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Image Processing for monitoring windmills

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ABSTRACT

The unforeseen failure of a component in a wind turbine or generator can have significant impact on the wind turbine economy; the right approach is to employ condition monitoring technique at every critical location of a wind turbine. The condition monitoring is a suitable method to prevent unplanned outages as a proactive maintenance strategy. Maintenance becomes vital for the prevention of unforeseen stoppages and complete breakdown of the machine in industrial facilities, their timely diagnosis and corrective measures cannot be over seated. The prevention of catastrophic failures through early detection of incipient faults in the machine increased the operational life with less failures and complete breakdown. To condition monitor and offer intelligent control for the wind turbines for investigation and integration of grid connected wind farms so as to identify and propose an optimal solution using image processing and intelligent techniques. This technique will offer a feed forward control.

Index Terms: Image Processing, Back Propagation Algorithm, Angular velocity, Blade sweep and feature extraction

1. INTRODUCTION

1.1. Need for wind energy

Wind energy as is the new trend of generating electricity as it is one of the promising renewable energy resources. Condition monitoring plays a vital role to determine early failure in the sub-systems and shift from preventive and corrective maintenance to condition based maintenance. It also ensures the balanced life for various components/subsystems. It provides reduction in the cost required for operation and maintenance. Hence an optimal design of WT using intelligent techniques will provide a cost effective solution for green energy.

1.2. Justification for Wind energy

The background for the project is the ever increasing demand for power and its generation through sustainable energy resources as these renewable energy sources becomes nonpolluting. No matter how much used today but in future wind energy will be the source of energy which is clean & nonpolluting, emits no air pollutants/greenhouse gases, and offsets emission of carbon dioxide and other pollutants. The wind farms have access to significantly better wind energy resources and hence offer larger energy generating capability. Since the transmission cost and efficiency is dependent on the distance, it is taken as the main criteria. Since wind power is variable in nature, control needs to be provided in the wind energy conversion system so as to optimize its performance. Hence intelligent technique is used to model and control the condition of wind mills become the state of the art.

1.3. Project Objectives

The objective is to increase the reliability of wind turbine in order to prevent any break down, power outages and to increase the avaibility of the wind turbine generator. The unforeseen failure of a component

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in a wind turbine or generator can have significant impact on the wind turbine economy; the right approach is to employ condition monitoring technique at every critical location of a wind turbine. The condition monitoring is a suitable method to prevent unplanned outages as a proactive maintenance strategy. Maintenance becomes vital for the prevention of unforeseen stoppages and complete breakdown of the machine in industrial facilities, their timely diagnosis and corrective measures cannot be over seated. The prevention of catastrophic failures through early detection of incipient faults in the machine increased the operational life with less failures and complete breakdown.

To condition monitor and offer intelligent control for the wind turbines for investigation and integration of grid connected wind farms so as to identify and propose an optimal solution using image processing and intelligent techniques. This technique will offer a feed forward control.

1. Modeling and control of wind turbine using Fuzzy logic
2. Condition monitoring using image processing.
3. To analyze steady state and dynamic performance thereby providing an optimal condition monitoring using intelligent techniques.
4. Comparative analysis of conventional and intelligent techniques for optimal condition monitoring
5. Validation

2. LITERATURE SURVEY

2.1. National Status

Electricity demand has continuously outstripped production, and a peak energy shortage of around 12.7% prevailed in 2009-104. To meet this shortfall as well as the National Electricity Policy target of ‘Electricity for All by 2012’5, the cleanest options available to India are Renewable Energy Technologies (RETs).

For the government to seriously consider meeting its promise of electricity for all by 2012, renewable energy options including wind power will have to play a crucial role in India’s emerging energy mix. Not only are they environmentally sound but also their project gestation periods are significantly shorter than those for thermal or nuclear power plants. The most widespread distributed generation alternatives are mini-hydros, wind generation, co-generation (CHP, combined heat and power) in industry or buildings, and small independent power generators (diesel, gas, or biomass). Wind generation, in particular, has placed new challenges on system operation and planning, because of the “undispatchable” nature of wind, the difficulty in forecasting, and the impossibility of storing it.

