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Review of MPPT Technologies for DFIG based Wind Turbines

[1] Sreenivasulu Meda*, [2] Dr.B.P.Muni, [3] Dr.K.Ramesh Reddy

[1] Research Scholar, JNTUH, Hyderabad, Telangana, India
ORCID ID 0000-0003-4479-9291
[2] Professor, Vasavi College of Engineering, Hyderabad, Telangana, India
[3] Professor, GNITS, Hyderabad, Telangana, India
Corresponding Author Email: [1] m.srinivasulu@staff.vce.ac.in, [2] bpmuni@gmail.com, [3] kollirameshreddy@yahoo.com

Abstract— ***Wind is considered one of the most widely used renewable energy resource for generation of electric power. Among the different configurations of wind generators, doubly fed induction generator is most commercially used generator due to the fact that it has low rated power electronics converters and its ability to generate more than rated power. In order to extract maximum power from generators, maximum power point (MPP) tracking algorithms are employed in wind generators. In this paper, a review of various types of MPP tracking techniques is presented and a comparison of those techniques is also presented.***

Index Terms— DFIG, MPP Tracking, renewable energy, wind.

I. INTRODUCTION

Depletion of fossil fuels, responsibility and awareness on environment, green practises emphasized by government bodies etc., led towards research in electrical generation using renewable resources and the emphasize on these methods of electricity generation is also increasing. The different forms of renewable energy sources for electricity generation are wind, solar, small hydro, bio mass, tidal, geo thermal etc. Among the various renewable energy sources, wind is the most used renewable energy resource in India. According to the annual report of Ministry of New and Renewable Energy (MNRE), by the end of the year 2023, the total renewable energy generation in India was 167GW, out of which wind electricity generation was 41 GW (24.5% of total renewable generation) and was second highest contributor. Hence, more emphasize is given to wind electricity generation. Wind turbines are classified as variable speed and constant speed turbines. Variable speed wind turbines are found to be more efficient when compared to fixed speed wind turbines. Among the various configurations of variable speed wind turbines, doubly fed induction generator based wind turbine is found to be most promising as it can generate power more than rated power and has low rated power electronic converters. The power extracted from DFIG varies with variation in wind speed. The operation of wind turbine is stopped when the wind speed is less than a threshold value or greater than rated wind speed. Within the operating range of wind speeds, for every wind speed, there exist a rotor speed for the power extracted from the generator is maximum. To achieve this rotor speed for all wind speeds, MPPT techniques are employed.

MPP tracking techniques can be classified as conventional, meta-heuristic, intelligent and hybrid techniques. Based on maximum power captured, conventional techniques are classified into two categories namely indirect power control (IPC) and direct power control (DPC). In IPC, the controller function is to maximize the captured mechanical power whereas in DPC the function of the controller is to maximize the output power of the generator. IPC controllers are further classified as tip speed ratio (TSR) control, power signal feedback (PSF) control, optimum torque (OT) control and hybrid control (combination of control techniques) and is as shown below:

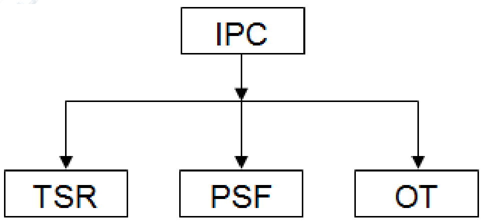

Fig 1: Classification of IPC MPP controls

The advantages of IPC controls are they are fast and simple to implement. However, they require some sensors or information on system parameters.

DPC controllers are further classified as Hill Climbing Search (HCS) control, Incremental Conductance (INC) control and Optimal Relation Based (ORB) control and are as shown below:

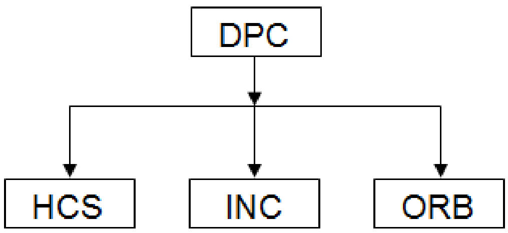

Fig 2: Classification of DPC MPP controls

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The advantage of DPC is they are sensorless methods and hence the cost of the system is less when compared with IPC controls.

