Analyzing the Impact of Wind Generation on System Frequency

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Abstract

With the increase of coordination between wind energy on the conventional power system, the effect of high penetration of injected wind power on power system stability turns into an important issue.

The huge contrast is that the wind energy source is inherently uncontrollable. Such uncontrolled real power output variations can affect the grid,including frequency variations. Frequency control is an important issue with high state of penetration of wind, in weak system.

As it has been seen that yield is variable in wind control generation yield, it will differ from time to time so as the frequency of the operation will get fluctuate, and frequency variation or deviation is to be alleviated to have a smooth power flow yield with less variations.

To have that steady flow of power or to match with the grid frequency it is required to utilize GSC (grid side convertor) and RSC (rotor side converter) which will act as the slip control recuperation system and henceforth the power from the slip will be recovered and utilized.

For the purpose of evaluating impact of large wind power penetration on system frequency Kundur's Two area system has been taken into consideration for the said aim,one of the conventional generators of area-1 has been replaced with group of wind generators. All the wind induction generator is of DFIG types. By changing penetration of wind power in the grid system frequency , ROCOF(Rate of change of frequency) and frequency nadir are the parameters of interest for the analysis. In order to improvise the system frequency, AGC has been considered. Under the influence of AGC wind generator can handle or cater more load sharing as compared to the situation when AGC was not present.The work further includes determination of critical penetration of wind power without loosing stability of the system. For incoming transients response and extending grid connection capability under 3-phase fault on transmission line in a weak power system is analyzed. At the time of fault, resistance in series with connecting bus of wind power penetration using a bypass breaker is considered based on this the system frequency and frequency nadir can be analyzed.

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Chapter 1

Introduction

1.1 General

India's energy sector is a diversified among the most broadened on the planet. Sources of power generation ranges from traditional sources, for example, coal, normal gas, oil, hydro and nuclear energy to suitable non-conventional, for example, wind, solar, and waste. Power demand in the nation has expanded and it is going to rise in future as well. With a specific end goal to take care of demand , enormous expansion to the introduced capacity is required.
In present power situation of India, aggregate introduced limit is 305.55 GW and RE (Renewable Energy) limit is 44.23 GW (as on August 2016). Around 27.151 GW wind energy is installed (as on Aug 2016). As per the (C-WET) Center for Wind Energy Technology, the wind power potential in India at 50 m hub tallness is evaluated to be 49,130 MW and 80 m center stature is assessed to be 1,02,788 MW. The extensive scale penetration of wind energy in the electrical power system is reliably impose challenges by giving an increasing proof of the impact between wind farms and the grid.

Presently , the demand of electrical energy is increasing step by step however the presence of coal, fossils are towards the end. So it is required to find alternative way to produce power. Wind energy is a non-traditional sources of energy and often introduced in remote, rural regions which have weak grids, often with voltage imbalances and under voltage scenarios. Wind energy has been the subject of late innovative work. With increase penetration of wind power into electrical systems, DFIG wind turbines are to a great extent sent because of their variable speed feature and consequently affecting system elements. This has made an interest for creating appropriate models for DFIG to be incorporated into power system.The regular pattern of having high penetration of twist power, lately, has made it important to present new practices.For illustration, grid codes are being updated to guarantee that wind turbines would add to the control of voltage and frequency furthermore to remain associated with the host arrange taking after an unsettling influence. Renewable vitality sources, particularly wind power, are turning into a vital segment of the aggregate era. Thus, inquire about concerning the dynamic conduct of wind vitality frameworks is essential to accomplish a superior control.In reaction to the new grid code prerequisites, a few DFIG models have been proposed as of late, including the full-model which is a fifth order model. These models utilize quadrature and direct segments of rotor voltage in a suitable reference frame to give quick control of voltage.

1.2 Problem Identification

As the penetration of the wind energy system is increasing step by step, mixing of RESs(Renewable energy sources) into power system grids have impacts on optimum power flow, power quality,voltage and frequency control ,system economics and load dispatch. Noteworthy frequency deviations may bring under/over frequency relaying and detach a few loads and generations.In the event of little or large disturbances, this may bring cascade fail and system failure.
Increasing levels of DFIGs alters the frequency behaviour constantly, and with that the system operator may become proactive in anticipation to meet the difficulties.

A sudden decrease in a vast wind power production, which is not properly forecasted, may likewise prompt to over-burden the issues in interconnection lines.

1.3 Objective

The principle goal of this exploration work is to analyze the difficulties arrived because of wind power integration on the grid on account of its variable speed nature.
Keeping in mind the end goal to give an understanding of the operation of the synchronous area with an emphasis on the impacts of the decrease of inertia because of the expansion of wind generation on the ROCOF(Rate of change of frequency) and the frequency nadir.

1.3.1 Key objectives are listed below

1. Creation of synthetic inertia from wind farms or the contribution of wind farm for frequency regulation.

2. It is essential that the variable RESs production which is displacing the conventional generators able to contribute to the provision of some of the ancillary services

and potentially provides new services like inertia to the system.

3. It also works as a back up system even for supporting the conventional grid or bearing the faulty conditions.

1.4 Methodology

- The wind generator is to be connected to the existing conventional system and observe the effect of the alteration of the frequency output with the penetration of the wind energy in the conventional system .

- The Wind energy would not be having any inherent inertia of its own, so artificial "emulating inertia" has to be developed and matched with the help of converters.

  Inertia control, droop control and the deloading control have been used as frequency control schemes.

- AGC is introduced to have improved frequency output and consequently the power sharing of DFIG improves to meet the load demand and AGC helps in increasing the fault limit.

- Fault current limiter(FCL) or Series dynamic breaking resistor (SDBR) there is an improvement in the transient stability limit by keeping the frequency improved/upheld and power output same.

Chapter 2

Wind Turbine Technologies

2.1 Doubly-Fed Induction Generator

Keeping in mind the end goal to accomplish high effectiveness, present day WTGs embrace a variable-speed operation by the utilization of power converters. Either immediate AC-AC frequency converter, for example, cycloconverter is utilized or a voltage source converters (AC-DC-AC). One such WTGs which has turned out to be extremely prominent nowadays is a system fusing the doubly-nourished induction generator.

The DFIG appeared in Figure 2.3 comprises of a WRIG with the stator winding associated specifically to matrix and the rotor windings interfaced through a consecutive bidirectional (back-to-back) voltage source converter. The consecutive converter (back-to-back) changes over power at different frequencies (rotor frequency) to DC and after that back to fixed frequency (grid frequency). In a DFIG wind turbine, the decoupling of active and reactive power is accomplished using power electronic converters utilizing field oriented control (FOC).Wind Turbine in view of doubly fed induction generator (DFIGs) are generally adopted in morden wind control industry in light of its capacity of augmenting the energy catch during variable wind condition and controlling the active and reactive power for better grid reconciliation(integration).
In induction generator which is used in DFIG is :-
For the most part the estimation of slip is much lower than unity and thus, Pr(Rotor electrical power yield) is just a small amount of Ps(Stator electrical power output).Since Tm(Mechanical torque connected to rotor) is sure for power generation and since Ns(Synchronous speed) is positive and steady for a consistent frequency grid voltage, the indication of Pr is an element of the slip sign. Pr is positive for negative slip (speed more prominent than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed).For super-synchronous speed operation,Pr is transmitted to DC bus capacitor and tends to rise the DC voltage. For sub-synchronous speed operation,Pr is taken out from DC bus capacitor and

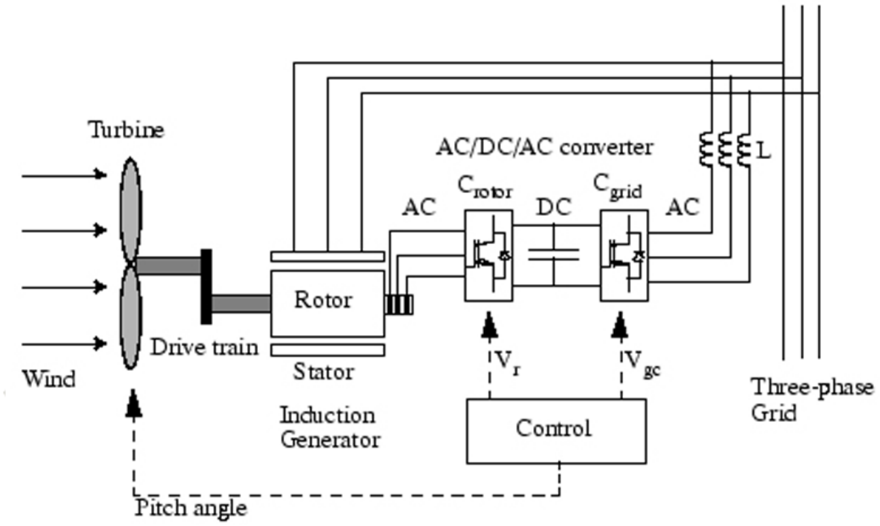


Figure 2.1: Doubly-Fed Induction Generator WTG

$$f_r = s * f_s \quad (1)$$

$$s = \frac{n_s - n_r}{n_s} \quad (2)$$

Where

f_s – stator field frequency
f_r – rotor field frequency
n_s – synchronous speed
n_r – rotor speed

Figure 2.2: Slip equation

tends to diminish the DC voltage. Cgrid is utilized to create or ingest the power Pgc (Cgrid electrical power yield) with a specific end goal to keep the DC voltage constant.In unfaltering state for a lossless AC/DC/AC converter Pgc is equivalent to Pr and the speed of the wind turbine is dictated by the power Pr assimilated or produced by rotor converter. The control is clarified underneath.

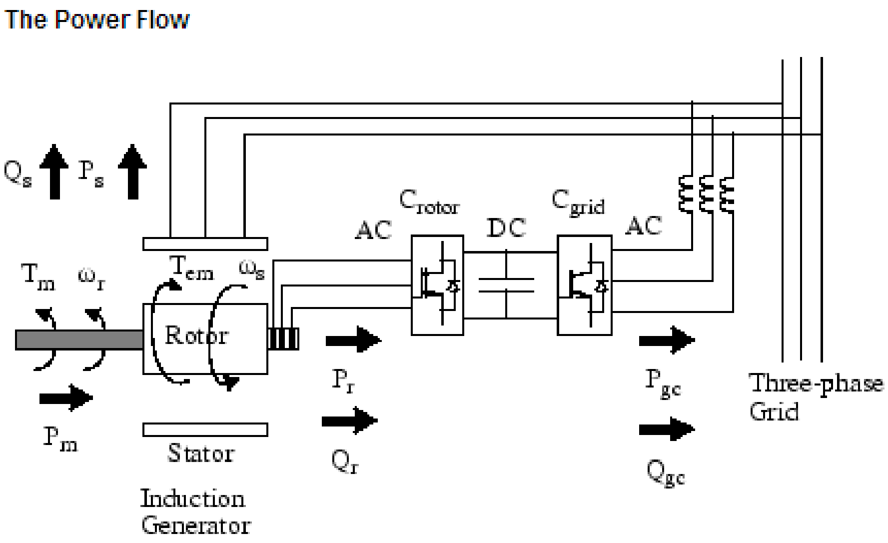


Figure 2.3: Power flow in Doubly-fed induction generator WTG

The phase sequence of AC voltage created by Crotor is positive for sub-synchronous speed and negative for super-synchronous speed.The frequency of this voltage is equivalent to the product of the system frequency and the total value of the slip. Crotor and Cgrid have the ability of producing or engrossing reactive power and could be utilized to control the reactive power or the voltage at the grid terminals.

Power Control:-

The power is controlled keeping in mind the end goal to take after a pre-characterized power-speed characteristics, named tracking characteristic. A case of such a trademark is represented in the Figure 2.6 , by the ABCD curve superimposed to the mechanical power attributes of the turbine acquired at various wind speeds. The genuine speed of the turbine Nr is measured and the relating mechanical power of the tracking characteristic is utilized as the reference power for the power control loop. The following track is characterized by four focuses: A, B, C and D. At point A in Figure 2.6 the reference power is zero. Between point A and point B the following track is a straight line, the speed of point B must be more prominent than the speed of point A. Between point B and point C the following track is the locus of max. power of turbine (maxima of the turbine control versus turbine speed curves). The following track is a straight line from point C and point D. The power at point D is one for each unit (1 pu) and the speed of the point D must be more prominent than the speed of point C. Past point D the reference power is a consistent equivalent to one for each unit (1 pu).

