REACTIVE POWER CONTROL FOR WIND UNIT IN COLLABORATION WITH GRID AND DIESEL POWER PLANT.

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ABSTRACT— As energy is being the life line for the economy of any country so to stabilize the economy the rapidly growing demand of energy,e specially power generation must be fulfilled. The conventional power generation cannot fulfill this power generation demand so for this purpose self sustaining generation sources are used. The wind farm unit is the most common and reliable green source of power generation but due to different load types of consumer, such as linear and nonlinear load and at the same time wind distributed generation unit integration with the other distribution unit in conventional power grid faces power quality problems. To improve the power quality of the power system the concept of micro grid is utilized. In Micro Grid different Distribution Generating units DGs are interconnected in the system and micro grid switches in its switching modes as per system requirements. During switching mode of operation from Grid-connected mode to Island mode power quality issues arise such as voltage variations or flickers. In this paper concept of Micro grid is applied with wind farm unit as renewable energy resource and industrial load is fed. The test model is simulated in MATLAB/SIMULINK. FACTS device D-STATCOM is used to overcome the power quality issues and two reactive power controls schemed are simulated and their results are compared with micro grid switching modes.

Index Terms— Wind Farm DFIG, Microgrid, PQ, FACTS, D- STATCOM.

I. INTRODUCTION

The renewable energy resources such as wind turbine, fuel cells and micro hydro turbines are implemented for sustainable and green energy production. As these sources are not capable to feed the total load of country so these sources are connected with the other conventional distribution generating units in power grid system. Usually these distribution generators are located close to the load centers and during their synchronization with the conventional power grid system many power quality problems arise [1]. To run together these multiple generating sources without any major modification the micro grid concept is implemented for precise control of distribution and generation. In micro grid implementation different power generating unit with their associated load are connected as a single entity. Although micro grid concept facilitate with more precise and reliable control over generating units and load management but it may not resolve all the power quality problems. In fact in case of renewable resource the micro grid may cause more severe power quality problems while switching from its one mode of operation to other mode of operation which results in major power quality and system reliability. As the output of renewable resources is directly dependent on the input parameters such as wind speed in case of wind farm unit, so the power quality or system reliability needs more attention because these input parameters may vary and result in poor power quality. Due to installation of these DG units in power system the reliability and quality of power system is always susceptible. Micro grid must perform its operations efficiently and it must be capable to drive the utility load in both of operating modes i.e. Island mode and Grid-Connected mode. As the inductive load caused legging power factor and at the transition from Grid-connect mode the micro grid may not be able to provide the power to the load due to sever dip in voltage level. Similarly in case of non-linear inductive load harmonics are produce in the power system which decreases the efficiency and life of load utilities. So to have high power quality DGs unit must fulfill the load requirements. But DG units have their own limitation and DG units cannot provide or involve in voltage regulations therefore a precise and reliable source is required to overcome these power quality problems. To maintain the constant voltage at the output terminals in medium and high voltage applications tape changer transformers are used. Capacitor banks are also utilized at the load end for purpose of voltage regulation. Similarly, synchronous machine can provides voltage regulations by controlling power factor through their filed current. The tape changer transformers and synchronous machines provide slow response so to get fast response the Flexible AC Transmissions FACTS devices are the best choices. These FACTS devices are based on semiconductor power electronics circuits [2]. Different FACTs devices are used to improve the power quality of the system depending on the system requirements such as DVR, D-STATCOM and SVC [3]. These devices provide voltage or power compensation in series or parallel mode depending on their connection installation in the existing power system.

In this paper the idea of micro grid is implemented with wind farm unit as renewable resource to drive the real-time industrial load. As during transition of micro grid from grid connected mode to island mode the load is fed only by the wind form and during this transition a sever voltage sag is observed at the load terminal which is not sufficient to drive this critical load. Similarly the most of industrial load is of inductive nature that causes degrading of power quality by introducing legging power factor. For the purpose of safe island transition and fulfill load requirement D-STATCOM is implemented in the system with two different reactive power control techniques and their results are compared in **MATLAB/SIMULINK** simulation.

The rest of the paper is sectionalized as; Section-II Presents a Renewable Resource used in Micro Grid; Section-III expresses power quality problems and solutions; Section-IV presents Test system Section-V discuses analysis & results and in Section-VI this paper is concluded.

II. MICRO GRID

Micro grid is a single entity that is composed of dependable sources of power generation, distribution network of medium or low voltage and utility load with precise control of load management [4]. Micro grid is implemented in compact area with distribution generation such as micro turbine, fuel cells or wind turbine with their related devices such as condensers, batteries and utility loads. The micro grid facilitates power system with more precise load management and reliability of power supply. The precise voltage and power control improved system efficiency by minimizing transmission loess and fast response. In order to enhance power supplied-costumer interaction micro grid comes with feature of smart metering.

