DFIG CONVERTED DESIGN FOR POWER GRID AND REACTIVE POWER MANAGEMENT

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Abstract- This paper explains about the operation of the Double Fed Induction Generator(DFIG) with the use of an integrated active filter for the Grid-side converter(GSC). The main objective of this paper is to control of the GSC to supply the harmonics with an addition of its slip power transfer. For supplying the required reactive power to the DFIG and to attain the maximum power extraction the rotor side converter(RSC) is used. When the wind turbine is under shutdown condition, Static compensator(STATCOM) is used for supplying harmonics which is the wind energy conversion system. In detail, the control algorithms for GSC and RSC are explained with the use of a digital signal processor (DSP) which is used to develop a prototype of the proposed DFIG – based WECS. Here MATLAB/Simulink is used as simulator to develop DFIG – based WECS.Simulated results are validated with test results of the developed DFIG for different practical conditions, such as variable wind speed and unbalanced/single phase loads.

I.INTRODUCTION

To have sustainable growth and social progress, it is necessary to meet the energy need by utilizing the renewable energy resources like wind, biomass, hydro, co-generation, etc. In sustainable energy system, energy conservation and the use of renewable source are the key paradigm. The need to integrate the renewable energy like wind energy into power system is to make it possible to minimize the environmental impact on conventional plant. Therefore, the wind energy is the most preferred out of all renewable energy sources. In the initial days, wind turbines have been used as fixed speed wind turbines with squirrel cage induction generator and capacitor banks. Most of the wind turbines are fixed speed because of their simplicity and low cost. By observing wind turbine characteristics, one can clearly identify that for extracting maximum power, the machine should run at varying rotor speeds at different wind speeds. Using modern power electronic converters, the machine is able to run at adjustable speeds. Therefore, these variable speed wind turbines are able to improve the wind energy production. Out of all variable speed wind turbines, doubly fed induction generators (DFIGs) are preferred because of their low cost. The other advantages of this DFIG are the higher energy output, lower converter rating, and better utilization of generators. These DFIGs also provide good damping performance for the weak grid. Independent control of active and reactive power is achieved by the decoupled vector control algorithm presented in [10] and [11]. This vector control of such system is usually realized in synchronously rotating reference frame oriented in either volt- age axis or flux axis. In this work, the control of rotor-side converter (RSC) is implemented in voltage-oriented reference frame.

TABLE I

[35] CURRENT DISTORTION LIMITS FOR GENERAL DISTRIBUTION SYSTEMS IN TERMS OF INDIVIDUAL HARMONICS ORDER (ODD HARMONICS) [35]

I_{sc}/I_L	<11	11 ≤ h ≤17	17 ≤ h ≤ 23	23 ≤ h ≤ 35	35 ≤ h	TDD
< 20	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10	4.5	4.0	1.5	0.7	12
100 < 1000	12	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

As the wind penetration in the grid becomes significant, the use of variable speed WECS for supplementary jobs such as power smoothening and harmonic mitigation are compulsory in addition to its power generation. This power smoothening is achieved by including super magnetic energy storage systems as proposed in. The other auxiliary services such as reactive power requirement and transient stability limit are achieved by including static compensator (STATCOM) in. A distribution STATCOM (DSTATCOM) coupled with fly-wheel energy storage system is used at the wind farm for mitigating harmonics and frequency disturbances [16]. However, the authors have used two more extra converters for this purpose. A supercapacitor energy storage system at the dc link of unified power quality conditioner (UPQC) is proposed in [17] for improving power quality and reliability. In all above methods [15]–[17], the authors have used separate converters for compensating the harmonics and also for controlling the reactive power. However, in later stages, some of the researchers have modified the control algorithms of already existed DFIG converters for mitigating the power quality problems and reactive power compensation [18]–[26]. The harmonics compensation and reactive power control are achieved with the help of existing RSC [18]–[23].

