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Negative Sequence Components Compensation using Statcom to Enhance Stability of Wind Farms During Grid Faults

Ambalam Sravani* and R.B.R Prakash**

Abstract: Now-a-days, wind power generation is a leading one in the family of renewable energy generation because of its several advantages. In these wind farms Squirrel cage Induction Generators are used especially in fixed speed wind turbines directly connected to the grid. Majority of the loads are nonlinear and unbalanced in nature. Due to these unbalanced loads and asymmetrical faults, negative sequence (-ve) components of currents are effected, i.e., negative sequence current increases. These increased negative sequence components will affect induction machine performance and it may damage the insulation of the winding. To mitigate this problem, STATCOM with an effective current controller to limit the negative sequence component of current by current injection is proposed. In this paper, consummation of the proposed system with dynamic load conditions is analyzed using MATLAB/SMULINK.

Keywords: Fixed Speed Induction Generator (FSIG), STATCOM, Negative sequence components.

1. INTRODUCTION

Day by day, conventional energy resources are decreasing and on the other side power demand is continuously increasing due to the industrialization, electrification or may be due to the little growth in GDP [7]. However and whatever, it is the duty of the government to take steps to bridge the gap. For extracting maximum energy from renewable resources, many optimization methods are being introduced [9].

Among these, wind power generation is the leading one compared to all other sources as a result of its other sources, its cleanness, pollution free nature and availability of high speed winds, its erection is increasing in the world. Basically wind farms are two types, ON shore and OFF shore wind farms [11]. Since the wind speed is more on the ground, power generation of OFF Shore wind farms are high contemplated to ON Shore. Now, extensive research has been progressing on type of generators used in wind generation to extract maximum energy from the wind at all speeds.

The type of generator used is decided based on the type of turbine used. Basically, two types of turbines are available i.e. Variable speed wind turbine and Fixed speed wind turbine. Generally doubly fed induction generator (DFIG) and permanent magnet synchronous generators (PMSG) are widely used for variable speed wind turbines because they offer variety of speed operations. Singly fed induction generators (SFIG) are used for fixed speed wind turbines [19]. In this paper, Fixed speed induction generator (FSIG) is taken in the proposed system and it is directly connected to the grid without using any converters. FSIG wind farm is not capable of providing reactive power, hence to meet the reactive power specifications, some external devices have to be connected in the system.

Particularly during abnormal conditions like voltage sags, FSIG will consume more reactive power and may be a chance for the loss of synchronism. From Past few years, the research is being done to find out an effective compensating devise to full fill the reactive power requirements [4] and to increase the fault ride through capability to maintain synchronism with grid.

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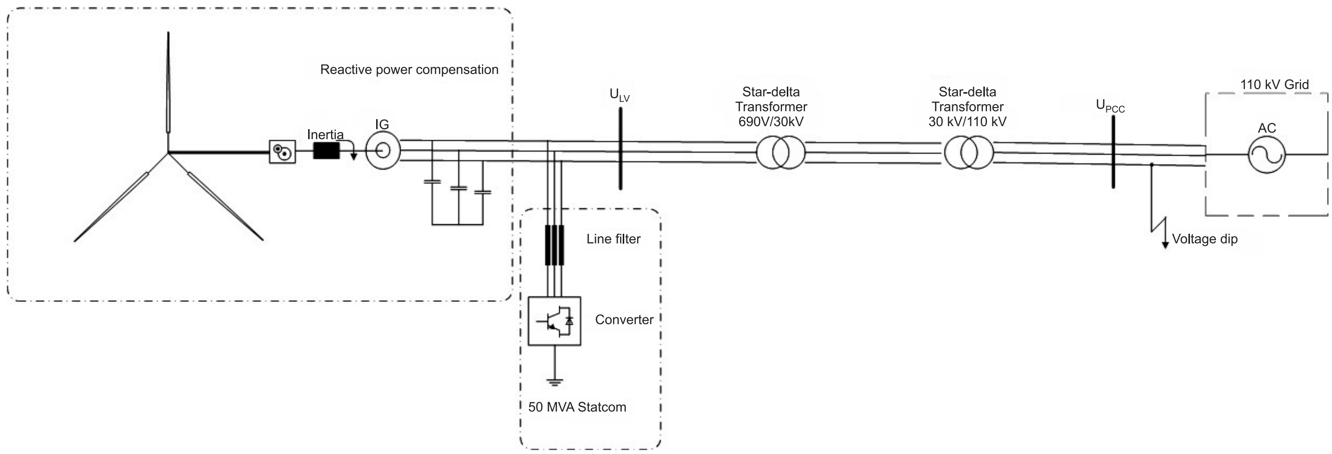


