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HARMONIC ANALYSIS OF A NON-CONVENTIONAL HVDC SYSTEM

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Abstract- The advent of power electronics and proliferation of non-linear loads in industrial power applications, power harmonics and their effects on power quality are a hot topic of concern. Harmonics are the by-products of modern electronics. They occur frequently when there are large numbers of personal computers (single phase loads), uninterruptible power supplies (UPS), variable frequency drives (AC and DC) or any electronic device using solid state power switching supplies to convert incoming AC to DC. Non-linear loads create harmonics by drawing current in abrupt short pulses, rather than in a smooth sinusoidal manner. The harmonics can be described as "a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency." Some references refer to "clean" or "pure" power as those without any harmonics. But such clean waveforms typically only exist in a laboratory. This paper aims to compare the harmonic outputs of the conventional inverter and star-delta inverter. PSCAD/EMTDC software is used in simulation of the output harmonics of the mentioned inverters. Results show that the star-delta inverter gives similar output harmonic behavior like the conventional inverters.

Keywords: Harmonics, HVDC, Inverters, Converters.

I. INTRODUCTION

HVDC systems are used for bulk power transmission and for system interconnection [1]. With a HVDC system, both the power flow level and the direction can be controlled rapidly and accurately. For some cases existing distribution systems can be increased very effectively by converting the AC lines into HVDC. Converting existing AC lines to DC for increasing power transmission have been an interesting topic for scientists [2, 3, 4]. For this purpose conventional converters have been used. Some researches have been done by considering dynamic model for an AC-DC power system for improving power system stability [5-6] also Islanding fault of rectifier and inverter substations are studied in HVDC system both in back to back and long transmission line systems [6-7].

New FACTS techniques provide an opportunity to realize the above-mentioned problems practically. FACTS and HVDC are complementary systems [9]. The star-delta converter is a converter developed for this purpose and enables to convert the three phase AC power to three lines of DC output at rectifier mode [10]. The star-delta converter converts the three lines of DC into three phase of AC in inverter mode.

II. STAR-DELTA CONVERTER

The Star- Delta converter is designed such that, the lower three valves are kept but the upper three valves are split into two halves as in Figure 1. This configuration enables to supply three different DC loads or use three present AC lines for DC transmission. The split pairs are controlled by the same gate signal as their parent valves.

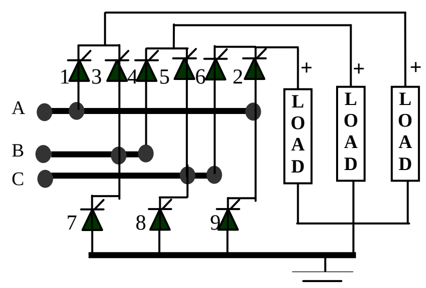

Figure 1. The star-delta three phase bridge rectifier

Figure 1 gives the rectifier configuration of the star-delta converter. The operation is the same as traditional six valve converters. The (1,2), (3,4) and (5,6) pairs of valves in Figure 1 are fired together like the three upper valves of traditional six valve converters. The lower three valves are also controlled in the same way as the six valve converter. This is the reason why the same control circuit for firing the valves can be used for star-delta converter. Figure 2 shows the hexagon design of the star-delta converter and this figure shows the star and delta configurations of valves and the load together and this is why the converter is called star-delta converter.

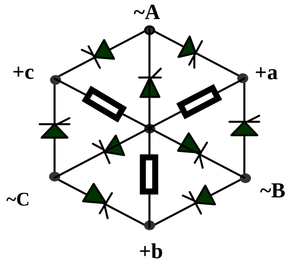

Figure 2. The star-delta rectifier bridge (hexahedron design)

III. HVDC SYSTEM BY THE CONVERTERS

The star-delta rectifier and inverter can be modified to have a more representative scheme in Figure 3 to explain the advantage of the transmission system to be designed by the converters. Figure 4 represents the inverter for AC-DC-AC power transmission. The control system of the converters is the same control system for traditional six valve bridge converters. The spitted pairs of the original converter are controlled by the same gate signal as their parent valves.

