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Power Compensation at Distribution Level using a VSC based DSTATCOM

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Abstract

A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end user equipments. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. The performance of the wind turbine and thereby power quality are determined on the basis of measurements and the norms followed according to the guideline specified in International Electro-technical Commission standard, IEC-61400. *The paper study demonstrates the power quality problem due to installation of wind turbine with the grid. In this proposed scheme distribution static compensator (DSTATCOM) is connected with a battery energy storage system (BESS) to mitigate the power quality issues. The battery energy storage is integrated to sustain the real power source under fluctuating wind power. The DSTATCOM control scheme for the grid connected wind energy generation system for power quality improvement is simulated using MATLAB/SIMULINK in power system block set. Finally the proposed scheme is applied for both balanced and unbalanced nonlinear loads.*

1. Introduction

Power quality is one of the most important topics that electrical engineers have been noticed in recent years. Voltage sag is one of the problems related to power quality. This phenomenon happens continuously in transmission and distribution systems. During a voltage sag event, amplitude of the effective load voltage decrease from 0.9 of the nominal load voltage to 0.1 in very short time (less than one. minute). Short circuit, transformer energizing, capacitor bank charging etc are causes of voltage sag. Voltage sag has been classified in 7 groups of A-G [1]. According to this classification most of voltage sags are companion with a phase angle jump (types C, D, F and G). Phase angle jump for power electronics systems such as ac-ac and ac-dc converters, motor drives etc is harmful [2]. Therefore, phase angle jump compensation is one of the voltage sag mitigation goals.

Most industries and companies prefer electrical energy with high quality. If delivered energy to these loads has poor quality, products and equipment of these loads such as microcontrollers, computers, motor drives etc are damaged. Hurt of this phenomenon in companies that dealing with information technology systems is serious. According to a study in U.S., total damage by voltage sag amounts to 400 Billion Dollars [3]. For these reasons power quality mitigation in power systems is necessary. Nowadays, Custom Power equipments are used for this purpose.

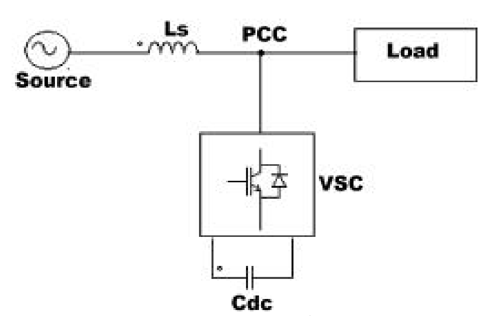


Fig.1 Shows the basic structure of DSTATCOM.

Many studies show that the usage of D-STATCOM is effective to improve power and voltage quality problems. In [4] the limiting of dc side over current is studied but an extra inverter is used for the control of negative sequence. In [5] the study is carried out in perunit value and investigates the D-STATCOM application under unbalanced conditions system voltages and it increases the capacitor size in order to obtain a better performance during unbalanced condition and it is not economical. In [8] the control scheme for the operation of D-STATCOM under unbalanced conditions is presented but the controller unbalances the compensator voltage in response the unbalanced system voltage.

2. Distribution Static Compensator (D-STATCOM)

A D-STATCOM consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer\ connected in shunt to the distribution network. Figure 2.1 shows the schematic diagram of D-STATCOM.

$$I_{out} = I_L - I_S = I_L - \frac{V_{th}-V_L}{Z_{th}} \qquad (2.1)$$

$$I_{out} < \gamma = I_L < (-\theta) - \frac{V_{th}}{Z_{th}} < (\delta - \beta) + \frac{V_L}{Z_{th}} < (-\beta) \qquad (2.2)$$

I_{out} = output current I_L = load current
I_S = source current V_{th} = Thevenin Voltage
V_L = load voltage Z_{th} = impedance

Referring to the equation 2.2, output current, Iout will correct the voltage sags by adjusting the voltage drop across the system impedance, (Z_{th}=***R+jX***). It may be mention that the effectiveness of D-STATCOM in correcting voltage sags depends on

a) The value of Impedance, Z_{th}= ***R+jX***

b) The fault level of the load bus

A. Voltage Source Converter (VSC)

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual.

