	かずみ　せいえど　もはまっど　らざ
氏　　　　　名	Kazmi　Syed　Muhammad　Raza
授　与　学　位	博士（工学）
学位授与年月日	平成２２年３月２５日
学位授与の根拠法規	学位規則第４条第１項
研究科，専攻の名称	東北大学大学院工学研究科（博士課程）電気・通信工学専攻
学位論文題目	Efficient Renewable Energy Conversion System with Novel Control Algorithm (新しい制御アルゴリズムによる効率的再生可能エネルギー変換システム)
指　導　教　官	東北大学教授　一ノ倉　理
論文審査委員	主査　東北大学教授　一ノ倉　理　東北大学教授　濱島　高太郎 東北大学教授　松木　英敏　教授　郭　海蛟 (東北学院大学)

論 文 内 容 要 旨

As acknowledged by the leaders of all the nations in Copenhagen Accord, the greatest threat that the humanity faces at present is the increasing emission of greenhouse gases. Researches have revealed that almost 45% of the domestic CO_2 emissions results from the electricity which is generated from the natural resources. Now with the steady depletion of these conventional energy resources and the alarming uprise of global warming, the only way to save our future is to go green. So any research leading a step forward in this direction is not just another scientific venture, but an endeavor to ensure our existence and survival with a better future for our next generation. The research work presented in this thesis is an earnest effort to serve as a milestone in making a common household immune to the shortage of natural energy resources by efficiently utilizing sustainable energy sources - solar and wind, available in their own backyard. Hence naming the motto as *"Energy from your home, to your home"*.

The research work of this thesis presents very efficient wind and solar energy conversion systems driven by novel control algorithms specially developed for fast and accurate tracking under varying environment with minimal sensor and hardware requirements. The main focus of this research is the maximum energy extraction because the energy yield from a renewable source highly depends upon the operating point of that source. Hence, specially in a home-scale renewable energy system, it is mandatory to perform maximum power point tracking (MPPT) in order to maximize the efficiency of the renewable energy system as well as to minimize the payback period, i.e. the time when the cost of the installed system gets equalized by the worth of the energy produced. Therefore the MPPT in wind and solar energy system is the main theme of this research work.

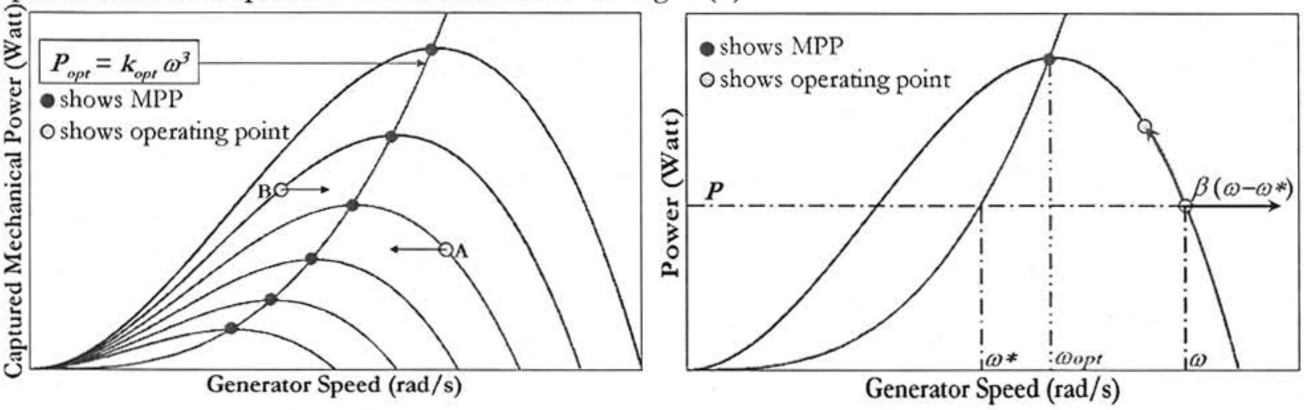
Chapter 1 of this thesis explains the background of the research work by first going through a brief overview of the various research areas corresponding to the development of renewable energy conversion systems. The perspective is with respect to the electrical system's engineering point of view and therefore mechanical and metallurgical aspects of energy capturing devices are beyond the scope. The section at the end elaborates upon the precise motivation of this research work and formally defines the research aims.