The main advantage of the designed converter system is the AC-DC and DC-AC converters have three extra bi-directional valves per converter, during AC-DC-AC they help fully utilize three lines of existing AC transmission as DC transmission (increasing the transmission capacity). Another advantage of the system is that, it is also possible to switch back to AC-AC transmission by keeping valves 1, 4 and 6 in conduction and turning off the rest six valves.

If all valves of the converters are bi-directional, the AC-DC-AC (HVDC) transmission will be also bi-directional, and each converter can be used as either rectifier or inverter depending upon the direction of AC-DC-AC transmission direction. The system enhances controllability

To gather detailed information the possibility of operation of the proposed system transient and steady state analysis have been conducted employing PSCAD/EMTDC modeling software Educational Edition version 3. PSCAD/EMTDC is an industry standard simulation tool for studying the transient behavior of electrical networks.

Its comprehensive library of models supports most AC and DC of power plant components and controls in such a way that FACTS, custom power, and HVDC models can be modeled with speed and precision [9]. For the system the star-delta rectifier and inverter are designed in PSCAD/EMTDC as given in Figures 3 and 4, respectively.

The HVDC STATCOM example of PSCAD/EMTDC is adapted for the star-delta system. The sending and receiving end Generation configuration are kept same as the PSCAD/EMTDC example as given in Figures 5 and 6, respectively. Electrical power can be transmitted both ways. The converters are Voltage Source Converters (VSC).

