Power Quality Enhancement for A Grid Connected Wind Turbine System

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***Abstract*— In this project, the harmonics present in the system has been reduced and the voltage dip has been mitigated. The method used to overcome these problems were the use of STATCOM controller to reduce the harmonics and TCSC system to mitigate the dip in voltage. The harmonics were reduced in the system from 0.70% to 0.69% in the wind turbine system. Harmonics in the source has been reduced from 6.9% to 0%. The reduction also takes place in the non-linear load from 29.29% to 27.88%. The TCSC system reduced the voltage dip from 30% to 0%. For future work, a controller could be designed which reduces harmonics of more that one nature since different wind turbines use different generators to convert mechanical energy to electrical energy.**

***Keywords*— Wind Turbine; Grid; STATCOM; Energy Storage; Efficiency**

I. INTRODUCTION

One of the most common problems with power quality is regarding voltage. Normally, it is not very difficult to notice voltage dips in the beginning of any industrial power system. It could occur from any part of the system like either in the equipment or the power lines connecting the system to the grid. As an example, most issues regarding voltage in a common household occur while using home equipment's like air-conditioner or a fridge. Internal energy storage of any and all equipment's vary from one another which means different equipment's ride through the voltage dip differently. Different electrical gadgets interact with the voltage dip differently by either working with it having a low power factor or they cannot comprehend the drop and stop working. This project can be used to mitigate those voltage dips and reduce the harmonic currents in a wind turbine system.

According to [1], in the most recent years the utilization of wind farms and other appropriated power generation systems has radically expanded. The question that should be raised is how those new generation systems will influence to the entire grid. A portion of the appropriate response must be acquired from the effect that they have on the power quality. On a basic level, wind energy can be viewed as unsafe source as far as power quality. In addition, when wind turbines are a piece of the grid. The power quality is by all accounts a complex issue which exceedingly depends upon the cooperation between the grid and the wind turbines. The primary effect on the grid by the wind turbines, concerning power quality, is identified with voltage dips and harmonic content.

[2] proposed a wind energy conversion system (WECS) based variable speed doubly fed induction generator (DFIG.) system which was utilized to synchronous energy production and filtration of harmonic in the grid. Vector control strategy was used to control WECS reactive and active forces. An enhanced symphonious time domain isolator, in accordance with another high signal filter (HSF) had been utilized. The initial power field-oriented control was integrated with a harmonic filtering loop. Before filtering, the THD of the framework current was equivalent to 8.73%. After the utilization of active filtering to the entire harmonics component by using HSF technique, the harmonic point of load currents was removed and THD was decreased to 4.9%.

[3] reviewed different types of FACTs technologies to improve the quality of power in energy systems which are renewable and are grid connected. FACTs gadgets are likewise utilized to enhance the quality of power generated. There are various kinds of FACTS gadgets, for example, Thyristor controlled series compensator (TCSC), Static VAR Compensator (SVC), Static synchronous compensator (STATCOM) and Static synchronous series compensator (SSSC).

[4] published their findings about simulating and modelling STATCOM with Superconducting magnetic Energy Storage system. The design considerations including the suitable material, converters, energy storage system and control scheme to develop the power quality enhancement system. According to the researchers, combination of STATCOM with an energy storage SMES can improve the efficiency of the STATCOM and the cost of power conversion unit is reduced which is used for SMES. To reduce power oscillation which was around the steady state power transmission a power oscillation damping method was used. When the rotationally oscillating generator increased, the mechanical input power also increased, so the electric power transmitted had to be used as a compensation. Using these techniques, the researchers were able provide more damping and were able to stabilize the system in a very short period of time in the case where STATCOM was used. This research was carried out using PSCAD/EMTDC software.

[5] proposed a STATCOM system which was in connecting with a battery energy storage system to improve the quality of the power of a wind turbine power system. Power electronic based FACTS gadgets like STATCOM was used to make better the quality of the power which was used by the consumer. To generate a source current which was free of harmonics and the phase-angle was an ideal value with respect to the source voltage, the STATCOM based inverter

that controls the current and voltage infused a current into the network grid. The quality of power was improved when the load harmonics and generator current was infused with the supplied current.