II.SYSTEM CONFIGURATION AND OPERATING PRINCIPLE

Schematic diagram of the proposed DFIG- based WECS with integrated active filter capabilities. In DFIG, the stator is directly connected to the grid as shown in Fig. 3.1. Two back-to-back connected voltage source converters (VSCs) are placed between the rotor and the grid. Nonlinear loads are connected at PCC as shown in Fig. 3.1. The proposed DFIG works as an active filter in addition to the active power generation similar to normal DFIG. Harmonics generated by the nonlinear load connected at the PCC distort the PCC voltage. These nonlinear load harmonic currents are mitigated by GSC control, so that the stator and grid currents are harmonic-free. RSC is controlled for achieving maximum power point tracking (MPPT) and also for making unity power factor at the stator side using voltage-oriented reference frame. Synchronous reference frame (SRF) control method is used for extracting the fundamental component of load currents for the GSC control.

A new control algorithm for GSC is proposed for compensating harmonics produced by nonlinear loads using an indirect current control. RSC is used for controlling the reactive power of DFIG. The other main advantage of proposed DFIG is that it works as an active filter even when the wind turbine is in shutdown condition. Therefore, it compensates load reactive power and harmonics at wind turbine stalling case. Both simulation and experimental performance of the proposed integrated active filter-based DFIG are presented in this work. The dynamic performance of the proposed DFIG is also demonstrated for varying wind speeds and changes in unbalanced nonlinear loads at point of common coupling (PCC).

III. DESIGN OF DFIG-BASED WECS

Selection of ratings of VSCs and dc-link voltage is very much important for the successful operation of WECS. The ratings of DFIG and dc machine used in this experimental system are given in Appendix. In this section, a detailed design of VSCs and dc-link voltage is discussed for the experimental system used in the laboratory.

3.1 Selection of DC-Link Voltage

Normally, the dc-link voltage of VSC must be greater than twice the peak of maximum phase voltage. The selection of dc- link voltage depends on both rotor voltage and PCC voltage. While considering from the rotor side, the rotor voltage is slip times the stator voltage. DFIG used in this prototype has stator to rotor turns ratio as 2:1. Normally, the DFIG operating slip is ±0.3. So, the rotor voltage is always less than the PCC voltage.

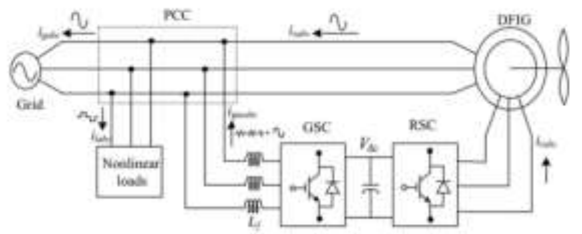


Fig. 3.1. Proposed system configuration

The line voltage at the PCC. Maximum modulation index is selected as 1 for linear range. The value of dc-link voltage.

$$V_{dc} \geq \frac{2\sqrt{2}}{\sqrt{3} * m} V_{ab}$$

3.2 Selection of VSC Rating

The DFIG draws a lagging volt-ampere reactive (VAR) for its excitation to build the rated air gap voltage. It is calculated from the machine parameters that the lagging VAR of 2 kVAR is needed when it is running as a motor. In DFIG case, the operating speed range is 0.7 to 1.3 p.u. Therefore,the maximum slip.

$$S_{\text{rated}} = \sqrt{P^2_{r\,\max} + Q^2_{r\,\max}}.$$

3.3Design of Interfacing Inductor:

DC-link,voltage and switching frequency of GSC.Maximum possible GSC line currents are used for the calculation. Maximum line current depends upon the maximum power and the line voltage at GSC. The maximum possible power in the GSC is the slip power. In this case, the slip power is 1.5 kW. Line voltage.

$$L_i = \frac{\sqrt{3}\,\mathrm{m}v_{dc}}{12 a f_m \Delta i_{gsc}} = \frac{\sqrt{3} \times 1 \times 375}{12 \times 1.5 \times 10\,000 \times 0.25 \times 3.76} = 3.8 \text{ mH.}$$

IV. CONTROL STRATEGY

Control algorithms for both GSC and RSC are presented in this section. Complete control schematic is given in Fig. 4.1. The control algorithm for emulating wind turbine characteristics using dc machine and Type A chopper.

4.1 Control of RSC

Main purpose of RSC is to extract maximum power with independent control of active and reactive powers. Here, the RSC is controlled in voltage-oriented reference frame. Therefore, the active and reactive powers are controlled by controlling direct and quadrature axis rotor currents.

