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MITIGATION OF VOLTAGE SAG WITH VARIOUS FIRING ANGLES ON REAL TIME

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Abstract
To improve power quality with adequate solutions, it is necessary to know what kinds of disturbances occurred. A measurement system must be able to automatically detect, characterize or classify disturbances and for mitigation. This paper investigates mitigation techniques for voltage sag in on line conditions with different defined firing angles. The results of investigations are presented. The focused area is the online voltage sag mitigation is carried out on a tailor made experimental set up using the various topologies of SVC and booster transformer. The Comparative analysis and these devices are presented. In this paper introduces the various topologies for mitigation of voltage sag. Here the main objective is to mitigate the voltage sag in real time with the use of different topologies of static var compensators with various defined firing angles. Under the Static var Compensator various combinations of inductor, capacitor and triac are used and results are discussed and compared. For static var compensator and booster transformer, the comprehensive results are presented to assess the performance of each device to mitigate the voltage sag. The switching events like change of transformer taps, starting of induction motor are used to create the voltage sag. These events are controlled through FPGA based algorithm.
Keywords – Static Var Compensator, Booster Transformer, Voltage sag, Fuzzy Logic, Firing Angle.

Introduction

The rapid development of power electronics technology provides exciting opportunities to develop new power system equipment for better utilization of existing systems. FACTS devices can be effectively used for power flow control, voltage regulation and mitigation of oscillations. It is defined as “a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability”.

Literature survey is useful to understand in the depth of knowledge of problem and for proper problem formulation. It shows that, research in the area of analysis of PQ disturbances has been increasing from last many years and it is still scope for innovations by developing new tools and techniques. Almost all of the articles presented have provided some new and relevant information.

EXPERIMENTAL SETUP AND PROPOSED REAL TIME VOLTAGE SAG MITIGATION ALGORITHM

The online performances of mitigation techniques for voltage sag are studied in the laboratories through tailor made experimentation setup. Figure 1 shows the block diagram of experimental setup used for mitigation of voltage sag in the laboratory of proposed algorithm. The main components of the system are Single phase transformer - 2 KVA, 230/230 V, having taps at every 10 volts on primary as well as secondary side, single phase induction motor used as source of voltage sag, Advantech data acquisition card (PCLD-8710), FPGA based Controlled switching logic controller for creation of sag at various inception angles, Mitigation device like SVC, booster transformer etc. are as under.

Firing angle controller scheme

Fuzzy logic controller is designed to achieve the firing angles for SVC such that it maintains voltage profile. In the decision-making process, there is rule base that linking between input and output signal. Figure 2 and 3 shows the input and output variables. When the error voltage (Vpu – Vbasepu) is small, firing angle is large.

The rule bases used in this FL controller are:

1. if (input1 is mf1) then (output1 is mf3)
2. if (input1 is mf2) then (output1 is mf2)
3. if (input1 is mf3) then (output1 is mf1

Proposed SVC topologies and Booster Transformer

Various topologies of SVC are implemented in the laboratory to mitigate the voltage sag. It is a thyristor-controlled or thyristor-switched reactor, and/or thyristor-switched capacitor or combination. The topologies used for experimental are shown in figure 4,5,6, and 7 respectively. The 1kVAr capacitor and triac BT-12 are used in the schemes. The single phase 120 VA, 230/12 volt transformer is used as a booster transformer.

To mitigate the voltage sag, the following steps are involved-

i. Captured the one cycle of voltage signals of power quality disturbance such as voltage sag occurred due to any possible causes by using data acquisition system.
ii. Detect voltage sag using RMS /Peak/ Fourier/Missing voltage/WNN method.
iii. If voltage sag is detected, then calculate and change the firing angle using fuzzy control technique.
iv. Repeat the steps i to iii continuously.

RESULT AND DISCUSSIONS OF MITIGATION OF VOLTAGE SAG WITH VARIOUS FIRING ANGLE

The performances of SVC and booster transformer are understood by implementing the various topologies in online condition. The performances of these devices are analyzed at various switching instants. The sag is created at defined instants like 0^0 , 45^0 , 90^0 ,135^0 ,225^0 and 270^0 .

