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ANALYSIS OF A D-STATCOM IN A 25 KV POWER DISTRIBUTION SYSTEM USING SIMULINK

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Abstract: This research paper focuses on the design and simulation of a D-STATCOM when connected to a distribution system. Simulink from MATLAB is used in the design and simulation of the D-STATCOM. With the struggle envisioned for trying the project in a real power system, the Sim-Power Systems (SPS) software provides me with the required simplicity and relative analytical power to rapidly design the D-STATCOM model example which had been validated from Power Systems Testing and Simulation Laboratory of Hydro-Quebec, a utilities lab situated in Canada. The D-STATCOM was tested by varying different parameters like the voltage, load etc. and from readings at different time intervals the inductive, capacitive and no load mode was seen. Many other factors that affect power quality are also describe from the simulation which production and reduction of active and reactive power, changes in the modulation index etc. The D-STATCOM's fast and effective response was proven through the simulations.

1. Introduction

High quality of power is required by many production houses and corporations. If the distributed energy to these production houses has reduced quality, yields of these production houses like motor drives, microcontrollers, computers etc. get spoiled. Bestowing to a research in United States, the overall harm by drop in voltage totals up to 400Billion U.S. Dollars. In producing and manufacturing plants, a consignment of products can be damaged by voltage rise and fall of very small period. The clienteles are aware of such voltage sag because every sag can cause them to pay a very large sum of money. Also small voltage sags are enough to damage parts of the motor drives like its contactor. Failure in a portion of the production stage may damage the properties of a product and necessitate the need of starting production process again. Therefore in such situations consumers demand high quality of power. Due to these issues mitigation of poor power quality in power distribution systems is very important. These days, Custom Power equipment are being used for this reason. DSTATCOM is one of these Custom Power equipment which can be fitted in parallel with the sensitive loads. These devices can mitigate the load voltage by adding necessary current to the power system. The D-STATCOM is able of producing constantly alterable capacitive shunt or flexible inductive re-compensation at a stage above the max (MVA) ratings. This device called D-STATCOM keeps on checking the line waveform w.r.t A.C. signal, and henceforth, it provides the right magnitude of lagging or leading reactive current recompense for reducing these voltage fluctuations occurring.

This paper discusses the main causes affecting the quality of power supply in a distributed power system are voltage drops, fluctuation in harmonics and poor power quality. The purpose of this paper is to explore and decrease these effects using DSTATCOM.

II. Operating Principle of a D-STATCOM

"The building block of a DSTATCOM is a voltage source converter (VSC) consisting of self-commutating semiconductor valves and a capacitor on the DC bus" (Singh et al, 2008). The power distribution system is connected in shunt with the VSC and other devices used in the operation of D-STATCOM with the help of a coupling inductance which is realized by the transformer's leakage reactance. Generally, the DSTATCOM is used for correcting power factor, reducing harmonic distortion and for balancing the load. The chief benefits of the D-STATCOM in comparison with the usual static VAR compensator (SVC) can produce the rated current at almost any network voltage, it improves the usage of low value capacitor on the DC bus and makes the dynamic response better. In steady- state production of reactive power the capacitor's size does not matter much, as a result there is a decrease in the size and cost of the compensator**.**

It can be described in the following points:

The DSTATCOM is a device which is considered as a current controlled source. The most fundamental purpose of a Voltage Source Inverter (VSI) is to generate AC voltages in sinusoidal forms with negligible harmonic disturbance occuiring from a D.C voltage source. The processes in D-STATCOM's operation are as mentioned:

AC bus voltage system's voltage (Vs) is first matched with voltage of the VSI voltage

- The D-STATCOM acts as an inductance connected to terminals of the AC system, when (Vc) voltage of the VSI is lower than that of the AC bus voltage.
- Or else the AC system sees the DSTATOM as a capacitance connected to its terminals i.e.AC bus voltage magnitude<Vc
- There will be no exchange of reactive power is both the voltages Vc and AC bus voltage are equal. The D-STATCOM supplies real power to the distribution system from its available DC or energy source. This is accomplished by calibrating the AC power system's phase angle with the D-STATCOM's phase angle.

"When phase angle of the AC power system leads the VSI phase angle, the DSTATCOM absorbs the real power from the AC system, if the phase angle of the AC power system lags the VSI phase angle, the D-STATCOM supplies real power to AC system" (Kumar.S et al, 2011). [1] The principle of operation a D-STATCOM can be seen in **Figure 1**.