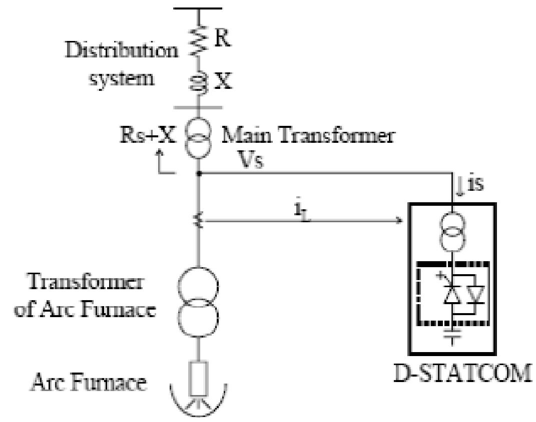


Figure.2 Schematic diagram of a D-STATCOM

It also converts the DC voltage across storage devices into a set of three phase AC output voltages [8, 9]. In addition, D-STATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, D-STATCOM is said to be in capacitive mode. So, it will compensate the reactive power through AC system and regulates missing voltages. These voltages are in phase and coupled with the AC system through the reactance of coupling transformers. Suitable adjustment of the phase and magnitude of the DSTATCOM output voltages allows effectives control of active and reactive power exchanges between D-STATCOM and AC system. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage [10].

B.Controller for DSTATCOM

The three-phase reference source currents are computed using three-phase AC voltages (*v*ta, *v*tb and *v*tc) and DC bus voltage (*V*dc) of DSTATCOM. These reference supply currents consist of two components, one in-phase (*I*spdr) and another in quadrature (*I*spqr) with the supply voltages. The control scheme is represented in Fig. 2. The basic equations of control algorithm of DSTATCOM are as follows.

B1. ***Computation of in-phase components of reference supply curren***

The instantaneous values of in-phase component of reference supply currents (*I*spdr) is computed using one PI controller over the average value of DC bus voltage of the DSTATCOM (*v*dc) and reference DC voltage (*v*dcr) as

$$I_{spdr} = I_{spdr(n-1)} + K_{pd}\{V_{de(n)} - V_{de(n-1)}\} + K_{id}V_{de(}$$

Where Vde(*n*) =(Vdcc-Vdc*n*) denotes the error in Vdcc and average value of Vdc *Kpd* and *Kid* are proportional and integral gains of the DC bus voltage PI controller. The output of this PI controller (*I*spdr) is taken as amplitude of in-phase component of the reference supply currents. Three-phase in-phase components of the reference supply currents (*i*sadr, *i*sbdr and *i*scdr) are computed using the in-phase unit current vectors (*u*a, *u*b and *u*c) derived from the AC terminal voltages (*v*tan, *v*tbn and *v*tcn), respectively.

$$U_a = V_{ta}/V_{tm} \quad U_b = V_{tb}/V_{tm} \quad U_c = V_{tc}/V_{tm}$$

where *V*tm is amplitude of the supply voltage and it is computed as

$$V_{tm} = \sqrt{[(2/3)(V_{tan}^2 + V_{tbn}^2 + V_{tcn}^2)]}$$

The instantaneous values of in-phase component of reference supply currents (*i*sadr, *i*sbdr and *i*scdr) are computed as

$$I_{sadr} = I_{spds}U_a \quad I_{sbdr} = I_{spdr}U_b \quad I_{scdr} = I_{spdr}U_c$$

B2. ***Computation of quadrature components of reference supply current***

The amplitude of quadrature component of reference supply currents is computed using a second PI controller over the amplitude of supply voltage (*v*tm) and its reference value (*v*tmr)

$$I_{spqr(n)} = I_{spqr(n-1)} + K_{pq}\{V_{ac(n)} - V_{ac(n-1)}\} + K_{iq}V_{ac(n)}$$

Where Vac = VtmcVmc(n) denotes the error in Vtmc and computed value *Vtmn* from Equation (3) and Kpq and Kiq are the proportional and integral gains of the second PI controller.

