Performance Evaluation of Static Transfer Switch

RAMESH PACHAR[1]
Electrical Engineering Department,
SKIT, M&G, Jaipur-302025
INDIA
hodee@mail.skit.ac.in,
http://www.skit.ac.in,

HARPAL TIWARI[2]
Electrical Engineering Department,
MNIT, Jaipur-302025
INDIA
harpaltiwari@yahoo.co.in
http://www.mnit.ac.in

Abstract: - This paper investigates the performance of GTO switches based STS system for improving the power quality of a sensitive three-phase RL load. Performance of the proposed system is compared with IEEE Benchmark System (STS-1). Extensive simulations are carried out to validate the use of GTO switches in medium voltage systems to achieve a lesser transfer time in network reconfiguration. Performance evaluation of GTO based STS system is carried out under various faults/disturbance conditions. Simulations are performed using simulink tool of MATLAB software package.

Key-Words: - Power Quality, Static Transfer Switch, Preferred Source, Alternate Source, Transfer Time, Detection Time, Sensitive load, Control Logic.

1 Introduction

In past few years power quality has gained a lot of importance among researchers due to its implications on sensitive residential and industrial loads. Availability of semiconductor devices at low and medium voltage levels has lead to development of *custom power devices* which provides much faster and efficient control in distribution system for network compensation and reconfiguration applications[1]. A STS is a network reconfiguration device and is widely used for power quality improvement of sensitive loads. It does so by flexibly changing the distribution configuration [1]-[5]. STS basically comprises of two sources namely preferred source and alternate source, a control logic scheme and a sensitive load whose protection is desired against the power quality disturbances. The performance of a STS system is analyzed with respect to transfer time. Definitions of detection, transfer and total load transfer times according to IEEE standards [1] are as follows; *Detection time (t_d):* The difference between the time at which a disturbance occurs and the time it is detected. *Transfer time (t_f):* The difference between the times at which a disturbance is detected and the time at which load is transferred. *Total load transfer time (t_t):* The sum of detection time and transfer time. With GTO based STS systems almost constant transfer time can be obtained and the total load transfer time can be reduced considerably [8]. A precise control scheme is of utmost importance for proper and reliable functioning of a STS system. Employed detection scheme must be capable of providing faster detection of disturbances. Suitable algorithms are available for precise recognition of power quality disturbances [9]-[10]. The basic structure of a single-phase STS is shown in Fig.1.

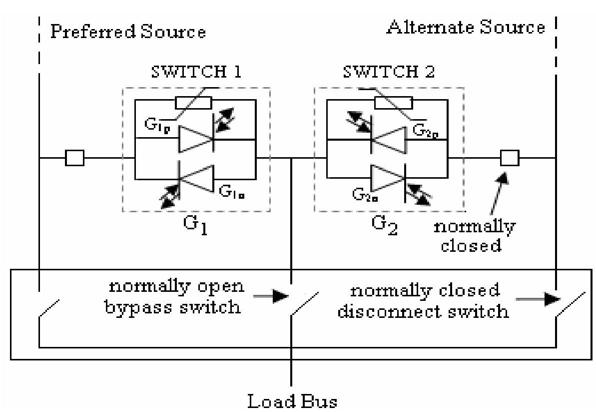

Fig.1: Basic structure of a single-phase STS

Section 2 describes the principle of operation of a three-phase STS system [1]-[3] including the functioning of control strategy employed for detection of power quality problem. Section 3 presents the simulations and analysis for (1) power quality improvement of sensitive three-phase R-L load and (2) a comparison between IEEE benchmark system(STS-I) and GTO equivalent of STS-I (configured as per parameters of IEEE Benchmark System STS-1).All relevant waveforms are also included for discussions. Results, scope of future work and conclusions are presented in sections 4, 5 and 6 respectively.