A. Operating Mode of Micro Grid

a. Grid Inter Connected Mode

The standard operating mode of micro grid is Grid Inter-Connected mode in which power is shared with utility grid system and micro grid.

b. Island Mode

As the power system protection isolate the faulty system from the healthy system so in case of any disturbance or fault near the utility grid bus or in utility grid, the micro grid is isolated from the utility grid and it goes into its Island mode. In island mode the local load is drive by the distributed generation units.

B. Types of Micro Grid

a. Micro Grid with Tri-generation

Tri generation phenomenon is also defined as CCHP in which hydrocarbons are burnt to generate electricity. The tri-generation is very efficient eco-friendly energy system

b. Multi Megawatt Micro Grid

In Multi megawatt micro grid the DG units with large power capacity are connected due to which conventional power inverter sources become impractical for switch. Usually internal combustion engine with synchronous generators are used in these micro grids

c. Industrial Micro grid

These micro grids fulfill high power requirements for commercial purpose. These micro grids provide onsite power generation which can feed the local industrial loads with maximum efficiency. Industrial micro grids are usually owned by the private companies for their local productions and implement smart load management as per their business requirements.

C. Characteristics of Micro-Grid

As micro grid is comprised of different generation sources and local utility loads with required compensation devices or equipment so switching of micro grid from one mode to other mode keeping in view the power quality of system [6]. For the purpose the micro grid control schemes to be flexible and self-guided the following two characteristics must be considered i.e. peer to peer, plug and play.

a. Peer-to-Peer

The peer-to-peer feature of micro grid ensures that the micro grid must be operational in case of any fault in any one of the generation source. The peer-to-peer characteristic enhances the power system reliability.

b. Plug and Play

The micro grid is connected with different power sources and these power sources can be connected or dis-connected as requirement of load. By utilizing the plug and play feature of micro grid these source can be control with complete ease.

D. Renewable Energy Resources

To fulfill rapidly growing energy needs of world it is necessary to mix up the conventional power sources with the renewable energy resources. Pakistan has great potential for these self-sustaining and green sources of energy especially for wind energy and solar energy. Many projects of wind power and solar energy are being installed in Pakistan and few of these projects have been commissioned and providing electricity in national grid. Although these energy resources are cheap and efficient but need real attention to maintain the high power quality of existing power system. The different types of wind farm units are available but in this work DFIG is used.

E. DFIG Wind Farm

The induction machines in which both of windings i.e. stator winding and rotor windings are being fed with AC current are known as Doubly Fed Induction Generators. In DFIG [5] [6] the output torque is produced by magnetic field of stator wind which has been results by interaction of rotor magnetic field. A discrete amount of power is available at wind turbine output as it is directly dependent on the input wind speed. On basis of operational speed function the wind farm units are classified as relatively fixed speed and variable speed machines. The figure-1 illustrate the simple model of DGIG in which a DC Capacitor link is working as a buffer between generator and grid side, stator windings are connected with utility grid through setup transformer.

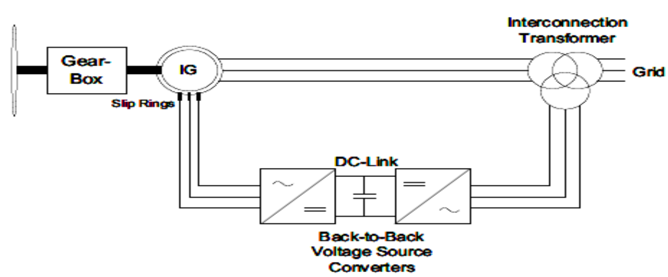

Figure 1: DFIG wind farm connection.

III. WIND FARM AND POWER QUALITY IN MICRO-GRID

Although Micro grid concept is one of the most emerging technology due to its diversified characteristics but in case of wind farm the power quality becomes a severe problem. The conventional power DG units can maintain desired voltage level at output terminal to run the local load but in case of Island mode or failure of convention power DG the renewable DG unit must be capable to drive the local load. Although for low penetration of wind farm high power quality can be observed but for high penetration of wind energy the balance of power network may be disturbed due to variation in wind speed or abrupt changes in system configuration. The balance of power is very important for reliable supply and smooth running of power system due to unbalance of power system the frequency of the system varies which ultimately result in total system collapse. At the same time the voltage stability is very important to keep power system synchronism in alive stage at time of micro grid switching from one mode to other mode or in case of sudden changes in load conditions. Similarly the short circuit fault near the main grid bus bar or at transmission lines may cause a sag in system voltage which results in voltage drop beyond the safe limit and power system may leads to total system blackout. Therefore to improve the power quality it is essential to have a voltage supporting system to maintain or stabilize the voltage level at desired value in case of utility grid disconnection in island mode of micro grid when the utility load is fed by the wind farm unit.