[6] proposed a power quality enhancement system which improved the quality of the power in an energy network which was connected to a grid which is at the PCC by utilizing STATCOM and a BESS. To get fast reaction time, minimal cost and high voltage capacity, the STATCOM was considered in that proposed model. Other than that, the STATCOM additionally can shield the delicate gadgets at the non-linear loads sides from getting damaged and tripped. The end results showed an increase of power factor when the grid was connected to the STATCOM-BESS system. Also, the voltage sags, THD at non-linear loads were shown to be improved. The limitations can be seen in the results where the harmonics in the nonlinear load and the current at the generator could be improved since the result does not vary from a grid which does not have the proposed system.

[7] proposed a system with VSC (Voltage Source Converters) based HT-SMES was created for accomplishing a high efficiency. The SMES could store the most amount of energy, while utilizing two devices of BSCCO and YBCO tapes, and high temp. superconductors. It was tried in a transmission control framework of 110kV by an experiment which used dynamic power fluctuation by utilizing 3 methodologies of controlling in China Electric Power Research Institute, CEPRI. the storage unit had a decent efficiency of current. At the point if a fault occurred at the line of transmission, the storage system could powerfully comprehend the ongoing waveforms of power and compensate the energy change utilizing the control systems with various methods to discharge and charge. The generator falls out of synchronism when the power angle is more than 90 degree or less than 0 degree and will stabilize vice-versa.

[8] discussed about various types of energy storage system and their functions. The researchers, discussed on Superconducting magnetic Energy Storage (SMES), Super-Capacitor (SC) and Battery Energy Storage system (BESS) and a few other methods. A regular BESS system comprises of lot of voltage/control battery cells which are low associated in parallel and series to accomplish an ideal feature. Different advantages are toughness, high reliability, low maintenance, long lifetime, and operation over a wide temperature limit. They are friendly to the environment and effectively reused. The efficiency is ordinarily around 90% and the discharge time is in the scope of a few seconds to hours.

[9] explains the working principle of a SMES system that could store a huge amount of electrical power in its superconducting coil. The energy deposited in the magnetic field in SMES is of DC form. The characteristics to be noted are, SMES has an efficiency of more than 90 percentage and a fast response time of more than 100ms. The components in this system are cooling gas, convertor, superconducting coil and refrigerator to maintain the coolant temperature.

[10] proposed an application which effects SMES in decreasing the droop/swell in voltage in electric power production framework with wind control. Squirrel cage induction generator (SCIG) was used in this project as a wind turbine and to improve the power factor a shunt capacitor bank was connected. SMES framework comprised of power conditioning framework, step-down transformer, vast inductance superconducting coil and DC-DC chopper. Wind energy generation system (WEGS) and SMES framework associated with network having a similar bus to accomplish better power quality. Fuzzy logic controller (FLC) was utilized for to control the exchange of power using DC-DC chopper between the SMES coil and the system framework. By utilizing the SMES system, the voltage sag was improved, and the voltage increased from 0.85pu to 0.95pu. Similarly, the voltage drop was decreased from 1.15pu to 1.04pu. This research was carried out using MATLAB/SIMULINK software.

[11] proposed an Impedance-based little signal examination which is a valuable tool to have resonance analysis between the grid system and type III wind turbines, since no complete or precise turbine model had been introduced for the range in frequency that spreads from a couple of Hz to a couple of kHz. Models which were existing either disregarded the impacts of the converters or didn't effectively demonstrate those impacts. Negative and positive arrangement impedance models of the turbine without and with phase lock loop were presented in this paper.

[12] designed a distribution system with shunt compensation to reduce or cancel the effects of harmonics. In the designed system, STATCOM was associated at the PCC where most loads are present alongside a BESS system to make the current of the source free of harmonics and to show the improved performance of the system. A dc capacitor supplied a voltage source inverter around which the STATCOM system was built. A gate drive circuit turned off and turned on switches which were present inside the inverter. The STATCOM system proposed was connected alongside a control scheme for current which used hysteresis for enhancing the quality of power, had objectives to maintain the source side power factor at unity. STATCOM was connected to a controller known as bang-bang for quick response. Another objective was to limit the THD rate at the waveform of PCC.

As the objective and intent of this project is to reduce the harmonics and voltage fluctuations, which will enhance the quality of the power in an electrical system, the system can would be able to fix the load at PCC. The system will be able to reduce the harmonic currents in the network. To fix the voltage problems, a storage system is connected.

