International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 11s
DOI: https://doi.org/10.17762/ijritcc.v11i11s.8184
***Article Received:** 28 June 2023 **Revised:** 22 August 2023 **Accepted:** 07 September 2023*

Reactive Power Management at PCC with DFIG Based Wind Energy System

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Abstract—Reduction in availability of conventional energy sources and their scarcity in the future has led to the research on adoption of renewable energy sources for electricity generation. Wind is recognized as the prominent renewable energy source for electricity generation. Due to the erratic pattern of wind, variable speed generators such as doubly fed induction generator (DFIG) are preferred over fixed speed wind generators which use synchronous generators. Due to the increase in contribution of electricity generation through renewable energy sources, power quality of the system is deteriorating. In the present paper, a new economical and tangible scheme of DFIG is proposed to compensate for the reactive power at PCC, thus improving the power quality of the grid. The effectiveness of the scheme in compensating for the reactive power is evaluated using MATLAB / Simulink environment.

Keywords- DFIG, GSC, Power quality, wind energy.

I. INTRODUCTION

Depletion of conventional energy resources motivated for augmented research in the field of renewable energy. Also, with the ever increasing demand of electrical energy, focus on renewable energy also increasing at a rapid pace. Wind is considered as one of the major energy contributor in electricity generation using renewable energy. At the closing end of the year 2022, India has a total installed capacity of 41.93GW wind power and is ranked at second position [1]. As the contribution of renewable energy is increasing, new challenges are being faced by the power at the grid. These power quality issues include voltage variations, deviation in sinusoidal waveform due to harmonic, increased reactive power demand etc. Also, with the revision of grid code requirements, renewable energy plants are required to support the grid in times of faults for a short period of time. Hence, different power electronics controllers are deployed at strategic locations for the improvement of power factor and thereby maintaining unity power factor at point of common coupling (PCC). Static synchronous compensator (STATCOM) gained more importance when compared to other devices due to its better dynamic response [2]. Installation of additional STATCOM increases the cost of the system. Research was also done to use grid side converter (GSC) of DFIG to compensate for reactive power. To reduce cost of the system, GSC of DFIG is used for reactive power support. In this case, back–to–back converters of DFIG are either connected between rotor terminals of DFIG and PCC or between the stator of DFIG and PCC. If the converters are connected between rotor and PCC, then the converters are rated to slip power and can supply low reactive power which is limited to 33% of DFIG rating. If the converters are connected between stator and PCC, the converters are rated to full rating of DFIG so as to supply more reactive power but in this case the cost of the system increased due to increased rating of power converters.

II. LITERATURE REVIEW

DFIG's have gained popularity as wind generators that are most commercially used in wind plants. Different topologies of DFIG's are proposed by various researches and all the topologies there is reactive power requirement that need to be met for successful operation of DFIG. To compensate for the reactive power, many researchers [3-15] have proposed STATCOM at strategic locations in the transmission system or at PCC. A shunt connected STATCOM using vector controlled technique is employed in distribution system for weak connected grid and it was concluded that STATCOM compensated for reactive power requirement effectively during grid faults and sudden load switching OFF conditions

[4,5]. [6] explored the application of STATCOM to overcome of Low Voltage Ride Through issue in DFIG based systems due to internal fault of converters in addition to grid faults. A state space model of approach and extended FOC approach is discussed to compensate for reactive power at PCC during normal operation and improve voltage profile whenever there is voltage sag [7-12]. A real time implementation of VSI based STATCOM is investigated and its efficacy in improving transient voltage stability is discussed [8]. [13-17] discussed about STATCOM modelling using fuzzy logic, neural networks, PSO rather than conventional PI controllers to enhance power quality at PCC. Coordinated control of DFIG using annealing optimization is proposed for controlling DFIG where GSC was used as STATCOM to compensate for reactive power [13].

[19] presented a comparative analysis on performance of GSC versus external STATCOM to compensate for reactive power and it was concluded that application of GSC as STATCOM offers more advantages in terms of economy and complexity. [20] modelled GSC as STATCOM for reactive power support but the system can support only for smaller voltage dips.

From literature review it can be concluded that application of GSC as STATCOM was explored to a very less extent. In the proposed system, a new strategy is employed to compensate for high reactive by partial uprating of back–to–back converters such that rotor side converter (RSC) is designed for slip power (33% of rated capacity) while the rating of GSC is augmented to rated capacity of DFIG and hence is found to support reactive power of high value. The system hence is economical at the same time provides reactive power support even during voltage dips of higher magnitude. Also, instead of sinusoidal PWM, space vector PWM is employed to generate pulses for GSC. The method proposed is validated for both inductive and capacitive under dynamic load profile. As the focus is on GSC as STATCOM, rotor design is not emphasized and its control only is presented.

The structure of the submitted paper is sectioned as follows. Section “DFIG operation” explains the components of DFIG and its operation. Section “RSC with OT control based MPPT” discusses about the modelling of RSC. Section “low power grid-side converter (GSC) operation & design” discusses about the modelling of GSC for slip power rating. Section “Design of GSC as STATCOM for high power” discusses about redesign of GSC with revised ratings for high reactive power compensation at PCC. Finally, the efficacy of system for different lagging and leading VAR is presented and conclusions are drawn.

