CHAPTER 4
Static Transfer Switch

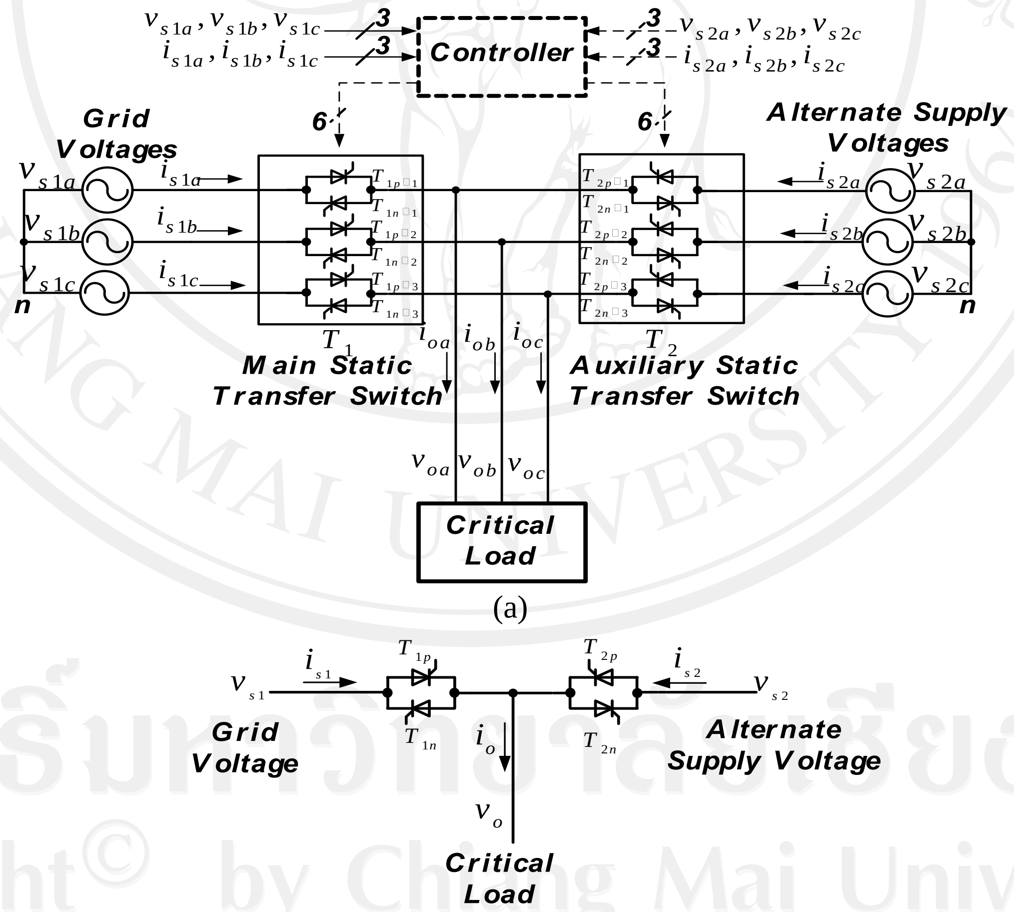
4.1 Introduction

Static transfer switch (STS) is one method of voltage compensations or mitigations. This is probably the simplest method of voltage sag detection among other methods, whereas its structure is not complicate when comparing with other voltage sag compensation methods.

4.2 Static transfer switch

STS is used for transferring the load from grid voltages to alternate supply voltages when the voltage sag occurred.

STS structure can be shown in Figure 4.1 (a) and single phase diagram is shown in Figure 4.1 (b). It can be seen that STS consists 6 of thyristors.



(a)

(b)

Figure 4.1 Thyristor based STS. (a) STS circuit diagram. (b) One phase circuit diagram.

In the normal mode, T1 or the main STS is closed or turned on for feeding the power from the grid voltages into the critical load. Whenever the voltage sag is detected by the controller, T1 is then instantaneously turned off and T2 is turned on in order for load transferring to alternate supply voltages.

