International Journal of Emerging Science and Engineering (IJESE)
ISSN: 2319–6378, Volume-1, Issue-11, September 2013

Wind Turbine Load Mitigation Using FX-RSL Feed-Forward Algorithm

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Abstract--* *A wind turbine is a device that converts kinetic energy from the wind, into mechanical energy; energy known as wind energy or wind power. The turbines are used for an increasingly important source of wind power-produced commercial electricity. The utilization of wind turbines can be a great way to capture the energy of the wind in a bid to convert this into useable electricity. Harnessing the winds energy with a wind turbine can provide a source of clean and renewable electricity for large or small industries. Wind energy is undoubtedly one of the cleanest forms of producing power from a renewable source. There is no pollution, there is no burning of fossil fuels, and unless something very drastic happens, you don't run out of wind. But it's not like we can erect a wind turbine anywhere and it will start generating power. There are lots of factors that can make an impact on the amount of energy we can generate out of wind, such as wind speed, height or altitude & the rotor size.

Recent researches have been done to regulate the rotor speed & reduction of the component loads with the help of feed forward controllers. Wind speeds measured by light detection & ranging system (LIDAR) will give information of wind variations at various distances and so are used along with FX-RLS feed forward controllers for better tracking & better load reduction when the wind turbine is running at beyond its operating point.

Keywords: FX-RLS feed forward algorithm, LIDAR

I. INTRODUCTION

According to the recent researches, it has been proved that efforts could be made to improvise the wind turbines efficiencies by providing the feed forward control systems which will propagate the wind speeds operating range. The utilization of Wind turbines can be a great way to capture the energy of the wind in a bid to convert this into usable electricity which provides a source of clean and renewable electricity for all industries.

There are lots of factors that can make an impact on the amount of energy we can generate out of wind, such as wind speed, height or altitude & the rotor size. Wind turbines operate at larger loads and therefore are subjected to fatigue. Because of the variation of the wind flow, the turbines may go beyond the operating speeds at times. These can be avoided by introducing the controllers for the wind turbines. Since the wind turbines are non-linear because of the variations of wind speeds, non-linear adaptive controllers are used. For example, EEC (extreme event control) algorithm is used to prevent the rotor from operating beyond the allocated speed range.

Manuscript received September, 2013.

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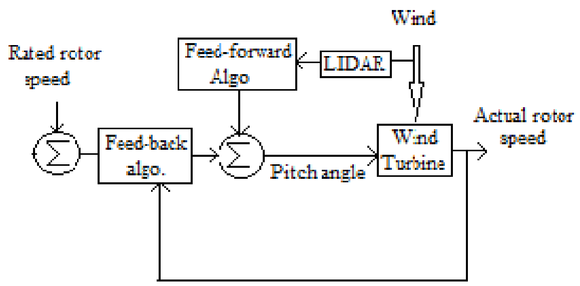
Recent researches have been done to regulate the rotor speed & reduction of the component loads with the help of feed forward controllers. Two types of controllers are taken into account –

1. Adaptive feed forward controller based on a filtered-x recursive least square algorithm (FX-RLS).
2. Non-adaptive feed forward controller based on a zero phase error tracking control (ZPETC).

Results show that, combining the PI feedback control with ZPETC feed forward control improves the blade loads but affects the tower loads which may lead to fatigue. Whereas FX-RLS gives better output & better reduction of blade & tower bending moments with only a smaller energy loss. Because of the variation of the wind flow, the turbines may go beyond the operating speeds at times.

As the Wind turbines operate at larger loads and therefore they are subjected to fatigue. These can be avoided by introducing the controllers for the wind turbines.

II. SYSTEM BLOCK DIAGRAM



III. SYSTEM MODELS

1 WIND TURBINE

Fig.2 shows a wind turbine which is a device that converts kinetic energy from the wind, also called wind energy, into mechanical energy; a process known as wind power.

Fig.2 Wind Turbine Models

If the mechanical energy is used to produce electricity, the device may be called a wind turbine or wind power plant.

If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump. Similarly, it may be referred to as a wind charger when used for charging batteries. The result of over a millennium of windmill development and modern engineering, today's wind turbines are manufactured in a wide range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging or auxiliary power on boats; while large grid-connected arrays of turbines are becoming an increasingly important source of wind power-produced commercial electricity.