Over a decade, several efforts have been made in the research and development for the study of grid connected Wind Energy Conversion Systems (WECS). The framework of adaptive control applied to a wind turbine is presented. The wind turbine is adaptively controlled to achieve a balance between two objectives, power maximization and minimization of the generator torque ramp rate. An optimization model is developed and solved with a linear weighted objective. The objective weights are autonomously adjusted based on the demand data and the predicted power production. Two simulation models are established to generate demand information. The wind power is predicted by a datadriven time-series model utilizing historical wind speed and generated power data. The power generated from the wind turbine is estimated by another model. Due to the intrinsic properties of the data-driven model and changing weights of the objective function, a particle swarm fuzzy algorithm is used to solve it**.**

An active-damping strategy is proposed for the suppression of speed and torsional oscillations in permanentmagnet synchronous generator (PMSG)-based Wind Energy Conversion Systems (WECSs). Direct-driven configuration with PMSG is an attractive choice for WECS because of the gearbox elimination and cost reduction due to small pole-pitch design. However, speed and torsional oscillations appear when the generator is directly connected to the wind turbine without any assistant damping device. Based on small-signal analysis, a low-bandwidth design for the power or generator torque controller of PMSG can help to reduce the oscillation amplitude, but the system dynamic performance is thus sacrificed. From the power-flow's point of view, the oscillation is reflected in the dc-link current. With the help of switch function modeling based on the space-vectormodulation scheme, the average dc-link current can be estimated and applied to the compensation strategy, which provides positive damping resulting in stability improvement. The simulation and experiment results verify the theoretical analysis and the validation of the proposed strategy.

A design of nonlinear rotor-side controller (RSC) is developed for a wind turbine generator based on nonlinear, H2 optimal control theory. The objective is to demonstrate the synthesis of a maximum power point tracking (MPPT) algorithm. In the case of a doubly fed induction generator, it is essential that the RSC and the MPPT algorithm are synthesized concurrently as the nonlinear perturbation dynamics about an operating point is either only just stable or unstable in most real generators. The algorithm is validated based on using nonlinear estimation techniques and maximizing an estimate of the actual power transferred from the turbine to the generator. The MPPT algorithm is successfully demonstrated both in the case when no disturbances were present, as it is a prerequisite for successful implementation, and in cases when significant levels of wind disturbances are present.

The emergence of distributed generation is coupled with the restructuring of the electric sector and the market orientation it received in recent years. This has opened business opportunities to private investors, non-institutional, in supplying power to the grid, resulting in a new inflow of capital to the sector, coming from sectors that traditionally were not investing in the energy business.

2.2. International Status

The growing importance of wind power and in modern power systems has raised some challenges in the emergence of distributed generation, and how computational intelligence and other modern techniques have been able to provide valuable results in solving the new problems. It presents some solutions obtained with a number of computational intelligence techniques and their application to real cases. Distributed generation is assuming an important role in modern power systems. The progress in technologies has allowed a portfolio of solutions to now be considered and found profitable, while only a few years ago one would witness arguments stating that only large centralized power stations would be economically feasible.

This has also presented new problems to an industry that was used to a tight control of their supply system. Suddenly, not only did planning become a difficult exercise, because the existence and location of new power plants became uncertain and dependent on the decisions of third parties, but also the operation was confronted with new degrees of uncertainty, not only as a result of private operators but also as a function of wind unpredictability.

A method is presented to analyze the effects small wind turbines' (WTs) output may have on the load frequency control process. A simulation model of a utility's automatic generation control (AGC) process is used with recorded realtime system load data modified by synthesized data characterizing the aggregate output of small WTs. A series of WT output scenarios are defined for various WT penetrations of the total system load. WT output scenarios, varying in frequency and magnitude, are combined with system load variations to test the effectiveness of present AGC control strategies. System performance change from the base case is assessed using area control error (ACE) values, time between zero crossings, inadvertent accumulation and control pulses sent to regulating units.

3. Initial Work Carried by The PI's Team

The PI and Co-PI's have contributed papers in both national and international conferences related to Image processing for process control. The work done and the results obtained are described briefly.

Image processing has been used in many scientific fields, such as in medicine or biology, where researchers represent different types of cells by its texture properties [4], or distinguish between the alive or the dead cells by analyzing their images [6]. In the renewable energy field, it has been also used to develop a field calibration technique for aligning a wind direction sensor to the true north [3], and to monitor the damage of wind turbine blades by measuring its bending [1].