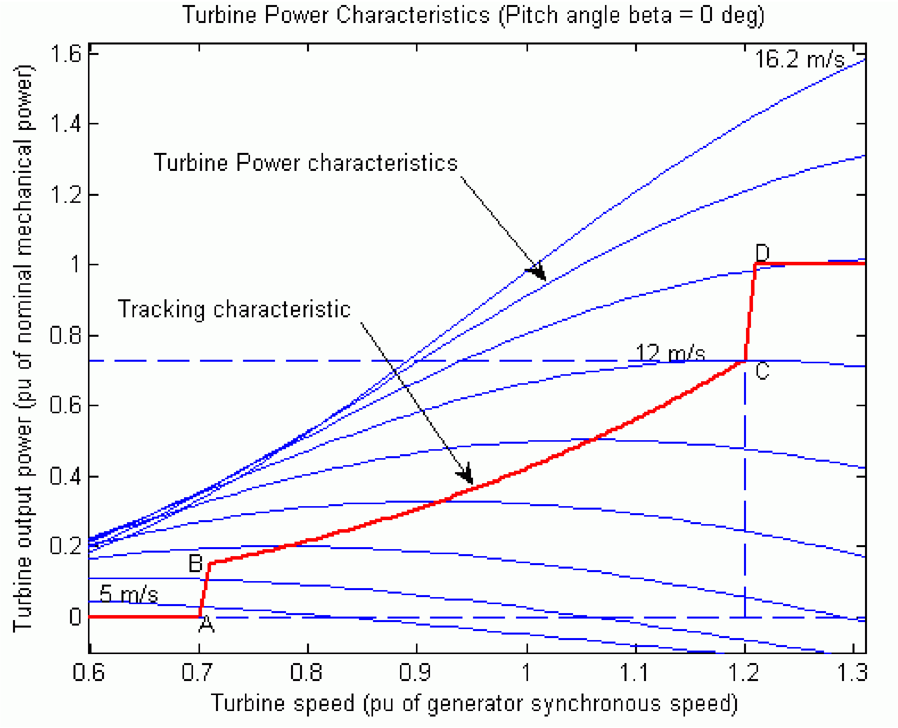


Figure 2.4: Turbine Power Characteristics

2.1.1 Rotor-Side Converter Control System:-

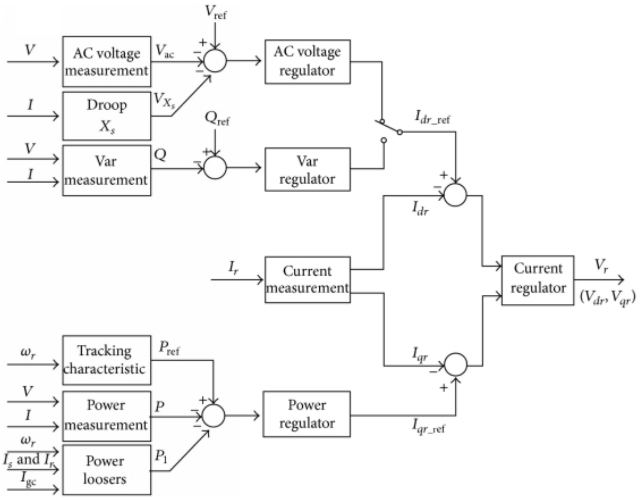


Figure 2.5: Rotor side converter control system

The voltage or the reactive power at grid terminals is controlled by the reactive current flowing in the converter rotor converter. The generic control loop is represented in the figure 2.7.
At the point when the wind turbine gets operate in voltage control mode, it displays the V-I characteristic as appeared in Figure 2.8.

2.1.2 Wind Turbine V-I Characteristic:-

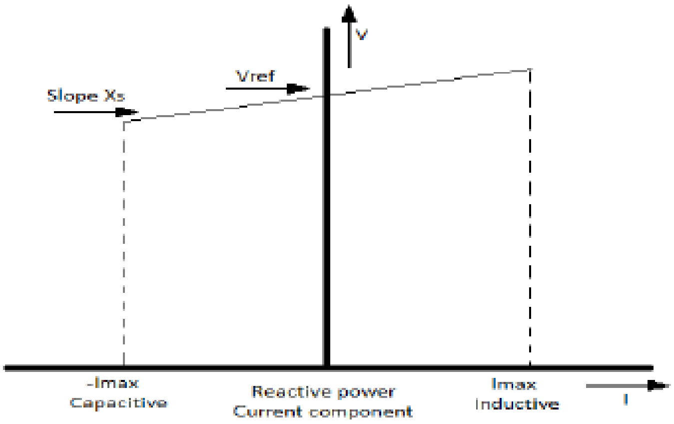


Figure 2.6: Wind turbine V-I characteristics

For whatever time the reactive current remains inside the max. current limits (-Imax , Imax).V-I attributes is portrayed by the accompanying condition:-

$$V = V_{ref} + IX_s$$

When the wind turbine is operated in VAR regulation mode the reactive power at grid terminals is kept consistent by a VAR controller.

2.1.3 Grid-Side Converter Control System:-

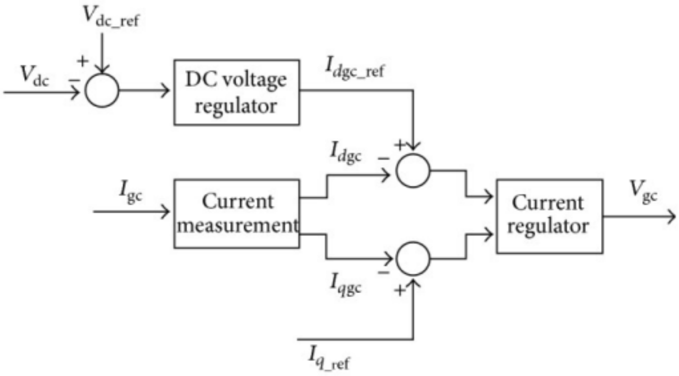


Figure 2.7: Grid-Side Converter Control System

2.1.4 Pitch Angle Control System:-

The pitch angle is kept consistent at zero degree until the speed achieves point D as appeared in Figure 2.10 speed of the following characteristic. Past point D the pitch angle is corresponding to the speed deviation from point D speed. The control system is outlined in the figure 2.10.

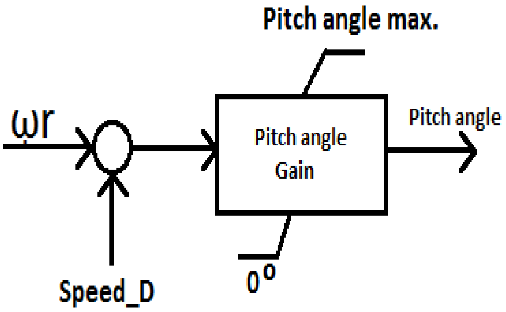


Figure 2.8: Pitch angle control system

The doubly-fed induction generator phasor model is the same as the wound rotor asynchronous machine with the accompanying two purposes of contrast:-

Only the positive-arrangement is considered, the negative-sequence has been wiped out.

An tripped input has been included. At the point when this information is high the induction generator is disengaged from the system and from Crotor.

Chapter 3

Literature Survey

3.0.1 Paper 1:- Participation of Doubly fed induction wind generators in system frequency regulation

[1]Rogerio G.de Almeida and J.A. Pecas Lopes ,**Participation of Doubly fed induction wind generators in system frequency regulation IEEE Aug 2007.**

The control technique characterized at the wind generator to supply primary frequency regulation ability exploits a curve of control of the static converters and pitch control, changing the rotor speed and the active power as per the deloaded ideal power extraction curve.

1. It is perceived that the nearness of an extensive wind control penetration (either as embedded generation or extensive wind parks) may prompt to a lessening of power system frequency regulation abilities.

2. Earlier because of increment in wind generation in the system prompts to diminish in the inertia of the overall system as the usage of synchronous machine lessens the inertial constant also decreases; so prior because of any unsettling fault or disturbance, the system gets influenced easily; however now a days because of increment in control activities or capacities of wind generators are permitting their participation in frequency control and subsequently giving an expansion in robustness of operation in such systems, enabling safe increment in wind power penetration.

3. DFIG can be utilized to contribute for primary frequency control . Two sorts of control can be adopted to give commitments to system frequency control:
   a) inertial control;
   b) primary frequency control

4. Inertia control can be given in a DFIWG through a supplementary inertia control loop, to reintroduce inertia reaction. The proposed strategy exploits the kinetic energy stored in the rotating masses of wind turbines, with the goal that the extra measure of force provided by the wind generator to the grid is corresponding to the system frequency.

5. A primary frequency control system has then been developed, with the end goal that the DFIWG can give a relative frequency reaction, as far as network infused active power, exploiting a pitch angle controller.

6. When a grid frequency excursions happens, an active power infusion happens through the underlying driving activity of the rotor-side electronic converter of the wind generator, trailed by the pitch control request to alter the mechanical power.

7. The pitch control is likewise in charge of constraining the mechanical power of the wind turbine during high wind speed.
Description of the developed control approach:-

The control scheme used to control the rotor-side Converter comprises of a d-q voltage controller in which both output active and reactive powers of the machine are controlled through Vqr and Vdr segments obtain from two separate arrangements of proportional basic (PI) controllers.

Through the rotor-side active power control loop, the wind turbine can be driven to work with max. power, once the reference active power input (Change in power) utilized as a part of the control system is obtain from a deloaded optimum power extraction curve. This reference power is likewise used to modify the rotor speed through the pitch control loop.

Adoption of a power reference that uses a deloaded control extraction curve, permits the increase of active power produced by the wind generator when frequency diminishes, as an result of a sudden load increment or loss of an extensive generation facility.

3.0.2 Paper 2:-Review on Frequency Control of Power Systems with Wind Power Penetration

[2]Yuan-zhang SUN, Zhao-sui ZHANG, Guo-jie LI, Member and Jin LIN **Review on Frequency Control of Power Systems with Wind Power Penetration'IEEE.**

The greater part of the publish control techniques we utilize can be characterized into 3 levels:-

1. Wind turbine level
2. Wind farm level
3. Power system level

1. Wind turbine level:- The wind turbine level control empowers wind turbines , especially the variable speed wind generators to give dynamic reaction and power reserve for primary frequency control by executing the :-
(A) Inertial (B) Droop (C) Deloading controller

2. Wind Farm level:- In this control disperses the central control command from the system to the local wind turbines.

The generation for the system is accomplished in the participation of central control (gets control instructions from system administrator or AGC and disperses it to the local control) and nearby control .

3. Power System level:- In this power system wind farms cordially with the traditional power plants for the secondary control to recover the frequency to the reference to the reference value speedier than for the no coordination case.

It is acquired by both frequency behavior got by coordination control between AGC controlled conventional thermal or coal power plants and the wind farms.
1. Wind turbine level:- For a frequency drop occasion :- three security lists:-

(A) Frequency change rate :- frequency change rate is dictated by inertia of entire system.

(B) Frequency Nadir:- Frequency nadir is dictated by the power aggravation (disturbance) ; the dynamic energy of the rotating masses , no. of generators subjected to primary control and the dynamic attributes of the generator , loads and controllers.

(C) Steady state frequency deviation:- it is dictated by the droop attributes of all benchmarks.

Inertial control supporters the frequency control in transient process.
The droop control simulates the comparative frequency droop attributes to that of synchronous generator.
The deloading control gives the power to the wind farm.

1. Inertial control:-
The essential purpose behind emulating the "hidden" inertia is to diminish the max. frequency change rate. Synchronous generators and fix speed wind turbines can naturally discharge the kinetic energy of the rotating mass for a sudden frequency change while variable speed wind turbines can't because of the decoupling operation.

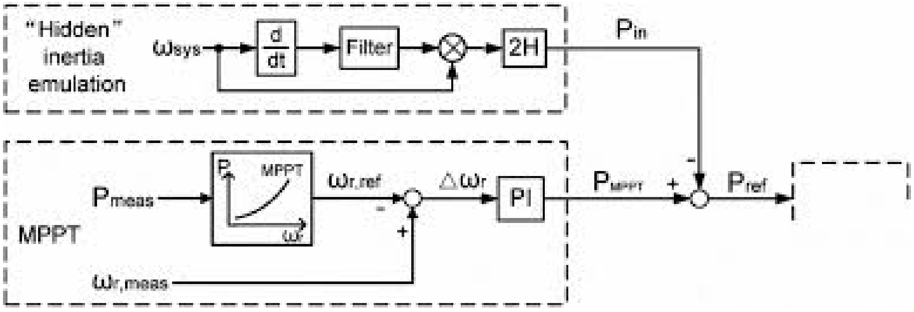


Figure 3.1: "Hidden" inertia emulation for variable speed wind turbines

$$H = Jw^2/2S \tag{3.1}$$

$$J = \frac{J_{tur}}{n^2} + J_{gen} \tag{3.2}$$

$$w_{r,ref} = w_r = \sqrt{w_{r0}^2 - 2\frac{P_{const}}{J}t} \tag{3.3}$$

The wind turbine can quick store or discharge a lot of kinetic energy in the rotating mass in view of the power electronic converter control, vast moment of inertia and wide rotational speed range.

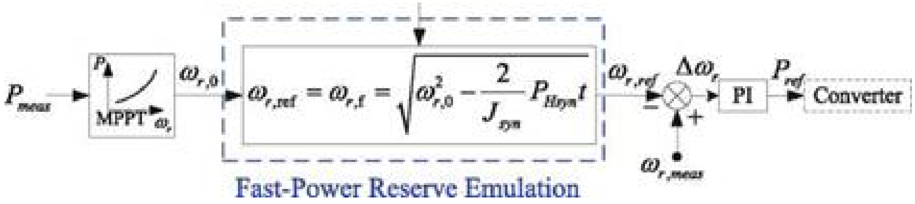


Figure 3.2: Fast power reserve emulation for variable speed wind turbines

2. Droop control:- The droop control is portrayed by the frequency droop attributes, to create a active power yield change which is corresponding to the frequency deviation . The frequency deviation is given by:

Change in frequency = F$_{(meas.)} - F_{(nom.)}$

Change in power = P$_1 - P_0$

3. Deloading Control:- Conventional wind turbines work on the MPPT Curve to extract the wind energy however much as could be expected. The deloading conceivable outcomes are acquired by pitching and overspeeding . The dynamic power can be changed by controlling the pitch point from Beta(min.) to a bigger esteem Beta(l) for a consistent wind speed Vwo and steady rotational speed.

