Static Transfer Switch (STS) model in EMTPWorks RV

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Abstract: *Due to the growing requirement for process controls in automated plants, electrical consumers are becoming increasingly more sensitive to the quality and reliability of the power supplies. Thyristor-based Static Transfer Switches (STSs) are able to provide critical loads with a fast transfer to a backup auxiliary source when the main source fails. In this paper, a Static Transfer Switch model in EMTP-Works RV is developed. Results from three test cases concerning the STS system are presented.*

Keywords: Power Quality, Static Transfer Switch, EMTP-Works RV

1. INTRODUCTION

To ensure continuity of electrical power supply with sensitive process controls, a critical load is normally supplied from two independent sources, one being the primary selection. Traditionally, the sources are often connected to mechanical switches incorporating controls that can recognize loss of the main power source and then automatically transfer to the backup source, thus maintaining a highly reliable source of power. These switches generally take from 0.3 to 3 or more seconds to make a transfer after an interruption of the main source supply.

However, as processes and process controls have become increasingly sensitive not only to loss of the power source but also to fluctuations in the voltage supplied (i.e. voltage sags and swells), mechanical transfer switches cannot transfer quickly enough to eliminate customer interruptions when such disturbances occur.

The Static Transfer Switch (STS) essentially consists of a pair of back-to-back thyristor switches. It takes the place of the mechanical transfer switch and enables a seamless transfer of energy from the main source to the backup source in order to avoid service interruption. As a result, this arrangement can provide reliable power to the customer well within the limits of the ITI (CBEMA) curves [2, 3].

2. METHODOLOGY

In this paper, a simulation model of STS system is developed with the latest version of the simulation program EMTP-Works RV. The test system includes:

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- Two independent power sources,
- Two sets of thyristor based ac switches,
- A normally inductive critical load, and
- A control circuit that is used for detecting the ac bus voltage disturbances and controlling the transfer process between two sources.

A. Power Circuit of the STS system

The power circuit of STS system is shown in Fig.1. The STS system is composed of the main source, backup source, STS and a critical three-phase load. Both sources include an internal impedance. The STS consists of two three-phase static switches; each switch is comprised of three thyristor modules corresponding to the three phases of the power system. In each thyristor module, two sets of thyristor switches are connected in opposite polarity to allow the load current to flow in either positive or negative directions.

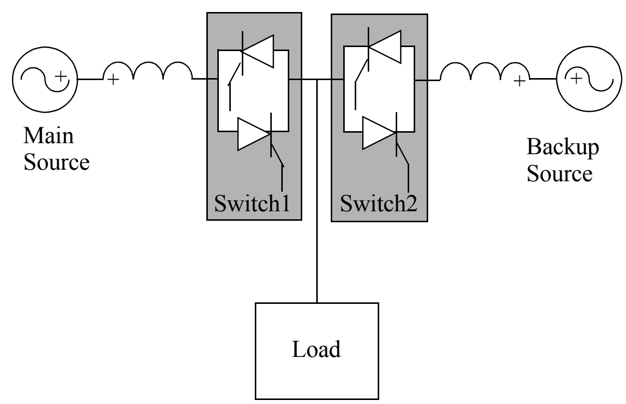

Fig.1. Power circuit of a STS system

B. Control Circuit of the STS system

The control circuit of the STS (Fig.2) is composed of four sections:

- Voltage detection,
- Gating enable generator,
- Phase locked loop (PLL), and
- Gating signal generator.

The control circuit is responsible for monitoring the quality of the main source and performing the transfer of the load from the main to the backup source, and vice versa. The required input signals to the control circuit are the three phase voltages from each source and phase currents from the load. The outputs of the control circuit are the gating patterns for the main and backup source thyristor switches.