The video of the wind turbine while working at various angular frequencies and blade sweep positions are acquired using a high resolution digital camera. The continuous video is then splitted into frames. The size of each frame acquired is 123×82. The preprocessing includes noise removal, conversion of colour image into grayscale image and edge detection to extract the Region of Interest (ROI). The next stage includes classification using intelligent schemes. To summarize an extensive study of off-shore wind farms will prove effective for a more tuned sustainable energy system and the modeling of WT using intelligent techniques towards a more cost effective solution.

3.2. Justification of the proposed Project work in context of work being pursued by other groups in the country:

Wind energy - the fastest growing source of energy in the world - can contribute substantially to global goals for reducing CO_2. Modern wind power technology has come a long way in the last two decades, and both globally and in India, improved technology has slowly and steadily improved capacity utilization. The existing and emerging trends in the development of wind power technology are the key trend in the Indian industry is the development of multi-mega watt turbines installed at greater hub heights. Larger diameter rotors mean that a single wind power generator can capture more energy, or more 'power per tower'. This allows WTGs to take advantage of higher altitudes with stronger winds and less turbulence (wind speed generally increases with height above the ground).

Subsequently larger machines have resulted in a steady increase in the capacity factor on average from 10-12% in 1998 to 20-22% in 2010. For two decades now, global average WTG power ratings have grown almost linearly, with current commercial machines rated on average in the range of 1.5 MW to 2.1 MW. The average size of WTGs installed in India has gradually increased from 767 kW in 2004 to 1,117 kW in 2009. The wind energy scheme proposed in our country is as shown in Figure 1. Currently, megawatt-scale turbines account for over half the new wind pozwer capacity installed in India. The average sized WTGs

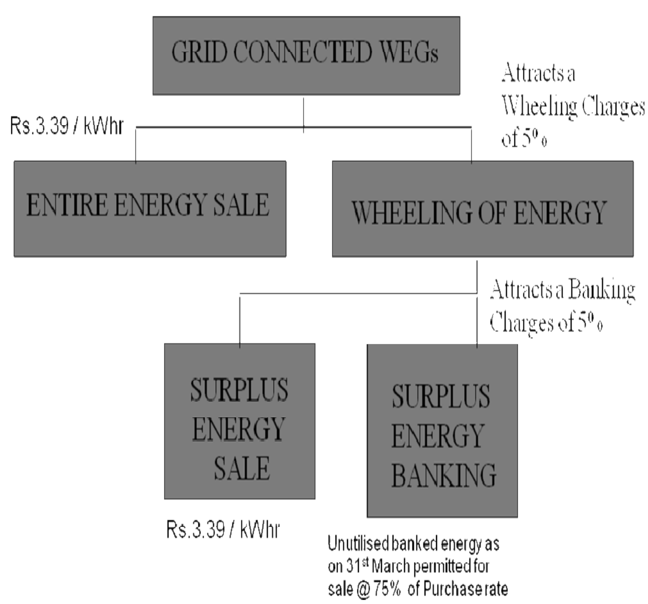

Figure 1: Wind Energy Schemes in India

are installed in all the major markets between the years 2004-2009. Also wind turbine and wind plant characteristics as viewed from the bulk transmission network are important for this study.

Details of the aerodynamic and mechanical aspects of individual turbine operation are important only to the extent that they influence the electrical behavior of the turbine or plant. Most developments in wind turbine technology over the past decade have been focused on reducing the cost of energy. A relatively few of these myriad changes and enhancements have been for the specific purpose of improving interconnection or integration with the bulk electric power system. Now that wind generation has become major presence in many areas of the nation, there are moves underway to address through requirements and interconnection standards some of the existing and emerging technical issues, such as the recent industry focus on wind turbine low-voltage ride-through capability. The current details of wind turbine models will be extensively analyzed and a cost effective model will be designed using intelligent techniques.

Overall, this project will present a preliminary analysis of the impact of high wind power penetration in the planning and operation of the Indian power system, as well as the grid integration and transmission of power in off shore wind farms along with optimal modeling and control of WT with the help of intelligent techniques. Electric power transmission may use AC or DC. However there are technical limitations to ac connections, as the longer the distance the power has to be carried, the less real power can be transferred. The alternate to AC is HVDC which has many advantages. A consolidated study of the impact of wind power is not available so far. The outcome of this project may be in terms of recommendations for the appropriate integration of the new wind generation foreseen for the Indian power system.