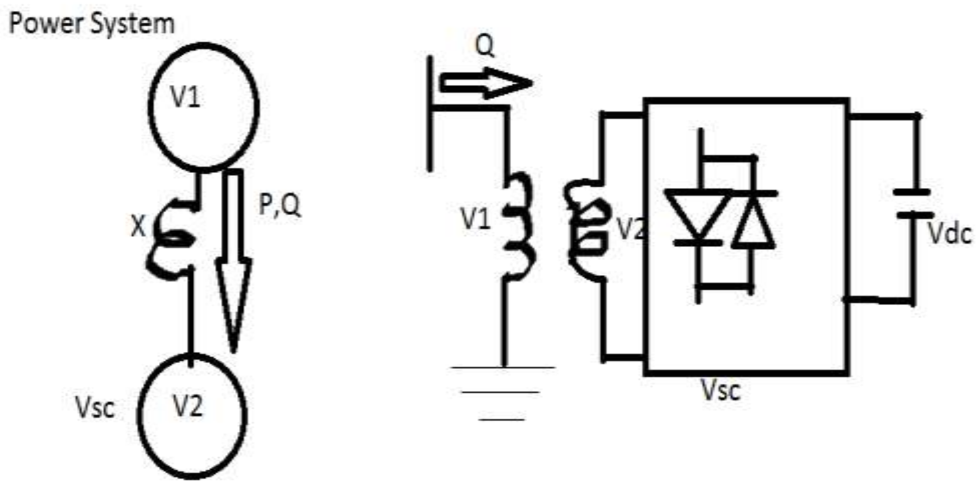

Figure1: Principle of Operation of a D-STATCOM

Control System of a D-STATCOM

- From Figure 2depicts the composition of a control system
- The 3 phase's primary voltage V1's +ve sequence part is coordinated amd matched with the phase locked loop (PLL). The quadrature and the direct axis components are calculated with the help of the outputs (angle Θ=ωt) from the PLL. The axis components are cyrrents and voltages from the 3-ϕ AC and are given in figure 2.4 as I_d,$I_q$andV_d,V_q.
- The q and d parts of AC positive-sequence voltage are calculated with the help of measurement systems and they also help in regulating V_{dc}.

- The regulation loop on the outer side is for regulating voltages which comprises of a DC and an AC voltage regulator. I_{qref} is known as the reference current and it is the output from the AC voltage regulator (I_q = quadrature current with voltage that is needed for controlling the flow of reactive power). $I_{d\ ref}$ (where Id is the current which is in phase with the voltage controlling the flow of active power) is produced by the DC voltage regulator.

- The current regulating device makes up the inner current regulation loop. The phase and magnitude of the generated voltage by the Pulse Width Modulator converter (V_{2d} V_{2q}) acquired from the I_{qref} and I_{dref} reference currents produced by the AC and DC voltage regulator(when operated in voltage control mode). Feed forward type regulator helps the current regulator in predicting V2 which is the voltage output (V_{2d} V_{2q}), from the V1 measurement (V_{1d} V_{1q}) and also finds leakage reactance of the transformer.