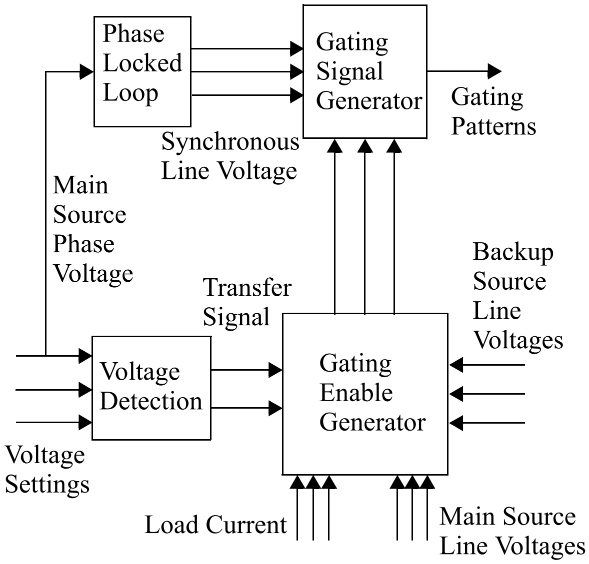

Fig.2. The control circuit of a STS system

(1). Voltage Detection Logic

Fig.3 shows the block diagram of the voltage detection circuit. Based on Park transformation, the instantaneous three-phase voltages of the main source are transformed into a synchronously rotating frame, eqs. (1) and (2)

$$\begin{bmatrix} v_d \\ v_q \\ v_o \end{bmatrix} = \frac{2}{3} \cdot \begin{bmatrix} \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ -\cos\theta & -\cos\left(\theta - \frac{2\pi}{3}\right) & -\cos\left(\theta + \frac{2}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (1)$$

$$\theta(t) = \theta(0) + \int_0^t \omega(\zeta) d\zeta \quad (2)$$

Where,

v_d, v_q, v_o are the dqo components of the main source voltage in the rotating frame,

v_a, v_b, v_c are the main source phase voltages,

ω is the rotating frame angular frequency, and

θ (0) is the initial value of θ.

The amplitude of the main source voltage vector,

$$v_p = \sqrt{v_d^2 + v_q^2} \quad (3)$$

is passed through the low-pass filters which attenuate impacts of voltage transients. Due to the fast response of the filter with a high cut-off frequency, a 1st order filter with fc=200Hz is selected to detect the voltage dip as quickly as possible. Due to its superior characteristics, a 4th order filter with fc=40Hz is selected to detect the voltage recovery. The filter outputs are then compared to two voltage settings: ***voltage_dip*** is to detect the voltage dip in the main source and ***voltage_recovery*** is for the detection of main source recovery. Outputs of comparators are used to generate the transfer signal that initiate either the forward transfer process, which transfers load from the main source to backup source, or the reverse process, which transfers load from the backup source to main source.

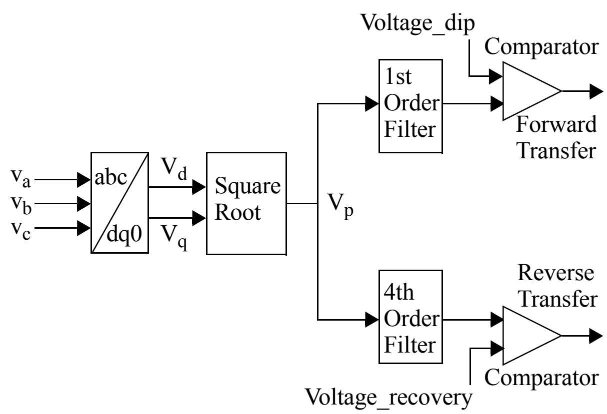

Fig.3. The voltage detection circuit

(2). Gating Signal Generator and PLL

The gating signal generator provides the gating patterns for the thyristor switches of the main and backup sources.

In this paper, the gating patterns are synchronized with the main source. This synchronizing strategy is implemented by a three-phase phase-locked-loop (PLL). This provides a clean synchronizing voltage and leads to the elimination of harmonic instability related problems [1].

(3). Gating enable generator

In some cases, a load transfer by a STS system may result in source paralleling, causing a circulating current to flow between the two sources [4, 6].

As shown in Fig. 4, if a fault is detected in the main source when the load current flows through thyristor TH11 (negative current), and if the instantaneous main source voltage is lower than the backup source voltage (i.e. thyristor TH21 forward biased), firing TH21 would allow the current of backup source to flow in the same direction as TH11 and make the backup source feed the fault too, as marked in Fig. 4. At this moment, the two sources become paralleled and a circulating current will flow between them.

