Simulation Study of GTO Based Static Transfer Switch Using MATLAB

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Abstract: - This paper investigates the performance of GTO based STS systems in improving the power quality of sensitive three-phase RL load. 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 of STS system is demonstrated under various faults/disturbance conditions. Simulations are carried out using 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 recent times the advancements in semiconductor technology has effectively marked up its presence in low and medium voltage applications involving network reconfiguration and network compensation. Static Transfer Switch is invariably used for protection of a sensitive load from power quality disturbances. A STS system does so by transferring sensitive load from one source (preferred source) to other (alternate source) when a fault/disturbance occurs in any of the sources feeding the sensitive load. The performance of an STS system is evaluated on basis of 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. Three cases of disturbances namely (1) L-G fault involving phase ‘a’ (2) L-L fault involving phase ‘a’ and ‘b’ and (3) Three-phase sag of 35% has been considered on preferred source to demonstrate the performance of STS system.

2 GTO Based Three Phase Static Transfer Switch

In this section three phase GTO based STS is discussed. Parameters of STS are configured as per Indian system at distribution level (Table 1).Two sources namely preferred and alternate source are connected to load via GTO switches.

2.1 Principle of Operation

The basic structure of a STS system is shown in Fig.1. The STS system is composed of [2]: (1) load which is sensitive to the variations in the utility supply voltage, (2) two independent sources one of which is the preferred source and the other one is the alternate source, (3) two GTO thyristor blocks G_1 and G_2 which connects the load to any one of the power sources and (4) a control logic to monitor voltage quality of both sources, which is responsible to detect voltage fluctuations in system (detection process), comparing power quality of both the sources and to perform load transfer from one source to the another if needed.

2.2 Three Phase STS System

Three phase STS system is composed of a power circuit and control logic[1], as shown in Fig.1. 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.2 and Fig.3). Inputs to control circuit are the voltages and currents of the two feeders and it performs a comparison between source voltage and the reference value. If the difference exceeds a specific amount (e_{tol}), a binary transfer signal is generated. Logical value (1) implements transfer of load to alternate source, where as logical value (0) implements load transfer back to the preferred source. For positive half cycle of preferred voltage G_{1p} conducts and for negative half cycle G_{1n} conducts and load is supplied by preferred source otherwise load is supplied by alternate source via G_{2p} and G_{2n} for positive and negative half cycles.