II. PROPOSED SYSTEM METHODOLOGY

Fig.. 1 shows the block diagram for the voltage dip and harmonic reduction system. The scopes have not been re-adjusted since the previous ones were still have the same objectives in the proposed system. The method to reduce voltage dip in the system has been changed and a justification for the change has been provided in the beginning of this section. Basically, the SMES system has been replaced since it has huge coils present within the system to store generated voltage which produces a huge amount of heat. To reduce the heat factor of the system, the SMES system also required a cooling system. On the other hand, a TCSC comparatively does not produce a huge amount of heat and also improves the flow of power. Now, the changes have been made and explained as to why they occurred, the working principle is pretty much similar to that of chapter 3. The AC Source of

250kV is stepped-down to 415V. The harmonic currents are then generated in the wind turbine system. The harmonics are filtered using STATCOM controller. TCSC are used to mitigate the voltage dip.

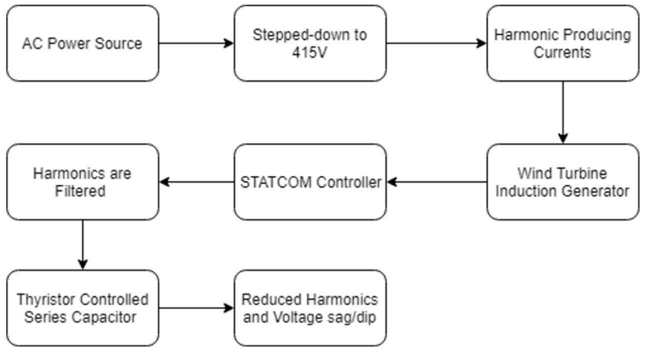

Fig. 1. Overall block diagram of the system

Fig. 2. shows the wiring diagram of the system for the voltage dip and harmonic reduction system. The simulation is be carried out using an asynchronous induction generator which is a three phase, 415V with a grid of 50Hz grid system. The source voltage which is used for implementing the proposed system is 250kV since a grid connection system has a power source of high voltage. The speed of the inductor is be set at 1440rpm which is a standard speed for an induction generator. The pitch angle and the wind speed were set to a constant value of 4 degrees and 12m/s. The voltage for STATCOMs DC link was set to be 800V and the current injected was set to be 50A. The voltage from the 250kV source had to be stepped down to 415V since the proposed system has one single asynchronous induction generator.

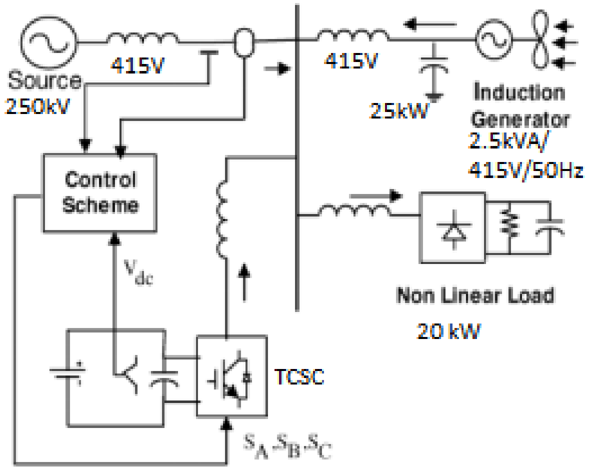

Fig. 2. Wiring diagram of the system

The voltage output from the wind turbine system connected with the non-linear load at PCC is then sent to the STATCOM controller for the reduction in harmonics in the grid framework. The controller consists of a PI controller which works as a filter to reduce harmonics, along with a PWM to generate the pulse required to be sent to the TCSC for increasing the voltage dip. The TCSC system with the STATCOM system is working side by side to improve the voltage dip issue of the overall grid system. The TCSC, comprises of an arrangement of a thyristor-controlled reactor shunting a capacitor bank to give a reactance which is variable series capacitive. Also, TCSC has a high switching frequency with a thyristor switching valve for manual switching, this is in the case of designing an actual TCSC with STATCOM system.

