Cascaded Two-Level Inverter-Based Multilevel STATCOM with Fuzzy Logic

J Nagendra Babu[1], Ch Rami Reddy[2]
[1]pursuing M.Tech (EEE), [2]working as Assistant Professor (EEE),
Nalanda Institute Of Engineering and Technology (NIET)Kantepudi(V), Sattenpalli(M),
Guntur (D)-522438, Andhra Pradesh.

Abstract-

This Paper concentrated on the static compensator utilizing a two level cascaded multi level inverter implemented for reactive power compensation. The technique consisting of two level designed inverters are integrated in cascaded manner with help of open ended windings from the three phase transformer. The capacitor acts as a dc-link capacitance which is used to control the generation of voltage from the STATCOM. Here fuzzy logic controller which is used to control and regulate the generation of voltage levels from the STATCOM by the fuzzy rules and conditions. The simulink models are tested and verified within the MATLAB/SIMULINK. The implemented models are controlled and compensated the abnormal conditions to normal conditions. The presence of Fuzzy controller the disturbances normalized which enhances system performances

Keywords — D*C-link voltage balance, multilevel inverter, power quality (PQ), static compensator (STATCOM), Fuzzy Logic Controller*

I. INTRODUCTION

THE utilization of adaptable air conditioning transmission frameworks (FACTS) controllers, for example, static compensator (STATCOM) and static synchronous arrangement compensator (SSSC), is expanding in force frameworks. This is because of their capacity to settle the transmission frameworks and to enhance power quality (PQ) in conveyance frameworks. STATCOM is famously acknowledged as a dependable receptive force controller supplanting ordinary var compensators, for example, the thyristor-exchanged capacitor (TSC) and thyristor-controlled reactor (TCR). This gadget gives receptive force pay, dynamic force swaying damping, gleam constriction, voltage regulation, and so on [1].

By and large, in high-control applications, var pay is accomplished utilizing multilevel inverters [2]. These inverters comprise of an expansive number of dc sources which are normally acknowledged by capacitors. Henceforth, the converters draw a little measure of dynamic energy to keep up dc voltage of capacitors and to repay the misfortunes in the converter. Then again, because of confound in conduction and exchanging misfortunes of the exchanging gadgets, the capacitors voltages are lopsided. Adjusting these voltages is a significant examination challenge in multilevel inverters.

Different control plans utilizing distinctive topologies are accounted for as a part of [3]–[7]. Among the three routine multilevel inverter topologies, course H-extension is the most prominent for static var remuneration [5], [6]. Be that as it may, the previously stated topology requires a substantial number of dc capacitors. The control of individual dc-join voltage of the capacitors is troublesome.

Static var pay by falling routine multilevel two level inverters is an alluring answer for high-control applications. The topology comprises of standard multilevel/two level inverters associated in course through open-end windings of a three-stage transformer. Such topologies are well known in high-power drives [8]. One of the benefits of this topology is that by keeping up uneven voltages at the dc connections of the inverters, the quantity of levels in the yield voltage waveform can be expanded. This enhances PQ [8]. Hence, general control is straightforward contrasted with customary multilevel inverters. Different var remuneration plans taking into account this topology are accounted for in [10]–[12]. In [10], a three-level inverter and two level inverter are associated on either side of the transformer low-voltage winding. The dc-join voltages are kept up by particular converters. In [11], three-level operation is gotten by utilizing standard two-level inverters. The dc-join voltage harmony between the inverters is influenced by the receptive force supplied to the framework.

In this paper, a static var remuneration plan is proposed for a fell two-level inverter-based multilevel inverter. The topology utilizes standard two-level inverters to accomplish multilevel operation. The dc-join voltages of the inverters are managed at awry levels to acquire four-level operation. To check the adequacy of the proposed control procedure, the reenactment study is completed for adjusted and lopsided supply-voltage conditions. A research center model is likewise created to accept the reenactment results.

From the nitty gritty reenactment and experimentation by the creators, it is found that the dc-join voltages of two inverters breakdown for certain working conditions when there is a sudden change in reference current. To research the conduct of the converter, the complete element model of the framework is created from the equal circuit. The model is straight zed and exchange capacities are inferred. Utilizing the exchange capacities, framework conduct is investigated for diverse working conditions.