III. DFIG OPERATION

DFIG is a slip ring or wound rotor induction machine with power flow in both stator and rotor windings. A slip ring induction machine may be made to operate as a generator by regulating flow of electrical power in both stator and rotor windings. The machine can work as generator at above and below the synchronous speed. DFIG has two converters namely RSC and GSC. Rotor-side converter (RSC) regulates flow of power while GSC regulates the DC link voltage and also supplies reactive power if needed by the grid. Figure 1 describes diagram of DFIG connected to grid.

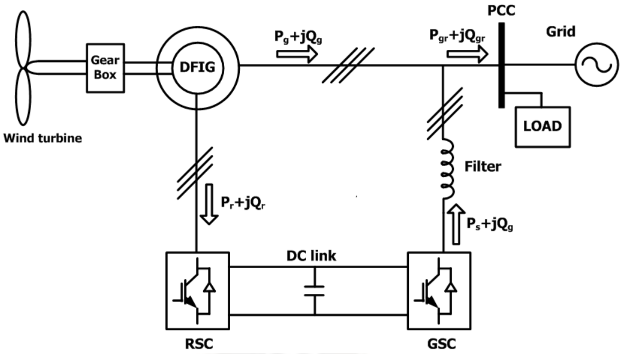

Figure. 1 Block diagram of DFIG

IV. RSC WITH OT CONTROL BASED MPPT

RSC regulates flow of electrical power between DFIG and grid. In this technique, optimum TSR for the wind turbine is taken and optimum rotor speed for that particular wind velocity is computed using equation (1). Based on the optimum speed, optimum torque value is obtained using (2). This optimum torque is taken as reference for generating q-axis component of rotor current and is indicated in figure 2.

$$P_{m-opt} = 0.5\rho\pi R^5\left(\frac{C_{p\max}}{\lambda_{opt}^3}\right)\omega_m^2 \qquad (1)$$

Where,
ρ = air density(kg/m^3),
R = turbine radius(m),
C $_{pmax}$ = co – efficient of maximum power,
λopt = optimum TSR and
ω_g = rotor angular velocity (rad/s)

The resulting reference optimum torque equation can be given as

$$T_{m-opt} = K_{opt}\omega_g^2 \qquad (2)$$

The rotor currents are sensed and converted to d-q frame to generated actual rotor dq components. From optimum torque, reference value of q-axis rotor current is generated. These are compared with reference values to generate three phase reference signals to sinusoidal PWM. Block diagram of rotor controlling circuit employing OT based MPPT is shown in Figure 2.

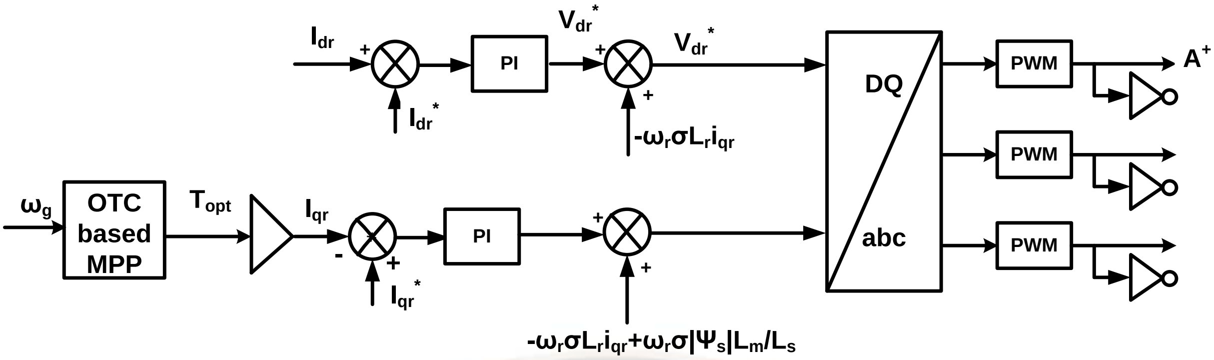

Figure. 2 Block diagram of RSC with OTC

V. LOW POWER GSC OPERATION & DESIGN

Figure 3 shows the block diagram of GSC. GSC is modelled in d – q axis reference frame. Voltage at DC link is to be kept constant so as to keep balance between RSC and GSC. At times of need, GSC can also be used to give reactive power support to the grid. As the goal of GSC is to control DC link voltage and control reactive power, voltage at the DC link and required reactive power are taken as references. Actual DC-link voltage and the reference voltage are compared and error is then given to PI controller to derive reference value for d-axis current. Depending on required magnitude of reactive power, reference value for q-axis current is derived. The 3 phase currents at (Point of Common Coupling) PCC are measured and are converted into d and q-axis components. Reference currents and d-q components are compared to generate pulses for GSC. Computation of DC link capacitance, DC link voltage and inductance value play an important role in designing STATCOM. In case of low reactive power requirement, for a 2MW DFIG, GSC is designed for 0.75 MVAR and the corresponding design calculations are as follows:

$$V_{DC}=\frac{2\sqrt{2}V_{LL}}{\sqrt{3}m}=1126V\cong 1200V \quad (3)$$

where,
V_{DC}=DC link voltage
V_{LL}=Line voltage at PCC
m=modulation index=1

$$C_{DC}=\frac{6kaVIt}{(V_{DC}^2-V_{DCmin}^2)} => C_{DC}\cong 0.05F \quad (4)$$

where,
V_{DCmin}=minimum DC link voltage
k=energy variation during dynamic
a=overloading factor
V=phase voltage
I=phase current
t=recovery time

$$\text{Inductor rating} = L_r=\frac{\sqrt{3}mV_{DC}}{(12*a*f_s*\text{ripple current})}\cong 0.4mH \quad (5)$$

where,
f_s=switching frequency=4000Hz

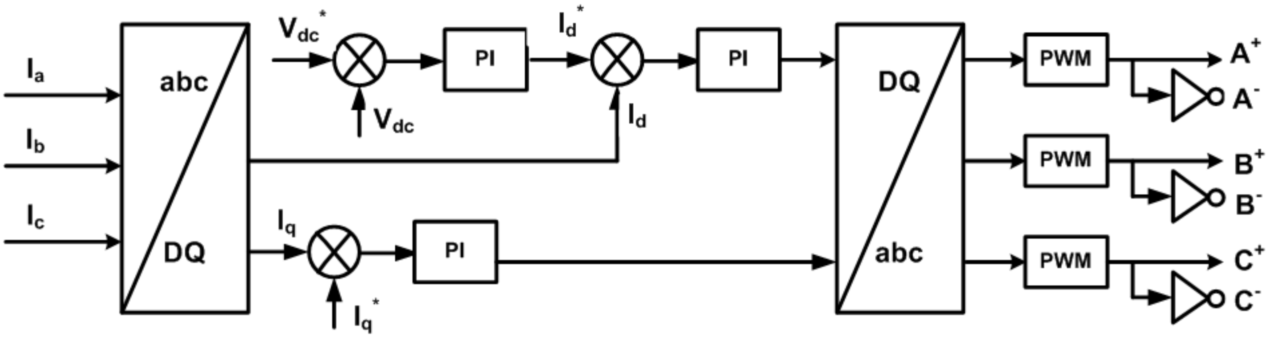

Figure. 3 Block diagram of GSC

VI. DESIGN OF GSC AS STATCOM FOR HIGH POWER

As current grid codes emphasize wind plants to remain connected during grid faults, in the proposed scheme, rating of GSC is increased while maintaining rating of RSC to 33% of rated power. In present case, STATCOM is designed to provide reactive power support upto 5MVAR and the revised values of C_{DC} and Lr are calculated as below

$$\mathbf{C_{DC}} = \frac{\mathbf{6kaVIt}}{(\mathbf{V_{DC}^2 - V_{DCmin}^2})} \Rightarrow \mathbf{C_{DC} \cong 0.3F}$$

$$\textbf{Inductor rating} = \mathbf{L_r} = \frac{\sqrt{\mathbf{3}}\mathbf{m}V_{DC}}{(\mathbf{12 * a * f_s * ripple\ current})} \cong \mathbf{0.12mH}$$

Also, instead of sinusoidal PWM, a novel space vector PWM [21] is used to generate pulses to GSC. Space vector modulation offers high DC link voltage utilization and reduced harmonics when compared with sinusoidal PWM. The corresponding block diagram is shown in figure 4.

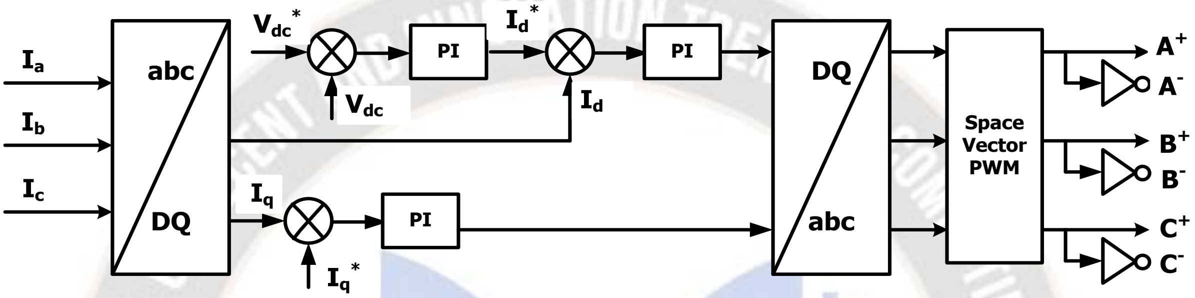

Figure. 4 Block diagram of GSC with space vector PWM

VII. SIMULATION RESULTS

Figure 5 shows the complete Simulink model of DFIG with load.

