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Enrichment of Power Quality using PID-Intelligence Controller with D-STATCOM in Wind Energy conversion system

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Abstract:
The wind is a renewable resource which is also green and pollution free and as fossil fuels are in exhausting condition, wind becomes an alternate source for generation of electricity. Renewable energy plays a major role for generation of electricity to overcome the scarcity of fossil. By harnessing wind in wind turbine, electrical power is produced. The generated power from wind gets fluctuated, as the motion of air in atmosphere fluctuates frequently. Thus the power quality of both consumer and grid network etc affected by the wind power insertion with grid. Voltage dip, swell, harmonic, reactive power and frequency variation are the common power quality issues in grid network. At Point of Common Coupling, Wind turbine incorporated with non linear load. Various issues are induced by frequent varying load. By FACTS devices, severity and consequences of this issue gets eliminated. In this paper, to overcome these issues, D-STATCOM based devices connected at point of common coupling (PCC) is preferred. To enhance the performance of the entire grid network, Conventional PID controller with D-STATCOM is used. To Custom device for injecting or absorbing reactive power from grid, PID Controller provides better support. It provides better compensation but the response has time delay. In proposed method, Artificial Neural Network techniques implemented with conventional PID controller to develop the performance of the system. The function of the controller is made faster than conventional by computing technique based controller. By MATLAB simulation tool, the performance can be analyzed.

Keywords- Power quality, PID-ANN, Custom device, wind energy, harmonics, Reactive power, D-STATCOM

INTRODUCTION

Nowadays many non-renewable sources, (Ex: Coal Fired) are used to produce the power. In few years these resources will get vanished. In such case, renewable sources are going to play a major role as an alternate. Ex: Wind, Solar, Bio gas, Geothermal etc. Among all renewable sources, wind is the only one source that produces abundant amount of electricity which can reduce the power crisis. The wind is harnessed by wind turbine blades through which electrical energy is generated. Due to shape of the earth and solar radiation in nature, the wind flow is always irregular. Generated power gets varied by Variable speed of wind. The generated power is injected in to the grid directly, due to the lack of electricity storage. Also at Point of Common Coupling, fluctuation in wind produces variation ingenerated power. Effect is inducement of different power quality issues. Considerable quantity of active power is produced by the power developed in wind turbine at fluctuating wind speed [1].Flicker effect at PCC, due to the voltage fluctuation. Wind turbine flicker effect is estimated as a major consequence while integrating. By active compensative devices such as SVC, D-STATCOM, UPQC, voltage variation is mitigated. Excellent support for stabilization of voltage can be provided by SVC based custom device, but in compensation of reactive power its performance is poor. Compared to other custom devices, UPQC performs in better way yet it is expensive. However, D-STATCOM can perform the best against various power quality issues such as voltage fluctuation, reactive power compensation elimination of harmonics and frequency maintenance and executes faster response and dynamic voltage control than SVC [2] [3]. Rather than power, power quality represents quality of voltage. It refers to maintaining sinusoidal voltage and current without losing magnitude and frequency. By implementing computing technique with conventional controller, responses of the compensating devices are enhanced. Compensation time is decreased by the End solution of implementing computing technique. In [4] to diminish the voltage fluctuation, the author employs STATCOM. In [5] the author narrates the mitigation of power quality using STATCOM with battery energy storage system.

Power fluctuation can be mitigated and reactive power absorption can be decreased by STATCOM with Battery Energy Storage System (BESS).For the improvement of performance of wind during various power quality issues, super conducting magnetic energy storage can be used which is described in [6]. In this without any fluctuation, the voltage and frequency are maintained constantly. At point of common coupling to enhance the response of the compensator D-STATCOM with PID-ANN controller is implemented in this proposed method. It is used to maintain the electrical parameters within acceptable limit. It leads to fast response

POWER QULAITY IMPROVEMENT

Power quality Standard, Issues and consequences

IEC Guidelines:

For power quality measurement of wind turbine, International standards are developed by working group of International Electro technical Commission. For determining the characteristics of wind turbine according to power quality, IEC standard 61400-21 describes the standard guidelines and procedure. Standard norms are.

a. IEC61400-21– Wind turbine generating system, Part-21 the power quality characteristics of grid connected wind turbine measurements and assessment.
b. IEC61400-13 –For determining the power behavior, Wind turbine measuring procedure.
c. IEC61400-3-7 –Assessment of fluctuating load emission limits.
d. IEC61400-12 –Wind turbine performance. For the utility assessment regarding a grid connection, the data sheet with electrical characteristics of wind turbine provides the base.