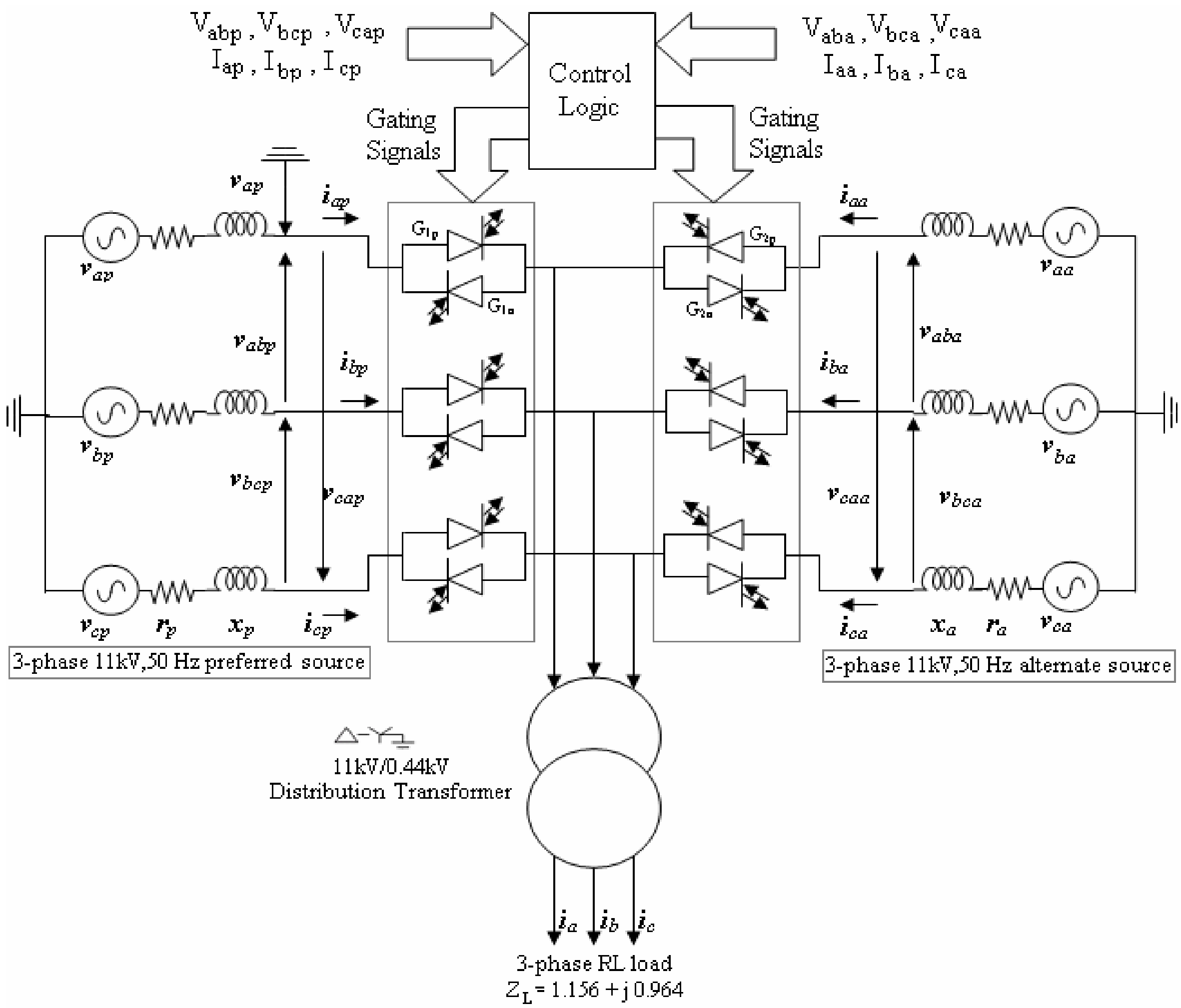

Fig. 1: Power Circuit of Three Phase STS System

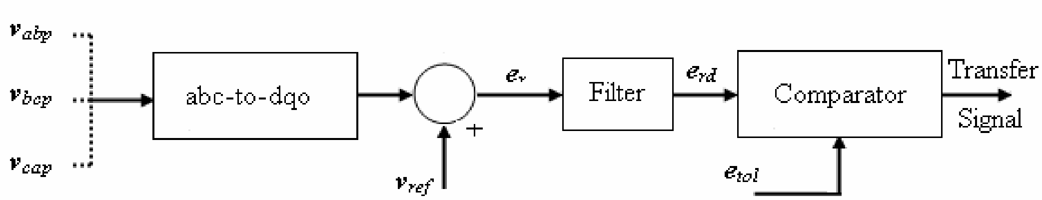

Fig. 2: Voltage Detection Scheme

(1) Voltage Detection Strategy

Fig.2 represents a block diagram of the voltage detection scheme [3]-[4].

$$v_{dqo_p} = K_s v_{abc_p}$$

where:

$$K_s = \frac{2}{3}\begin{bmatrix} \sin(\theta) & \sin(\theta-120^\circ) & \sin(\theta+120^\circ) \\ \cos(\theta) & \cos(\theta-120^\circ) & \cos(\theta+120^\circ) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

and

$$(v_{dqo_p})^T = \begin{bmatrix} v_{d_p} & v_{q_p} & v_{o_p} \end{bmatrix}$$
$$(v_{abc_p})^T = \begin{bmatrix} v_{ab_p} & v_{bc_p} & v_{ca_p} \end{bmatrix}$$

v_{ab_p}, v_{bc_p}, and v_{ca_p} *are* preferred source line voltages; and v_{d_p}, v_{q_p}, and v_{o_p} *are* 'dqo' component of the preferred source voltages in the rotating frame;

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

ω *is* angular frequency of the rotating frame; $\theta(0)$ is initial value of θ. The magnitude of $(v_{d_p} + jv_{q_p})$ is calculated as:

$$v^{\gamma}{}_p = \sqrt{v^2{}_{d_p} + v^2{}_{q_p}}$$

The output of the transformation block, i.e.V^{γ}_p, is compared to a dc reference, i.e.,V_{ref}. 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 a transfer process if the preferred source fails [2].

(2) Gating strategy

Fig.3 shows the gating scheme. The gating strategy is composed of three identical sets of logic for the three phases of the STS system. 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 GTO's of 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 of the preferred side GTO switch and triggers the alternate side GTO switch.

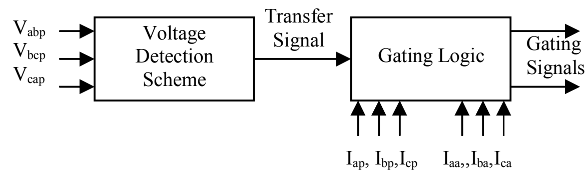

Fig.3: Gating Strategy

The load is fully transferred to the alternate side. When the disturbance is cleared, the load is transferred back to the preferred source without any time delay.

