ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 19, April 2017

USING OPTIMISED ICOSΦ DSTATCOM IN A DFIG BASED WIND FARM for POWER QUALITY IMPROVEMENT

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ABSTRACT

A novel control technique for the DSTATCOM is presented in this paper. The Distributed Static Compensater is related to a distribution system with a DFIG based wind farm which performs as a source. The DFIG here is measured to be in use in islanding mode.In this paper reduced THD level is obtained by projecting a novel optimized Icosφ controller. The organizer consists of two PI blocks, The KP and Ki values of the two PI blocks are optimized using Particle Swarm Optimization technique. The prototype has been simulated in MATLAB/SIMULINK and its corresponding results are given. Effective and efficient mitigation of both voltage sag and current harmonics than the conventional PI controlled UPQC , thus making the grid connected wind power system more reliable by providing good quality of power. It is observed that the optimized Icosφ controller diminish the Threshold level to a huge extent.

KEY WORDS
DSTATCOM, DFIG, Icosφ, novel controller, PSO.

1. INTRODUCTION

wind energy is the most common and feasible option for generation of power in the current era of renewable power generation, This is because of wind energy generation indemnities like huge number of potential sites for wind farm install and swift progress of distinct technologies of wind power generation. There are different types of generator designs that are used in wind turbines with a substantial amount of work has been done in modelling it. Doubly Fed Induction Generators (DFIG) is the most common type of wind generator used in present era, because of its wide operating range of DFIG and its ability to operate at different speeds. The incorporation of wind farm to the electrical grid affects the power quality due to wind speed fluctuations. Modern technologies use power electronic strategy for the combination of wind turbines into the grid. The Doubly Fed Induction Generator used in that paper uses back to back power electronic converters.which injects current harmonics in the line and causes transformer heating, eddy current loss and skin effect loss. The presence of lightly damp inductances (plant transformer) and large capacitance in wind plants also gives rise to resonance. Resonance can give rise to high sung current flows and amplified distortion of voltage. It depends on the number of turbines operating and the conditions of the grid. These harmonics and resonance causes various power quality problems like voltage sag, voltage swell, degradation of power quality at the customer end.

The augment of power quality is a cause of concern for both customers as well as the utilities.Due to rapid advancement in the field of power electronics devices the intrusion of linear and nonlinear devices in the industry has increased to a large extent. This tremendous involvement of power electronic devices gave rise to various power quality problems like disturb in voltage and current, voltage sag or swell, flickering and most importantly harmonics. Increment in the number of power electronic devices and nonlinear loads and sensitive electronic equipment is a generation of harmonic currents. These harmonic currents results in extra losses in distribution equipment and interferes with the normal working of the control systems and communication systems. In the purpose of overcoming this power quality problems both in low and medium distribution voltage level a class of compensating devices are implemented named as custom power devices (CPD). Distribution Static Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR), Unified Power Quality Controller (UPQC) is some common members of the CPD family. The DSTATCOM is one of the custom power devices that are shunt connected to the distribution system and

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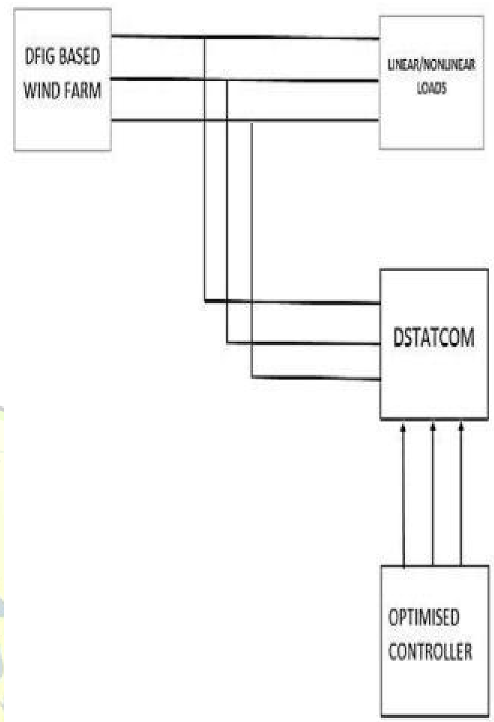
helps in injecting current through an interfacing inductor at the point of common coupling. Various types of configuration and control techniques for DSTATCOM control has been discussed in. In general aspect the control of the firing of the gate terminals is the key in calculating a DSTATCOM. various types of control techniques available like Synchronous reference frame control (SRF), unity power factor based control (UPF), Instantaneous reactive power theory (IRPT) etc... A detailed analysis of the synchronous reference frame controller (SRF) has been done in. In these papers the concept is aptly described and the control scheme is explained in detail. This paper clearly states that the SRF control is fairly easy to implement because this controller here deals with DC voltage. In this paper we have proposed a new control system called the Icosφ control. An inbuilt MATLAB Model of DFIG based wind farm is taken as a source. A nonlinear load of power rating 10 kilowatts and having a nominal voltage of 400 V is connected to the wind farm. The DSTATCOM is connected in Shunt to the distribution system, connected at the point of common coupling (PCC).