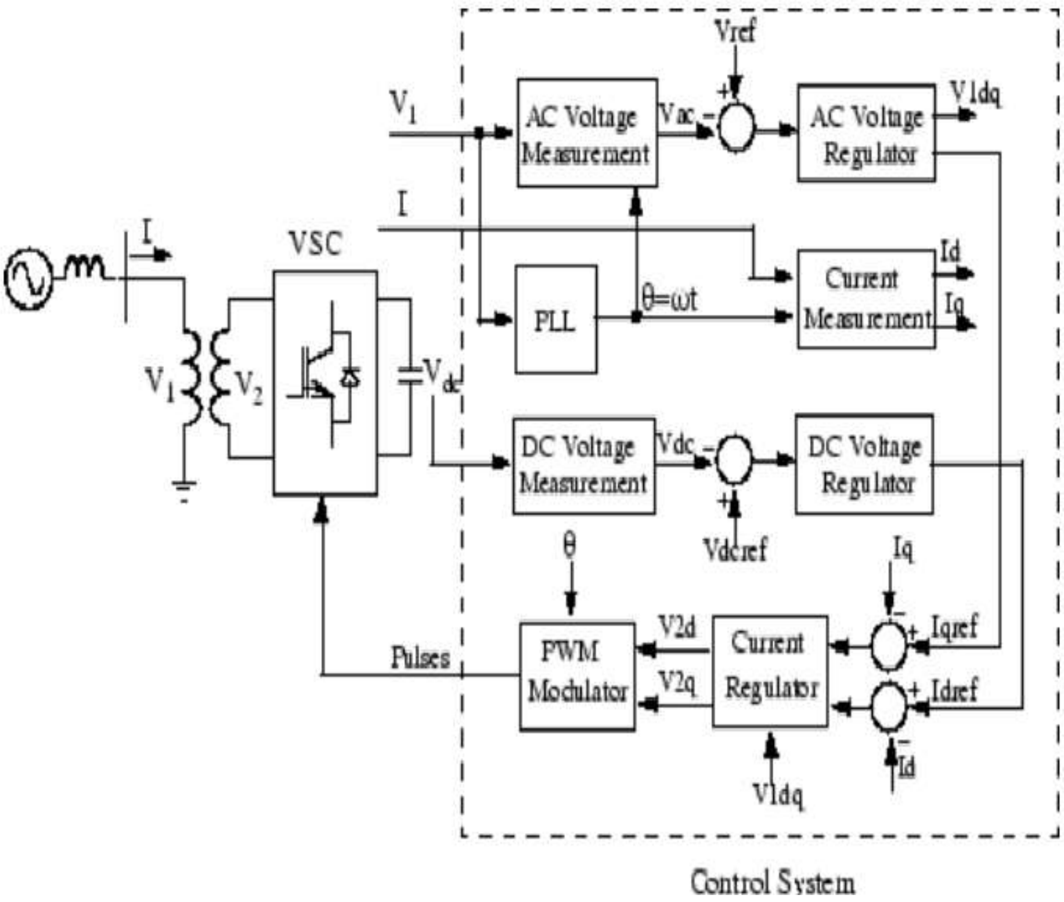

Figure 2: Block Diagram of the Control System [1]

III. Modes of Operation of a DSTATCOM

Figure 3, 4 depicts three operation modes of D-STATCOM with its output current known as I , it changes according to Vi. If Vi = Vs, then reactive power will be 0 and also the D-STATCOM will not produce or reduce the reactive power. Whenever Vi will be greater to Vs, the D-STATCOM will depict an inductive reactance over its terminal. Current known as I, moves across the transformer's reactance from D-STATCOM to A.C system, and the equipment will generate capacitive reactive- power. When Vs is more than Vi , the D-STATCOM is seen by the system as capacitive reactance. When the flow of the current is from the A.C. sys. to the D-STATCOM it will result in the absorption of the inductive power.

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From figure 3, we see that part (a) shows the No-load mode (Vs = Vi), part (b) shows the Capacitive mode (Vi >Vs), part (c) shows the Inductive mode (Vi<Vs)

