Large scale integration of renewable sources with STATCOM for reactive power compensation and power quality improvement

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ABSTRACT

The power quality is considerably affected by interconnection of renewable energy sources to the grid . In this paper STATCOM(Static synchronous Compensator) system has been projected as a device for reactive power compensation and as Power Quality improvement device while connected to Point of Common Coupling (PCC) of Large Scale Renewable Energy Converters (RECs). Wind turbine (Doubly Feed Induction Generator- DFIG) and Solar PV converters are simulated in this paper. A hysteresis current control scheme , which has simple and robust structure , is proposed . Using this method STATCOM generates current wave in opposition to the disturbance wave and hence compensates the harmonics produced by large scale RECs and works as Active Power Filter. This paper presents the limit for amount of power generation from RECs after which support from STATCOM become mandatory for further RECs interconnection considering stability of grid. Simulation carried out in MATLAB/ Simulink validate the effectiveness of the proposed strategy.

Keywords: Large scale RECs integration ,DFIG, Solar PV,STATCOM, APF.

I. INTRODUCTION:

Electric power generation from renewable energy sources (RES) like wind and solar has increased substantially during past few years and presently holds a significant proportion of the total power generation in the country. This renewable energy generation is concentrated in a few geographical locations across the country, but, to the extent that it cannot be considered as marginal generation, serious thought needs to be given to balance the variability of such generation. There is an ambitious programme for increase of such renewable generation and therefore, it is an important task to work out a way forward for facilitating large scale integration of such RES keeping in view the security of the grid.

With increased RES generation, and with increase in non linear loads, the power quality aspect of the grid has become an issue of prime importance. This issue is primarily due to use of power electronics converters having non-linear characteristics, which changes sinusoidal nature of supply by adding harmonic components in the grid. If these loads are connected in a grid-connected wind energy conversion system (WECS), it will definitely affect the waveform of current and voltage at the point of common coupling (PCC) and the wind-turbine generator (WTG), which produces more heat and ultimately decreases efficiency and life span of WTG. In addition to this ,various studies [7], [11], [12] show that interconnection of REC itself with power system injects a certain amount of harmonics at PCC. However, the number of solutions that can troubleshoot this issue are evolving and new techniques are being formulated and classical ones being reformulated or improved.

One of the viable solutions is to use active and passive filters. In [13],[14],review of passive and active filter techniques is presented. Passive filters are simple in construction and easy to implement. However, passive filter have drawback that it only compensates the system for under and over compensation. Also it uses passive elements like capacitances and inductance which reduces system efficiency. Active Power Filter offers an excellent solution to the issue of power quality, which allow the mitigation of current harmonics along with reactive power compensation. In [7] review of such mitigation techniques is presented.

This paper focuses on operating the STATCOM converter in order to regulate the voltage, reactive power and power quality by working as active power filter while connected to PCC of wind farm and solar farm with grid. This paper is organized as follows: In Section II - the system model is presented . Section III - presents modelling information of wind farm and solar farm. Section IV presents detailed modelling of STATCOM converter for working as reactive power compensation device and as active filter. The simulation results are given in section V. The conclusion is presented in section VI.

II. SYSTEM MODEL

A simple system was built to accurately evaluate the performance of system, shown in Figure:-1. It consists of 1000MW load (combination of linear and non-linear load), connected to a 66kV bus. The 66kV bus is energized by transmission network of 200km. A synchronous generator is also connected to the network to simulate the actual grid. In addition to that power generated from the RECs is delivered in to the grid at 220KV PCC . RECs are connected to main grid through a transmission network of different line length. The generated power from RECs are stepped up and delivered to PCC . PCC is a 220KV bus which further transmit the power to the load . In addition to that , STATCOM is also