Therefore, in order to make a correct transfer from the main source to the backup source, firing pulses to the thyristors in switch 1 are inhibited, and firing pulses are enabled only to the thyristor of switch 2; this allows the current to flow in the opposite direction (i.e. thyristor TH22 in Fig. 4).

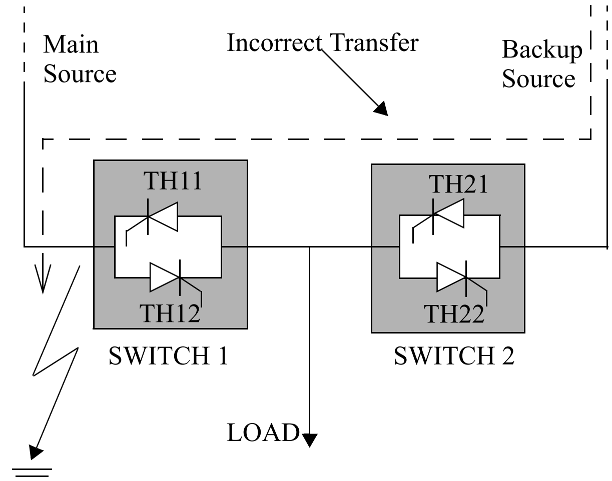

Fig. 4. Incorrect transfer in case of upstream fault [4]

To prevent such a circulating current in a STS system, a gating enable generator (Fig.2) is employed. This module is based on comparing the polarity of the load line current with the polarity of corresponding source line voltage. When both polarities are identical, the enable signals are generated, which then initiates a transfer process.

3. TESTS

A voltage dip, which can lead to the failure of an automated process, is the most common form of voltage disturbance in the distribution system. Since the loads of typical customers are normally inductive, the performance of the STS system is considered for an 80% phase voltage dip at the ac bus having a lagging power factor of 0.8. Behavior of the voltage detection circuit and three practical test cases concerning the STS system are examined.

A. Behavior of the voltage detection circuit

Figs. 5~7 depict the behavior of the voltage detection circuit in a three-phase STS system for the cases of a three-phase balanced, a two-phase and a one-phase unbalanced fault respectively. Since a 2nd order harmonic is present at the output of the abc-to-dq0 transformation circuit for unbalanced faults, a 1st order low-pass filter (Fig. 3) is used for the fast detection of a fault, and a 4th order low-pass filter is used for the correct detection of the main source recovery. In Figs. 5~7, v-fil1 and v-fil2 are the responses of the 1st and 4th order low -pass filters respectively, and vt is the transfer signal.

In Fig. 5, a threshold of 0.8 pu is used to detect the 80% three-phase balanced voltage dips, which results in a fast detection of the fault. However, when the same 0.8 pu threshold is set for the detection of a 80% two-phase unbalanced voltage dip in Fig. 6, this results in a slower detection speed. To detect an 80% one-phase unbalanced voltage dip, a threshold of 0.9 pu must be chosen (Fig. 7). Moreover, the filter output has different values when load is transferred to the backup source for those three cases.

Therefore, the threshold setting in this voltage detection circuit has to be chosen differently for the detection of different

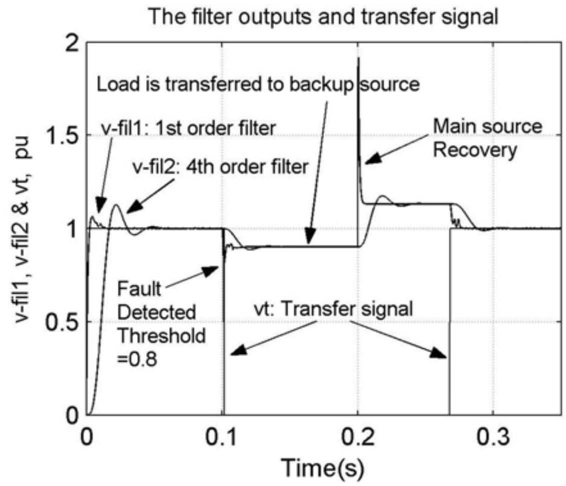

Fig 5. Three-phase balanced fault, 80% voltage dips in three-phases at the main source bus.