This can be achieved by running the DFIG at a rotor speed for a particular wind speed. Therefore, the outer loop is selected as a speed controller for achieving direct axis reference rotor current.

$$i^*_{dr}(k) = i^*_{dr}(k-1) + k_{pd}\{\omega_{er}(k) - \omega_{er}(k-1)\} + k_{id}\omega_{er}(k)$$

estimated by optimal tip speed ratio control for a particular wind speed.

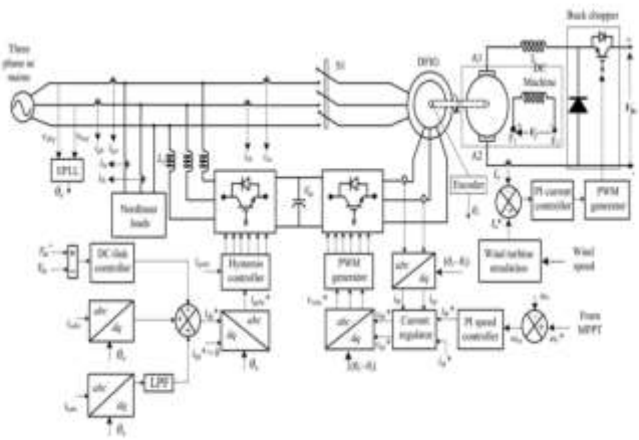


Fig. 4.1 Control algorithm of Proposed WECS.

The tuning of PI controllers used in both RSC and GSC are achieved using Ziegler Nichols method. Initially, selected such that the stator reactive power Q s selected for injecting the required reactive power.

$$i_{dr} = 2/3 \begin{bmatrix} i_{ra} \sin \theta_{slip} + i_{rb} \sin(\theta_{slip} - 2\pi/3) \\ + i_{rc} \sin(\theta_{slip} + 2\pi/3) \end{bmatrix}$$

$$i_{qr} = 2/3 \begin{bmatrix} i_{ra} \cos \theta_{slip} + i_{rb} \cos(\theta_{slip} - 2\pi/3) \\ + i_{rc} \cos(\theta_{slip} + 2\pi/3) \end{bmatrix}$$

$$v^*_{ra} = v^*_{dr} \sin \theta_{slip} + v^*_{qr} \cos \theta_{slip}$$

$$v^*_{rb} = v^*_{dr} \sin(\theta_{slip} - 2\pi/3) + v^*_{qr} \cos(\theta_{slip} - 2\pi/3)$$

$$v^*_{rc} = v^*_{dr} \sin(\theta_{slip} + 2\pi/3) + v^*_{qr} \cos(\theta_{slip} + 2\pi/3).$$

4.2 Control of GSC

The novelty of this work lies in the control of this GSC for mitigating the harmonics produced by the nonlinear loads.

The control block diagram of GSC is shown in Fig. 4.1. Here, an indirect current control is applied on the grid currents for making them sinusoidal and balanced. Therefore, this GSC sup-plies the harmonics for making grid currents sinusoidal and balanced.These grid currents are calculated by subtracting the load currents from the summation of stator currents and GSC currents. Active power component of GSC current is obtained by processing the dc-link voltage error (vdce) between reference and estimated dc-link voltage (Vdc and Vdc) through PI.

V. EXPERIMENTAL IMPLEMENTATION AND OPERATING SEQUENCE

A prototype of the DFIG-based WECS with integrated active filter capabilities is developed using DSP (dSPACE DS1103) in the laboratory. In this experimental system, DFIG is coupled with a dc machine. Wind turbine characteristics are emulated using Type A chopper and a dc machine. The dc machine flux is made constant by keeping the field voltage constant. Therefore, the torque of the machine is controlled by controlling the armature current. The torque of the dc machine is selected from the wind turbine characteristics for a particular wind speed and the rotor speed. The armature current is calculated from the demanded torque using flux constant (kΦ). The duty ratio of the chopper is obtained from the current controller.

Initially, the stator of the DFIG is kept isolated from the grid using switch S1 and the dc machine runs at constant speed by giving fixed duty ratio to the chopper. The GSC is controlled for maintaining the voltage at the dc link. Initially, this GSC works like a simple active filter for supplying the reactive power and harmonics of the local nonlinear loads. Now, this RSC is made ON for making the voltage of the DFIG same as the grid volt-age by adjusting the reactive component of rotor current (iqr). An active power component of rotor current (idr) is made zero for making sure that the stator voltage and the grid voltage are in same phase. Now, the switch S1 is made ON. The control of dc machine is changed from fixed duty ratio mode to wind turbine mode. Still, as there is no active power flow from DFIG to grid, the speed of the machine ramps to maximum depending upon the inertia of the machine. Now, the speed controller is activated. Therefore, the machine speed settles to the reference speed and the active power is fed to the grid.

