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Improve Power Quality by D-STATCOM using New External Energy agreement

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ABSTRACT: *In distribution side STATCOM is used to improve quality of power, hence that STATCOM is called D-STATCOM, In D-STATCOM compensation depends upon a capacity of storage device, The conventional method states rating of capacitor is √6 times of the source voltage, so due to this reason rating of capacitor is large and the device becomes bulky and increases the overall cost of device, so using some method we can reduces the size of capacitor without compromising the compensation operation.*

INDEXTERMS: *Introduction, Design, Simulation & Conclusion.*

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I. INTRODUCTION

The area of power quality must improve and fulfil the requirement of customers is necessary, so the devices are used for improve poor power quality and increase the satisfaction result of customers side. So the devices used for this purpose are called "Customer Power Devices", in past time the capacitor banks are used for improvement of power quality but now a days new technology are used like FACTs devices, The FACTs devices are used to improve the power quality in electrical side. The STATCOM is used in distribution side is called D-STATCOM,. D-STATCOM can give good response which depends upon its energy storage capacity. If selection of energy storage device is of feasible value then it give good response but it also increases the rating of storage device so it increases the cost of storage device. So for this reason some researcher use external storage devices like super capacitor, BESS, flywheel generator, SMES etc. but it has also some problem. So the objective is to make an arrangement of capacitors which can reduce the problem of external storage devices and gives a better response without compromise system parameters. Because we can reduce the cost of system and also rating of storage device for D-STATCOM.

II. D-STATCOM PERFORMANCE

The D-STATCOM is capable of generating continuously variable inductive or capacitive shunt compensation. The D-STATCOM continuously senses the line waveform with respect to a reference ac signal, and therefore, it can provide the correct amount of leading or lagging reactive current compensation to reduce the amount of voltage fluctuations. It is connected in shunt near to the load Via the coupling transformer. Depending on the type of load the DSTATCOM can be of 3-phase 3-wire or 3-phase 4- wire.

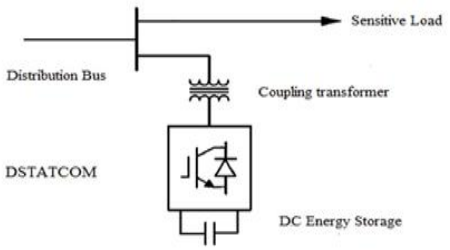


Fig 1 Configuration of D-STATCOM

The operation of the D-STATCOM is same as STATCOM the power exchanging between STATCOM and line such as STATCOM. The reactive- and real-power exchange between the STATCOM and the AC system can be controlled independently by itself using this device. STATCOM is real power generation or

absorption with VAR generation or absorption is achievable if the STATCOM is equipped with an energy-storage device of suitable capacity, as depicted in Fig. 2.

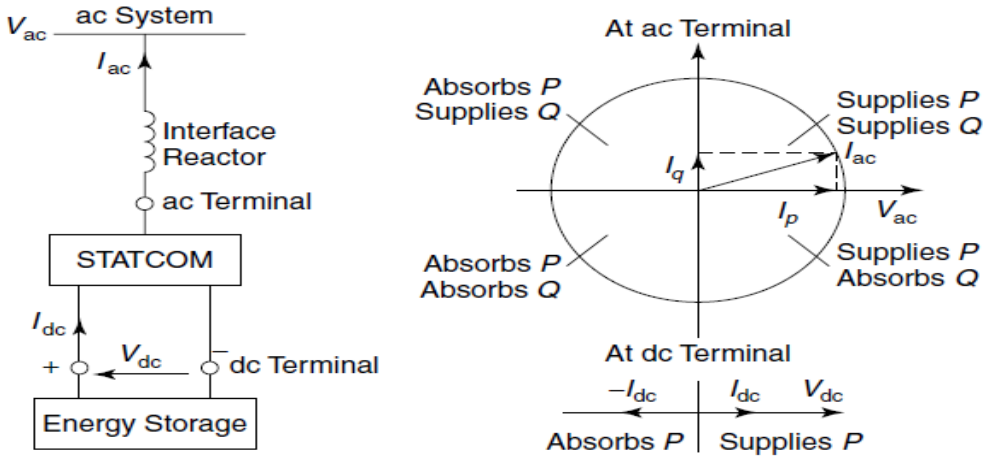


Fig.2 The Power Exchange Between STATCOM & the AC System

COMPONENTS OF DSTATCOM [5]:-

- **Voltage Source Converter (VSC):** Generate a sinusoidal voltage with any required magnitude, frequency and phase angle, and injects appropriate current in the system
- **Coupling Transformer:** Step up and electrical isolation the ac low voltage supplied by the VSC to the required voltage.
- **AC-Filter:** This filter rejects the switching harmonic components from the injected voltage and suppresses harmonics.
- **Control System:** The aim of the control scheme is to regulate the PCC voltage, and compensate the reactive power.