2. CONFIGURATION OF DSTATCOM

The system depicted in figure 1 shows the DSTATCOM is attached at the point of common coupling where the voltage fluctuations are maximum. In this figure the point of common coupling (PCC) is the point where all the DGs(Distributed generation units) are coupled together and is supplied to the load. In this work the DFIG is assumed to be working in the islanding mode.. The DSTATCOM is basically a voltage source inverter with a DC capacitor in the input. This DC capacitor is basically the source of the reactive power that is supplied by the DSTATCOM. The basic model of the DSTATCOM is shown in figure 1.



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In the above figure the ripple filter comprises of a coupling filter Lf and an equivalent filter resistance Rf. The output voltage of the inverter is taken as Esa, Esb and Esc respectively. The voltage at the PCC is considered to be Vsa, Vsb and Vsc respectively.

Here
Vsa, Vsb, Vsc: Voltage at point of common coupling
Eca, Ecb, Eco : Inverter Output Voltage

Relationship between PCC voltage, inverter o/p voltage and currents are:-

$$R_f i_a + L_f \frac{dI_a}{dt} = v_{sa} - E_{ca} \quad (2)$$

$$R_f i_b + L_f \frac{dI_b}{dt} = v_{sb} - E_{cb} \quad (3)$$

$$R_f i_c + L_f \frac{dI_c}{dt} = v_{sc} - E_c \quad (4)$$

Therefore

$$\frac{dI_a}{dt} = -R_{f/Lf} i_a + 1/L_f (v_{sa} - E_{ca}) \quad (5)$$

$$\frac{dI_b}{dt} = -R_{f/Lf} i_b + 1/L_f (v_{sb} - E_{cb}) \quad (6)$$

$$\frac{dI_c}{dt} = -R_{f/Lf} i_c + 1/L_f (v_{sc} - E_{cc}) \quad (7)$$

Writing the equations in matrix form,

$$\frac{d}{dt}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} -R_f/L_f & 0 & 0 \\ 0 & -R_f/L_f & 0 \\ 0 & 0 & -R_f/L_f \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + 1/Lf(V_{sabc} - E_{abc}) \quad (8)$$

Transforming the above set of equations to synchronous reference frame using Park's transformation we get:

$$L_f \frac{dI_d}{dt} + R_f i_d = v_{sd} + L_f \omega i_q - mV_{dc}\cos\alpha \quad (9)$$

$$L_f \frac{dI_q}{dt} + R_f i_q = v_{sq} - L_f \omega i_d + mV_{dc}\sin\alpha \quad (10)$$

Where ω= system frequency, m= modulation index.

Writing in matrix form,

$$\frac{d}{dt}\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \begin{bmatrix} -R_f/L_f & \omega \\ -\omega & -R_f/L_f \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L_f}\begin{bmatrix} E_d - V_{sd} \\ E_q - V_{sq} \end{bmatrix} \quad (11)$$

Where neglecting the harmonics,

$$E_d = mV_{dc}\cos\alpha \quad (12)$$

$$E_q = mV_{dc}\sin\alpha \quad (13)$$

By power balance theory:

$$P_{dc} = V_{dc}I_{dc} = 3/2(E_d i_d + E_q i_q) = 3/2m(i_d\cos\alpha + i_q\sin\alpha). \quad (14)$$