Fig. 3. shows the flow chart of the proposed system for the Voltage dip and harmonic reduction system. The flowchart is basically the same provided in Chapter 3. The only modification done is replacing the SMES system with a STATCOM-TCSC system. The justification for the change has been provided in the beginning of this chapter. The working principle for this harmonics and voltage dip reduction system consists of two main components. Firstly, the identification of harmonics has been done using Total Harmonic Distortion (THD) method where the calculated value for the harmonics has been compared to the simulated value in the following chapter under the section “Discrepancy between the theoretical and experimental results”. To reduce the systems harmonics, Static Synchronous Compensator (STATCOM) was be used. STATCOM was also being used to dampen the oscillation. Other component like asynchronous induction generator, rectifier, transformers and wind turbine have been used in the development of the system. For issues regarding the voltage dip, an STATCOM connected system, known as Thyristor Controlled Series Compensator (TCSC) system has been implemented. To integrate to two systems together, a DC-DC bus convertor was added.

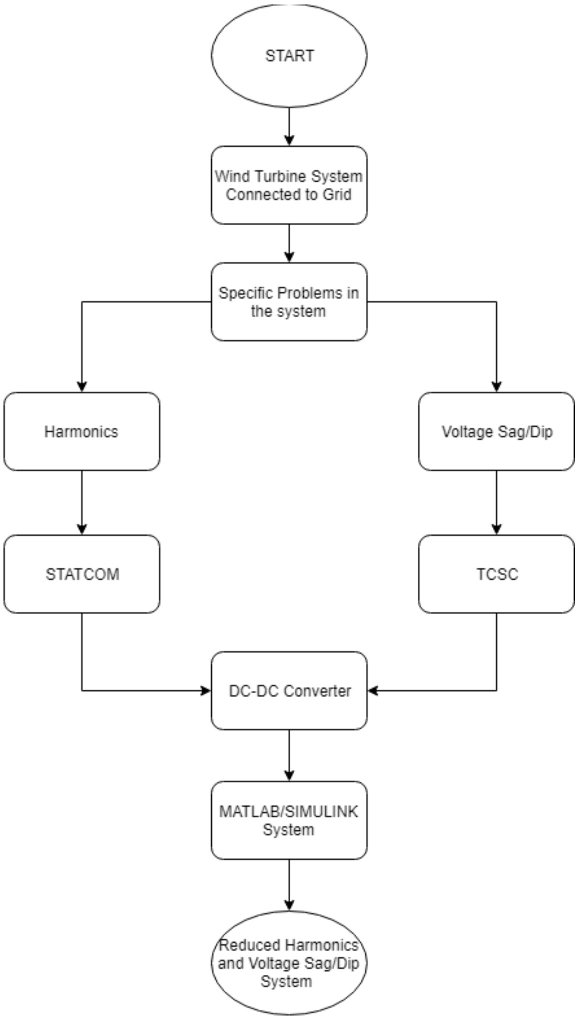

Fig. 3. Flow chart of the proposed system

A constant DC bus current was used as the flow of power for a constant DC bus voltage. Constant wind topology has been used for wind generation for this proposed conFig.uration. Separate field circuit has not been required due to the simplicity of the induction generator. The induction generator has been connected along variable and constant loads due to the simplicity factor. The entire development has been connected at the PCC since it is the point of multiple loads. The development which has been done in this project has been shown in simulation method using MATLAB/SIMULINK software.

The logic behind this flowchart is that it helped by confirming the steps in modelling the system which is basically all the successful research works done in chapters 2 and 3 that were relevant in the implementation phase of this project for instance, the conFig.uration in which the wind turbine system should be connected, the type of harmonic reduction to be used, and a method to improve the voltage dip. Abiding by this flowchart helped in easing the troubleshooting part of this project as well as time management.

III. SIMULATION RESULTS

Fig. 4 shows the simulation model of the proposed system for the voltage dip and harmonic reduction system. The parameters for components have been provided in the wiring diagram section of this chapter.