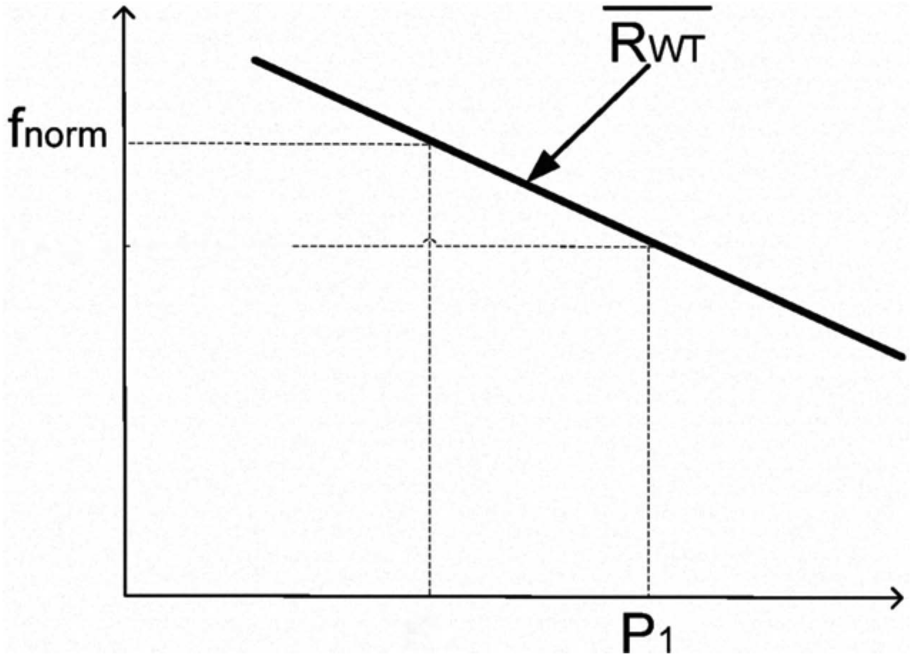


Figure 3.3: Frequency droop characteristics

3.0.3 Paper 3:-Renewable energy sources and frequency regulation: survey and new perspectives

[3] H. Bevrani1 A. Ghosh2 G. Ledwich2 1Department of Electrical and Computer Engineering, University of Kurdistan, Sanandaj, Kurdistan, Iran 2School of Engineering Systems, Queensland University of Technology, Brisbane, Australia **Renewable energy sources and frequency regulation: survey and new perspectives**

Integration of RESs into power system grids have impacts on optimum power stream , power quality ,voltage and frequency control , system financial aspects and load dispatch.Interconnection frequency deviation can bring about under/over frequency relaying and separate a few loads and generations. Under ominous conditions, this may bring about cascading failure and system collapse.
With the increasing pattern of interfacing high penetrations of wind energy transformation system to the transmission systems comes the test of upgrading the grid code for the association of high limit RESs. However the novel way of some RESs advancements ,,
A sudden diminishment in a vast RESs power creation , not appropriately estimated, may likewise prompt to over-burden issues in interconnection lines.

Regional over-burdening of transmission lines in ordinary operation and additionally

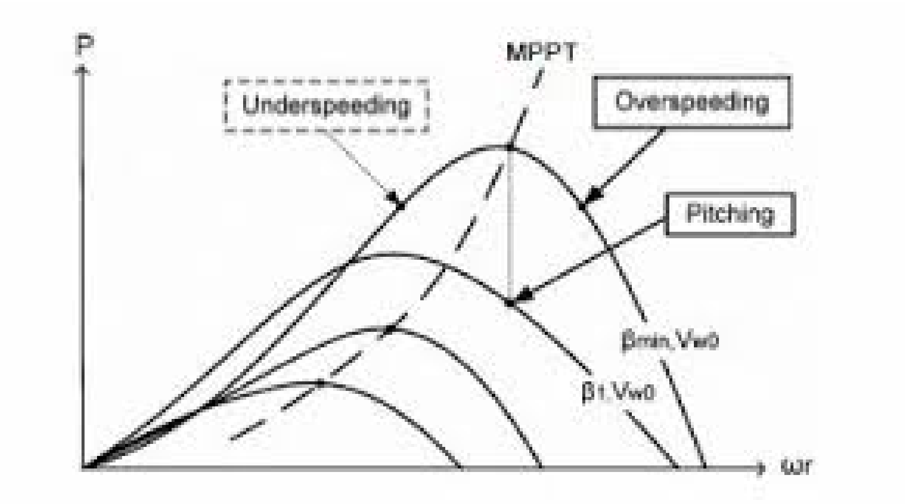


Figure 3.4: Deloading possibilities - overspeeding and pitching

in emergency conditions, decrease of accessible tieline limits because of expansive load flows, frequency execution, expanding requirement for adjust power and save limit, expanding power system misfortunes, expanding reactive power influence, and effect on system security and financial issues .
The new generation of variable-speed, substantial wind turbine generators with high moments of inertia from their long turbine blades can filter power fluctuations in the wind farms. A strategy is exhibited into let variable speed wind turbine emulate inertia and support primary frequency control.
The proposed coordinated control system incorporates two control levels (supervisory system and machine control system).For an expansive RESs penetration, the traditional LFC reserve might be inadequate to keep up frequency inside the limits for service quality.

3.0.4 Paper 4:-An Assessment of the Impact of Wind Generation on System Frequency Control

[4]Ronan Doherty, Member, IEEE, Alan Mullane, Gillian (Lalor) Nolan, Daniel J. Burke, Alexander Bryson, and Mark OMalley, Fellow, **An Assessment of the Impact of Wind Generation on System Frequency Control**IEEE

A secure power system ought to have the capacity to withstand the loss of the biggest online generator during normal working conditions and in this manner anticipate pointless load shedding or system collapse. In isolated system which as of now have a moderately little inertial base, these adjustments in generator attributes may posture difficulties to administrators attempting to control system frequency. While fixed speed wind turbines [squirrel-cage induction generators (SCIG)] make their

stored kinetic energy accessible to the system during frequency occasions (inertial reaction), variable speed wind turbines [doubly-fed induction generators (DFIG) and full converter designs] generally don't.
The review concentrates on two critical lists of element system frequency security, in particular the maximum rate of change of frequency (ROCOF) and the base estimation of frequency recorded, the nadir.
Wind turbines on the island are spinning and fit for giving kinetic energy to the power system during a frequency deviation occasion.
It can be seen from the outcomes that SCIG units have altogether less effect on ROCOF than DFIG units, as the SCIG machines do give some inertial reaction in the generation in which the ROCOF is measured.

The outcomes demonstrate that the probabilistic between reliance of key system variables, for example, wind yield, load demand, and traditional plant control creation is huge, and can only be appropriately capture with the broad time-arrangement testing approach as discussed in this paper.

The effect of DFIG wind penetration is to have a noticeable "spreading" impact on both the positive and negative ways. The adjustments in nadir are because of the varying dispatches with wind power, i.e., altered levels of system inertia and the diverse element reactions of the units demonstrating reserve.

It can be seen that while expanding pentration of DFIG wind generator limit adversly affect the frequency nadir, the inverse is valid for the SCIG wind penetration.It can likewise be seen that there is a huge effect as far as the improving probability of outrageous occasions on the system with expanding interconnection and DFIG wind capacity.

It is this measure of energy that they add to the system that will maily decides how they affect on the frequency nadir. Expanding wind penetration will adjust the merit order and the kind of unit giving primary reserve, what's more, along these lines, the combination of dynamic frequency reaction of the system's traditional plant.

As the reserve and inertial element reactions are separate elements which can be either opposing or complimentary for every individual system hourly dispatch working state, a separate situation was look after regularly.

System frequency control (i.e., ROCOF and nadir). The more outrageous max. ROCOF and frequency nadir occasions that may happen in a future framework with expanding measures of DFIG wind penetration and more noteworthy HVDC interconnection display huge difficulties for system operators.

The outcomes demonstrate that both increased DFIG wind penetration and HVDC limit detrimentally affect both most extreme ROCOF and nadir execution, while the impact of SCIG wind is tempered by its inertial reaction. Comparative outcomes would likely apply to other power systems with arrangements to build wind penetration levels.

3.0.5 Paper 5:- Investigating the Impacts of Wind Power Contribution on the Short-Term Frequency Performance

The DFIG wind turbines are not having that feature to take an participate in frequency reaction since the machines is decoupled from the grid by consecutive(ie. back-to-back) voltage based converters.So the absence of inertia and essential(primary) frequency reaction - like traditional generators-of this wind at high penetration of wind power, can bring about a bigger Rate of Change of Frequency (ROCOF) and unfaultering state deviation from nominal or scheduled frequency.

The mixing of inertia and PFR of wind power resources is essential at high wind control penetration in power system to capture electrical frequency changes before activating underfrequency load shedding relays.

For 2 MW DFIG, the measure of inertia of rotor is roughly six times that of its electrical generator. So the stored kinetic energy of the rotors of the variable scale wind homesteads is adequate to support the lessened inertia of power system because of high penetration of variable-speed wind turbines by including the additional control loops, delicate to the system frequency.

The stored kinetic energy in rotating masses of DFIG could be used to give brief frequency support like the droop reaction and inertial reaction of traditional generators by including additional proportional loop that is delicate to ROCOF and frequency change.

The measurements that utilized as a part of this review to investigation the frequency performance is:-
1-Value of nadir frequency (point C)
2-Value of settling frequency (half quart B)
3-Transition time from point A and B.
4-Transition time from guide C toward B.
5-The proportion of guide C toward point B as known as C_{br} metric.

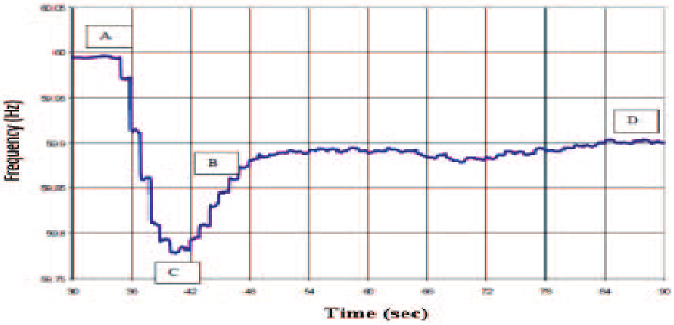


Figure 3.5: Description of frequency response matrics

Conventional generators and FSIG wind turbines can discharge their kinetic inertia in rotating masses to the control system for sudden mismatch of load and generation. While variable speed wind turbines can't support inertial reaction because of the decoupling between rotor speed and system frequency as a result of consecutive(Back to back) converter that utilized as a part of this kind of wind turbines.

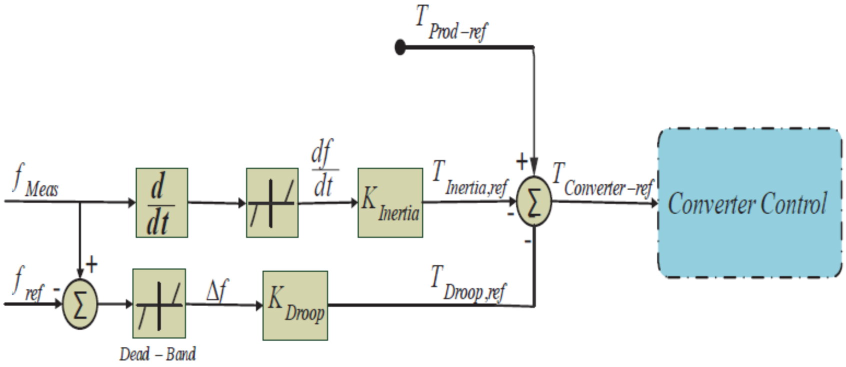


Figure 3.6: Proposed control strategy for DFIG wind turbines

Set point (Tprod.- Tref.) used as a contribution for converter controller by controlling the generator current. This control technique embraced the torque set point as an element of blend of ROCOF and matrix frequency changes ($\triangle f$).

The required energy is taken from stored kinetic energy of rotating masses of WECS. The measure of discharge dynamic kinetic energy for emulating inertial reaction relies on upon the legitimately tuned estimation of Kinertia that contrasted and using of pitch edge control support.

The imperative issue that must be noted is applying the limit of dead-band that considered for this control loop.If it requires too long to initiate the droop support of wind turbine after the grid event, the acquired support might be less. Then again, on the off chance that it enacts the support too soon, the support from prime mover and traditional representative reaction may not be begun and afterward the vast majority of the required incidentally dynamic power support to the system will originate from the wind turbine as it were. We have picked the limit of dead-band of droop control loops in a way the droop support from wind turbines will be begun at the same time with the reaction of routine governors and prime movers.

By giving inertia control support, the transition time to frequency nadir increased with addition in wind penetration levels. This is on the grounds that, the inertia(only) control reduces the declining of the ROCOF. On the other hand with slowing down of the rotor speed of wind turbines by injecting inertia support and reduction in the output active power of wind farms under the nominal output in recuperation period, the transition time to settling frequency (point B) is increased. By providing droop support (around 2 percent of evaluated wind farms power) the settling estimation of frequency (Point B) and frequency nadir increased and additionally wind penetration level increased. This is a direct result of addition available PFR from further introduced wind farms in higher wind penetration Levels.

In this work, the lower esteem for CBR shows more improvement in frequency performance, as a result of the huge change in nadir frequency contrasted with settling frequency change. As specified beforehand, this issue is because of decrease in measure of stored kinetic energy to support PFR in the wake of infusing the inertia support from wind farms to system frequency regulation.