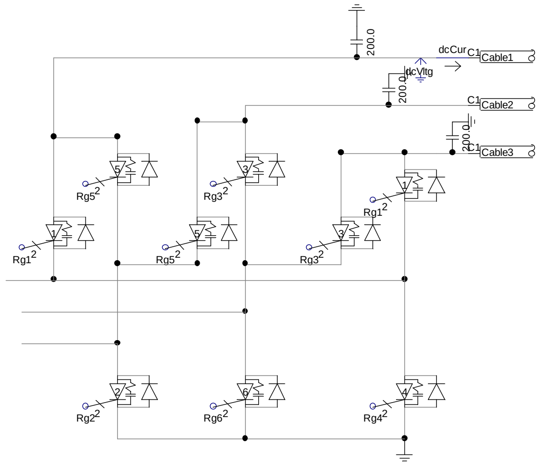

Figure 3. The star-delta rectifier applied to PSCAD

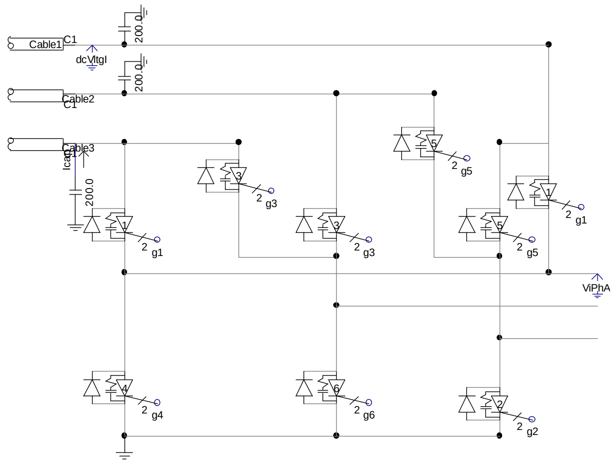

Figure 4. The star-delta inverter applied to PSCAD

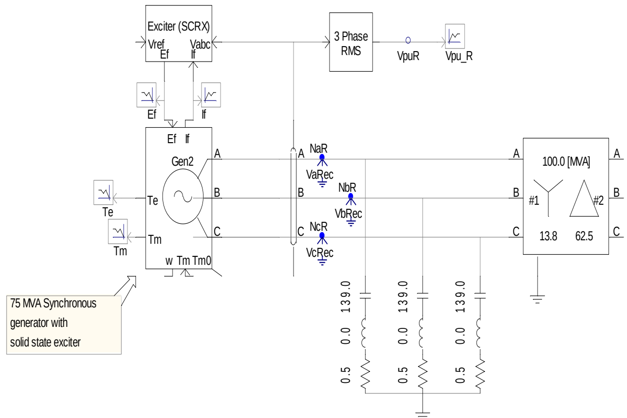

Figure 5. Sending end configuration with PSCAD

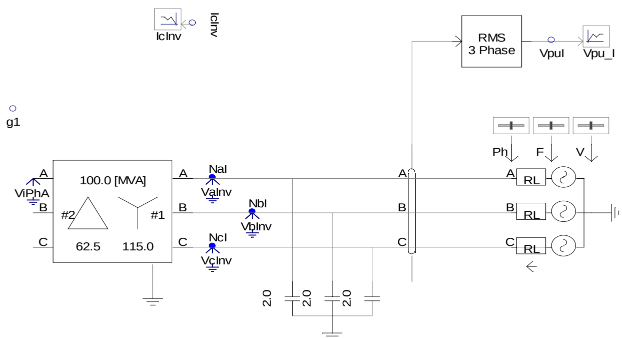

Figure 6. Receiving end configuration with PSCAD

PSCAD/EMTDC software was used to observe if the model is functional and to see the differences between the traditional six-valve converter and the designed star-delta system model. Figure 7 gives the active, reactive and DC power curves of the star-delta Transmission system. The PSCAD/EMTDC results for the same system with traditional VSC converters (six valves) and single line DC transmission are given in Figure 8 [10].

The star-delta transmission system is retested for the dynamic stability by applying a single line to ground fault to one phase of the Inverter output for the duration of 0.05 seconds initialized 2.1 seconds after operation. The graphs are as given in Figure 9 and for traditional system in Figure 10 [10]. The designed star-delta rectifier is proved to be functional and has dynamic stability [10].

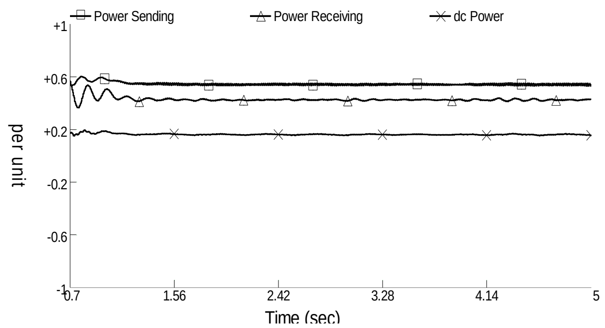

Figure 7. Active power at sending and receiving end and the DC power

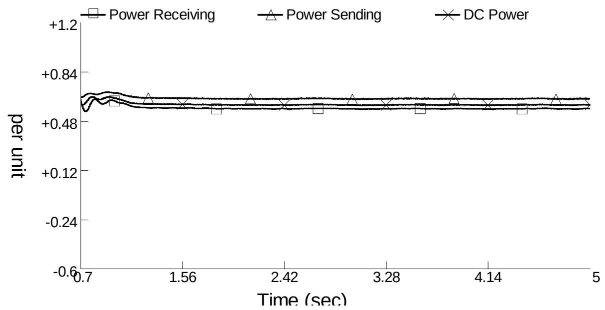

Figure 8. Power at sending and receiving end and the DC power for dynamic stability (traditional)

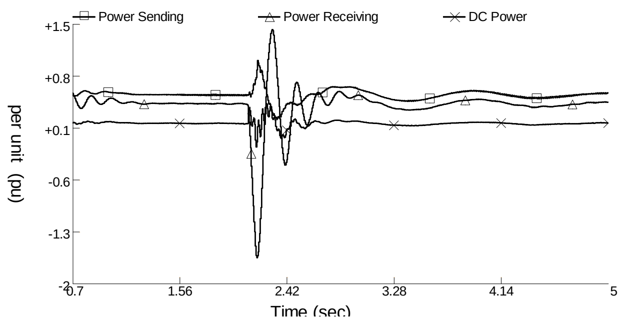

Figure 9. Active power at sending and receiving end and the DC power

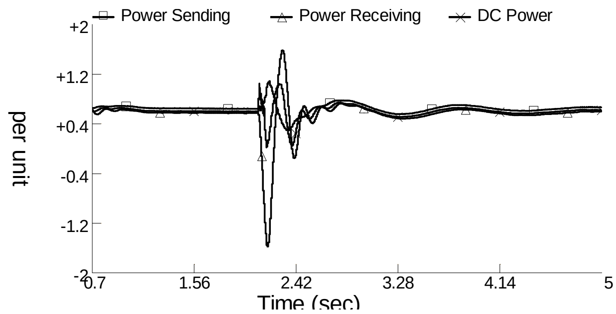

Figure 10. Power at sending and receiving end and the DC power for dynamic stability (traditional)

IV. HARMONIC ANALYSIS

Large-capacity Static VAR Compensator (SVC) and fuel-cell power generation have been developed in electric power and electric industry fields and have been actually introduced in power systems in recent years. For the design of an inverter, inverter loss reduction and harmonic reduction have been important considerations.

