The Effect of the Static Transfer Switch on Power Quality of Power System

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***Abstract* — Voltage drop and voltage fluctuations are one of the most important power quality problems of power networks. There are so many sensitive loads like electronic controllers, microprocessors and instrumentations like PLCs in power system that are very sensitive to disturbances and their operation could be affected easily by Power Quality Problems. Uninterruptable sources and static switch are used to prevent disturbance in sensitive loads. When a fault occurred in main source side, a static switch can disconnect the main source and connect the alternative source in few milliseconds. In this paper, the impact of static transfer switch performance on power quality in presence of any faults such as one phase, two phase and tree phase faults and motor starting in power system are studied.**

***Index Terms* — Power quality, Static transfer switch, Sensitive loads, Flicker, THD.**

I. INTRODUCTION

In recent years the quality of power delivered to sensitive loads such as uninterruptible power supplies (UPSs), processors and microprocessors and electronic controllers, computers, data systems, telecommunication systems and etc… are taken into consideration. The Electric Power Research Institute (EPRI) has predicted that in the near future, more than half of the loads connected to the power system will be equipped with microprocessor devices [1]. Using power electronic semiconductors devices such as thyristors in distributed power systems with fast and effective control of power supply has led consumers to feed continuously unaffected by any fault. One of these semiconductor devices is static transfer switches (STS's) that plays important role in delivering high quality power to the sensitive loads [2-3]. Sensitive loads in power systems, often are fed by two separate sources (main and alternative sources). In the event of a fault in the main source, it must be quickly disconnected from the system and the alternative source feeding the load as soon as possible. Power transfer operation can be performed by a typical switches or static transfer switches. Static transfer systems are intelligent switches providing increased supply availability, automatically transferring loads to alternative power sources when the primary power source fails or is not available. Static switches are equipped with a control system that compares the voltage in two sides, identifies the faulted sources, disconnect it and connect the other one. Fig.1 schematically shows an overview of a power system with an STS.

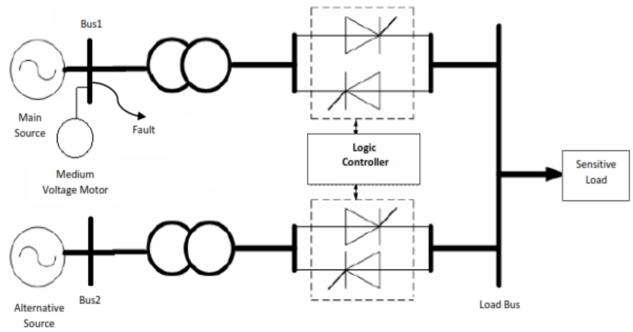

Fig.1. Typical schematic of a power system equipped with STS [4]

Static transfer switches are used as a main part in on-line UPSs. Recently, because of the extremely high speed of STS than regular switches, these switches preferred to use in low voltage and medium voltage networks. In addition to reducing the delay time caused by switching between two power sources, using STS can led to reducing the fault level of the network. This advantage has an important role in developing distribution networks (typical and smart) such as connecting some DGs. In general, using static switches helps to improve the power quality of the network. Other studies show that if the static switch is used, the amount of voltage sag can be reduced from 10% to less than 5% [4]. According to research in reference [5], the switching time of STS in presence of fault, has been estimated among 0.95 to 6.25 milliseconds that seems to be very short in comparison to typical switches'

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operation. In reference [6], the STS's operation time at motor startup was obtained between 5.2ms to 5.43ms. Studies in reference paper [7] showed that if the static switch is used instead of a typical switch, moreover reducing the time interval moreover from seconds to milliseconds, system reliability increases greatly. In this paper, the STS operation's impact on the power quality of the network in presence of any fault has been evaluated.

II. CASE STUDY SYSTEM'S CHARACTERISTICS

A sample network shown in Fig. 1 consists of two main and alternative sources. Table I shows the system's characteristic. Static switches are connected through the power transformer to the grid. A medium voltage motor is connected to Bus 1 for studying the performance of static switch at startup time.

TABLE I
Characteristics of the Studied System

No	Element	Characteristic
1	Power system	50Hz, 6.3kV
2	Motor	6.3kV, 2MVA, 50Hz
3	Transformer	3ph, 2 Winding Star-Delta, 6.3kV/0.415kV, 5MVA
4	Sensitive RL load (ohm)	1.156+0.964j
5	Static Switch	Thyristor

Then, the performance of static switch and typical switch in presence of various types of faults and medium voltage motor starting has been evaluated. Fig. 2 shows the performance of STS. At first the voltage converted from ABC to dq0 form. Then a comparator unit sends a performance command to switches by comparing the sources voltage. NOT gate turns on the main source's off-thyristors and the alternative source connect to system. It should be mentioned that the fault detection units are same in two types of switches.