The STS operation is divided into 2 modes, i.e. normal mode and transfer mode as shown in Figure 4.2.

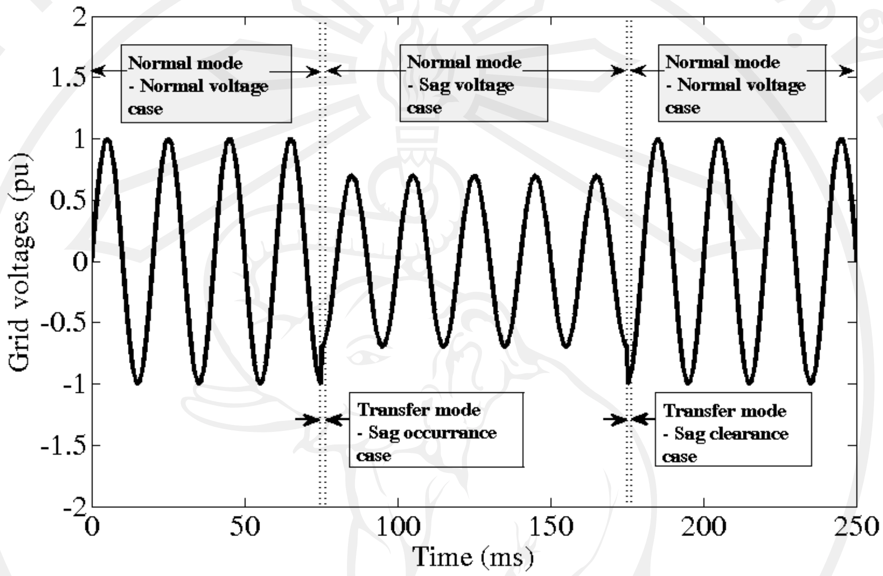


Figure 4.2 Operation modes of STS.

A. Normal mode operation

The normal mode operation is also divided into 2 cases i.e. normal voltage case and sag voltage case.

In the normal voltage case, T1 is turned on for feeding the power from grid voltages into load. While in the sag voltage case, T2 is turned on for feeding the power from alternate supply voltages into load.

The sequential gate drive signals of main static transfer switch are shown in Figure 4.3. It can be noticed that the sequential gate drive signals of auxiliary STS are identical to the gate drive signals of the main STS.

B. Transfer mode operation

The transfer mode operation is also divided into 2 cases i.e. sag occurrence case (transfer from T1 to T2) and sag clearance case (transfer from T2 back to T1).

In case of sag occurrence, T1 is turned off and T2 is turned on respectively. The transfer in this stage is critical operation and should be transferred as fast as possible, otherwise the load voltage will be affected from voltage sag. When the voltage sag is cleared, the reverse process is taken place.

The essential of STS in transfer mode is the thyristor commutation since thyristors are not the gate turn off device. The thyristor commutations for load transfer are divided to 2 methods, natural commutation or zero current commutation and forced commutation [15].