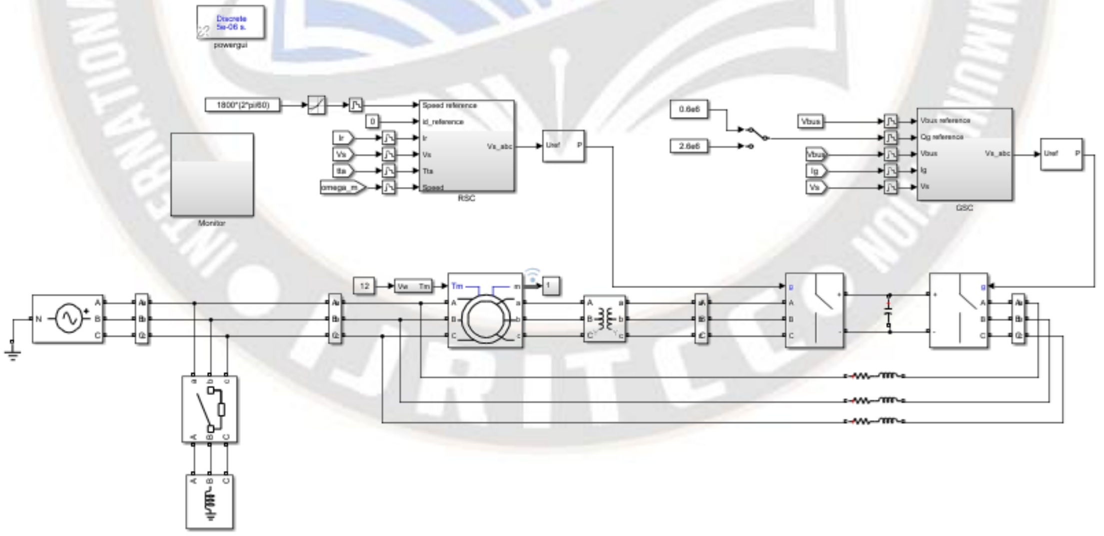

Fig 5. Simulink model of DFIG with MPPT

A. *Case 1: GSC is used only regulating DC bus voltage*

Figure 6 indicates the active and reactive transported by DFIG. Figure 7 shows active and reactive power at grid. At steady state under no load for wind speed of 12m/s, it was observed that DFIG is delivering active power of 1.8MW to grid while drawing a reactive power of 0.6MVAR from grid. At 5 sec an inductive load of 2MVAR is added at PCC, as a result the additional required reactive power was also drawn grid. Figure 8 indicates the waveforms of voltage and current at PCC. Figure 8 clearly indicates that there is lagging power factor at PCC.

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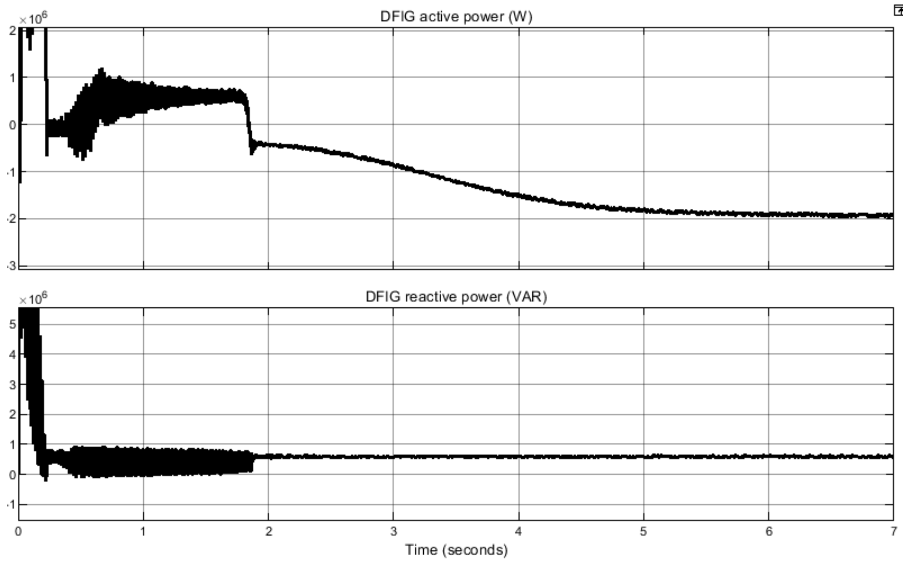