4. WORK METHODOLOGY

The work methodology includes the data collection and images of the wind mill. For simulation study MAthematical LABoratory (MATLAB) is used. The Figure 2(a) shown below demonstrates the Methodology for carrying out the entire project.

Renewable energy plays a vital role in power industry to fulfill the growing demand of power in industrial sector and other utilities. Especially the wind power industry enormously expanded during the last few years. The fast expansion of the wind power market has also come with some problems that have been reported. The entire scope of the work is shown in Figure 2(b) below.

Image processing has been used in many scientific fields, such as in medicine or biology, where researchers represent different types of cells by its texture properties [4], or distinguish between the alive or the dead cells by analyzing their images [6]. In the renewable energy field, it has been also used to develop a field calibration technique for aligning a wind direction sensor to the true north [3], and to monitor the damage of wind turbine blades by measuring its bending [1].

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The study report focuses on the benefits for using a condition monitoring system for early fault detection. Various conventional and latest techniques of condition monitoring including signal processing methods for vibration analysis have been added to this project. A basic frame work for the future work of condition monitoring system in wind turbine is also included. As a result of the study, the image processing based online condition monitoring for wind system, has been proposed as a part of this work. This technique is

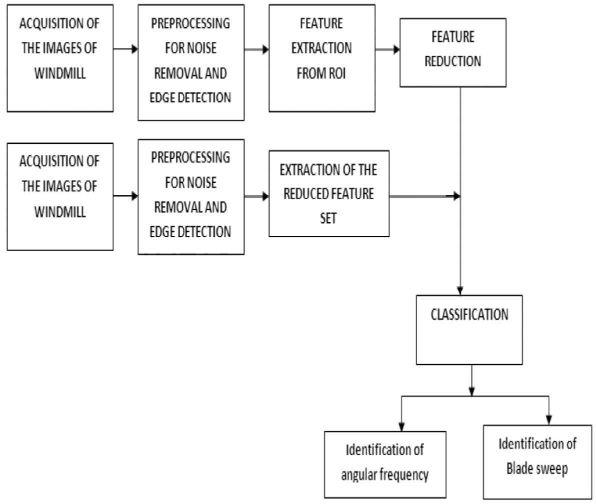


Figure 2 (a): Methodology for Monitoring windmills using Image Processing

proposed as an integrated condition monitoring system to be used with the existing monitoring system as a retrofit design to increase the performance of early fault detection system.

4.1. Acquisition of images

This includes capturing of the images of the windmill installed at various places in Tamil Nadu, for example Tuticorin. Nearly 51 images corresponding to various angular frequencies and blade sweep were captured. These frames are obtained from the continuous video displayed on the CRT of the control room. The video splitter like Cannon is used for extracting the frames whose size is 123 × 82. The picture of the windmill is shown in Figure 3. The Table 1 and 2 indicates the values of the angular frequencies and blade sweeping acquired simultaneously along with the video of the windmill under various operating conditions.

4.2. Preprocessing

The preprocessing includes converting of the colour images to gray scale images, noise removal and edge detection. The colour images obtained are converted to grayscale images and corresponding intensity values

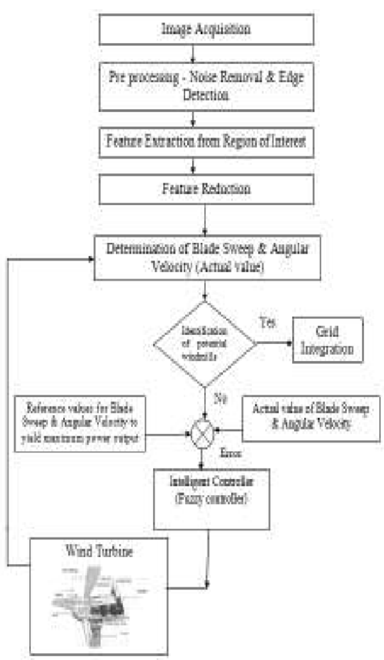


Figure 2 (b): Scope for modeling and control of WTusing Image processing

Figure 3: Sample video frame of the windmill

Figure 4: Video frame of the windmill

Table 1
Angular frequencies compounded by using the proposed method for the wind turbines that appear in the video