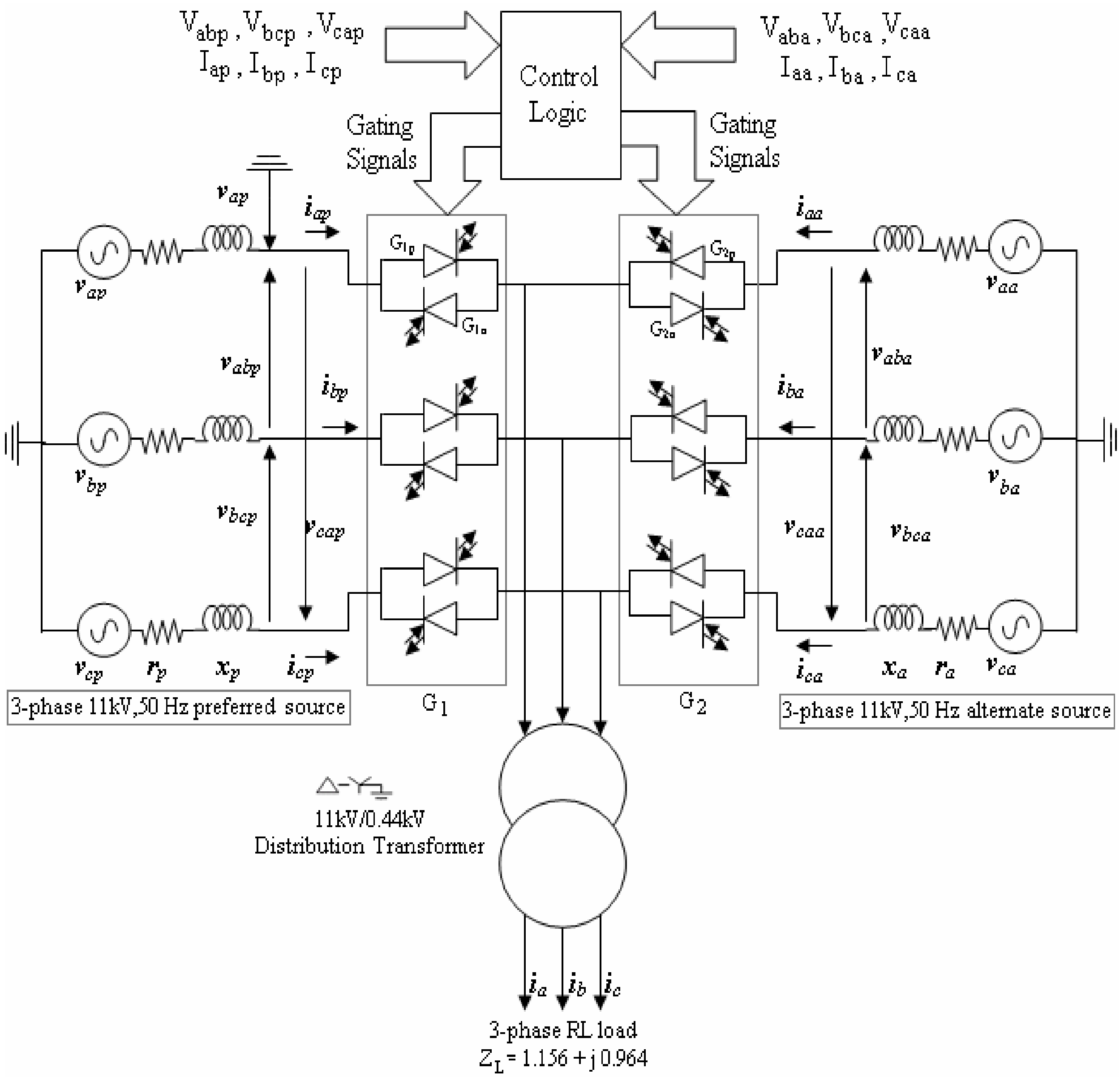

Fig. 2: Power Circuit of Three Phase STS System

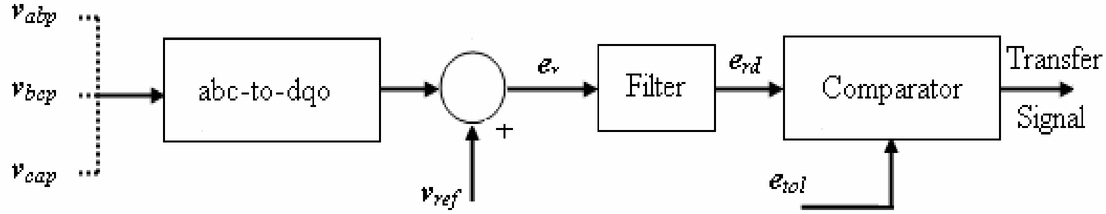

Fig. 3: Voltage Detection Scheme

Derived conclusions are presented in section 5. Simulation model is developed using the simulink and simpowersystems utilities of MATLAB.

Disturbances (sag/swells) are created by intermediate pausing of simulation and implementing necessary changes in the source voltage values whereas faults are implemented with help of fault block present in the elements library of simpowersystems block set.

2 Principle of Operation

The power circuit of STS system is shown in Fig.2. The system is composed of:

- A load which is sensitive to variations of utility supply,
- Two independent sources one of which is the preferred one and the other is the alternate one,
- Two GTO blocks G_1 and G_2 which connect the load to the power sources and
- Control logic to monitor voltage quality of both sources, detect voltage fluctuations in the system (detection process), compare the two sources, and perform a load transfer from one source to the other one if needed. STS blocks G_1 and G_2 each contain three modules corresponding to the three phases of the system. Each GTO module includes two anti-parallel GTO switches (G_{1p}/G_{1n} and G_{2p}/G_{2n}).

Under normal operating conditions, i.e., when the preferred source meets load voltage requirements, the control logic trigger only the thyristors of G_1. If the preferred source doesn't meet voltage requirements, the control logic will transfer the load to the alternate source if it is in a better condition than the preferred one. This is achieved by removing gating signals from thyristors G_1 and triggering thyristors of switch G_2. In case of voltage recovery, the load is transferred back to the preferred source. Input signals in Fig. 2 are those required for controlling the STS operation.

2.1 Three Phase STS System

Three phase STS system is composed of power circuit and control logic [1], as shown in Fig.2. It consists of two 11 kV distribution feeders connected with two 11 kV three phase sources. The voltage sources are represented by ideal sources in series with lumped resistances and inductances. The combination of three-phase RL load and distribution transformer (11 kV/0.44 kV) is connected to sources through GTO blocks G_1 and G_2. Control logic of STS consists of voltage detection and gating strategy sections (as shown in Fig.3 and Fig.4). Inputs to control circuit are the voltages and currents required to detect disturbances and to initiate transfer process.

(1) Voltage Detection Strategy

Fig.3 refers to a rather common detection technique based on Park transformation. The instantaneous three-phase voltages $V_a(t), V_b(t)$ and $V_c(t)$ are transformed into a fixed two-axis coordinate system, called αβ-coordinate system, as in equation *(1)*;

$$\begin{bmatrix} V_\alpha(t) \\ V_\beta(t) \\ V_0(t) \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 1\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} ------(1)$$

Where $V_0(t)$ *is* the zero-sequence voltage component, which will no longer be considered. The voltage vector thus obtained is further transformed into a rotating *dq*-coordinate system, according to

$$\underline{V}^{(dq)}(t) = e^{-j\theta(t)} \underline{V}^{(\alpha\beta)}(t) ------(2)$$

the equation:

$$\theta(t) = \theta(0) + \int_0^t \omega(\xi) d\xi ------(3)$$

Where $\theta(t)$ is the transformation angle, calculated as Finally the amplitude of supply vector is calculated

$$V_{dq} = \sqrt{V^2{}_d + V^2{}_q} ------(4)$$

as indicated by equation no. *(4)* and is compared with the reference value to identify a disturbance. The error e_r is passed through a second order mid reject filter, which attenuates impact of voltage transient. The filter output e_{rd} is then compared to a voltage change tolerance limit (e_{tol} *-10 % of* V_{ref}). Output of the comparator is a transfer signal, which initiates the transfer process if the preferred source fails [2].The output of detection scheme is a binary signal. A low (0) value indicates healthy condition of preferred source whereas high (1) value indicates a disturbance and initiates the transfer process.

(2) Gating strategy

Fig.4 shows the gating scheme. The gating strategy is composed of three identical sets of logic for the three phases of the STS system.

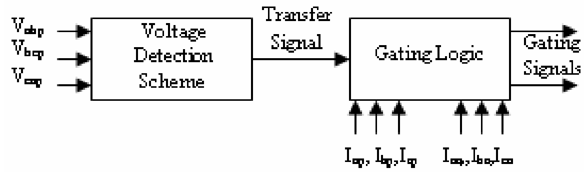

Fig.4: Gating Scheme

It provides selective gating pattern to GTO switches which results in a fast load transfer process and prevents source paralleling. The selective gating pattern is based on the transfer signal. If the transfer signal is low then the gating pattern turns on the preferred side switch and turn off GTO's of the alternate side switch. In normal operation, the preferred source delivers power to sensitive load. When a fault or voltage sag occurs on preferred side, responding to transfer signal the gating pattern generation circuit stops firing pulses to the preferred side switch and triggers the alternate side switch.

3 Simulations and Analysis

Extensive simulations are carried out to study and analyze the performance of proposed system for power quality improvement of a sensitive R-L load against various disturbances (sag/swell/faults). Next a three-phase GTO equivalent to IEEE Benchmark STS-1[2](which provides guidelines for digital computer simulations of STS systems) is obtained and its performance is compared with STS-1 system. A tolerance of 10% (deviation of source voltage from nominal rms value) has been considered for entire simulation studies. MATLAB simulation circuit is shown in Fig.5.

3.1 Power Quality Improvement of R-L load

The simulation circuit is prepared as per power circuit shown in Fig.2. Different cases of disturbance in preferred source are considered out of which three cases: (1) a L-G fault on phase 'a' of preferred source (2) a L-L fault involving phases 'a' and 'b' of preferred source and (3) three-phase sag are discussed in detail. Results are tabulated in Table2. The STS system parameters are shown in Table 1.