II. CASCADED TWO-LEVEL INVERTER-BASED MULTILEVEL STATCOM

Fig. 1 demonstrates the force plan fantastic considered in this paper [13]. Fig. 2 demonstrates the circuit innovation of the fell two-level inverter-based multilevel STATCOM utilizing standard two-level inverters. The inverters are related on the low-voltage (LV) side of the transformer and the high-voltage (HV) side is associated with the framework.

The dc-join voltages of the inverters are kept up steady and balance files are controlled to accomplish the required goal. The proposed control plan is gotten from the air conditioner side of the comparable circuit which is appeared in Fig. 3.

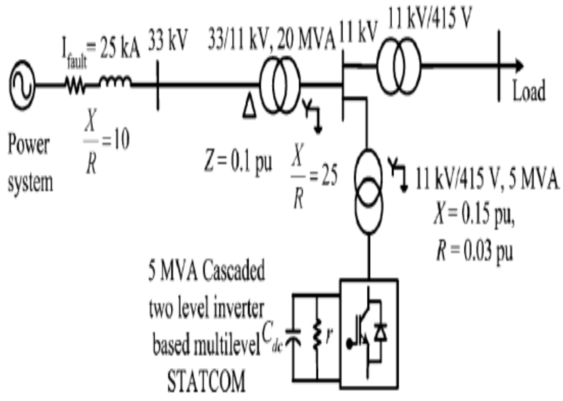


Fig. 1. Power System and the STATCOM Model.

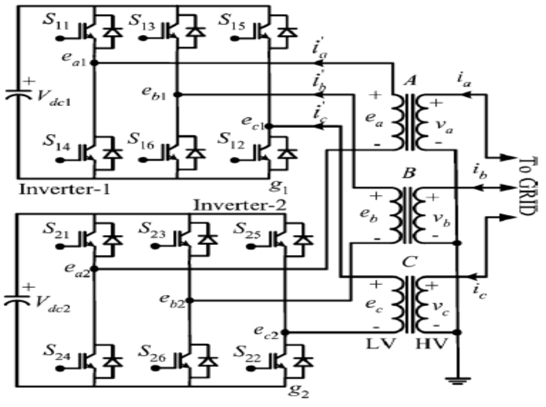


Fig. 2. Cascaded Two-Level Inverter-Based Multilevel

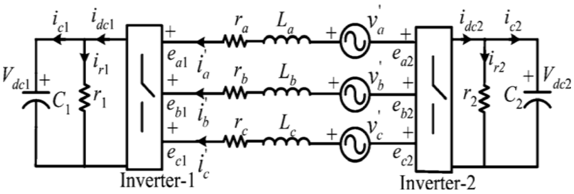


Fig. 3. Equivalent Circuit Of The Cascaded Two-Level Inverter-Based Multilevel STATCOM.

In the figure, Va, Vb and Vc are the source voltages alluded to LV side of the transformer, ra, rb and rc are the resistances which speak to the misfortunes in the transformer and two inverters, La, Lb and Lc are spillage inductances of transformer windings, ea1, eb1, ec1 and ea2, eb2, ec2 are the yield voltages of inverters 1 and 2, respectively.r1, r2 are the spillage resistances of dc-connection capacitors C1 and C2, separately.

Accepting ra = rb = rc = r, La = Lb = Lc=L and applying KVL on the air conditioner side, the dynamic model can be determined utilizing as

$$\begin{matrix} \frac{di_a^1}{dt} \\ \frac{di_b^1}{dt} \\ \frac{di_c^1}{dt} \end{matrix} = \begin{matrix} \frac{-r}{L} & 0 & 0 \\ 0 & \frac{-r}{L} & 0 \\ 0 & 0 & \frac{-r}{L} \end{matrix} * \begin{matrix} i_a^1 \\ i_b^1 \\ i_c^1 \end{matrix} + \frac{1}{L} \begin{matrix} V_a^1 - (e_{a1} - e_{a2}) \\ V_b^1 - (e_{b1} - e_{b2}) \\ V_c^1 - (e_{c1} - e_{c2}) \end{matrix}$$