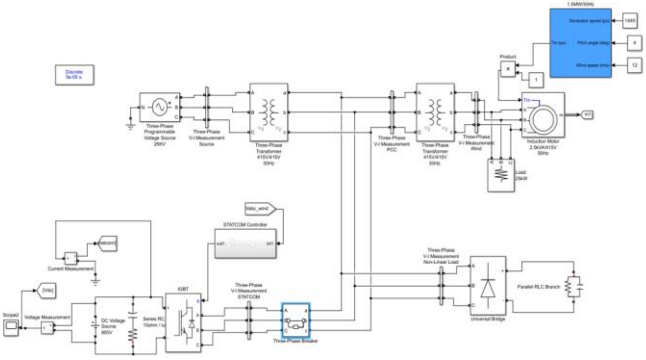

Fig. 4. Simulation model of proposed system

Fig. 5 shows the voltage of wind turbine of the proposed system for the voltage dip and harmonic reduction system. The voltage dip seen in the Fig.ure above is generated from the wind turbine system when it is not connected to the STATCOM-TCSC system. The voltage dip occurs in the first few cycles. Considering the first 10 cycles, it can be seen that the voltage drops for a value of 30%. According to Electrical Easy (2014), on account of an independent induction generator an external force known as a prime mover will keep up a consistent speed (in this case, a reactive power of 25kW) and move the rotor but due to less availability of Magneto-Motive Force (MMF) in the machine, the machine cannot be self-excited and build up voltage of the stator required to make the flow of current of the stator to which then creates adequate MMF. AC windings primary objective is to create turning MMF wave in an electrical motor. Regardless, windings in AC has to be planned in such a way, that the MMF wave generated comprises overwhelmingly of the crucial sinusoidal component. An induction generator is also very sensitive to frequencies, in this case the frequencies are of harmonic nature.

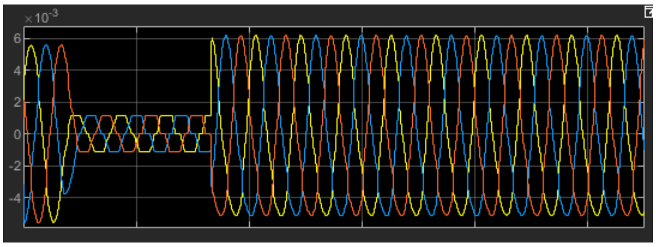

Fig. 5. Voltage of wind turbine of the proposed system

Fig. 6 shows the voltage of wind turbine of the proposed system with STATCOM-TCSC for the voltage dip and harmonic reduction system. The voltage dip seen in the Fig.ure above is generated from the wind turbine system when it is connected to the STATCOM-TCSC system. Considering the first 10 cycles, it can be seen that the voltage drops for a value of 0% which shows that the system has mitigated the voltage dip.

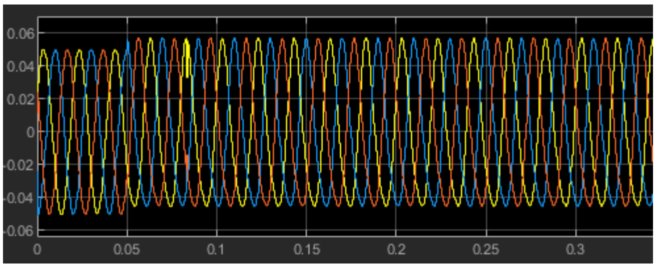

Fig. 6. Voltage of wind turbine of the proposed system with STATCOM-TCSC

Fig. 7 shows the current waveform of wind turbine of the proposed system with STATCOM-TCSC for the voltage dip and harmonic reduction system. The generated THD of the wind generator current is 0.70 percent without the use of STATCOM-TCSC. The distorted waveform for interval of 10 cycles in the FFT window which will be provided in the next chapter since there are more than 30 cycles in every second the simulation takes place. After associated the STATCOM-TCSC with the grid system, the level of THD is varied marginally and the waveform has a less distortion signal. The value obtained after the system was connected to the STATCOM-TCSC is 0.69 percent.

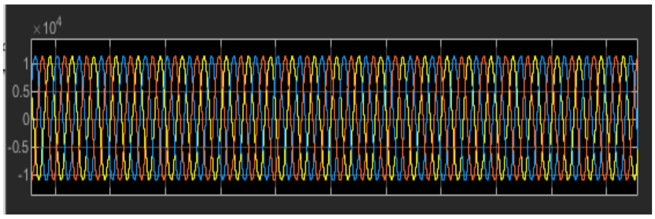

Fig. 7. Current waveform of wind turbine of the proposed system with STATCOM-TCSC

IV. TESTING OF THE PROPOSED DESIGN

A. *THD at the source without the STATCOM-TCSC System*

For this test, THD present in the source without the use of STATCOM-TCSC system is done to compare the results when the source is connected with the harmonic reduction and voltage dip reduction system. Figures 8 and 9 shows the voltage waveform of source of the proposed system without the use of STATCOM-TCSC. The value of THD is shown as 6.97 percent. The tabulated values for the graph are provided in Table I.