Voltage Variation:

Voltage variation is created by Generator torque and change in wind velocity. With variation in real and reactive power this voltage variation is directly related. The common voltage issues are:

- Short interruption
- Long duration voltage variation
- Voltage swell
- Voltage sag.

The main source for flicker effect is the frequent variation in wind and load. To measure flicker effect directly the flicker meter is used. Voltage fluctuation depends on grid strength, network impedance, and phase angle and power factor of wind turbine.

Harmonics:

Power electronic converters are used to create Harmonics extremely. At suitable level, voltage and current depends on harmonics should be maintained. The harmonic current allows only limited input as per IEC 61400-36 guidelines to maintain harmonic voltage within a limit.

Wind turbine location:

Various power quality issues are influenced by wind energy generating system connected with grid network. The network structure is depended by both the connection point and the operation of wind turbine.

Grid co-ordination rule

In United States, for adoption of grid code, American Wind Energy Association (AWEA) had taken an effort. Distribution stage is mainly focused by the grid code. The United States wind energy developed its own grid code for stable operation of grid. At distribution network, IEC61400 – 21demonstrates the rule for grid operation of wind generating system. For references, the grid quality characteristics and limits are given [3]

Voltage Rise:

The main factor for voltage rise at point of common coupling is the change in turbine maximum apparent power (Smax). Grid impedance are denoted as R and X and its phase angle is represented by the equation given below

$$\Delta u = S_{max}(R\cos\emptyset\ - X\sin\emptyset)/U^2$$

Δu - Voltage rise
S_{max} - Maximum apparent power
Φ - Phase difference
U - Nominal grid voltage less than the voltage rise is limited 2%

Voltage Dip:

During the starting of wind turbine which results sudden reduction in voltage, the voltage dip occurs. Percentage of voltage gets reduced due to the switching operation of wind turbine. It is represented in the equation given below.

$$d = K_u \frac{S_n}{S_k}$$

d - Relative voltage changes.
S_n-Normal Apparent power
S_k- Short circuit apparent power
K_u -Sudden voltage reduction factor
Acceptable voltage reduction is limited to less than 3%.

Flicker:

At 10min -2h period is the specified maximum number of switching operation at wind turbine. It is given in the below equation.

$$P_{lt} = C(\varphi_k)\frac{S_n}{S_k}$$

P_{lt} – Long term flicker
$C(\varphi_k)$ - Flicker Co-efficient

From Ray-Leigh distribution of the wind speed, it is calculated. With average time of 2h, the flicker co-efficient limiting value is less than or equal to 0.4.

Harmonics:

For variable speed wind turbine with power electronics converter at PCC, the harmonics distortion is reviewed. In the below equation the total harmonics distortion is given.

$$V_{THD} = \sqrt{\sum_{h=2}^{40} \frac{V_n^2}{V_1}} 1oo$$

V_n= n^{th} harmonics voltage
V_1= Fundamental frequency (50Hz)
Total harmonic distortion is limit for 132KV is less than 3%
Total harmonic distortion for current is

$$I_{THD} = \sqrt{\sum_{h=2}^{40} \frac{I_n}{I_1}} 1oo$$

I_n= n^{th} harmonics current
I_1= Fundamental frequency (50Hz)
For 132KV, total harmonic distortion of current limit is less than 2.5%

Grid Frequency:
For wind farm connection, Grid frequency of India is limited for 47.5 Hz -51.5 Hz. Up to 0.5Hz, the variation frequency can be withstand by the wind farm.

WIND TURBINE GENERATING SYSTEM MODELING

D-STATCOM is a shunt compensation voltage source converter. By injecting or absorbing current from the grid network, at point of common coupling for providing compensation it is connected. Through the shunt connection with the grid, it cancels out the harmonics and it gives good support for reactive power compensation.
Along with custom power devices, Grid connected wind energy system is represented in below fig (1)