Figure 1: DFigure wind farm integration with STATCOM

In spite of its restrained capability to indulge voltage and frequency control, fixed speed wind turbine has been used because, wind power plants with type1(squirrel cage induction generators) wind turbines endow to system frequency support besides accomplishment of maximum efficiency at one appropriate wind speed, for the reason that each and every distinct wind turbine generator is directly connected to the power grid. Among FACTS devices, STATCOM [16] can give effective solution in stability enhancement. STATCOM is one type of shunt active filter and it consists of voltage source besides a converter [3]. It provides reactive power mitigation, dynamic stability improvement and maintains the grid code.

The system will work effectively under balanced condition, at faulted and over load condition also it will maintain synchronism up to their capabilities. But, for unbalanced load and unsymmetrical fault conditions, system goes to unbalanced condition leading to the effect on negative sequence components of currents [11]. These effected currents will increase the temperature of the machine inculcating the failure of major and minor insulations [10]. STATCOM control is introduced to control the negative sequence currents by using different current injection methods [1].

Application of STATCOM, coupled to FSIG wind farms is illustrated in this paper. It will control the sequence voltages at fault conditions and improves the consummation of the wind farm. The STATCOM can adequately control the torque ripple and negative sequence components, at dynamic load conditions for the better performance. Here, 3ϕ symmetry is lost as a result of which the synchronous frame voltage regulator works. The unbalances are inculcated by facilitating separate control loop for +ve and –ve sequence components. This regulator, restrains the STATCOM to enhance ride through, without disconnecting from the grid and also injects the –ve sequence components in phase opposition with main cause by which the average of these two reduces neutral currents.

2. PROPOSED SYSTEM-SPECIFICATIONS

Table 1
Description about grid and transformer

	Grid	*HV transformer*	*MV transformer*
Base apparent power	1000.0 MW	100.0 MW	100.0 MW
Rated voltage	110.0 kV	30.0 kV	690.0 V
Stray impedance (X_g)	0.980 pu	0.050 pu	0.10pu
Resistance (R_g)	0.020 pu	pu	0.20pu

The proposed system is depicted in Figure 1 FSIG based wind farm is interfaced directly to grid and STATCOM is connected in shunt. The system parameters are as shown in table 1 and 2 [18].

Table 2
Parameters of Induction Generator and STATCOM

Induction Generator	*Rated values*
Base apparent power	57.50 MW
Rated active power	50.0 MW
Rated voltage (line to line)	690.0 V
Stator resistance (R_s)	0.01080 pu
Stator stray impedance ($X_{s\sigma}$)	0.1070 pu
Mutual impedance (X_h)	4.40 pu
Rotor resistance ($R^1{}_R$)	0.012140 pu
Rotor stray impedance ($X^1{}_{R\sigma}$)	0.14070 pu
Compensation Capacitors	0.170 pu
Mechanical time constant H	3.0s
STATCOM Specifications	
Rated power	50.0 Mvar
Rated voltage	690.0 V
Line filter L_{filter}	0.150 pu
L_{NetZ}	–
DC voltage U_{DC}	1200.0 V
Current capability	1.0 pu

3. INDUCTION GENERATOR UNDER VOLTAGE DIP

Positive sequence component of torque (T^+) and induction machine stator voltage (V_s^+) [12] are calculated as

$$T^+(s) = 3\cdot\frac{\rho}{2}\cdot\frac{R_r}{s\omega_s}\cdot\frac{(V_s^+)^2}{\left(R_s+\frac{R_r}{s}\right)^2 + j(X_s+X_r)^2} \tag{1}$$

Here

R_s = Resistance of stator

R_r = Resistance of rotor

X_s = Reactance of stator winding

X_r = Reactance of rotor winding

ω_e = System frequency

p = number of poles

S = slip

At faulted condition transients in torque will affect the system stability, up to their withstand capacity it remains in synchronism. i.e. for small voltage variations. For high faults torque slip characteristics was changed highly then voltage drops drastically the system loss synchronism [5].