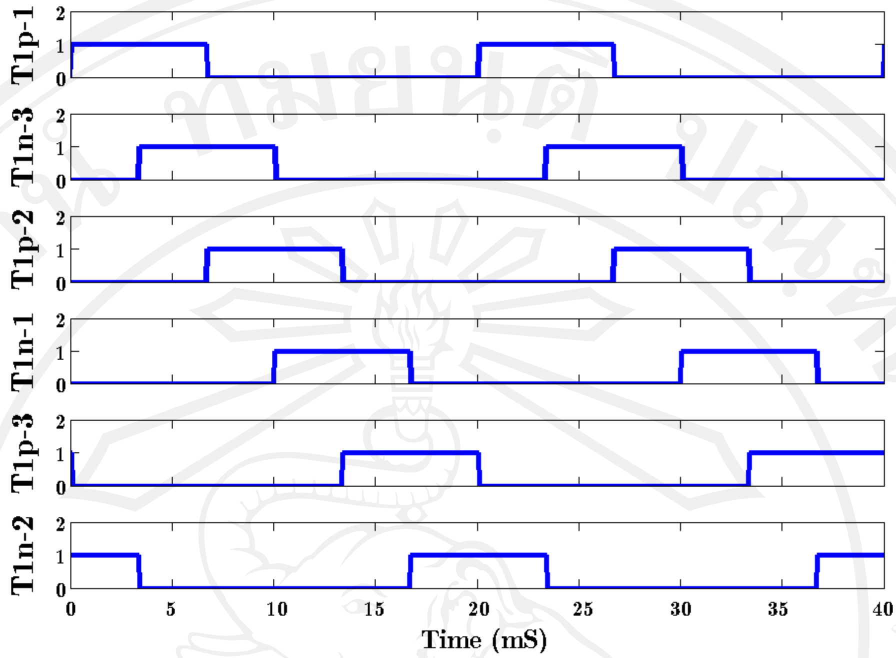


Figure 4.3 The sequential gate drive signals of main static transfer switch.

In the zero current commutation, the target thyristor trigger pulse is inhibited and the target thyristor current is naturally decreased into zero. The target thyristor is then turned off and the next thyristor trigger pulse is initiated. This is also called “Break Before Make, BBM”. In the forced commutation, the target thyristor is forced to turn off by inhibition of the target thyristor trigger pulse and immediate initiation of the next thyristor trigger pulse. This is also called “Make Before Break, MBB”.

The forced commutation method is more suitable for load transfer because delay time is eliminated [16]. But in case of inductive loads, the load current and load voltage under voltage sag sometimes have different direction and then the forced commutation cannot be applied for whole cycle [39] as following discussion.

The relation between current direction and voltage polarity under voltage sag is divided into 4 stages, t1-t4, as shown in Figure 4.4.

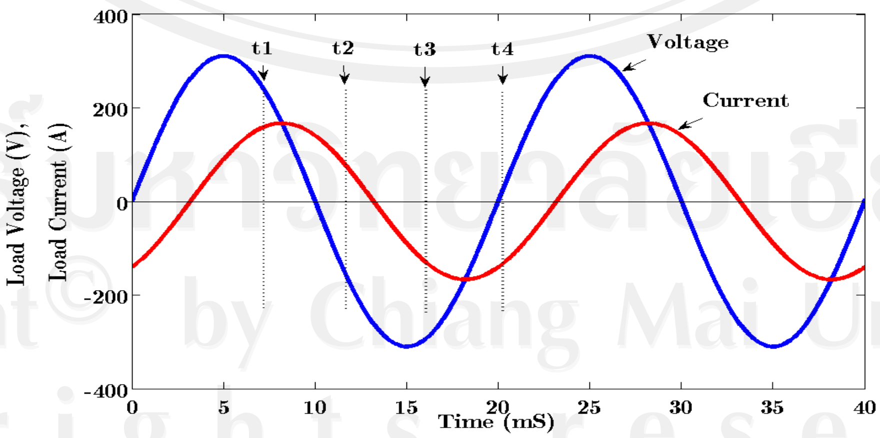


Figure 4.4 Key waveforms of the load current and load voltage in case of inductive load.

Figure 4.4 shows the key waveforms. The four operation stages are briefly described as follows:

[t1]: The voltage polarity and current direction are both positive and T1p is already turned on as shown in Figure 4.5. Due to voltage sag, the grid voltages are lower than alternate supply voltages. The transfer is started by inhibition of T1p trigger pulses and initiation of T2p trigger pulses [40], then T1p is turned off by reverse bias voltage, this operation is transfer mode. When T1p is completely turned off, the normal mode operation is started by initiation of the next thyristor trigger pulses (T2n).