IEC Standards [7] address the power quality problems during operation of micro grid.

The wind farm unit efficiency is directly related to following distinct features;

1- The useful life period of utility or power equipment is mainly depend on the voltage stability and at the same time voltage variations may result erroneous tripping of power source which leads unnecessary interruption in power supply.

2- Due to unnecessary tripping of DG units the power System reliability is always on risk.

3- Sudden variations or switching from one mode to other mode in micro grid produce harmonics in power supply due to which consumer at load end faces poor power quality.

. Reactive power control techniques

In AC circuits the part of apparent power which is temporarily stored in capacitive or inductive element during the first quarter of AC input cycle is a Reactive power. It is actually an oscillatory power that stored in first half quarter and fed back in system in the following next half quarter. The reactive power has the direct impact on the power quality of power system as the system voltage level is dependent on reactive load so the voltage can be limit to desired level by controlling the flow reactive power. For the compensation of reactive power VAR controller connected in Series/Parallel configuration or power electronics based FACTs devices are used.

a. Shunt Configuration

Figure-2 presents the simple AC power system with legging power factor which is depicted in its phasor diagram. V_2 is the load voltage and it is clear that load current Ip is legging this reference load voltage by certain angle φ,. This is uncompensated power system and additional reactive power has to be generated due to which voltage stability is affected.

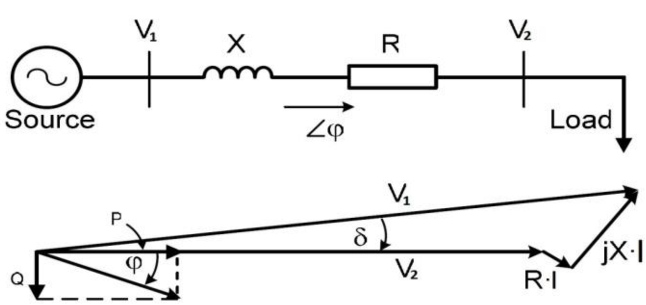

Figure 2: Power System without Compensation.

The more current is drawn from the circuit which causes more power losses. To minimize these additional power losses a compensation system is required figure-3 presents the parallel configuration for shunt compensation.

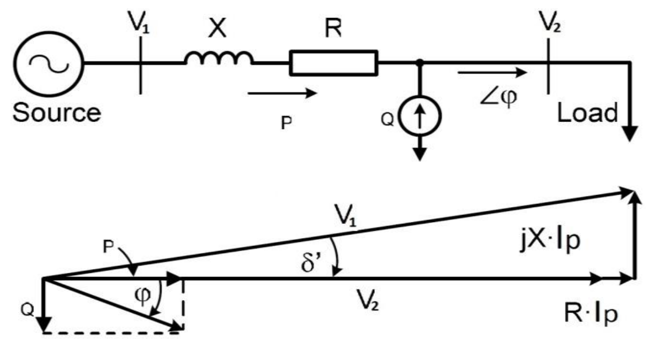

Figure 3: Shunt Compensation for power system.

b. Series Connection

In series configuration capacitor banks are installed in series of the power system due to which the equivalent reactance of the system is reduced and voltage is injected in the system as shown is figure-4

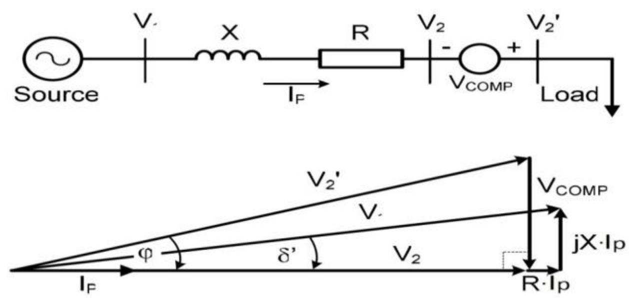

Figure 4: Series Compensation for power system.