When the system goes to unbalanced condition the negative sequence components are affected. Then negative sequence component of current increases highly, it will damage the system

$$I_{s,\,pu}^- = \frac{V_s^-}{\omega_s.\sigma.L_s.I_{s,N}} \tag{2}$$

Here

σ = Leakage factor

I_s = Current of stator

L_s = Inductance of stator

$$T^{+} \approx 3.\frac{\rho}{2\omega_s}.V_s^{+}.I_{sd}^{+} \tag{3}$$

The generated negative sequence component of currents can cause torque oscillations at two times of its frequency. Negative sequence component of torque is

$$T^{-} \approx 3.\frac{\rho}{2\omega_s}.V_s^{+}.I_s^{-} \tag{4}$$

The calculation of negative sequence currents can be carried out by using the following equations

$$v_{\alpha-} = \frac{1}{2} \times (v'_{\alpha} + qv'_{\beta}) \tag{5}$$

$$v_{\beta-} = \frac{1}{2} \times (v'_{\alpha} - qv'_{\beta}) \tag{6}$$

From sequence analysis positive sequence component of torque is reduced due to voltage reduction. Then reduction of average voltage will reduce the torque and it affects turbine shaft. The negative sequence components of voltage and torque are compensated by STATCOM.

4. STATCOM CONTROL STRUCTURE

STATCOM control consists of reactive power control, outer vector voltage control and inner current controlled in cross structure. The control parameters are calculated in direct axis and quadrature axis components why because PI controller can give better performance when parameters are in synchronous reference frame.

$$G_{PI}(s) = V_R \frac{1 + s.T_n}{s.T_n} \tag{7}$$

Calculation of control gain constants of voltage controller was mentioned in [14]-[16], resonant control is added in control design.

$$G_{Res}(s) = K_{res}.\frac{s}{s^2 + (2.\omega_0)^2} \tag{8}$$

The effected negative sequence components of currents will be controlled by estimating the percentage of effected components comparing with the reference components besides the error components are reduced by PI controller [2]. The structure of the controller is depicted in Figure 1.

The effected voltage and dc component will be restrained with outer voltage control loop of STATCOM control by measuring voltage at PCC. From measured voltage sequence components are calculated then comparison and controlling is performed. Then effected component of current measured from current at PCC, it was controlled by duel actuated PI controllers and it was put the current in the limits.

Induction generators operate with variety of control strategies [18] leading to the clarification of the impact of the –ve sequence voltage compensation which are performed out for analysis beneath the unbalanced grid fault [13]. The purpose of the first and second methods is to diminish the +ve & -ve sequence potential differences respectively. While the respective opposite sequence voltages will remain unchanged.

A. Purpose of DSOGI PLL

Basically, Phase Locked Loop (PLL) technique is used for the synchronization of the grid in which the potential difference components of the three phase signal of natural reference frame are converted into two phase rotating dq reference frame. For detecting the phase angle of the three phase systems we use SRF PLL. Specially, the SOGI based PLL are designed to decouple the +ve & −ve sequence components and hence the correlated phase angle for both the sequence components are properly detected.

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} & 0 \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} & 0 \end{bmatrix} \begin{bmatrix} v_\alpha \\ v_\beta \\ v_0 \end{bmatrix} \tag{9}$$

The sustaining fundamental of the DSOGI PLL is dependent upon the Instantaneous symmetrical component method for the estimation of -ve sequence components of the grid potential difference vectors in the stationary (α-β) domain. Once the synchronization is done we obtain all the control variables in dc values.