Comparison (1) speaks to the numerical model of the fell two-level inverter-based multilevel STATCOM in the stationary reference outline. This model is changed to the synchronously turning reference outline. The – tomahawks reference voltage segments of the converter ed* and eq* are controlled as [14]

$$e_d^* = -x1 + \omega L i_q^{'} + v_d^{'}$$
$$e_q^* = -x1 + \omega L i_d^{'} + v_q^{'}$$

Where Vd' is the - hub voltage segment of the air conditioner source and id', iq' are dq - tomahawks current segments of the fell inverter, individually. The synchronously turning casing is adjusted to source voltage vector so that the q-segment of the source voltage Vq' is made zero. The control parameters x1 and x2 are controlled as takes after:

$$X1=(k_p^1 + \frac{K_i^1}{s})(i_d^* - i_q^{'})$$
$$X2=(k_p^2 + \frac{K_i^2}{s})(i_d^* - i_q^{'})$$

The -axis reference current i*d is achieved by

$$i_d^* = k_p^3 + \frac{Ki3}{s})[(V_{dc1}^* + V_{dc2}^*) - (V_{dc1} + V_{dc2})]$$

Where V*dc1, V*dc2 and Vdc1, Vdc2 are the reference and real dc-join voltages of inverters 1 and 2, individually.

The q –axis reference current i*q is acquired either from an external voltage regulation circle when the converter is utilized as a part of transmission-line voltage bolster or from the heap if there should arise an occurrence of burden remuneration.

A. Control Strategy

The control unit outline is appeared in Fig. 4. The square flags cos wt and sin wt are created from the stage bolted circle (PLL) by method for three-stage supply voltages (Va, Vb, Vc). The converter streams (i'a, i'b, i'c) are changed to the synchronous turning reference casing utilizing the unit signals.

The exchanging recurrence swell in the converter current segments is dispensed with utilizing a low-pass channel (LPF). From (V*dc1+Vdc*2) and i*q circles, the controller creates d-q tomahawks reference voltages, e*d and e*q for the fell inverter.

With these reference voltages, the inverter supplies the sought receptive current (i'q) and draws required dynamic current (i'd) to manage complete dc-join voltage V*dc1 + V*dc2.

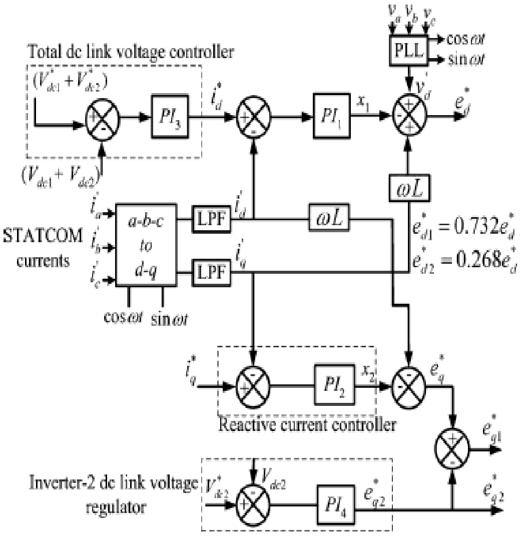


Fig. 4. Control Block Diagram.

B. DC-Link Balance Controller

The dynamic force exchange between the source and inverter relies on upon δ and is generally little in the inverters supplying var to the matrix. Henceforth, can be thought to be corresponding to e_q . Consequently, the - hub reference voltage part of inverter-2 e_{q2}^* is inferred to control the dc-join voltage of inverter-2 as is derived to control the dc-link voltage of inverter-2 as

$$e_{q2}^* = (k_p^4 + \frac{Ki4}{s})[(V_{dc1}^* + V_{dc2}^*)$$

The - hub reference voltage part of inverter-1 e_q1^* is gotten as

$$e_{q1}^* = e_q^* - e_{q2}^*$$

The dc-join voltage of inverter-2 V_dc2^ is controlled at 0.366 times the dc-join voltage of inverter-1V_dc1^ . It results in four-level operation in the yield voltage and enhances the consonant range. Communicating dc-join voltages of inverter-1 and inverter-2 regarding complete dc-join voltage, Vdc as