A. FACTS Devices

The DFIG initially draw reactive power from the system and the grid system or other DG units are not equipped to perform voltage regulation. To overcome this power quality problem an external voltage supporting system is installed that is known as Flexible AC Transmission Systems. These devices are simple reactive power controllers which control the reactive power flow. Depending on their operations different FACTS are used i.e. UPFC, SVC,D-STATCOM, and DVR [8].

a. Distribution Static Compensator

D-STATCOM is installed in parallel configuration as shown is figure-5. The D-STATCOM is power factor compensation device which stabilized the system voltage

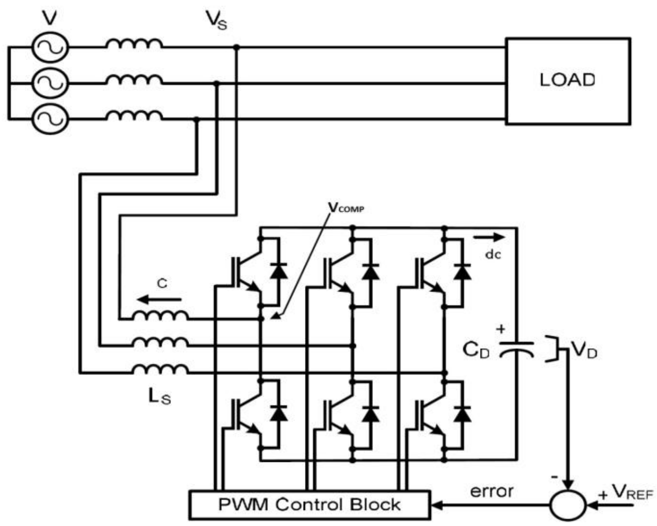

Figure 5: Connection of D-STATCOM [9].

The Voltage Source Converter (VSC) and DC capacitor are the key components of D-STATCOM [10]. The desired amplitude, phase angle and frequency of the input voltage are achieved by VSC. A sophisticated control scheme is implemented to control the reactive power flow.

B. Control Schemes for D-STATCOM

The control scheme plays a vital role for control of reactive power is D-STATCOM configuration. The control scheme generates a sequence of pulse which control the 3-phase inverter in D-STATCOM. In this section, two control techniques are discussed

a. Park's Transformation Based Control Scheme

The park's transformation performed conversion of 120° spaced out three-phase coordinate vectors (abc) to two phase rotating dq coordinates. The source voltage phases are converted to dq component for wave shaping of SRC. Similarly sensed compensating current and load current is also converted into dq-axis. This scheme provides a technique to linearly control the current and voltage of the system by converting into dq co-ordinates. The figure-6 shows the simple control block for the park's transformation.

In Generalized control algorithm PID controller is used with inputs of DC bus voltage V_{dc} and V_{dc}^{*}. This PID produce Ism* current at output which is used to estimate summation of source reference currents (I_{sa}^{*},I_{sb}^{*}, I_{sc}^{*}). This current is actually sum of in-phase component and quadrature component. The average voltage at DC bus is sustained by in-phase component or active power component while quadrature component provides reactive power to the load to attain unity power factor. The generalized control algorithm utilized the benefits of active power filtration and simple flow of this scheme is shown in figure-7. The pulse pattern for switching is obtained for Voltage Source Inverter used in control algorithm.

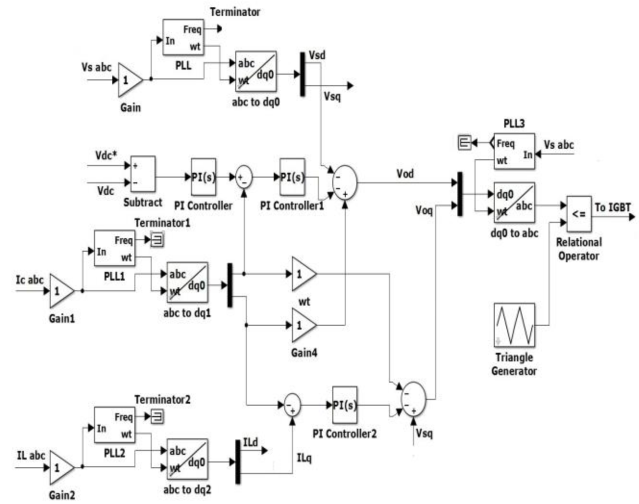

Figure 6: Park's Transformation Control Algorithm [11].