Similarly

$$Q = 3/2(E_d i_q - E_q i_d)$$

Now when $\omega=0$, $E_q=0$

$$\therefore Q \propto E_d I_q,\ E_d = E$$

We have

$$V_{dc} i_{dc} = (3/2)(E_d i_d + E_q i_q)$$

$$\therefore I_{dc} = (3/2)m(i_d\cos\alpha - i_q\sin\alpha) \quad (15)$$

$$\therefore \frac{d}{dt}\begin{bmatrix} I_d \\ I_q \\ V_{dc} \end{bmatrix} = A\begin{bmatrix} i_d \\ i_q \\ v_{dc} \end{bmatrix} - \frac{1}{L_f}\begin{bmatrix} V_{sd} \\ 0 \\ 0 \end{bmatrix} \quad (16)$$

Where

Lf : Inductance of coupling filter
Rf : Equivalent filter resistance
ω : System frequency
m : Modulation Index
Vdc : DC Voltage across the Capacitor

The three phase system voltage or the per phase instantaneous PCC voltage is given as:

$$A = \begin{bmatrix} -R_f/L_f & \omega & -\frac{m}{L_f}\cos\alpha \\ -\omega & -R_f/L_f & \frac{m}{L_f}\sin\alpha \\ \left(\frac{3}{2}\right)\left(\frac{m}{c}\right)\cos\alpha & \left(\frac{3}{2}\right)\left(\frac{m}{c}\right)\cos\alpha & 0 \end{bmatrix}$$

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \sqrt{(2/3)}V_s \begin{bmatrix} \sin\omega t \\ \sin(\omega t - 2\pi/3) \\ \sin(\omega t + 2\pi/3) \end{bmatrix} \quad (17)$$

$$P = V_{sd}i_{sd} + V_{sq}i_{sq}$$

$$= V_{sd}i_d = V_s i_d$$

$$Q = V_{sq}i_d - V_{sd}i_q$$

$$= -V_{sd}i_q = -V_s i_q \quad (18)$$

Vs = rms value of the PCC voltage

Thus the DSTATCOM performance can be controlled by controlling the active and reactive component of current I_d and I_q.

3. DESIGN OF THE CONTROLLER

The control algorithm deployed to produce the necessary and appropriate reference currents in order to fire the IGBTs is based on the I cos φ algorithm. The control is mainly divided into three sections namely DC voltage controller, AC voltage controller and reference current estimator. This control overcomes the limitation of the SRF control as said in [6, 9] by keeping the THD level beyond the IEEE limit. This algorithm is thereby proposed to reduce the current harmonic components and supplies reactive power to the load. In this control the source currents (isa, isb, and isc), load currents (ILA, ilb, ilc) and the dc voltage (Vdc) are apprehended as feedback signals. In the proposed algorithm it is presumed that the active current components are furnished only by the source. I.e. I cosφ (where I= fundamental component of the load currents and φ= angle by which the load current is displaces with respect to the PCC voltage). The entire control topology comprised of Phase Locked Loop (PLL), a The main function of the PLL is to generate the sine and cosine of the phase angles in synchronism with the PCC voltages. Christo Ananth et al.[4] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles.

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The dc voltage error i.e. the voltage across the capacitor and the dc reference voltage is compared and the difference is sent to the PI block in order to generate the Ismd component of current (reference d component current). The PI AC voltage controller is mainly used to maintain and regulate the PCC voltage. The ac voltage error i.e. the difference between the PCC voltage and the reference voltage is passed through another PI block to generate Ismq (reference q component current). These two current outputs are taken as inputs to the reference current estimator and the three phase reference source currents are generated. At any instant let the expression of load currents

$$i_{La} = \sum_{n=1}^{\infty} I_{Lan} \sin(n\omega t - \varphi_{an})$$

where n ranges from 0,1 to ∞.

$$i_{Lb} = \sum I_{bn} \sin(n\omega t - \varphi_{an} - 120^{o}) \quad (20)$$

where n ranges from 0,1to ∞

$$i_{Lc} = \sum I_{cn} \sin(n\omega t - \varphi_{an} - 240^{o}) \quad (21)$$

where n ranges from 0,1 to ∞.

Where n ranges from 0, 1 to ∞. In this proposed concept φabc is the phase angles of the fundamental components in a, b and c phase. Φ (ABC) n can be interpreted as the phase angles of the nth harmonic components in a, b and c phases.