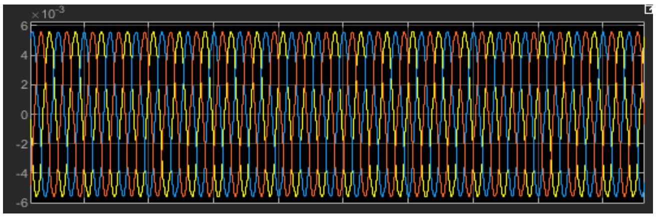

Fig. 8. Voltage waveform at the source without proposed system

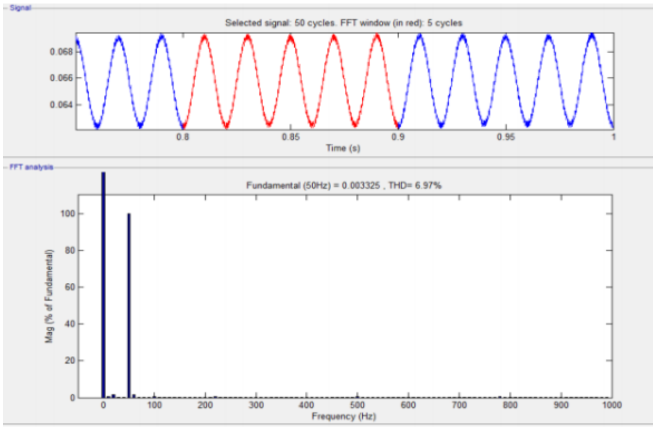

Fig. 9. Data analysis for THD at source without the proposed System

TABLE I. DATA COLLECTION FOR THD AT SOURCE WITHOUT THE PROPOSED SYSTEM

Frequency (Hz)	***Magnitude (% of Fundamental)***
10	1
20	4
30	0.8
40	0.8

B. THD at the source with the STATCOM-TCSC system

For this test, THD present in the source with the use of STATCOM-TCSC system is done to view the results when the source is connected with the harmonic reduction and voltage dip reduction system. Figures 10 and 11 shows the voltage waveform of source of the proposed system with the use of STATCOM-TCSC. The value of THD is shown as 0 percent which compared to the system without STATCOM-TCSC is basically negligible. The tabulated values for the graph are provided in Tabl2 II.

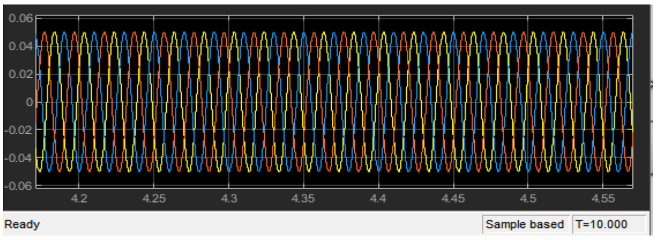

Fig. 10. Voltage saveform at the source with references

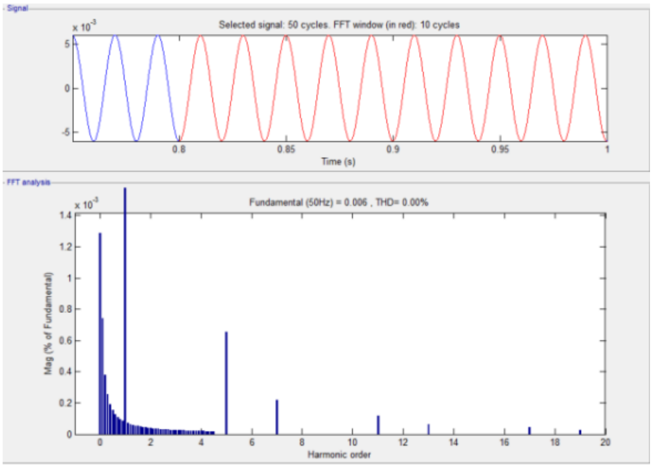

Fig. 11. Data analysis for THD at source with STATCOM-TCSC

TABLE II. DATA COLLECTION FOR THD AT SOURCE WITH THE PROPOSED SYSTEM

Harmonic Order	***Magnitude (% of Fundamental)***
1	1.54
2	0.07
3	0.05
4	0.06

C. THD at the wind turbine without the STATCOM-TCSC System

For this test, THD present in the wind turbine without the use of STATCOM-TCSC system is done to view the results when the wind turbine is not connected with the harmonic reduction and voltage dip reduction system. Figures 12 and 13 shows the voltage waveform of wind turbine of the proposed system without the use of STATCOM-TCSC. The value of THD is shown as 0.70 percent. The tabulated values for the graph are provided in Table III.