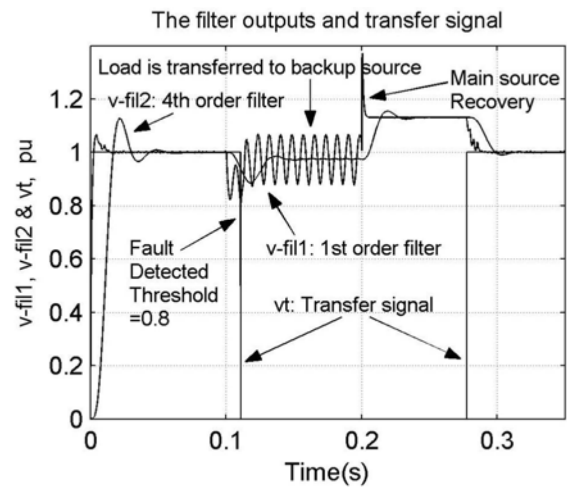

Fig. 6. Unbalanced fault,80% voltage dips in phases A & B at the main source bus.

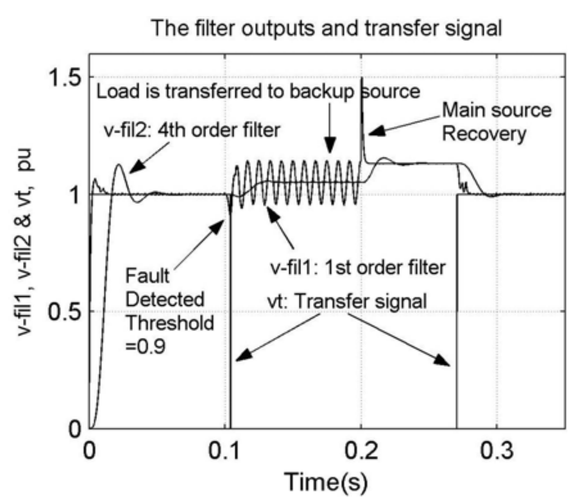

Fig 7. Unbalanced fault, 80% voltage dip in phase A at main source bus.

faults in order to detect the voltage dips in the system quickly and accurately. However, since the fault in the power system is generally unpredictable, the pre-setting of a detection threshold can only be suitable for certain kinds of faults. Therefore, over-estimation or under-estimation of the fault cannot be avoided sometimes if only a simple voltage detection scheme is employed.

B. "Hunting" situation

A voltage dip detection circuit (Fig. 3) is used to monitor the voltage at the main source bus. When a fault is detected at the main source bus, a transfer signal is immediately issued by this circuit and the load is transferred to the backup source. If the fault is not cleared, the main source bus voltage would increase to a much higher value due to the loss of load as the load has been transferred to the backup source (Figs. 5-7).

Now, if the threshold setting for transferring the load back to the main source is the same as the threshold for transferring from main source to the backup source, or if the threshold is improperly chosen, there would exist the possibility of a "hunting" situation, where a series of forward and reverse transfers of the load could take place. This case is shown in Fig. 8 where v_l, v_m and v_b are the voltages at the load side, main source and backup source bus respectively; i_l, i_m and i_b represent the currents through the load, main source and backup source respectively; and v_t is the transfer signal. (In the results that follow, these same signals are presented in the same order).

Since the test results of single- and three-phase systems were almost the same, for reasons of brevity, only simulation results of the single-phase STS system are presented in the rest of this paper.

To avoid such a "hunting" problem, two measures are necessary:

- The threshold for transferring back to the main source is application dependent, and
- A transfer back from the backup source to the main source is permitted only after a time delay of 10 cycles, whenever such a transfer is requested.