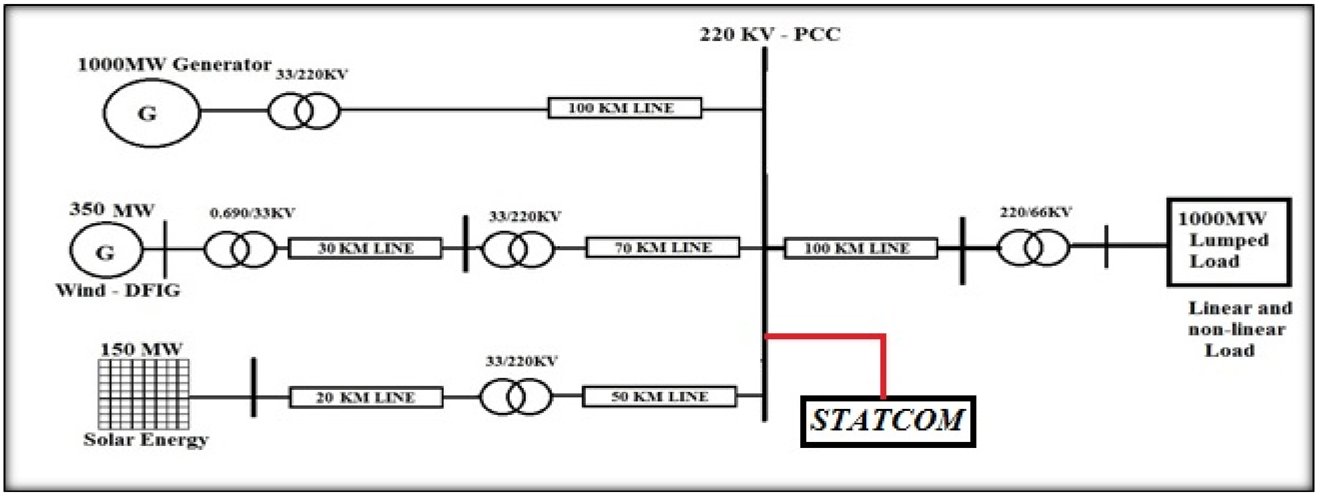

Figure:-1: Test system

connected at PCC for reactive power compensation**.** To simulate harmonics produced by the generating station the synchronous source is considered in such a way that injects 1% of harmonics in the network. All the efforts have been made to simulate closest approximate model to current utility grid.

III. MODELLING OF RECs.

Here two types of RECs are considered:

- *1st , 350MW Wind energy converter – Doubly Feed Induction Generator (DFIG)*
- *2nd , 150 MW Solar Energy Converter(SEC)*

Modelling information of both RECs are shown in Table-1 and Table-2. DFIG model is described in d-q reference frame and grid side converter is utilized for controlling the voltage at 690V bus of wind turbine. SEC is based on DC/AC converter model working on 12 pulse PWM firing control strategy

The study is focused on the harmonics injection from the various RECs and power quality variation in all possible cases. In order to understand its operation and to evaluate its behavior with power quality issues , the performance evaluations have been made with a simulation model using MATLAB.

WIND TURBINE DATA - DFIG			
Turbine electrical power	[P]	2100	KW
Nominal system voltage	[V]	690	V
System frequency	[f]	50	Hz
Stator resistance	[Rs]	0.1748	Ω
Rotor resistance	[Rr]	0.0325	Ω
Stator leakage inductance	[Ls]	0.0259	H
Rotor leakage inductance	[Lr]	0.026	H
Mutual Inductance	[Lm]	0.0249	H
Moment of inertia	[J]	139	Kg m^2
Rated wind velocity	[Vm]	12	m/s
Detail of combination			
Total elec. Power of plant		**350**	**MW**

Table-1 : DFIG turbine data

SOLAR ENERGY CONVERTER-SEC		
Detail of one PV array		
Nominal elect. power	280	W
Max. DC voltage	37	V
Max. DC current	8	A
No. of series array	800 / 800	
Detail of combination		
Nominal elec. power	**150**	**MW**
Nominal voltage	33	KV

Table-2 – SEC design data

IV. MODELLING OF STATCOM

A. STATCOM

STATCOM is the acronym for Static synchronous compensator and refers to a group of devices used to overcome certain limitations in the static and dynamic transmission capacity of electrical networks. STATCOM is widely used as reactive power compensation device and considered as prime topic of study , due to its low harmonic generation, quick adjusting speed and wide operating range.