3.0.6 Paper 6:- Investigating the Impacts of Wind Generation Participation in Interconnection Frequency Response

System inertia is the cumulative synchronous generation and load inertia that injects or extracts stored kinetic energy from the rotating mass of the machine and slows the speed of the frequency deviation.As of now, variable energy resources rarely provides PFR. As they are not synchronous to the grid, they additionally don't add to system inertia. Bring down system inertia as a consequence of increase renewable penetration will bring about increasing rates of progress of frequency instantly taking after an disturbance. Frequency reaction has been declining during the last several years. Physical purposes behind this incorporate excessive governor deadbands, generators that work in modes that don't offer PFR.

The estimation of H will diminish with every wind penetration level due diminished number of conferred synchronous units.

Wind turbine droop:-

A wind turbine must work in diminished mode to give enough reserve for PFR reaction during under-frequency conditions.During ordinary working conditions with close nominal system frequency, the control is set to give a predefined edge by producing less power than is accessible from the unit. The reserve accessible (or "headroom") is the accessible power diminished appeared as the reserve between the operational point and P_0.

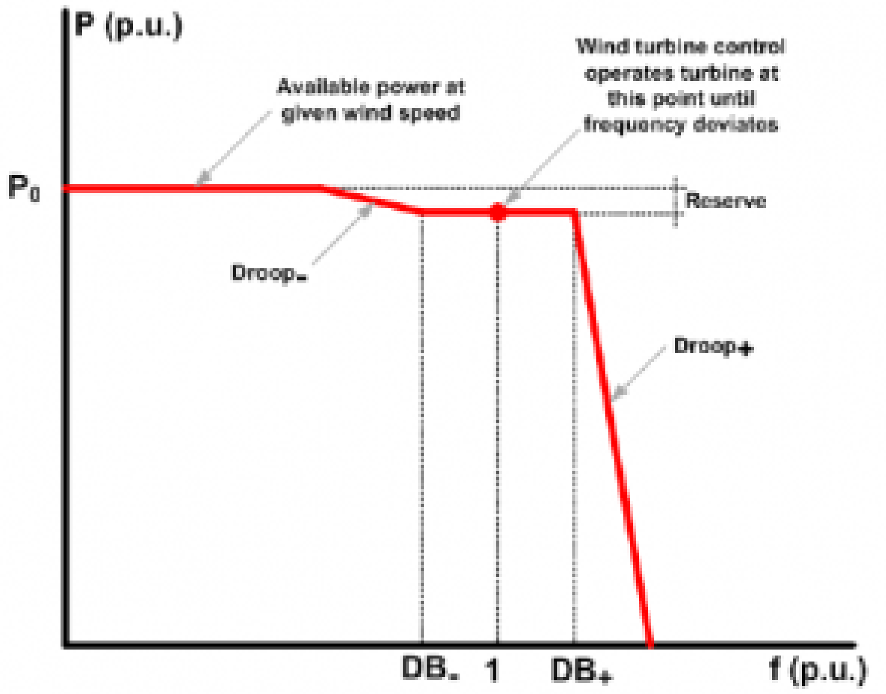


Figure 3.7: Wind power droop

Different penetration levels of wind:-

For lower penetration levels,the inertial control by wind indicates minor change in the frequency nadir contrasted with the other case.

At higher penetration levels, the frequency nadir was basically the same as that of the base case at 40 percent penetration and lower than the base case at 50 percent penetration. In the extreme high 80 percent penetration case, the frequency nadir was underneath the main UFLS at 59.5 Hz for both the base case and inertial case. Additionally, the nadir transition time increased with increasing entrance levels. This is on the grounds that inertial control alone diminishes just the underlying rate of decrease of the frequency, which comes to the detriment of backing off the wind rotors. On account of this stoppage, the wind turbines leave from their max. power point, subsequently making an insufficiency of active power (the time of underproduction in respect to the underlying prefault working point) and bringing about a slower frequency recuperation time.it takes more time to settle at a consistent state frequency (i.e., there is a more drawn out move to Point B).

Then again, enabling PFR makes some improvement in frequency reaction, bringing about better nadir and higher enduring state frequency.

The frequency nadir of the PFR-just case did not change altogether with penetration level. In any case, it was reliably higher than the base case nadir for all penetration cases. The recuperation of frequency was nearly as quick as in the base case, with some oscillatory conduct contingent upon penetration level. The greatest improvement was in the settling frequency level, which in the 80 percent case increased from 59.72 to 59.95.Control methodology brought about a generally higher frequency nadir with a slower recuperation time than that of the PFR case(only).

Impact of power controls on frequency nadir:-
Another conclusion appeared in fig. is that giving inertial control just does not give adequate changes contrasted with the base case. Indeed, at penetrations more noteworthy than 30 percent, the inertial control brought about lower frequency nadir contrasted with the base case.

The most astounding wind entrance level of 80 percent brought about a frequency nadir that was around 0.05 Hz beneath the UFLS setting.

In any case, it is possible that some outrageous conditions that were not imagined in the review may bring about unacceptable execution. In such manner, the propelled controls by wind power can give enhanced frequency reaction and unwavering quality of the power system.

3.0.7 Paper 7:- Impact of Wind Active Power Control Strategies on Frequency Response of an Interconnection

The wind turbine must work in curtailing mode to give enough reserve to a Droop reaction when the frequency drops.The control is set to give a predefined edge by producing less power than is accessible from the unit. For instance, consider a 1 MW wind turbine for which the maximum yield based on accessible wind speed is 950 kW or 0.95 of max. yield. With a specific end goal to acquire a 5 percent edge for droop reaction, the Pa esteem appeared in fig. ought to be set to the greatest accessible yield based on wind speed, or 0.95 and the Pbc esteem appeared in the curve is set to 0.90 for every unit. This yields a reserve edge (or "headroom") of 5 percent of aggregate limit (= 0.95-0.90).

Control gives an inertial reaction ability to wind turbines, emulating inertial reaction as gave by synchronous generators, for extensive under-frequency occasions. The reaction is given by briefly increasing the power yield of the wind turbines in the range of 5 to 10 percent of the rated turbine control.

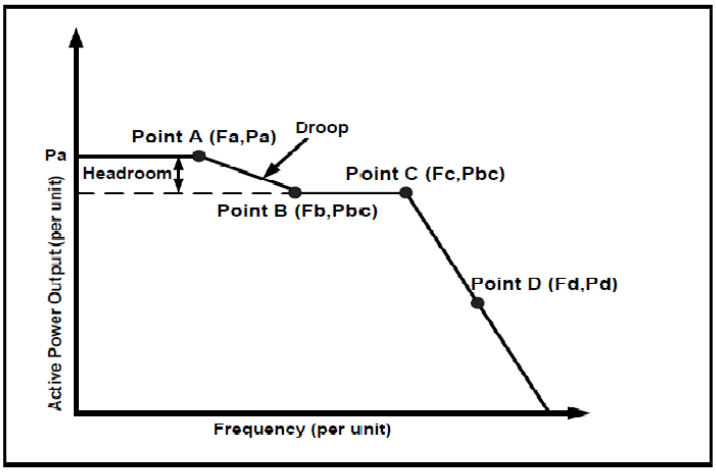


Figure 3.8: Droop-like Curve for Active Power Control

As the penetration gets increase , the frequency gets destabilize increasingly.

The frequency nadir for the case with wind giving neither inertial or essential frequency reaction was 59.69 Hz, while with droop control enable is 59.80 Hz i.e. a change of 0.11 Hz. It gives the idea that wind giving inertial reaction causes a slower recuperation time. This ease back reaction is because of the intrinsic attributes of the inertial control when WTGs are working at a lesser wind speed compared to the rated wind speed. As talked about before, the inertial reaction is given by briefly

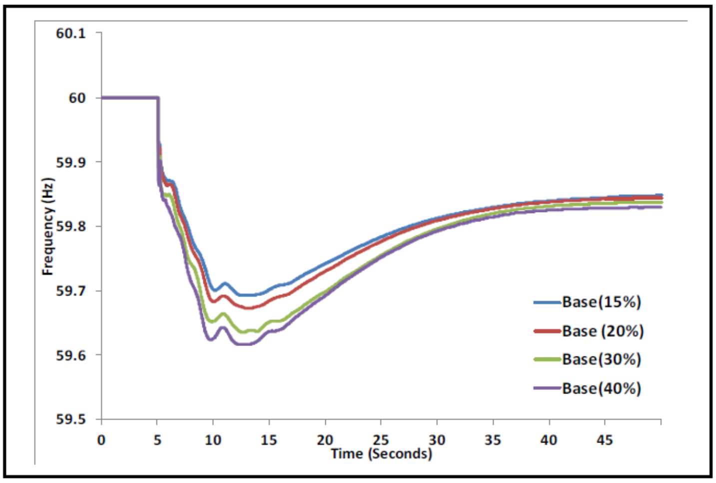
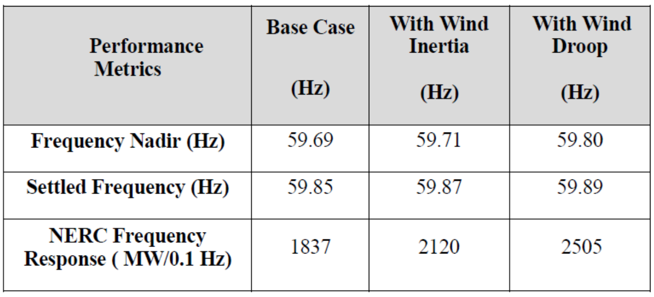


Figure 3.9: WECC Frequency Response for 15, 20, 30 and 40 percent Wind Level (No Wind Inertia and Droop)

increasing the power yield of the wind turbines in the range of 5 to 10 percent of the evaluated turbine control. This extra power is given by discharging kinetic energy of the wind rotor and relies on upon the wind rotor speed.

The WTGs providing inertial reaction characteristically should take back the energy it surrenders by slowing down to ensure that the turbine does not stall or loose efficiency. Therefore, after a time of increment generation, the WTG will encounter a time of under-production with respect to the underlying working point in the event that it is working underneath evaluated wind speed.



Performance Metrics	Base Case (Hz)	With Wind Inertia (Hz)	With Wind Droop (Hz)
Frequency Nadir (Hz)	59.69	59.71	59.80
Settled Frequency (Hz)	59.85	59.87	59.89
NERC Frequency Response (MW/0.1 Hz)	1837	2120	2505

Figure 3.10: Performance matrics for 15 percent wind level

The improvement in penetration nadir is more conspicuous at higher wind infiltration levels.

3.0.8 Paper 8:- Frequency support from doubly fed induction generator wind turbines

Synchronous generators give frequency support as inertial reaction, essential ie. Primary and secondary reaction, high-frequency reaction and spinning reserve and, obviously, voltage support through the control of responsive power.For a 2 MW DFIG wind turbine, the moment of inertia of the rotor is around six times that of its electrical generator. Along these lines the put away kinetic energy of the whole rotor is high and can be utilized to support the power system.

In a variable-speed wind turbine, the inertia reaction might be acquired by controlling the set-torque of the controller, and the gain of the inertial control loop decides the reaction that it can give.

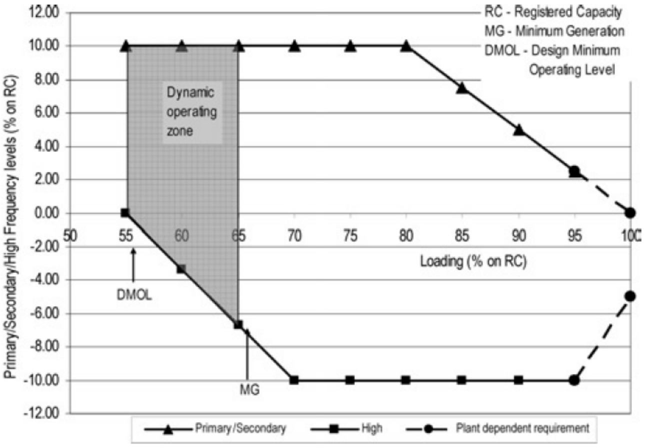


Figure 3.11: Minimum Frequency response required for a +0.5 or -0.5 Hz frequency change

The expression 'Minimum Generation' (MG) in Fig. is characterized as the base yield which a generating unit can produce under stable operating conditions. The term 'designed minimum operating level' (DMOL) is characterized as the yield underneath which a producing unit has no high-frequency reaction ability.

Each generation plant with an rated limit more noteworthy than or equivalent to 100 MW must be capable for providing essential reaction.

With respect to the rotational speed of the DFIG, power can be delivered to the grid through the stator, and the rotor, though the rotor can likewise absorb power. In the event that the DFIG keeps running at a sub-synchronous speed, the rotor absorbs power and a small amount of the stator power enters the rotor circuit. Interestingly, if the DFIG keeps running at supersynchronous speeds, the rotor produces power,

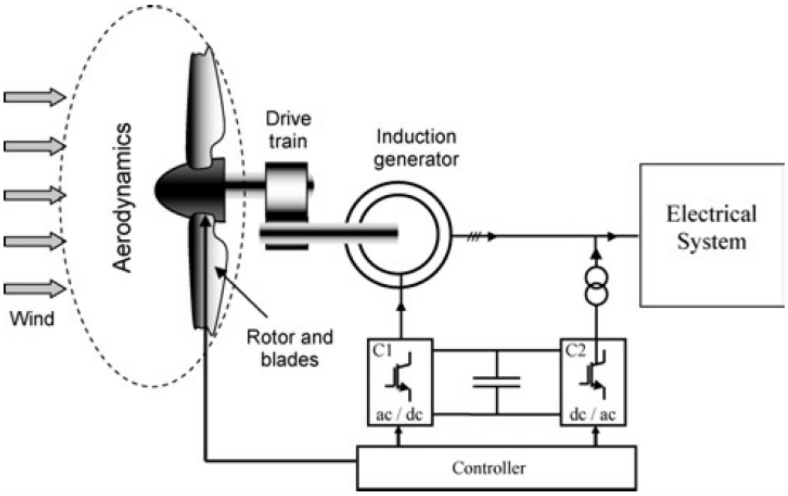


Figure 3.12: Doubly fed induction generator (DFIG) configuration

and the power is delivered to the grid by means of both the stator and rotor circuit. The speed of the DFIG is controlled in order to extract the greatest conceivable power from the wind.