Video	*Wind turbine*	*during the video*											
1	1	2.38	2.28	2.38	2.28	2.28	2.28						
	2	2.38	2.38	2.38	2.28	2.38	2.28						
2	1	2.38	2.28	2.38	2.28	2.38	2.28	2.49	2.28	2.09	2.49	2.49	
	2	2.38	2.38	2.28	2.28	2.38	2.38	2.62	2.09	2.18	2.38	2.28	
3	1	2.49	2.18	2.76	2.28	2.33	2.38	2.38	2.01	2.38	2.62	2.01	3.08
	2	2.49	2.28	2.38	2.38	2.28	2.62	1.94	2.76	2.38	2.28	2.18	2.62

Table 2
Blade sweep for each wind turbine corresponding to the video

Video	*Wind turbine*	*s of the video when the blade sweeping happens*												
1	1	0.60	1.48	2.40	3.28	4.20	5.08	6.00						
	2	0.04	0.92	1.80	2.68	3.60	4.48	5.40						
2	1	0.32	1.20	2.12	3.00	3.92	4.80	5.72	6.56	7.48	8.48	9.32	10.16	
	2	0.56	1.48	2.35	3.28	4.20	5.08	5.96	6.76	7.76	8.72	9.60	10.52	
3	1	0.60	1.44	2.40	3.16	4.08	4.96	5.84	6.88	7.76	8.64	9.44	10.48	11.16
	2	0.04	0.88	1.80	2.68	3.56	4.48	5.28	6.36	7.12	8.00	8.92	9.88	10.68

are obtained in all the three planes namely the RGB plane. The output for converting the colour image to gray scale is shown in Figure 3.

The histogram analysis is done to identify which plane contains the most useful information. It is also inferred that the plane -2 (G plane) can be considered for further analysis, since the histogram corresponding to this plane has a wide dynamic range. The Figure 5(a), (b) and (c) shows the histogram for the images of the windmill in R plane, G plane and B plane respectively.