Figure. 6 Active and Reactive powers of DFIG for wind speed of 12 m/s

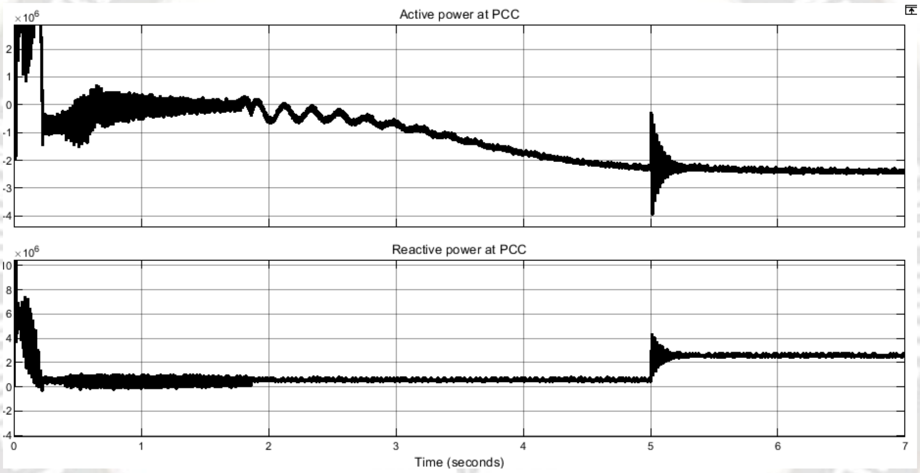

Figure. 7 Active and Reactive powers at PCC for wind speed of 12 m/s

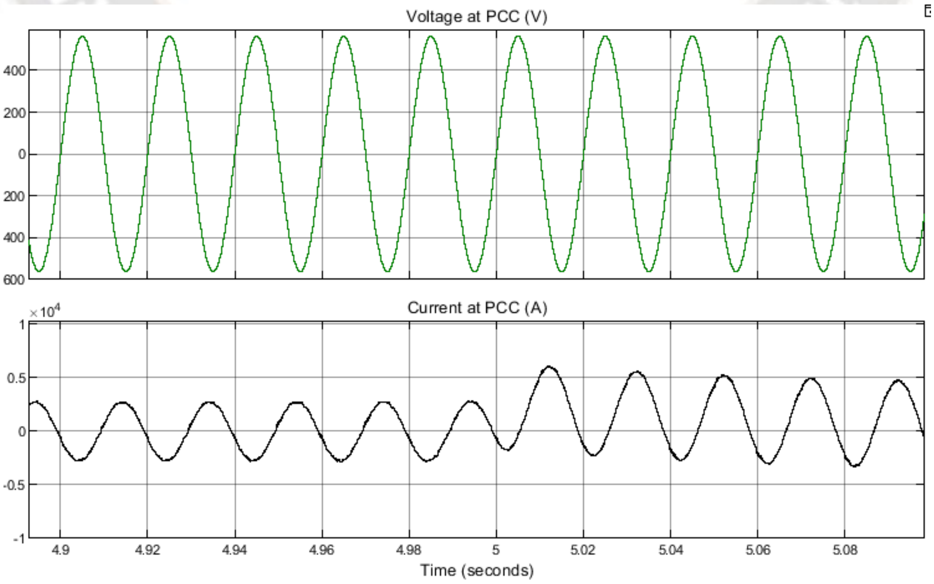

Figure. 8 Voltage and current at PCC for wind speed of 12 m/s

B. Case 2: GSC as STATCOM for 30% of DFIG rated capacity

Figure 9 indicates the active and reactive transported by DFIG. Figure 10 shows active and reactive power at grid. At steady state under no load for wind speed of 10m/s, it was observed that DFIG is delivering active power of 1.4MW to grid while maintaining unity power factor at PCC. At 5 sec an inductive load of 3MVAR is added at PCC. In this case, as GSC is rated only 33% of rated capacity, the additional required reactive power was drawn grid. Figure 11 clearly indicates that there is lagging power factor at PCC.