Switching instants is defined as instant through which a voltage signal is passing. The sag is created on the tailor made system using starting of induction motor, tap changing and sudden increase in load. For both Static Var Compensator and Booster Transformer developed for each method provide mitigation of the voltage sag. Due to space limitations, figure shown only anyone instance and in tabular form shows the various instance results.

Performance of topology –I

The performance of this topology is checked in real time by creating the sag using induction motor start and changing the tap position. The topology-I found useful in reduction of sag in depth and duration. Referring to figure 8[A] shows the voltage signal (p.u.) captured during the starting of induction motor. This motor is switched when voltage wave is passing through 0^0 rising. This figure shows nature of sag when with and without compensation provided. From this figure, the lowest value of voltage after disturbance observed is 0.7363 p.u. and after compensation i.e. topology-I it improves to 0.7488. Figure 8[B] shows the flag created when the sag has occurred. It is clear that, the duration of sag for without compensation technique is 14 cycles and reduces to 4 cycles when compensated. Figure 8[C] shows that the changes in the firing angle created by the fuzzy controller. Expanded view of voltage sag of figure 8 is shown in the figure 9. First 20 samples of voltage sag for without and with compensation are plotted. In this figure it is found that the duration of sag reduces considerably.

The performance of this topology during various switching instants is given in the table 1.

Performance of topology –II

In this topology, the controlling devices i.e. triac are connected in series with inductor. The lagging power is controlled through change of the current through inductor. Lot of challenges was faced for control of reactive power in this topology, as the current lags in inductive circuit. Figure 10[A] shows the voltage signal captured during the starting of induction motor. The motor is switched at 45^0 inception angle. From this figure, the lowest value of voltage after disturbance observed is 0.7539 p.u. and after compensation i.e. topology-I it improves to 0.7578. From figure 10[B], measured duration of sag for without compensation is 12 cycles and reduces to 2 cycles when compensated. Figure 10[C] shows that the changes in the firing angle created by the fuzzy controller. The performance of this topology during various switching instants is given in the table 2. Expanded view of this figure 10 is shown in the figure 11. In this figure it is found that the duration of sag reduces considerably.

Performance of topology –III

In this topology leading reactive power is controlled by insertion of triac in series with the capacitor. Here, again the sources of sag used are a) Start of induction motor b) Tap change of transformer.

The results of sag created due to the induction motor starting is shown in figure 12. Result shown is for inception angle of 90 degrees. From figure 12[B], during the sag, the lowest value of voltage observed is 0.7333 p.u. and after compensation it improves to 0.738. Duration of sag improves by approximately 9 cycles. Figure 12[C] shows that the changes in the firing angle created by the fuzzy controller. The expanded view is given in figure 13. The depth and duration obtained for various inception angles are tabulated in table 3.

Performance of booster transformer

The booster transformer is used for reduction of sag in this experiment. The experimental results for the sag crated due to induction motor start is shown in figure 14 and 15. It is observed that depth and duration of sag improves to 14% and 79.1 % respectively for switching instant of 135 degrees. The depth and duration recorded for various switching instants are given table 4.

Figure 14[B], it is clear that, the duration of sag for without compensation technique is 128 cycles and reduces to 30 cycles when compensated.

Table 1: Performance of topology-I at defined switching instants

Switching instant	DEPTH OF SAG(Lowest value of voltage after disturbance)		DURATION OF SAG	
	WITHOUT COMPENSATION	WITH COMPENSATION	WITHOUT COMPENSATION	WITH COMPENSATION
0	0.7363	0.7488	13.93	3.9
45	0.7345	0.7401	12.82	3.8
90	0.7372	0.7587	12.99	3
135	0.7493	0.7652	13	5
180	0.7193	0.7322	12.91	2.9
270	0.7312	0.7521	14.03	3.8

Table 2: Performance of topology-II at defined switching instants
(Source of sag- induction motor start)

Inception Angle	DEPTH OF SAG(Lowest value of voltage after disturbance)		DURATION OF SAG	
	WITHOUT COMPENSATION	WITH COMPENSATION	WITHOUT COMPENSATION	WITH COMPENSATION
0	0.7533	0.7807	11.94	2
45	0.7539	0.7578	11.62	2
90	0.7561	0.8031	11.6	2.8
135	0.7474	0.7604	11.88	2.8
180	0.7575	0.7865	12.95	1.9
270	0.7506	0.7617	11.83	2.7