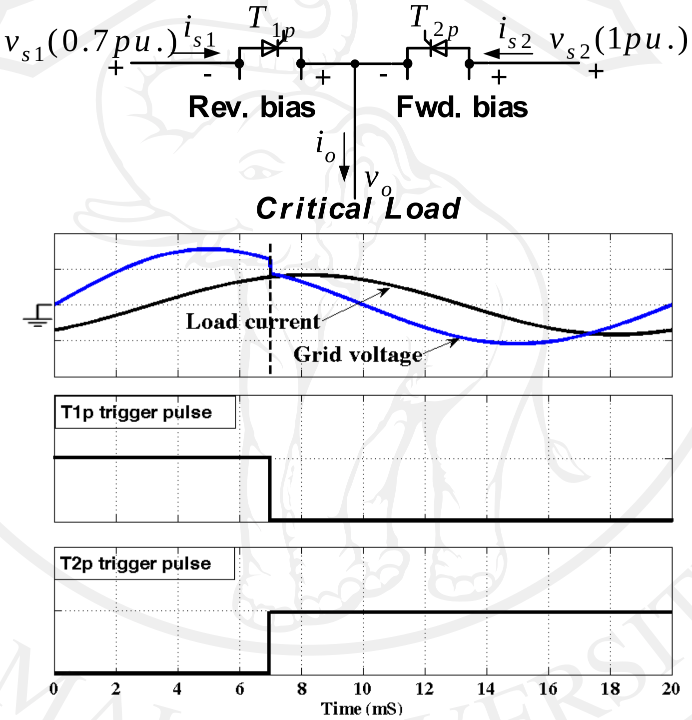


Figure 4.5 Load transfer in t1 stage.

[t2]: The voltage polarity is negative, current direction is positive and T1p is already turned on as shown in Figure 4.6. The transfer is started by inhibition of T1p trigger pulse and the delay time is required until T1p current become zero [15] (as transfer mode by zero current commutation) since voltage across T2p is reverse bias and then next thyristor (T2n) is trigged as normal mode operation. It can be noticed that forced commutation is not taking place and the delay time is introduced.

[t3]: This operation is identical to t1 stage, but the voltage polarity and current direction in this stage are both negative as shown in Figure 4.7. The transfer is started by inhibition of T1n trigger pulses and T2n trigger pulses is initiated respectively as transfer mode operation and T2p is subsequently trigged as normal mode operation.

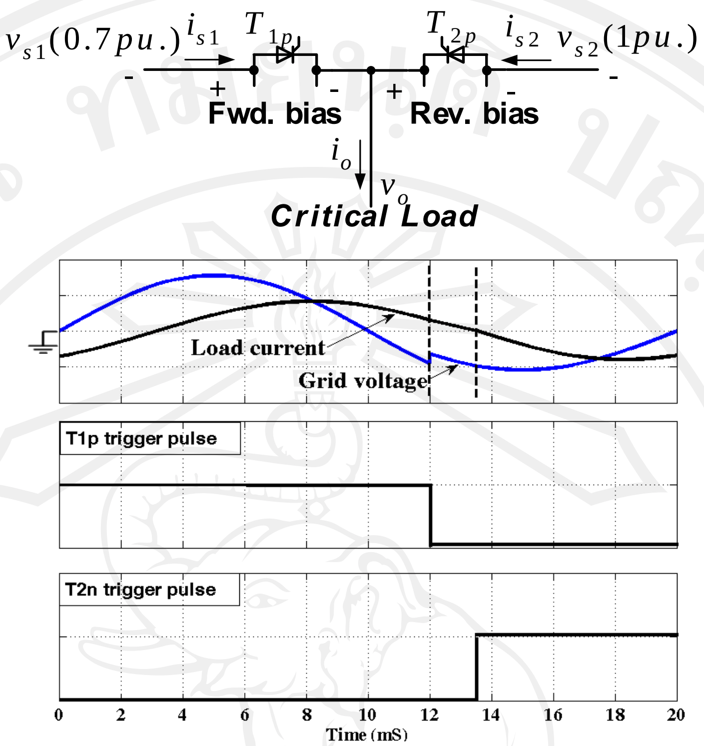


Figure 4.6 Load transfer in t2 stage.