Table 1: System Parameters

System Quantities	Values
System frequency	50 Hz
Preferred source	11 kV(rms),phase angle $0°$
Alternate source	11 kV(rms),phase angle $0°$
Preferred feeder and source	Impedance: 0.45 + j3.0Ω / ph
Alternate feeder and source	Impedance: 0.45 + j3.0Ω / ph
Sensitive RL Load	3-ph load : 1.156 + j0.964 Ω
Distribution transformer	11 kV / 0.44 kV, Delta-Star, with neutral grounded

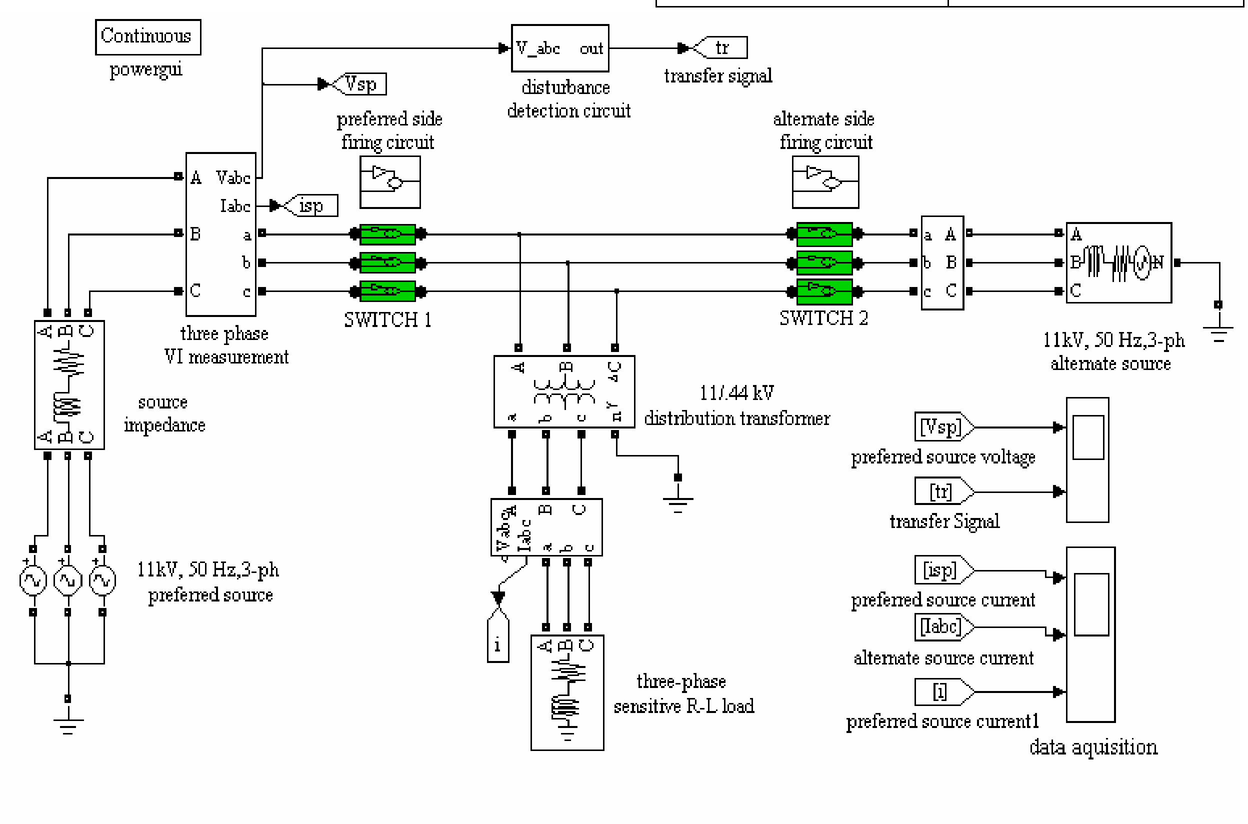

Fig.5: Simulink model of three-phase STS system

GTO Specifications:
$R_{on} = 0.01\ \Omega$, Forward voltage $V_f = 1$ V
Current 10% Fall Time $T_f = 10\mu s$
Current Tail Time $T_t = 20\ \mu s$
Snubber Circuit Parameters:
Resistance $R_s = 5000\ \Omega$, Capacitor $C_s = 0.05\ \mu F$.
Parameters of Mid Reject Second Order Filter:
Cutoff Frequency = 5 kHz
Damping Ratio z = 0.8

3.1.1 Simulations (RL load)

Case1: *When L-G fault occurs on phase 'a' of preferred source:*

In this case, a single line to ground fault occurs at time 0.21562 sec. The fault is detected at time 0.21783 sec. The detection time is 2.21 ms. Transfer time is 0.05 ms, which in turn results in a total load transfer time of 2.26 ms. The peak value of the 'dqo' transformed voltage of faulted phase and transfer signal are shown in Fig.6. As soon as the fault is detected the control logic transfers the sensitive R-L load to alternate source after a suitable delay ensuring turn-off of preferred side switch. The system behavior is depicted in Fig.7.

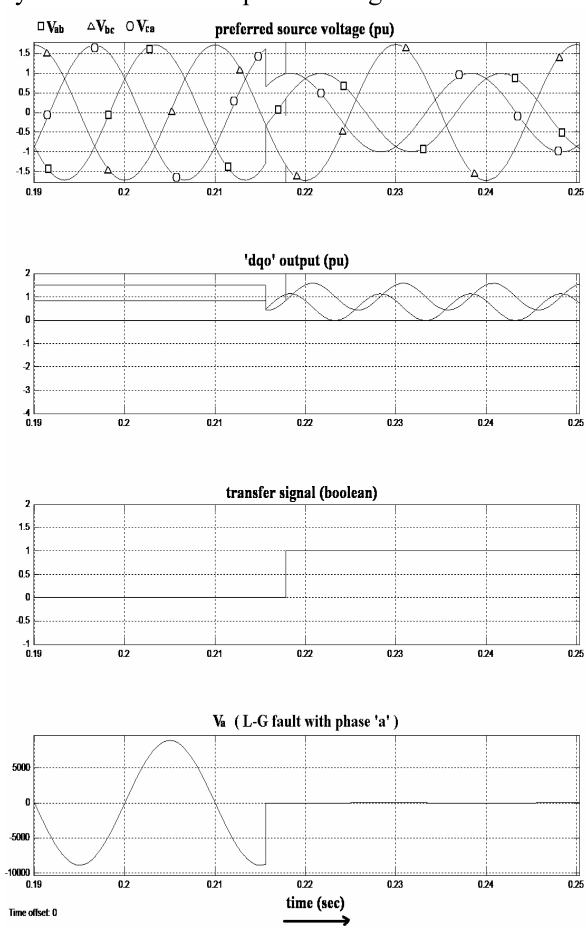

Fig.6: Source voltage and transfer signal

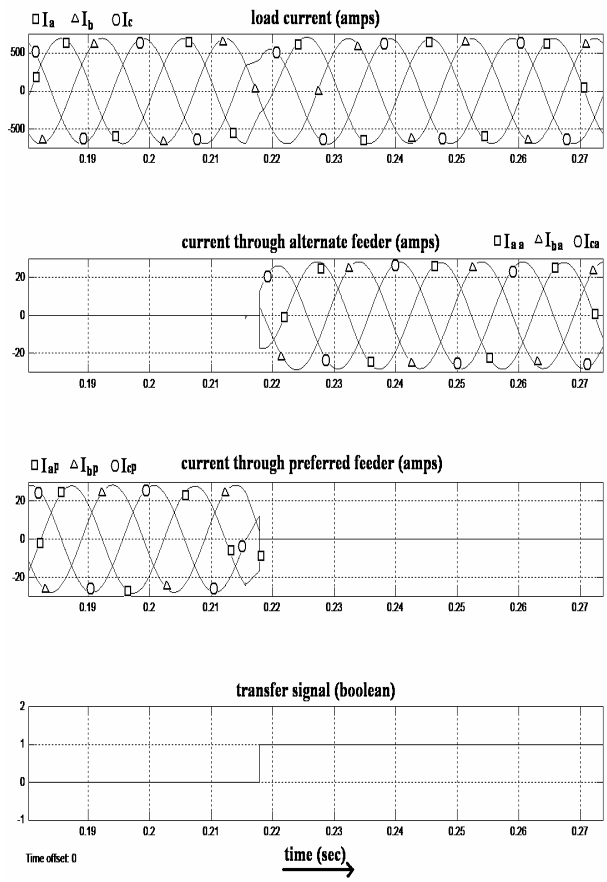

Fig.7: Current through load

Case2: *When L-L fault involving phases 'a' and 'b' occurs on preferred side feeder:*