Table 3: Performance of topology-III at defined switching instants

FIRING ANGLE	DEPTH OF SAG(Lowest value of voltage after disturbance)		DURATION OF SAG	
	WITHOUT COMPENSATION	WITH COMPENSATION	WITHOUT COMPENSATION	WITH COMPENSATION
0	0.7477	0.7671	12.76	3.6
45	0.7477	0.7558	12.61	4.6
90	0.7333	0.738	13.12	4.7
135	0.7573	0.8094	12.58	3
180	0.7427	0.7552	12.57	2.7
270	0.74	0.7862	12.73	3.9

Table 4: Performance of booster transformer at various inception angles

FIRING ANGLE	DEPTH OF SAG(Lowest value of voltage after disturbance)		DURATION OF SAG	
	WITHOUT COMPENSATION	WITH COMPENSATION	WITHOUT COMPENSATION	WITH COMPENSATION
0	0.6364	0.6636	42.75	4.6
45	0.6526	0.6836	16.93	5
90	0.6601	0.6661	18.87	8.8
135	0.6491	0.6706	17.91	10
180	0.6576	0.6751	17.02	7
270	0.6582	0.6659	17.95	9.9

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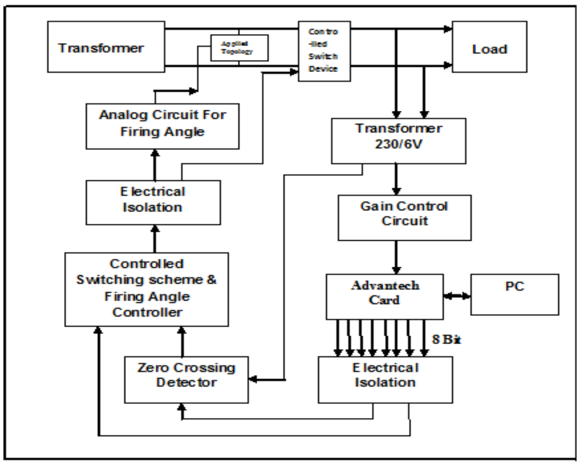

Figure 1: Block diagram of Experimental setup

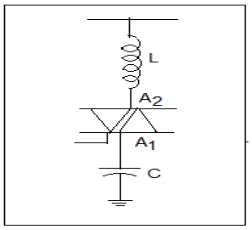

Figure 4: TSC Topology (topology-I)

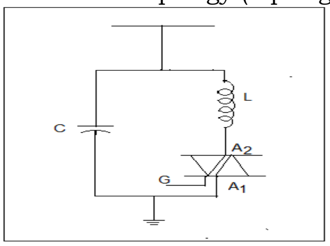

Figure 5: TCR-FC topology (Topology- II)