In an actual system with an inverter is connected, an over current control against system disturbances such as voltage dip has been also an important consideration from the viewpoint of inverter operation.

In this part the simulation of conventional HVDC system will be analyzed by the point of current and voltage harmonics with PSCAD software simulation conventional inverter phase one current total harmonic distortion is in Figure 11. The star-delta current harmonics are given in Figure 12. The voltage harmonics are given in Figure 13 and Figure 14 for traditional and star-delta converters, respectively.

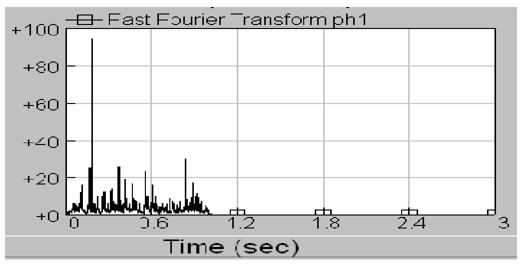

Figure 11. Inverter current harmonics (traditional)

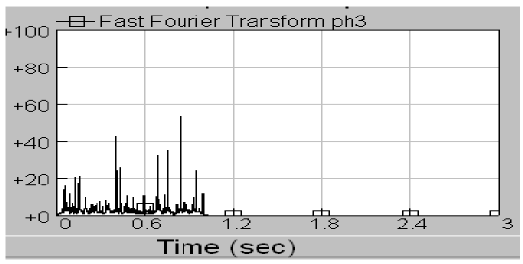

Figure 12. Inverter current harmonics (star-delta)

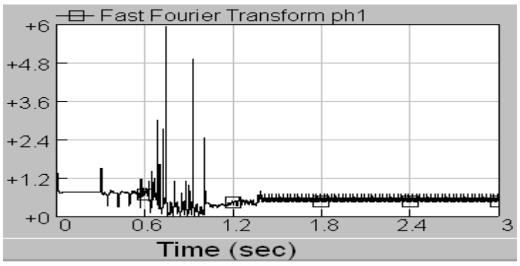

Figure 13. Inverter voltage harmonics (traditional)

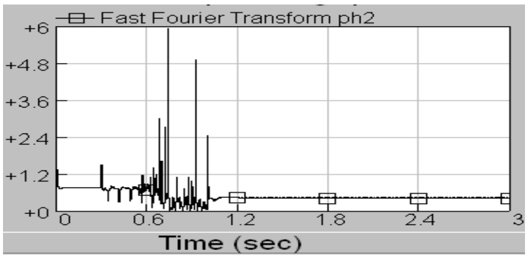

Figure 14. Inverter voltage harmonics (star-delta)

The star-delta HVDC prototype is designed in laboratory conditions to convert three phase AC power to three lines of DC output at rectifier mode and enables to convert back three DC lines into three phase of AC at inverter mode. The star-delta converter prototype is used to test the inverter side harmonic outputs experimentally in laboratory. The figure of the HVDC prototype with star-delta converter is in Figure 15 and the laboratory test is in Figure 16. The harmonic analysis of the star-delta converter's inverter side is performed by using FLUKE 43B Power Quality Analyzer which enables to capture the single phase harmonic distortion over a certain period of time. Total harmonic distortion of voltage of each phase is recorded to see the changes during the operation period. The output harmonics is illustrated in Figure 17.