3 Simulation Results and Discussions

The performance of GTO based three-phase STS for sensitive passive RL load is simulated by MATLAB software package. The simulation circuit is prepared as per power circuit shown in Fig.1. Two different fault cases are considered, one is L-G fault on phase 'a' of preferred source and other is L-L fault involving phases 'a' and 'b' of preferred source. A fault resistance of 0.01 Ω is considered in both cases. Under voltage disturbances (three phase sag) are created by reducing the amplitude of the preferred source voltage during the simulation. 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

GTO Specifications:

R_{on} = 0.01 Ω , Forward voltage V_f = 1 V

Current 10% Fall Time T_f = 10µsec

Current Tail Time T_t = 20 µsec

Snubber Circuit Parameters:

Resistance R_s = 5000 Ω

Capacitor C_s = 0.05 µF.

Parameters of Mid Reject Second Order Filter:

Cutoff Frequency = 5 kHz

Damping Ratio z = 0.8

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.4. As soon as the fault is detected the control logic transfers the sensitive RL load to alternate source after a suitable delay ensuring turn-off of preferred side switch. The system behavior is depicted in Fig.5.

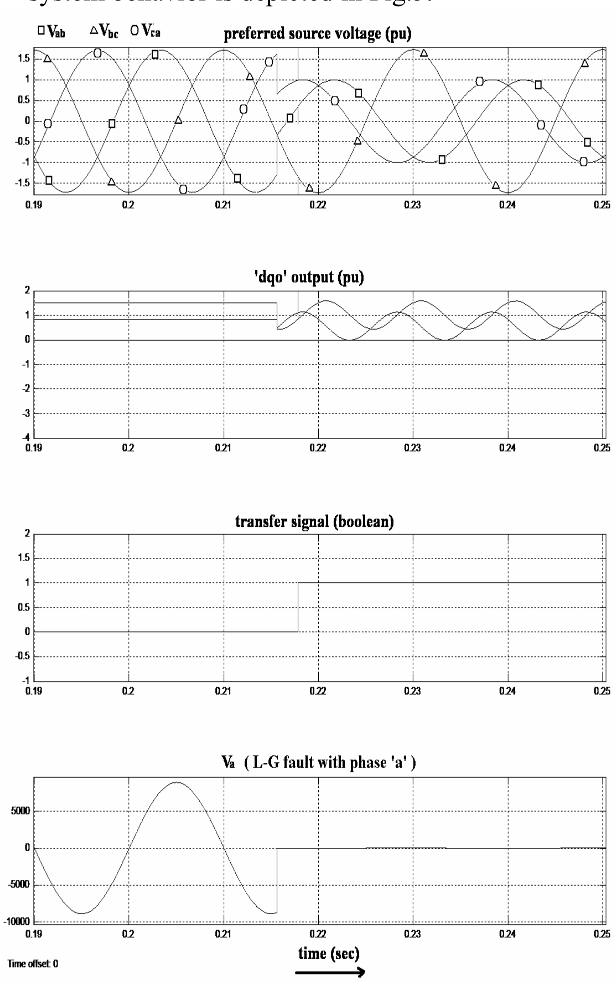

Fig.4: Preferred source voltage, 'dqo' output, transfer signal and voltage of Phase 'a'