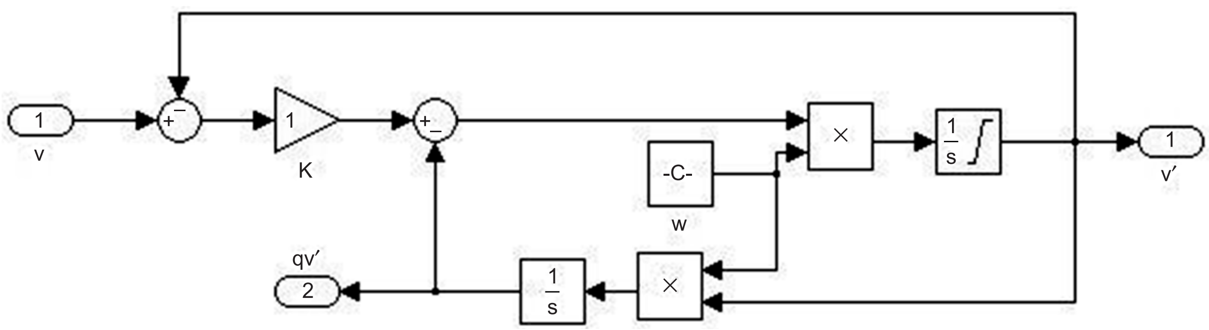
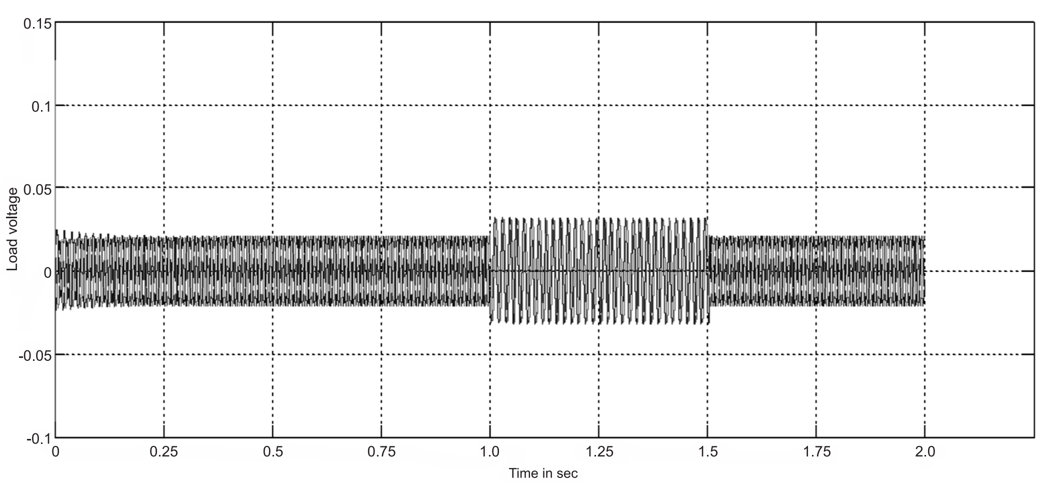


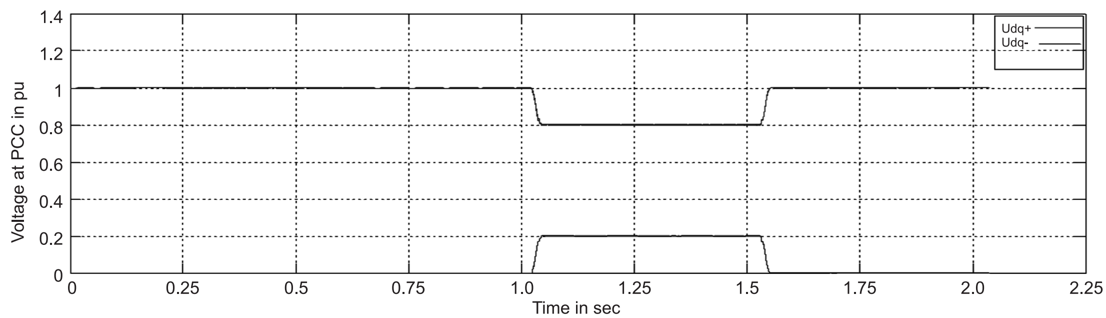
Figure 2: SOGI Quadrature signal generator