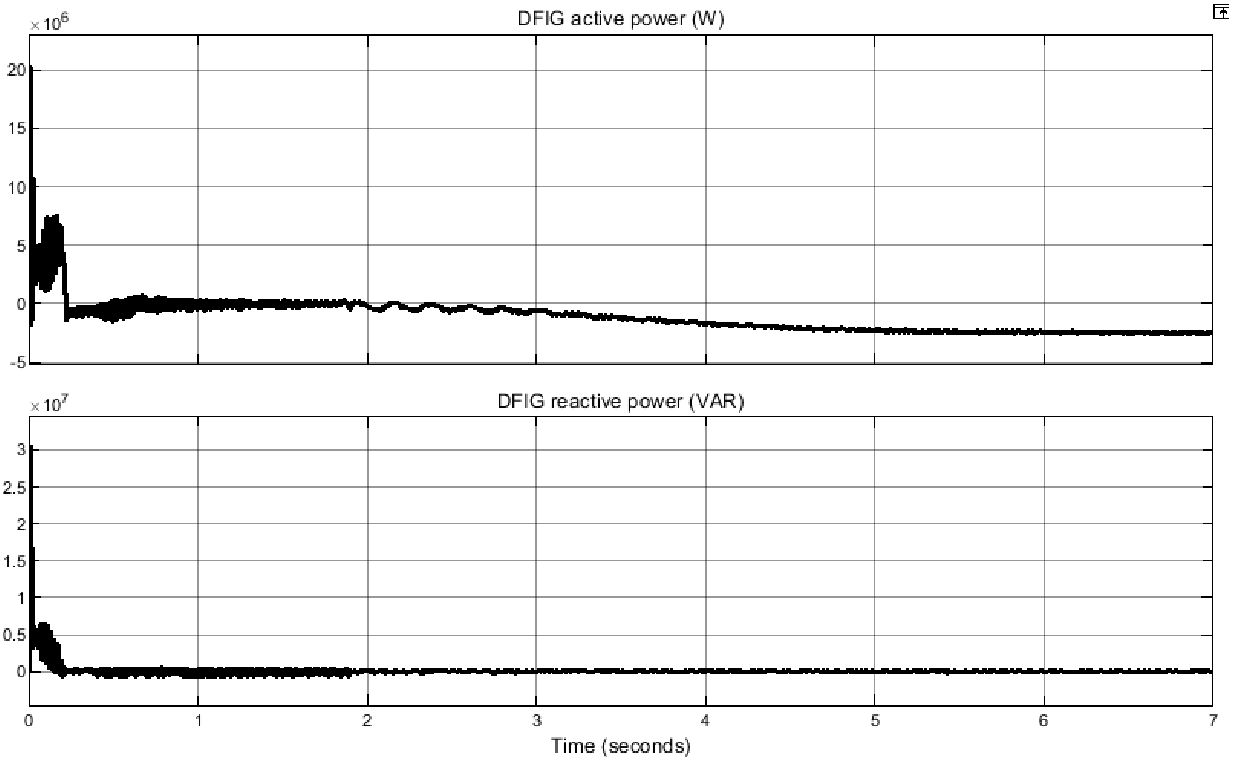

Figure. 9 Active and Reactive powers of DFIG with 30% GSC rating

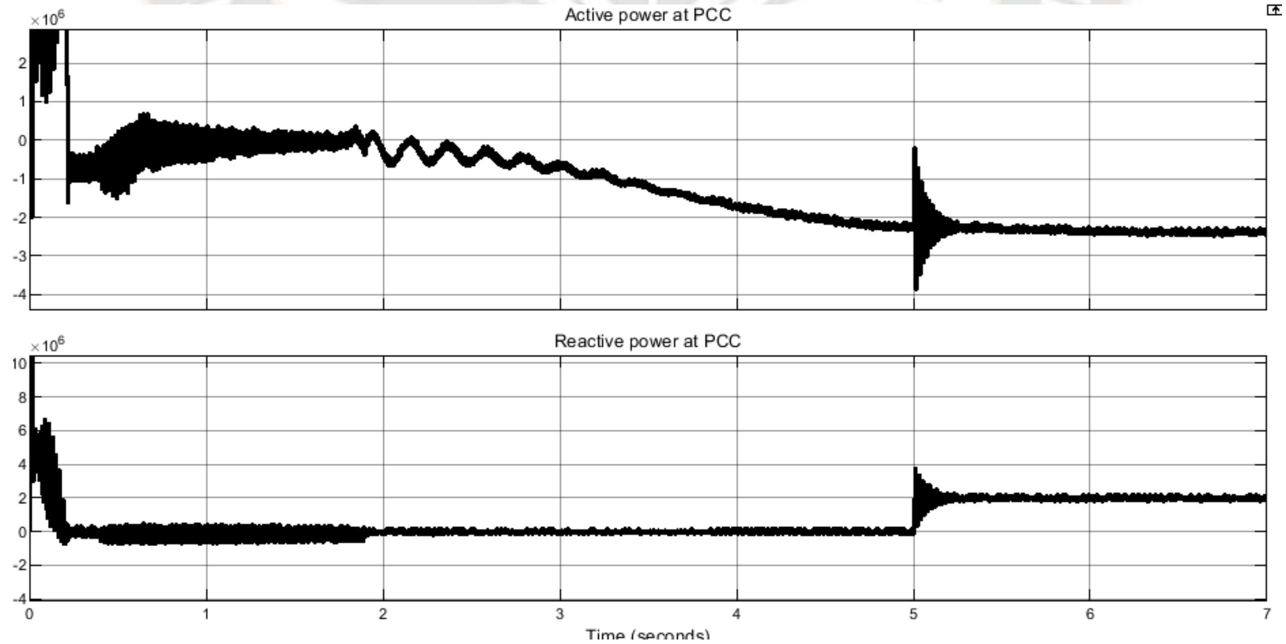

Figure. 10 Active and Reactive powers at PCC with 30% GSC rating

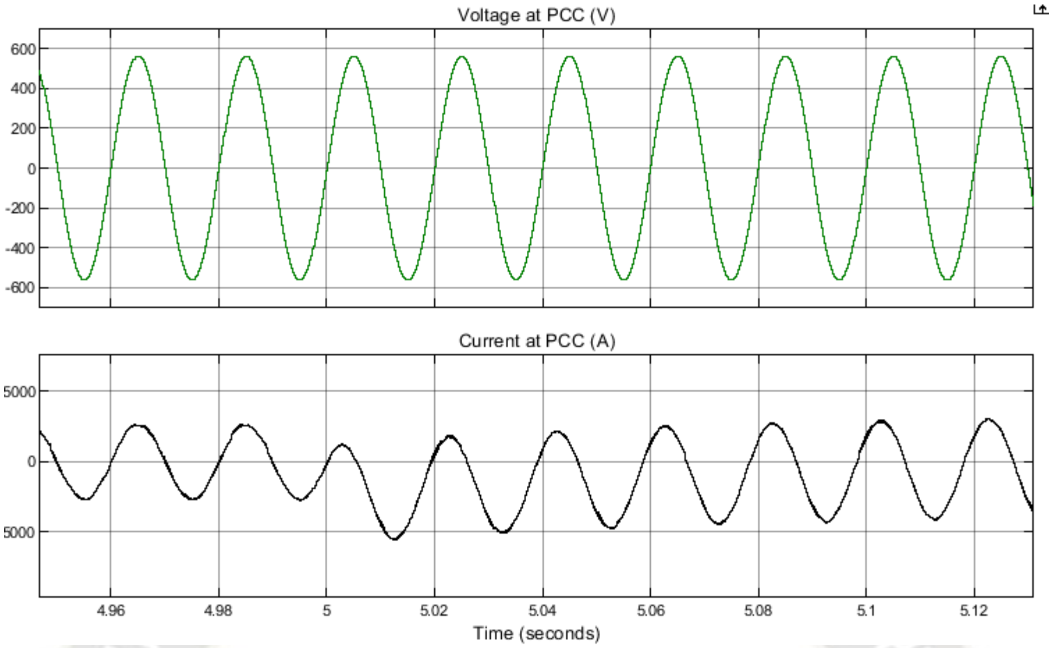

Figure. 11 Voltage and current at PCC for 30% GSC rating

C. Case 3: GSC as STATCOM for 100% of rated capacity while rating RSC RSC for 33% only

Figure 12 indicates the active and reactive transported by DFIG. Figure 13 shows active and reactive power at grid. At steady state under no load for wind speed of 10m/s, it was observed that DFIG is delivering active power of 1.4MW to grid while maintaining unity power factor at PCC. At 5 sec an inductive load of 3MVAR is added at PCC. In this case, as GSC is rated to 100% of rated capacity, the additional required reactive power was also supplied by DFIG and not by grid. Figure 14 clearly indicates that power factor at PCC is unity.

