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# Analysis of Reactive Power Flow for Wind Power Generator

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## Abstract

Doubly fed induction generators are frequently used in variable speed wind turbine. These induction generators consume reactive power. The reactive power flow analyses are presented in this paper using Static synchronous compensator (STATCOM) device at different locations and at different modulation indices (MI). The Proportional and integrator (PI) control and Maximum power point track (MPPT) analysis is also presented to understand the different parameters of wind generation. The reactive power flow and power generation demand is varied with varying STATCOM generation


**Keywords**: STATCOM, MI, PI, Load, distance, duty ratio, slip current

## INTRODUCTION

Now days the demand for power is increasing due to industrialization and economic growth. So utilizing natural wind power at high wind places is essential. But due to uncertainty of wind power the controlling is also important along with battery storage.

The doubly fed induction generator is very much suitable for variable speed mode of wind generation to get better efficiency. The induction generator will operate at lagging power factor because it is consuming reactive power. So incorporating the STATCOM will reduce the reactive power consumption and improve the power factor. So to control the reactive power consumption, the STATCOM switching duty ratio to be controlled at proper distance from the wind plant. The location of STATCOM also gives the impact on Reactive power control. The PI control is needed to make automatic reactive power controlling so that power factor is within the limits. MPPT control will enhance the extract of maximum power from the generator.

## REACTIVE POWER ANALYSIS

Doubly fed induction generator takes the slip power from the system to the rotor. Now days the wind power available at the speed of 200km/hr in maximum and 52km/hr in average to get better efficiency.

The tip speed

$$\lambda_{opt} = (\omega_{opt} \cdot r) / v. \qquad - \qquad (1)$$

The coefficient of power $C_p$ will be maximum at $\lambda_{opt}$ with zero pitch angle β. The power generation will depend on Cp and cube of the velocity [1-2]. The doubly excited model has d-q axis analysis on both stator and rotor side [3]. The model taken for reactive power analysis is given in the below

Figure 1

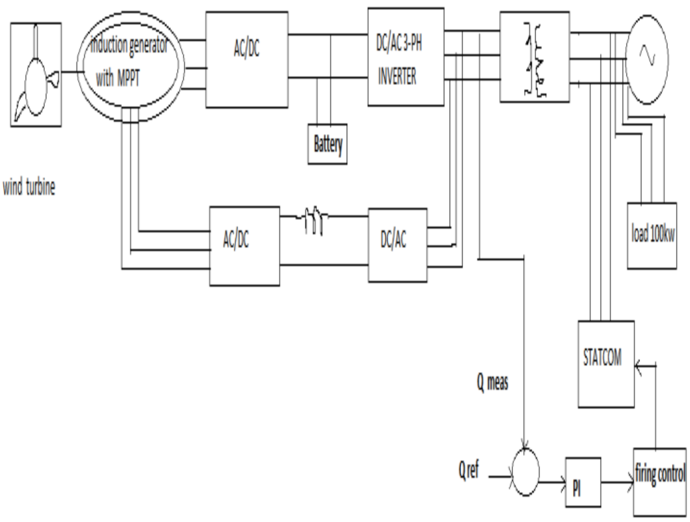


**Figure 1**: Block diagram of reactive power measurement

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The doubly fed induction generator is also known as slip ring induction generator and it can be modeled in d-q axis for stator and rotor voltages [4]

For stator

$U_d = r_s i_{ds} - (x_s i_{qs} + x_m i_{qr}) + d\psi_{ds}/dt$ (2)

$U_q = r_s i_{qs} + (x_s i_{ds} + x_m i_{dr}) + d\psi_{qs}/dt$ (3)

For rotor

$U_d = r_r i_{dr} - s\,(x_r i_{qr} + x_m i_{qs}) + d\psi_{dr}/dt$ (4)

$U_q = r_r i_{qr} + s\,(x_r i_{dr} + x_m i_{ds}) + d\psi_{qr}/dt$ (5)

$\Psi = f(L_S \text{ or } L_R, L_M, i_s, ir)$ (6)

the reactive power for stator as well as rotor is

$q = 1.5\,(U_q\, i_d - U_d\, i_q)$ (7)

The Table-1 shows the reactive power versus distance. At Vrms =150v , battery volts =327v , MI =0.8 at transformer ratio of 460:11000 with no load the reactive power consumption is increasing with distance of STATCOM compensator

**Table 1:** Reactive power versus distance

| S.NO. | Distance (in km) | Reactive power In vars |
|---|---|---|
| 1 | 100 | -0.2 |
| 2 | 200 | -0.204 |
| 3 | 300 | -0.21 |
| 4 | 400 | -0.2281 |
| 5 | 500 | -0.2615 |
| 6 | 1000 | -0.46 |

Similarly Table 2 shows the reactive power varying with modulation index of STATCOM at distance of 100km and at carrier frequency of 2000 $H_z$.