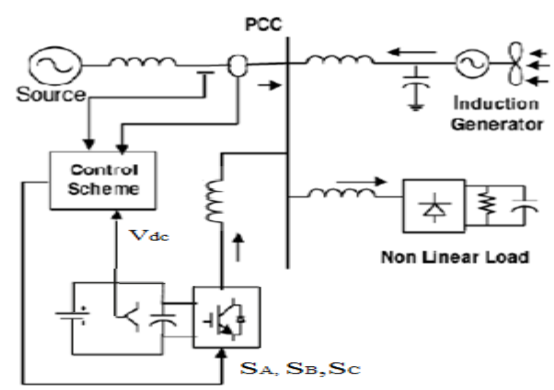
$$W_a = \{-U_b + U_c\}/\{\sqrt{3}\}$$

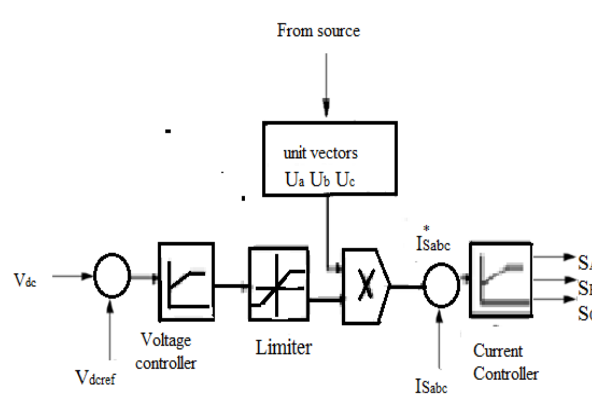
$$W_b = \{U_a\sqrt{3} + U_b - U_c\}/\{2\sqrt{3}\}$$

$$W_c = \{-U_a\sqrt{3} + U_b - U_c\}/\{2\sqrt{3}\}$$

Three-phase quadrature components of the reference supply currents (*i*saqr, *i*sbqr and *i*scqr) are computed using the output of second PI controller (*I*spqr) and quadrature unit current vectors (*w*a, *w*b and *w*c) as

$$i_{saqr} = I_{spqr}W_a, i_{sbqr} = I_{spqr}W_b, i_{scqr} = I_{spqr}W_c,$$





B3 Computation of total reference supply currents

Three-phase instantaneous reference supply currents ($i$sar, $i$sbr and $i$scr) are computed by adding in-phase ($i$sadr, $i$sbdr and $i$scdr) and quadrature components of supply currents (i_{saqr}, i_{sbqr} and i_{scqr}) as

$$i_{sar} = i_{sadr} + i_{saqr}, \quad i_{sbr} = i_{sbdr} + i_{sbqr}, \quad i_{scr} = i_{scdr} + i_{scqr}$$

A hysteresis pulse width modulated (PWM) current controller is employed over the reference ($i$sar, $i$sbr and $i$scr) and sensed supply currents ($i$sa, $i$sb and $i$sc) to generate gating pulses for IGBTs of DSTATCOM.