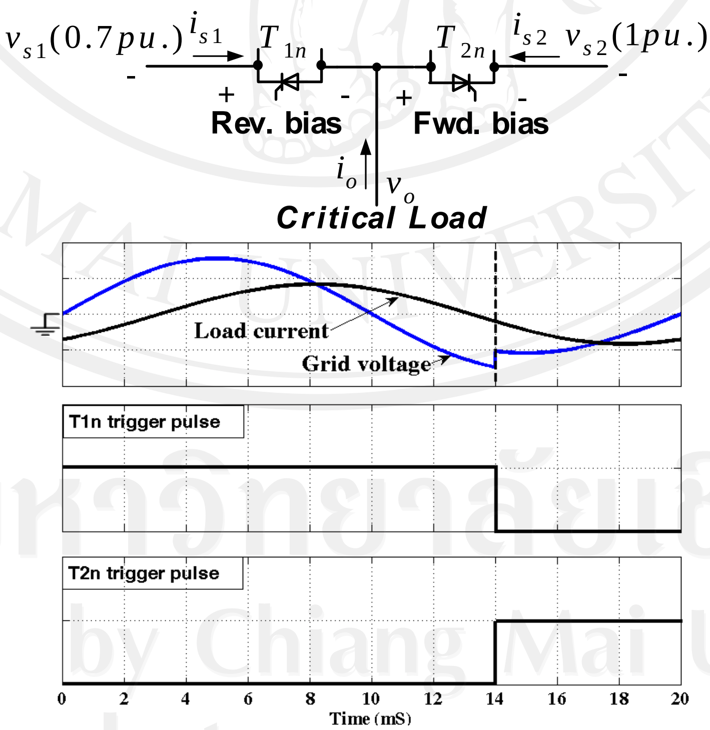


Figure 4.7 Load transfer in t3 stage.

[t4]: This operation is identical to t2 stage, but the voltage polarity is positive and current direction is negative as shown in Figure 4.8. The transfer is started by inhibition of T1n trigger pulses and waiting for T1n zero current (as transfer mode by zero current commutation) and the next thyristor, T2p is subsequently trigged as normal mode operation.

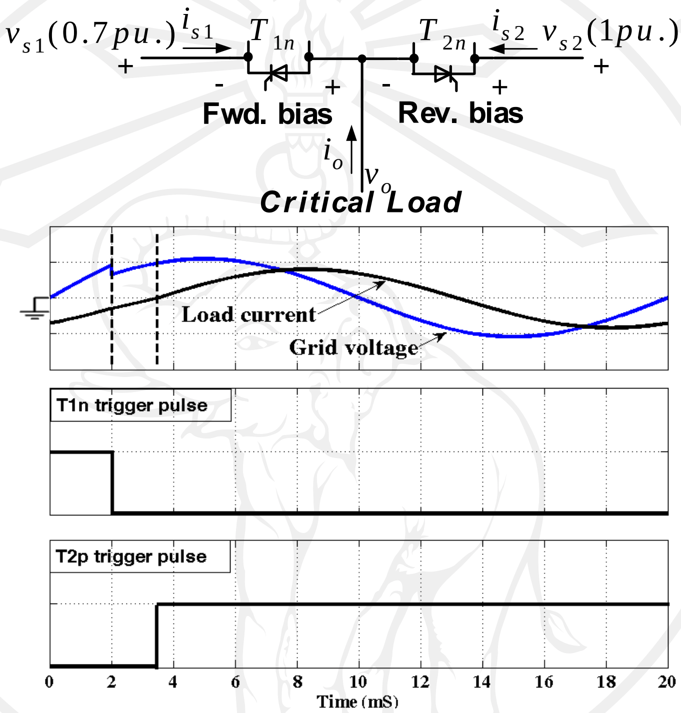


Figure 4.8 Load transfer in t4 stage.