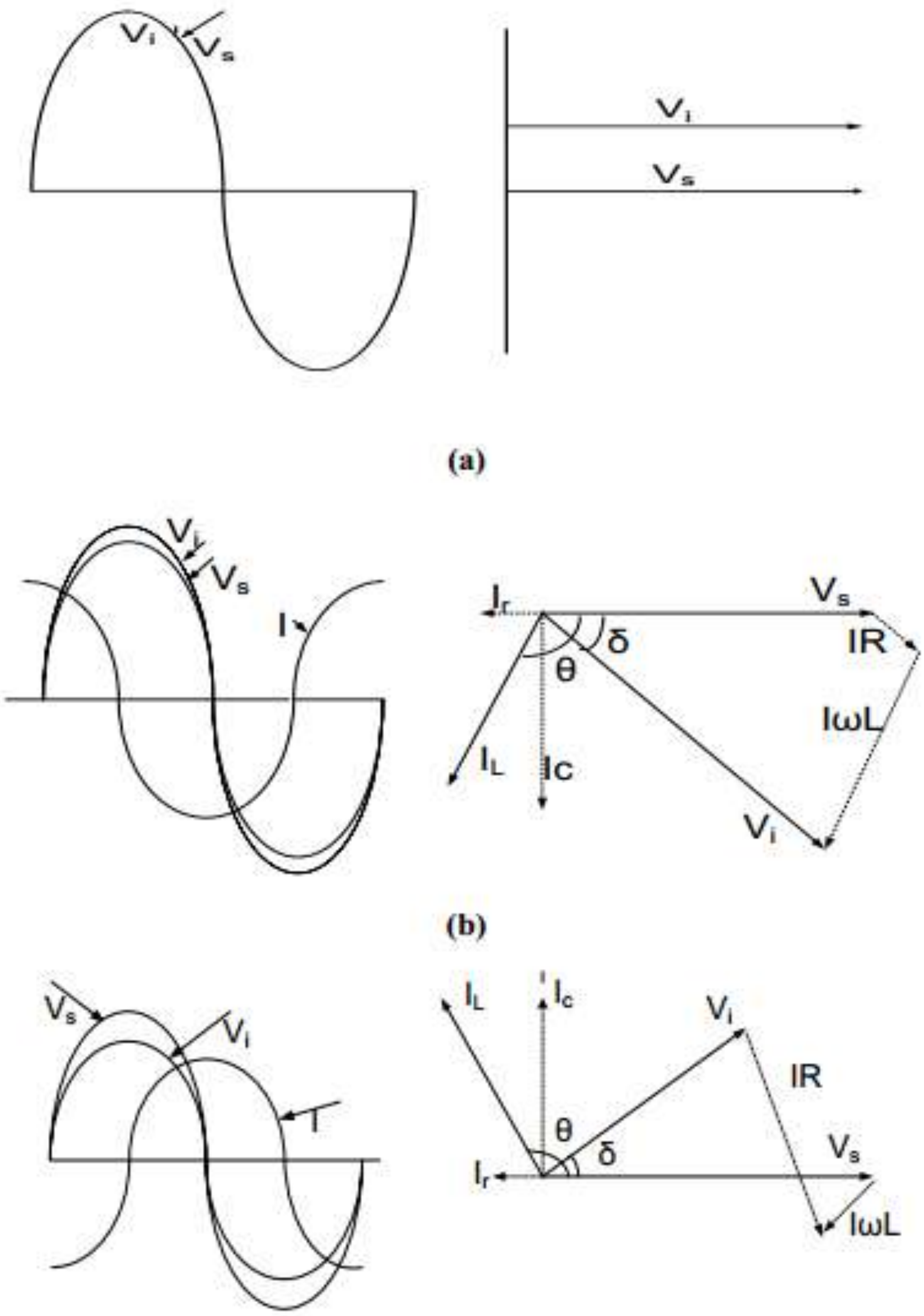

Figure 3: Showing different modes of operation (Mahyavanshi, et al., 2012)

MATLAB DESIGN for 25kVA power distribution system:

The MATLAB design is used and modified from the help library and Figure-4 depicts the modified MATLAB design.

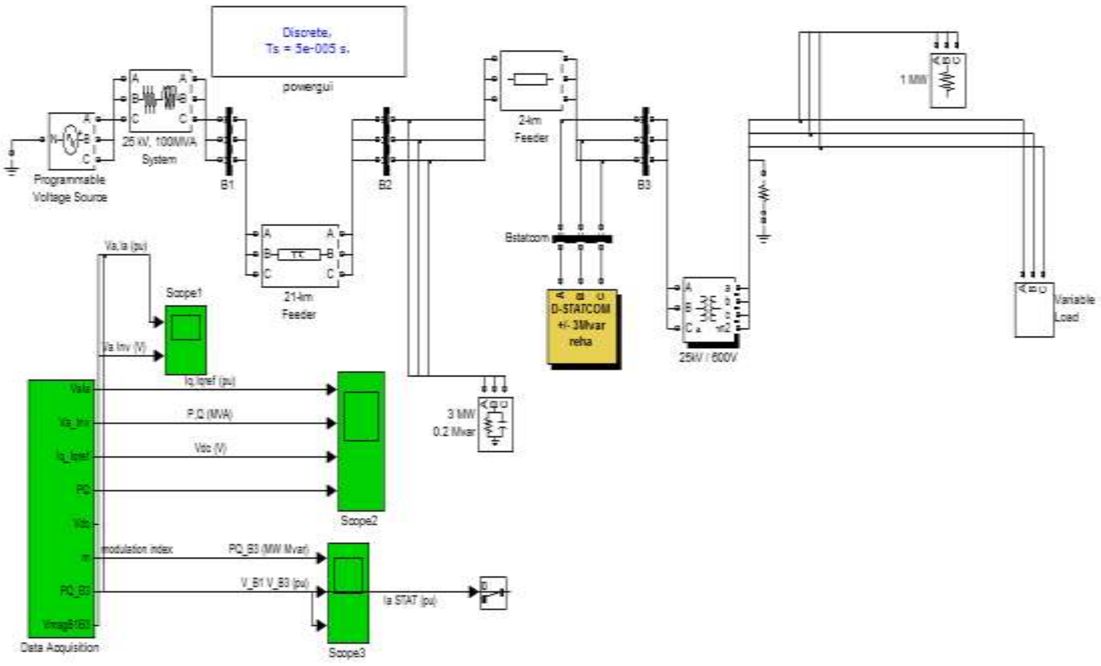

Figure 4: Showing the Matlab design for 25kV Distribution

First we have to simulate the program with voltage flickering for that the following changes shall be made, the "Time Variation of" limit is altered to "None" in Prog. Voltage Source menu. The modulation timings of the variable load are changed as such: the modulation timings are set to 0.15 to 1 and it is not multiplied by 100. Lastly, in the DSTATCOM Controller diagram as depicted in Figure 5, the Operation Mode is changed from voltage regulation to Q regulation. This is done so that, the DSTATCOM is free and does not do any voltage rectification as presented in figure 6.