b. Generalized Control Algorithm

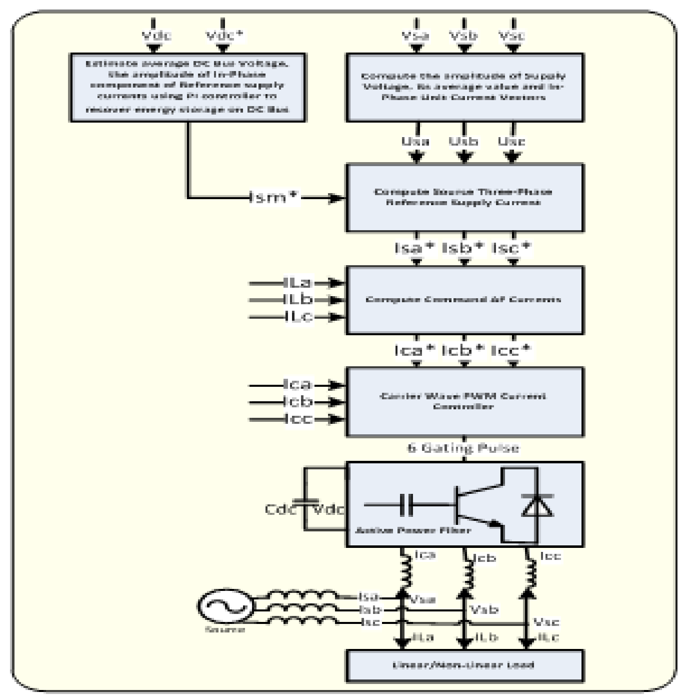

Figure 7: Generalized Control Algorithm [12]

C. Medium Voltage Distribution Network with Local Industrial Load

Test system is implemented in MATLAB/Simulink. A Medium Voltage network with local industrial load is devised. As in Pakistan 11KV is the distribution voltage level for local industries. This 11KV source is swing type and provides 2.5 MVA power to load in grid connected mode. This 11KV is fed through HT conductor of length 5KM that is "Dog" type with current capacity of 200 amps. As the industrial load is run at 400 Volts so a distribution step down transformer 11/.40 KV is simulated. As to observe the micro grid mode of operation the static switches are used as circuit breakers which work to control the operation of micro grid and also isolate the faulty section in case of a fault. To have a renewable energy resource in micro grid a DFIG wind farm unit with capacity of 1.8 MVA is simulated as shown in figure-8

IV. TEST SYSTEM MODEL

A Medium Voltage Test model distribution network with real time load of local fiber industry is implemented in MATLAB/SIMULINK. This industrial load utility grid feeder of 11KV and DFIG wind form is implemented to utilize the concept of Micro grid. The DFIG must provide the power supply for continues operation of this local industrial load in island mode. When micro grid switches to Island mode the DFIG initially draws reactive power from the system and results in voltage dip at the system bus. The D-STATCOM is installed to maintain desire voltage by controlling reactive power. In this section two control schemes are devised to analysis the effectiveness of D-STATCOM for improvement of voltage stability.

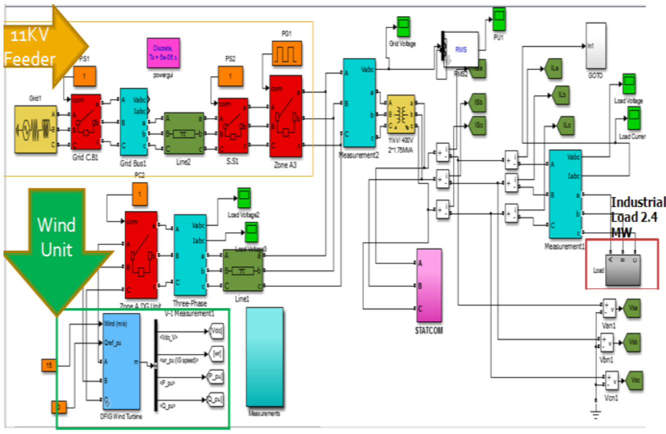

Figure 8: MV Network model based on Matlab/Simulink.

A. MODEL OF RENEWABLE DFIG

The renewable wind farm unit based on DFIG is implemented using MATLAB/SIMULINK as presented in figure-9. As the AC current is fed through both stator and rotor windings therefore two converters are simulated. A PMW based inverter composed of IGBTS is simulated. The DFIG wind farm has power rating of 1.8 MVA and its stator winding is connected to the grid bus through setup transformer and provides required power to load.

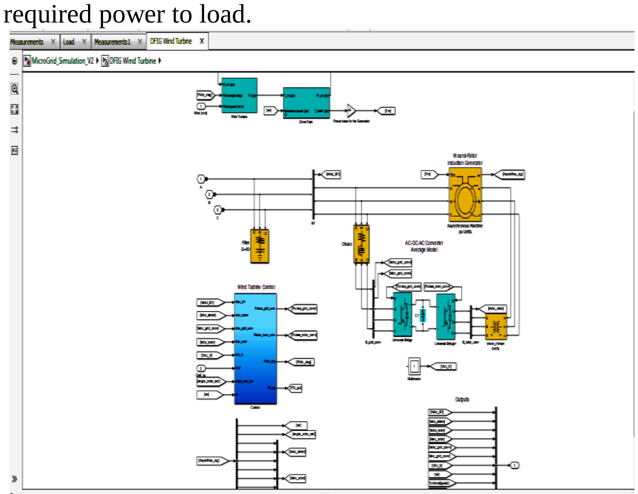

Figure 9: Matlab/Simulink Model For DFIG.