In this case, the behavior of GTO based three phase STS system is discussed when a L-L fault occurs in the preferred feeder at time 0.2156 sec. The fault is detected at time 0.2218 sec. The detection time is6.2 ms. Load is transferred to alternate source at t=0.22185 seconds giving a transfer time of 0.05 ms. The total load transfer time in this case comes out to be 6.25 ms. The system behavior is depicted in Fig.8 and Fig.9. Even though the disturbance in this case is severe than previous one but the time taken by detection scheme is more. This indicates the dependency of detection time on point-on- wave where fault has initiated and also on other parameters like difference in feeder impedances and filter parameters. The choice of filter has considerable effect on performance of detection scheme. A high value of damping factor will reduce detection time but scheme will become more prone to transients. On the other hand choosing a larger value for damping will result in delayed detection. The solution to this problem is not straightforward. For choosing an optimum damping factor a compromise with both situations is must.

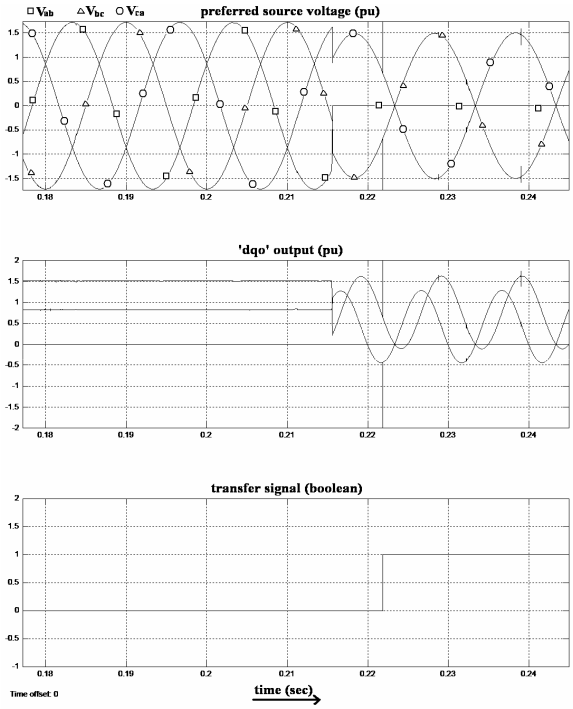

Fig.8: Occurrence and detection of fault

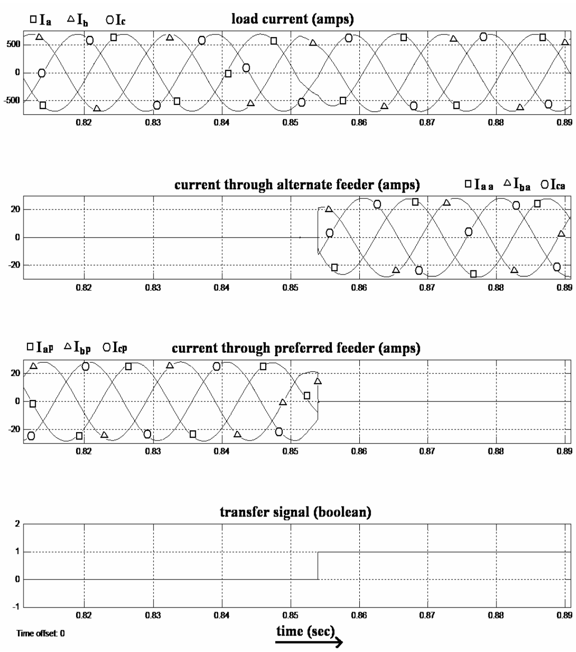

Fig.9: Detection of fault and load transfer

Case3: *When three phase sag (35%) occurs in preferred source voltage*

Fig.10 shows sag (35%) in preferred source voltage. Sag occurs at time 0.8513 seconds and it is detected at 0.8539 sec. Load is transferred to alternate source at 0.85395 sec. Detection and transfer time for this case are 2.6 and 0.05 ms respectively. This result in a total load transfer time of 2.65 ms. Fig.11 shows all relevant waveforms.