VI. RESULTS

6.1 Simulation circuit diagram of proposed Model-1 DFIG based WECS at fixed wind speed of 10.6m/s(rotor speed of 1750 rpm).

Simulated output waveforms for the proposed model-1 DFIG- based WECS at fixed wind speed of 10.6m/s with a rotor speed of 1750 rpm. At this case, as the proposed DFIG is operating at MPPT, the reference speed of the DFIG is selected as 1750 rpm. The load currents are observed to be nonlinear in nature. The GSC is supplying required harmonics currents to the load for making grid currents (i_{gabc})and stator currents (i_{sabc}) balanced and sinusoidal. Fig. 5.2 also shows the stator power (P_s), GSC power (P_{gsc}), load power(P_l), and grid power (P_g). At above synchronous speed, the power flow is from the GSC to PCC, so the GSC power is shown as positive.

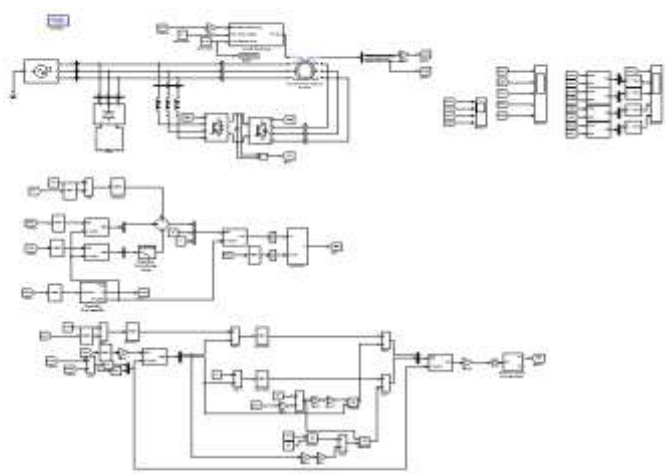


Fig: 6.1.1 Simulated circuit diagram of the proposed model-1 DFIG-based WECS at fixed wind speed of 10.6 m/s (rotor speed of 1750 rpm).

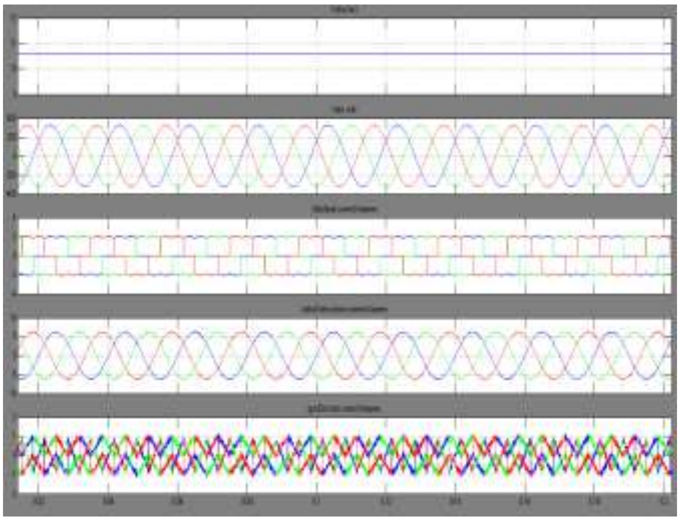
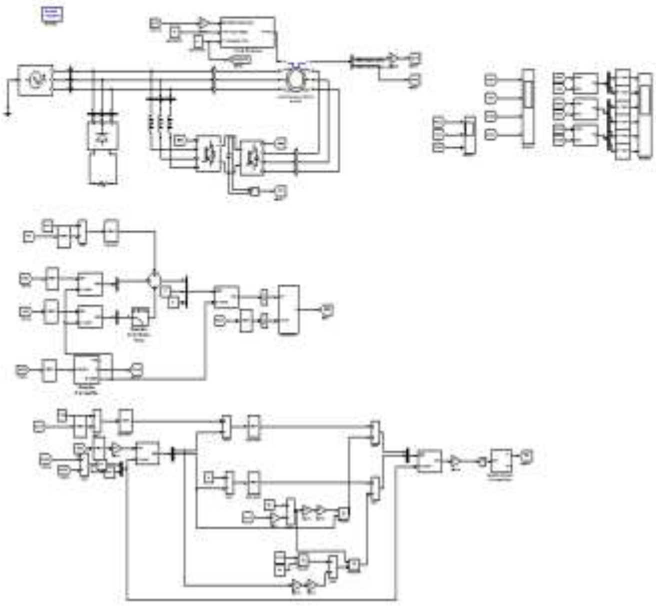