C. Circulating current between two sources

A conducting thyristor can be turned off naturally only at the zero crossing of its conducting current. If there is no detection of the polarities of source voltage and load current, the thyristors connecting the backup source may not be selectively fired when a transfer process is triggered. For example, because of a fault, a circulating current might exist between the two sources and the thyristor that was conducting from the main source side may be unable to turn off. Consequently, the two sources operate in parallel and the transfer process may fail. This case is shown in Fig. 9.

When the two sources become paralleled, a circulating current between them is established. The magnitude of this circulating current is limited only by the line impedances which are normally small. Therefore, this circulating current can be quite large and can often activate the protection devices in the system.

However, if the detection of polarities of source voltage and load current is employed, i.e., the thyristors at backup source are correctly fired, there would be no circulating current between the two sources. The transfer process is smoothly completed and the energy transfer becomes seamless, as shown in Fig. 10.

D. Effect of point-on-wave at fault initiation

The point-on-wave at which a fault is initiated could affect the detection and transfer times [4, 5]. It would also have an impact on the transfer process if harmonic distortion exists in the source voltages.

When the backup source is an inverter, Figs. 11and 12 depict the simulation results for the faults at point-on-wave of α=5ºand α=175º respectively in a single-phase STS system.

It can be seen that the transfer process is almost seamless when the fault occurs at α=5º. However, there exists both over-voltage and over-current at load side during the transfer