$$V_{dc1}.=0.732V_{dc}.$$
$$V_{dc2}.=0.268V_{dc}.$$

Since the dc-join voltages of the two inverters are directed, the reference - pivot voltage part e_d^* is partitioned in the middle of the two inverters in extent to their individual dc-join voltage as

$$e_{d1}^* = 0.732 e_d^*$$
$$e_{d2}^* = 0.0.268 e_d^*$$

Diminishes. Hence, power exchange to inverter-2 increments, when it decreases for inverter-1. The force exchange to inverter-2 is straight measured, when for inverter-1, it is controlled by implication. Along these lines, through unsettling influences, the dc-join voltage of inverter-2 is restored to its reference fatly contrasted with that of inverter-1. Utilizing and, the reference voltages are created in stationary reference outline for inverter-1 and utilizing and for inverter-2.

The reference voltages produced for inverter-2 are in stage restriction to that of inverter-1. From the reference voltages, door signs are produced utilizing the sinusoidal heartbeat width regulation (PWM) strategy. Since the two inverters' reference voltages are in stage resistance, the prevalent symphonies show up at twofold the exchanging recurrence.

C. Unbalanced Conditions

System voltages are uneven because of topsy-turvy blames or unequal burdens. Subsequently, negative-arrangement voltage shows up in the supply voltage. This reasons a twofold supply recurrence part in the dc-join voltage of the inverter. This twofold recurrence segment infuses the third symphonious part in the air conditioner side. In addition, because of negative-arrangement voltage, expansive negative-succession current moves through the inverter which may bring about the STATCOM to trip.

In this manner, amid unbalance, the inverter voltage is controlled in a manner that either negative-succession current streaming into the inverter is wiped out or lessens the unbalance in the framework voltage. In the last case, STATCOM needs to supply expansive streams subsequent to the interfacing impedance is little. This may prompt stumbling of the converter. The negative-grouping reference voltage parts of the inverter and are controlled like positive-succession segments in the negative synchronous turning edge as

$$e^{*}_{dn} = -x3 + (-\omega L i'_{qn})_{+} v'_{dn}$$

$$e^{*}_{qn} = -x4 + (-\omega L i'_{dn})_{+} v'_{qn}$$

Where V'dn, V'qn are - tomahawks negative-arrangement voltage segments of the supply and I'dn, iqn are d–q tomahawks negative-grouping current parts of the inverter, separately. The control parameters and are controlled as takes after:

$$\text{X3=(}k_p^5 + \frac{K_i^5}{s})(i^{*}_{do} - i'_{do})$$

$$\text{X4=(}k_p^6 + \frac{K_i^6}{s})(i^{*}_{qo} - i'_{qo})$$

The reference values for negative-succession current segments i*dn and i*qn are set at zero to piece negative-arrangement current from moving through the inverter.

D. Stability Analysis

Considering the dc side of the two inverters in Fig. 3, the complete progress of the framework are determined in the Appendix. The exchange capacity is as per the following:

$$\frac{\Delta}{\Delta}\frac{\hat{V_{dc1}}(s)}{\hat{\delta_1}\ (S)} = \frac{num1(S)}{den(S)}$$

$$\frac{\Delta}{\Delta}\frac{\hat{V_{dc2}}(s)}{\hat{\delta_2}\ (S)}$$

And the transfer function

$$\frac{\Delta}{\Delta}\frac{\hat{V_{dc2}}(s)}{\hat{\delta_2}\ (S)} = \frac{num2(S)}{den(S)}$$

Where and are given in the Appendix.

From the exchange capacities (26) and (27), it can be watched that the denominator is an element of resistances(R,R1,R2), reactance's,(Xt,Xc1,Xc2) and regulation indices(m1,m2) and . In spite of the fact that the denominator incorporates a working condition term, the item is constantly positive. Henceforth, the shafts of exchange capacity dependably lie on the left 50% of the - plane.

Nonetheless, numerators of the exchange capacities are elements of the working states of . The positions of zeros fundamentally rely on upon . The indication of these variables changes as indicated by the method of operation.

Thusly, zeros of the exchange capacities movement to the right 50% of the - plane for certain working conditions. This framework is said to be non-least stage and there is a farthest point on achievable element reaction. The framework may show oscillatory insecurity when there is a stage change in reference for high controller additions. In this way, the controller increases ought to be planned suitably to keep away from the shakiness. This conduct is like that of the two-level inverter-based STATCOM.