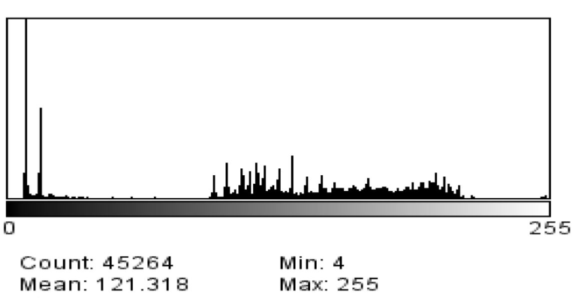


Figure 5 (a): Histogram for the windmill image in R plane

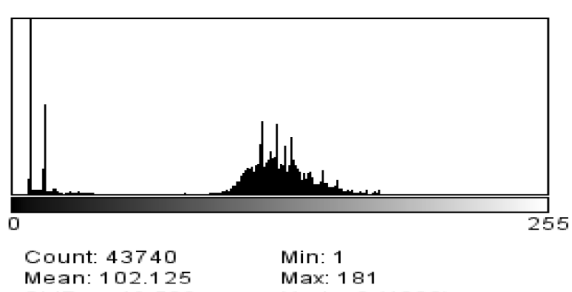


Figure 5 (b): Histogram for the windmill image in B plane

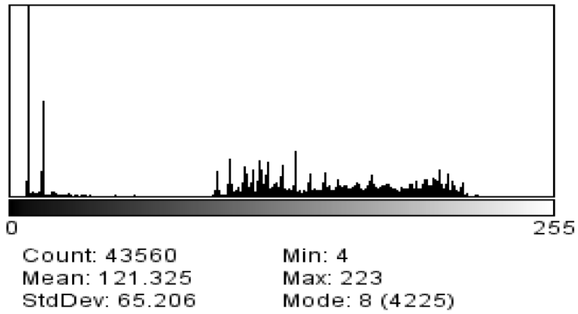


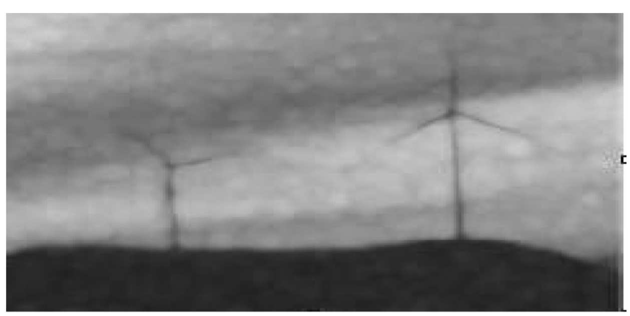
Figure 5 (c): Histogram for the windmill image in G plane

The acquired images may be corrupted by noise, in particular salt and pepper noise (as video frames are commonly prone to this noise). An analysis is also done to find a suitable filter for filtering the salt and a pepper noise. The various filters include the mean filter, median filter, maximum filter etc. The Peak Signal to Noise Ratio (PSNR) is calculated which indicates that median filter performs noise removal efficiently. The Figure 6 shows the outputs for filtering done using median filter. The Table 3 contains the PSNR values after filtering. This clearly indicates that the PSNR value corresponding to the median filter is high which recommends this filtering technique.

Any further operations done on the images of the windmill should be carried out on a square image. This involves the task of identifying the portion of square image that is to be extracted from the entire

(a): Output for Median filter

(b): Output for Mean filter



(c): Output for maximum filter

Figure 6: Outputs for various filtering techniques

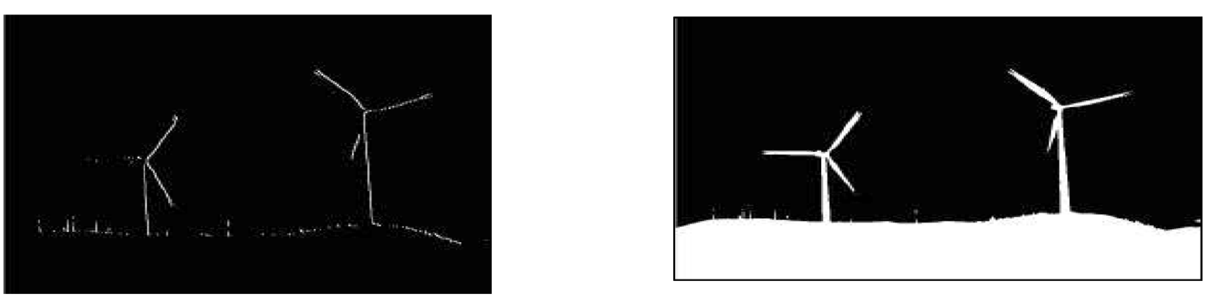


Figure 7: Outputs for edge detection and noise removal

Table 3
PSNR values for various filtering techniques

S. No	Name of the Filter	MSE	PSNR (dB)
1.	Median filter	0.0038	62.33
2.	Mean filter	0.146	56.49
3.	Maximum filter	0.83	48.94

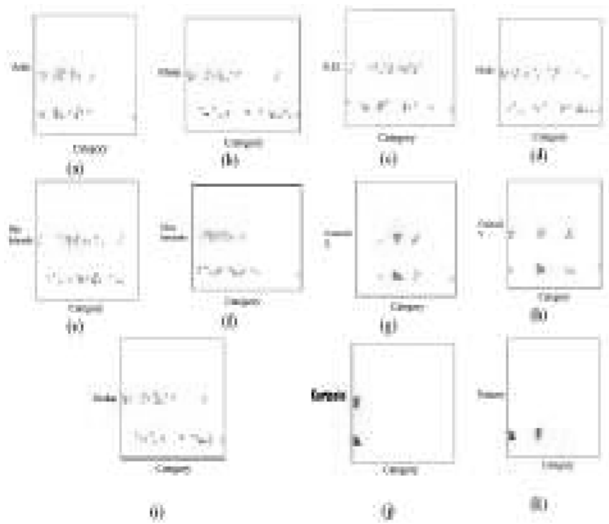


Figure 8: Variation of features from SVM feature evaluator

Table 4
Ranking of Features by SVM

Ranking	Features
1.	Perimeter
2.	Area
3.	Minimum Intensity
4.	Median
5.	Centroid about Y
6.	Centroid about X
7.	Maximum Intensity
8.	Kurtosis
9.	Mode
10.	Standard deviation
11.	Mean

image for extracting the features. The edge detection is done to extract the portions of the blades in the windmill. The type of mask that is used for edge detection is the Sobel mask. The output for edge detection is shown in Figure 7.