B.

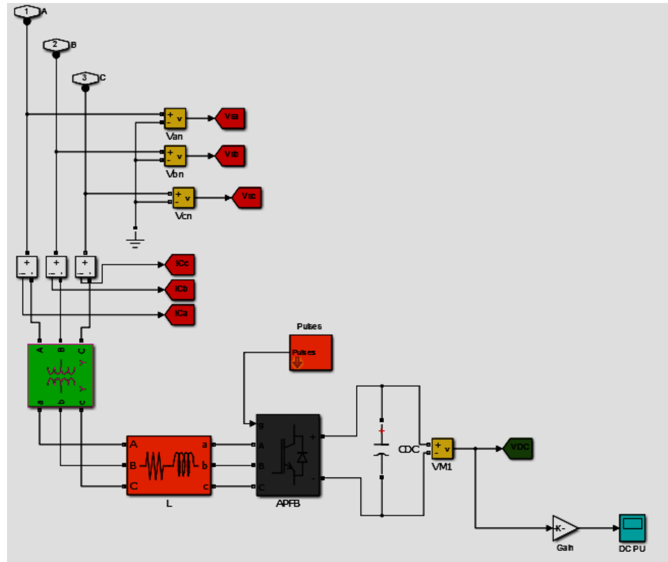

Figure 10: D-STATCOM Model.

V. ANALYSIS AND RESULTS

In this section the result for the two control schemes are discussed and voltage stability of the system is analyzed..

a. Simulation Results with D-STATCOM

Figure-11 depicts the transitive voltage sag during the time of switching of micro grid such voltage sag is not acceptable for smooth running of power system.

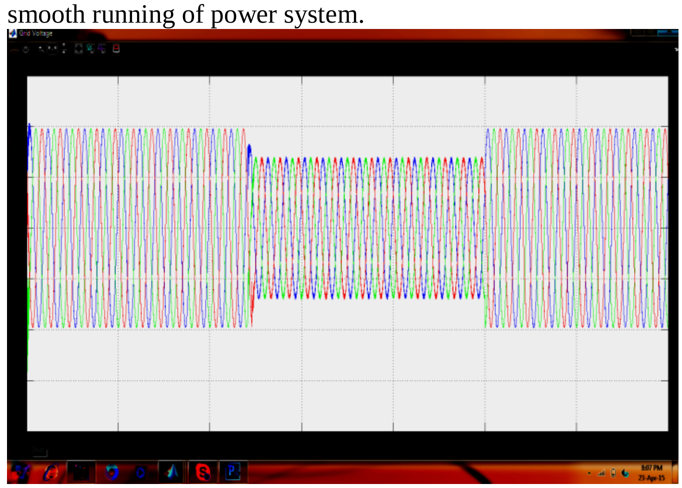

Figure 11: Voltage sag during Micro grid Operation.

At the same time reactive and active powers are analyzed as figure-12 illustrates. It is clear that the reactive power is drawn from the system at the time switching from Island mode to grid-connected mode.

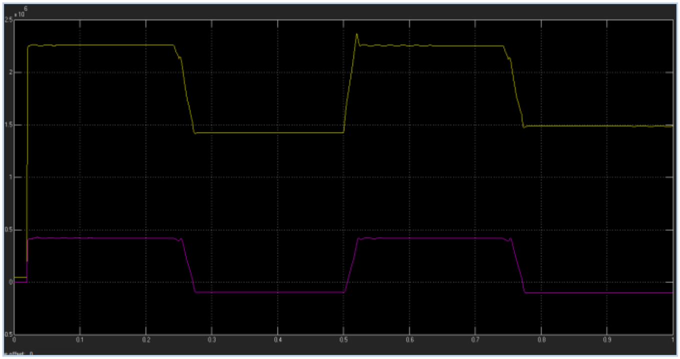

Figure 12: Reactive power drawn from grid during Microgrid Mode Switching without DSTATCOM.

To mitigate such voltage dip D-STATCOM is used which can easily handle and mitigate such a voltage dip. Reactive power compensation is performed as presented in figure-13.

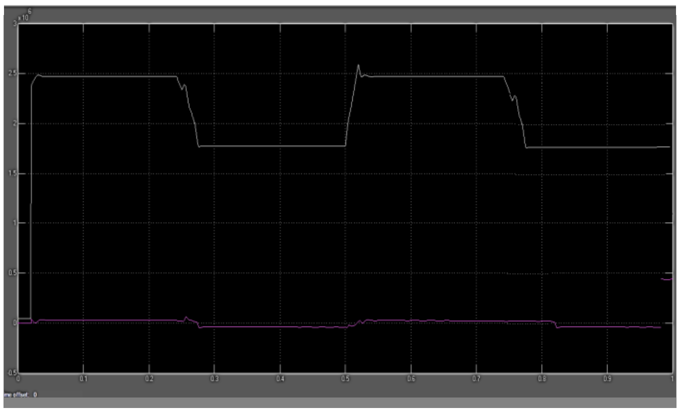

Figure 13: Reactive power Compensation with D-STATCOM.