ADVANTAGES OF D-STATCOM [5]:-

- Quick response time (a D-STATCOM has a step response of 8 ms to 30 ms).
- Active power control is possible (with optional energy storage on DC circuit).
- No potential for creating a resonance point. Because no capacitor bank or reactor required to generate reactive power for D-STATCOM.
- It has smaller installation space.

ENERGY STORAGE DEVICE[9]:-

By using energy storage devices, a FACT'S device can work such like "synchronous compensator". So when voltage across capacitor is decreased it's nominal value then it absorbed a reactive power (like under excited synchronous compensator) and when voltage across capacitor is increased at its nominal value then it supply a reactive power (like over excited synchronous compensator) [9].

Storage device is connected with VSI. If D-STATCOM/STATCOM, used as a compensating device for transmission/ distribution line then D-STATCOM/STATCOM design considering energy storage devices are used in two manner.

(1) Without external storage device or
(2) With external storage device

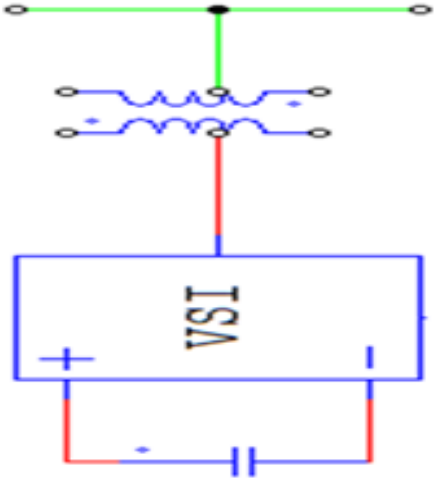


Fig 2 VSI Without External storage devices

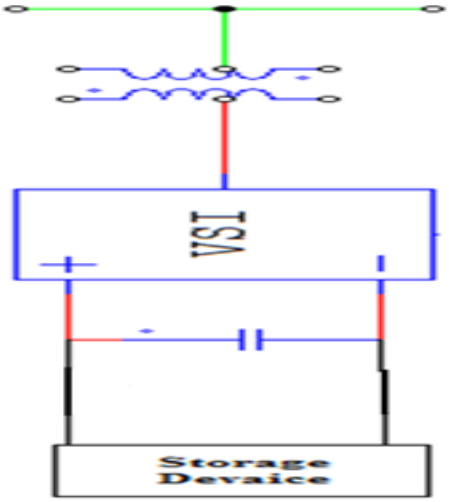


Fig 3 VSI With External storage devices

In traditional D- STATCOM / STATCOM for designing as a compensating device then only one energy storage devices are used like capacitor. There is only one capacitor used and value of capacitor is selected by considering system voltage. Some literature is said that value of capacitor used as a storing device then it's value should √6 times of system nominal voltage [8]. Also, when capacitor supply/absorb reactive power at PCC then voltage across capacitor should be constant because voltage fluctuation of capacitor voltage can distort operation of compensating devices. So, for that control system must design careful manner and for taking a constant voltage by using control system PI controller must select careful then it can regulate error signal generated by comparing references signal. Also, higher value of references value is needed. Here figure is given arrangement of energy storage device at D-STATCOM/STATCOM.

A new approach for energy storing device with main storage device of D-STATCOM/STATCOM is connected with another storage device externally which can be able to store and release energy at required value to VSI. For using these methods, storage devices can supply extra reactive power at PCC when voltage is exceeding then nominal value without compromising compensating device rating [8]. So, we can use small rating of capacitor for compensating device so rating of capacitor required is small. An arrangement of external storage device shown in figure From we can observe that external energy storage device is connected in parallel manner with main storage device. Also, we can add interfacing system between external and main storage system for control power from external storage device [10]. There are some type of energy storage devices which are used and as well as combination of more than one external storage devices can also be used which can also use to make system flexible and efficient. Here some external storage devices are alternatively used for D-STATCOM/STATCOM [10].

(1) Super Conducting Magnetic Energy Storage System(SMES)
(2) Super Capacitor
(3) Flywheel Generator
(4) Battery Energy Storage System (BESS).

1. Super Conducting Magnetic Energy Storage System (SMES):-

This system can store energy in the magnetic field created by flow of direct current in a superconducting coil which has been cryogenically cooled to temperature below its superconducting critical temperature. This system includes three parts (1) superconducting coil (2) power conditioning system and cryogenically cooled refrigeration. This systems limitation is required more space [10].

