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Rotor Angle Stability Improvement of DFIG Using Grid Side and Rotor Side Converter Control

Mathusoothanan.T[1], Dr. R. Karthik[2]
[1]PG Scholar, [2]Associate Professor, Department of Electrical and Electronics Engineering ,
Valliammai Engineering College

Abstract—Wind energy generation with Doubly Fed Induction Generator is dominant one in wind farms. High penetration of DFIG is creating more instability in rotor side and grid side. Applying a set of optimized control parameter, the stability can be further enhanced. In this paper variable load condition rotor angle stability of the DFIG is improved by Grid Side (GSC) and Rotor Side Converter (RSC) control. In DFIG, the frequency of the rotor excitation input, real and reactive powers are modified based on rotor speed and load variation. The simulation result shows the effectiveness and performance of the DFIG with GSC-RSC converter control techniques.

Keywords—Doubly Fed Induction Generator (DFIG); Grid Side Converter (GSC); Rotor Side Converter (RSC); frequency; real and reactive power.

I. INTRODUCTION

In Previous day's power generation is mostly based on the non-renewable sources but now-a-days power generation with renewable energy is more efficient and growing one. Variable speed wind turbines employing Doubly Fed Induction Generator (DFIG) is the most popular technology in currently installed wind turbines .With the continuous increase in penetration level of DFIG wind turbines, power system stability becomes an important issue which needs to be properly investigated [1],[5].Wind power generation with DFIG is optimal one and high penetration of this DFIG creates some instability in rotor and grid side. By replacing Variable Speed Wind Turbine (VSWT) generation with equivalently rated synchronous units, the small-signal stability and transient stability of the system was assessed. But efficiency of the system is reduced and it creates more stress in gear system. Power electronic converter of the DFIG acts as an interface between DFIG generator and the grid. And increased penetration of DFIG, the effective inertia of the system will be reduced. DFIGs are not synchronously coupled to the power systems, the wind turbines do not participate in electromechanical oscillations. This DFIG frequency of the stator is based on the frequency of the rotor and it is varied by the controllers.

If wind speed is less than the rated speed, frequency of the rotor is increased. It is ensured in eq1.

$$fstator=(nrotor\times Npoles/120)+frotor \quad (1)$$

Wind speed is more than the rated speed, frequency of the rotor is reduced. It is ensured in eq2.

$$fstator=(nrotor\times Npoles/120)-frotor \quad (2)$$

The following equation represents the rotor frequency changes in variable wind speeds,

$$frotor= fnetwork – (nrotor\times Npoles/120) \quad (3)$$

In this method reactive power is supplied by wind generation and rotor angle stability was examined. The study concluded that transient stability could be improved and the oscillations damped more quickly if the terminal voltage of the wind generation is controlled. For this control process GSC is implemented in this system and control based on the grid supply voltage and DFIG supply voltage .The available reactive power is utilized by this two control strategies and DFIG-GSC is act as reactive power source in grid fault conditions. The main objective of Rotor Side Converter (RSC) is to regulate Stator side active and reactive power independently. DFIG stator voltage can be regulated to achieve a certain limit by controlling stator reactive power through RSC. The rotor side power converter can be act as a current controlled voltage source converter [2],[7]. By utilizing the integrated capabilities of wind generation, specifically reactive power control process and requirements placed on conventional synchronous generation could be eased and system security could be improved. This analysis will examine how reactive power of the wind generation can be used as a mitigation tool to ease the stress on variable speed generation and increase system stability. Variable speed wind turbines are capable of controlling active and reactive power and both could be used to improve small signal stability.

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II. METHODOLOGY

In this method rotor angle stability is improved by design of converter control technique. Grid side converter implementation is based on the reactive power modifications and it is also compensate the grid reactive power variations.