**Table2:** Reactive power versus MI

| S.NO. | Modulation index | Reactive power In vars |
|---|---|---|
| 1 | 0.2 | -0.395 |
| 2 | 0.4 | -0.33 |
| 3 | 0.6 | -0.2664 |
| 4 | 0.8 | -0.2 |
| 5 | 1 | -0.1382 |

At 1kw load with modulation index =0.8 and with transformer ratio of 1:1 , the distance versus reactive power variation is shown in Table 3

**Table 3:** Reactive power versus distance

| S.NO | Distance (in KM) | Reactive power in vars |
|---|---|---|
| 1 | 100 | 3.3 |
| 2 | 1000 | -1.25 |

Figure 2 and 3 show the variation nature of reactive power with distance and modulation index respectively

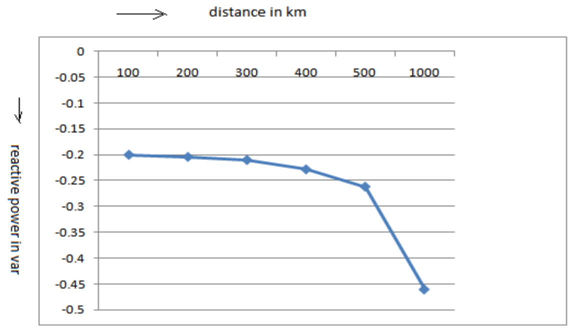


**Figure 2**: variation of q with distance

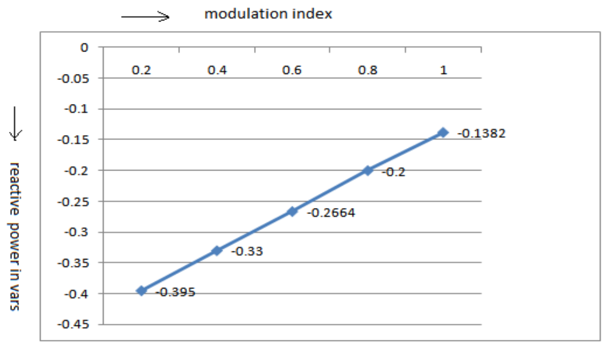


**Figure3** : variation of reactive power with MI

Figure 4 shows the 3-dimention variation of MI, Distance and q

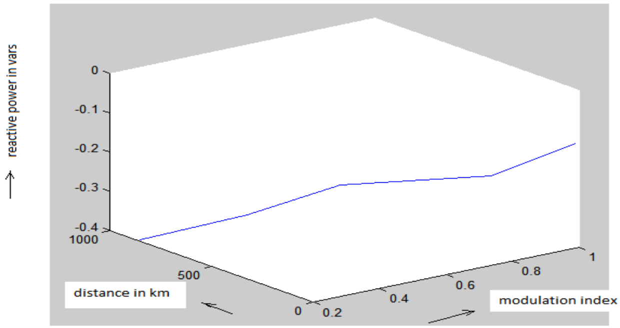


**Figure 4:** 3-dimetional variation of q

These graphs can help to decide how much q to be set using closed loop feedback control with PI. The reactive power consumption increases when STATCOM location d increases. Similarly reactive power consumption decreases with MI increment

So the q= f(d)

The function is depending on mathematical curve fitting

from the graph in figure 2. This curve can be approximated as

$$q=ad^2+ bd +c \tag{8}$$

Similarly the variation of q with MI can be approximated as

$$q = K (MI) - d \tag{9}$$

## CLOSED LOOP PI CONTROL FOR REACTIVE POWER

In this closed loop control q is set according to the requirement to control the reactive power consumption under connected load of 100 kw with 1:1 transformer ratio. The PI control will give the settling time delay along with STATCOM firing control delay in cascading mode. For every set point ,$K_I$ to be adjusted to reduce the steady state error and settling time. The Figure 5 shows the PI control with set point of -0.25var when $K_P$=20 and $K_I$= 40. The Figure 6 shows the output measured with $q_{meas}$= -0.27 var using

Mat lab simulation.