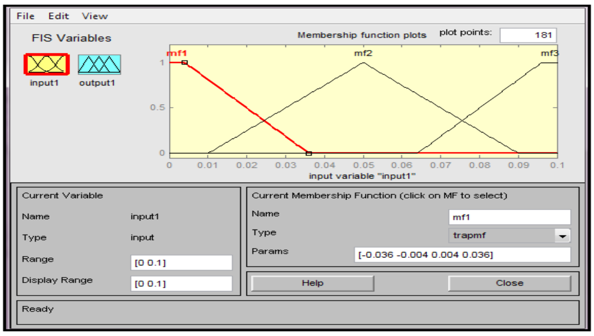

Figure 2: Input variable

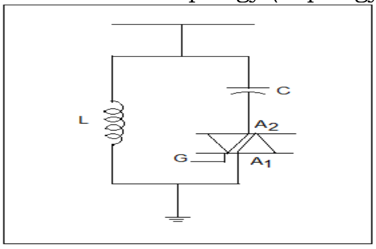

Figure 6: Topology- III for SVC

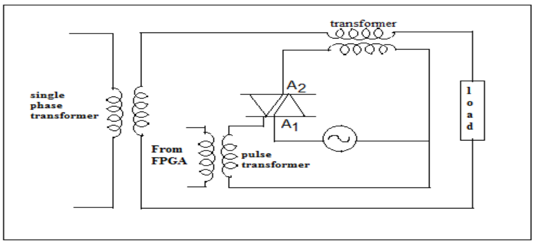

Figure 7: Booster transformer

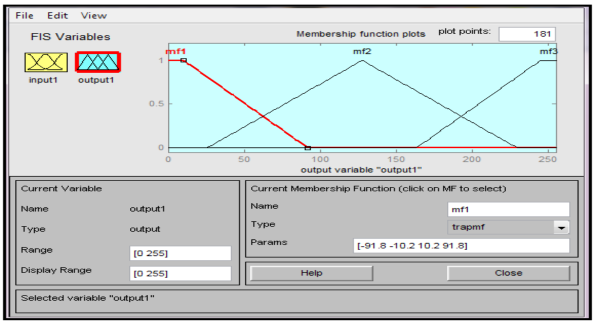

Figure 3: Output variable

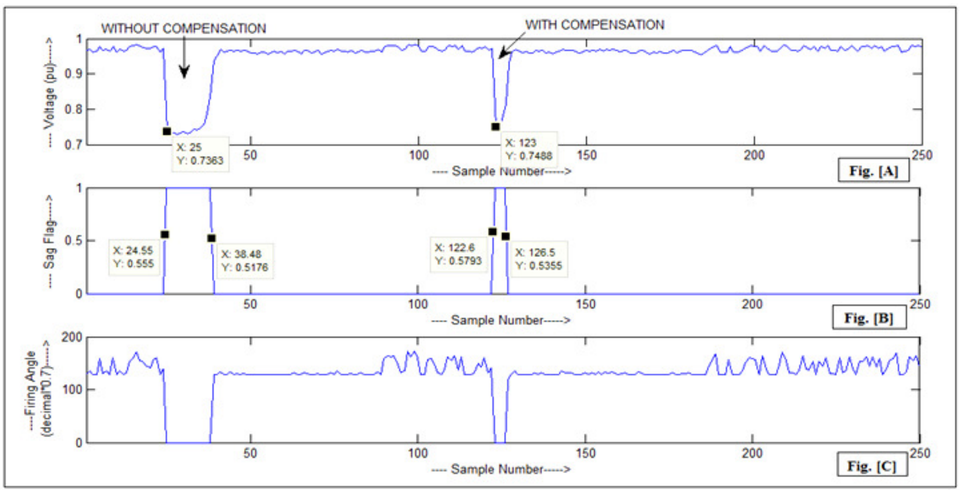

Figure 8: Online mitigation of voltage sag using topology 1 at 0° switching instant (starting of an induction motor)

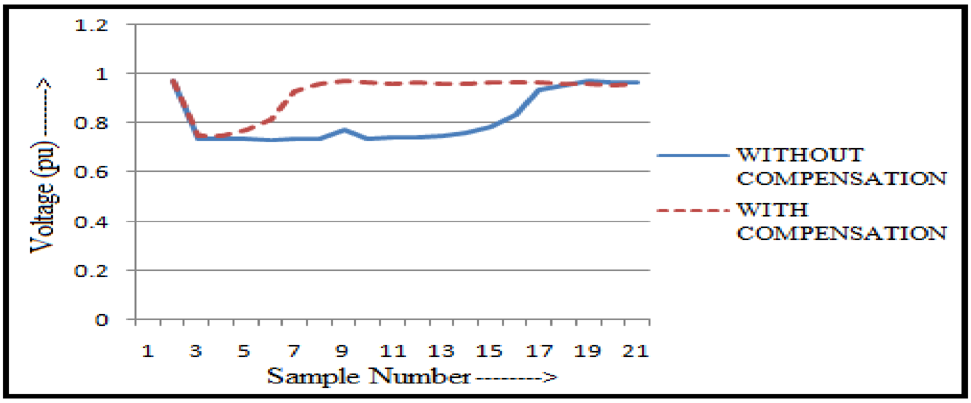

Figure 9: Expanded view of voltage sag (due to induction motor Start) during with and without compensation, using topology 1 at 0° switching instant