2. LIDAR (LIGHT DETECTIONAND RANGING)

A LIDAR (LIght Detection And Ranging) is an instrument that operates by emitting laser light and detecting the light reflected back by objects towards the unit. LIDAR is similar to RADAR (RAdio Detection And Ranging), but uses laser pulses rather than radio waves. The device can only collect information for objects the same size as the wavelength emitted or larger, but not smaller. Since the laser pulses have wavelengths 105 times smaller than those of radio waves, LIDAR can detect much “smaller” particles. This fact helpful when studying the structure and composition of the atmosphere especially concerning the very tiny aerosols and cloud particles. In this application light from laser is reflected back from particles in the air such as pollen, dust or water droplets.

By measuring the Doppler Effect, a slight change in frequency of the backscattered light caused by those particles, the LIDAR is able to ensure wind speed and Wind direction. The Doppler frequency shift gives information about the wind speed component along the line-of-sight of the beam.

A laser typically has a very narrow beam which allows the mapping of physical features with very high resolution compared with radar. In addition, many chemical compounds interact more strongly at visible wavelengths than at microwaves, resulting in a stronger image of these materials. Suitable combinations of lasers can allow for remote mapping of atmospheric contents by looking for wavelength-dependent changes in the intensity of the returned signal.

The LIDAR shown in Fig.3 emits laser beams up to 70m horizontally in a radius of 60 degrees. The speed and direction are measured for a large field in front of the blades. Every second wind data is transmitted to the controller to enable it to respond quickly and optimize the turbine. It is a very versatile technology that has been used for atmospheric studies, bathymetric surveys, glacial ice investigations, and numerous other applications and also it offers high precision.

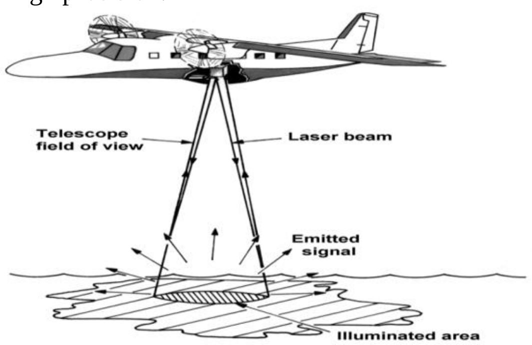


Fig. 3 LIDAR Working Principle

LIDAR which is an active sensor which is used to illuminate objects and to detect and analyses signals which originate from that object as a result of the illumination

3 ADAPTIVE CONTROLS

Adaptive control is an active field in the design of control systems to deal with uncertainties. The key difference between adaptive controllers and linear controllers is the adaptive controller’s ability to adjust itself to handle unknown model uncertainties.

This is the control method used by a controller which must adapt to a control system with parameters which vary, or are initially uncertain. For example, as an aircraft flies, its mass will slowly decrease as a result of fuel consumption; a control law is needed that adapts itself to such changing conditions. Fig.6 shows the Adaptive control model.

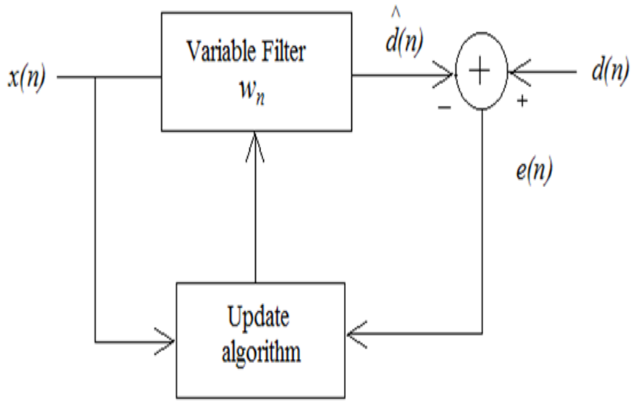


Fig. 4 Adaptive Control Model

Adaptive control is different from robust control in that it does not need a priori information about the bounds on these uncertain or time-varying parameters; robust control guarantees that if the changes are within given bounds the control law need not be changed, while adaptive control is concerned with control law changing them.

Classification of adaptive control techniques

A. Feed-forward Adaptive Control

B. Feedback Adaptive Control

Feed-forward control is almost always implemented as an add-on to feedback control. The Feed-forward controller takes care of the major disturbance, and the feedback controller takes care of everything else that might cause the process variable to deviate from its set point.