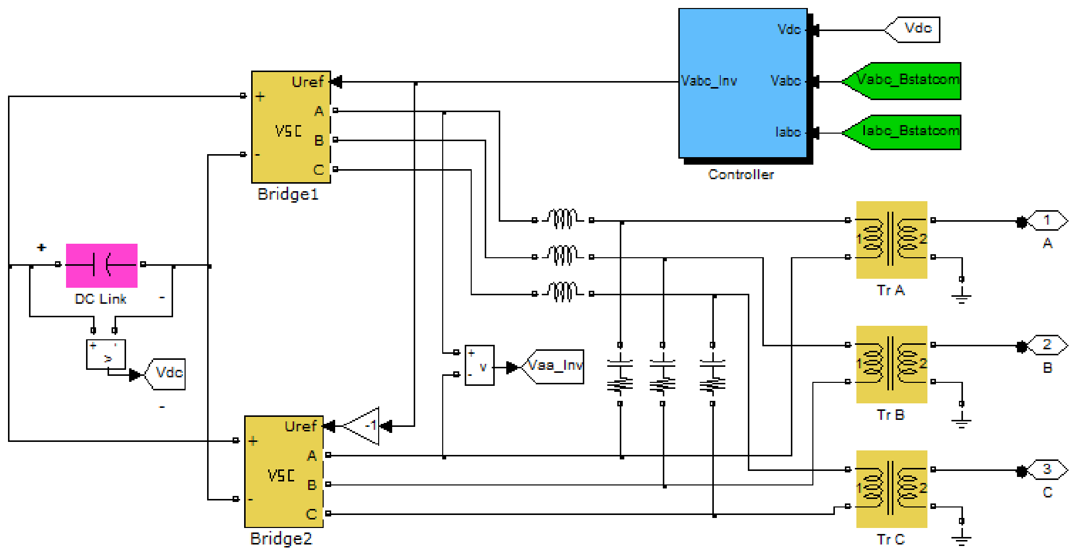

Figure 5: Controller design of a DSTATCOM

List of Parameters used for simulation show in Table 4.1

Table 4.1 Parameter values of the system

Sno.	Parameters	Values
1	Source	3 phase,25kV,60Hz
2	Source Resistance and Inductance	0.625 ohms,16.578mH
3	Three phase 2 winding transformer	100MVA,60Hz
4	Winding 1	25kV,0.26042 ohm,0.041447H
	Winding 2	600kv,0.26042ohm,0.041447H
4	DC voltage source for inverter	10000 microfarad capacitor
5	Filter	Anti-Aliasing for acquiring V and I
6	Filter in series with capacitor	Gives quality factor of 40 at 60 Hz
7	IGBT	2 IGBT bridges
8	Total line length	23km
9	DC link voltage	100 mVA

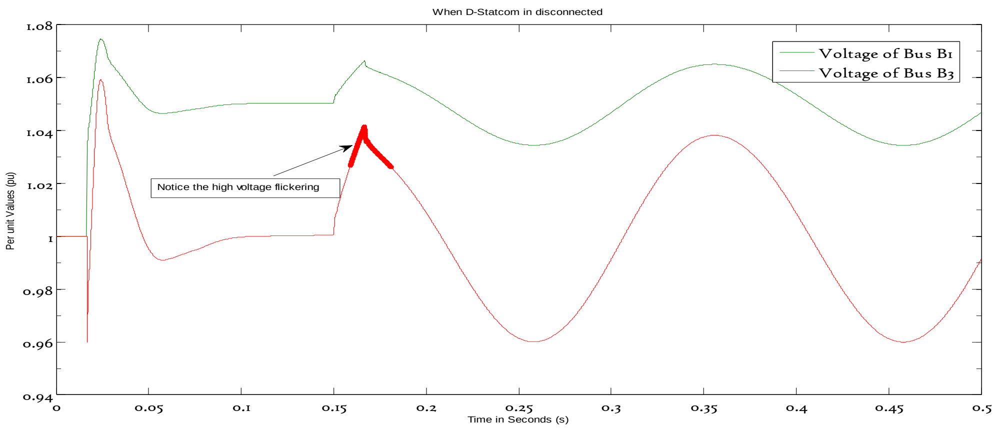

Figure 6: Showing voltage flickering when the D-STATCOM is disconnected.