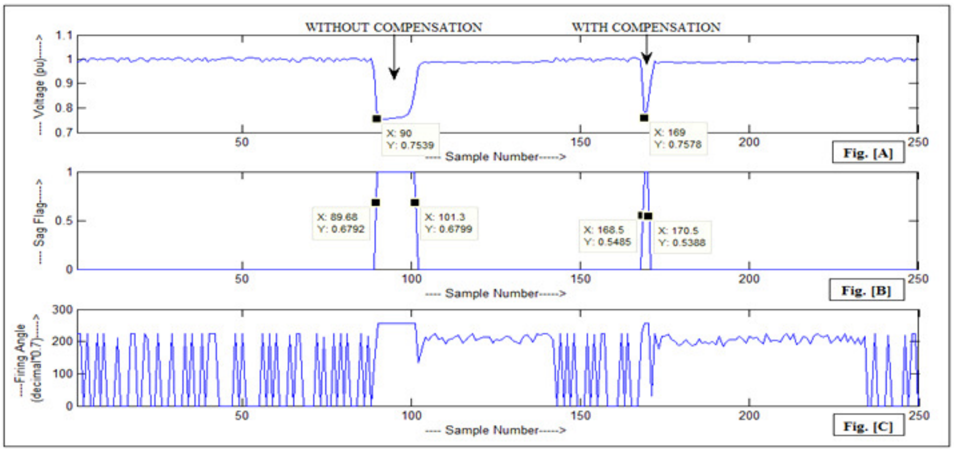

Figure 10: Online mitigation of voltage sag using topology-II at 45° switching instant (starting of an induction motor)

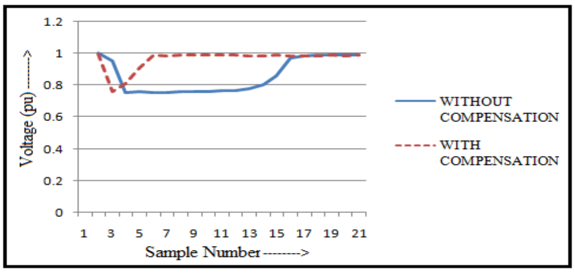

Figure 11: Expanded view of voltage sag (due to induction motor Start) during with and without compensation, using topology-II at 45° switching instant

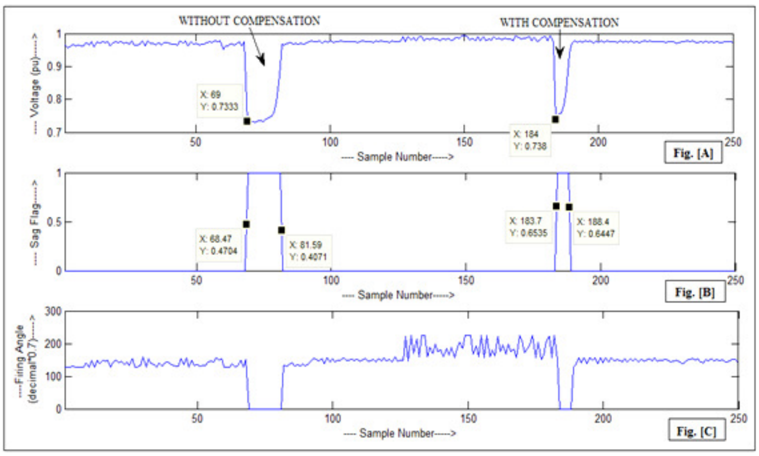

Figure 12: Online mitigation of voltage sag using topology-III at 90° switching instant (starting of an induction motor)

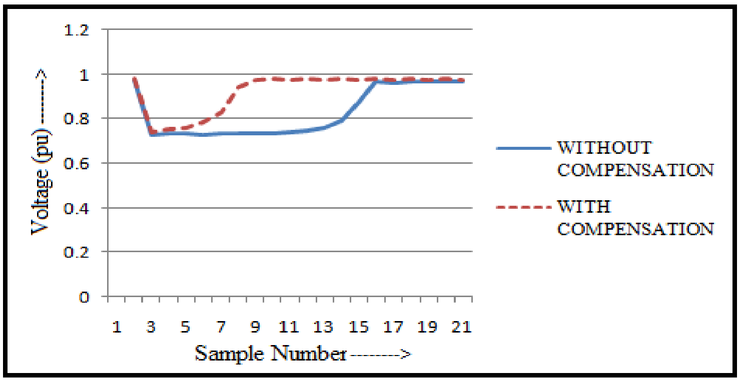

Figure 13: Expanded view of voltage sag (due to induction motor Start) during with and without compensation, using topology-III at 90° switching instant