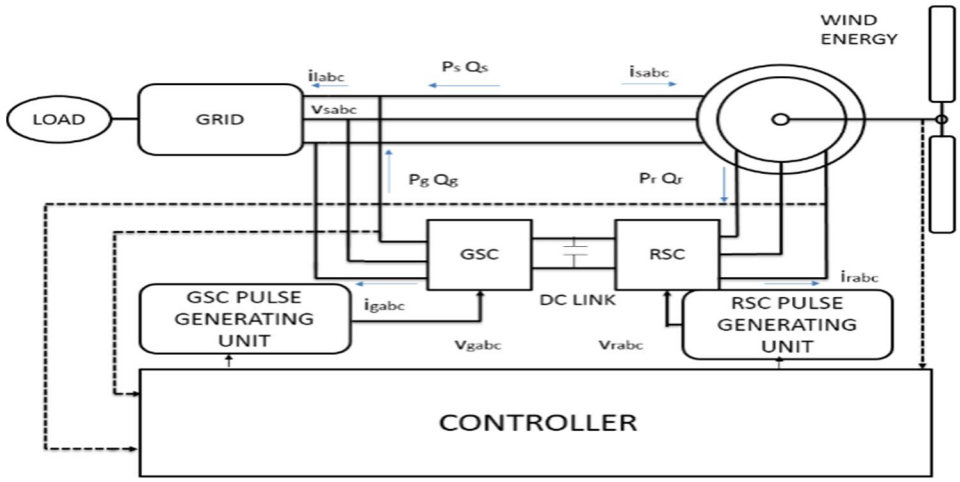

Fig 1 DFIG with RSC-GSC control

Rotor side converter implementation is based on the frequency, real and reactive power modifications. DFIG speed variations are based on the RSC output current frequency. This two converter pulse generation is controlled by PWM technique.

III. MODELING OF DFIG

The DFIG is comprised of a wound rotor induction generator with a rotor coupled back-to-back converter system. The Rotor Side Converter (RSC) is connected to the GSC using a DC link capacitor [5],[6]. During grid disturbances, due to the magnetic coupling between the stator and the rotor, a high transient rotor current is excited. Hence, to avoid damage to the converter, the RSC is short circuited using a resistor bank, which is commonly known as the crowbar. The crowbar effectively decouples the back-to-back converter unit from the wound rotor induction generator, and enables the DFIG to operate as a squirrel cage induction motor. Transition from a DFIG to SCIG absorb more reactive power from the grid so this condition GSC-DC link section act as a STATCOM and supply reactive power to the DFIG.

And the wind flow variations are creating the instability in rotor function and also create torsional vibrations by the process of electromechanical interactions. To eliminate this problem Rotor Side Converters (RSC) are used to modify the frequency, real and reactive power of DFIG rotor excitation current. These processes are obtained by the Rotor Side (RSC) and Grid Side Converter (GSC) control methods [3].

A. Modeling of Rotor Side Converter (RSC)

The rotor side converter controller used to control the DFIG active power output for tracking the input power of the wind turbine, and maintains the terminal voltage to the reference value. The active power and voltage are controlled independently via vqr and vdr, respectively.

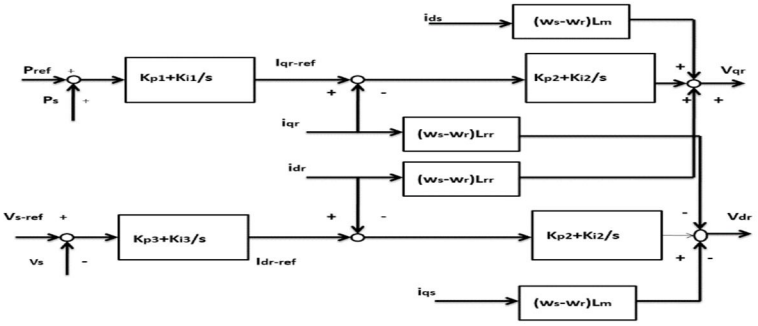

Fig 2 RSC control process

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The control block diagrams are shown in Fig 2 with introducing the intermediate variables *x*1, *x*2, *x*3 and *x*4, the following equations are obtained

$$dX1/df = Pref + Ps$$
$$Iqr\text{-}ref = Kp1(Pref+Ps)+Ki1X1 \quad ----(4)$$
$$dX2/df = iqr = iqr\text{-}ref\text{-}iqr$$
$$= Kp1(Pref+Ps)+Ki1X1\text{-}iqr \quad ----(5)$$
$$dX3/df = Vs\text{-}rq\text{-}Vs$$
$$= Kp3(Vs\text{-}rq\text{-}Vs)+Ki3X3 \quad ----(6)$$
$$dX4/df = idr\text{-}ref\text{-}idr$$
$$= Kp3(Vs\text{-}ref\text{-}Vs)+Ki3X3\text{-}idr \quad ----(7)$$