Calculation of the in phase reference current components

The active components of the load currents are given in magnitude as:

$$I_{La(R)} = |I_{La1}| \cos \phi_{a1} = |Re(I_{La1})| \quad (22)$$

$$I_{Lb(R)} = |I_{Lb1}| \cos \varphi_{b1} = |Re(I_{Lb1})| \quad (23)$$

$$I_{Lc(R)} = |I_{Lc1}| \cos \varphi_{c1} = |Re(I_{Lc1})| \quad (24)$$

Consequently the active components of the three phase load currents are harnessed at the point of zero crossing of the unit vector pattern in phase with the PCC voltages. Low pass filters with 50 Hz cut off frequency are used for infusing the fundamental load currents. In case of a balanced load current condition the active current components of the reference source currents can be given as

$$I_{s(R)} = [\frac{|I_{La}|\cos\varphi_{a1} + |I_{Lb}|\cos\varphi_{b1} + |I_{Lc}|\cos\varphi_{c1}}{3}] + i_{smd} \quad (25)$$

In this context 1 Laa Icos ϕ

, 1 Lbb Icos ϕ

And 1 Lcc Icos ϕ

Are the amplitude of the active load current components? Ismd as already stated is the output of the DC voltage PI controller. Again recapitulating the DC voltage error, the difference in the DC voltage at nth instant is calculated as,

$$V_{dce(n)} = V_{dcr(n)} - V_{dc(n)} \quad (26)$$

This DC voltage error is fed to a PI block and the output at n[th] instant of time is given by

$$i_{smd(n)} = i_{smd(n-1)} + K_p(V_{dce}) + K_i \int V_{dce} dt \quad (27)$$

Here KP and Ki are the proportional and integral gains of the PI controller respectively. Now the amplitude of the three phase voltages are given as

$$V_t = \{\frac{2}{3}(V_a^2 + V_b^2 + V_c^2)\}^{1/2} \quad (28)$$

Next we calculate the in phase unit vector components as

$$u_a = \frac{V_a}{V_t};\ u_b = \frac{V_b}{V_t};\ u_c = \frac{V_c}{V_t} \quad (29)$$

Now the estimation of the in phase components of the reference source currents is done as follows

$$i^{*}_{sa(R)} = I_{s(R)} u_a \quad (30)$$

$$i^{*}_{sb(R)} = I_{s(R)} u_b \quad (31)$$

$$i^{*}_{sc(R)} = I_{s(R)} u_c \quad (32)$$

The quadrature vector components can also be calculated with reference to [9]

$$w_a = \frac{-u_b + u_c}{\sqrt{3}} \quad (33)$$

$$w_b = \frac{\sqrt{3}u_a}{2} + \frac{(u_b - u_c)}{2\sqrt{3}} \quad (34)$$

$$w_c = -\frac{\sqrt{3}u_a}{2} + \frac{(u_b - u_c)}{2\sqrt{3}} \quad (35)$$

The actual reference current can be calculated as in [6]

$$i^{*}_{sa} = i^{*}_{sa(R)} + i^{*}_{sa(Q)} \quad (36)$$

$$i^{*}_{sc} = i^{*}_{sc(R)} + i^{*}_{sc(Q)} \quad (37)$$

These reference currents $(i^{*}_{sa}, i^{*}_{sb}, i^{*}_{sc})$ are then compared with the source currents (i_{sa}, i_{sb}, i_{sc}) and the output is put as an input to a discrete PWM block in order to generate the gating signals for the IGBT based VSI working as a DSTATCOM.

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4. DESIGN OF PSO OPTIMISED CONTROLLER

One of the main metaheuristic techniques for finding out optimal solutions is Particle Swarm Optimization. The concept of PSO has come from the social behavior exhibited by than that of SRF.

5. SIMULATION RESULTS: The model of the proposed system along with the controller is simulated in MATLAB/SIMULINK. The total time of the simulation is carried up to 2 sec