Feed Forward Involves a Measurement, Prediction and Action: The traditional PID controller takes action only when the process variable has been moved from set point, to produce a controller error, e (t) = set point – process variable. A feed forward controller measures the disturbance, D, uses it to predict an impact on process variable, and then computes pre-emptive control actions, The goal is to maintain the process variable at set point (PV = SP) throughout the disturbance event.

PID parameters are tuned by any conventional method in order to assure a good load disturbance rejection and the reference signal to the closed-loop system is obtained by filtering appropriately the set-point step signal.

Combined Feed-forward plus feedback control can significantly improve performance over simple feedback control whenever there is a major disturbance that can be measured before it affects the process output. In the most ideal situation, Feed-forward control can entirely eliminate the effect of the measured disturbance on the process output.

Even when there are modeling errors, Feed-forward control can often reduce the effect of the measured disturbance on the output better than that achievable by feedback control alone. The economic benefits of Feed-forward control can come from lower operating costs and/or increased salability of the product due to its more consistent quality.

Feed-forward control is always used along with feedback control because a feedback control system is required to track set point changes and to suppress unmeasured disturbances that are always present in any real process.

4 RLS ALGORITHM

The Recursive least squares (RLS) adaptive filter is an algorithm which recursively finds the filter coefficients that minimize a weighted linear least squares cost function relating to the input signals. This is in contrast to other algorithms such as the least mean squares (LMS) that aim to reduce the mean square error.

In the derivation of the RLS, the input signals are considered deterministic, while for the LMS and similar algorithm they are considered stochastic. Compared to most of its competitors, the RLS exhibits extremely fast convergence. However, this benefit comes at the cost of high computational complexity.

5 FILTERS

Filter is a device which is used to remove the unwanted part of input signal. There are basic two types of filters; FIR filter and IIR filter.

IIR filters are difficult to control and have no particular phase, whereas FIR filters make a linear phase always possible. IIR can be unstable, whereas FIR is always stable. IIR is derived from analog, whereas FIR has no analog history. IIR filters make polyphase implementation possible, whereas FIR can always be made casual.

FIR filters are dependent upon linear-phase characteristics, whereas IIR filters are used for applications which are not linear. FIR's delay characteristics are much better, but they require more memory. On the other hand, IIR filters are dependent on both input and output, but FIR is dependent upon input only. IIR filters consist of zeros and poles, and require less memory than FIR filters, whereas FIR only consists of zeros.

IIR filters can become difficult to implement, and also delay and distort adjustments can alter the poles & zeroes, which make the filters unstable, whereas FIR filters, remain stable.

FIR stands for Finite Impulse Response filters, whereas IIR stands for Infinite Response filters. FIR filters are more widely in use, because they differ in response. FIR filters have only numerators when compared to IIR filters, which have both numerators and denominators.

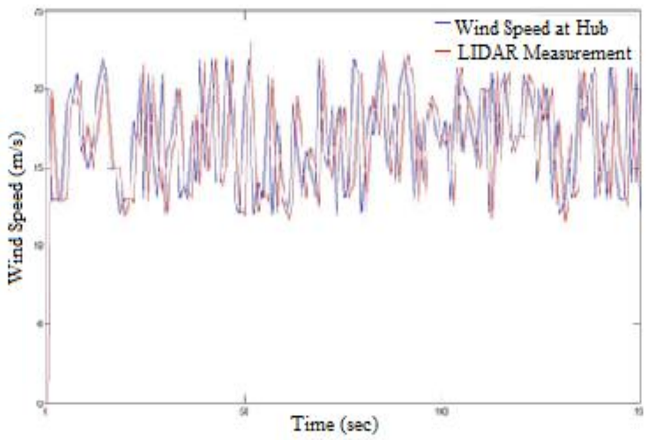
Where the system response is infinite, we use IIR filters, and where the system response is zero, we use FIR filters. FIR filters are also preferred over IIR filters because they have a linear phase response and are non-recursive, whereas IIR filters are recursive, and feedback is also involved. FIR cannot simulate analog filter responses, but IIR is designed to do that accurately. IIR's impulse response when compared wind speeds measured by light detection & ranging system (LIDAR) and will give information of wind variations at various distances.

