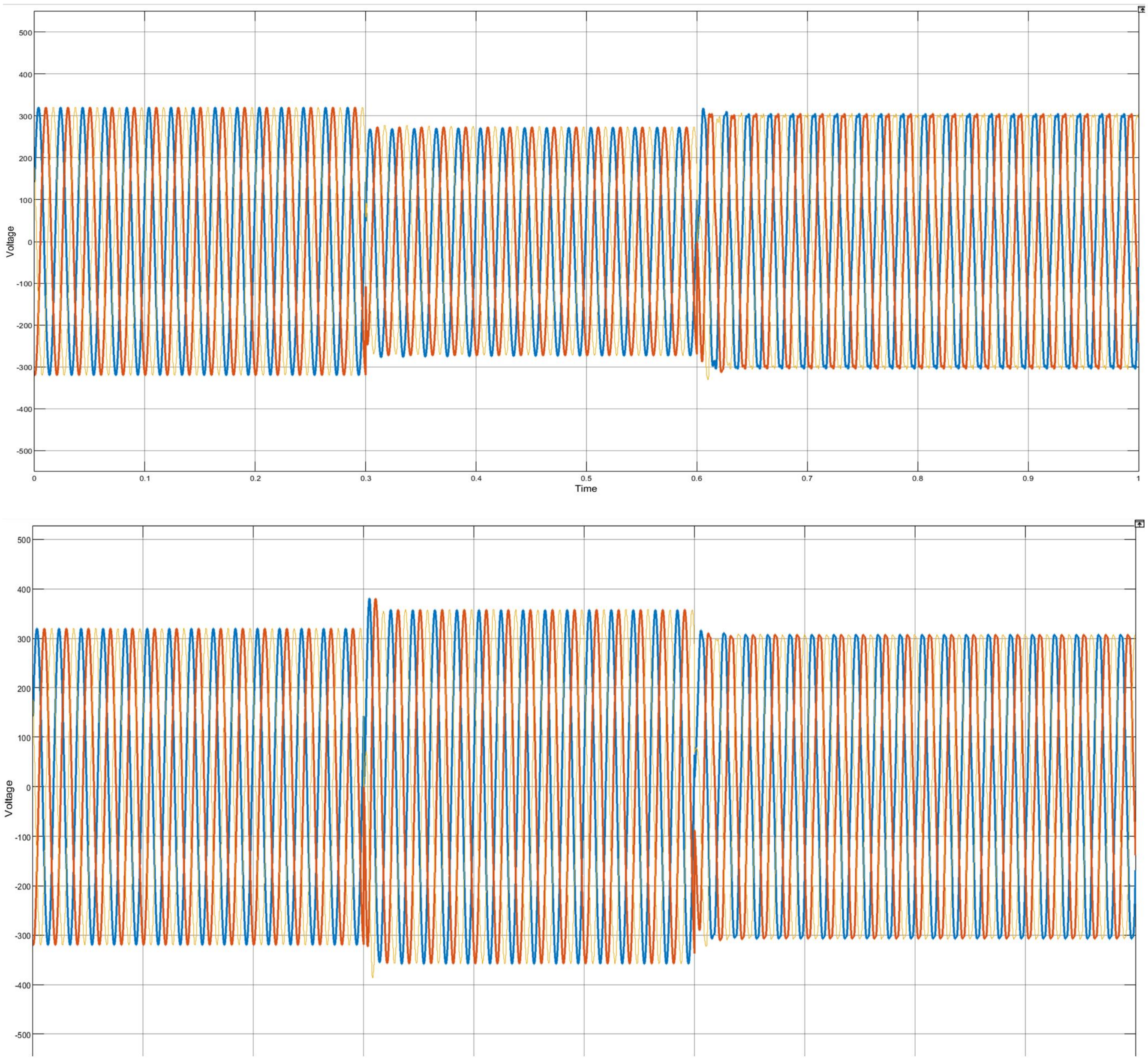

Fig. 7 Waveforms of Mitigation of Voltage sag and swell using IRPT theory

A. Instantaneous Reactive Power theory (IRPT) Results

As explained [5] before the sag swell are made to occur using additional load connected with the help of circuit breaker at particular instances. In the waveform shown in fig. 7 we can see that the sag occurs at 0.3 sec instance means at that time additional load gets connected to circuit with the help of breaker. At 0.6 sec the sag which was there gets mitigated, this happens because the STATCOM gets connected to the system which rectifies the voltage variations and mitigates the sag. Similar happens in case of swell as shown in fig. 7. At 0.3 sec capacitor bank gets connected to the system, and at 0.6 sec since STATCOM gets connected to the system with the help of circuit breaker the swell gets mitigated. In this way the synchronous reference frame theory contributes for mitigation sag and swell in system.