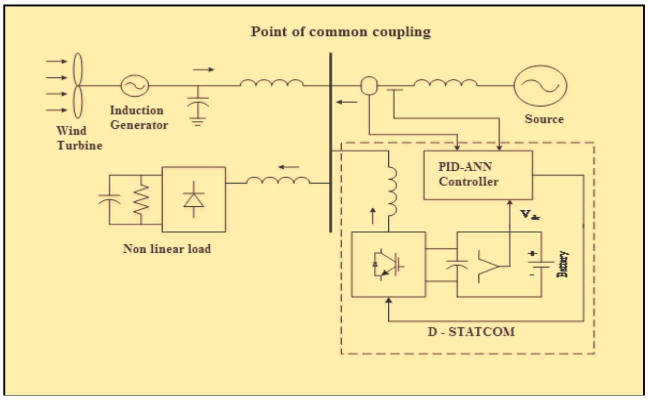

Figure 1: Wind generating system

Wind Energy Generation System:
In this proposed system, for generation of electricity induction machine is used in wind turbine. At both constant and variable load condition, the machine can operate. Against the condition of short circuit, it gives better protection. The kinetic energy of wind energy conversion system is derived from Newton's second law of motion.
E symbolizes kinetic energy in air. It is given in below equation [27] [26]

$$E = \frac{1}{2} m V_{wind}^2$$

m – Mass of air (Kg)
V_{wind}–Speed (m/s)

The kinetic energy formulation is based on the condition that the mass of solid is constant
Mass of air denotes as

$$m = \rho A V_{wind}$$

ρ - Air density (Kg/m^3)
A– Mass flow area
Generated power from wind turbine over an area (A) is given from the rate of change of kinetic energy. It represents as follows [17]

$$P = \frac{1}{2} \rho A V_{wind}^3$$

Developed power from wind turbine represent as

P_{wind}= C_p x wind

C_p- power coefficient (or) Betz limit
Mechanical power developed from wind turbine is extracted from the rotor blades. It is derived as follows

$$P_{mech} = \frac{1}{2} \rho \pi R^2 V_{wind}^3 C_p \text{ [7]}$$

D-STATCOM:
A three phase reactive power compensating device is the D-STATCOM. To maintain electrical parameters constant at point of common coupling it generates or absorbs reactive power. Coupling transformer with leakage reactance, voltage source converter and DC capacitor are consisted in it. In accordance with voltage magnitude and phase angle, solid state power switching device can provide continuous controllability for three phase supply. Regulating the bus voltage is its main function. Through leakage reactance of coupling transformer reactive power transfer is done [8].
In this compensator, it performs the function of injection of reactive power, if the output voltage is greater than system voltage and it performs the function of absorption, if the output voltage is less than required voltage [5].

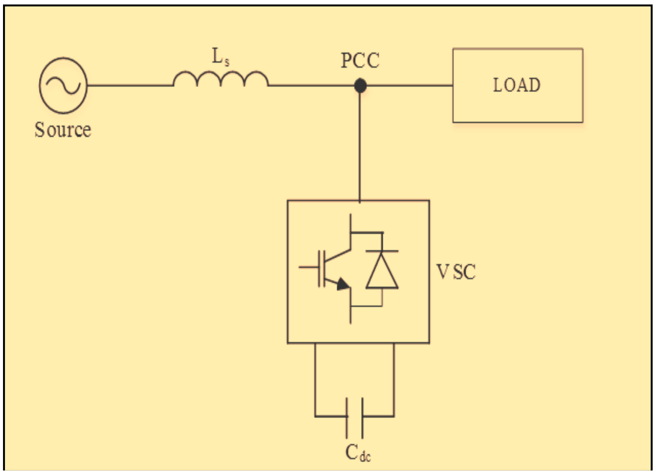

Figure2: D-STATCOM

CONTROL SCHEME

The entire grid system performance is controlled by various compensators. By various controllers, addition performances of compensator are improved. To enhance the performance of custom power devices as well as the performance of grid network in proposed system along with conventional PID controller optimization technique is implemented.

PID Controller:
Conventional PID controller has three parameters which is proportional, integral and derivative gain constant.PID structure is mentioned in fig [3]

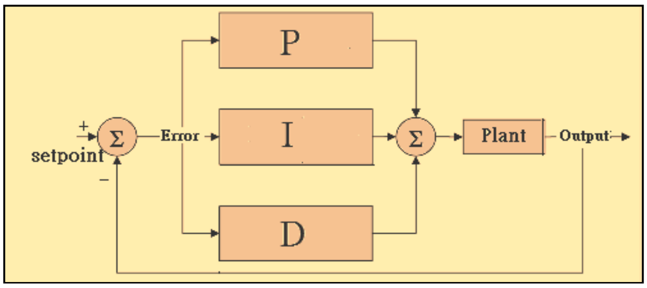

Figure 3: Structure of PID controller

Tuning of PID controller depends on tuning of controller parameters. The performance of PID controller is the best compare to other conventional controller. Basic PID control algorithm is as follows

$$e(t) = r(t) - y(t)$$
$$v(t) = K_p\, e(t) + K_i \int_0^t e(t)dt + K_d \frac{d\, e(t)}{dt}$$

K_p, K_i, K_d are proportional, integral, derivative gain constant.