Due to random variation in wind velocity, non linear behaviour of system, conventional MPP tracking techniques are either less sensitive to sudden change in wind velocity or unable not track new MPP accurately. Hence, the concept of meta-heuristic optimization techniques was employed in MPP tracking.

To overcome the dependency on wind turbine parameters and to enable fast and accurate MPP tracking intelligent techniques have been employed.

In this paper, a review of these 4 types of MPP tracking controls and their comparision is presented. The remaining of this paper is structured as follows: Section II discusses about conventional controls.. Section III discusses meta-heuristic techniques. Section IV describes about intelligent techniques Section V discusses about hybrid controls. Finally section VI provides a comparision of all the controls and concluding remarks are presented in section VI.

II. CONVENTIONAL CONTROLS

A. Tip Speed Ratio (TSR) Control

In this method, as the wind speed varies, the rotational speed of the generator is varied so as to obtain optimum TSR such that power coefficient (Cp) is at its maximum value [1,23]. To achieve this task, wind speed and turbine speed measurement is required. Also, memory is required to store the optimum values of look-up table.

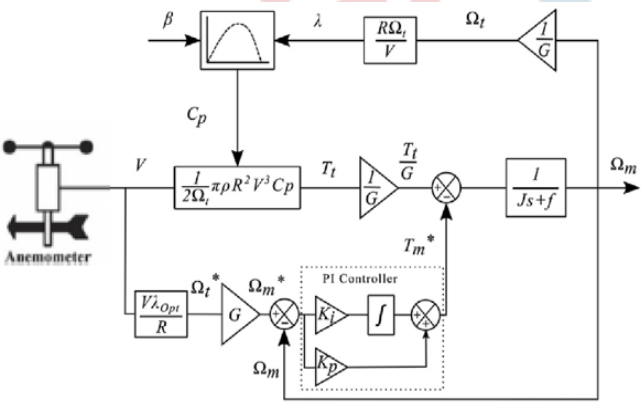

Fig 3: Block diagram of TSR control

Advantages

TSR control is simple, fast tracking and more efficient technique.

Disadvantages

This method has limitations due to measurements or look-up table. Measurements of wind and turbine speed require sensors. As a result, cost of the system increases. Also, the measurement may not be accurate and depends on location and quantity of measuring devices. Look-up table is generated based on the assumption that the turbine parameters are constant. However, these parameters drift from its constant value due to different factors such as air density, aging and varying efficiency of wind energy conversion system. Also, cost of the system increases due to sensors.

B. Power Signal Feedback (PSF) Control

In this method, a look up table is used to store the optimum value of power for various wind speeds. The optimum power is used as reference and control signal is generated so as to track optimum power. The block diagram of PSF control is shown in figure 4.

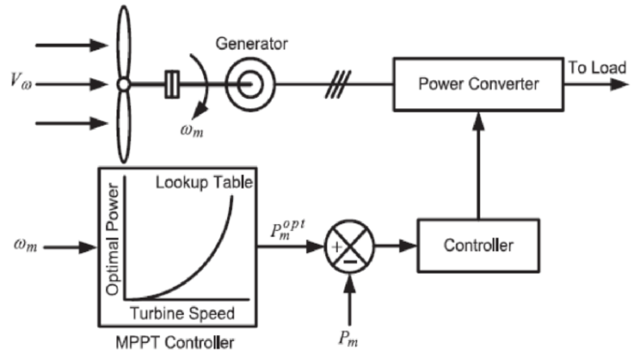

Fig 4: Block diagram of PSF control

Advantages

PSF control is a robust and economic control technique.

Disadvantages

PSF control requires sensor to measure wind speed. As a result, cost increases and reliability decreases. Owing to high inertia of wind turbine, the wind generator speed response is sluggish during sudden change in wind speed. Variation of generator parameters may lead to difference in optimum torque value when compared with look up table.

C. Optimal Torque (OT) Control

OT control is similar to PSF control, with the exception that toque is maintained at optimal value instead of power. Look up table consists of the values of wind speed and corresponding optimum torque which is obtained either by performing hardware experiment or by using simulation. Block diagram for OT control is shown as below.