4.3. Feature Extraction and Feature Reduction

The features are the basic pattern that appears repeatedly in an image. These features that are to be extracted varies based on the type of the images acquired and the application to which it is associated with. The features include mean, kurtosis, blade sweep through area, Standard Deviation, Mode, Centroid, Perimeter, minimum intensity, maximum intensity, Median, etc. The extracted features are reduced using Support Vector Machine (SVM) for improving the classification efficiency.

The Table 4 denotes the features that ranked by the SVM feature evaluator. The Figure 8 shows the variation of the features for various categories of the angular velocity and blade sweep area.

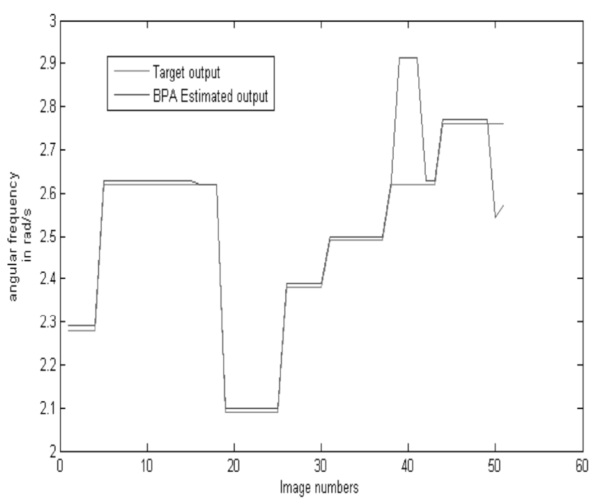
4.4. Classification using conventional and intelligent techniques

The classification techniques include conventional and intelligent techniques. The conventional classifier that will be used is the Euclidean Distance Classifier and the intelligent classifier is the Feed Forward Neural Network (FFNN) trained with Back Propagation Algorithm (BPA).

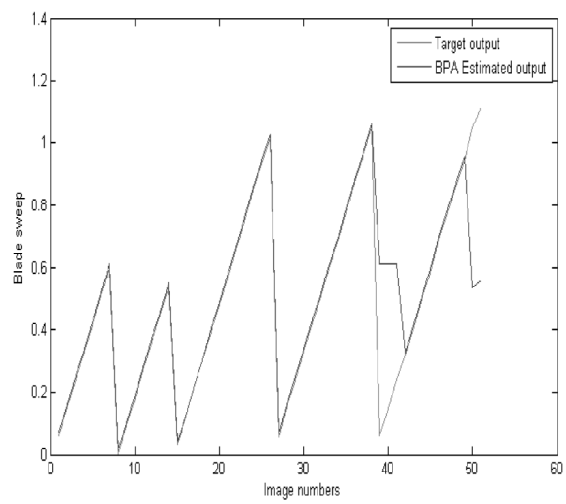
Thus the main aim of this project is to determine the optimal site specific wind turbine design, which is the design that results in the lowest cost of energy at that particular site? There are many decisions that have to be made in designing a modern wind turbine. The optimal wind turbine design for one location is not necessarily the optimal design for another location because the wind speed distribution may vary between locations. As a result modeling and control of wind turbines using image processing and intelligent techniques can designed for optimal operation. The results for classification is also available which states that almost for 51 images of the windmill, its corresponding blade sweep and angular frequency was determined.

Proposed Work Plan to achieve targets

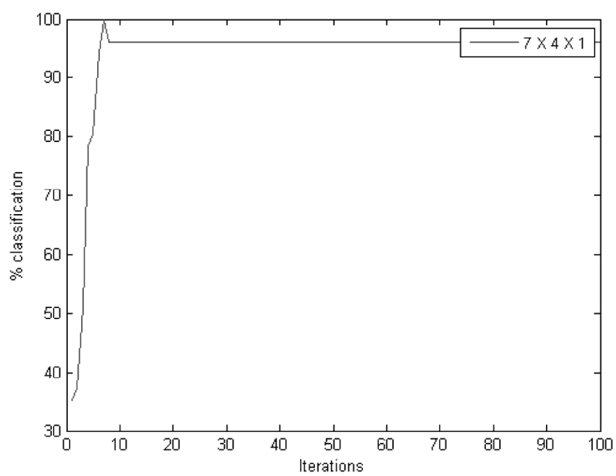
1. To identify the existing issues in wind farm integration to grid and study of existing models of Wind Turbine (WT).