III.PROPOSED SIMULINK SYSTEM

The implemented simulink model consisted of three phase voltage source it is acts as a supply system which is distributed the power to load by utilizing the distribution transformers at normal and abnormal conditions. In any distribution mechanism the efficiency levels are reduced due to the presence of disturbances which leads to reduced power quality in the networks.

To improve the power quality levels in the system facts technology provided in this model. The model designed with cascaded two level STATCOM is interconnected in parallel in distribution network. The block diagram which is shown in figure 5.

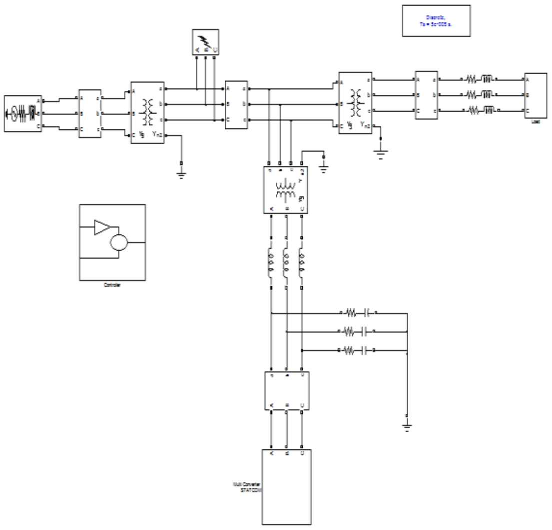


Fig 5: Simulink Model for Two Level STATCOM Connected Distribution System

The statcom consisted the two voltage source converter which is used identify the faulted conditions in the networks by the controlling strategies.

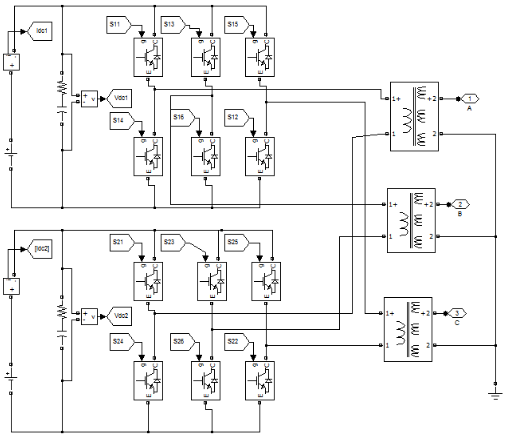
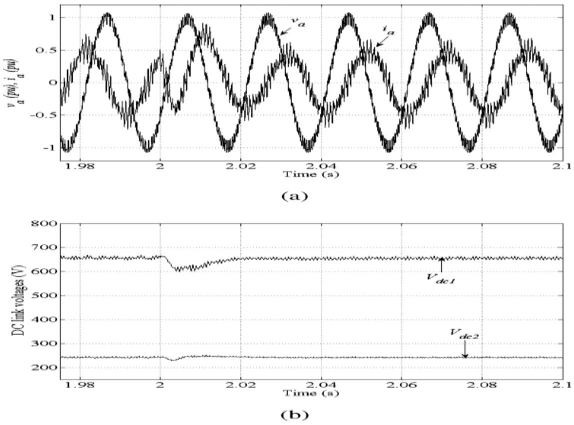


Fig 6: Two Levels STATCOM MODEL

Each voltage source converter having six IGBTS to detect the faults and to compensate the faults by proper firing pulses from the controller. The dc-link capacitance which is used to charge the energy at normal conditions and to release energy levels at abnormal conditions.

It is also utilized inductor to mitigate the ripple contents in the networks and also to absorb the unnecessary voltage from the network. Finally it will deliver the required relevant power to load at faulted conditions by Fuzzy Logic Controller strategy to enhance the power quality in power systems. The statcom representation is given in the below figure6.