Reduction of Voltage flickering when D-STATCOM is connected again:

The Operation Mode is changed from Q regulation back to Voltage regulation in the controller to start the DSTATCOM. When the simulation is started again, it is seen that on Scope 3, at bus B3 the fluctuation of voltage is now reduced to +/- 0.9 %. The DSTATCOM recompenses voltage as shown below in Figure 7 and by adding a reactive current modulated at 5 Hz as shown in figure 8 it is seen as fluctuating between 0.6 pu capacitive when voltage is low and 0.55 pu inductive when voltage is high.

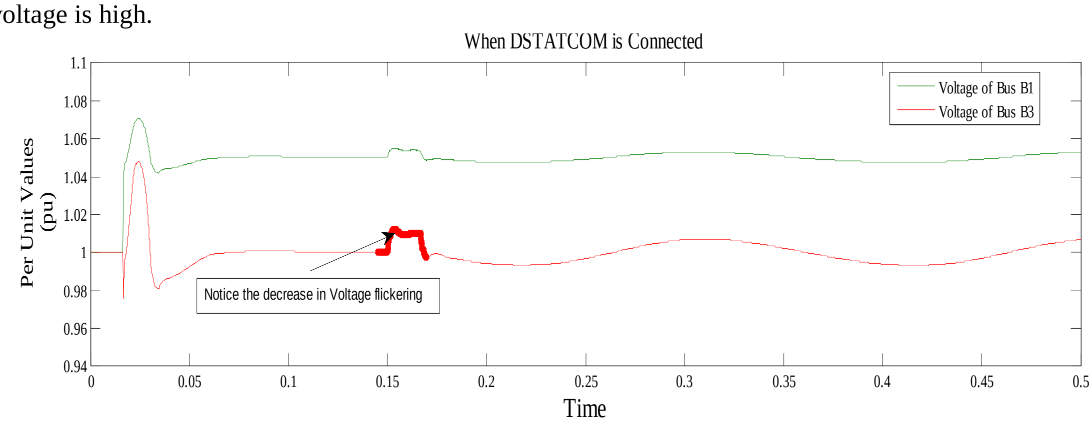

Figure7: Decrease in voltage flicker when the D-STATCOM is connected

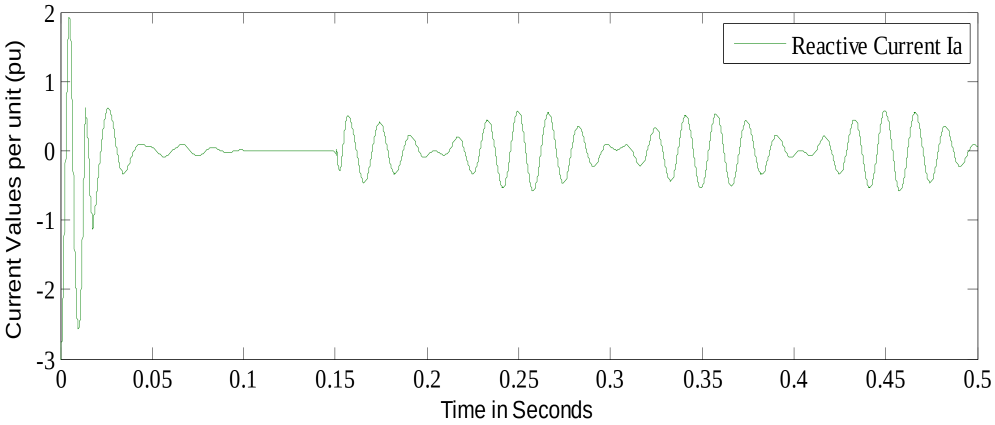

Figure 8: Fluctuation of reactive current

Injection and Absorption of Q Power (reactive power) upon increasing and decreasing the Source Voltage respectively to maintain 1 pu voltage:

In this test the variable load is kept constant and the voltage is modulated. The modulation timings of the variable load are changed as such: the modulation timings which were set to 0.15 to 1 are made greater than simulation time so that the modulation doesn't occur. The first Programmable Voltage Source block is used to moderate the internal voltages of the 25-kV correspondent. The voltage is set first to 1.066 pu in order to intially keep the DSTATCOM floating (Bus B3 voltage=1 pu and the reference voltage V_{ref} =1 pu). The 3 steps are programmed to 0.2s, 0.3s and 0.4s for increasing the source voltage by 7%, then decreasing it by 7% and then bringing it back to its initial value (1.066 pu).