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

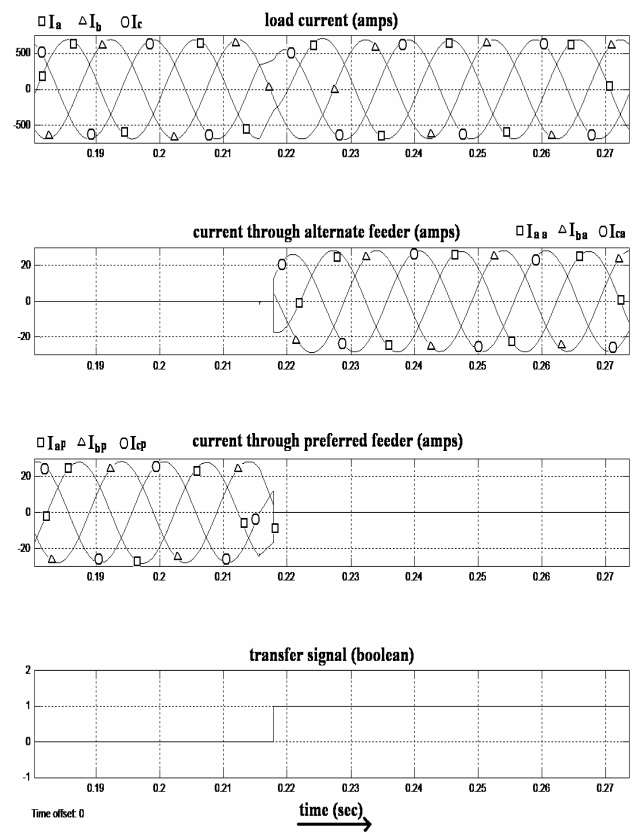

Fig.5: Current Through Both the Switches and Load

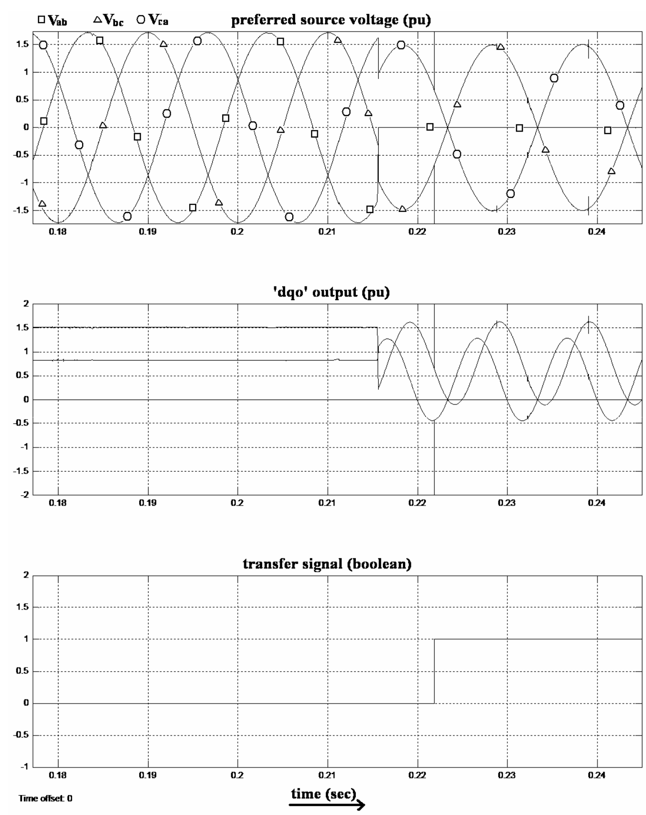

Fig.6: Preferred Source Voltage and Transfer Signal

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.6 and Fig.7.

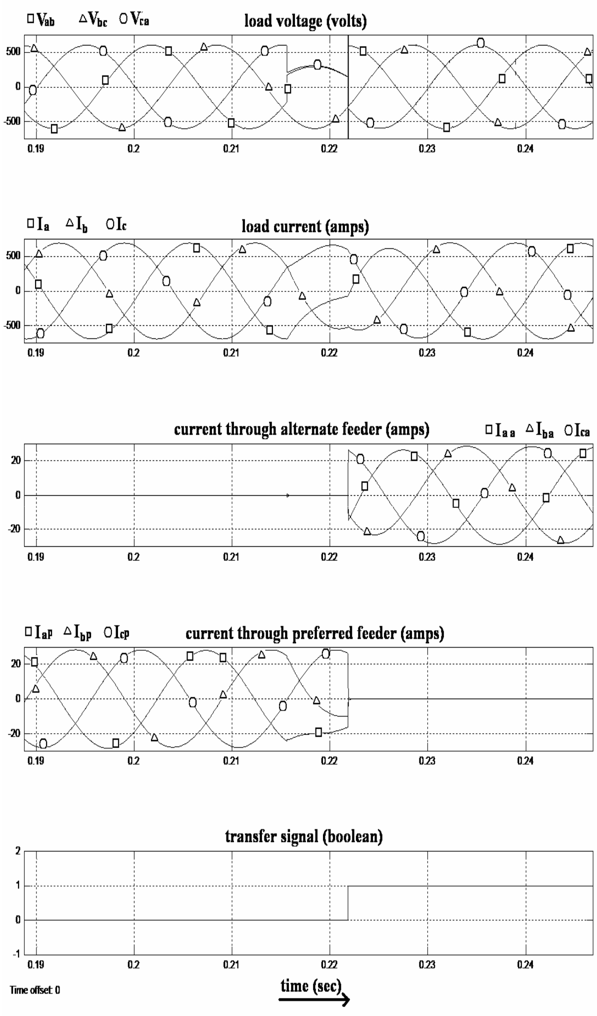

Fig.7: Current through both Switches and Load

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

Fig.8 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 results in a total load transfer time of 2.65 ms. Fig 9 shows all waveforms related to this case.