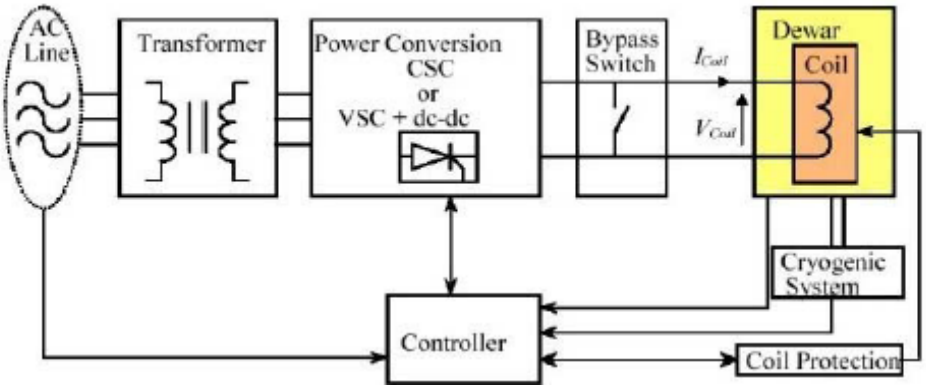


Fig 4 Basic arrangement of SMES

2. Super Capacitor: -

Super capacitor is now begun to use as a storing device. This device is used in distribution system because it can charge and discharge energy very fast so it is required where transient takes place at distribution network [10]. Super capacitor can store small of energy so the numbers of series parallel connection is required.

3. Flywheel Generator:-

In this system one flywheel is connected with one dc generator and interfacing with VSI, Speed of flywheel is depending upon energy storage system supply or absorb reactive power. The supply and absorb energy depends upon positive and negative torque of flywheel. This system is mostly use at wind system. Here control system is designed that the variation of speed is detected and it will control a reactive power generation and absorbed by energy storage system. Generally, flywheel is connected with PMSM (Permanent Magnet Synchronous Machine). [11]. Here Arrangement is given below in figure.

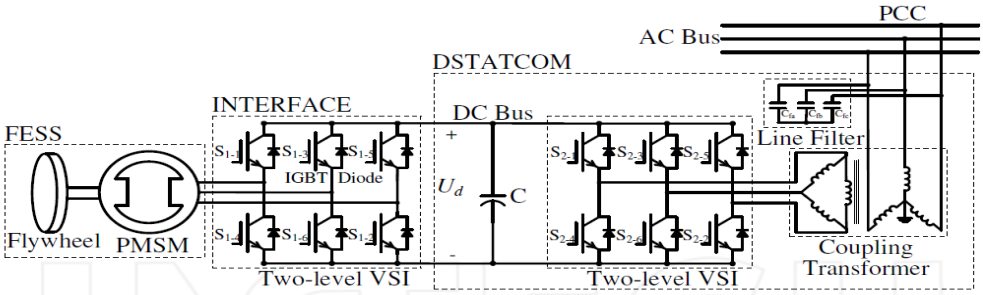


Fig 5 Structure of FESS

4. Battery Energy Storage System:-

The most effective external energy storage system is battery energy storage because there is no any mechanical part and also no required series parallel connection. A required energy from storage devices can get easily from battery no any kind of complex control system is required for maintaining constant voltage across it. It can directly be connected with main storage device and also it will beneficial if it interfacing with DC-DC converter for controlling it voltage. The arrangement is given in figure.6

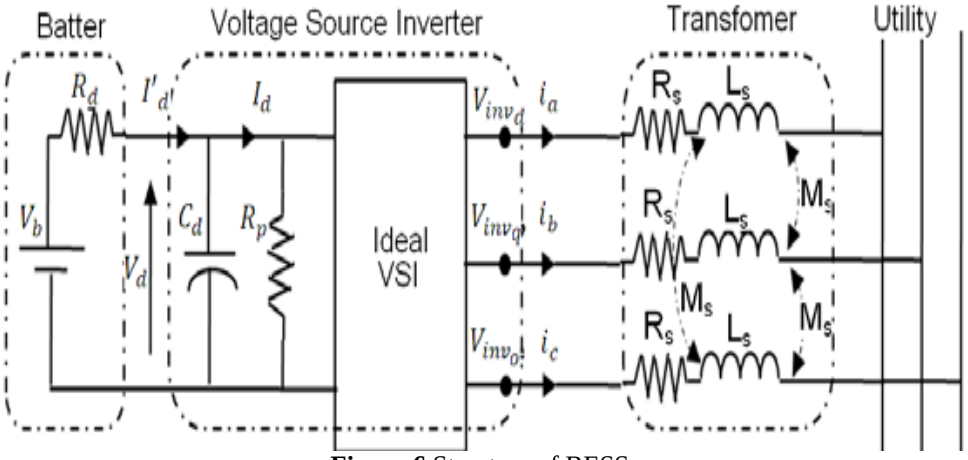


Figure 6 Structure of BESS

- **Limitation:-**

- SMES:- Required lots of space, High shielding for its magnetic effect
- Super Capacitor: - It can be able store small amount of energy so required number of series parallel capacitor
- Flywheel:- It has mechanical inertia
- BESS:- If batteries are cycled at very high current rates then batteries life deteriorates very fast in case of full discharge and also may lead to safety problem due to thermal runaway.