$$Vqr = Kp2(Kp1\Delta P+Ki1X1\text{-}iqr)+Ki2X2$$

$$Vdr = Kp2(Kp3\Delta V+Ki3X3\text{-}idr)+Ki2X4$$

The rotor side power converter can be modeled as a current controlled voltage source converter. Therefore, the crowbar resistance must be chosen carefully. After the fault is cleared out, a delay time between 60 and 120 ms is needed to allow the machine flux transients to die down. Then, the crowbar can be switched OFF and the RSC goes back to control the DFIG. If this time taken more than 120 ms it causes more short circuit current in rotor winding and reduce the life time of the doubly fed induction generator rotor winding [4]..

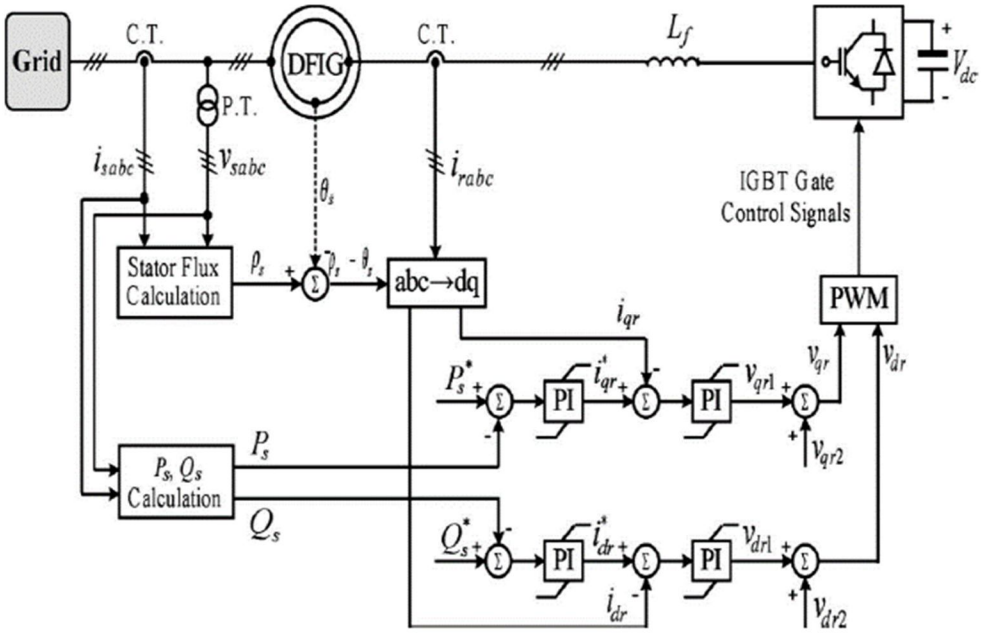

Fig 3 Rotor Side Converter control

This method basic stator flux calculation and real and reactive power calculations are obtained by the help of current and potential transformer and this process simplified by the d-q transformation system. Then these method proportional integral (PI) techniques are used for on time reference value creation and feedback process. Pulse with modulation (PWM) techniques is used for pulse generation and it is give control signal to the rotor side converter [3]. But the RSC is deactivated during large transient disturbances, and GSC-DC links are producing reactive power to protect the DFIG.

B. Modeling of Grid Side Converter (GSC)

The grid side converter controller is used to maintain the DC link voltage, and control the terminal reactive power. The voltage of

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the DC link is controlled by *idg* while the reactive power is controlled by *iqg*[6]. The GSC is reconfigured as a reactive power source during decoupled operation to support the reactive power demand of the induction generator and support local voltage during grid disturbances.

The reactive power reference is generated considering a voltage measurement taken at the PCC of the DFIG. The GSC reactive power support is only activated below a specified voltage value at the PCC, since a voltage drop below acceptable range may restrict the reactive power capability of the voltage control scheme implemented using RSC or suppress the IG reactive power requirement during decoupled operation.