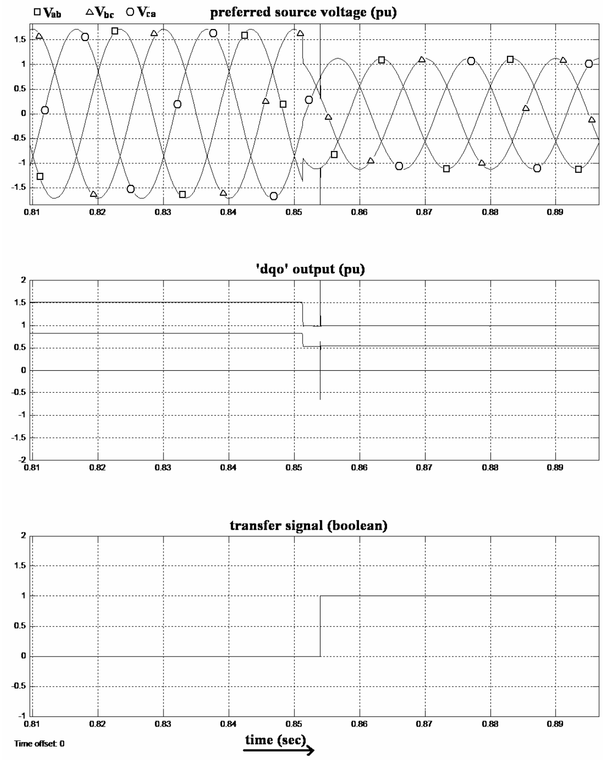

Fig.10: Three Phase Sag (35%) in Preferred Source Voltage

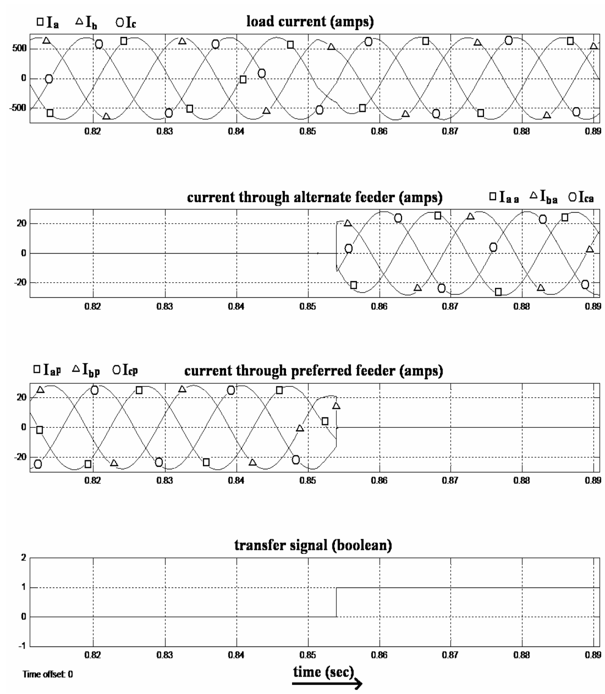

Fig.11: Current through both switches and load

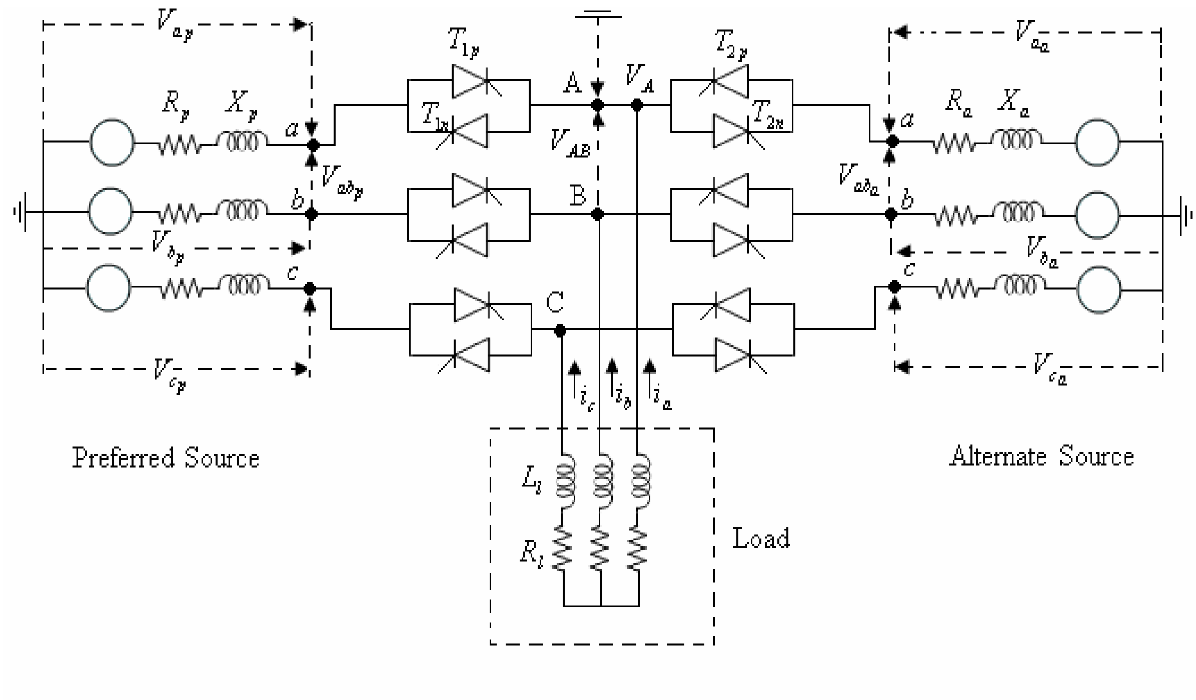

Fig.12 : IEEE STS - I system configured with RL load

3.2 Comparison between IEEE STS-1 and GTO Equivalent of STS-I

In this section a comparison between SCR based IEEE STS-I and GTO based equivalent STS is presented. For comparison purpose "Benchmark System for Digital Computer Simulation of a Static Transfer Switch" [2] is considered which provides:

1) Guidelines for digital simulations of STS systems.
2) Basis for performance evaluation of simulation programs used for STS analysis and 3) Benchmark performance for various detection or control strategies adopted for STS systems. Two benchmark systems are discussed in [2]. Each of them consists of 1) supply system, 2) STS, and 3) sensitive load. The two benchmark systems are referred to as STS-I and STS-II and are SCR based. Simulations are carried out using PSCAD/EMTDC software package. GTO based STS is configured as per parameters of STS-I system and simulation results are compared with two cases of disturbances considered in STS-I when STS system is delivering power to sensitive R-L load.

Parameters of SCR based STS-1 System
With respect to Fig.2 parameters of STS-1 benchmark system [2] are as follows:
• Preferred and alternate source systems
12 kV, 60 Hz
Source impedances are identical.
$R_p = R_a = 0.015\ \Omega$, $X_p = X_a = 3.6\ \Omega$

• *Three-phase Delta-Star load transformer*
12 kV/480 V, 1 MVA, 60 Hz
Leakage Reactance = 12%
Resistance representing winding losses = 1.5%,
Resistance representing core losses = 0.5%

• *Each pair of thyristor valves has a snubber circuit composed of:*

R = 1 M Ω and C = 0.001 μF (Impact of snubber circuit on the STS system is insignificant [2]).

• *Load system is composed of:*
Three-phase RL load in parallel with an induction motor (here only the case of *RL* Load is considered)
The series RL load has the following parameters:
$R_l = 0.402\ \Omega$, $X_l = 0.225\ \Omega$
• *Control circuit parameters*
$V_{ref} = 16.97$ kV, Voltage-change tolerance limit
$E_{tol} = 10\%\ V_{ref}$
Filter cut-off frequency fc = 50 Hz, Zero, current threshold limit i_{zth} = 4.8 A (at nearly no load condition).
Thyristor turn-off time =1 ms.
Sampling rate = 6660 Hz.
The results of STS-I IEEE Benchmark system [2] are given in Table 3. Simulations are carried out using EMTDC tool. GTO equivalent of STS-1 is analyzed for two cases of disturbances (1) L-G fault (involving phase 'a') and (2) three-phase voltage sag (35%). Results for the same are shown in Table 4.

3.2.1 Transfer Time Estimation

Transfer-time estimation of a STS is not a straightforward process due to its dependence on commutation between the thyristor switches in each phase. The commutation process itself is determined by the system parameters and the component characteristics. The following realistic assumptions are made to make the estimation task manageable.

- Preferred and alternate sources are in-phase. This is a realistic assumption for practical distribution systems.
- Voltage drops across the thyristors are negligible with respect to the system voltage.
- Line impedances are negligible compared to the Load impedance.
- No cross current flows during the transfer process.

Considering the above assumptions, transfer time is analytically estimated for RL loads under various fault/disturbance conditions. If the incoming thyristor, e.g., T_{2p} of Fig.12, is negatively biased when a disturbance is detected, commutation fails. In this case, the line current in the corresponding phase decays as a function of the system parameters, e.g., the load power factor and the fault conditions. Commutation begins when a voltage zero-crossing is reached and the incoming thyristor is forward biased. The following subsections describe the procedure of estimating the transfer time in case of symmetrical and asymmetrical disturbances.