5. RESULTS AND DISCUSSIONS

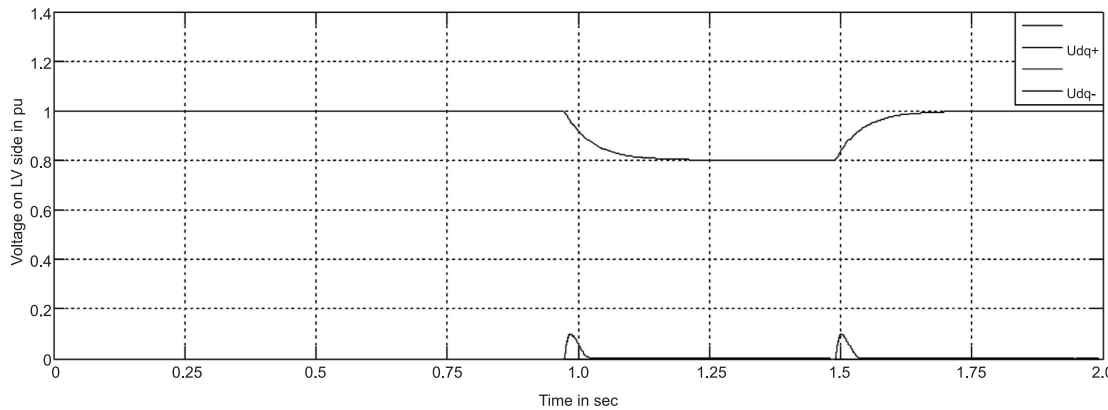
The system performance is analysed from its outputs as shone bellow. Here dynamic load conditions are observed, it will shows some effect on system performance. Balanced dynamic loads are used that's why the harmonic content will reduced why because the fundamental value going to increase compare to harmonic component THD will reduced.