4 Simulation Results

Results of simulations for all the three cases are given in Table 2. Simulations were performed for the same system for all the three cases of power

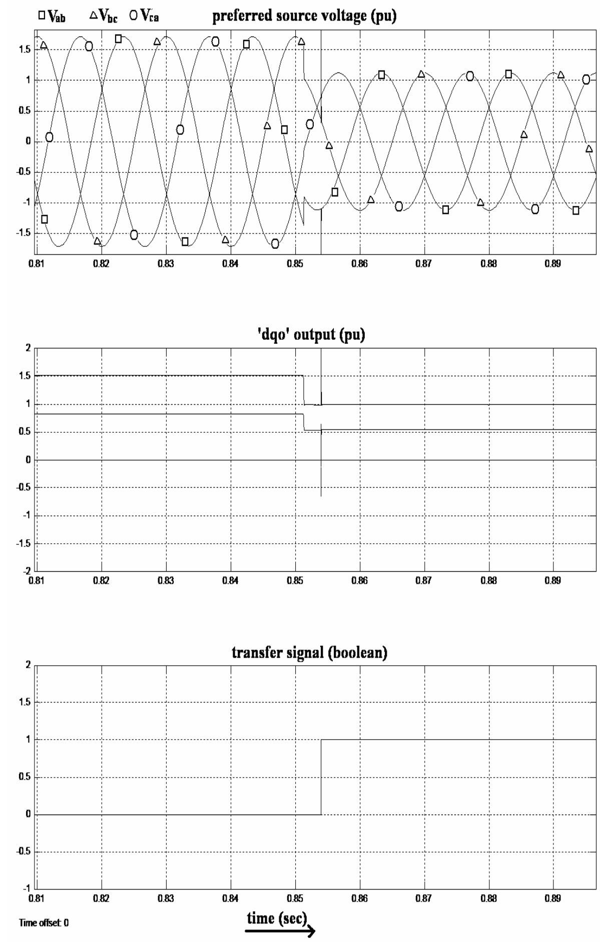

Fig.8: Three Phase Sag in Preferred Source Voltage

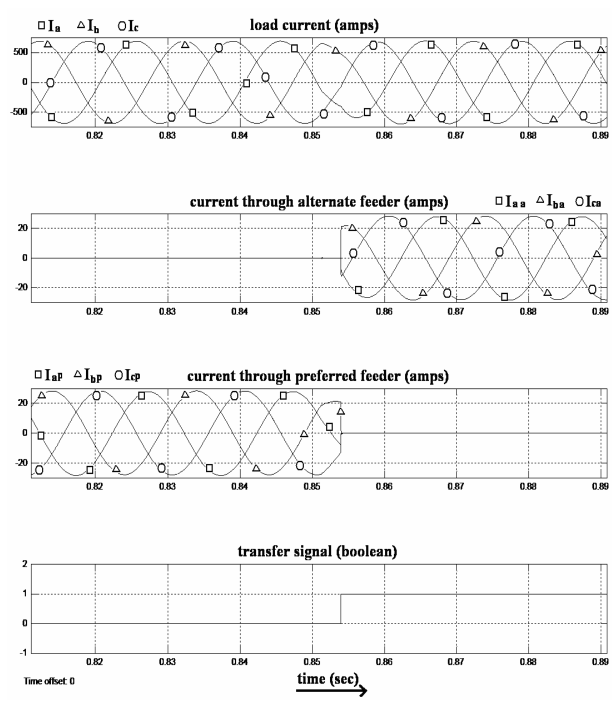

Fig.9: Current through both Switches and Load

quality problems occurring at different instants. The variations in the detection time indicate its dependency on various factors namely difference in feeder impedances, point of initiation of fault on the voltage wave and on type of power quality problem [5]-[7].

Table 2

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	L-L fault involving phases 'a' and 'b'	6.2	0.05	6.25
3	Three phase voltage sag (35%)	2.6	0.05	2.65

5 Conclusions

In GTO based STS we conclude that complexity in control is reduced as it do not require current direction and current zero crossing detection circuits where as they are must with SCR based STS systems. Fast witching of GTO devices enables to obtain an almost constant transfer time of 0.05 ms as observed during simulations. The comparison of total load transfer time for GTO and SCR based systems suggests that GTO based STS will speedup the transfer process as observed during simulations. It is observed that with GTO switches STS systems will have the capability to interrupt the fault currents before they attain damaging levels. Furthermore the transfer time (0.05 ms) is almost negligible and also independent of type of disturbance.

Hence it is concluded that GTO based STS systems are much faster than SCR based STS systems and will prove to be much safer and reliable.

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