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B. Synchronous Reference Frame Theory (SRF)

As explained before the sag swell are made to occur using additional load connected with the help of circuit breaker at particular instances. In the waveform shown in fig. 8 we can see that the sag occurs at 0.3 sec instance means at that time additional load gets connected to circuit with the help of breaker. At 0.6 sec the sag which was there gets mitigated, this happens because the STATCOM gets connected to the system which rectifies the voltage variations and mitigates the sag. Similar happens in case of swell as shown in fig. 8. At 0.3 sec capacitor bank gets connected to the system, and at 0.6 sec since STATCOM gets connected to the system with the help of circuit breaker the swell gets mitigated. In this way the instantaneous reactive power theory contributes for mitigation sag and swell in system.

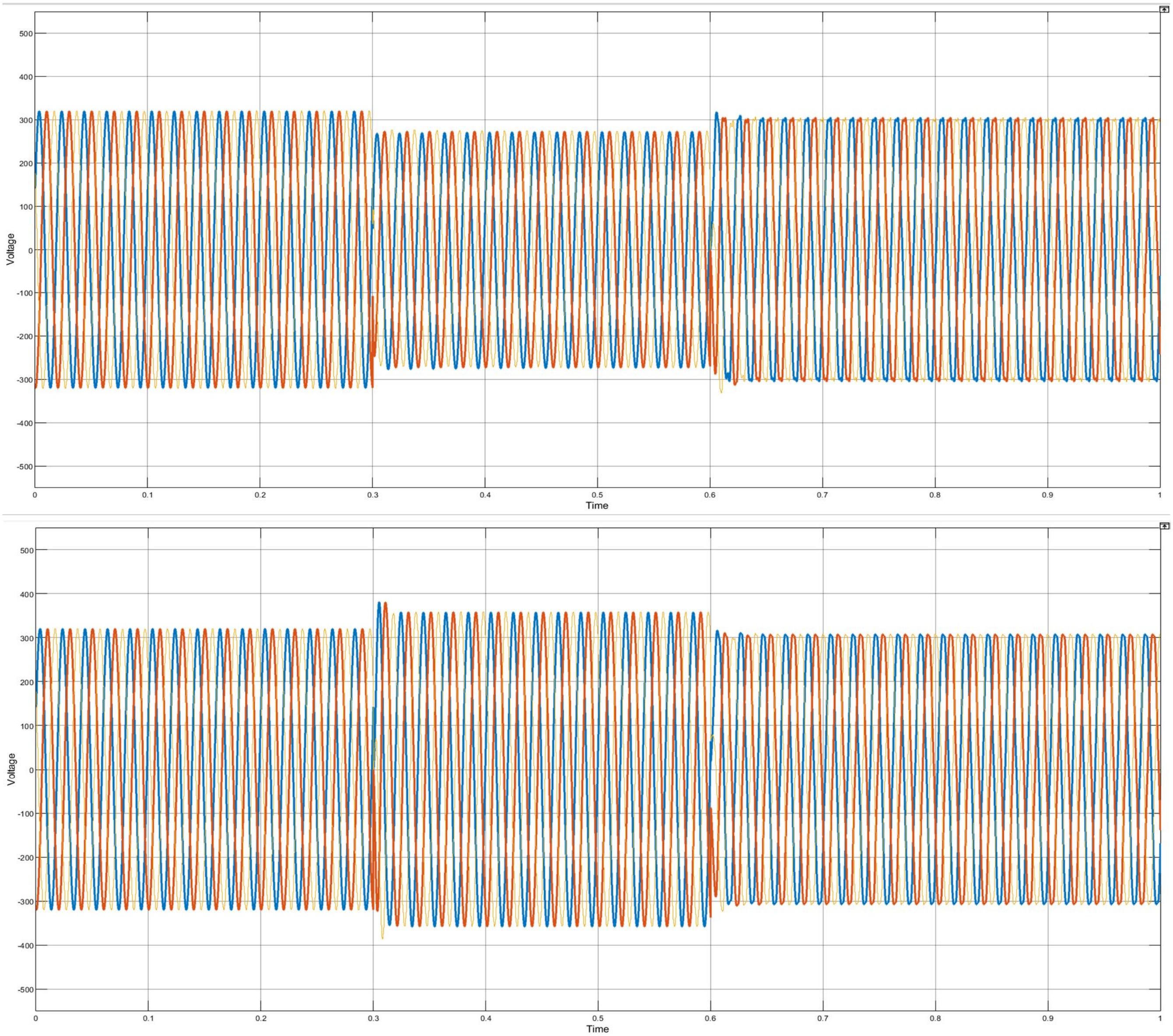

Fig. 8 Waveforms of Mitigation of Voltage sag and swell using SRF theory

VIII. CONCLUSION

In this paper two control strategies are used for mitigation of sag and swell which at load end in our system. The first is IRPT theory and second is SRF theory both were used to designed D-STATCOM. Here D-STATCOM is designed using three level NPC inverter. Th simulation results shows that both strategies were successful for compensation of sag and swell in the system. The future work which can be done in this project is by increasing the level of inverter. From the two strategy the SRF theory is superior if STATCOM is used for harmonics compensation. But for voltage sag and voltage swell mitigation both shows same results.

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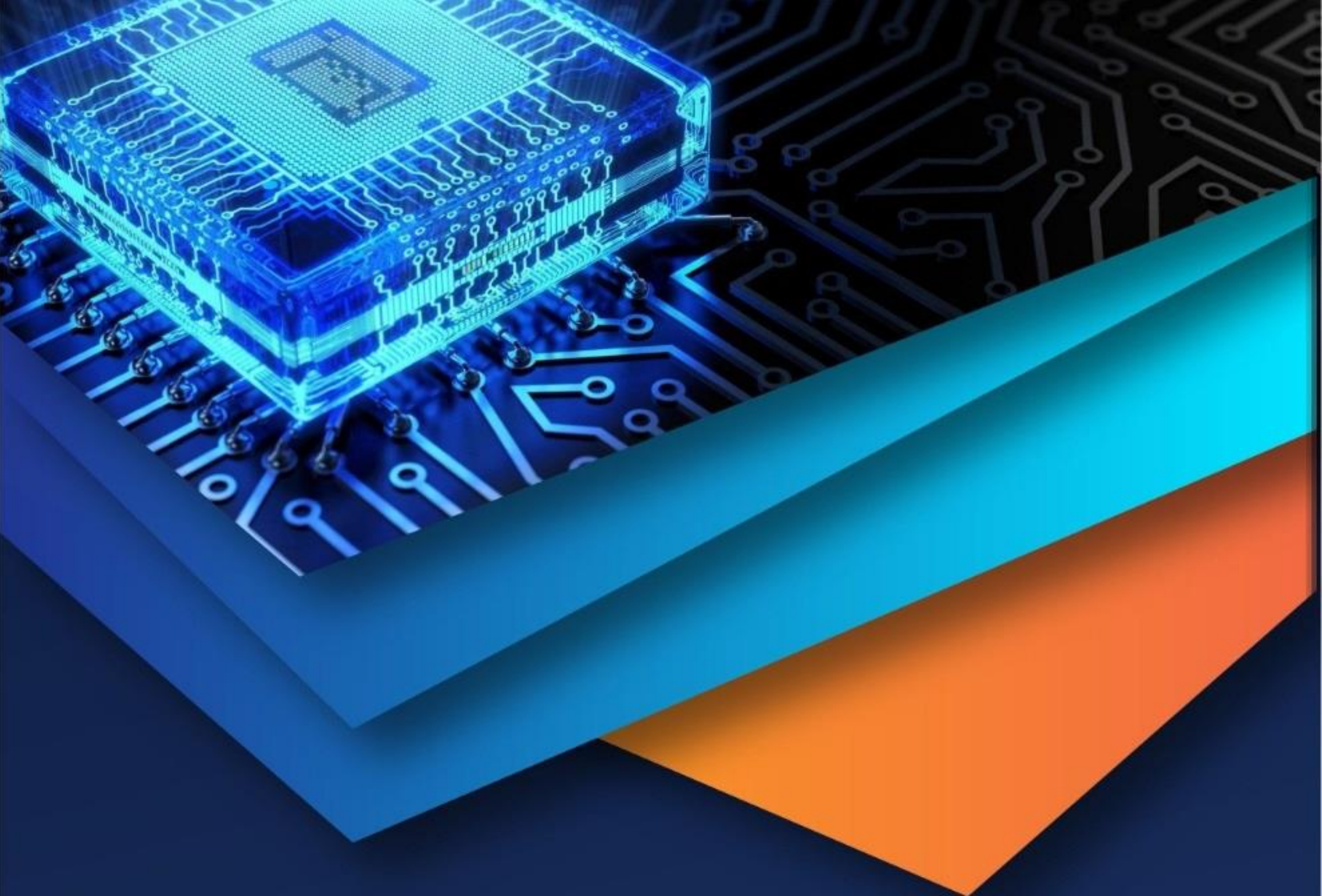

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