With the reactive power control the system voltage is maintained for specific level illustrated in Figure- 14 and Figure-15.

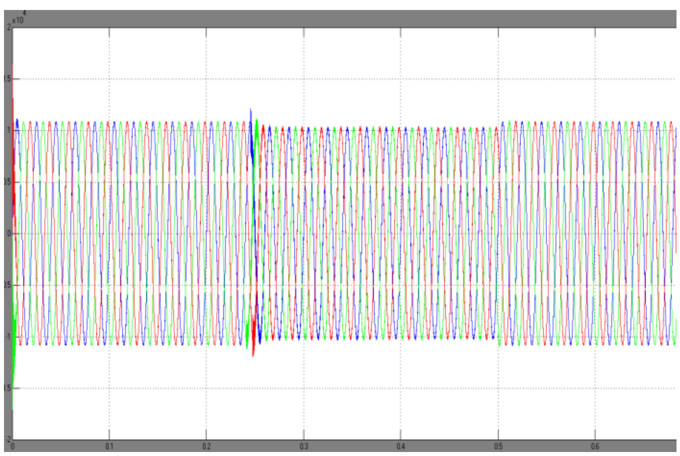

Figure 14: Voltage compensation with D-STATCOM.

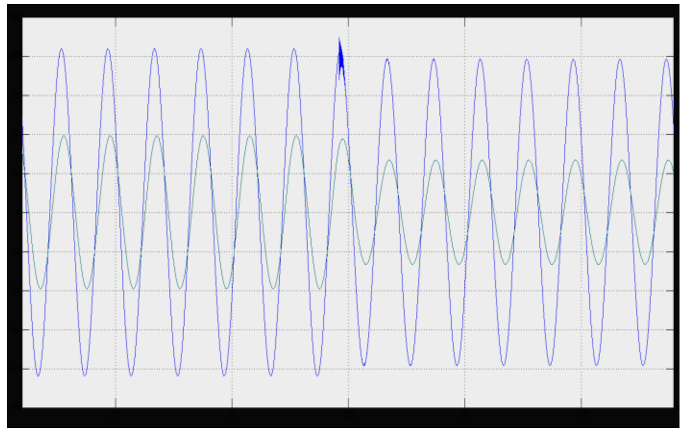

Figure 15: Stable voltage at Load with D-STATCOM.

Now FFT analysis is performed on current and voltage wave form for both control techniques. Without D-STATCOM compensation THD in voltage wave form is 11.345% and 24.1% in current wave form as depict in figure-16 and figure-17. But for high power quality it must be less than 5% according to IEEE-519.

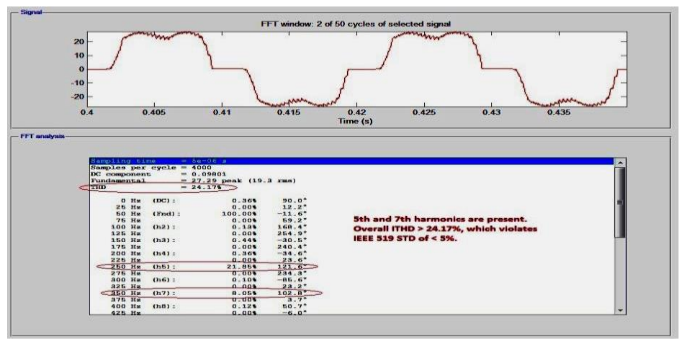

Figure 16: FFT analysis for Current wave form without Compensation.

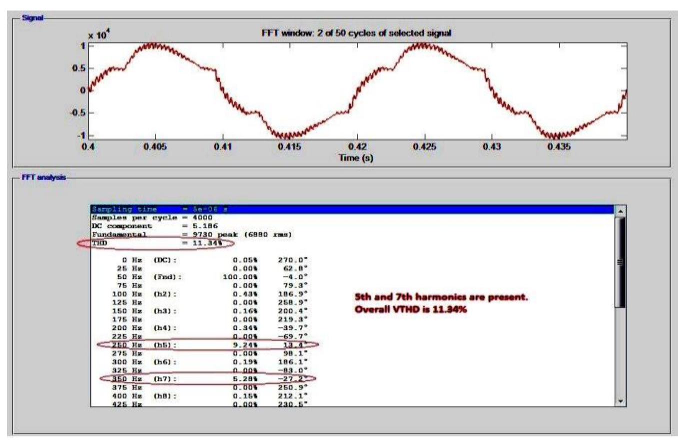

Figure 17: FFT analysis for Voltage wave form without Compensation.