If wind speed exceeds the rated wind speed then control algorithm is use to regulate the rotor speed of wind turbine and also to reduce the component load. Hence this LIDAR information about wind speed is used along with feed forward controllers for better tracking & better load reduction when the wind turbine is running at beyond its operating point. Since the wind turbines are non-linear because of the variations of wind speeds, non-linear adaptive controllers are used.

LIDAR information with feed forward controller and feedback controller is used for adjusting or for controlling the pitch angle of blade. Pitch control means that the blades can pivot upon their own longitudinal axis. And this pitch angle used for controlling turbine rotor speed.

Software used for simulation is MATLAB. Initially by assuming some turbine specifications like Hub height, Rotor diameter, maximum pitch rate, rated rotor speed, rated power etc. wind is modeled. For wind modeling, as we know wind is non-linear in nature so have to model it non-linearly by adding Gaussian noise to it. And by taking delay of 1sec between wind measured at LIDAR and wind measured at turbine hub, wind is modeled. And both the winds are show on the same graph by different colors.

IV. SIMULATION RESULTS



Wind Modelling

In the above graph two graphs are denoted by different colors in which red graph indicated the wind measured by LIDAR and blue graph indicate the wind measured at turbine hub. And there is tiny gap is present between this two graphs which is nothing but a delay of 1sec which we assumed initially while modeling the wind.

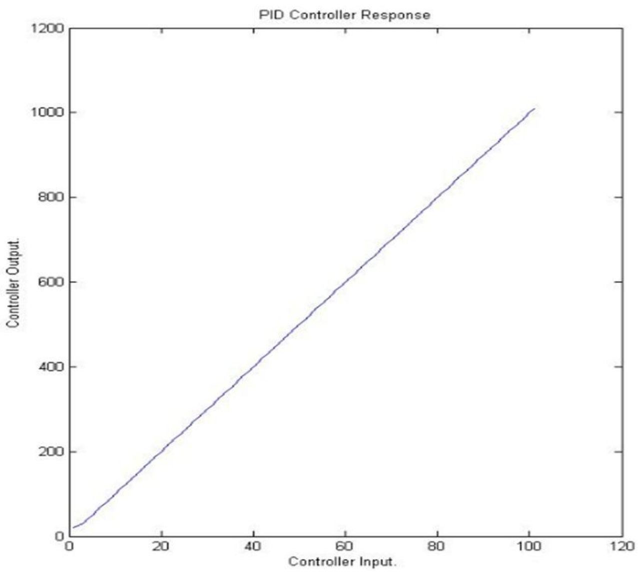


Fig 5 PID Controller Response

Fig. 5 shows the ideal response of PID controller. PID controller takes action only when the process variable has been moved from set point, to produce a controller error. The goal is to maintain the process variable at set point throughout the disturbance event.

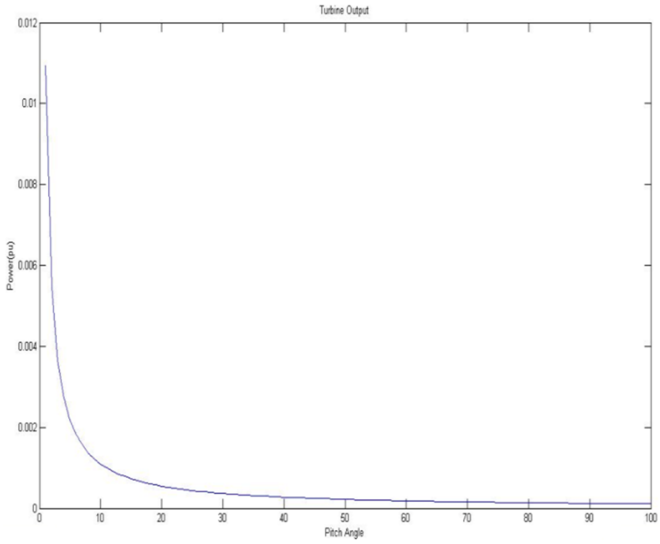


Fig. 6 Turbine Output

Fig.6 Shows the output of Wind turbine in a graphical manner in which x-axis shows the pitch angle while y-axis shows the output power i.e. power generated by turbine. And these both the parameters are inversely proportional to each other because initially blade of the turbine is perpendicular to wind direction that means pitch angle is 0 degree so when wind strike the blade, rotor starts and turbine produce the power but as pitch angle increases power generation start decreasing because at some point blade become parallel with wind direction so the output also become zero.