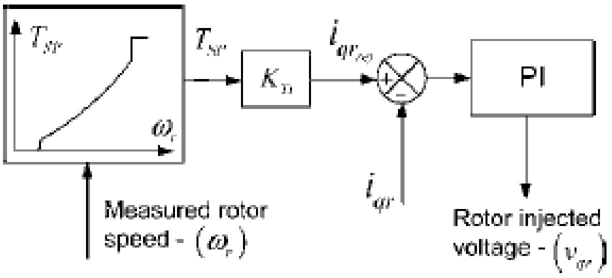


Figure 3.13: dq-based controller for optimum power extraction

A torque set point, Tsp, is decide by the rotor characteristics curve for max. power extraction. A reference rotor current iqrref is gotten from the electromagnetic torque condition and afterward contrasted and the measured current iqr.

The operation of this controller is with the end goal that lone the rotor speed is measured and that is utilized to control the wind turbine to work at a speed comparing to greatest power extraction.

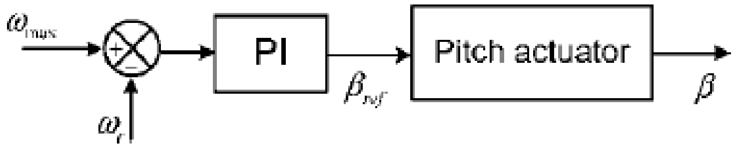


Figure 3.14: Pitch controller

The reference rotor speed is compared with the actual value and the error is regulated by a PI controller to obtain the reference pitch demand. Pitch demand is sent to the pitch actuator for pitching the wind turbine blades.

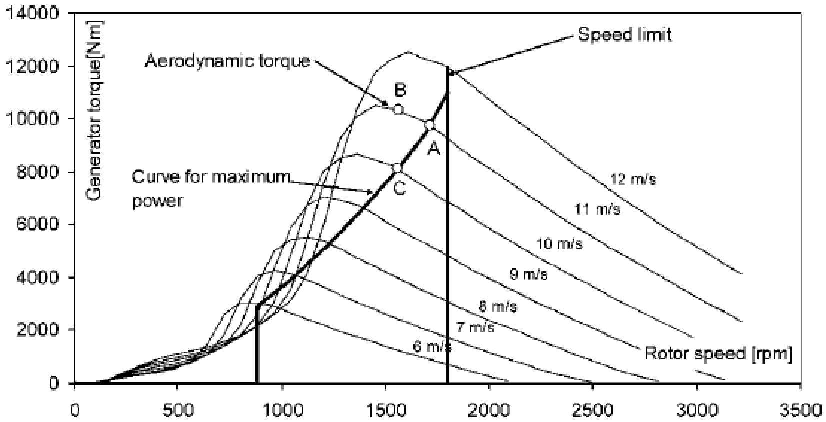


Figure 3.15: Torque Speed characteristic of a DFIG wind turbine

Machine Inertia:- (a)Attributable to the diminishment in frequency, the speed of the generator begins dropping. This can be considered as a deceleration torque, Tdec., following up on the rotating mass. The decelerating torque can be found by separating the kinetic energy discharged by the mass and after that by partitioning the proportionate power by the rotational speed v. Along these lines the decelerating torque is corresponding to dv/dt and hence to. df/dt.

(b)As the speed diminishes, the generator electromagnetic torque, Te, is diminished by the control system along the most extreme power extraction curve (from working point A towards C). In the meantime, the streamlined (aerodynamic) torque, Tm, begins increasing from working point A towards B (this is an slow activity contrasted with the adjustment in Te). The adjustment in Te and Tm brings about a accelerating torque, Tacc., which will go about as a restoring torque for the speed change.

With a specific end goal to restore the inertia reaction, Tdec. ought to be increased and Tacc. ought to be counteracted in this manner permitting the machine to work at a decreased speed.

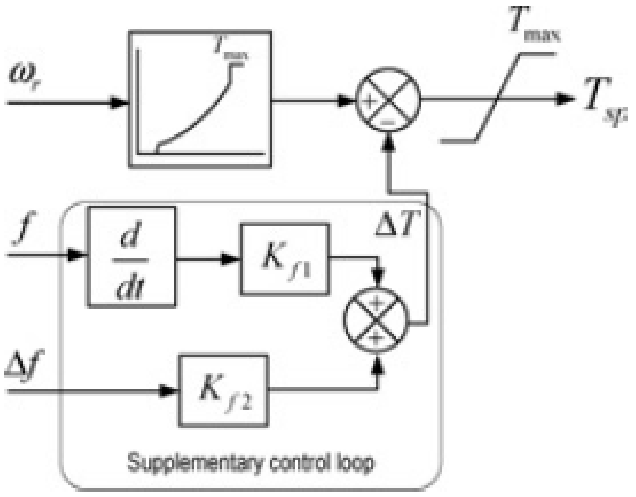


Figure 3.16: Modified DFIG controller for inertia response

3.1 PERFORMANCE WITH AUTOMATIC GENERATION CONTROL

It is known that AGC helps in keeping the power output level same with any of the changed condition of load or with small disturbance as well. AGC keep the power output level same by improving the following things to keep intact the output power level:- (a). Frequency Nadir (b). ROCOF (c). Inertial Power
And in this case it can be seen that the power output level can be achieved by increasing the power level of the Wind generator not by increasing the power output level of the synchronous generator. That indicates that the extra load is to be cater out by the Wind induction generator.

3.2 AGC action with faulty situation

:-

With AGC and the faulty condition in the system helps in giving the improvement in the P(inertial) power. Which hence shows that with the introduction in AGC in a faulty condition helps in giving the same frequency and power output by upbringing the inertial power.So AGC can be used for such improvement in such scenarios as well.

3.3 Crowbar System in Doubly Fed Induction Wind Generators

As demonstrated by new system code requirements, wind turbines must stay connected with the grid during unsettling disturbances. Moreover, they ought to similarly add to voltage support during and after system fault. The crowbar is essentially to maintain the continuation or separation of the DFIG from the system during faults. The consideration of the crowbar in the rotor circuits for a concise time enables a more prominent terminal voltage control.

Wind turbines the DFIG have the stator windings related clearly to the grid, making the rotor winding vulnerable against high currents initiates during grid faults. The rotor windings are related to the network by methods for a back to back converters ie. consecutive, which is particularly delicate to over-currents. The most surely understood way to deal with maintain a continuation from high activated incited currents in the rotor side converter (RSC) with the use of a crowbar system.

The addition of the rotor resistance modifies the electrical torque curve giving diverse potential results of the steady operation. The initiation of the crowbar system deduces that the DFIG transform into a squirrel-cage induction generator with an extra rotor resistance. With low wind power penetration the infusion of reactive current during grid faults are not required, subsequently, the crowbar system routinely works during the whole time allotment. Exactly when more restrictive methodologies are in need the operation of the crowbar system must be limited to start the infusion of reactive current by the RSC before the fault clearance. The voltage connected to the rotor windings by the control of the RSC in like manner changes the electromagnetic torque curves and increases the fundamental rotor speed (CR) in a more effective path than the constrained activity of the crowbar system.When the associated value is extended, the maximum. electromagnetic torque for generator operation (negative Te ie. electromagnetic torque) is furthermore augmented,consequently, the greatest torque for motor operation (positive Te ie. electromagnetic torque) is reduced.

The control technique embraced during fault for this analysis is depicted: the RSC is blocked and the crowbar system is enacted; the GSC controls the DC-connect voltage; the RSC is restarted and crowbar system is expelled after the fault elimination. This is the most widely recognized operation mode during flaws for nations with no reactive current infusion necessity.The terminal voltage increments before the elimination of the fault.The infusion of reactive power (positive) during the fault by the RSC adds to expand the terminal voltage.

The RSC should be over dimensioned in order to have a large current capacity.

3.4 PERFORMANCE WITH FAULT CURRENT LIMITER AND SERIES DYNAMIC BREAKING RESISTOR

SDBR approach shows a resistor bank related in course of action with the stator side or rotor side. It is used to assemble the stator voltage or decline the rotor current under grid voltage droops, independently, subsequently, relieving the destabilizing depression of electrical torque and power during fault.

The bypass switch arrangement is more affordable than that of Breaker operation. The bypass switch for the SDBR is in on-state under normal operation. With nearness of faults achieving an rising of rotor current or DC-connecting voltage to a predefined constrain, it is turn off deliberately. In this way, the stator currents are diverted to the course of action related resistors from the bypass switch. Right when the faults are cleared and the system is recovered, the bypass switch is turned on and the stator circuit restores to its conventional state. In the SDBR control system, the stator voltage is proportionate to the summation of the lattice side voltage and the voltage over the SDBR Vsdbr.

Consequently, the limit of the SDBR is to keep up the stator voltage at any required level under grid voltage sags.

It is a favorable circumstances to limit the rotor voltage started by the transient stator flux, henceforth, to confine the rotor current peaks. Furthermore, the rotor current limitation can in like manner diminishes the charging current to the DC-interface capacitor, consequently avoiding DC-associate overvoltage which could affects and damage the DFIG control converter. The SDBR can moreover improve the reactive power limit of the DFIG under system imperfect or faulty operation, and consequently, can in like manner upgrade the FRT capacity.

The point of confinement of the SDBR value is controlled by two criteria.The first is to maintain a control-ability of the RSC, suggesting that the rotor voltage in respect of the transient stator flux at the presence of grid faults should be limited to the maximum permissible input voltage of the RSC. The second one is that the summation of the network side voltage under faults and the voltage over the SDBR should not surpass the pre-determined value most outrageous stator voltage during the abnormal operation.

3.4.1 System Without SDBR

There is a voltage dip without SDBR during a faulty situation. It can be seen that the stator voltage drops to something around zero and the rotor current ranges to ideal around four times of its nominal value. Because of transients and high rotor current peaks, a broad voltage overshoot appears in the DC-interface, which may bring the failure of DC-connected capacitors.

3.4.2 System With SDBR

It can be seen that the stator voltage is expanded with the SDBR value, which infers an improved capacity to keep away from the loss of control of RSC and to limit the rotor current. Therefore, the rotor current is diminished with the increment of the SDBR value. It should be seen that the RSC is for the most part made with a rating of 2-3 times of the rated rotor current in DFIG systems.

It can be seen that the reactive power limit of the wind induction generator is improved with the improved in the estimation of SDBR value.

During operation, the semiconductor switch is on and the dc current is made to flow through the dc reactor to the IGBT switch.Additionally, the dc current (idc) is continually compared and e reference current(iref). If there should be an occurrence of a fault, idc turns out to be more prominent than the reference current (iref). The control circuits distinguish this and open the IGBT switch. In the wake of opening the IGBT switch, the high impedance of shunt way (Rsh) is connected with the fault,restricting the fault current rapidly.