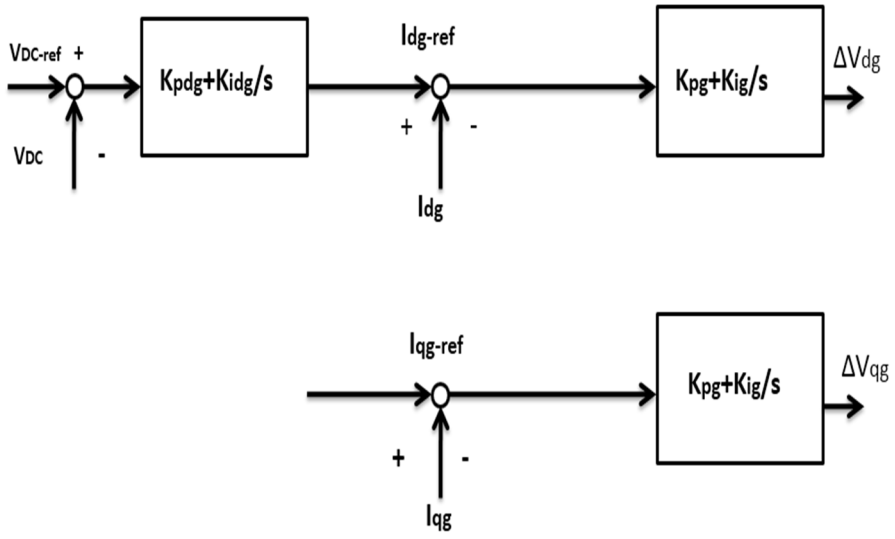

Fig 4 GSC control process

$$dX5/dt = VDC\text{-}ref - VDC \quad \text{---(8)}$$

$$Idg\text{-}ref = -KpdgΔVDC + KI \quad \text{---(9)}$$

$$dX6/dt = idg\text{-}ref - idg$$
$$= -KpdgΔVDC + KidgX5 - idg \quad \text{---(10)}$$

$$dX7/dt = idq\text{-}ref - iqg \quad \text{---(11)}$$

$$ΔVdg = Kpg\ dx6/dt + KigX6$$
$$= Kpg(-KpdgΔVDC + KidgX5 - idg) + KIgX6$$

$$ΔVqg = Kpg\ dx7/dt + Kig\ X7$$
$$= Kpg(idq\text{-}ref - iqg) + KIgX7$$

The GSC reactive power control scheme is only activated as an improved voltage support scheme during Fault ride through operation [2],[9]. Block diagram of the GSC control scheme implemented with the decoupled control approach. In GSC-DC link mode, the GSC prioritizes reactive power control through the GSC once the terminal voltage drops below a preset voltage[4].GSC starts to inject reactive power soon after a fault is initiated in the network otherwise this fault current affects the grid power quality and rotor stability.

The DC link transient is also slightly reduced, due to the reactive power prioritization of the GSC. Vector Phase Locked loop is used to convert the Vabc to frequency and theta value[5],[8]. This values are given to the dq transmission system for simplify process. And power calculation unit is used for reactive power calculation and this

power is varied based on the rotor current frequency and the reactive power variation. This calculated power variation and Phase Locked Loop (PLL) output frequency variation are compared to the reference values. Based on this reference values, control pulses are generated by PWM pulse generator.

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S.NO	PARAMETERS	VALUES
1	Generated voltage	120 KV
2	Grid voltage	565 V
3	DFIG power	1.5 MW
4	No of DFIG	4
5	Total DFIG power	6 MW
6	Pars of poles	3 p
7	Wind speed variation	10-30 m/s
8	Stator resistance	0.023 Rs(pu)
9	Stator inductance	0.18 Lls(pu)
10	Rotor resistance	0.016 Rr(pu)
11	Rotor inductance	0.16 Llr(pu)
12	Magnetizing inductance	2.9 Lm(pu)
13	Inertia constant	0.685 H(s)
14	Friction factor	0.01 F(pu)

Table 1 Parameters of DFIG

The GSC-DC link capability was slightly reduced during the sub synchronous and super synchronous modes of operation due to the active power transfer. Then the GSC-DC link operation has reduced the DFIG rotor acceleration following a transient event, due to the development in wind farm voltage by reactive power control. In addition, the DC link transient has also reduced with the GSC-DC link mode for all three operating modes of the DFIG[5]. The GSC-DC link operating time can be varied based on the voltage setting, and can be used under general operating conditions to support the grid voltage.