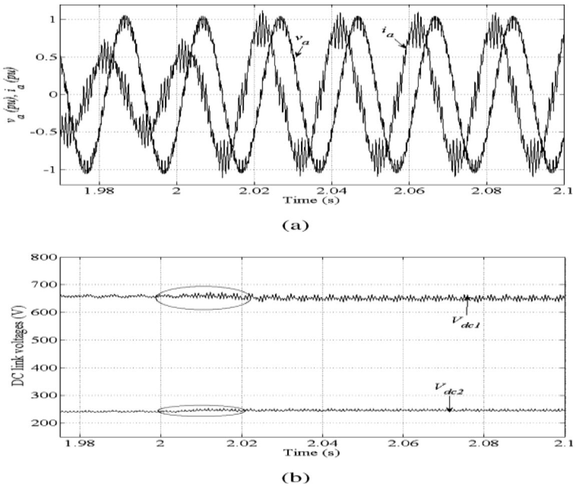
(a)

(b)

Fig. 7. Reactive Power Control. (A) Source Voltage and Inverter Current. (B) DC-Link Voltages of Two Inverters.

A. *Reactive Power Control:*

In this case, reactive power is directly injected into the grid by setting the reference reactive current i ∗q component at a particular value.



(a)

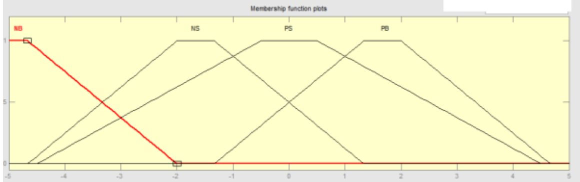
(b)

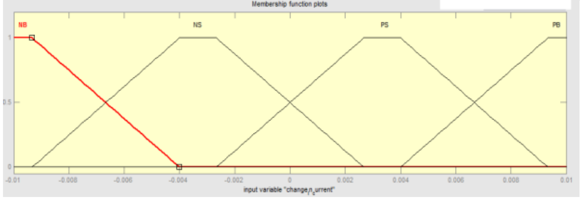
Fig. 8. Load Compensation. (A) Source Voltage and Inverter Current. (B) DC-Link Voltages of Two Inverters.

Initially, i ∗q is set at 0.5 p.u. At t=2.0 s, i ∗ q is changed to 0.5 p.u. Fig. 7(a) shows the source voltage and converter current of the phase. Fig. 7(b) shows the dc-link voltages of two inverters. From the figure, it can be seen that the dc-link voltages of the inverters are regulated at their respective reference values when the STATCOM mode is changed from capacitive to inductive. Moreover, the dc-link voltage of inverter 2 attains its reference value faster compared to that of inverter 1.

B. *Load Compensation:*

In this case, the STATCOM compensates the reactive power of the load. Initially, STATCOM is supplying a current of 0.5 p.u. At t=2.0 s, the load current is increased so that STATCOM supplies its rated current of 1 p.u. Fig. 8(a) shows source voltage and converter current, while Fig. 8(b) shows the dc link voltages of two inverters. The dc-link voltages are maintained at their respective reference values when the operating conditions are changed. The fig 9 and 10 shows the membership functions coordination with fuzzy rules for the proposed system.





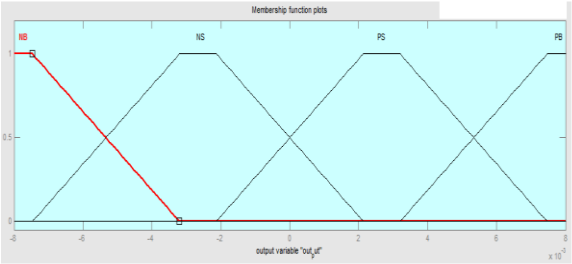


Fig. 9: Membership Function: (A) Input*δp* , (B) Input*δi*, And (C) Output*δd*.

∆P/ ∆E	**NB**	**NS**	**PS**	**PB**
NB	PB	PB	NB	NB
NS	PS	PS	NS	NS
PS	NS	NS	PS	PS
PB	NB	NB	PB	PB

Fig 10: Fuzzy Rules

C. Operation During Fault Condition:

In this case, a single-phase-to-ground fault is created at t=1.2 s, on the phase of the HV side of the 33/11- kV transformer. The fault is cleared after 200 ms. Fig. 11(a) shows voltages across the LV side of the 33/11-kV transformer.