Control Strategy: -

D-STATCOM is a custom power device which is made up from STATCOM. Means it is a new version of STATCOM which is specially used in distribution side. The D-STATCOM design and control strategy is same as STATCOM, but it is used in LV (Low Voltage) side or distribution side. [15] Generally for non-linear load Sinusoidal control strategy is most efficient control to any other control. In this control scheme SRF method or p-q theory is used. Main object of any compensation scheme it should be a fast response easy to implement and flexible. So mainly control algorithm implemented for D-STATCOM in the following steps: -

- To measure system voltage and current
- Conditioning signal
- Compensating signal calculation
- Generation of firing angle of switching device

In this method reference theory based on transformation of current synchronously rotating frame d-q frame if θ is phase angle then current transformation α-β into d-q frame. From the above figure is given a scheme of SRF theory, In this scheme first load current transform into 3-F to 2-F using Clark's transformation and same 2-fF to 2-F Park's transformation the phase angle sin θ and cos θ are generated by extracting source voltage Va,Vb,Vc by using PLL circuit, that current id and iq are passed to low pass filter after that converting this current 2-F into 3-F by using reverse Park's and Clark's transformation.

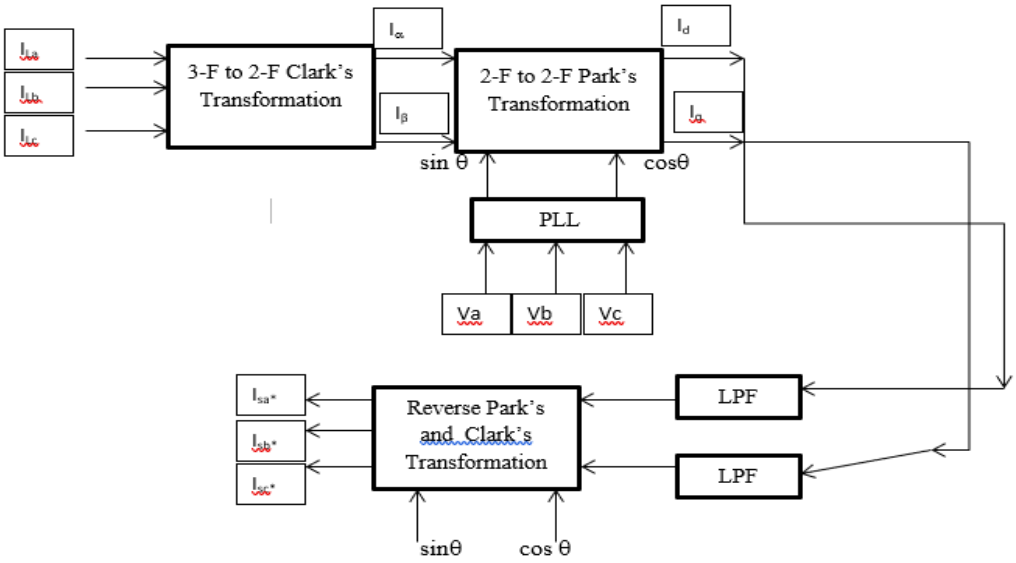


Figure 7 Synchronous Reference Frame theory

Problem analysis: -

Generally, in D-STATCOM storage device is most important part along size & rating consideration. When chosen right rating of capacitor then it performs good operation for injecting real power but to maintain voltage across capacitor is very vital point. For fluctuation of voltage across capacitor control strategy must design to fulfil this condition or operation. So for that PI control is used. Although when we use large size capacitor, system becomes bulky and costly. Even though size of capacitor is √6 times of system voltage. But many research papers have found that without increasing value of capacitor, we can reduce non-linearity of supply, means by reducing size of capacitor, we can compensate system reactive power. By studying papers & analysis small rating of small number of capacitors with arrangement we can reduce non-linearity or reactive power of system N Although if we increase size of capacitor than also size of voltage source (VSI) is increased. So considering this point of we can improve above problem: -

Summary of problem: -

- Increased size of system
- Become costly
- Size of capacitor is large
- Protection of capacitor rating is large (ex. fuse)

Proposed Method: -

In the proposed method the hardware circuit of the devices is considered and design to reduce the size of device without compromising its operation. Here arrangement of main storage device and external storage devices are given in fig.8

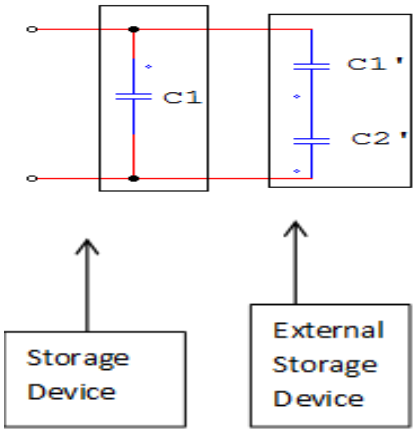


Fig 8 Proposed Method

The connection with VSI for D-STATCOM becomes a compensating device arrangement of storage device and external storage device is given below fig 9.