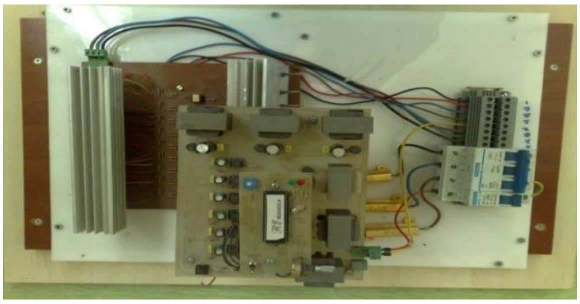

Figure 15. Picture of star-delta HVDC prototype

Figure 16. Harmonic analysis of star-delta prototype

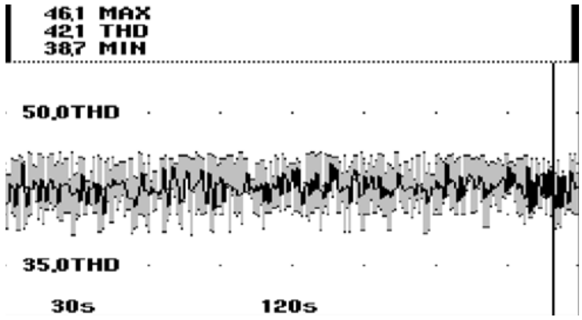

Figure 17. Harmonic output of star-delta prototype

According the simulation of PSCAD/EMTDC software, the harmonic analysis results of the conventional and star-delta based HVDC systems are in Tables 1 and 2. The experimental harmonic analysis results of star-delta based HVDC system are in Table 3. Table 4 shows IEEE maximum voltage distortions limits.

Table 1. Conventional based HVDC system THD_V PSCAD simulation results

Conventional based HVDC system (PSCAD simulation results)			
	Phase 1	Phase 2	Phase 3
THD_V	0.59	0.45	0.46

Table 2. The star-delta based HVDC system THD_V PSCAD simulation results

Conventional based HVDC system (PSCAD simulation results)			
	Phase 1	Phase 2	Phase 3
THD_V	0.56	0.45	0.46

Table 3. The star-delta based HVDC system THD_V experimental results

Conventional based HVDC system (PSCAD simulation results)			
	Phase 1	Phase 2	Phase 3
THD_V	0.48	0.43	0.42

Table 4. Maximum voltage distortions according to IEEE

Maximum Distortion (%)	System Voltage		
	< 69 kV	69 - 138 kV	> 138 kV
Single Harmonic	3.0	1.5	1.0
Total Harmonic	5.0	2.5	1.5

The results obtain are compared with the Tables 1-4, which is IEEE Maximum Voltage Distortions Limits. Comparison parameter is System Voltage > 138 kV, IEEE permits the $THD_V = 1.5$. So according to the result we obtain from the simulations for conventional and star-delta based HVDC systems are satisfies the IEEE requirements. Means that star-delta based HVDC system can be used in real life applications as conventional based HVDC systems.

V. CONCLUSIONS

The voltage and current harmonic analysis of the star-delta based HVDC system was the main topic of this paper. The star-delta based HVDC system harmonic outputs compared with the conventional based HVDC system to investigate the difference between them. To simulate the star-delta and conventional based HVDC systems, PSCAD/ETMDC software is used which is powerful power system analysis tool to analyze the harmonic outputs of both system.

Prototype of star-delta based HVDC system was constructed to analyze the star-delta based HVDC system harmonic behaviors in practically in laboratory conditions. The conditions let us to took only the voltage harmonic outputs of the star-delta based HVDC system inverter side three phases.

The aim of the paper is to find out the harmonic behavior of the star-delta based HVDC system both in simulation and experimentally to compare the results with conventional based HVDC system harmonic analysis results. It is proven that the system is operational and the distortion level is in the acceptable range of the IEEE standards. Example of an application is, connecting the wind turbines to the main power distribution grid [11].

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BIOGRAPHIES

Ozgur Cemal Ozerdem was born in Ankara, Turkey, on November 11, 1967. He received the B.Sc. and M.Sc. degrees in Electrical and Electronic Engineering from the Eastern Mediterranean University, G. Magusa, Northern Cyprus, in 1992 and 1994, respectively and the Ph.D. degree from the Near East University, Nicosia, Cyprus, in 2005. He is currently with the Department of Electrical and Electronics Engineering, Near East University as an Associate Professor and Chairman of the Electrical and Electronic Engineering. His field of interest is power engineering.

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