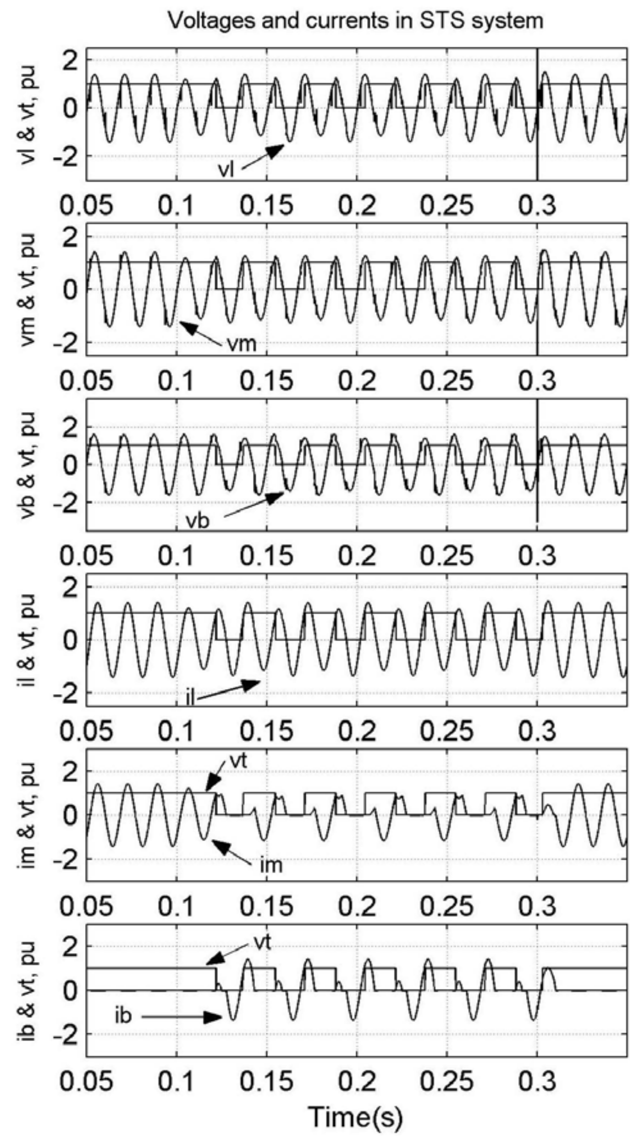

Fig 8. 80% voltage dip at main source bus, "hunting" situation

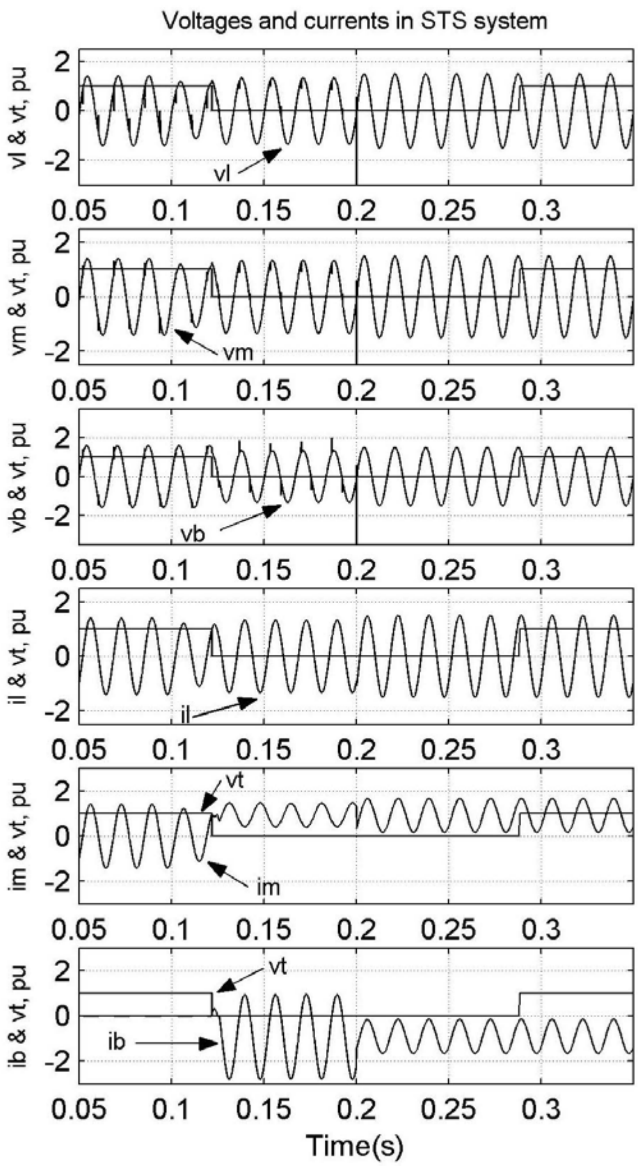

Fig. 9. Problem of circulating current between the two sources without detection of polarities of source voltage and load current