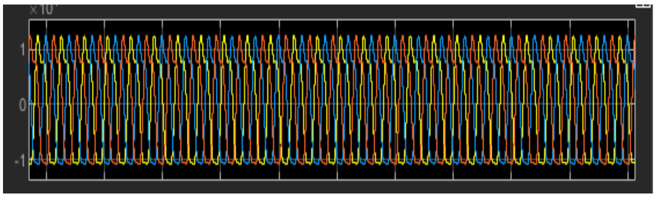

Fig. 12. Current waveform at the wind turbine without proposed system

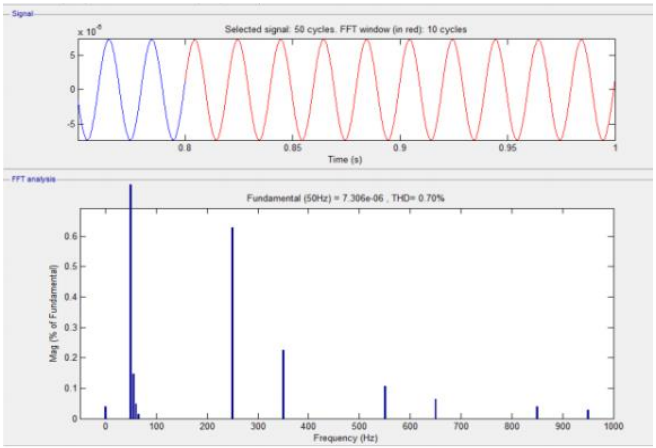

Fig. 13. Data analysis for THD at wind turbine without the proposed system

TABLE III. DATA COLLECTION FOR THD AT WIND TURBINE WITHOUT THE PROPOSED SYSTEM

Frequency (Hz)	*Magnitude (% of Fundamental)*
50	2.2
60	0.15
70	0.05
80	0.02

D. *THD at the wind turbine with the STATCOM-TCSC system*

For this test, THD present in the wind turbine with the use of STATCOM-TCSC system is done to view the results when the wind turbine is connected with the harmonic reduction and voltage dip reduction system. Figures 14 and 15 shows the voltage waveform of wind turbine of the proposed system with the use of STATCOM-TCSC. The value of THD is shown as 0.69 percent which compared to the system without STATCOM-TCSC is not a significant difference but a difference nevertheless. The tabulated values for the graph are provided in Table IV.