1. Three-Phase Under-Voltage Disturbances

If a three-phase under-voltage disturbance occurs in the preferred source and commutation between the incoming and outgoing thyristors of only phase-a fails, from Fig.12, one deduces

$$V_{a_p} - V_{b_a} = R_l(i_a - i_b) + L_l\left(\frac{di_a}{dt} - \frac{di_b}{dt}\right) \quad (5)$$

$$V_{a_p} - V_{c_a} = R_l(i_a - i_c) + L_l\left(\frac{di_a}{dt} - \frac{di_c}{dt}\right) \quad (6)$$

$$i \;\; + i_b + i_c = 0 \quad (7)$$

Where $i_{a,}$,i_b and i_c are the load currents. Solving (5)–(7) for i_a yields

$$\frac{di_a}{dt} + \frac{1}{\tau_l} i_a = \frac{2V_{ap} + V_{aa}}{3L_l}; \tau_l = \frac{L_l}{R_l} \quad (8)$$

The preferred and alternate sources are in-phase; therefore, if u is the percentage of under voltage during the transfer process, then

$$V_{a_a} = \hat{V}_p \cos(\omega t + \phi) \quad (9)$$

and

$$V_{a_p} = \left(1 - \frac{u}{100}\right)\hat{V}_p \cos(\omega t + \phi) \quad (10)$$

Where $\hat{V}_p$ is the peak value of phase voltage, ω frequency, and ϕ is the initial angle. From *(8), (9)* and *(10)*, i_a is deduced

$$i_a(t) = (i_{ao} - K_m \cos(\phi - \xi))e^{t/\tau_l} + K_m \cos(\omega t + \phi - \xi \quad (11)$$

where i_{ao} is phase-a current when load transfer begins, ξ is the load angle and

$$K_m = \frac{\hat{V}_p(1 + 2u)}{3\sqrt{R_l^{\,2} + (\omega L_l)^2}} \quad and \quad \xi = \tan^{-1}\left(\frac{\omega L}{R_l}\right) \quad (12)$$

The transfer process is completed when crosses zero. Therefore, transfer time is found by solving (11) for $i_a(t)=0$. The maximum transfer time occurs when the transfer process begins at a voltage zero-crossing. Load transfer is completed at the next current zero-crossing. It is observed that with the increase of the percentage of under voltage, the transfer time increases and the total load-transfer time decreases. The decrease in the total load-transfer time is due to the fact that more severe voltage drops are detected faster, thus decreasing the detection time. The results also show that at higher load power factor, the transfer time and the total load-transfer time are shorter.

2. Single-Phase-To-Ground Fault

When a single-phase-to-ground fault is detected, if the alternate-source phase voltage and the preferred-source line current direction corresponding to the faulty phase have the same polarity, commutation occurs and the transfer time is negligible. Otherwise commutation fails, and the transfer time will be determined by the current zero-crossing. If phase-a is the faulty phase, then from (11) and for $u=0$, i_a can be found from

$$i_a(t) = (i_{ao} - K_m \cos(\phi - \xi))e^{t/\tau_l} + K_m \cos(\omega t + \phi - \xi \quad (13)$$

where i_{ao} is phase-a line current at the instant of fault/disturbance detection, ξ is the load angle, and

$$K_m = \frac{\hat{V}_p}{3\sqrt{R_l^{\,2} + (\omega L_l)^2}}$$

For some cases, e.g., $0 < \phi < 30°$, the transfer time is only the commutation time which can be neglected. The transfer time in the case of loads with a power factor of 0.8 or 0.9 is also negligible. The reason is that the polarities of the corresponding phase voltage and line current are the same at the instant of fault detection resulting in a successful commutation between the incoming and outgoing thyristors.

3. Phase-To-Phase Fault

From Fig. 12, if a phase-to-phase fault occurs between phase-a and phase-b of the preferred source, the equations expressing line currents are

$$L_l \frac{di_a}{dt} + R_l i_a = \frac{1}{3}(2V_{AB} + V_{BC}) \qquad (14)$$

$$L_l \frac{di_b}{dt} + R_l i_b = \frac{1}{3}(V_{BC} + V_{AB}) \qquad (15)$$

where V_{AB} and V_{BC} are the load line voltages, and i_a and i_b are phase-a and phase-b line currents. During the fault period

$$V_A = V_B = \frac{1}{2}(V_{a_a} + V_{b_a}) \text{ and } V_C = V_{c_a} \qquad (16)$$

Therefore, during the detection process

$$L_l \frac{di_a}{dt} + R_l i_a = -\frac{1}{2}V_{ca} \qquad (17)$$

$$L_l \frac{di_b}{dt} + R_l i_b = -\frac{1}{2}V_{c_a} \qquad (18)$$

Solving (17) and (18) for i_a and i_b yields:

$$i_a(t) = (i_{ao} - K_m \cos(\phi + 120^\circ - \xi))e^{-t/\tau l} + K_m \cos(\omega t + \phi + 120^\circ - \xi) \qquad (19)$$

$$i_b(t) = (i_{bo} - K_m \cos(\phi + 120^\circ - \xi))e^{-t/\tau l} + K_m \cos(\omega t + \phi + 120^\circ - \xi) \qquad (20)$$

where i_{ao} and i_{bo} are phase-a and phase-b currents at the fault instant, and

$$K_m = -\frac{\hat{V}_p}{2\left(\sqrt{R_l^2 + (L_l\omega)^2}\right)} \qquad (21)$$

When a fault is detected, depending on the load voltage and current, commutation may or may not occur. If phase-b is transferred to the alternate source at t_2, phase-a is transferred at t_3 and $t_3 > t_2$, since $V_B = V_{b_a}$, then during $t_2 < t < t_3$ from (14):

$$L_l \frac{di_a}{dt} + R_l i_a = -\frac{3}{4}V_{ca} \qquad (22)$$

and phase-a current is

$$i_a(t) = (i'_{ao} - K_m \cos(\phi + 120^\circ - \xi))e^{-t/\tau l} + \mathrm{K_m} \cos(\omega t + \phi + 120^\circ - \xi) \qquad (23)$$

where

$$i'_{ao} = (i_{ao} - K_m \cos(\phi + 120^\circ - \xi))e^{-t_2/\tau l} + \mathrm{K_m} \cos(\omega t_2 + \phi + 120^\circ - \xi)$$

and

$$K_m = -\frac{3\hat{V}_p}{4\left(\sqrt{R_l^2 + (L_l\omega)^2}\right)}$$

Equation (23) is used to obtain the transfer time. In some cases, e.g., $150^\circ < \phi < 180^\circ$, the transfer time is only the commutation time which is negligible.

3.2.2 Simulations (RL load)

Simulation is carried out using MATLAB software package. Performance of GTO based three-phase STS is analyzed for two types of disturbances on preferred feeder.

Case 1: ***RL load, Single Phase to ground fault***

Case 1 presents the simulation results when phase-'a' of preferred source is subjected to a single-phase-to-ground fault. Source voltage and feeder currents are shown in Fig.13 and Fig.14 respectively. The fault is considered to occur at time t = 0.2158 sec. The disturbance is detected at 0.2191 sec which results in a detection time of 3.3 ms. Load is transferred at t = 0.2192 sec. Here total load transfer time is 3.4 ms. Fault current is shown in Fig.15.