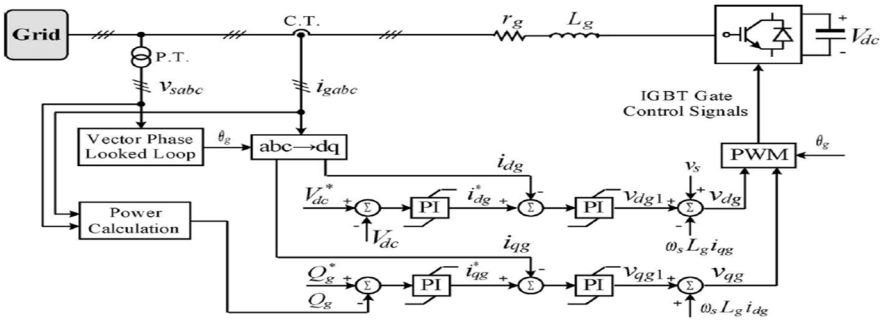

Fig 5 Grid Side Converter control

IV. SIMULATION

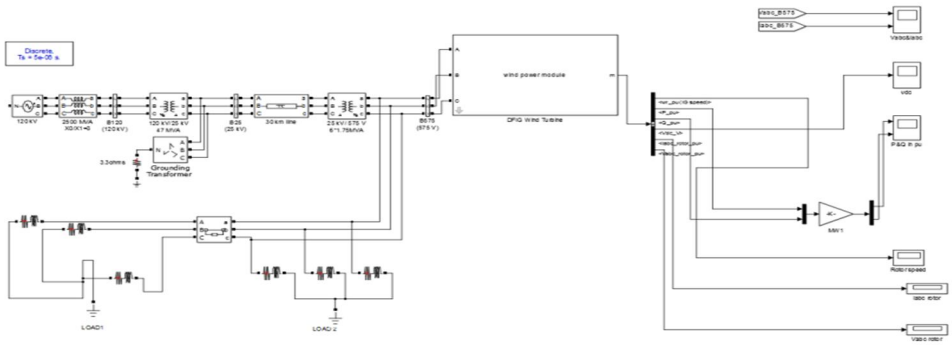

Fig 6 Simulation of Rotor Angle Stability improvement of DFIG with GSC and RSC control system.

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V. SIMULATION RESULTS

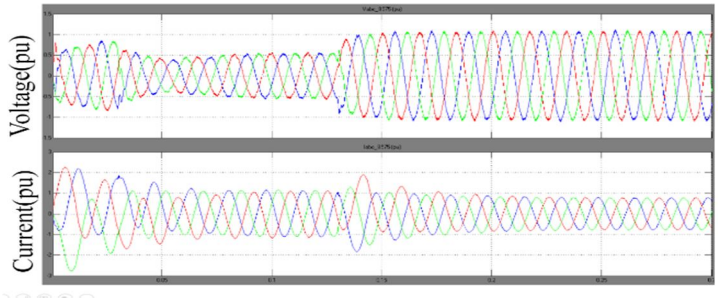

Fig 7 Simulation result of DFIG output Vabc and Iabc with grid connection.

This results represents the load variation in 0.01 ms to 0.05 ms and this variations compensated with in 0.15 ms. It is shown in fig7.

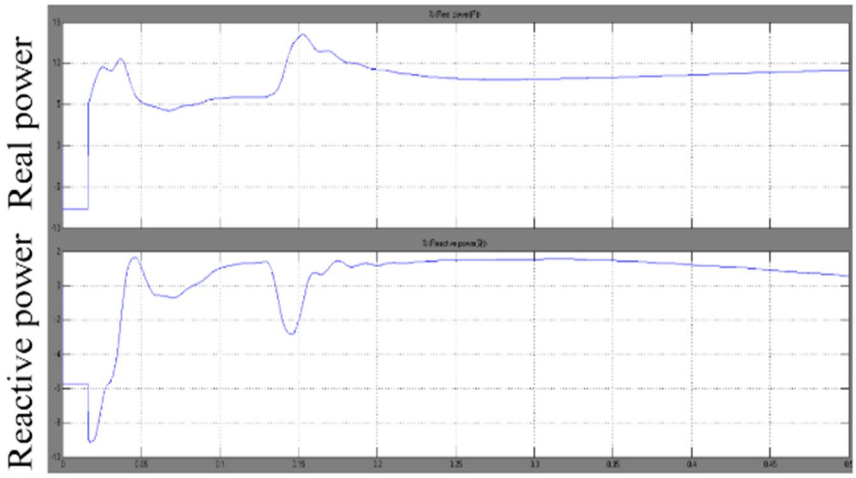

Fig 8 simulation result of DFIG real and reactive power variations.