Artificial Neural Controller:
The feed forward structure of artificial neural network is shown in Fig [1]. The structure has an input, hidden neurons and output [9].

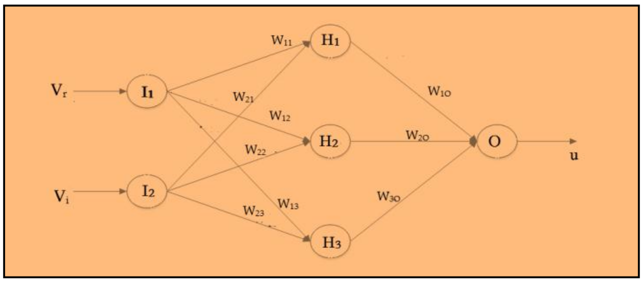

Figure 4: Structure of ANN

Classic PID controller which has an input r (t), output v (t) and the feedback is y(t).This y(t) which generate new out from the controller v (t) with target value r (t)
The error signal sent as feedback in conventional control. The tuning of PID controller takes place as per the feedback signal. Intelligence controller performs superior compared to the conventional method. It reduces the response time of entire controller system.

PID Neural Controller:
The Neural controller has the standard controller structure of two: three: one. The input of Neural controller that are X_1, X_2 specified by the numeric value three then the hidden neuron $\dot{X}_1$, X_2, $\dot{X}_3$ specified by the numeric two and the numeric one indicate the output function $\ddot{X}_1$.

P- Neuron
x(t) is the symbol for the function of P neuron. Then the function of P neuron as follows.

$$X(t) = \begin{cases} -1 & u(t) < -1 \\ u(t) & -1 \le u(t) \le 1 \\ 1 & u(t) > 1 \end{cases}$$

u(t) – Neuron input
X(t) – Neuron output

I- Neuron
The transfers function of I-neuron as follows.

$$X(t) = \begin{cases} -1 & x(t) < -1 \\ x(t-1) + u(t) & -1 \le x(t) \le 1 \\ 1 & x(t) > 1 \end{cases}$$

x (t-1) – Previous output

D- Neuron
The D-neuron transfer function as follows

$$X(t) = \begin{cases} -1 & x(t) \le -1 \\ u(t) - u(t-1) & -1 \le x(t) \le 1 \\ 1 & x(t) > 1 \end{cases}$$

u (t-1) – Previous input

The aim of PID controller is to minimize

$$J = \sum_{t=1}^{N} E_t = \frac{1}{N}\sum_{t=1}^{N}\big(r(t) - y(t)\big)^2$$

r(t) – desired output
y(t) – real system output
N – Number of samples

ANN Processing steps

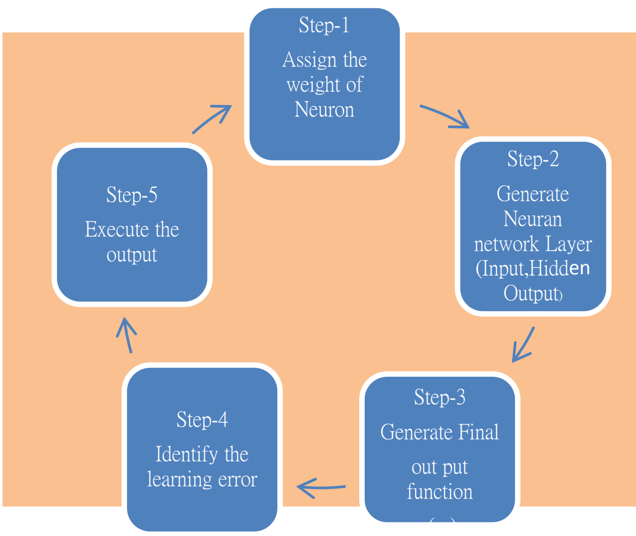

Figure 5: ANN processing steps

Steps involved in ANN processing are

Step: 1 the weights for neurons has to be assigned

Step: 2 the neural network has to be generated. It has two input I_1, I_2, three hidden layers H_1 ,H_2 ,H_3, and one output layer O.