3. Matab/Simulink Modelling of DSTATCOM

3.1 Modelling of Power Circuit

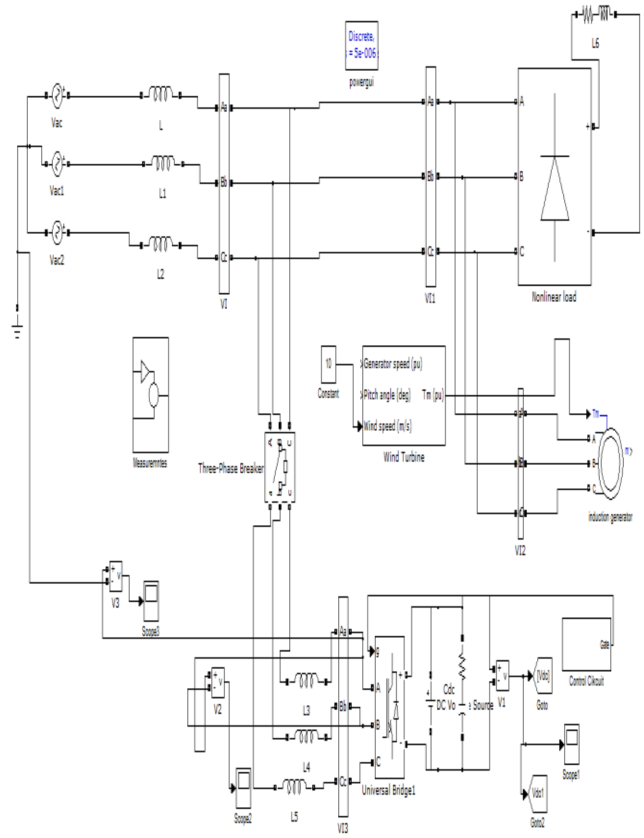


Figure. 3 Matlab/Simulink Model of DSTATCOM

Fig. 3 shows the complete MATLAB model of DSTATCOM along with control circuit. The power circuit as well as control system are modeled using Power System Block set and Simulink. The grid source is represented by three-phase AC source. Three-phase AC loads are connected at the load end. DSTATCOM is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus. An IGBT-based PWM inverter is implemented using Universal bridge block from Power Electronics subset of PSB. Snubber circuits are connected in parallel with each IGBT for protection. Simulation of DSTATCOM system is carried out for linear and non-linear loads. The linear load on the system is modeled using the block three-phase parallel R-L load connected in delta configuration. The non-linear load on the system is modeled using R and R-C circuits connected at output of the diode rectifier. Provision is made to connect loads in parallel so that the effect of sudden load addition and removal is studied. The feeder connected from the three-phase source to load is modeled using appropriate values of resistive and inductive components.

3.2 Modelling of Control Circuit

Fig. 4 shows the control algorithm of DSTATCOM with two PI controllers. One PI controller regulates the DC link voltage while the second PI controller regulates the terminal voltage at PCC. The in-phase components of DSTATCOM reference currents are responsible for power factor correction of load and the quadrature components of supply reference currents are to regulate the AC system voltage at PCC.

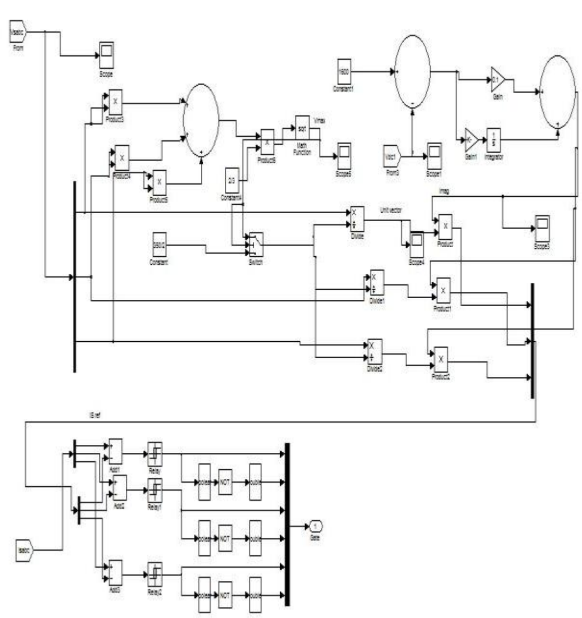


Figure. 4 Control Circuit

The output of PI controller over the DC bus voltage (*I*spdr) is considered as the amplitude of the in-phase component of supply reference currents and the output of PI controller over AC terminal voltage (*I*spqr) is considered as the amplitude of the quadrature component of supply reference currents. The instantaneous reference currents (*i*sar, *i*sbr and *i*scr) are obtained by adding the in-phase supply reference currents (*i*sadr, *i*sbdr and *i*scdr) and quadrature supply reference currents (*i*saqr, *i*sbqr and *i*scqr). Once the reference supply currents are generated, a carrierless hysteresis PWM controller is employed over the sensed supply currents (*i*sa, *i*sb and *i*sc) and instantaneous reference currents (*i*sar, *i*sbr and *i*scr) to generate gating pulses to the IGBTs of DSTATCOM. The controller controls the DSTATCOM currents to maintain supply currents in a band around the desired reference current values. The hysteresis controller generates appropriate switching pulses for six IGBTs of the VSI working as DSTATCOM.

4. Simulation Results

Here Simulation results are presented for two cases. In case one reactive power and harmonic compensation, case two active power, reactive power and harmonic compensation is considered.

4.1 *Case one*

Performance of DSTATCOM connected to a weak supply system is shown in Fig.5 for power factor correction and load balancing. This figure shows variation of performance variables such as supply voltages (*v*sa, *v*sb and *v*sc), terminal voltages at PCC (*v*ta, *v*tb and *v*tc), supply currents (*i*sa, *i*sb and *i*sc), load currents (*i*la, *i*lb and *i*lc), DSTATCOM currents (*i*ca, *i*cb and *i*cc) and DC link voltage (*V*dc).

Fig. 5 shows the source current, load current and compensator current and induction generator currents plots respectively. Here compensator is turned on at 0.1 seconds.