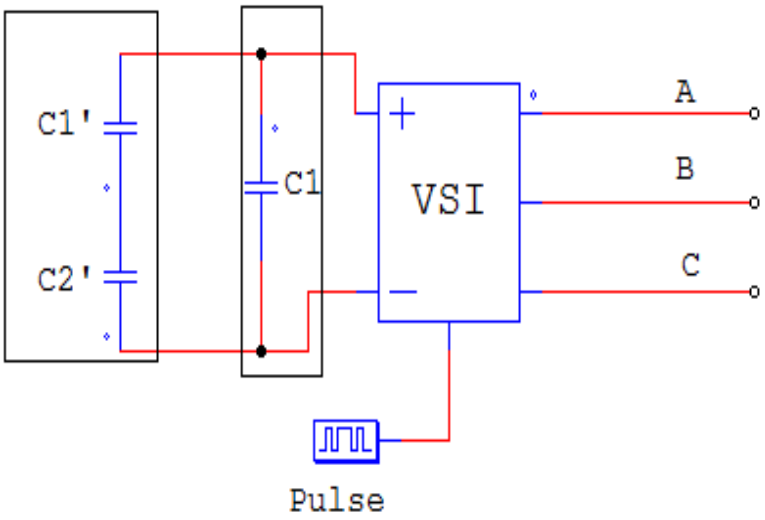


Fig 9 Arrangement external Storage Device with VSI

- **Why series parallel connection: -**

Capacitor can be connected together they can be connected in series and parallel. Here we see that how series parallel connection can benefits for reducing size of capacitor. Suppose we take one system which has source voltage is V_{LL} 440 V connecting with non-linear load. So, it is obvious that non-linearity is generated in waveform, So we have to compensate this non-linearity by connecting D-STATCOM because it is used in LV side. Generally, in D-STATCOM energy storage device is vital point as we have studied in pervious section, so to find the value of storage devices (capacitor) fundamental method said storing capacity of capacitor is √6 times of phase voltage. So, using fundamental method storing capacity is 623V so for that capacitor rating is 2300uF capacity required. If we connect less rating of above capacitors in series parallel connection so we can increase storing capacity with reducing size of capacitor. Suppose three capacitor rating is 511 uF connecting shown in fig.21 manner (delta). Capacitors across voltage is 440 V when $Vs>V_{L.}$ Here C1 is main storage device and C1' & C2' are externally connecting with C1. All Ratings are same.

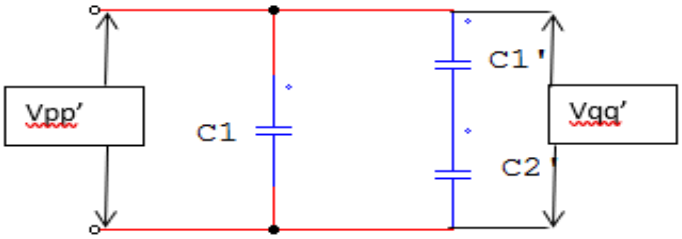


Fig 10 Arrangement of Capacitor

So Initial charge of capacitor
q1=C1*V= 511uF * 440= 0.22 C.
same as q1'= C1'*V=q2'=C2'*V=0.22 C.
After the three capacitors are connected in delta the **charge will be redistributed it self .**The charge on the three capacitor after the system settles down are
equal to Q1 Q1',Q2', since charge is a conserved quantity there is a relation between q1,q1' & q2', and Q1,Q1',& Q2',
q1 – q1'= Q1-Q1' (Eqn.1)
q1' + q2'= Q1'+Q2' (Eqn 2.)
q1 + q2'= Q1+Q2' (Eqn 3.)

The voltage between P & P" and Q and Q" can be expressed in terms of C2' & Q2' or in terms of C1,C1' & Q1,Q1'

VPP"=Q2'/C2' (Eqn 4.)

VQQ"=Q1/C1 + Q1'/C1' (Eqn 5.)

From above equation Q1 and Q2 can be obtained

Q1= q1 + q1' – Q2' (Eqn 6.)

Q2= q1' + q2' – Q2' (Eqn 7.)

Put Eqn6. and Eqn 7 in Eqn 5. We get

VQQ"= (q1+q2'-Q2')/C1 + (q1'+q2'-Q2')/C1' (Eqn 8.)

Combining Eqn. 8 & 4 Q3 can be expressed in terms of known variable.

Q2'*(1/C1 + 1/C1' + 1/C2') = (q1 + q2')/C1 + (q1' + q2')/C1'

So after putting the known value we get

Q2' = 0.27 C. After finding this value find Q1 and Q2 so we get values

Q1 = 0.17 C. and Q1"= 0.17C.

So putting value to Eqn 4. and Eqn 5. We get

VPP"= 528 V and VQQ" = 665 V

Design Of Capacitor :-

½ CV^2 = ½ Ceq V^2 Eqn 1.