Estimation of angular frequency

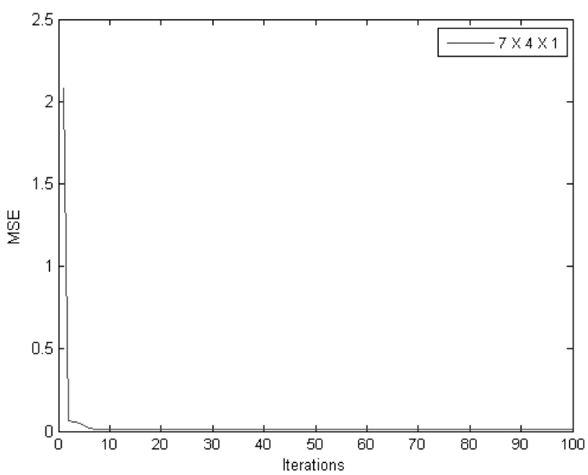


Estimation of Blade sweep

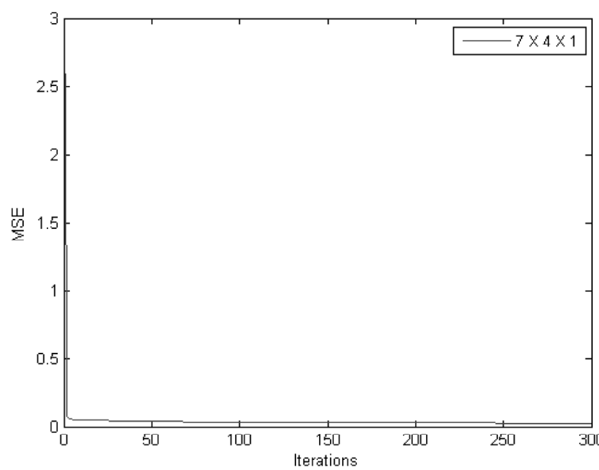


Classification efficiency for angular frequency

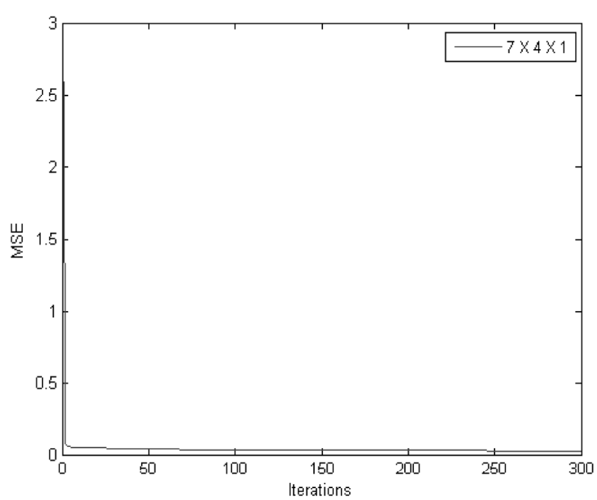
2. Comparative analysis of Induction generator WT model, Synchronous generator WT model and DFIG WT model.
3. Grid integration of different models of WT.
4. To analyze the steady state conditions of grid connected wind farms.
5. To model a Fuzzy controller using intelligent and image processing techniques for analyzing the integration issues.
6. Comparison of the results for conventional controllers with the intelligent controllers.
7. To propose suitable models for wind systems with doubly fed induction generator controlled by intelligent techniques.
8. Converter modeling and comparative analysis of various types of converters.
9. HVDC link design and analysis.
10. To summarize the study and to recommend guidelines for connecting the wind farms using HVDC links.
11. To suggest suitable methods / devices for performance improvement.



MSE for angular frequency Estimation



Classification efficiency for Blade sweep



MSE for Blade sweep Estimation

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