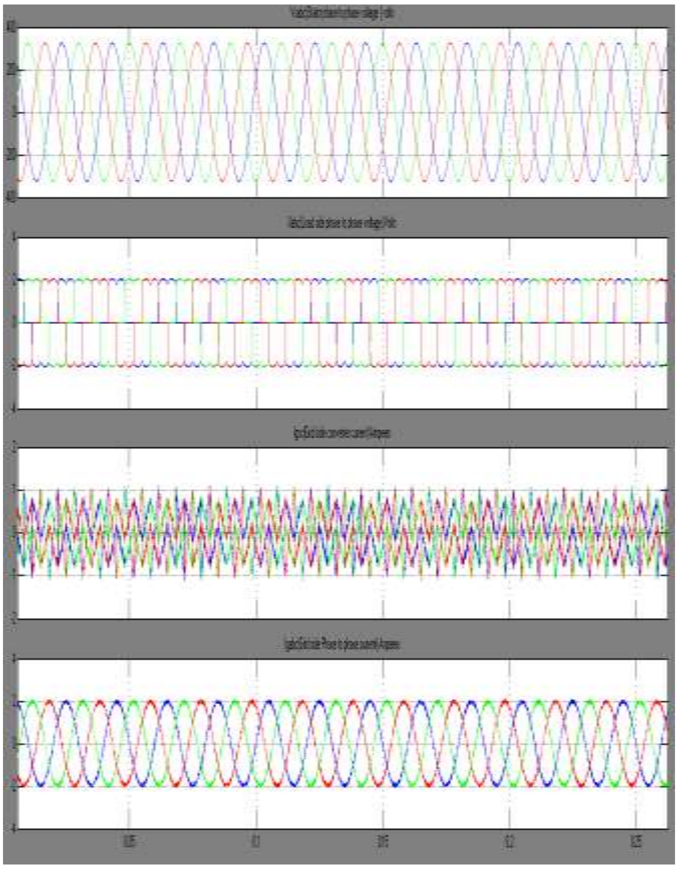
Fig: 6.1.2 Simulated performance of the proposed DFIG-based WECS at fixed wind speed of 10.6 m/s (rotor speed of 1750 rpm).(a)ω_r(b) V_{abc} (c) I_{labc} (d) I_{sabc}(e)V_{abc}(f) I_{gsc}(g) I_{gabc}(h) P_s (i) P_{gsc} (j) P_l (k) P_g

6.2 Simulation circuit diagram of proposed Model-2 DFIG based WECS working as a STATCOM at zero wind speed.

The below figure the simulated results of GSC working as an active filter even when the wind turbine is in stall condition. Here, stator currents are zero, as there is no power production from the DFIG. The load power is supplied from the grid. Therefore, the grid power (Pg) is observed to be negative. Now, this GSC supplies harmonics currents and reactive power. So, the reactive power taken from the grid (Qg) is observed to be zero. Grid currents are observed to be balanced and sinusoidal even load currents are nonlinear. Fig. 8 shows harmonic spectra of load current and grid current. Even the load current THD is very high, grid current THD is under a limit of IEEE-519 standard.