IV. D-STATCOM's dynamic response

The simulation is started and the following figures are observed. Figure 9 shows current waveforms and voltage of phase A of the DSTATCOM.

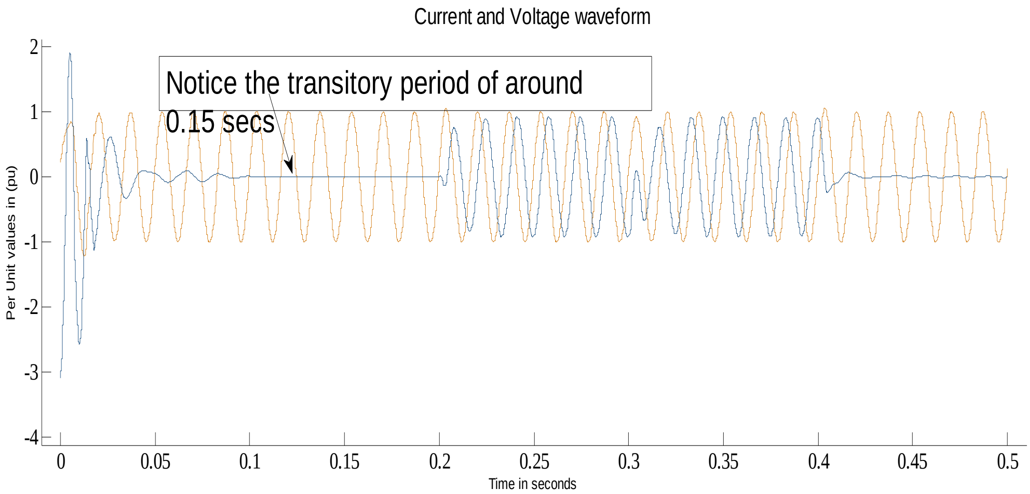

Figure 9: Current waveform and voltage of phase A of the DSTATCOM

After a transitory period of about 0.15 sec., the steady state is reached. In the beginning, the source voltage is at a quantity such that the DSTATCOM is not active. Therefore it doesn't produce or absorb any reactive power from the network. When time t= 0.2s, the source voltage is added by 6%. The DSTATCOM recompensates for this increase in voltage by absorbing (decreasing) the reactive power Q from the network as it is shown in Figure 10. Where Q=+2.69 Mvar.

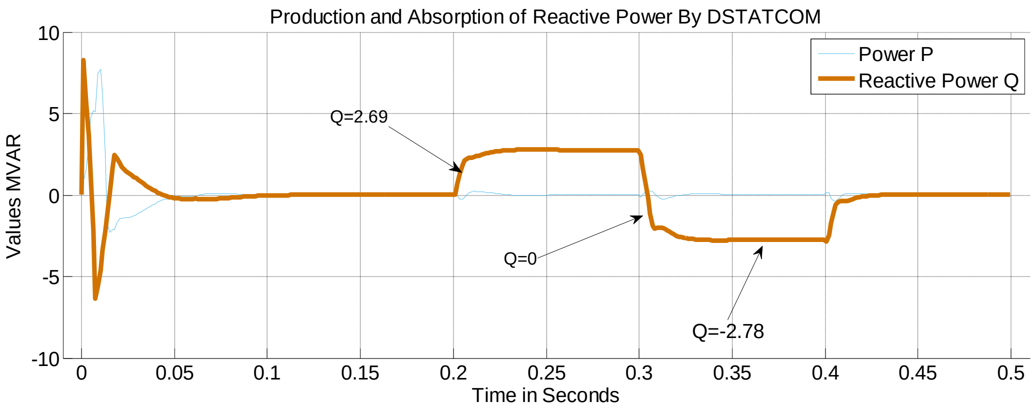

Figure 10: Showing the absorption and production of Q power for maintaining 1 pu voltage.

At t=0.3s, the source voltage is decreased by 7% from the value corresponding to Q = 0. The DSTATCOM produces reactive power for maintaining 1 pu voltage (Q changes from +2.69 MVAR to -2.78 MVAR). It is seen that when the DSTATCOM's mode of operation changes to capacitive from inductive. We can also see the function of the PWM inverter in Figure 11, here PWM inverter's modulation index is increased from 0.49 to 0.89 which links to a proportionate increase in the voltage of the inverter.