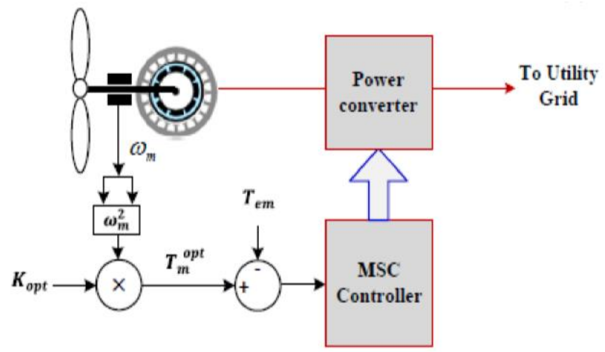

Fig 5: Block diagram of OT control

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Advantages

OT control is a simple, robust and economic control technique.

Disadvantages

This technique requires sensor to measure wind speed. As a result, cost increases and reliability decreases. Owing to high inertia of wind turbine, the wind generator speed response is sluggish during sudden change in wind speed. Variation of generator parameters may lead to deviation of optimum torque value from the reference curve.

D. Hill Climbing Search

In HCS technique, a control variable affecting the power output of generator is varied in steps. As the variable is varied the change in power output is observed. If the power output is increased then the control variable is further increased. If the power output is decreased then the control variable is decreased. The process repeats until maximum power output is reached. The operation of HCS algorithm is as shown in figure 6.

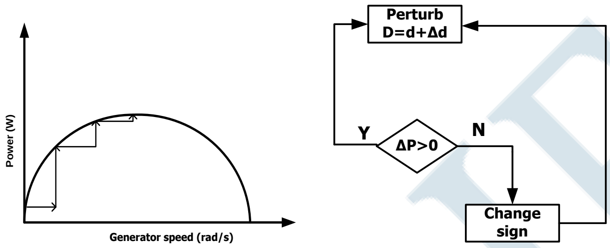

Fig 6: HCS control

Advantages

HCS is a simple technique. It neither requires prior knowledge of turbine parameters nor any sensor.

Disadvantages

In this MPP technique, oscillations are observed around MPP and is not suitable for sudden change in speeds especially at low speeds. Tracking of MPP is not guaranteed.

E. Incremental Conductance control

The electrical output power of a wind generator is a function of DC link voltage.

$$P = viP = vi \quad \frac{dP_{dc}}{dv_{dc}} = \frac{d(vi)_{dc}}{dv_{dc}} = i_{dc} + v_{dc}\frac{di_{dc}}{dv_{dc}}$$

$$\frac{dP}{dv} = i + v\frac{di}{dv} => \frac{di}{dv} + \frac{i}{v} = \frac{1}{v}\frac{dP}{dv}$$

For maximum power output,

$$\frac{di}{dv} = -\frac{i}{v}$$

From the above equation in can be concluded that the slope in power vs voltage characteristic is zero when MPP is reached, positive on RHS of MPP and negative on LHS of MPP. This is depicted in figure 7. Also, when the power output is far from MPP step size is large and MPP tracking is faster. However, as actual power output approaches MPP, step size is smaller and as a result oscillation around MPP is reduced.

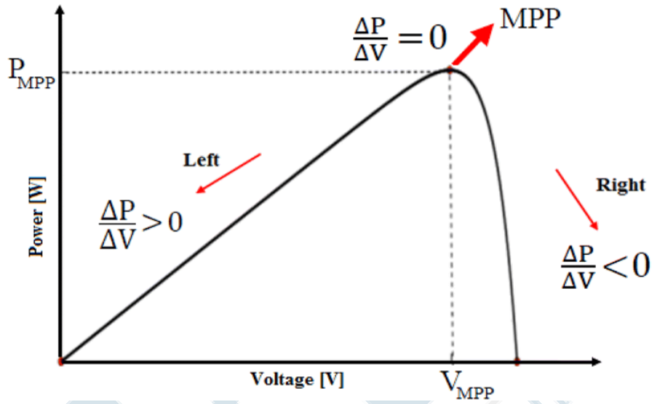

Fig 7: INC control

Advantages

This is a simple technique. Sensor is not required and as a result reliability and efficiency of algorithm is increased.