With STATCOM, a number of valuable benefits can be attained in power systems:

- *Increased power transmission capability and stability, without any need to build new lines. This is a highly attractive option, costing less than new lines, with less time expenditure or environmental impact*

- *Reactive power control- Dynamic voltage control, to enable limiting of over voltages over long, lightly loaded lines and cable systems, as well as prevent voltage depressions or even collapses in heavily loaded or faulty systems*
- *Facilitating integration of renewable power by maintaining grid stability and fulfilling grid codes, as well as making room for this additional power in existing grids*
- *Power quality improvement by providing sinusoidal current in opposition to the disturbances of the grid and there by filtering the grid harmonics by switching the voltage source converter*

In this paper reactive power compensation and power quality aspect of STATCOM are discussed.

B. Hysteresis current control logic

To achieve the objective of power quality improvement aspect, hysteresis band current controller (HBCC) is proposed for generation of gate pulse for Active Power Filter (APF).

The key function of the gate drive circuit is to generate suitable gate pulse for switching of APF circuit based on the reference signal. The working of the hysteresis control is explained in Figure:-2. It works as instantaneous control that forces the compensating current in such a way that the actual current $I_f$lies within the estimated band of reference signal I_{f_ref}. The band 'H'of the control system is designed and imposed on the I_{f_ref} to form the upper (+H/2) and lower (-H/2) hysteresis band . The actual signal I_f is than measured and compared with the reference signal I_{f_ref} and error signal I_{error} is generated . This error signal determines the hysteresis control and generates the gate pulse whenever it exceeds the upper or lower band limits. When error is within the limits , no corrective actions will be taken. The corrective action will only be taken if the error crosses the upper or the lower hysteresis band limits .

Hysteresis bands of the width 'H' are defined around each reference value of the phase currents (If). The goal is to

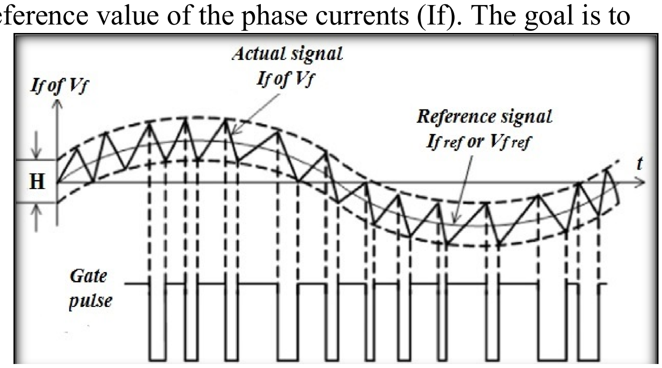

Figure:2-Working of HBCC

keep the actual value of the currents within their hysteresis bands all the time. As the three currents are not independent from each other, the system is transformed into (α - β) coordinate system. With the transformation of the three hysteresis bands into this coordinate system, they result in a hysteresis hexagon area. The reference current vector I_{f_ref} points toward the centre of the hysteresis , as can be seen in Figure:-3. In steady state, the tip of the reference current moves in circle around the origin of the coordinate system (Figure:-3). Therefore, the hexagon moves on this circle too.

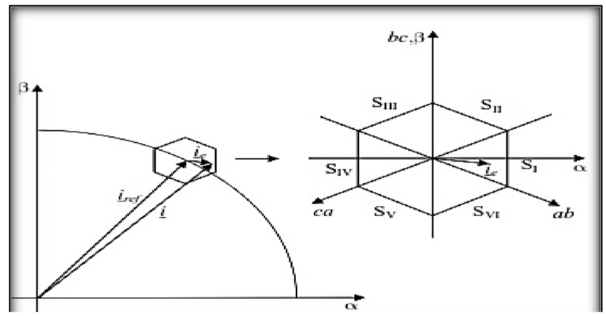

Figure:-3-Hysteresis hexagon in α-β plane

The actual value of the current I_f has to be kept within the hexagon area. Each time when the tip of the I_f touches the border of the surface heading out of the hexagon, the inverter has to be switched in order to force the current into the hexagon area. The current error is defined as:

$$I_{error} = I_f - I_{f\_ref}$$

The error of each phase current is controlled by a two level hysteresis comparator, which is shown in Figure:-4. A switching logic is necessary because of the coupling of three phases. When the current error vector I_{error} touches the edge of the hysteresis hexagon, the switch logic has to choose the most optimal switching state with respect to the following :