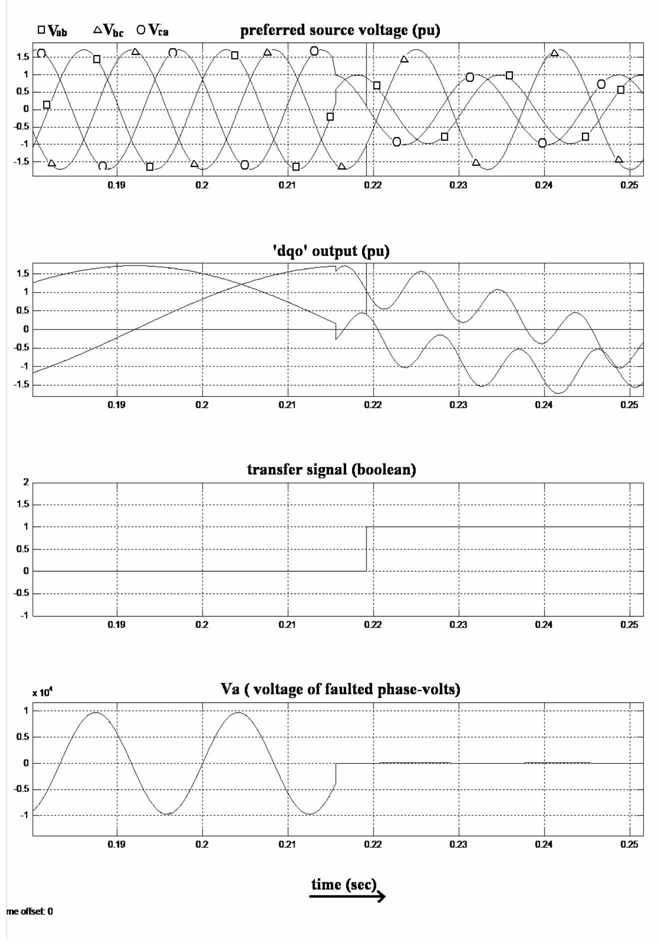

Fig.13: Source voltage and transfer signal

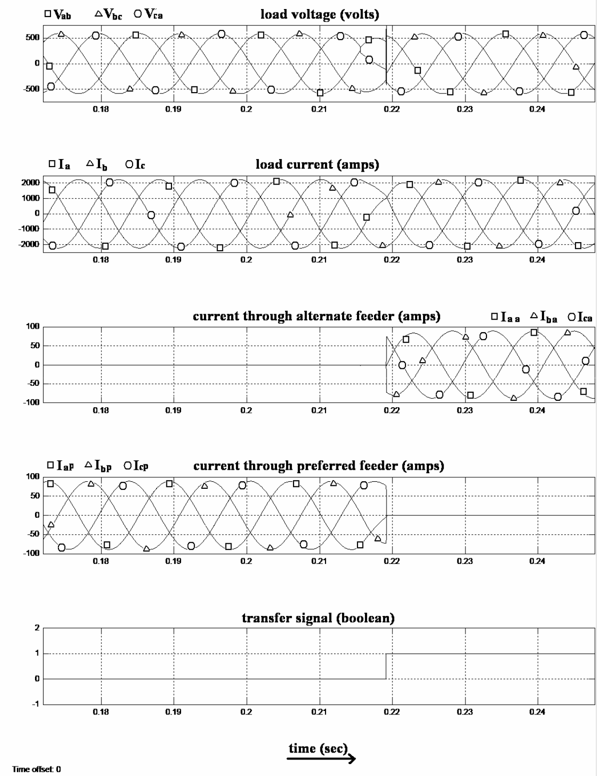

Fig.14: Load current and transfer signal

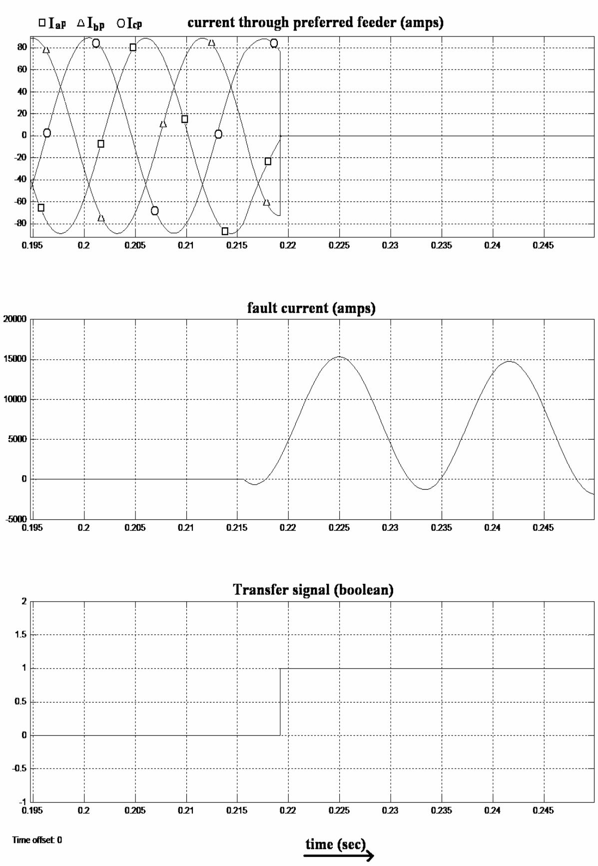

Fig.15: Fault current and transfer signal

Case 2: ***RL load, Three Phase Under Voltage***

Fig.16 shows a case in which a 35% three phase under voltage occurs in the system at t = 0.112 sec. The disturbance is detected at 0.1131 sec which results in a detection time of 1.1 ms. Load is transferred to alternate feeder at t = 0.11315 sec. This gives a transfer time of 0.05 ms. In this case total load transfer time is 1.15 ms. Fig.17 shows the preferred feeder and alternate feeder currents.