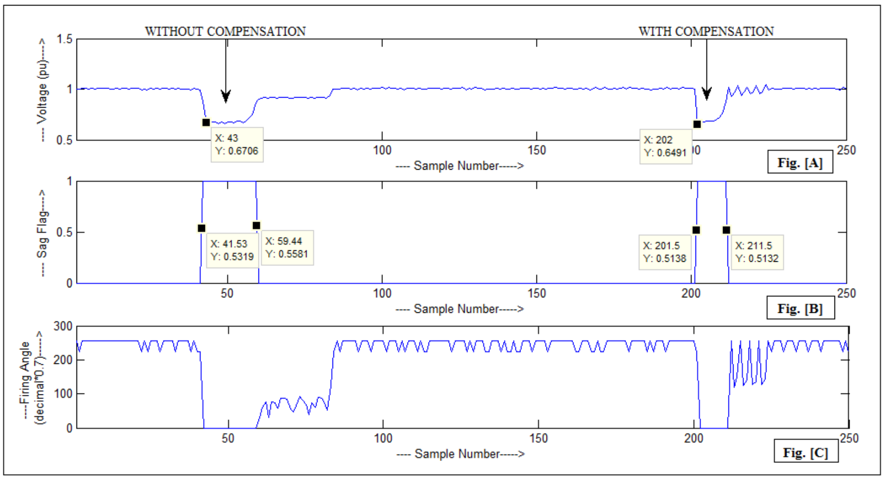

Figure 14: Online mitigation of voltage sag using booster transformer at 135° switching instant (starting of an induction motor)

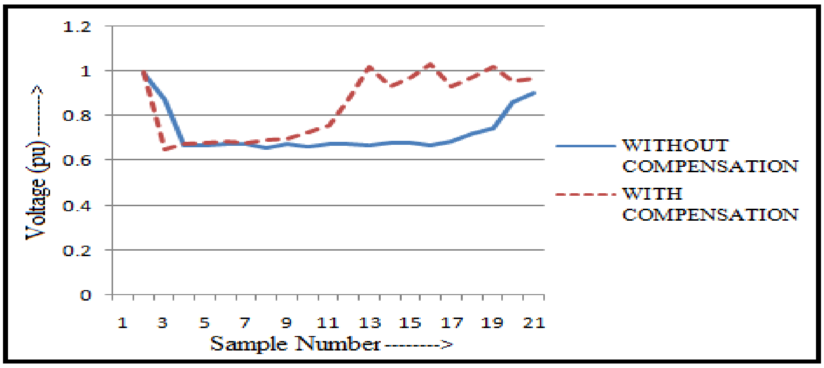

Figure 15: Expanded view of voltage sag (due to induction motor Start) during with and without compensation, using booster transformer at 135° switching instant

Conclusion

The power quality signatures or categories are defined with their cause and effects in this paper. The most important power quality signatures are the voltage sag, because it can occur on utility systems both at distribution voltages and transmission voltages. The detailed theoretical and experimental work is carried out for mitigation of voltage sag signature.

Online results are presented in this paper. The experimental work is carried out on the tailor made system for the mitigation of voltage sag. The voltage sag is created using various means like-starting of induction motor, tap changing of transformer. Mitigation of voltage sag is done in real time using the two devices i.e. Static var Compensator and booster transformer. The inception angles of switching of these devices are controlled through FPGA based controlling algorithm and different inceptions angles are provided in this paper.

Topology-III of SVC provides better control of reactive power to mitigate the sag. The best result obtained for this topology in improvement of depth and duration of sag is 13.485 % and 41.1% respectively. In booster transformer, the best result obtained is 26.06 % in reduction in depth and 98% reduction in duration of sag.

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