Step:3 Final output function of neural network is as follows

$$O=\sum_{m=1}^{3}\frac{W_m^O}{1+\exp(-\sum_{n=1}^{2}I_nW_{nm}^i)}$$

m – Number of hidden neurons

n - Number of inputs

I_n - n^{th} input value

W_m^o - Weight between hidden and output layer

W_{nm}^i -Weight between hidden and input layer

The training function artificial neural network is carried out by varying the parameters of PID controller.

Step: 4 learning error identification

$$Learning\ Error\ e_i=\frac{1}{2}(Actual\ Value-Obtained\ Value)^2$$

SIMULATION RESULTS AND DISCUSSION

The custom power device D-STATCOM is demonstrated by the proposed system. By tuning of various controllers, this compensating device performance is improved. The tuning function of conventional controller is not at expected point. Intelligence based controller function is implemented along with conventional controller technique to overcome the drawback. The simulation result is executed by MATLAB/Simulink.

In voltage sag condition, than the voltage at point of common coupling, the power generated by wind turbine is lower. At that condition to inject the current into PCC, Artificial Neural based PID controller set off the D-STACOM. Fig (6) shows the performance of controller for the period of voltage sag condition.

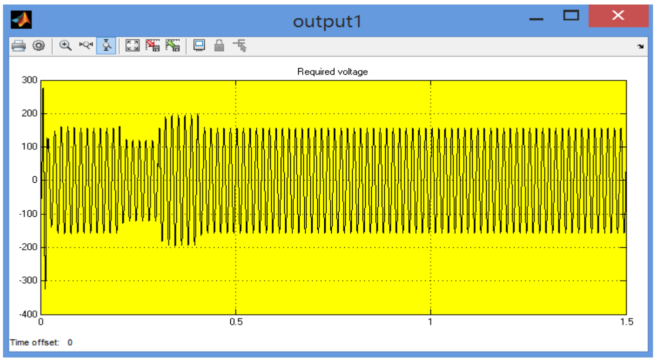

Figure 6: Voltage sag at required voltage condition

Fig (7) shows the power generated by wind turbine at voltage sag condition.

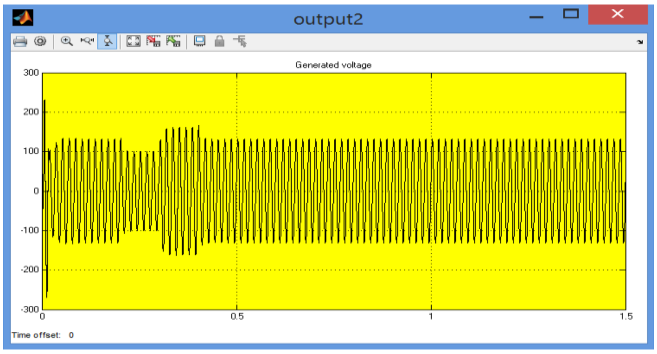

Figure 7: Voltage sag at generated voltage condition

The compensated signal generated by custom devices D-STATCOM based Artificial PID controller is used to maintain the voltage at PCC is shown in fig (8)

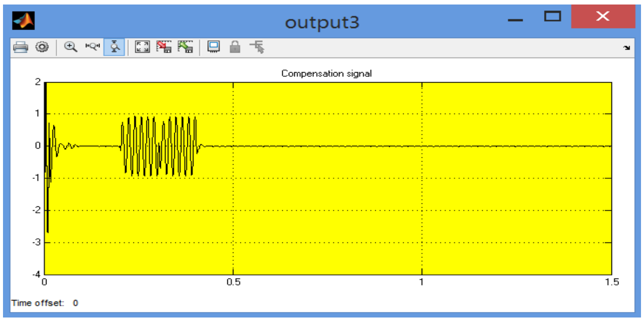

Figure 8: D-STATCOM compensated signal at voltage sag

In fig (9), during variable wind speed condition the power generation by wind turbine is shown