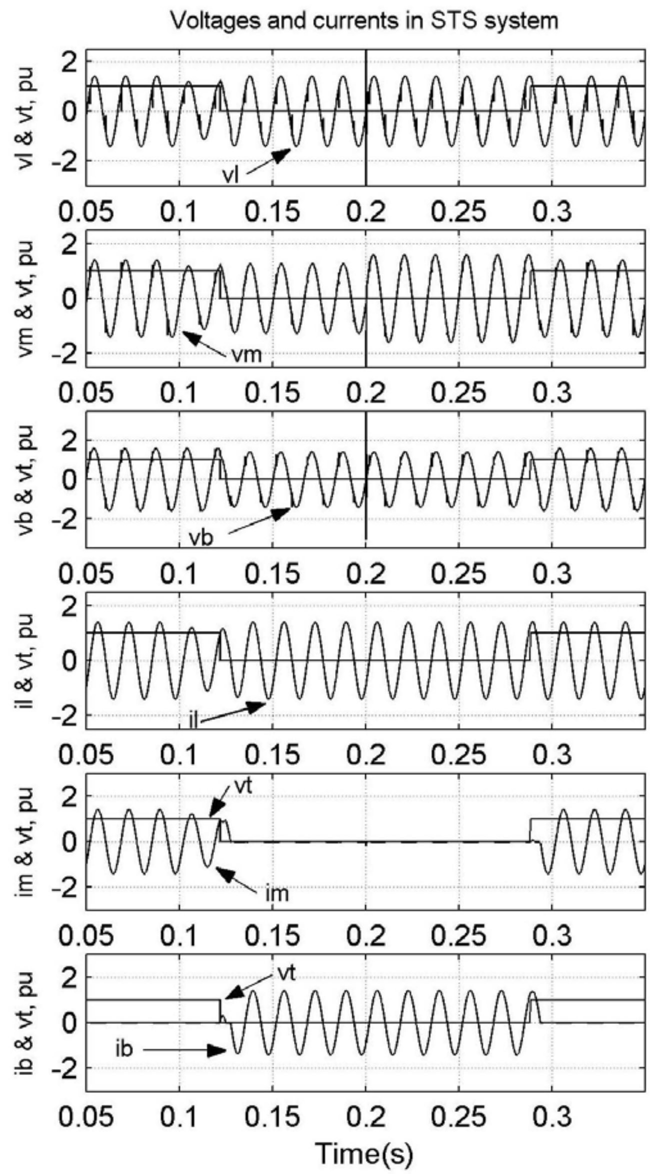

Fig. 10. Problem of circulating current between the two sources with proper detection of polarities of source voltage and load current

process when a fault occurs at α=175º because of the distortion and over-voltage of inverter output under the no-load condition. The voltage and current transients render the transfer process no longer seamless.

4. CONCLUSION

A model of a thyristor-based static transfer switch (STS) in EMTPWorks RV (the newest version of EMTP) is presented in this paper. The STS connects a critical load to its regular and back-up power supplies. Three practical test cases concerning the STS system are studied by means of simulation. These cases deal with (a) a “hunting” problem when a switching between the regular and backup sources takes place, (b) possibility of a circulating current between the two sources, and (c) the effect of point-on-wave switching at fault initiation.

For all cases, the use of synchronized switching by means of a PLL is essential; this is especially the case when the sources may be subjected to harmonic distortion under both load and no-load conditions.

The “hunting” problem could be solved by choosing proper threshold settings for transferring between sources and employing a delayed triggering of the transfer between the two sources. The circulating current could be avoided by correct detection of the polarities of source voltage and load current. The point on wave switching tests demonstrate that the moment of fault initiation has an important bearing on the behavior of the STS system in terms of over-currents and over-voltages. The design of the switch must take this into account.

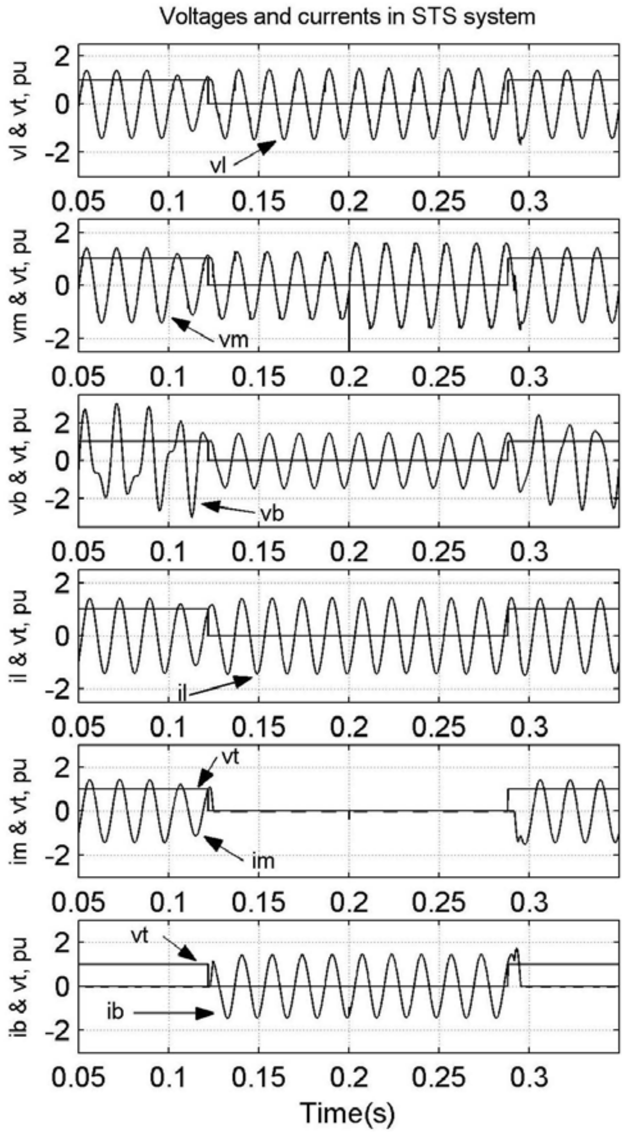

Fig. 11. Main source bus with 80% voltage dip at α=5º.