If Suppose Ceq=C△

Where $C\triangle=\frac{C_{AB}*C_{BC}*C_{CA}}{C_{BC}+C_{CA}}$ Eqn.2

So put that value in equation We get

C△=2/3 C Eqn 3

And that will apply to find the Vdc

So,

½ C△[Vdc^2-Vdc_1^2]= P(inverter) Eqn.4

½ C△[Vdc^2-Vdc_1^2] = 3*V*I*α*t[10] Eqn.5

Where V=System line Voltage

I= Line Current

α =Overloading Factor

t= Time Period of Switching

From put Eqn (8) into eqn (10) we get

1/3 C [Vdc^2-Vdc_1^2]=3*V*I*α*t [8] Eqn.6

TEST AND SIMULATION WORK: -

To determine the performance of D-STATCOM taken non-linear system The details of non-linear system are as follow:-

Input voltage	11KV, 50Hz
Line Parameter	R=0.1ohm L=0.1mH
Transformer	11KV/440V,50Hz, 25KVA
Non-linear load	Diode Rectifier Load= 2KW,1KVAR
Capacitor Rating,	Cdc= 1600uF,Vdc=700V.
VSI Parameter	Rser =9 ohmLser =7mH

Table 1 Parameter of Test System

Here makes a system which has input voltage is 11kV and connected with transformer which supplied the voltage to non-linear load through 11kV voltage and step down from11kV/440V. The non-linear load basically rectifier and inverter set which first convert A.C. into D.C. then convert that D.C. into A.C. The inverter is a 3-ph inverter which has switching frequency set 10KHz. Here changing the load by step by step and then observe the result. First operate the system without D-STATCOM, and the with D-STATCOM by varying the type of load. In the simulation we compare conventional and proposed method with the above system. The simulation of proposed method.To control reactive power by D-STATCOM sinusoidal current control strategy is used because this strategy is efficient for controlling reactive power for non-linear load. Here first simulation work of compensation of reactive power for non-linear load by using conventional method using only one energy storage.

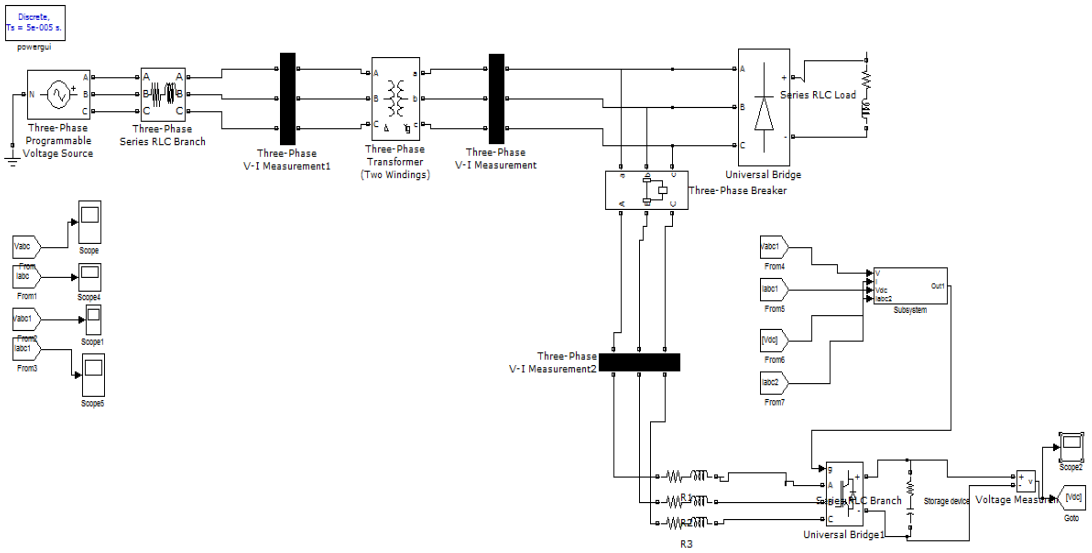


Fig 11 Simulation of conventional method of D-STATCOM

Proposed Method: -

After then this same system is design by using proposed method the simulation is as follow but value of storage capacitor is calculated by equation of given in design of capacitor topic. And also, Lser also not present because by using external storage device if voltage is exceeding from its value then it can provide real power by it and also we can remove a filter inductor [8] In this simulation work same control strategy is used. But reference value is changed and it can reduce. To control reactive power by D-STATCOM sinusoidal current control strategy is used because this strategy is efficient for controlling reactive power for non-linear load.

Input voltage	11KV, 50Hz
Line Parameter	R=0.1ohm L=0.1mH
Transformer	11KV/440V,50Hz, 25KVA
Non-linear load	Diode Rectifier Load= 2KW,1KVAR
Capacitor Rating ,	C1=356uF,C1' C2'=356uF
VSI Parameter	Rser =9 ohm