This results represents the reactive power variation in grid and DFIG. This variations are compensated by the GSC-DC link section. It is shown in fig8.

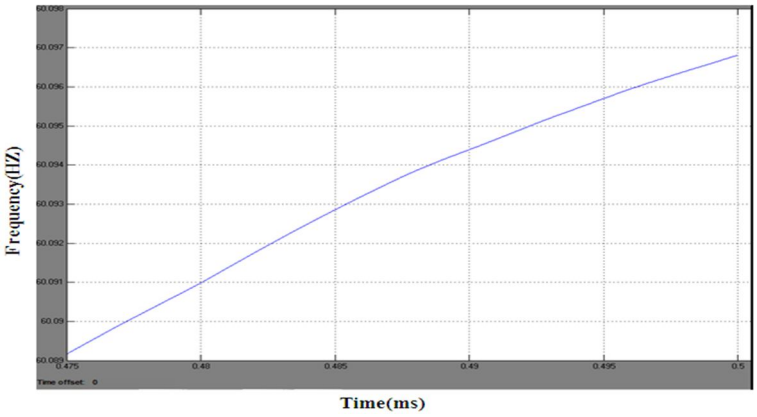

Fig 9 simulation result of DFIG's frequency of grid input voltage

This simulation result fig 9 and fig10 represents the variation of grid frequency and rotor speed in load variation time 0.01 to

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0.05.After the compensation this two functions are get normal operating condition.

S.NO	PARAMETERS	VALUES
1	Load 1 ON Time	0.01 ms
2	Load 2 ON Time	0.05 ms
3	Rotor angle stability without controller	More than 5 ms
4	Rotor angle stability with controller	0.15 ms

Table 2 Output parameters of DFIG

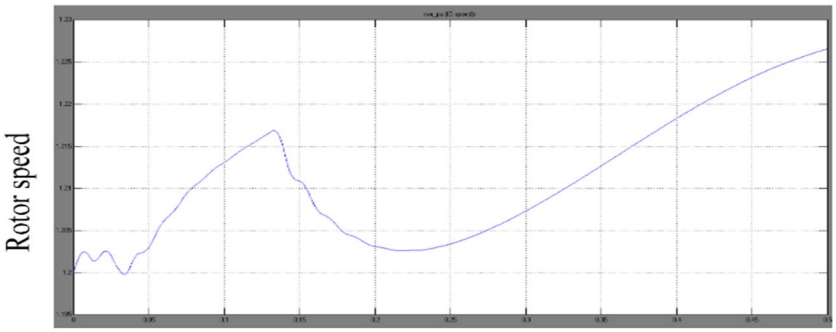

Fig 10 simulation result of DFIG variable rotor speed.

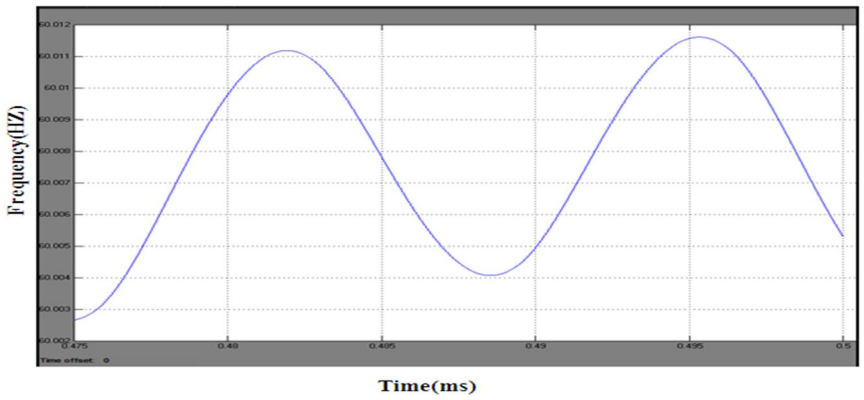

Fig11 simulation result of DFIG's Frequency of Rotor Excitation Input

VI. CONCLUSION

In this paper, the issues of high penetration of DFIG based wind forms and high load variations are create the instability in rotor angle and output of DFIG. These impacts are reduced by the grid side and rotor side converter control. Grid side converter with reactive power changes and rotor side converter with frequency, real and reactive power changes are used to mitigate these issues in this method. This grid side converter reactive power support is compensating the reactive power variation in grid side. Then RSC control is used to analyze the variation of wind speed and frequency for improve the rotor angle stability of the DFIG.