1. *The current error I_{error} should be moved back towards the middle of the hysteresis hexagon as slowly as possible to achieve a low switching frequency*
2. *If the tip of the current error I_{error} is outside of the hexagon, it should be returned in hexagon as fast as possible (important for dynamic processes).*

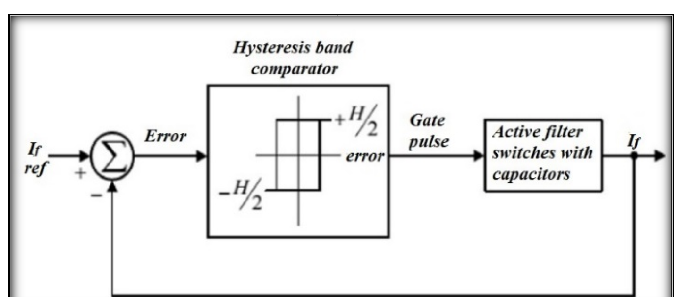

Figure:-4-Hysteresis current comparator

The major advantage of the hysteresis current control method is that it provides excellent controllability and improved dynamic performance within a specified band .In addition to this the implementation of the controlling logic is robust and simple. However, the key drawback of the system is the non-uniform switching frequency of the controller. This may result in unwanted resonances on distribution network and reduced APF efficiency.

Figure:5 shows the MATLAB simulation circuit for HBCC . PCC voltage and current are used for calculation of reference values and with reference to error signals , the gate circuit generates gate pulses to switch IGBT connected to capacitors. Figure:6 shows the gate pulse generated by HBCC simulation circuit in MATLAB.