Chapter 2 introduces the fundamentals and concepts involved in a wind energy conversion system (WECS). It is a brief but concise introduction of the physics, terminologies and the technologies involved in wind energy systems. The concept of MPPT in WECS has been particularly introduced with sufficient detail. It overviews the different WECS classified according to the structure of wind turbine as well as the speed of generator. Lastly it presents the drive train modeling technique for deriving the dynamic simulation models of WECS.

Chapter 3 explains the important phenomena related to PV energy generation. It starts off with the mathematical modeling of a PV cell which is the basic building block of a PV energy generation system. The most important part of this chapter is the concept of MPPT in PV. Also the phenomenon of partial shading which is of paramount importance in PV energy system has been covered in this chapter.

Chapter 4 is on the maximum power point tracking (MPPT) of wind energy conversion system (WECS), which is the heart of this research work. First a very comprehensive review and critical analysis of the research papers published till date on MPPT in WECS is carried out. Such a review is unique in itself because so far there is no publication detailing such an insightful and up to date review of research papers. The drawbacks and limitations of the existing techniques as pointed out in this review, are necessary to be understood in order to appreciate the novelty and effectiveness of the new MPPT algorithm developed in this research. The proposed novel algorithm has been shown to be free from the shortcomings and drawbacks of the reviewed techniques. It offers one complete solution with all the desirable attributes, naming: 1) it does not use any system specific equations or pre−recorded data, 2) it does not need any mechanical sensor, 3) it intelligently adapts the step size for the fast tracking and as the operating point converges to maximum, the step size automatically reduces to zero — hence keeping the maximum control efficiency without any compromise on the tracking speed, 4) despite the sharp wind changes, the algorithm can drive the system towards the maxima, 5) it has a self-tuning capability to cope with the inconsistent efficiencies and parameter changes in the system.

The basic principle of the novel MPPT algorithm for WECS can be briefly explained via Fig. 1. Fig. 1(a) shows the typical power curves of a wind turbine. The loci of maximum power points (MPP) exhibits a cubic curve characterized by a unique constant k_{opt}. The proposed algorithm first determines this constant online with a novel peak detection technique and then uses this constant for future perturbation by calculating the distance of the current operating point from the cubic optimal curve. The perturbation size and direction, both are adjusted according to the distance vector of the operating point from the optimal curve as shown in Fig. 1(b).



(a) (b)

Fig. 1. Principle of the Novel MPPT algorithm

As shown with the experimental data in this chapter, this optimal cubic curve is not unique for output electrical power where it changes with the change in wind or load. The proposed algorithm has the capability to cope up with this change via self-tuning.

Also the very attractive feature of this algorithm is its sensorless nature. A very simple and smart scheme has been devised to make the algorithm free from mechanical sensors i.e. the wind sensor and generator speed sensor. Wind change is detected from the abrupt variations in the generator speed. Whereas the generator speed is estimated by taking into account the cyclic nature of the generator phase current whose frequency (and hence the number of zero crossings) is directly proportional to the speed of the generator. In contrast with the existing speed-sensorless techniques which require generator model or observer and therefore is applicable to only the machine it is developed for, the sensorless scheme devised here is absolutely generic and can be applied to a wide class of WECS as it does not require any system modelling.

Chapter 5 is on the MPPT in PV energy systems. It details the research work performed to achieve a very efficient maximum power point tracking (MPPT) controller which is not only the fastest than the existing techniques but also can cope with the multiple peaks that can occur in the system due to partial shading or module mismatching. First this chapter presents a critical analysis of the existing techniques published till date on MPPT in PV. Four criteria have been defined for the review which not only form a clear comparison of the existing techniques but also layout the motivation for an improved algorithm. These four review criteria are: 1) system independence of the technique, 2) time lapse to global MPP, 3) sense of tracking direction, 4) complexity of the controller hardware. The review clearly shows that so far there is no technique which possesses all the desirable features like no extra switches, absolutely generic and very simple control, correct sense of tracking direction and fast self tuning capability under the environment changes. Hence an improved very fast, efficient and self-tuning MPPT controller is proposed for PV energy system in this research. The main feature of the proposed algorithm is the One Step Control which directly adjusts the duty ratio of the MPPT controller such that the system reaches the maximum or close in just a single step. Then in order to cope with the non-concavity of the system which may happen due to the partial shading, the controller scans for the global maximum about the local maximum. At the end of the scanning process the controller tracks the global maxima and seizes the further control action until a deviation is detected due to environmental or load change. When such change is detected then the algorithm retunes itself for the new maximum. Hence it offers one complete solution where the other techniques fall short.