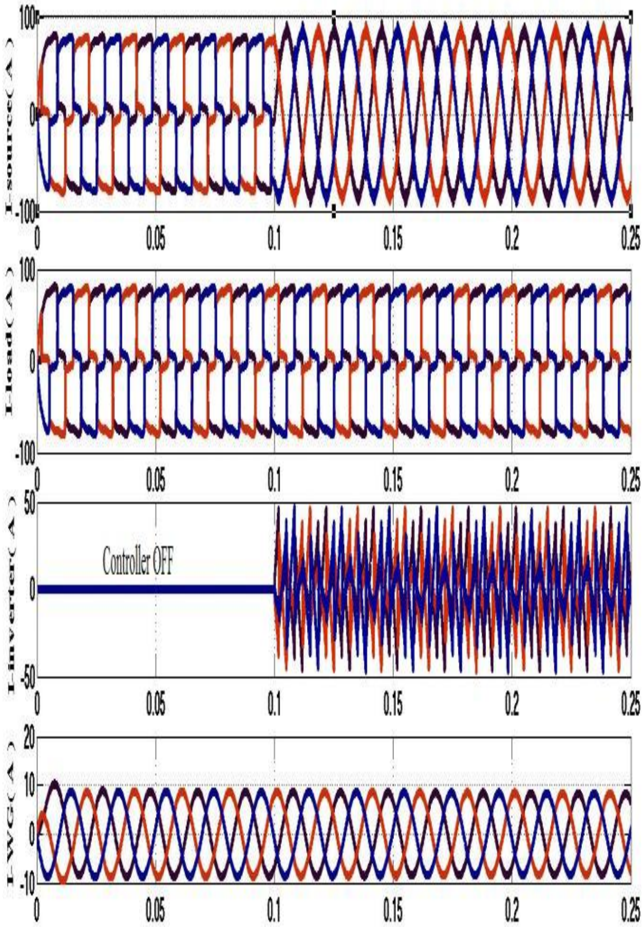


Figure. 5 Simulation results for Balanced Non Linear Load (a) Source current. (b) Load current. (c) Inverter injected current. (d) wind generator (induction generator) current.

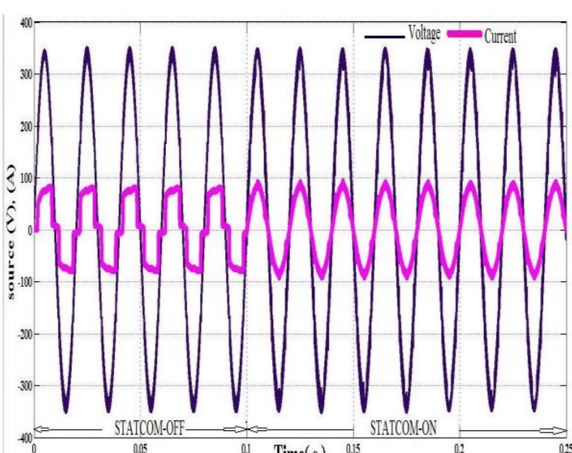


Figure. 6 Simulation results power factor for Non linear Load

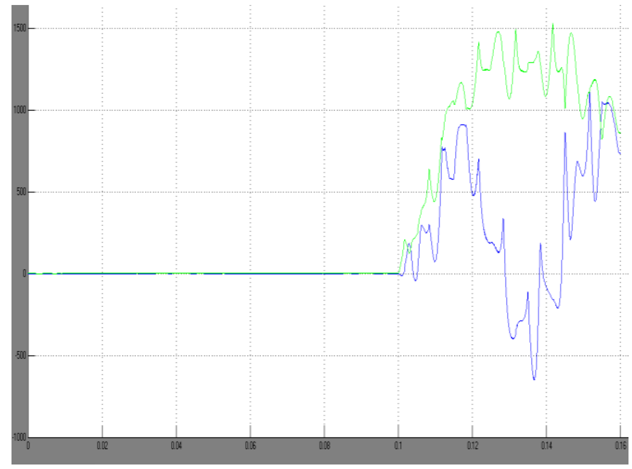


Figure. 7 Active and reactive power from DSTATCOM with Battery

From the above figure it is clear that DSTATCOM is compensating both active and reactive power.

4.2 Case two

A Balanced three-phase non-linear load is represented by three-phase uncontrolled diode bridge rectifier with pure resistive load at its DC bus. Fig. 7 shows the transient responses of distribution system with DSTATCOM without battery for supply voltages (*v*sabc), supply currents (*i*sabc), load currents (*i*la, *i*lb and *i*lc), DSTATCOM currents (*i*ca, *i*cb and *i*cc) along with DC link voltage (*V*dc) and its reference value (*V*dcr) at rectifier nonlinear load.