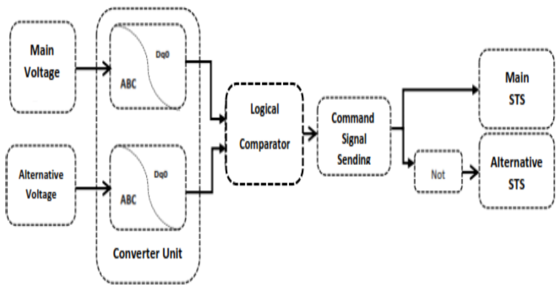

Fig.2. Fault Detection and Switching System

III. POWER QUALITY PARAMETERS

A. Voltage Sag

Voltage sag is the one of the parameters of power quality that occurs between 8 milliseconds to a minute. The factors caused voltage sag are motor starting and also faults in power transformers [7, 8]. Equation (1) is used to calculate the voltage sag. Often the voltage sag varies between 10 to 90 percent of system voltage.

$$V_{sage}\% = \frac{V_{avg} - V_{\min}}{V_{avg}}\% \qquad (1)$$

B. Flicker

Flicker is Gleaming light in lamps that caused by voltage domain's Fluctuating. Switching various loads is the one of the reasons, because generally the inrush current at startup moment (switching) is higher than the steady state. One of the typical and important resources of flicker phenomenon is motor starting in grids. Also loads that work periodically such as arc or spot-welding machines, electric arc or induction furnaces make sudden changes in supply voltage and thus will cause flicker. Other source of flicker is power factor correction capacitors in the networks. STS switching can cause flicker. There are some differences between voltage sags and flicker because flicker occurs periodically, but voltage sag occurs only once [9, 10].

To evaluate the severity of flicker, flicker-meters are used. IEC61000-4-15 standard has been introduced a simple tool for describing the light flicker through voltage flicker [10]. Flicker-meter is a device that modulates the flicker contaminated voltage, evaluate it by flicker curves and then run a Statistical Analysis on processed information. This tool simulates the transfer function "lamp-eye-brain" and introduces a basic criterion of short-term flicker (Pst) [11]. If 50% of sample participants observed the gleam of light by voltage fluctuations, the Pst value considered to be equal to one. For measuring the short-term flicker or Pst criteria it is necessary to sample the voltage for ten minutes. Another benchmark for flicker is Plt that voltage sampled for over two hours long and calculated by equation (2) [12].

$$P_{lt} = \sqrt[3]{\frac{\sum_{i=0}^{N} P_{sti}^{\ 3}}{N}} \qquad (2)$$

N is equals 12 for two-hour measurements.

C. Harmonics

Sources of harmonics in the power network are equipment often non-linear and switching power supplies like transformers, fluorescent lamps, power electronics, rectifiers, and etc…, which have a negative impact on system performance, and other sensitive loads [12]. So, the amount of total harmonic distortion (THD) in the power grid mustn't exceeded values specified in the standard. Voltage and current total harmonic distortions are calculated in equations (3) and (4) [13].

$$THD_v\% = \frac{\sqrt{\sum_{n=2}^{n_{\lim it}} V_n^2}}{V_1} \quad (3)$$

$$THD_i\% = \frac{\sqrt{\sum_{n=2}^{n_{\lim it}} I_n^2}}{I_1} \quad (4)$$

V_n and I_n are the rms value of voltage and current. For more certainty consider $n_{\lim it}$ equal to 50.

IV. SIMULATION RESULTS

In normal condition, main source feeds the motor and sensitive load. But when a fault occurs, STS's logical controllers send the disconnecting main source signal and connect the alternative one. The consumer which is connected to grid is a sensitive RL load. All of simulations in this paper has been done in PSCAD / EMTDC software. To calculate the severity of flicker, MATLAB software is used. Source transmission time (delay), the severity of flicker (Pst), rate of voltage sag and THD are calculated for both static and normal switches in different fault situations (single-phase to ground, two-phase, two-phase to ground, three-phase, three-phase to ground), out of phase (one-phase, two-phase, three-phase) and motor starting. All types of faults are occurred in t_f=100s.

The continuation time of all types of faults is equal to 1 second. Fig.s (3-4) show load voltage-time curve of the two types of static switch (green curve) and typical breaker (blue curve), respectively under the conditions of three-phase to ground fault and three-phase outage at t_f=100s. As the Fig. 3 and Fig. 4 show, till the fault not occurred, the load voltage curves in both type of switch are coincided but after fault occurrence, typical switch brought back voltage curve to normal condition with higher delay than STS. Also, the effect of typical switch and STS performance on load's voltage during motor start up is shown in Fig. 4.