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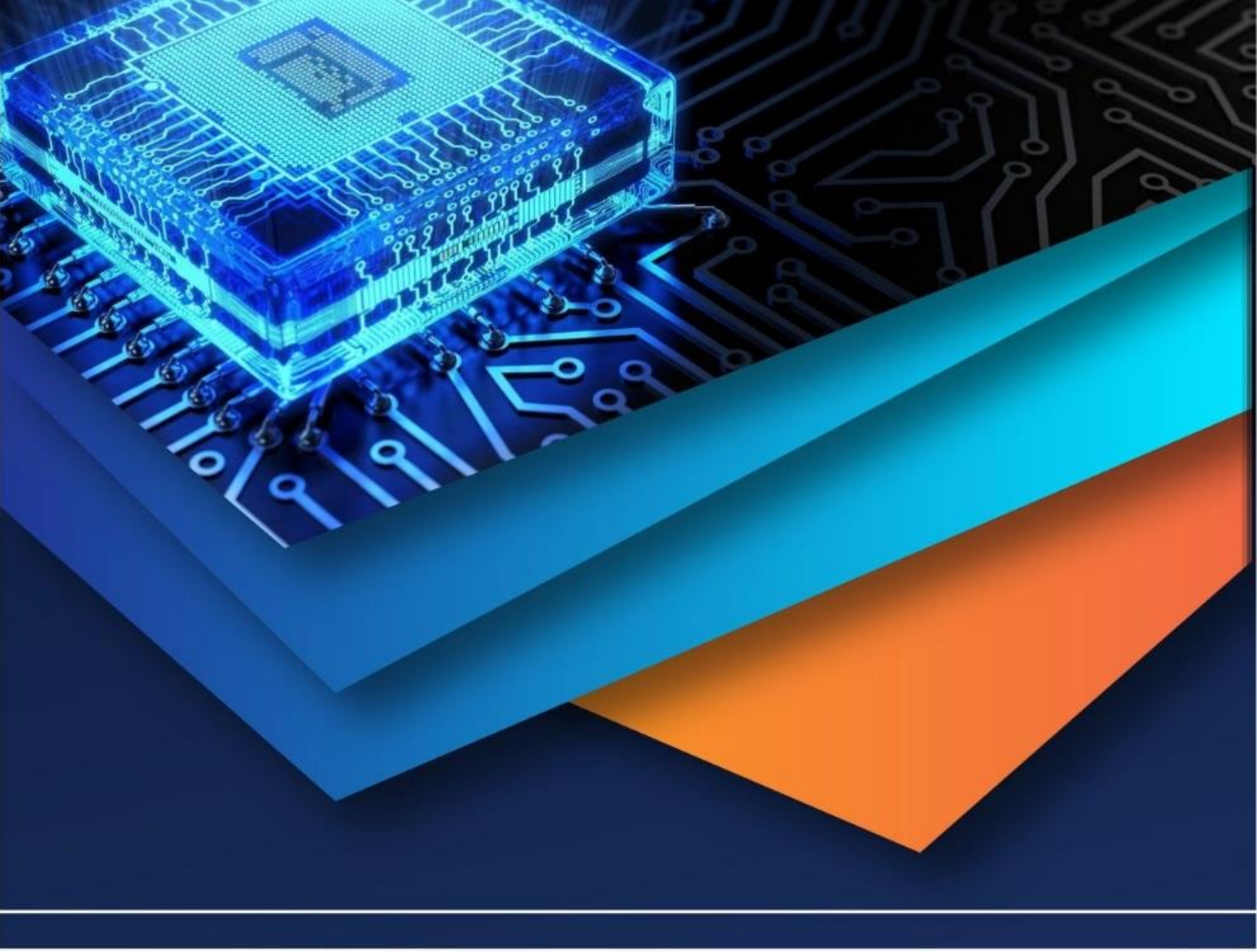

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