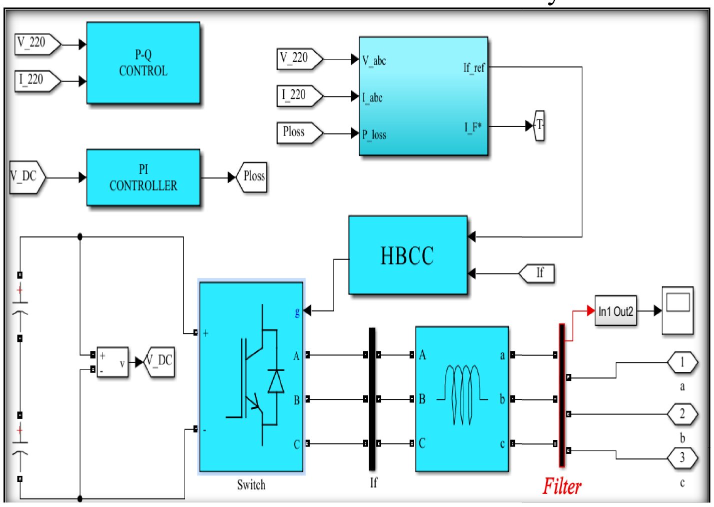

Figure:5-Hysteresis control in MATLAB simulation

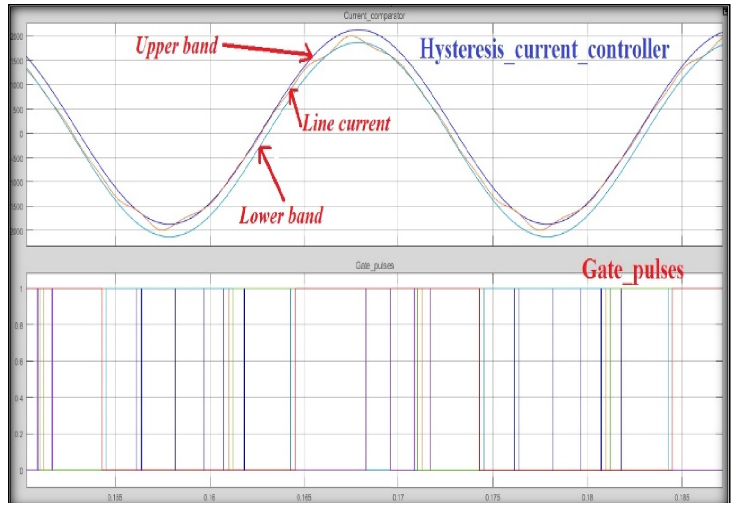

Figure:6-Gate pulse generated by HBCC circuit

V. SIMULATION AND RESULTS

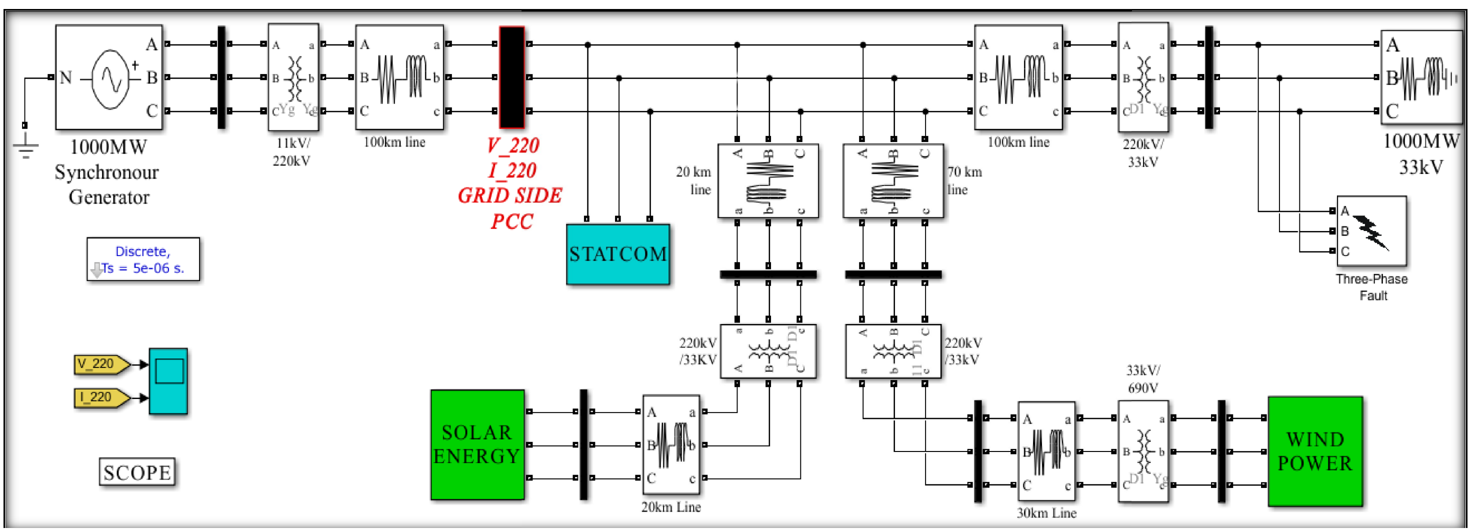

Figure:7- MATLAB simulation of test system

Figure:7 presents the test system simulated in the paper. Here all the transformer and generator reactance are considered as per IEC 60076-5. Total load of 1000 MW is supplied by the combination of the conventional grid source and RECs (DFIG+SEC). On the PCC of the RECs STATCOM is connected for the purpose of reactive power compensation and power quality improvement. All the measurements are considered at 220kV grid side PCC as shown in Figure:7 .Figure:8 shows the reduction of the reactive power drawn from the grid side source by switching on STATCOM at t =0.2s.