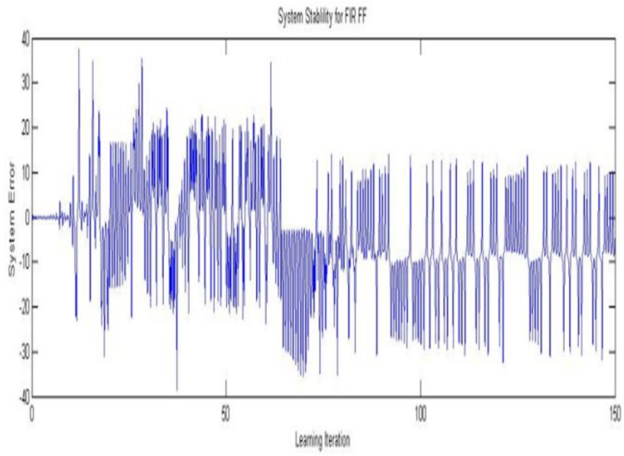
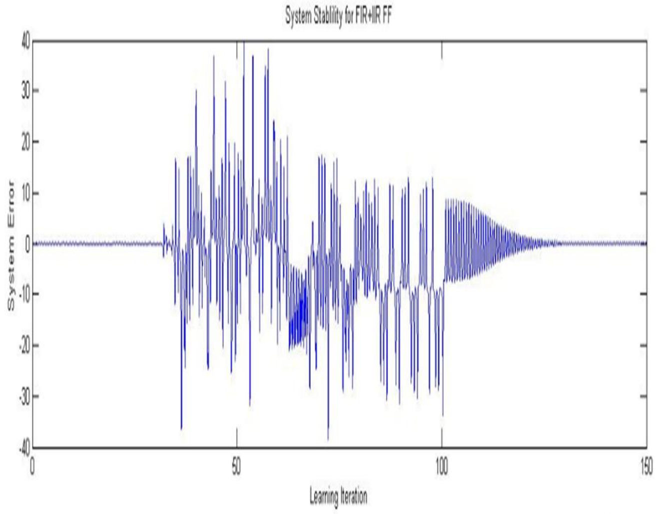


Fig.7 System stability for FIR filter

Fig.7 shows the response of the turbine control system using only FIR filter. X-axis shows the number of iterations while y-axis shows the vibration error in the system. As FIR filters are highly stable filters so the vibration error become zero but it will take time to reduce the error and make it zero.
In this graph we observe the error is slowly reducing and trying to become zero but it will take time that means it will take the large wind speed range. So over large wind speed range turbine facing the vibration error problem so there are chances of damaging the turbine over that large wind speed range.



FFig.8 System stability for FIR + IIR filter

Fig. 8 shows the response of the turbine control system using FIR filter along with IIR filter. X-axis shows the number of iterations while y-axis shows the vibration error in the system.
Vibration error range is reduced because in this case FIR filter is used along with the IIR filter in spite it has the disadvantages like Infinite impulse response and instability here concentrating only on his advantage like more it will have instability more it will move towards reality part.
So in this graph it is clearly observed that system error is reduced to zero earlier than the first graph that means chances of turbine damage is also get reduced while range of wind speed will get increase over which turbine will be stable without getting damage.

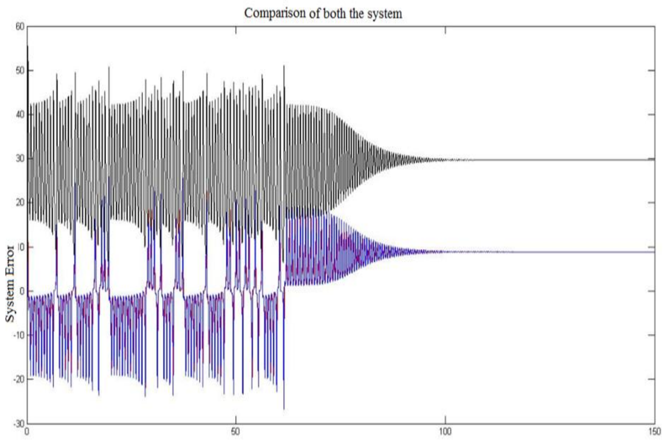


Fig. 9 Comparison graph.