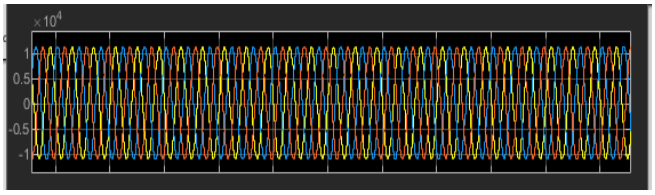

Fig. 14. Current waveform at the wind turbine with proposed system

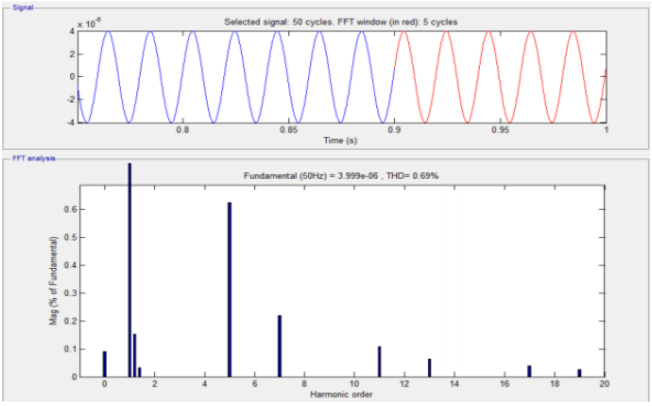

Fig. 15. Data Analysis for THD at Wind Turbine with STATCOM-TCSC

TABLE IV. DATA COLLECTION FOR THD AT WIND TURBINE WITH THE PROPOSED SYSTEM

Harmonic Order	*Magnitude (% of Fundamental)*
1	1.2
3	0
5	0.6
7	0.21

V. DISCUSSION

It was clearly shown that to reduce the harmonics in the system, a STATCOM controller was used. The STATCOM used PI controller for to filter the harmonics in the system. The harmonics present in the system was 5th in nature TCSC system was designed to mitigate the voltage dip present in the system. A TCSC, which comprises of an arrangement of a thyristor-controlled reactor shunting a capacitor bank to give a reactance which is variable series capacitive. A TCSCs works as an essential part in the activity and control of power frameworks, for example, improving transient and dynamic stability, upgrading power flow, constraining fault current. The results show mitigation in voltage dip from 30 percent to 0 percent. The testing has been done for current waveform in the wind turbine with and without STATCOM-TCSC system, current waveform in the source with and without STATCOM-TCSC system, and current waveform in the non-linear load with and without STATCOM-TCSC system. The testing shows that the harmonics in each portion of the simulation has reduced.

REFERENCES

[1] V. Preciado, M. Madrigal and E. Muljadi, “Harmonics in a Wind Power Plant,” In IEEE Power and Energy Society General Meeting. Denver, Colorado and 26th – 30th pp. 1-5, 2015.

[2] M. Kesraoui, A. Chaib, A. Meziane and A. Boulezaz, “Using a DFIG. based wind turbine for grid current harmonics filtering,” Energy Conversion and Management. vol.78. pp. 968-975, 2014.

[3] F. H. Gandoman, A. Ahmadi, A. M. Sharaf, P. Siano., “Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems,” Renewable and sustainable energy reviews Vol. 82, pp. 502-514, 2018.

[4] R. Sedaghati, M. Hakimzadeh, A. Davodi, and N. Javidtash, “Dynamic modeling and simulation of a STATCOM/SMES compensator in power systems,” Int. J. Elec., Comput., Energ., Electron. Commun. Eng., vol.8 no. 5, pp. 806-809, Nov.2014

[5] C. S. S. S.Tripathi, “Power Quality Improvement in Wind Grid Energy System using STATCOM With BESS -Control Scheme,” International Journal of Innovation and Scientific Research, vol. 9, pp. 237-245, September, 2014.

[6] S. A. Rufus, P. K. Karunakaran, “ Power Quality Improvement on Wind Energy System by Using STATCOM,” In Applied Mechanics and Materials, Vol. 833, pp. 33-40, 2016.

[7] J. Zhu, Q. Cheng, B. Yang, W. Yuan, T. A. Coombs and M. Qiu, "Experimental Research on Dynamic Voltage Sag Compensation Using 2G HTS SMES," in IEEE Transactions on Applied Superconductivity, vol. 21, no. 3, pp. 2126-2130, June 2011.

[8] Z. Haoran, Wu. Qiuwei, Hu. Shuju, Xu. Honghua and R. Claus, “ Review of energy storage system for wind power integration support,” Applied Energy vol. 137, Pp. 545-553, 2014.

[9] N. Kumar, ‘‘Superconducting magnetic energy storage (SMES) system,’’ Feb. 2015. [Online]. Available: https://www.researchgate.net/ publication/261204920_Superconducting_Magnetic_Energy_Storage _ SMES_System.

[10] S. M. Said, M. M. Aly, and M. Abdel-Akher, “Application of superconducting magnetic energy storage (SMES) for voltage sag/swell supression in distribution system with wind power penetration,” in 2014 16th International Conference on Harmonics and Quality of Power (ICHQP). IEEE, 2014, pp. 92–96, 2014.

[11] I. Vieto, and J. Sun, “Small-Signal Impedance Modeling of Type-III Wind Turbine,” in Proc. Power & Energy Society General Meeting (PESG), pp. 1-5, 2015.

[12] E. Deepika, “ Power Quality Improvement In Grid Connected Wind Energy System,” International journal of electronics and electrical engineering. Vol. 8, pp. 47-55, 2015.