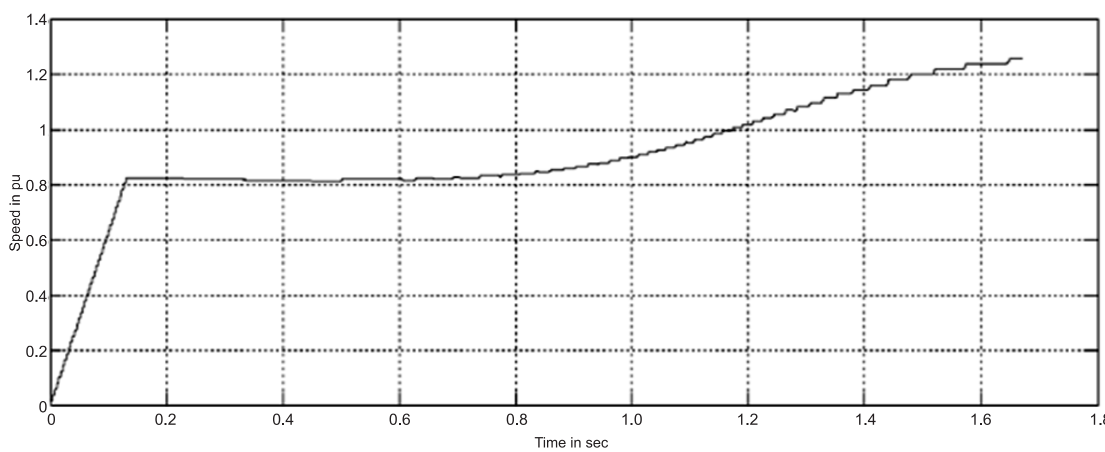
(a) Load voltage at PCC



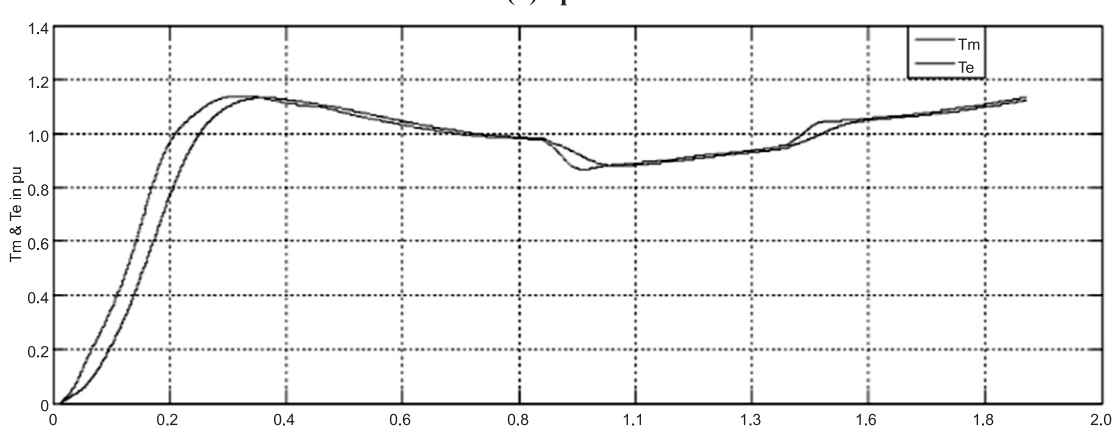
(b) Voltage at PCC



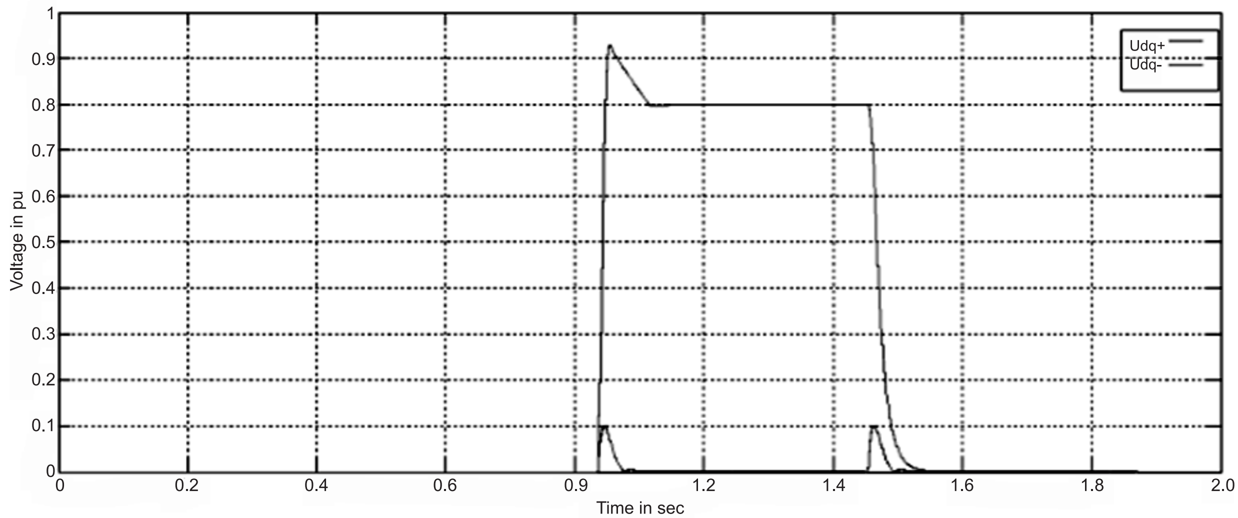
(c) Voltage at LV side



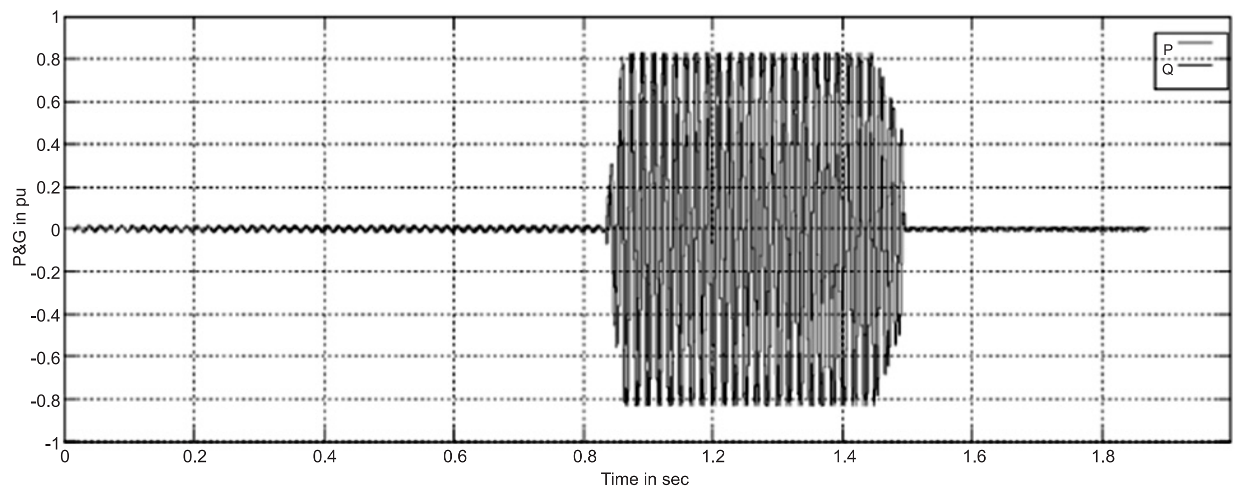
(d) Speed



(e) Torque



(f) Statcom currents



(g) P& Q of statcom

Figure 3: The above results are the response of the DFigure system under dynamic loading condition

The THD analysis is done under steady load and dynamic load conditions with both the generators working with STATCOM.