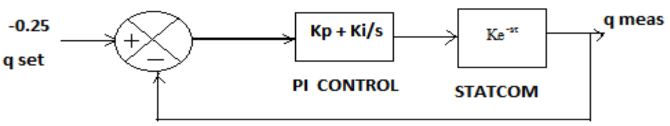


**Figure5** : STATCOM control with PI

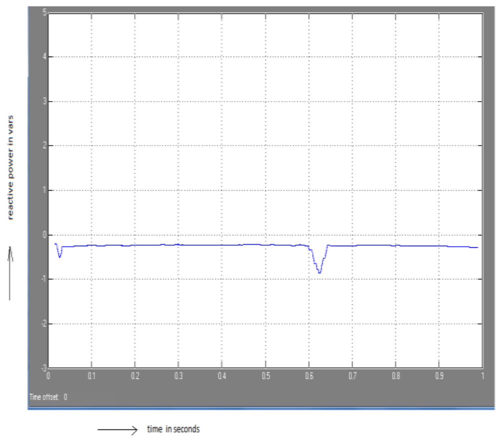


**Figure 6** : Reactive power output with pi control

## MPPT CONTROL FOR WIND GENERATION

The maximum power point can be obtained by varying the duty ratio. Using MOSFET connected in parallel the power point will be varied. As the duty ratio decreases, the voltage will be increased. The Figure 7 shows the dc output voltage at 20% duty ratio. The slight overshoot at initial stage due to offset caused by inductor in MPPT.

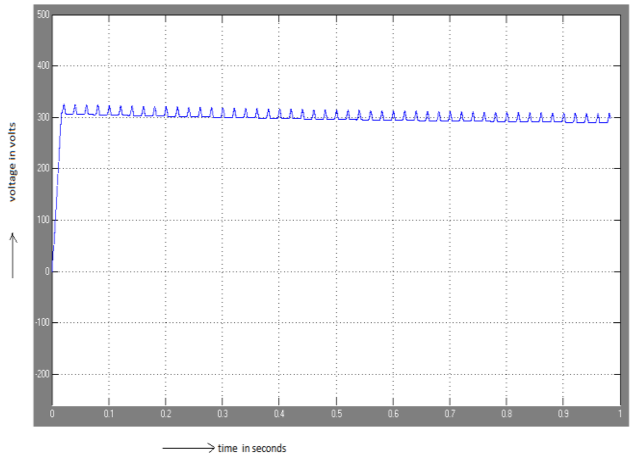


**Figure 7**: MPPT Average DC output voltage at duty ratio =20%

The slip current in DC side with slight ripples is shown in Figure 8

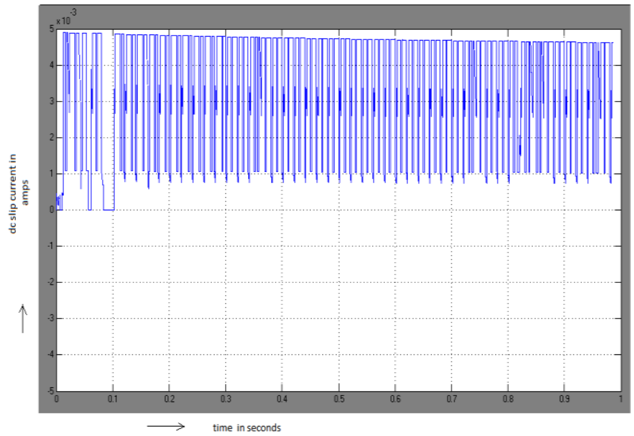


**Figure 8**: Dc Slip current at duty ratio = 20%

The power demand for the generator reduced with increasing modulation index and reduction in STATCOM location distance. The power at 400km and 0.2 MI is -1.27w and at 200km and 0.8 MI is -1.012w

Compared to the power flow, the q flow is limited to small distances. The 3-phase inverter output will reduce the harmonics compared to the single phase output. Condition for maximum power at the optimum point is dP/dD =0. At higher speeds dP/dD >0 and at lower speeds dP/dD<0 [5-7]. MPPT control can also be effectively performed with PI and fuzzy.