Fig.8 shows the Source current, load current and compensator current and induction generator current. From the figure it is clear that even though load is unbalanced source currents are balanced and sinusoidal.

From Fig:9 it is clear that DSTATCOM is compensating only reactive power and active power is negative because DSTATCOM draws active power for compensation of losses.

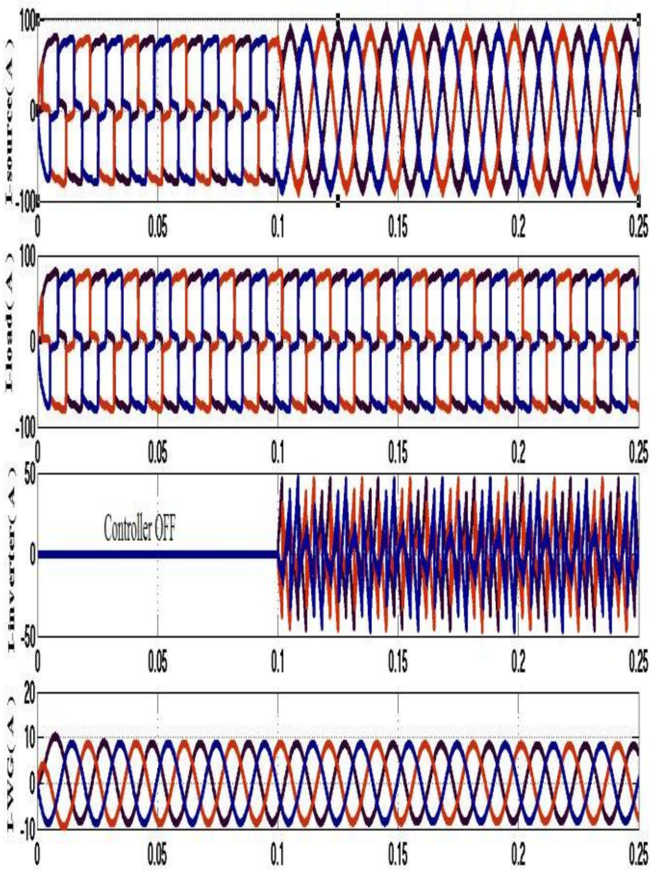


Figure. 8 Simulation results Non- Linear Unbalanced Load(a) source voltage (b) source current (c) load current (d) Induction generator Current

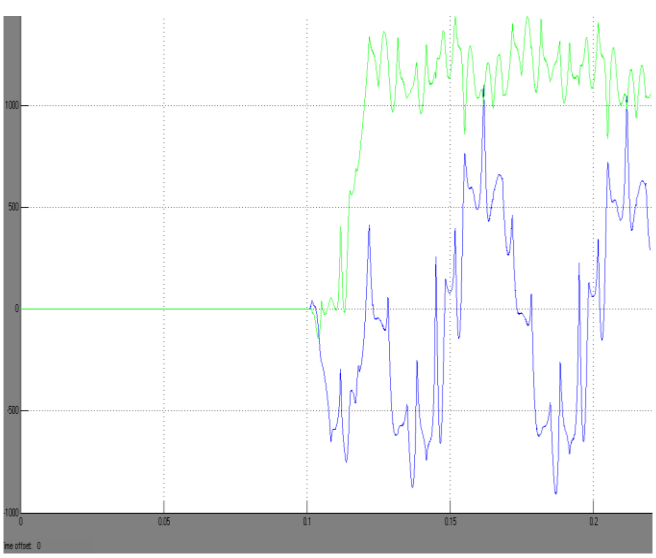


Figure. 9 Active and reactive power from DSTATCOM without Battery

5. Conclusion

This paper has presented the application of DSTATCOM to improve the power quality in wind power system with and without battery. DSTATCOM system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. DSTATCOM compensator is a flexible device which can operate in current control mode for compensating voltage variation, unbalance and reactive power and in voltage control mode as a voltage stabilizer. The latter feature enables its application for compensation of dips coming from the supplying network. The simulation results show that the performance of DSTATCOM system has been found to be satisfactory for improving the power quality at the consumer premises. Rectifier-based non-linear loads generated harmonics are eliminated by DSTATCOM. When single-phase rectifier loads are connected, DSTATCOM currents balance these unbalanced load currents. Finally Matlab/Simulink based model is developed and simulation results are presented.

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