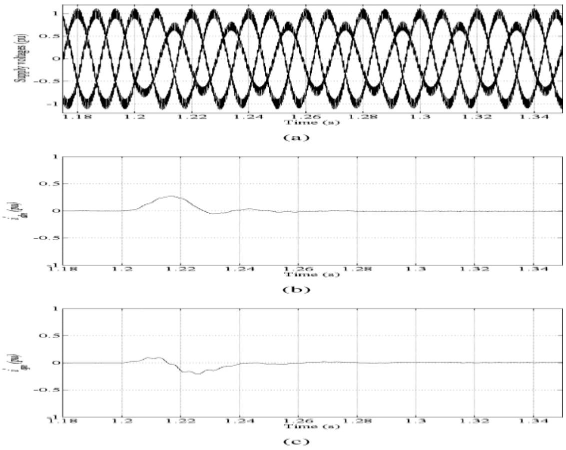
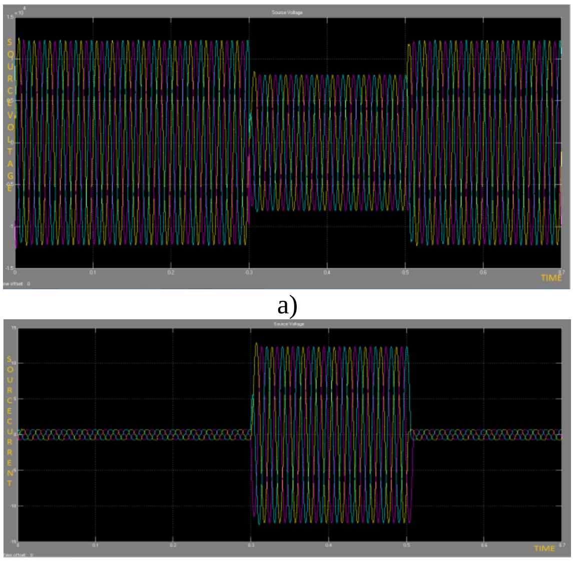


Fig. 11. Operation During Fault. (a) Grid Voltages on the LV Side of the Transformer. (b) -axis Negative-Sequence Current component i 'qn . (c) -axis Negative-Sequence Current Component i'dn .

Fig. 11(b) and (c) shows the d-q axes components of negative-sequence current of the converter. These currents are regulated at zero during the fault condition.

D. Simulation Results:

This waveform represents under abnormal conditions. In this network the total simulation time which is operated 0.7sec. in this the problem is initiated from 0.3 to 0.5. The below wave form which is related to the source side results.

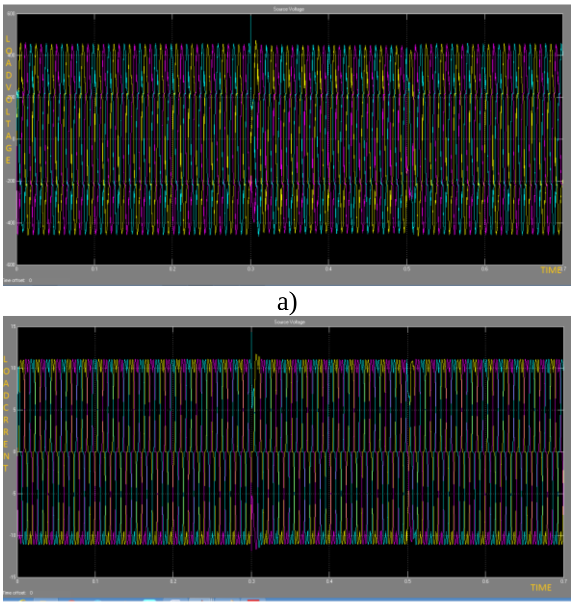


a)

b)

Fig 12: A) Results Of Supply Side Voltage And B) Current Measurement

The waveform which is related to the load side voltage and current. These are maintained constant voltage and constant current because these are related after fault compensation from the cascaded two levels STATCOM.



a)

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Fig 13: A) Results Of Load Side Voltage And B) Current Measurement