In case of resistive load or practical non linear load such as traditional AC/DC converter, only t1 and t3 stage is taken place since the voltage polarity and current direction are always the same. In other words, there is no delay time from thyristor commutation for resistive and practical non linear load transfer.

4.3 Simulation results

To verify the validity of a static transfer switch operation, the computer simulation was used. This computer simulation is based on Matlab/Simulink program with various types of loads as shown in Table 4.1

It can be seen that the point-on-wave initiation of 0.7-pu voltage sags occurred in t1 stage (i.e. 126 degrees or 7 ms) and t2 stage (i.e. 198 degrees or 11 ms). The voltage sag detection time was supposed to be 1 ms.

4.3.1 Case of linear load (inductive load)

The inductive load in this simulation consists of 10-Ω resistor and 50-mH inductor in series. This inductive load has the power factor of 0.537 (57.5 degrees or 3.19 ms)

Table 4.1 Simulation Setup Parameters.

Grid phase voltage	220 Vrms, 50 Hz
Point-on-wave(POW) initiation of voltage sags	-t1: 126 degrees(7 ms) -t2: 198 degrees (11ms)
Voltage sags	0.7pu
Voltage sag detection time	1 ms
Loads	-Linear loads (RL) -Nonlinear load (Rectifier + RC)

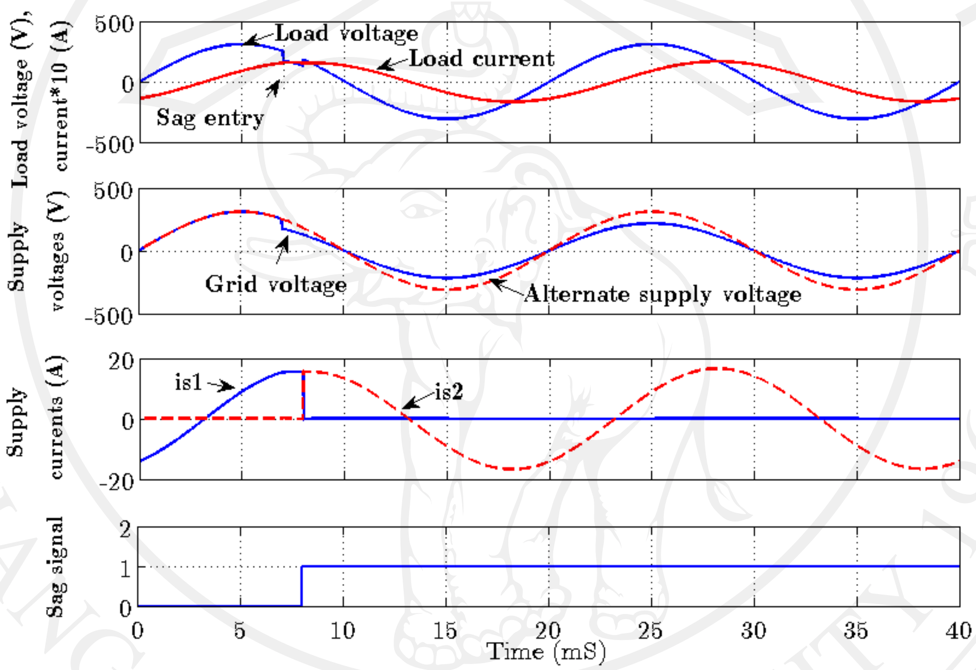


Figure 4.9 Operation of STS with inductive load in t1 stage.

A. Operation of STS in t1 stage

In this simulation, the voltage sag was taken place at 126 degrees or 7 ms and STS was started the transferring process after the voltage sag was detected in 1 ms later on.

From Figure 4.9, it can be seen that the load voltage amplitude was reduced by 0.3pu during the time of 7 ms to 8 ms. This is because of the voltage sag occurred but the transfer process is still not initiated.