As the following figures show, STS connect the alternative source in less time than conventional switch and its voltage curve is much more continuous than typical one. In general, the effect of the static switching compared to the conventional switching on power quality of the network has been studied and so the results are written in Tables II to V.

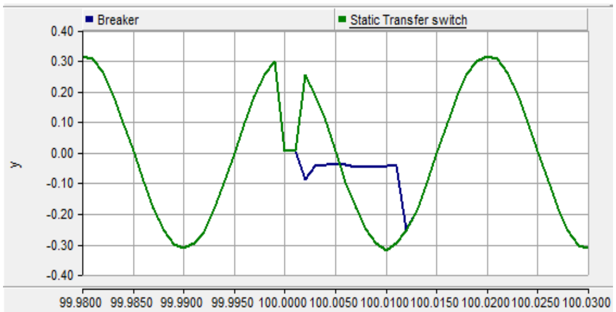

Fig. 3. Performance comparison between STS and conventional switch when a three-phase to ground fault is occurred.

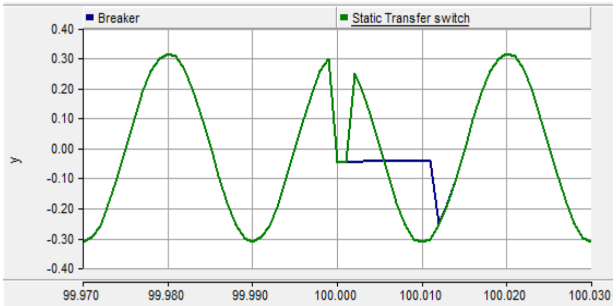

Fig. 4. Performance comparison between STS and conventional switch when a three-phase outage is occurred.

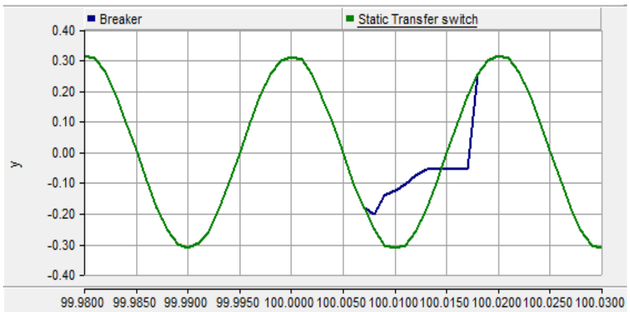

Fig. 5. Comparison of load voltage curve in two types of switch performance when a MV motor is started.

V. CONCLUSION

This paper has been investigated the effect of switching in typical and static thyristors on power quality of network like load transmission time (delay), voltage sags, voltage harmonics (THD), and the severity of flicker (Pst). As shown in the simulation results, the static switch in every type of fault has a higher speed (10 to 20 times faster) than the normal switch and also the lower voltage sag percent. STS produces harmonics higher than other one but less than low voltage standard values. With using STS, Pst is lower in every fault condition. But in general, STS has more acceptable performance than typical one.

TABLE II
Transfer Time Comparison in STS and Typical Switch (in milliseconds)

Fault type	Static switch	Typical switch
Single phase	2.8	12.8
Two-phase	1.2	11.4
Two-phase to ground	0.6	10.8
Three-phase	0.6	10.8
Three-phase to ground	0.6	10.8
Motor starting	0.64	13
Single-phase outage	2.4	13.4
Two-phase outage	0.6	11.4
Three-phase outage	0.6	11.4

TABLE III
Pst Comparison in Static and Conventional Switches

Fault type	Static switch	Typical switch
Single-phase	0.2622	3.0155
Two-phase	0.466	2.8994
Two-phase to ground	1.5793	2.7551
Three-phase	1.6150	2.9196
Three-phase to ground	1.8108	2.9193
Motor starting	0.9602	2.9486
Single-phase outage	1.2672	3.1657
Two-phase outage	0.9950	2.9335
Three-phase outage	2.0770	2.8667

TABLE IV
THD Comparison in Static and Conventional Switches

Fault type	Static switch	Typical switch
Single-phase	0.710	0.656
Two-phase	0.621	0.675
Two-phase to ground	0.689	0.641
Three-phase	0.653	0.728
Three-phase to ground	0.685	0.573
Motor starting	0.775	0.760
Single-phase outage	0.569	0.570
Two-phase outage	0.583	0.569
Three-phase outage	0.587	0.584

TABLE V
Voltage Sag Percent Comparison in Static and Conventional Switches

Fault type	Static switch	Typical switch
Single-phase	1.88	26
Two-phase	8.49	25.4
Two-phase to ground	17.45	25.94
Three-phase	17.92	30.18
Three-phase to ground	20.23	29.71
Motor starting	2.83	33.01
Single-phase outage	0.48	25.47
Two-phase outage	6.13	29.71
Three-phase outage	15.1	30.66

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