Disadvantages

Step size variation is limited and is dependent on parameters of the generator.

F. ORB control

Control techniques uses optimum relation between parameters of wind turbine such as power and torque, power and speed etc.

Advantages

ORB control does not require any sensor and also have fast response.

Disadvantages

More memory is required to store data of pre – determined curves.

III. META – HEURISTIC CONTROL

To track MPPT efficiency by optimizing search, meta – heuristic algorithms such as Particle swarm optimization, Grey Wolf, Ant colony, Artificial bee colony etc. are employed by various researches. In these techniques, particles are placed randomly on power – speed curve of a wind generator and particles are moved towards MPP by adjusting the movement of the particles in each iteration based on local best and global best particles.

Advantages

Efficient searching of MPPT

Disadvantages

Oscillations are observed around MPPT point. Convergence takes time depending on the size of population.

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IV. INTELLIGENT CONTROL

Due to erratic wind speed and non – linear behaviour of the system intelligent techniques such as Fuzzy logic, Artificial neural network, Genetic algorithm, Machine learning etc are employed for accurate MPP tracking. These techniques are employed in two methods. In the first method, conventional PI controllers employed in controlling of converters are replaced with these intelligent techniques and the gains of the controllers are also adjusted online. In the second method, the reference values of currents in the converter controllers are generated by using these intelligent techniques and are compared with actual values. The error is given to PI controllers for corrective action and is shown in figure 8.

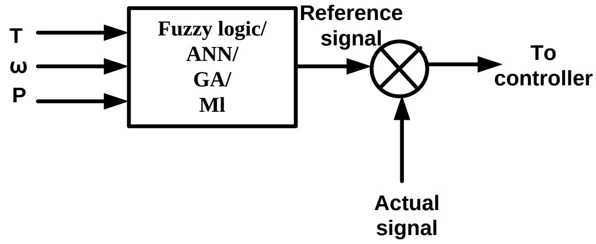

Fig 8: AI control

V. HYBRID CONTROL

Hybrid MPPT controls combined feature of any of the above discussed control techniques to have better dynamic as well as steady state performance in achieving MPPT. Some combinations for hybrid controls include TSR and HCS, PSO & HCS, Fuzzy & ANN, PSO & ANN, OTC & ANN etc.

VI. COMPARATIVE ANALYSIS

A comparative analysis of the techniques is tabulated in table1.

Table 1

Technique	Complexity	Convergence	Measurements required	Memory required	Dynamic performance	Efficiency	Oscillations around MPP
TSR	Simple	Fast	Yes	No	Moderate	High	Do not occur
PSF	Simple	Fast	Yes	No	Moderate	Moderate	Do not occur
OT	Simple	Fast	Yes	No	Moderate	Moderate	Do not occur
HCS	Simple	Fast	No	No	Moderate	Low	Occurs
INC	Simple	Low	No	No	Moderate	Low	Occurs
ORB	Simple	Medium	No	Yes	Moderate	Moderate	Do not occur
PSO	Moderate	May vary	No	Yes	May vary	Moderate	Occurs
Fuzzy Logic	High	Medium	May vary	Yes	Good	High	Do not occur
ANN	High	Medium	May vary	Yes	Good	High	Do not occur
GA	Simple	Fast	May vary	Yes	Good	High	Do not occur
ML	High	Fast	May vary	Yes	Good	High	Do not occur
Hybrid	High	Fast	May vary	May vary	Good	High	Do not occur

VII. CONCLUSION

Wind energy is one of the most promising form of energy for electrical power generation. This paper presents a review of MPPT technique from conventional to advanced techniques. Conventional techniques are found to be simple but they suffer from one of the disadvantages such as low convergence speed, sluggish response, oscillations at MPP etc. Advanced techniques employing intelligent control are complex to implement and require design experience. However, they offer the advantage of high efficient tracking and good dynamic response. Finally, in the present state of art, hybrid controls techniques are dominating as they are capable of giving better steady state and dynamic performance with low cost.

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