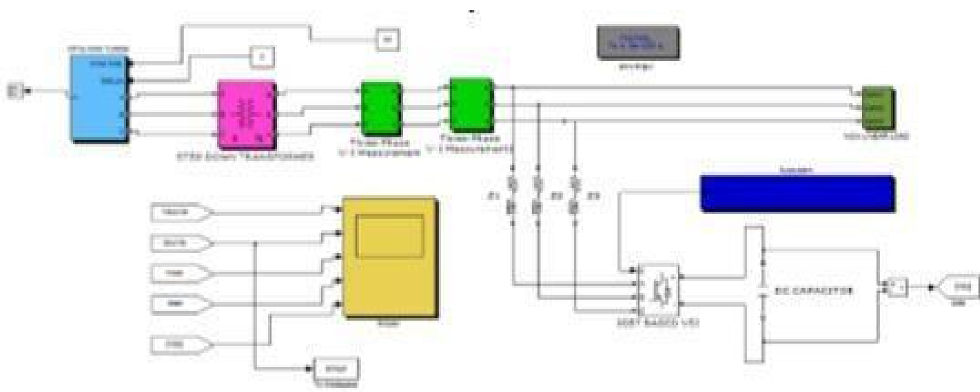

Fig. 2: Simulink model of the system

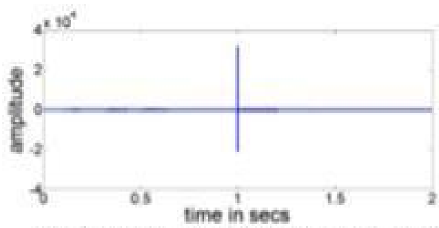

Fig. 3: source current during capacitor switching

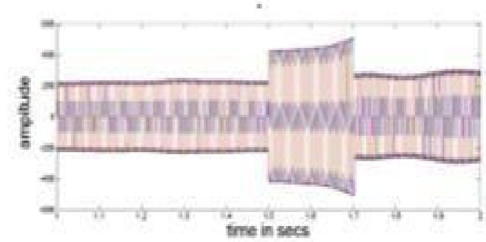

Fig. 4: three phase fault

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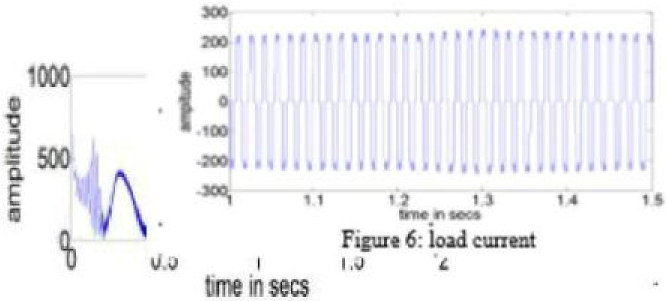

Figure 6: load current

Fig.8: Capacitor voltage

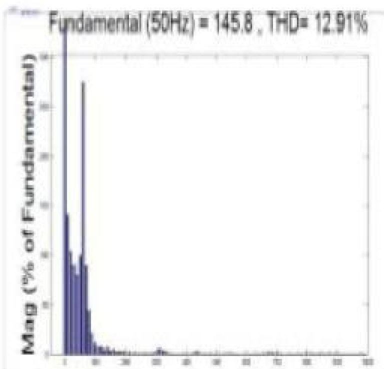

Fig.9: THD graph

APPENDIX A:

DC CAPACITANCE	2800 µF
DC VOLTAGE	700 V
CAPACITOR USED FOR SWITCHING	4000µF
FILTER IMPEDENCE	0.1+j0.003
RESISTIVE LOAD	2 KW,
THREE PHASE SERIES RLC LOAD	5 KW, INDUCTIVE POWER-100 Var
INVERTER LOAD	10 KW, INDUCTIVE LOAD-100 Var
OPTIMIZED CONTROLLER PARAMETERS	Kp1=0.1699 Kp2=14.3532 Ki1=0.4591 Ki2=154.4827
PSO GAINS	c1=0.5, c2=0.5
DFIG WIND FARM(Rating of one generator × 6)	Nominal Power= 1.6 MVA Stator voltage(nominal)= 575 V Rotor Voltage(nominal)= 1975 V

TABLE 1: COMPARISON OF THD VALUES IN THE ABSENCE AND IN THE PRESENCE OF DSTATCOM (KP AND KI VALUES ARE OPTIMISED BY PSO)

Loads Connected	Without DSTATCOM	With Optimised Icosφ DSTATCOM	SRF controlled DSTATCOM
Rectifier loads without extra loads	320.58%	12.91%	26.96%
Rectifier loads with extra loads	397.25%	12.78%	26.56%

6. CONCLUSION

In this paper Optimized I cosφ method of controlling the DSTATCOM is presented. The gains of the two PI blocks used are optimized using PSO to have better performance. The results are verified by comparing with conventional control techniques most commonly being the SRF. The THD levels are also being compared and it can be concluded that the THD is reduced more in Optimized Icosφ algorithm

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