When the voltage sag was detected then the load transferring process can be immediately initiated. This is because of the similarly of load voltage polarity (+) and load current direction (+), therefore the transferring process can be started by stopping the T1p trigger pulse and then starting the T2p trigger pulse. It can be noticed that the conducting of T2p will generate the reverse bias voltage of T1p and the T1p was force commutated by this reverse bias voltage. Finally the load current was transferred from T1p to T2p immediately. It can be seen that the transfer process was succeeded whenever the voltage sag was detected.

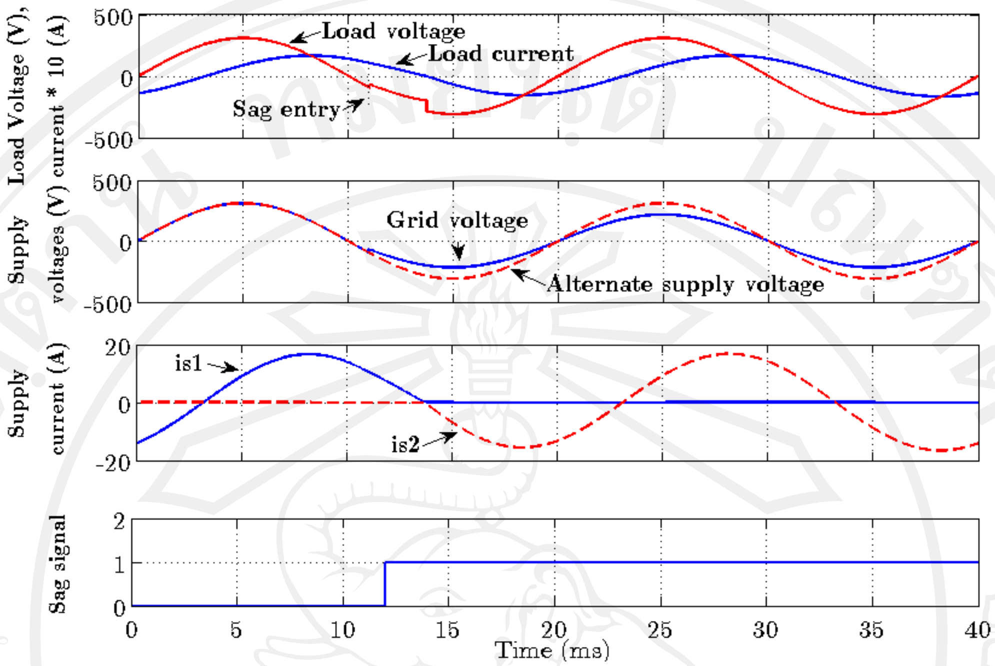


Figure 4.10 Operation of STS with inductive load in t2 stage.

B. Operation of STS in t2 stage

Figure 4.10 shows the simulation result in case that voltage sag occurred at t2 stage (198 degrees or 11 ms) and the static transfer switch was initiated the transfer process at the time of 12 ms by stopping the trigger pulse of T1p. It can be seen that the voltage polarity of grid voltage is negative and the load current direction is positive then the T2p was reverse biased and T1p is still conducted even no trigger pulse. The load transferring will be succeeded when the load current decreases to zero at the time of 13.19 ms then the T2n was trigged to start the normal mode operation.

It can be noticed that transferring of the inductive load in t2 stage will provide some delay time. This delay time was defined as Td2 and equal to power factor angle – voltage sag detection time (Td1) – point-on-wave initiation time (3.19 ms – 1 ms – 1.19 ms) as shown in Figure 4.11.