Now D-STATCOM is connected in system with generalized control technique and it is observed voltage and current output in figure-18 and figure-19 respectively, it is clear that THD is less than 5% for both current and voltage.

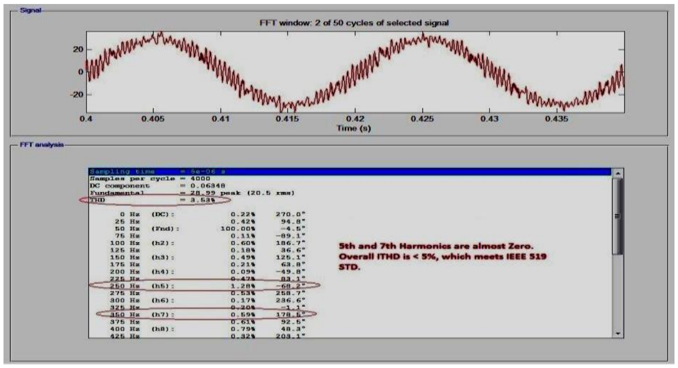

Figure 18: FFT analysis for Voltage wave form with D-STATCOM based on generalized technique.

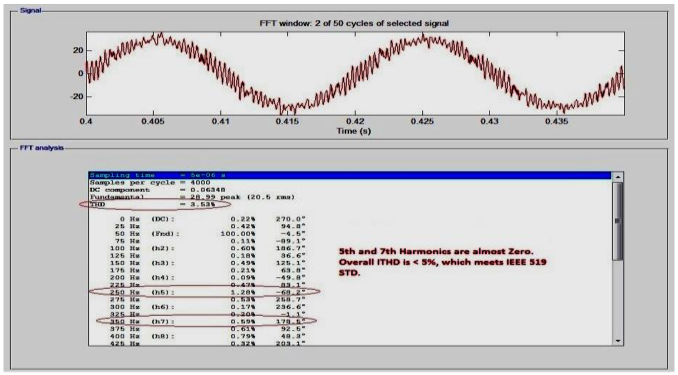

Figure 19: FFT analysis for Current wave form with D-STATCOM based on generalized technique.

Now D-STATCOM is simulated with Park's transformation control scheme and it is witness in figure-20 and figure-21 that THD is reduced to low value effectively.

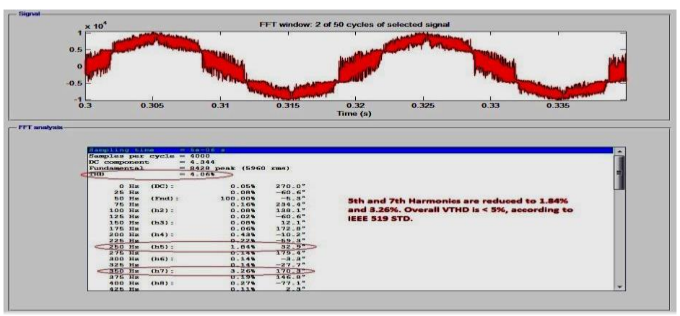

Figure 20: FFT analysis for Voltage wave form with D-STATCOM based on Park's Transformation technique.

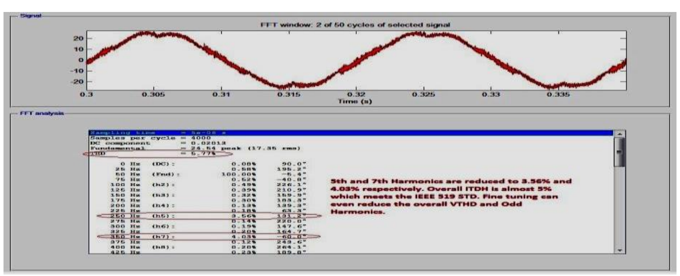

Figure 21: FFT analysis for Current wave form with D-STATCOM based on Park's Transformation technique.

VI. CONCLUSION

The result presented in this paper show that Micro grid concept with DFIG as Renewable Resource can be effectively used with D-STATCOM for improvement of power quality i.e. is voltage stability, harmonic suppression and reactive power control. The power factor can be corrected and two control scheme park's transformation and generalized control scheme are employed to eliminate total harmonics distortion in the system. Regarding future work the FACTS devices control with artificial Intelligence techniques used in micro grid can give more precise control with batter power quality.

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