Chapter 4

Simulation and Result

4.1 Conventional system connected with DFIG

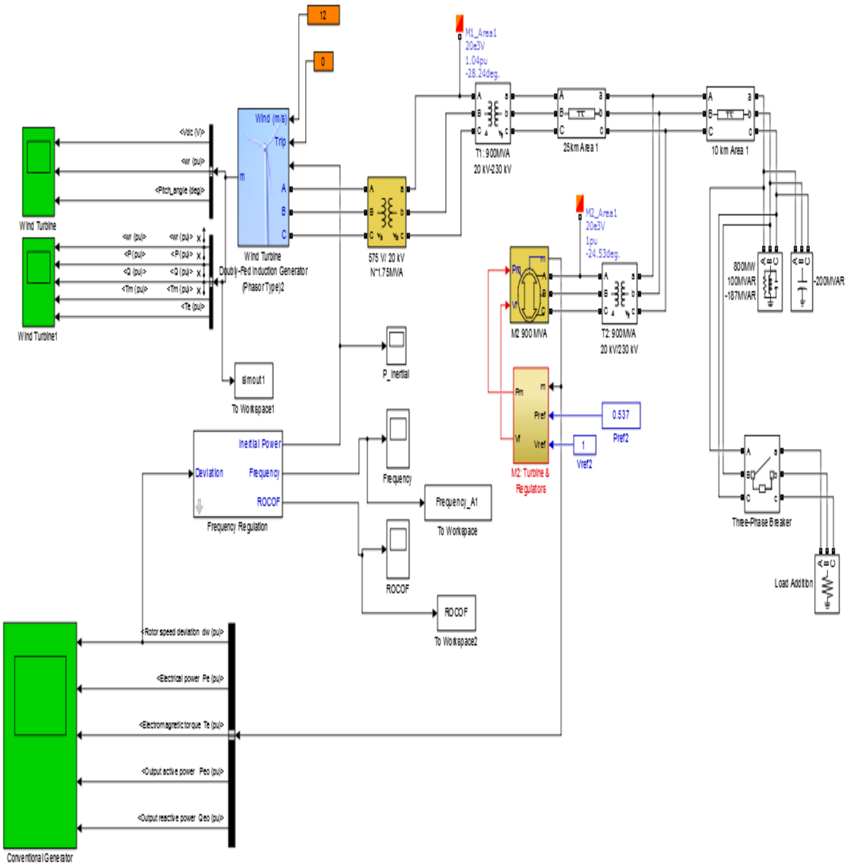


Figure 4.1: Conventional system connected with DFIG

4.2 Analysing the frequency by adding AGC

4.2.1 Waveforms without AGC control (Keeping penetration level as 30 percent)

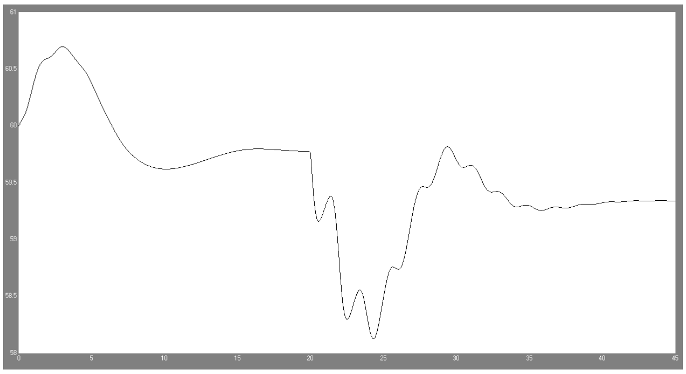


Figure 4.2: Frequency without AGC

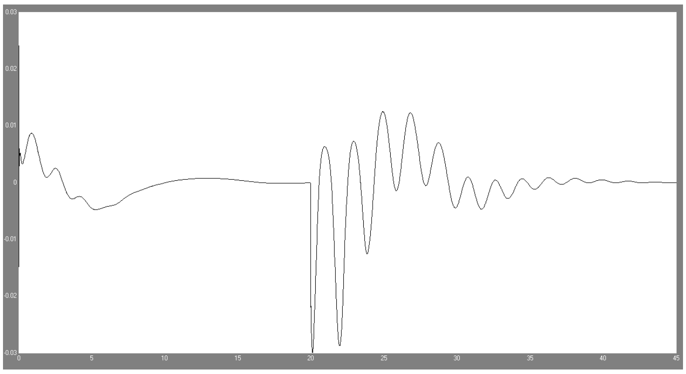


Figure 4.3: ROCOF without AGC

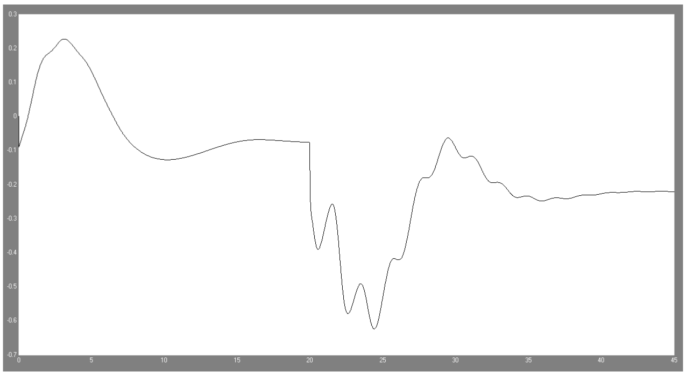


Figure 4.4: Inertial Power without AGC

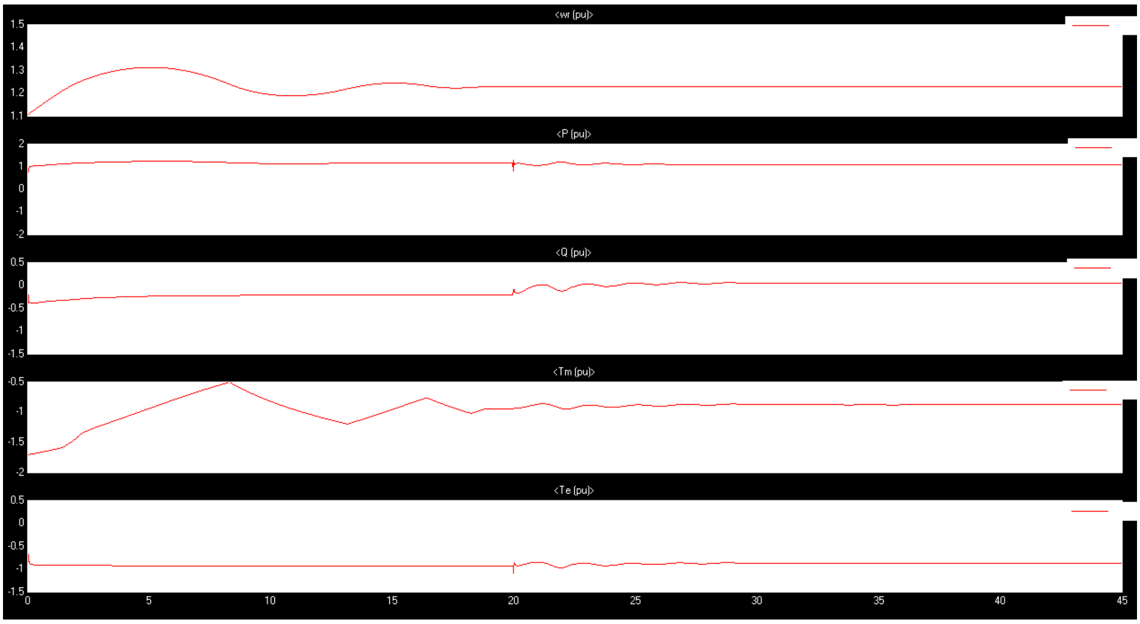


Figure 4.5: Wind turbine generated powers, speed and torques

4.2.2 Waveforms with AGC control (Keeping penetration level as 30 percent)

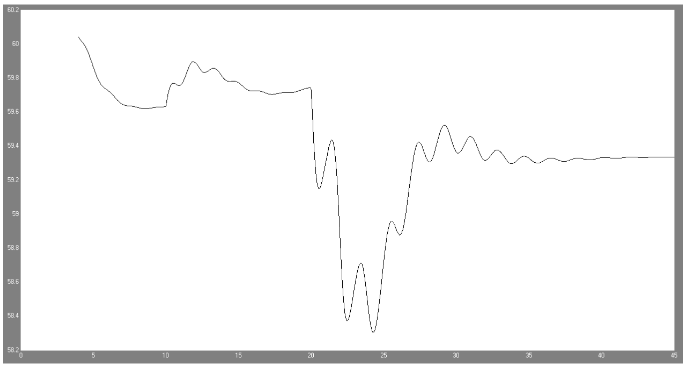


Figure 4.6: Frequency with AGC

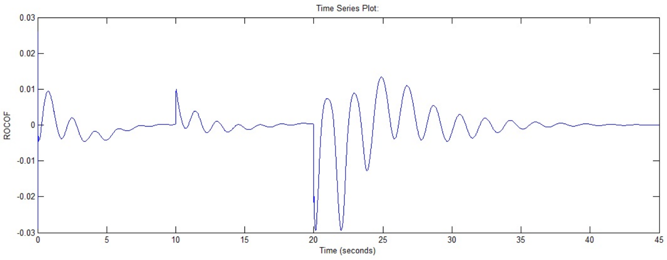


Figure 4.7: ROCOF with AGC

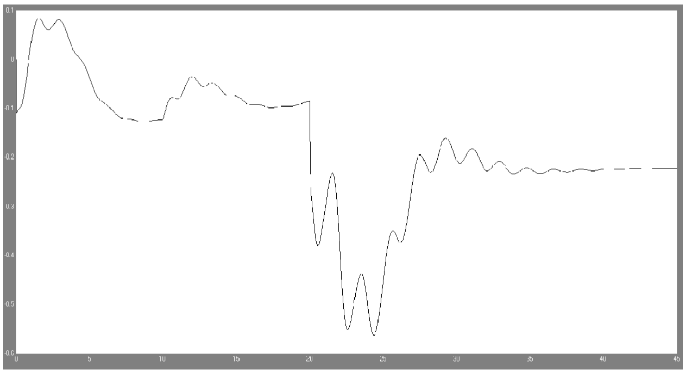


Figure 4.8: Inertial power with AGC

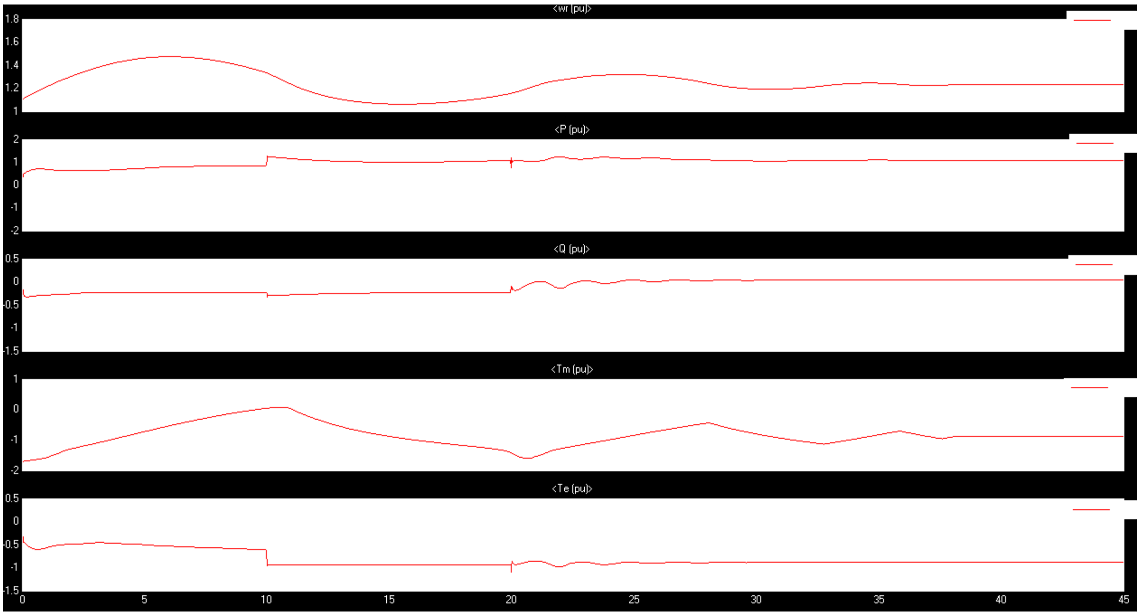


Figure 4.9: Wind turbine generated powers, speed and torques

4.3 Pinertial effects with fault condition by incorporating AGC

4.3.1 Pinertial effect without AGC in a faulty state

without AGC.png

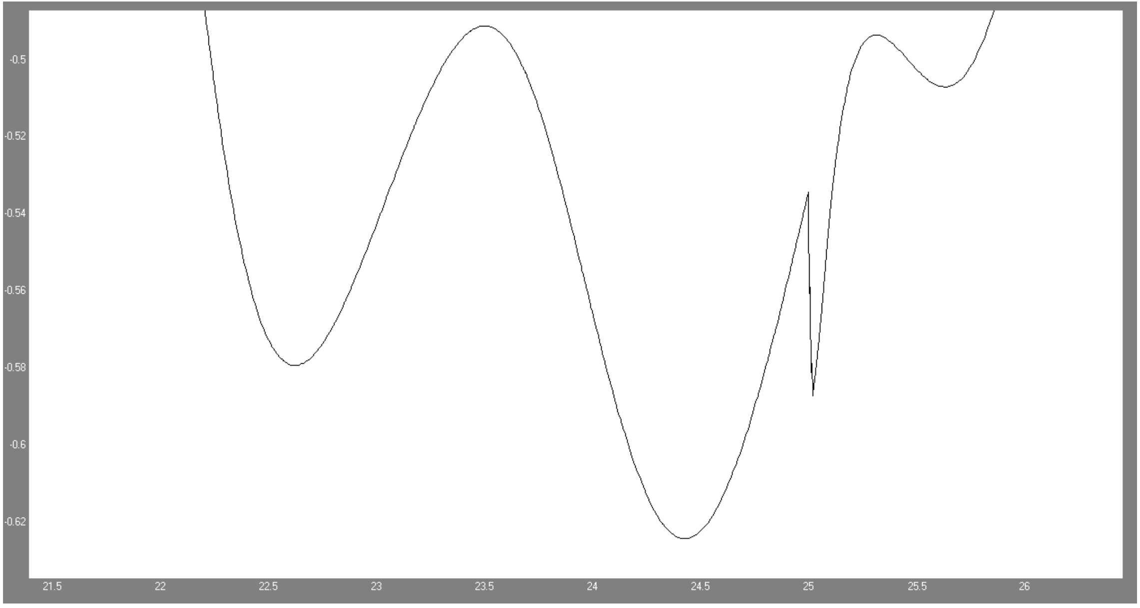


Figure 4.10: Pinertial Without AGC in a Faulty Condition

with AGC.png

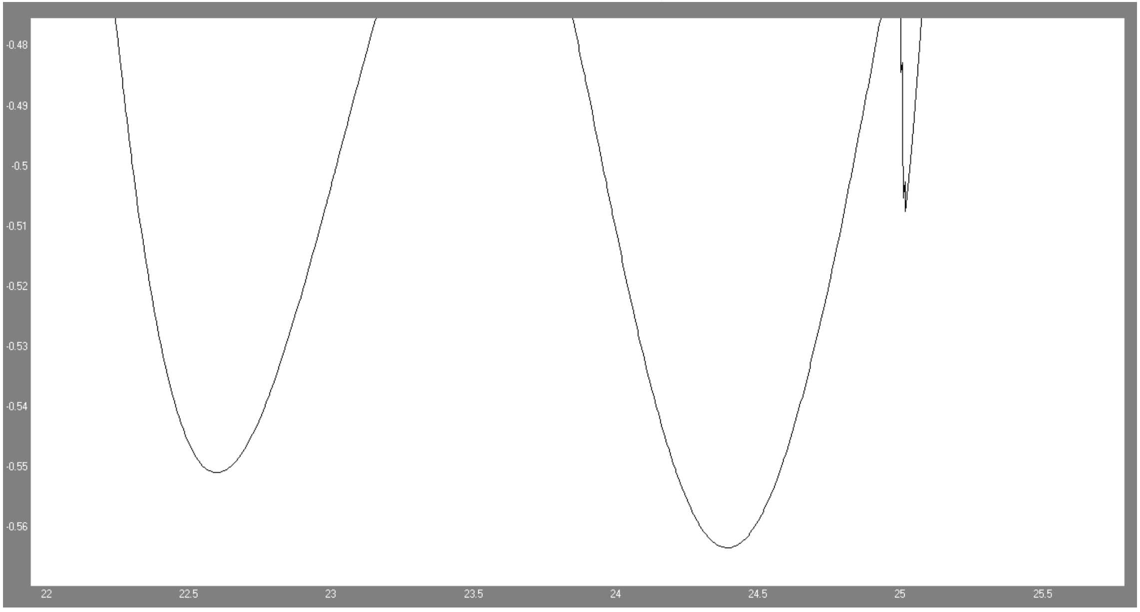


Figure 4.11: Pin with AGC in a Faulty Condition

4.4 Effect of including the FCL or SDBR

4.4.1 Without FCL/SDBR

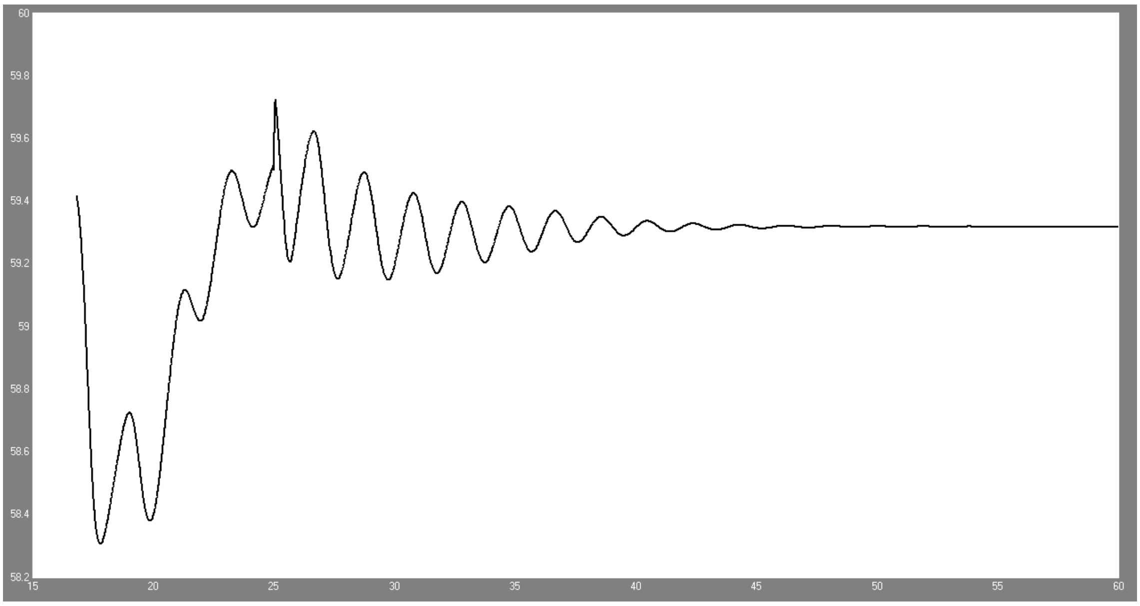


Figure 4.12: Frequency response Without FCL

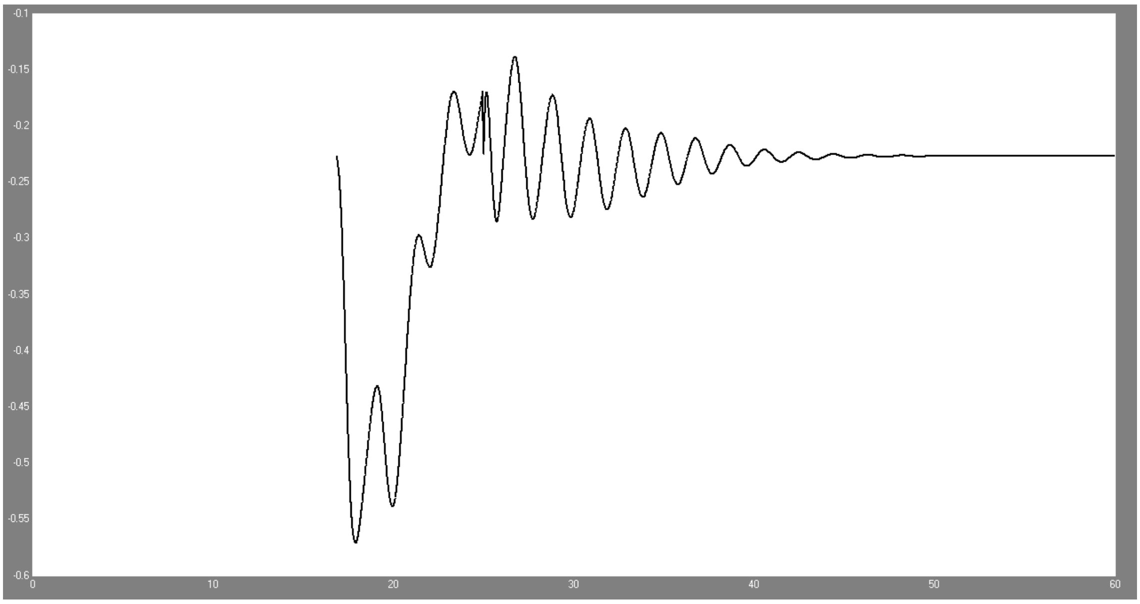


Figure 4.13: Pinertial response Without FCL

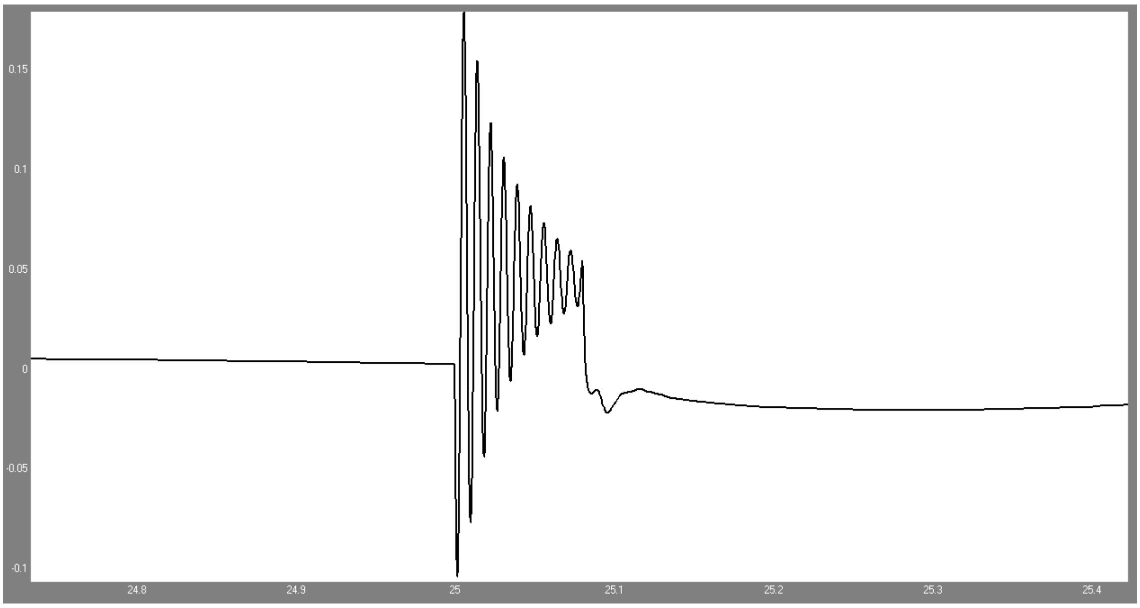


Figure 4.14: ROCOF Without FCL

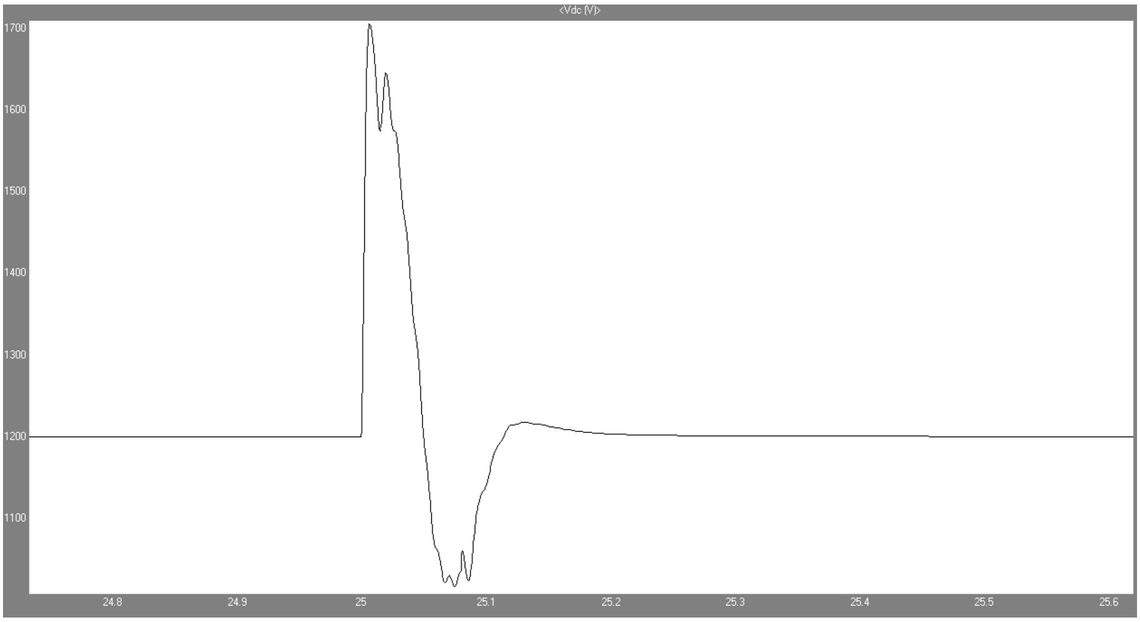