Fig.6 shows the comparison graph of both systems in which black graph indicate the output of the FIR filter system while other blue color graph shows the output of FIR+IIR filter system. It is clearly shows that error in blue graph is minimum as compared to black graph that means when FIR filter is used along with IIR filter turbine operating range can be improved in great extent by minimizing the vibration error.
And a vibration of turbine get reduced it can give stable response over large wind speed range without getting damage. In this way system improves turbine’s wind speed range so that wind of maximum speed does not damage the turbine

Results for different Signal:
Fig.10 and Fig.11 shows the results in which different system parameters are calculated while Table 1 shows all these results in tabular form.

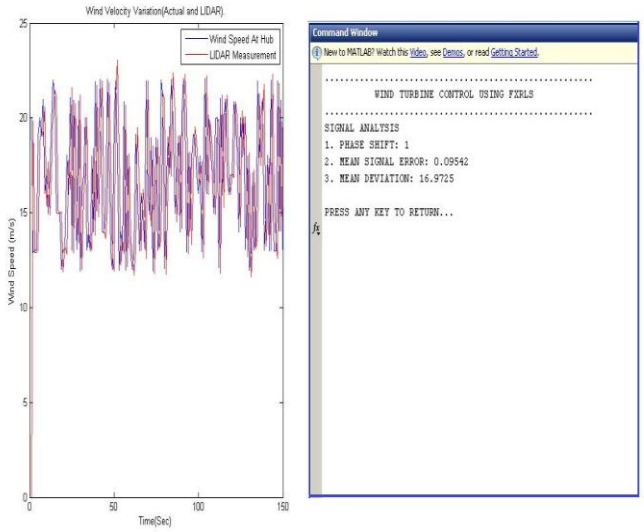


Fig.10 Result for signal 1 (Phase shift is 1)

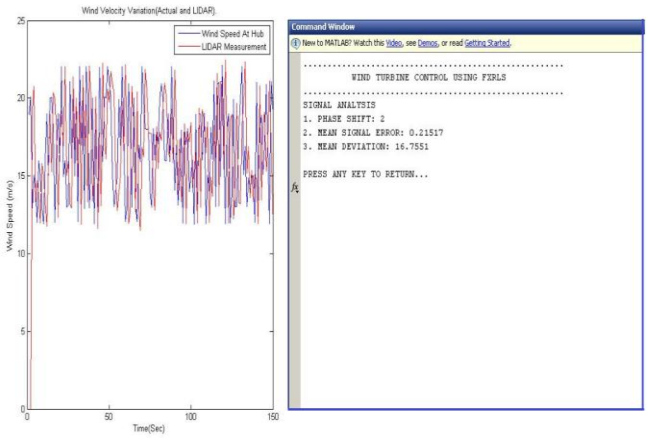


Fig.11 Result for signal 2 (Phase shift is 2)

V. PERFORMANCE MEASURE FOR VARIOUS PARAMETERS

TABLE 1

Input Signal	Phase Shift	Mean Signal Error	Mean Deviation
Signal 1	1	0.09542	16.9725
Signal 2	2	0.21517	16.7551

VI. CONCLUSIONS

To conclude the project, it is an approach for Wind turbine control system using Feed-forward and feed-back algorithm with LIDAR technique is used to improve the turbines wind speed range. This technique is useful to improve the stability of the turbine which means it can improve the performance of wind turbine at higher wind speeds when turbine operated above its rated value.

In the feed-forward algorithm FIR filter is used but FIR filter is concentrating more on the stability without concentrating on time require to stabilize the system. But in this case with the stability, time is also an important factor which cannot ignore hence to solve these problem in this system IIR filter is used along with FIR filter in order to reduce the time require to stabilize the system.

So that turbine can sustain in the high speed wind also. From the experimental results it is also shows that as phase change of input signal occurs then system controlling parameters like mean signal error and mean deviation also increases.

Hence it is also needed to more concentrate on phase of the input signals. This system improves the wind speed range and minimizes the vibration error for better stability but computational complexity of the system increases.

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Ms. Ajita Babar pursuing (ME (E&TC) Sinhagad College of Engineering, Pune, Published the paper on same Project topic in international conference "POWER SYSTEM OPERATING & ENERGY MANAGEMENT" held in Mumbai also Published the paper on Project topic in national conference "NATIONAL SYMPOSIUM ON PERVASIVE COMPUTING" organized by Sinhagad College of Engineering in Pune

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