Table 2 Parameter of Test System

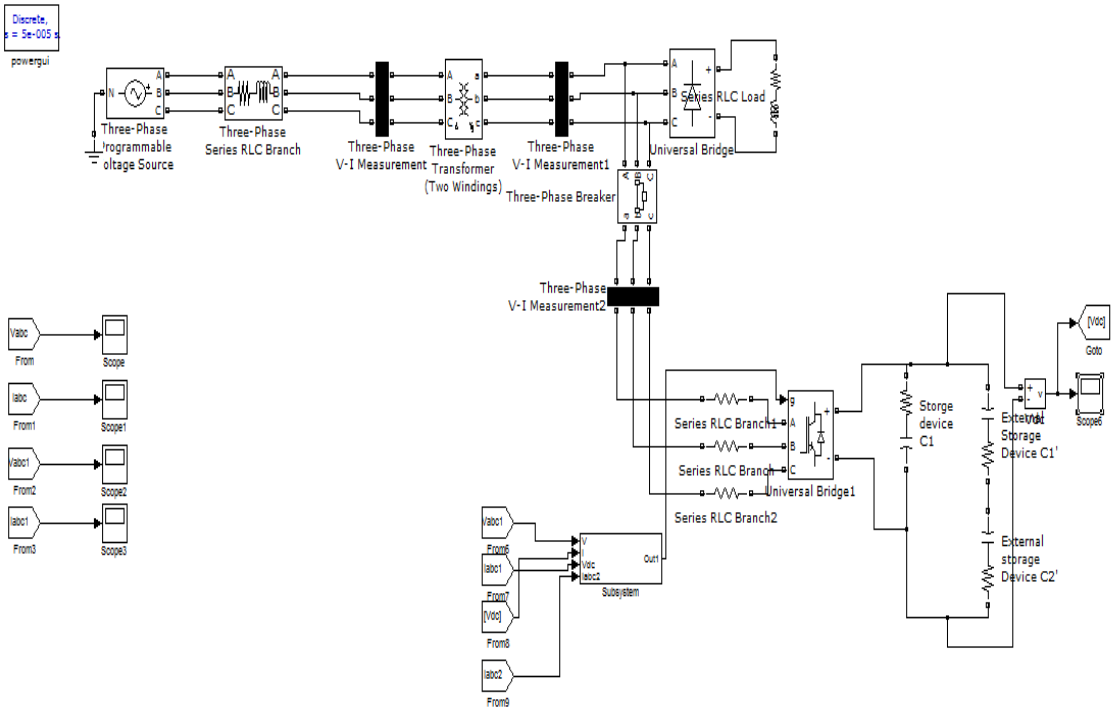
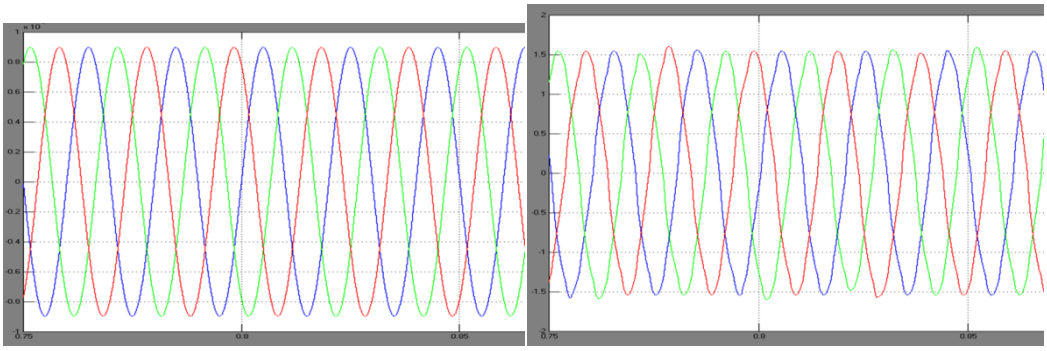