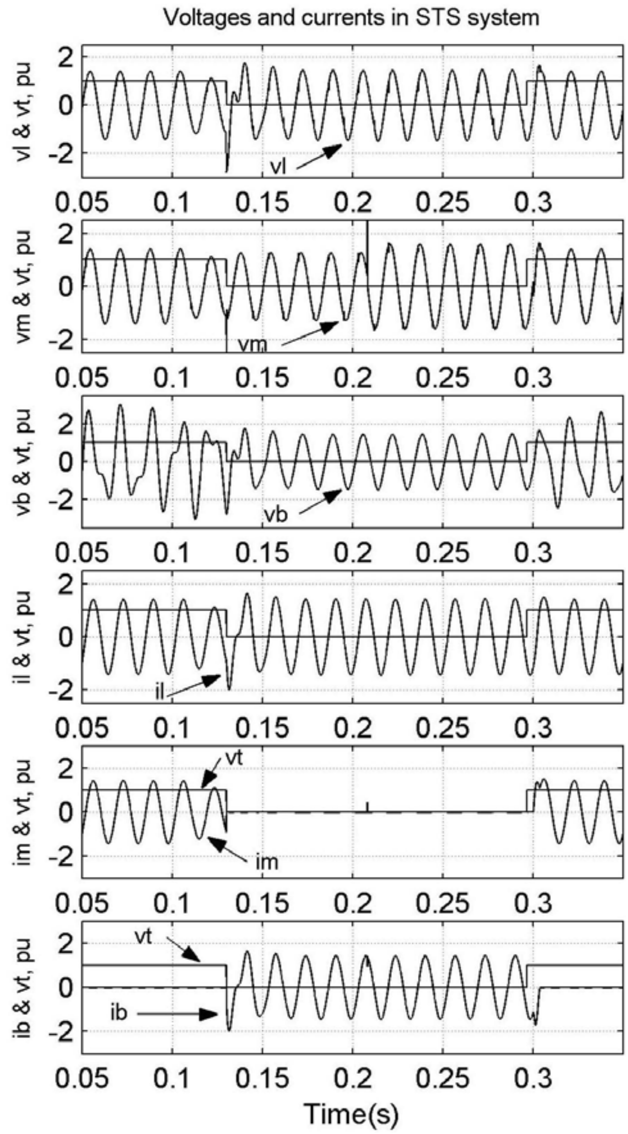

Fig. 12. Main source bus with 80% voltage dip at α=175º.

5. ACKNOWLEGEMENT

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6. REFERENCES

[1] V. Khatri, V.K. Sood, H. Jin, "Performance Assessment as using EMTP of two grid firing units for HVDC converters operating with weak ac systems", International Conference on Power System Transients, Sept.3 1995, Technical University of Lisbon, Portugal, PP517~522.

[2] J. W. Schwartzenberg, R. W. DeDoncker, "15kV Medium Voltage Static Transfer Switch". IEEE Industry Applications Conference, 1995; Conference Record of the 1995.

[3] C. Shapiro, R. O'Leary, J. Rajda, "Medium-Voltage high-speed Source-Transfer Switching System - A new tool to solve power quality problems". IEEE Power Delivery / POWER-GEN International'96.

[4] A. Sannino, "Static Transfer Switch: Analysis of Switching Conditions and Actual Transfer Time". IEEE Power Engineering Society, Winter Meeting, 2001. Volume: 1, 28 Jan-1 Feb 2001.

[5] H. Mokhtari, S. B. Dewan, M. R. Iravani, "Benchmark Systems for Digital Computer Simulation of a Static Transfer Switch". IEEE Transactions on Power Delivery, October 2001.

[6] H. Mokhtari, "Performance Evaluation of Thyristor-Based Static Transfer Switch with Respect to Cross Current". IEEE Transmission and Distribution Conference, 2002.