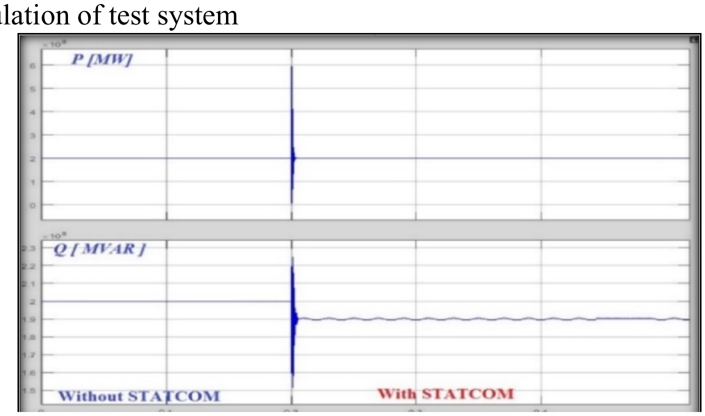

Figure:8-Reactive power drawn from grid with and without STATCOM

Figure:-9 shows current FFT results on the grid side 220kV PCC without any RECs. As the RECs are integrated in to the grid , the harmonics level of the grid increases. Figure:-10 and Figure:- 11 show injected harmonics from SEC and DFIG respectively .Figure:-12 presents overall harmonics injection in to the grid by combination of DFIG, SEC and load.

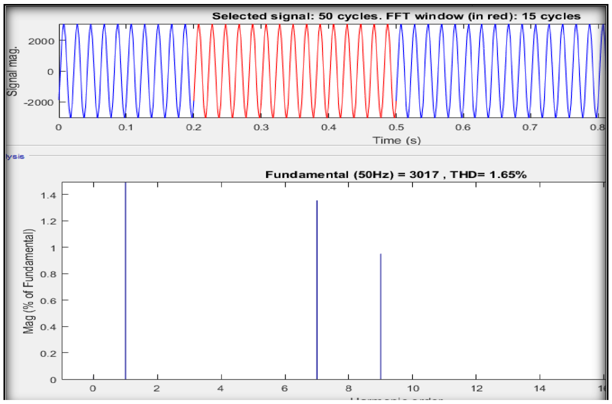

Figure:9-FFT Without REC*[FFT=1.65%]*

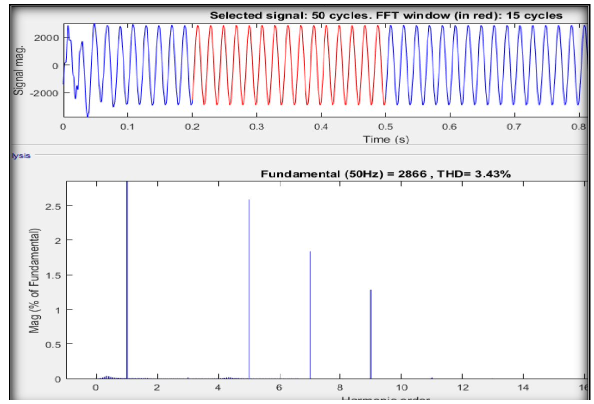

Figure:10-FFT With only solar REC*[FFT=3.43%]*

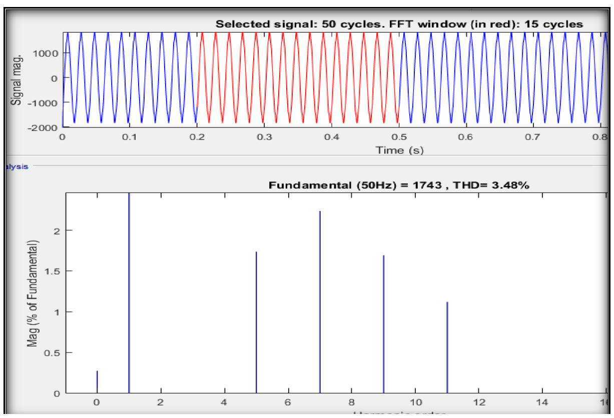

Figure:11-FFT With only Wind REC*[FFT=3.48%]*

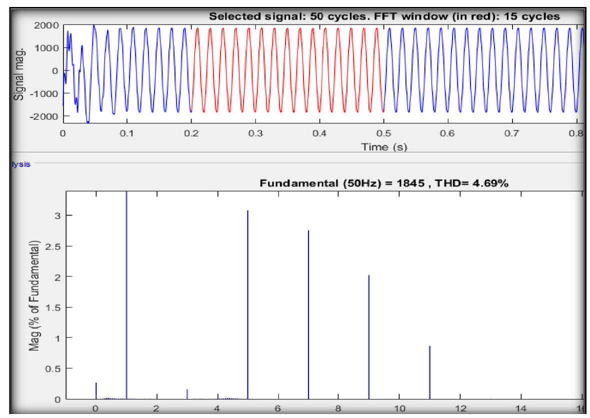

Figure:12- FFT With both RECs*[FFT=4.69%]*

As described in previous section, the system is supported by STATCOM as active harmonics filter. Hysteresis current control scheme is used for the purpose and the FFT results of filtered currents are shown in Figure:-13. It clearly indicates that the harmonics content of system current decreased to 1.02% from 4.69%. The remaining 1.02% of harmonics are supplied by grid side source and hence need to be filtered from generating station only.