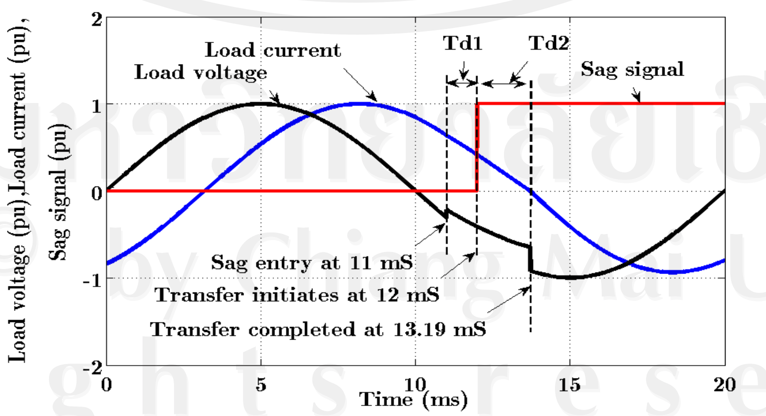


Figure 4.11 Extended view of delay time from inductive load transferring in t2 stage.

4.3.2 Case of nonlinear load

The load in this case consists of three-phase bridge diode with 4,700 *m*F capacitor and 10 W resistor.

Figure 4.12 shows the simulation result, it can be seen that the voltage polarity and current direction are identifical for the first half cycle or the second half cycle. When the voltage sag is taken place at time of 22 ms and the transfer process begins at 23 ms. It can be seen that the transfer process was succeeded whenever the voltage sag was detected without delay time. This is the same case as inductive load transferring at t1 and t3 stage and load voltage was temporary dropped and equal to only voltage sag detection time (Td1).

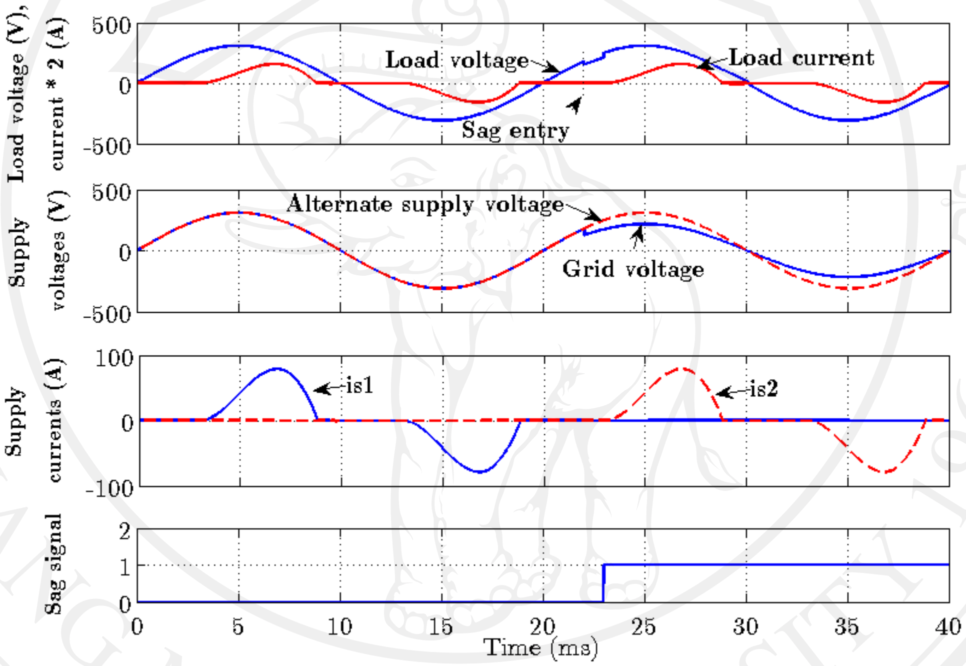


Figure 4.12 Simulation result of non linear load transferring.

4.4 Conclusion

The static transfer switch (STS) was described in this chapter. The STS is necessary device for transferring the load from grid voltages to alternate supply voltages when the voltage sag occurs. However the process of load transferring depends on type of loads. In case of resistive load and non linear load (rectifier+RC), the current transferring can be performed without delay time in any of stage (t1, t2, t3 or t4). This is because of the grid voltage polarity and load current direction is identifical in any time. In case of inductive load, the current transferring can be performed without delay time in only t1 stage and t3 stage but transferring at t2 stage and t4 stage will lead to some delay time (Td2).