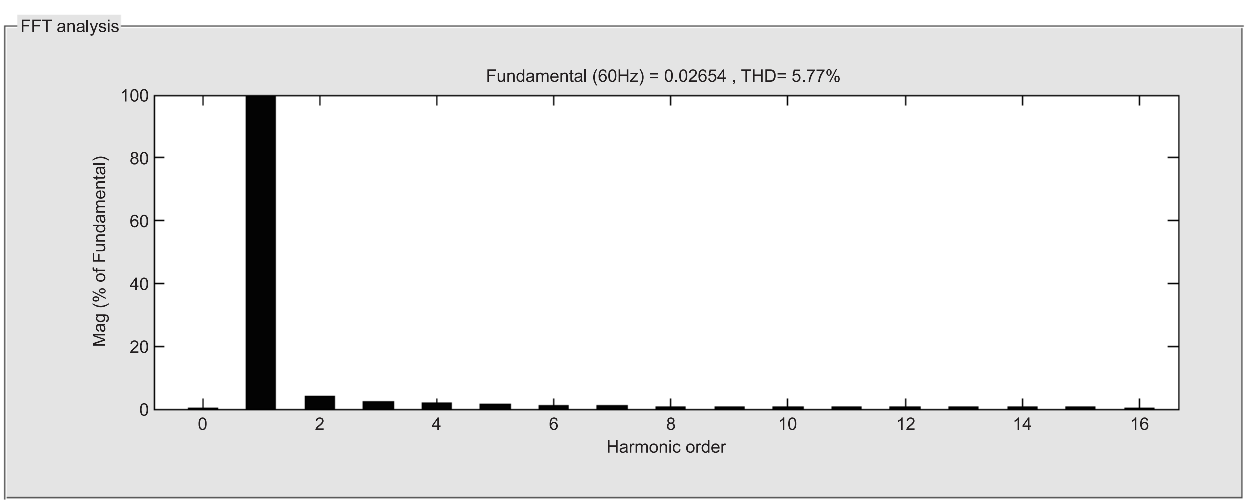


Figure 4: FSIG with steady load

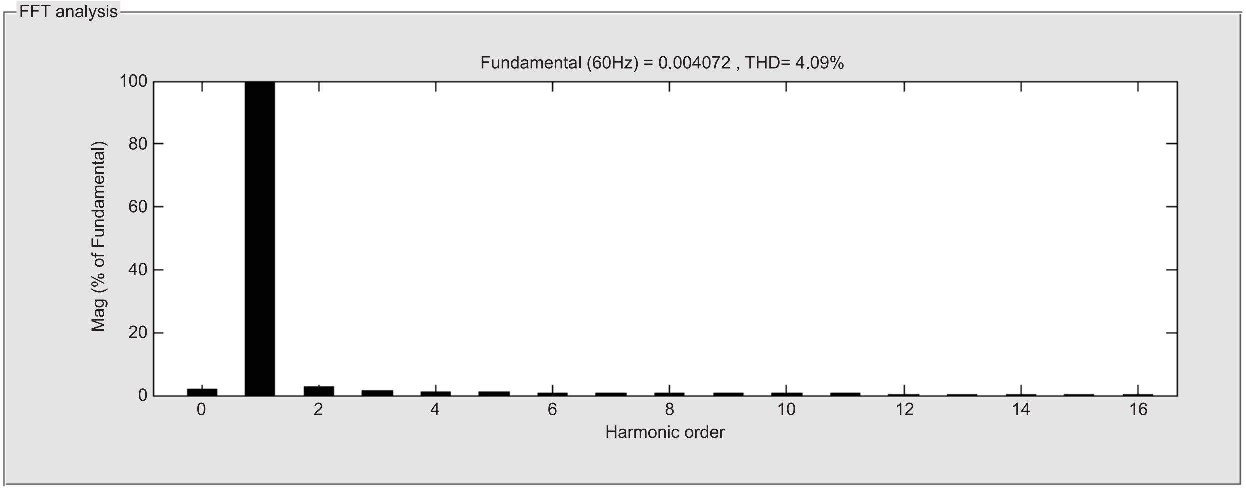


Figure 5: FSIG with dynamic load condition

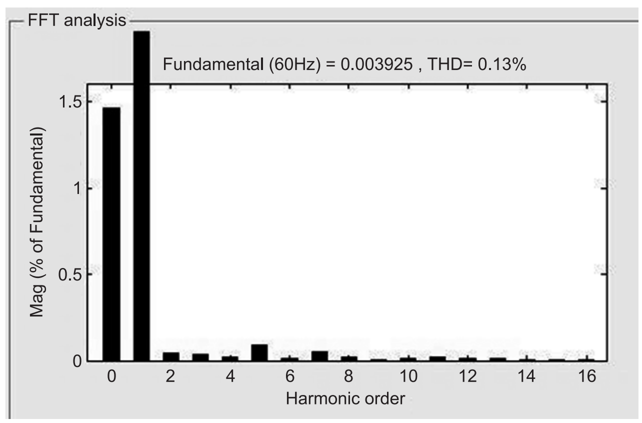


Figure 6: DFigure with dynamic loading condition

The system dynamic loads are 15kw are continuously is in on condition, 120 kw of load ON at 0.4s, 143 kw of load ON at 0.9s and 1900w load operated at 1.3-1.7s.The unsymmetrical fault is applied at 1-1.5s, at this condition STATCOM starts current injection, the STATCOM power injections are shown in Figure 3(g). The voltage variations at PCC with STATCOM are observed from Figure 3(b).

Non-linearity of electrical equipment produces distortion of fundamental sine wave associated with a phenomenon called harmonic disturbance causing raised currents, power losses and probable damaging overheat in equipment, Limitations in communication circuits. Restrictions on the Total Harmonic Distortion (THD) along with specific harmonics [8] are set up by the specific standards of Harmonics.

Variable speed wind turbines with a specified switching frequency uses Power electronic converters performing in a peculiar mode as on and off, shifts the harmonics to higher frequency by which they can be easily eliminated with the help of small filters. Novel wind turbines are used to meet the standards of harmonics practically.

Table 3
THD at different loading conditions

Load condition	*% of THD*
Steady load condition	5.790
Dynamic load condition	4.090

6. CONCLUSION

The grid Integration of wind farms can give wide area of operation compared to Islanded micro grid operations. The STATCOM incorporation with wind farm can give better performance and the fault rides through potentiality of wind farms are increased. The STATCOM with effective current control can keep negative sequence component of current in the limits, incorporated with other voltage and reactive power controllers. System performance with STATCOM under dynamic load condition is improved compared to steady load condition. The %THD in fundamental wave is reduced from 5.79 to 4.09. Finally system stability is enhanced with introducing STATCOM in wind farm grid integration.

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