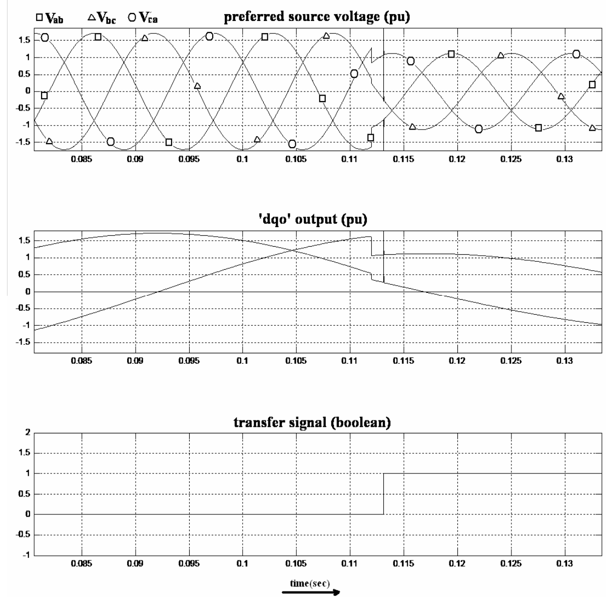

Fig.16: Three phase under voltage in preferred source and transfer signal

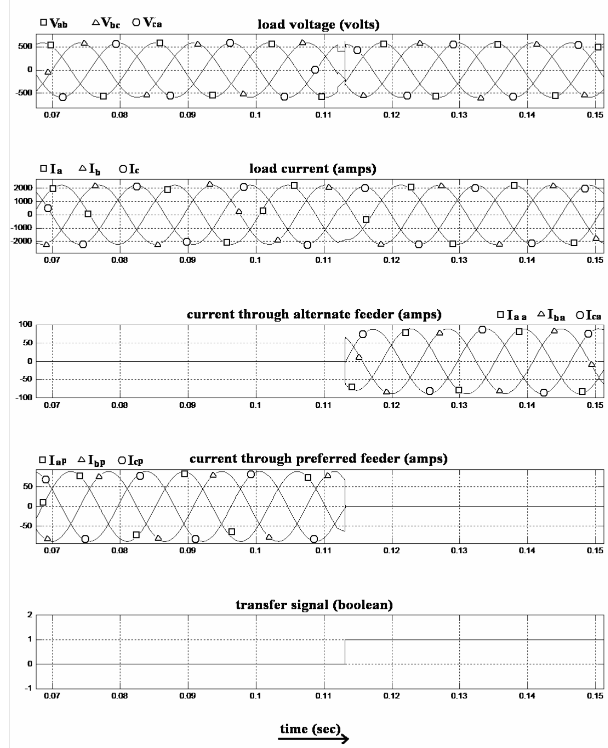

Fig.17: current through both feeders and load

4 Simulation Results

Results of simulations for (1) power quality improvement of sensitive R-L load against different types of disturbances (2) SCR based (IEEE Benchmark STS-1) and GTO equivalent of STS-1 are given in Table 2, Table3 and Table 4.

Table 2: Power Quality Improvement of R-L load

Case No	Type of event on preferred side source (Sag/swell/fault)	Detection Time(t_d) ms	Transfer Time(t_f) ms	Total load transfer time (t_t) ms
1	L-G fault in phase 'a' with R_f= 0.01 ohms	2.21	0.05	2.26
2	Single-phase sag (35%)	4.79	0.05	4.84
3	Single-phase sag (50%)	3.61	0.05	3.66
4	L-L fault involving phases 'a' and 'b'	6.2	0.05	6.25
5	Two-phase sag (35%)	3.3	0.05	3.35
6	Two-phase sag (50%)	3.0	0.05	3.05
7	Three phase voltage sag (35%)	2.6	0.05	2.65
8	Three phase voltage sag (50%)	1.92	0.05	1.97
9	Three phase voltage sag (70%)	1.32	0.05	1.37
10	Three phase voltage sag (80%)	0.9	0.05	0.95

Table 3: Benchmark STS-1 system (SCR based)

Type of event on preferred side source (Sag/swell/fault)	Detection Time(t_d) ms	Transfer Time(t_f) ms	Total load transfer time (t_t) ms
L-G fault in phase 'a' with R_f= 0.01 ohms	1.39	3.05	4.44
Three phase voltage sag (35%)	4.38	0	4.38

Table 4: GTO based STS (equivalent to STS-1)

Type of event on preferred side source (Sag/swell/fault)	Detection Time(t_d) ms	Transfer Time(t_f) ms	Total load transfer time (t_t) ms
L-G fault in phase 'a' with R_f= 0.01 ohms	3.3	0.1	3.4
Three phase voltage sag (35%)	1.1	0.05	1.15

5 Scopes for Future Work

Some suggestions for future work in this field are given below:

- The effect of feeder impedances on the operation of STS system can be studied.
- Lumped feeder parameters are considered in this work. Study with distributed parameters can be done.
- Effect of fault at load terminals can be studied.
- Performance of STS for hybrid loads can be studied.
- New techniques can be incorporated in voltage detection scheme to make it much faster.
- Multicriteria optimization of distribution systems using network configuration [11].

Some important contributions of STS system for improving power quality in custom power and power distribution system are as follows:

- To protect the sensitive load from the effect of disturbances.
- To provide continuous power supply to consumers of Custom Power Park.
- To use as a bus coupler at grid sub station.

6 Conclusions

In this paper a detailed simulation study of GTO based STS is presented. The proposed system reduces complexity in control as it do not require current direction and current zero crossing detection circuits. Fast switching of GTO devices enables to obtain an almost constant transfer time of 0.05 ms. Moreover the transfer time is almost negligible and also independent of type of disturbance. The comparison of total load transfer time for GTO and SCR based IEEE-STS-1 benchmark system suggests that former one will speedup the transfer process. In addition to this it is observed that the proposed system will have the capability to interrupt fault currents before they attain damaging levels.

References:

[1] M.N. Moschakis and N. D. Hatziargyroiu, A Detailed Model for a Thyristor Based Static Transfer Switch, *IEEE Transactions on Power Delivery, Volume: 18, Issue: 4,* Oct. 2003, pp. 1442 - 1449.

[2] H. Mokhtari, S.B. Dewan, M.R. Iravani, Benchmark Systems for Digital Computer Simulation of A Static Transfer Switch, *IEEE Transactions on Power Delivery, Volume: 16, Issue: 4* October-2001, pp. 724 - 731.

[3] H. Mokhtari, S.B. Dewan, M.R. Iravani, Performance Evaluation of Thyristor Based Static Transfer Switch, *IEEE Transactions on Power Delivery, Volume: 15*, July 2000, pp.960 -966.

[4] A. Sannio, Static Transfer Switch: Analysis of Switching Conditions and Actual Transfer Time, *IEEE Power Engineering Society Winter Meeting*, Columbus, Ohio, 2001.

[5] H. Mokhtari, S.B. Dewan, M.R. Iravani, Analysis of a Static Transfer Switch With Respect to Transfer Time, *IEEE Transactions on Power Delivery, Volume: 17, Issue: 1,* 2002, pp. 190 -199.

[6] H. Mokhtari, Impact of Feeder Impedances on the Performance of a Static Transfer Switch, *IEEE Transactions on Power Delivery, Volume: 19 Issue: 2,* 2004, pp.679-685.

[7] A. Ghosh and G. Ledwitch, *Power Quality Enhancement Using Custom Power Devices,* Kluwer Academic Publishers, Boston, 2002.

[8] R. K. Pachar, H. P. Tiwari, N. Jhajharia, S. L. Surana, Simulation Study of GTO Based Static Transfer Switch Using MATLAB, *6th WSEAS International Conference on CSECS*, Cairo, Egypt, Dec-2007, pp. 264-269.

[9] Hu Guo-Sheng, Ren Guang Yong, Jiang Jin-Jian, Power Quality Faint Disturbance Identification Using WPEE and WSVMs, *WSEAS Transactions on Power Systems, Volume:2, Issue:7,*July 2007, pp. 1625-1639

[10] Maha Sharkas, A Combined DWT and DCT with PCA for Face Recognition, *WSEAS Transactions on Systems , Volume:4, Issue: 10,*October 2005, pp. 1707-1734.

[11] R.C. Berredo, L.N. Canha, P.Ya. Ekel, L C.A. Ferreira and M.V.C. Maciel, Experimental Design and Models of Power System Optimization and Control, *WSEAS Transactions on Systems and Control, Volume: 3*, *Issue: 1*, January 2008, pp. 40-49