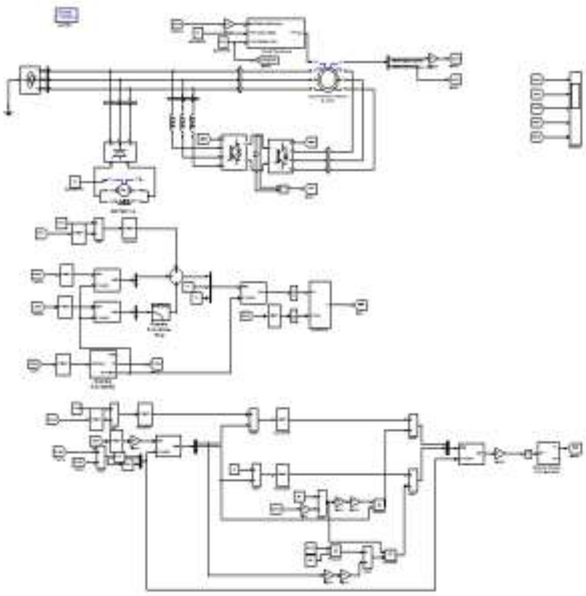


6.2.1 Simulated circuit diagram of the proposed model-2 DFIG-based WECS working as a STATCOM at zero wind speed.

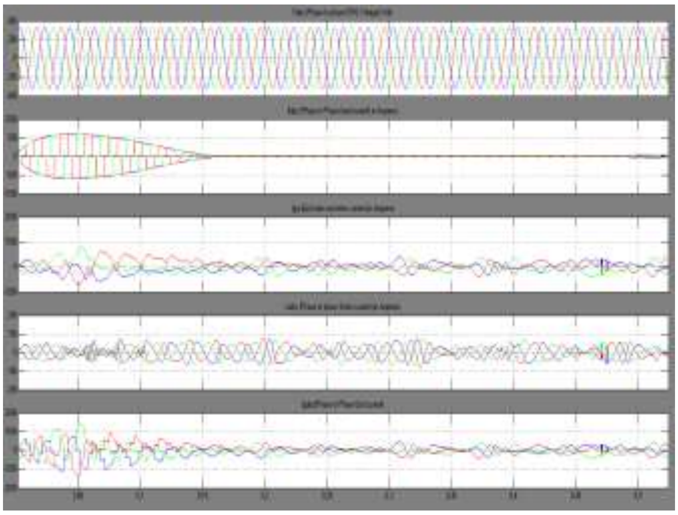


6.2.2 Simulated performance of the proposed model-2 DFIG-based WECS working as a STATCOM at zero wind speed (a) V_{abc}(b) I_{labc} (c) I_{gsc} (d) I_{gabc}(e)P_l (f) q_l
(g) P_g(h) q_g (i) P_{gsc} (j) q_{gsc}

6.3 Simulation circuit diagram of proposed Model-3 DFIG based WECS at fixed wind speed and dynamic load region with coordinated control of STATCOM/SVC



6.3.1 Simulated circuit diagram of the proposed model-6 DFIG-based WECS for fixed wind speed of 10.6m/s.(rotor speed of 1750 rpm) with coordinated control of STATCOM/SVC.



6.3.2 Shows the dynamic performance of this proposed DFIG-based WECS at fixed wind speed of 10.6m/s.(rotor speed of 1750 rpm) with coordinated control of STATCOM/SVC.

CONCLUSION

The GSC control algorithm of the proposed DFIG has been modified for supplying the harmonics and reactive power of the local loads. In this proposed DFIG, the reactive power for the induction machine has been supplied from the RSC and the load reactive power has been supplied from the GSC. The decoupled control of both active and reactive powers has been achieved by RSC control. The proposed DFIG has also been verified at wind turbine stalling condition for compensating harmonics and reactive power of local loads. This proposed DFIG-based WECS with an integrated active filter has been simulated using MATLAB/Simulink environment, and the simulated results are verified with test results of the developed prototype of this WECS. Steady-state performance of the proposed DFIG has been demonstrated for a wind speed. Dynamic performance of this proposed GSC control algorithm has also been verified for the variation in the wind speeds and for local nonlinear load.

SCOPE FOR THE FUTURE WORK

- Performance of the GSC to meet the required reactive power control may further be enhanced by implementing different intelligent control algorithms like Fuzzy-Genetic, Evolutionary algorithm.
- Instead of Static Synchronous Compensator (STATCOM) + Thyristor Switched Capacitor (TSC) model, a fuzzy controller design may also be optimized to manage reactive power for power grid to damp the generator oscillations.
- The proposed control model can be extended to all types of power system faults in generation side to maintain the grid voltage and to maintain the power quality.

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