Figure 4.15: Vdc response Without FCL

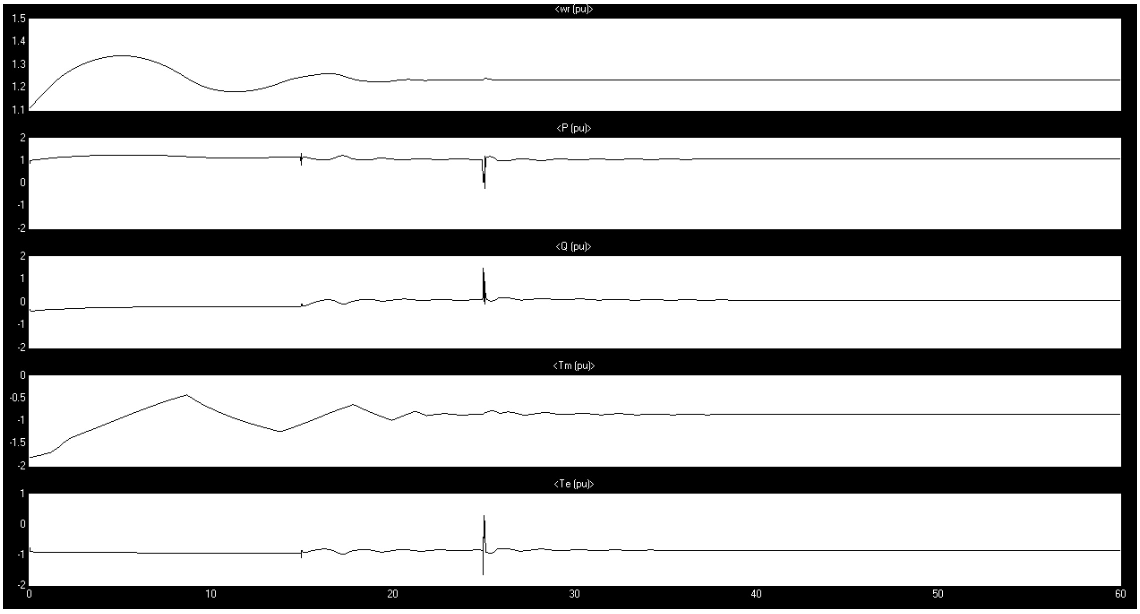


Figure 4.16: Wind turbine response Without FCL

4.4.2 With FCL/SDBR

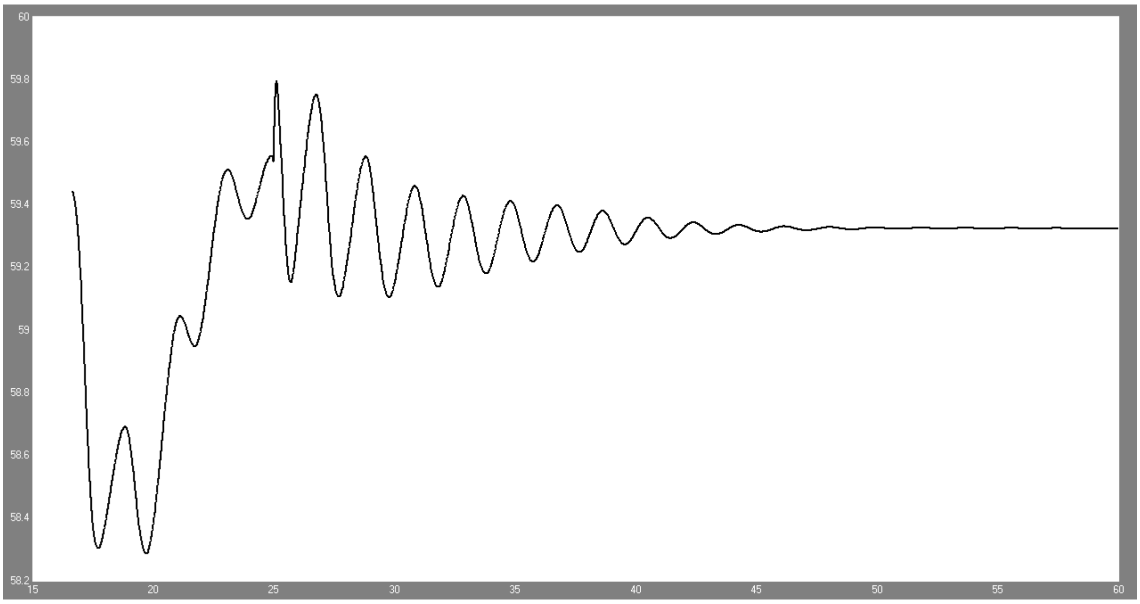


Figure 4.17: Frequency Response with FCL

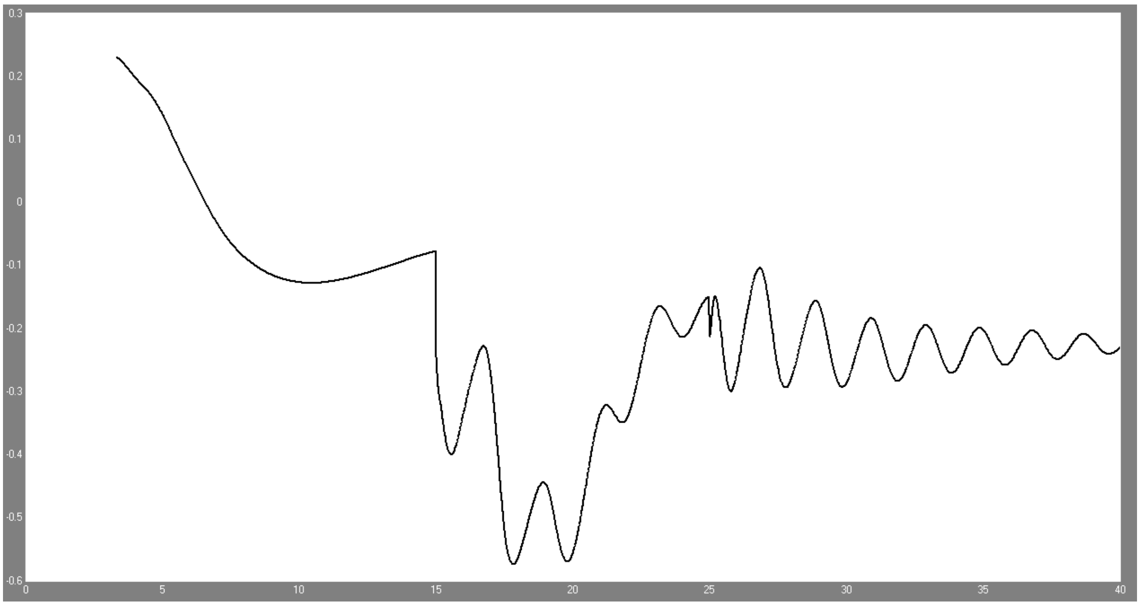


Figure 4.18: Pinertia Response with FCL

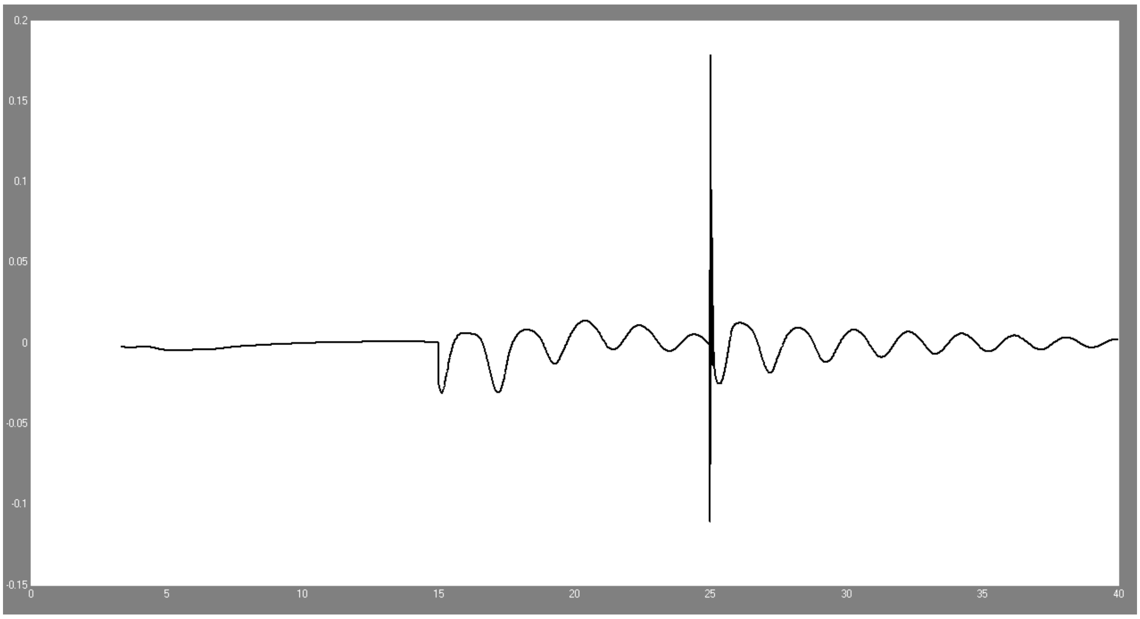


Figure 4.19: ROCOF With FCL

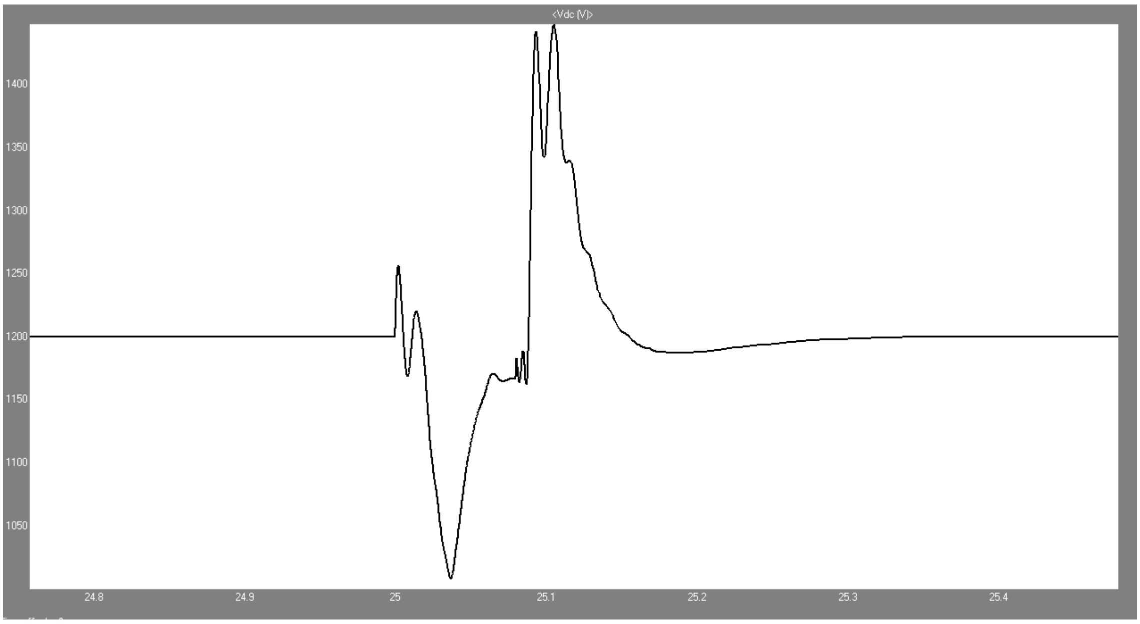


Figure 4.20: Vdc With FCL

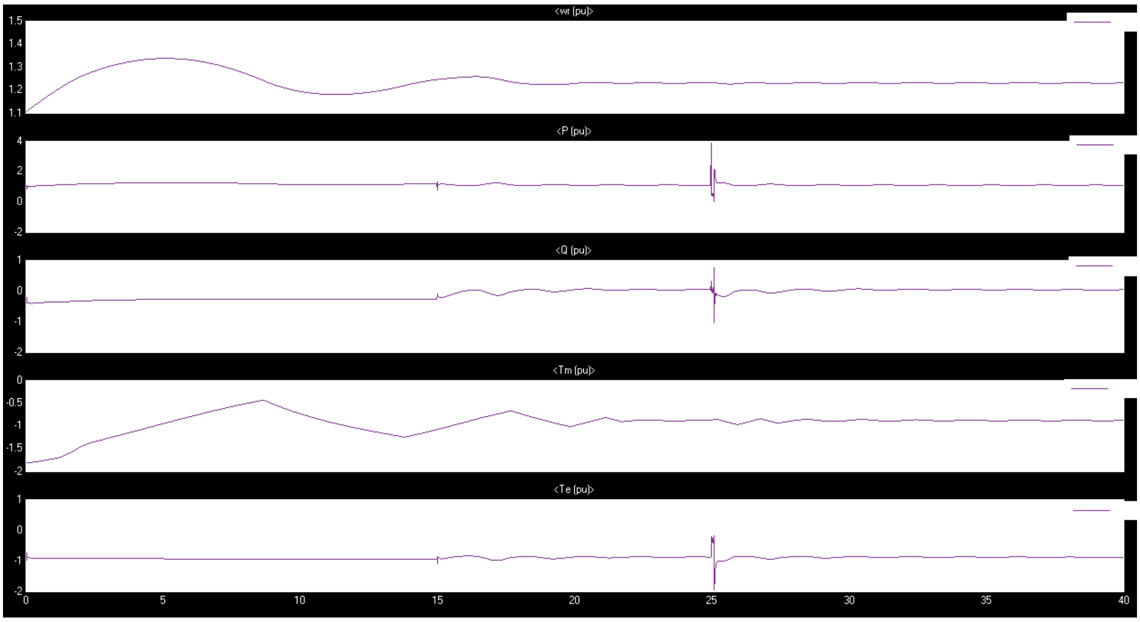


Figure 4.21: Wind turbine response With FCL

Chapter 5

Conclusion and Future work

5.1 Conclusion

The general result of expanding wind penetration levels for the transient frequency reaction of the power system rely on upon system dispatch . One might say however that a future power system with a noteworthy level of DFIG wind penetration will presents significant frequency control difficulties to system administrators.

The wind turbine level control supports the primary frequency control. The inertial, droop and deloading controllers are installed on the power electronic converters of variable speed wind turbines or pitch controllers in DFIG type of wind turbines. The inertial control emulates the "hidden" inertia or fast power reserve to slow down the frequency change rate in the transient process (ROCOF).

The frequency nadir can be increased by both inertial control and droop control. The deloading possibilities are achieved by two approaches of overspeeding and pitching. The deloading control stores the deloaded power as reserves for the wind farm to reduce the steady state frequency deviation.