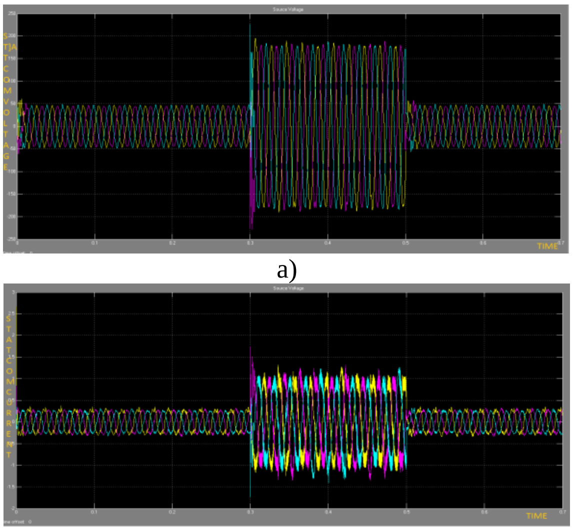

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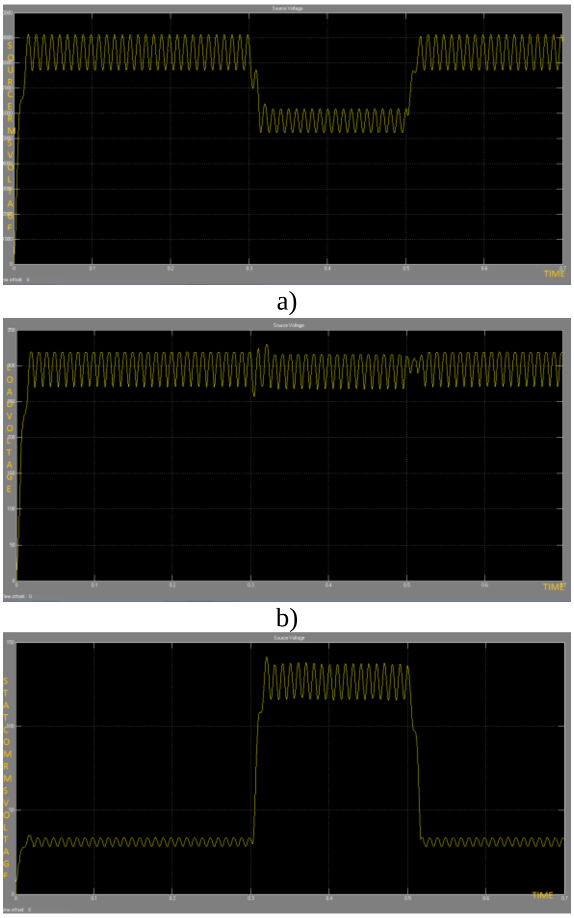
Fig 14: A) Results Of STATCOM Voltage And B) Current Measurement



a)

b)

c)

Fig 15: A) Results of R.M.S Voltage Waveforms at Source, B) Load and C) STATCOM

Parameters	Ratting
Supply Voltage	11Kv
Load Voltage	400V
Dc link Voltage 1	659V
Dc link voltage 2	241V

Table 1: Existed Simulation Results

Parameters	Ratting
Supply Voltage	15Kv
Load Voltage	440V
Dc link Voltage	900V
Load Active power	2500Kw
Load Reactive Powers	1000 Kvar

Table 2: Proposed Simulation Results

The waveforms which are related to the voltage and currents from the STATCOM under faulted conditions. The generation these voltage and currents are injected to the load side to compensate the active and reactive powers to enhance the power quality levels in the distribution networks.

The waveforms which are related to R.M.S voltages of source side, load side and statcom side. We will conclude that in the load side the problems of power quality issues are compensated by STATCOM with the help of fuzzy logic controller.

IV. CONCLUSION

This paper concentrated on the voltage imbalance problem main issue in the distributed lines which leads to inaccurate power quality. The paper implemented STATCOM based multi level cascaded two level inverter for the distribution. Here the reactive power compensation is achieved by function of STATCOM with dc link capacitance under abnormal conditions.

The simulink models which are tested and verified within the MATLAB/ SIMULINK under normal and abnormal conditions by taking the reference current controlling strategies.

The model involved with number of transfer functions which can improves the stability responses. The presence of fuzzy logic controller can minimize the ripple content by calculating effective gains which are represented in the fuzzy rules. The STATCOM operated with current controlling principles which reduce the harmonics and finally power transfer function is achieved.

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