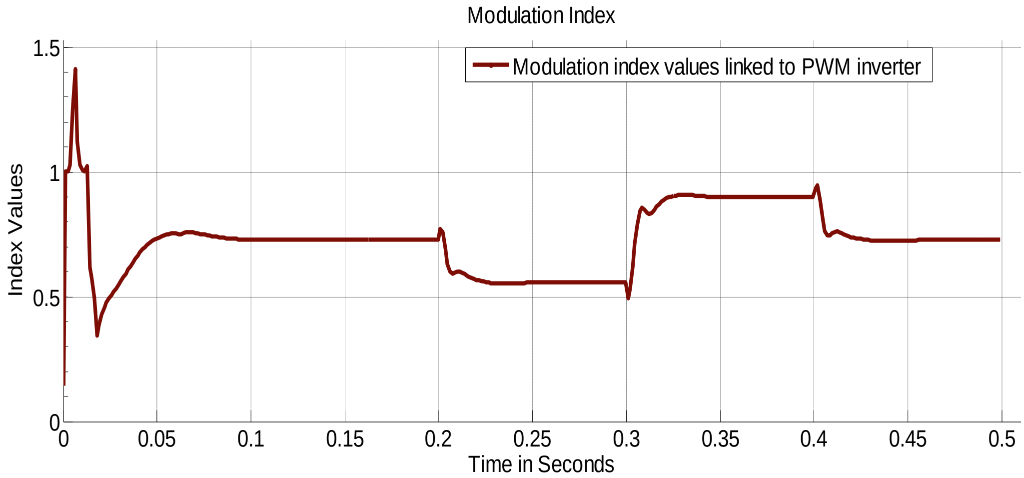

Figure 11: Showing PWM inverter's modulation index

The reactive power is reversed very fast, approximately in one cycle, as observed on D-STATCOM current which is shown in Figure 12.

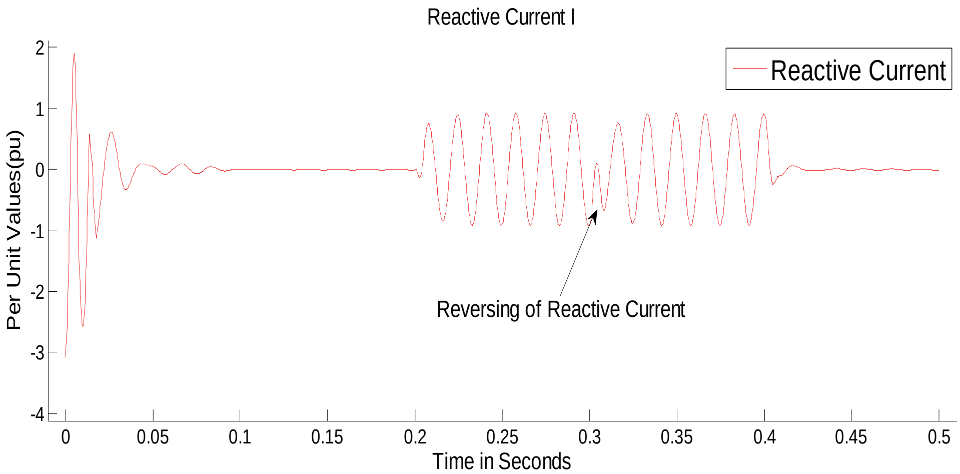

Figure 12: Red color shows the reactive current

V. Conclusion

Comprehensive MATLAB simulations were showed to achieve an understanding into the influence of D-STATCOM on supplying reactive power, voltage flickering, harmonic disturbance and correction of power factor. From the simulation we also learned that unlike a STATCOM which only corrects compensates reactive power a DSTATCOM does a lot more like it also checks and correct power factor, regulates the voltage and also reduces harmonic distortion.Under varying load conditions the D-STATCOM performed as expected and the results were very satisfactory.

Future Scope:

Designing a Transformer-less D-STATCOM by using a multi-level converter which is cascaded, by designing a control system which regulates the DC voltage in the cells connected in series in the operation of DSTATCOM, thus making the removal ofDC sources from the cells in the H-Bridge possible. Minus the DC sources the D-STATCOMS will be more compact and will weigh less.

Nomenclature:

AC	Alternating current		m	m Mille
DC	Direct current		s	Time in second
Eq.	Eq. Equation		THD	Total Harmonic Distortion
PCC	Point of common coupling		∫	Integration
R	Resistance		ϕ	Phase angle
L	Inductance		%	Percentage
C	Capacitance			

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