The availability of wind generators working with such a frequency control may add to build framework vigor, diminishing frequency trips taking after system unsettling influences ie. disturbance. Such a control approach permits expanding wind control penetration in a existing system.

The nadir in frequency taking after the disturbance of load can be enhanced by machine of the variable-speed wind turbines generators with inertia and PFR control support.The consistently expanding of wind power penetration, influence the customary (ie. conventional) power framework frequency regulations in two ways: first the diminishment in absolute framework system inertia, on account of penetration of Asynchronous power changes and, second, the lack of commitment of this power transformations in frequency regulation inertial and PFR controls for wind power brought a recurrence nadir that was continually expanding with infiltration level and had the best nadir execution at any wind entrance level than other control techniques. In any case, when wind power generators work at above evaluated rated wind speed to give synthetic inertia, they will give better frequency performance that leads to quick frequency recovery.

With the use of AGC the reference power can be increased which therefore increases the power output from the wind turbine system and consequently the frequency nadir, ROCOF and the inertial power can be improved.

5.2 Future Work

1. In future, contribution of wind penetration in frequency control during loss of generation is to be investigated.

2. Effects of Different types of wind generators on such frequency control strategies is to be discussed.

3. Determination of the 'Critical system inertia' w.r.t any Country's grid code ie. the amount of maximum penetration which can be allowed is to be calculated.

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