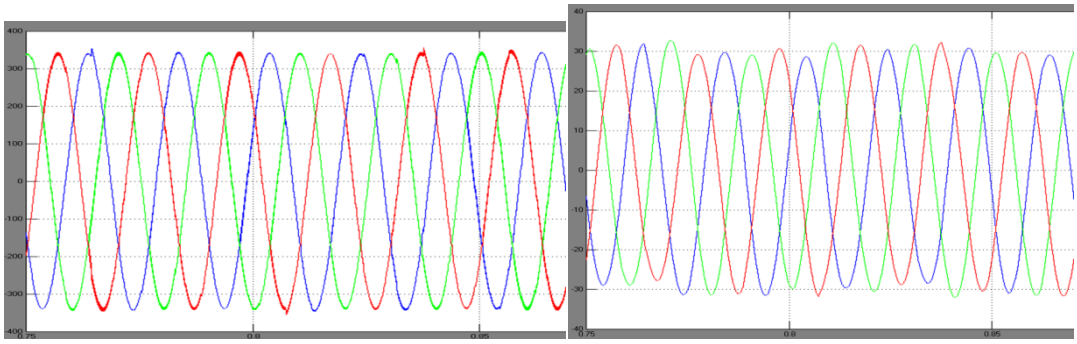
Fig 12 Simulation of Proposed Method

RESULT:-

1. For Conventional Method



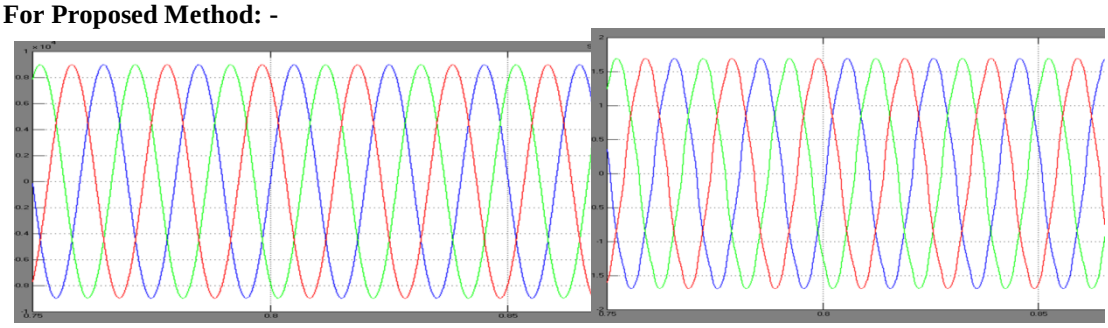
Source Voltage **Source Current**



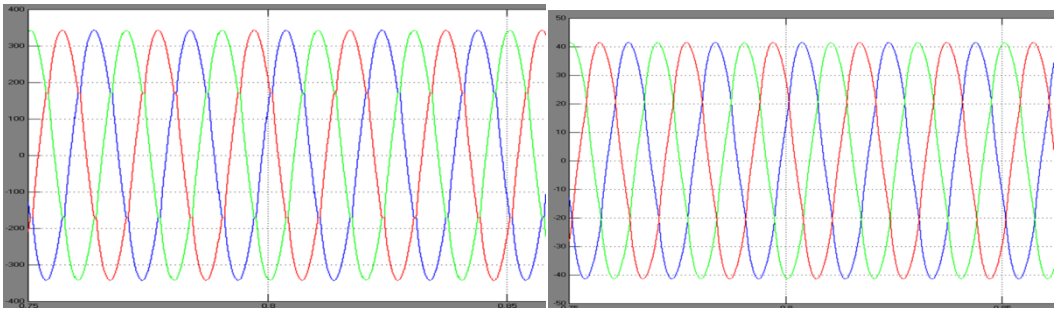
Load Voltage **Load Current**

Fig 13 Results of Conventional Method

2. For Proposed Method: -



Source Voltage Load Current



Load Voltage **Load Current**

Fig 14 Results of Proposed Method

FFT Analysis: -

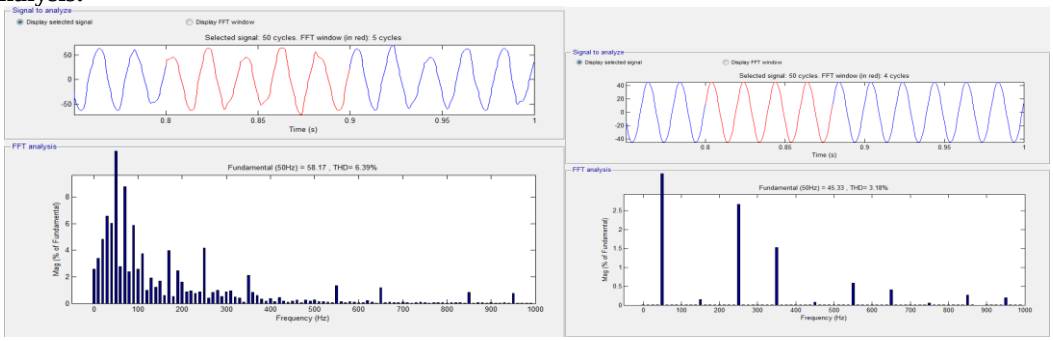


Fig 15 FFT Analysis

Schemes	%THD
With conventional Method	6.39
With Proposed Method	3.18

Table 1 % of THD

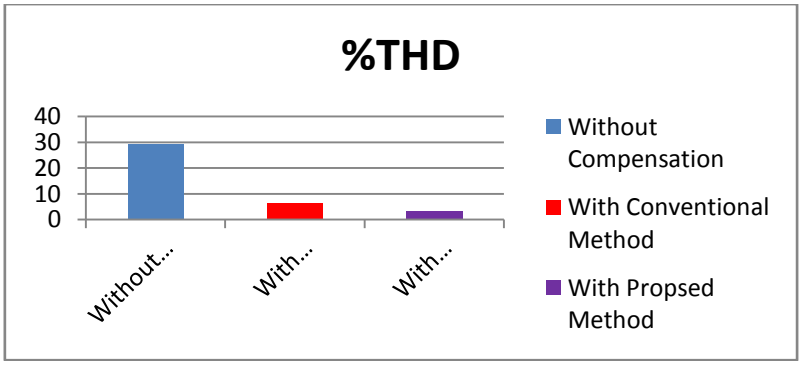


Fig 16 Graph of %THD

CONCLUSION:-

In this work, the investigation on the role of D-STATCOM is carried out to improve the voltage regulation and power compensation in distribution networks with static non-linear loads. The Proposed method can improve non-linearity of non-linear system with reducing size of capacitor without compromising compensation operation. Also, it can reduce cost of system. By using MATLAB software, a result which determines by its simulation we can proved that proposed method can reduce size of capacitor, and also FFT analysis is how it advantageous against conventional by analyzing THD

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