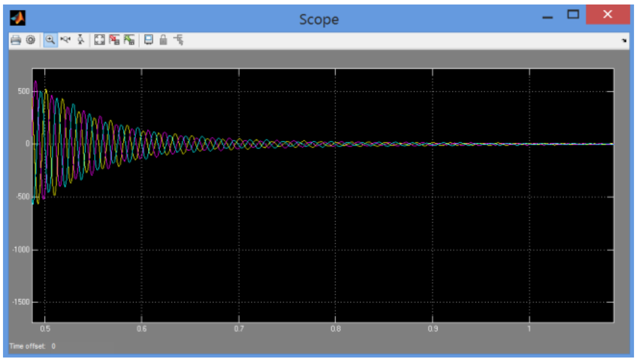

Figure 9: At variable wind speed output of wind turbine

The power generated by wind turbine is advanced than the grid voltage at PCC at the voltage swell condition. At swell condition, the custom device based artificial controller absorbs the voltage from the grid to cancel out this voltage issue. It retains the voltage within the range. The act of controller during swell condition is exposed in fig (10)

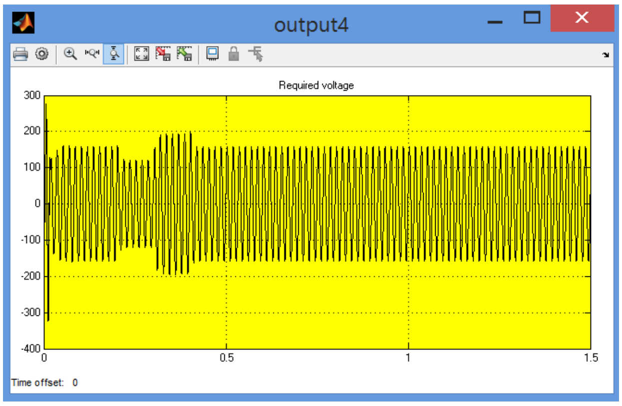

Figure 10: Voltage swell at required voltage condition

The power generated by wind turbine for the period of voltage swell is shown in Fig (11)

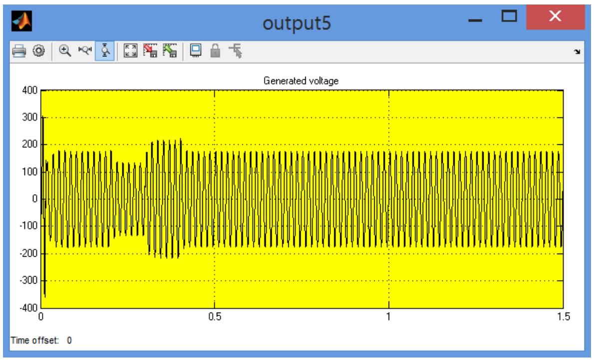

Figure 11: Voltage swell at required voltage condition

Voltage at PCC gets fluctuated at the Period of voltage swell. The compensated signal generated D-STATCOM based artificial controller is used to overcome this issue. The generated compensated signal is shown in fig (12)

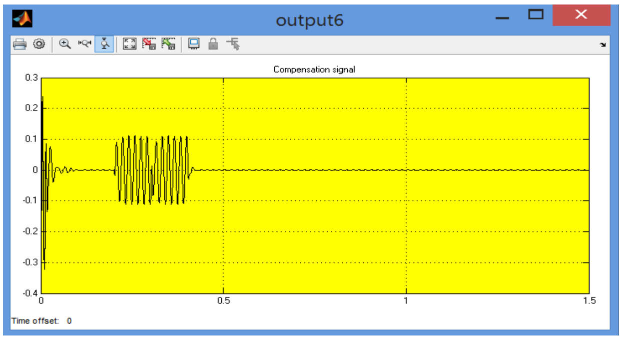

Figure 12: D-STATCOM compensated signal at voltage swell

CONCLUSION

Various power quality issues that occur in wind turbine which is connected with the grid network [10][11] is elaborated in this paper. D-STATCOM based FACTS devices are implemented at grid system to provide revival to avoid these variouspower quality issues. By implementing various controllers along with this, the performances of D-STATCOM are enhanced. The performance of PID controller is good among the various conventional controllers. But response consumes more time to provide compensation. The intelligence based controller action is implemented along with conventional controller to fix the time delay. Using artificial based PID controller, the performance of D-STATCOM is fast. The compensation is achieved by t=0.03s.This paper concludes the response time is superior while using Intelligence controller based PID-D-STATCOM.

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