In Table-3 the FFT results of system current are shown for different amount of power injected by RECs . The results show that STATCOM filters harmonics generated by RECs of up to 50% of load capacity. In Table-4 comparison of individual harmonics component is presented. The TDD limit of the line current is 1.5% as per IEEE 519-2014. However, the harmonics generated by REC increase the harmonics level to 4.69%. The proposed STATCOM - HBCC scheme compensate the REC injection and bring the individual components back within limits.

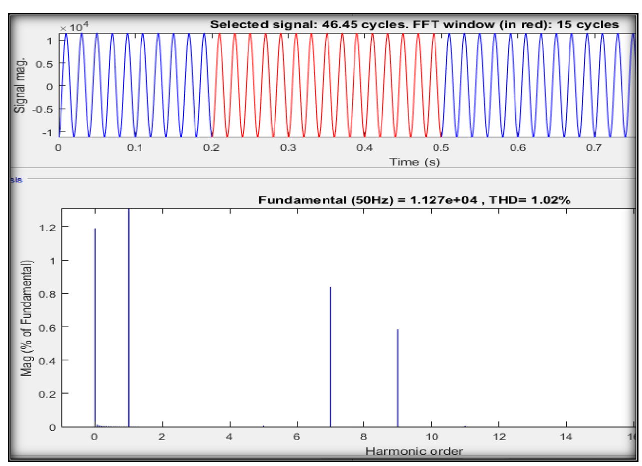

Figure:13- FFT With STATCOM*[FFT=1.02%]*

Total load [MW]	REC share [WTG+SEC] Generation [MW]	THD on 220kV PCC W/O STATCOM [%]	THD on 220kV PCC with STATCOM [%]
1000	0	1.65	1.02
1000	10	2.49	1.02
1000	**20**	**3.15**	**1.02**
1000	30	3.35	1.02
1000	40	3.94	1.02
1000	50	4.69	1.02

Table:3- FFT results on 220kV grid side PCC

Harmonic Order	As per IEEE 519	Actual Value W/O STATCOM	Actual Value With STATCOM
5th	1%	3.02%	0.06%
7th	1%	2.61%	0.85%
9th	1%	2.02%	0.60%
11th	1%	1.00%	0.01%
Total %TDD	***1.5%***	***4.69%***	***1.02%***

Table:4- Individual harmonic component comparison of line current as per IEEE 519-2014

VI. CONCLUSION:

A control scheme for STATCOM using Hysteresis current control has been presented in this paper. This work presents a STATCOM connected to PCC of RECs in HV transmission system. It is clear from the simulation results that the STATCOM using HBCC is simple , instantaneous and generates gate pulses by comparing the reference signal for power quality improvement and reactive power compensation. The performance of STATCOM has been investigated through MATLAB simulation circuit. Simulation results presents that through proposed scheme of HBCC , STATCOM generates the current wave in opposition to the disturbance signals in this grid current . Simulation results also show the decrease in individual harmonics components and is there by working as an Active power filter. Hence STATCOM can work as a multifunctional device for working as reactive power compensating and APF device.

In addition to this , one more outcome of the study is the limitation of RECs interconnection without STATCOM. It is shown in Table-3 that for power generation of more than 20% of total load requirement , the STATCOM become mandatory . Any further increase in the RECs injection may cause harmonics distortion to rise beyond the IEEE-519-2014 limits. To reduce the amount of current distortion use of active power filter is a must. Hence , in addition to reactive power compensation , STATCOM with HBCC can provide viable solution for power quality issues for large scale integration of RECs with the grid.

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