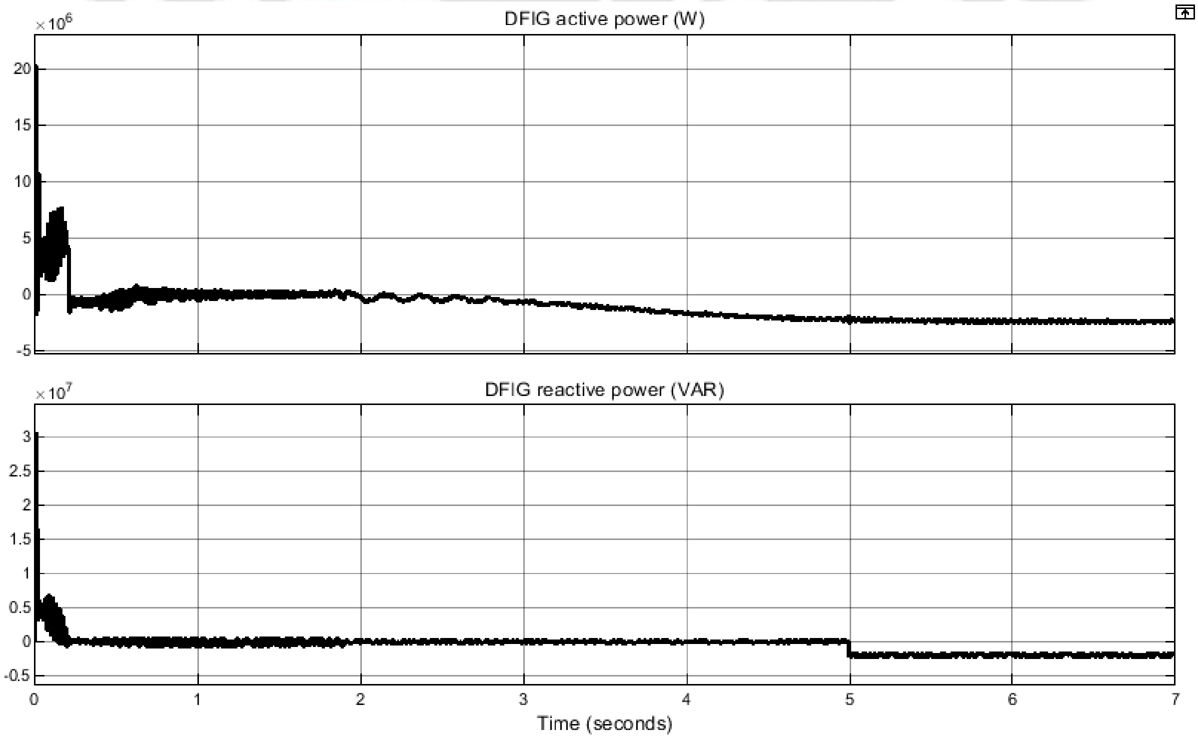

Figure. 12 Active and Reactive powers of DFIG with 100% GSC rating

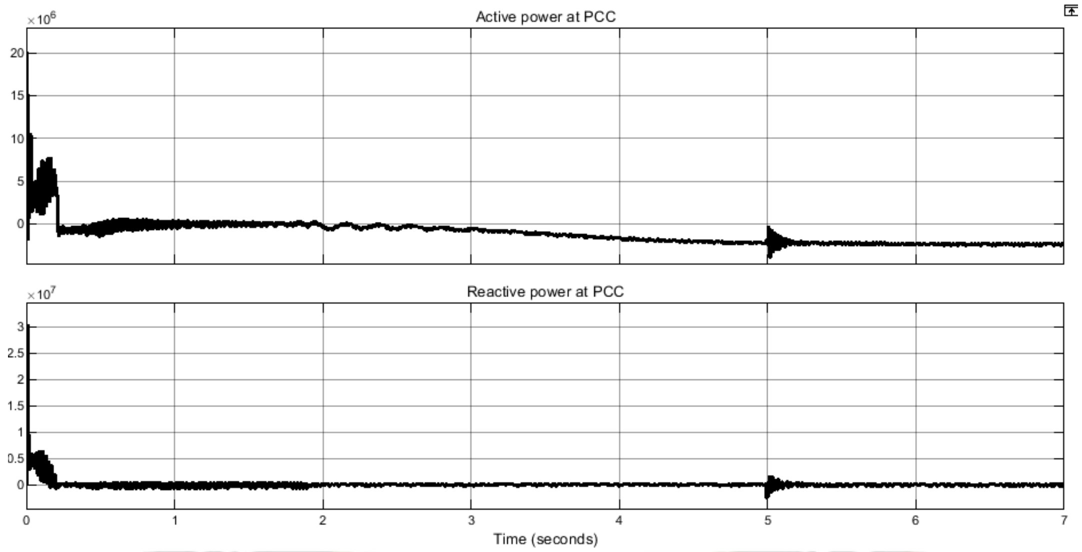

Figure. 13 Active and Reactive powers at PCC with 100% GSC rating

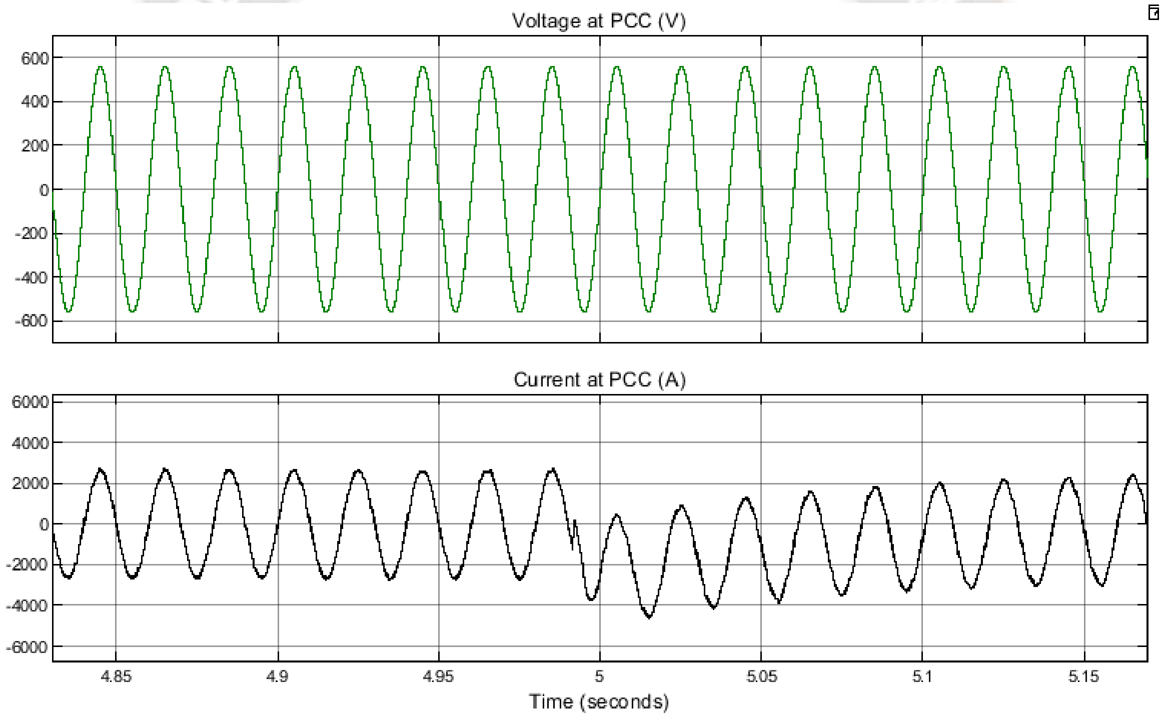

Figure. 14 Voltage and current at PCC for 100% GSC rating

VIII.CONCLUSION

This paper proposed a new economical strategy to manage reactive power at PCC by upgrading GSC to rated capacity and operating it as STATCOM instead of installing additional STATCOM. The design calculations for the upgraded GSC are discussed. Results conclude that GSC can be effectively used for reactive power management at PCC even for high reactive power requirement.

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