## SIMULATION RESULTS

The simulation results of various parameters are observed with the analysis of wind power

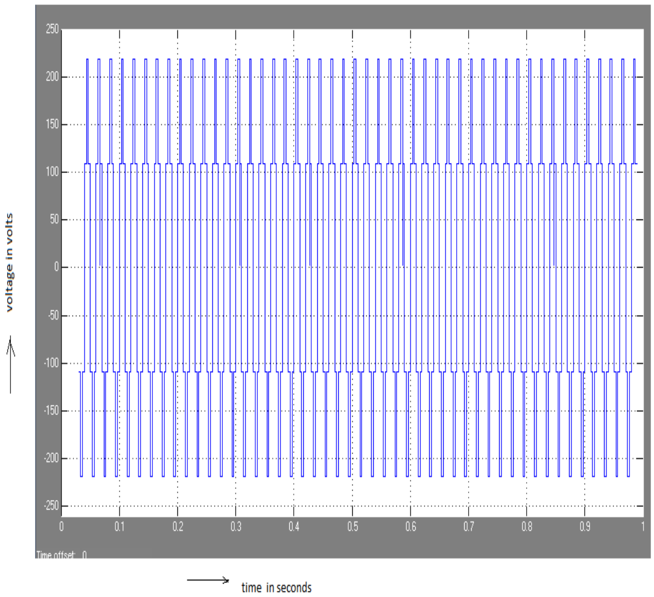


**Figure 9**: Output instantaneous voltage at inverter

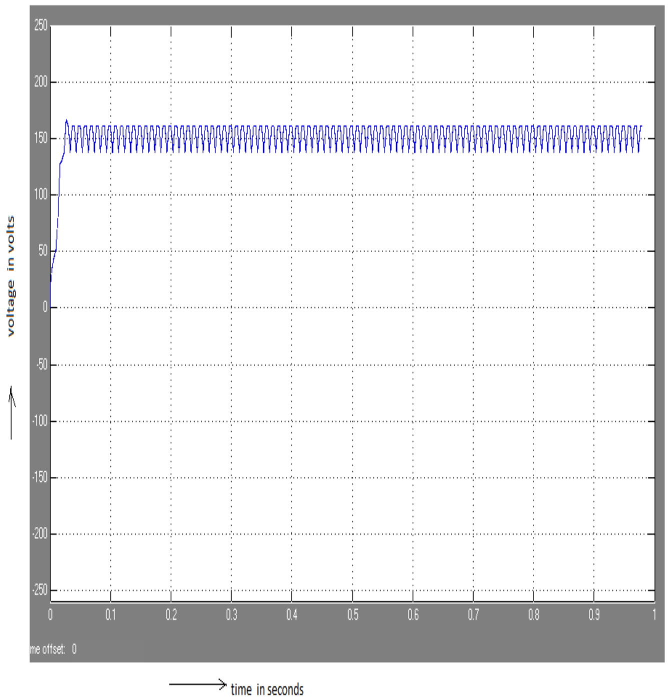


**Figure10**: output RMS voltage at inverter

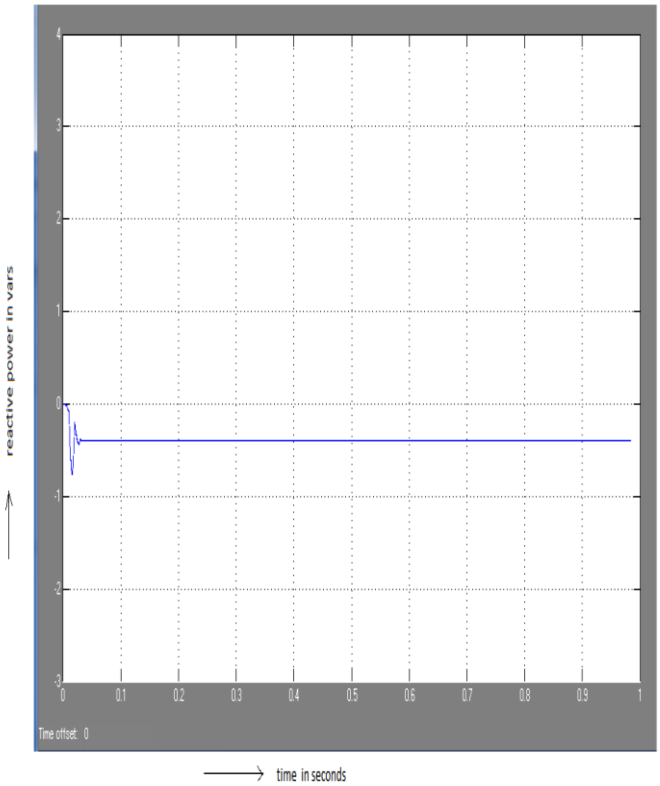


**Figure 11**: Reactive power at MI =0.2

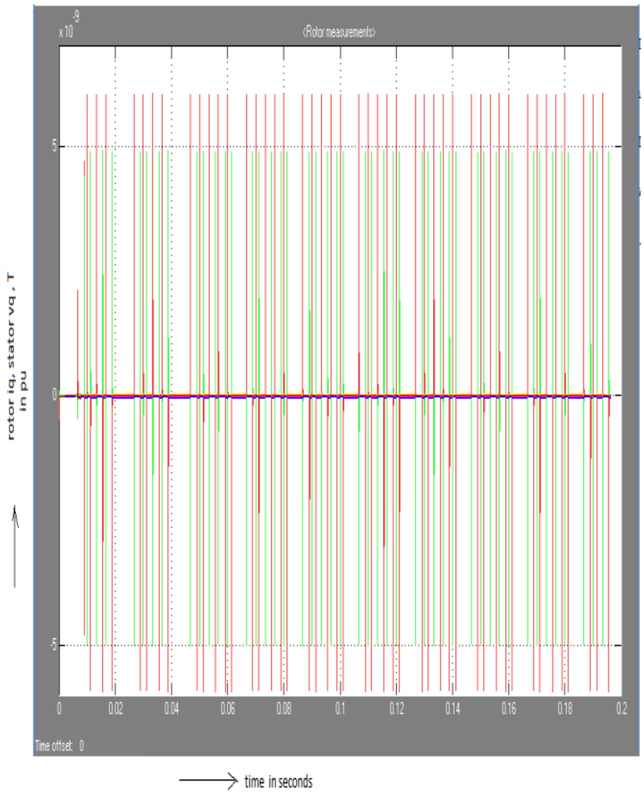


**Figure 12**: per unit rotor Iq, stator Vq, Torque at 1:1 Transformer, 200km distance with 1kw load

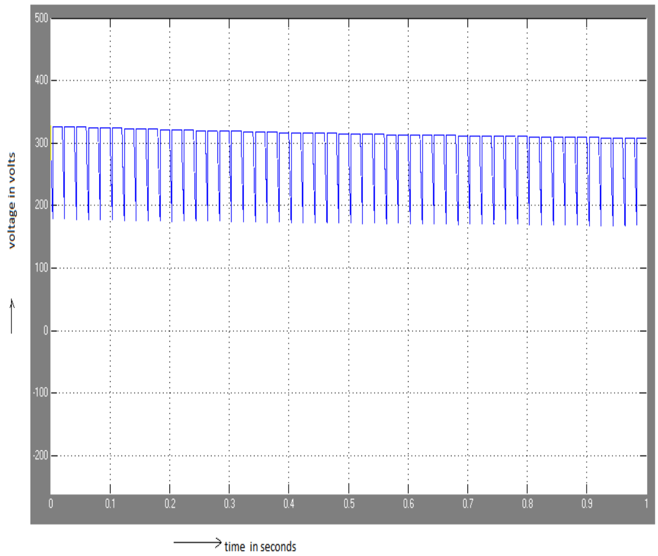


**Figure13:** MPPT instantaneous output at duty ratio 20%

## CONCLUSION

**Fr**om the above results, the STATCOM control will improve the power factor with doubly excited induction generator. By measuring q of wind generator with STATCOM at different MI and at different distances ,the amount of reactive power requirement will be justified. With the help of predetermined tests, the controlling of STATCOM power is easier. The test results are useful for better STATCOM control using PI and MPPT techniques.

## ANNEXURE

Wind turbine details:

Wind speed =55 m/sec

Generator speed =10pu

Pitch angle =0

Induction generator details:

Nominal power = 1.5kw

Nominal voltage = 460 v ph-ph at 50 Hz

Battery capacity=20Ah

STATCOM DC voltage=7000v

Capacitor =1uf

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