Chapter 6 concludes this dissertation with a summary of the research work.

論文審査結果の要旨

近年，地球温暖化対策と脱化石エネルギーの必要性から，太陽光発電や風力発電など，自然エネルギーを利用した発電システムの導入が促進されている．これらの発電システムにおいて，不規則な自然エネルギーを有効に利用するために，日射量や風速に応じて出力を制御する，いわゆる P_{max} 制御が欠かせないが，利用率を向上させるためにはより高速で確実な P_{max} 制御が望まれる．本論文は，比較的小規模な風力ならびに太陽光発電システムを対象に，不規則なエネルギーを効率よく利用するための制御アルゴリズムを提案したもので，全編6章からなる．

第1章は緒言であり，本論文の背景および目的を述べている．

第2章では，風車の出力特性について考察し，これまでの P_{max} 制御における問題点として，急激な風速変化に対する応答遅れを指摘している．また，風車と発電機が接続されたときの運動方程式に基づいて，風力発電システムの動特性を評価するためのシミュレーションモデルを導出している．

第3章では，太陽電池の出力特性に基づいて，複数のモジュールで構成される太陽電池アレイの詳細なシミュレーションモデルを導出している．これは，さまざまな日射条件におけるアレイの出力曲線を求めることができるもので，太陽光発電システムの定量的な評価に有用なものである．

第4章では，風力発電システムにおける効率的 P_{max} 制御法を提案している．これまでの P_{max} 制御は，一定の制御ステップで発電機出力を調整しながら最大出力点を探索する，いわゆる山登り法が主であったが，風速変化が大きい場合には探索に時間を要するという問題があった．本論文では，風車の理想出力曲線において，風速が変化したときの最大出力と回転数の関係がユニークに与えられることに着目し，大域的には回転数から予想される最大出力と実際の発電機出力が一致するように負荷調整を行い，その周辺でローカルな山登り法を適用して最大出力点を探索するアルゴリズムを提案した．サーボモータと永久磁石発電機，整流器ならびにDC-DCコンバータを組み合わせて模擬的な風力発電システムを構築し，実風速のデータに基づいて実験を行ったところ，提案した制御手法によって，風速が急激に変化しても高速かつ確実に最大出力点を探索できることが明らかになった．これは実用的で優れた手法である．

第5章では，太陽光発電システムにおける効率的 P_{max} 制御法を提案している．雲などで太陽電池アレイが部分的に翳った場合には出力曲線に複数の極大点が生じることがあるため，通常の山登り法では真の最大出力点を確実には探索することができない．本論文では，ある日射における最大出力は，そのときの開放電圧と短絡電流の積に実験的な係数をかけることによって大略決定されることに着目し，これに基づいて大域的な出力制御を行い，その周辺でローカルな山登り法を適用することによって最大出力点を探索する．このとき可変ステップで出力調整を行なうことにより，部分日射においても真の最大出力点を探索できるようなアルゴリズムを提案した．これは有用な成果である．

第6章は結言であり，各章の成果をまとめている．

以上要するに本論文は，風力発電や太陽光発電などの自然エネルギー利用システムにおいて，風車や太陽電池の出力特性に着目した大域的な制御とローカルな山登り法を併用することによって，風速や日射状況の不規則な変化に対して高速かつ確実に最大出力点を探索するアルゴリズムを提案したもので，パワーエレクトロニクスならびに制御工学の発展に寄与するところが少なくない．

よって，本論文は博士(工学)の学位論文として合格と認める．