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RESEARCH ARTICLE

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A STUDY OF VARIOUS CONVENTIONAL METHODS IN TRACKING OF MAXIMUM POWER IN VARIABLE SPEED WIND TURBINE SYSTEM

S.PRAGASPATHY[1]*, Dr.B.ANAND[2], C.M.SIBU[3]

[1]Assistant Professor, [2]Associate Professor, [3]UG scholar,

Department of Electrical and Electronics Engineering, Nehru Institute of Engineering and Technology affiliated to Anna University - Chennai, Coimbatore, Tamilnadu, India

S.PRAGASPATHY

Dr.B.ANAND

C.M.SIBU

ABSTRACT

An efficient controller to track the maximum power point of a variable speed wind energy conversion system (VSWECS) incorporating permanent magnet synchronous generator (PMSG) is presented in this paper. The power extracted from the turbine is affected by various voltage ripples present in the DC link of the system. So many new techniques and innovations has been introduced in short frequency so that fluctuations are stabilized both at PMSG end and converter end. Here in this paper a detailed study on various maximum power point tracking (MPPT) algorithm has been surveyed and introduced an adaptive mechanisms to track the MPP along with the ripple reductions. The proposed method is implemented, analyzed and verified in MATLAB/SimPowerSystem. The simulation results obtained shows the effectiveness of the proposed control strategy for WECS based on the PMSG.

Key Words—MPPT, PMSG, WECS, Ripple reduction, VSWECS.

I. INTRODUCTION

Wind power has become a rapidly growing technology for distributed power generation producing 300 GW by 2014. Out of which 45 GW (19 %) capacity has become operational in 2014 alone, adding the highest generation by any renewable source. In the WECS, the variable speed system is the dominant technology compared to the fixed speed system. Although the fixed speed systems are robust and reliable, the power captured by them is sub optimal and reactive power compensation is required. Whereas on the other hand the VSWECS is designed to operate at a wide range of speeds facilitating to extract the maximum power from a given wind speeds resulting in higher efficiency and lower mechanical stress on the system.

Nowadays, from the existing variable speed wind power generators, PMSG with multiple pole is considered for the VSWECS design. Its features like elimination of the gear box, lower operating speeds with smaller pole pitch and the self-excitation capability of the PMSG with lighter weight and lower maintenance leads to high power factor and efficient operation. In the current state of art for the power converters integrating the WECS to the grid, the ac-dc-ac configuration with the boost converter is the optimum available topology considering the cost and voltage stress on the DC-DC converter. The boost converter controls the speed of the turbine regulating the duty cycle (D) and the inverter stabilizes the output to the grid at the point of common coupling regulating the modulating index (M).

The boost converter and the inverter are coupled with a large capacitor known as DC link which is responsible for buffering the pulsating component of the power. This pulsating component of power is very clearly seen in a single phase inverter system compared to three phase inverter system. In general the larger capacitors in use are electrolytic capacitors which are bulky and less reliable, thereby reducing the reliability of the entire system. In order to overcome the reliability problem, the new film capacitors are replacing the electrolytic capacitors. But these capacitors are very costly compared to the electrolytic capacitors increasing the cost of the system. So, the optimum solution is to reduce the ripples with the help of power conditioning units such as DC-DC converters or inverters and use lower capacity thin film capacitors increasing the reliability of the system.

There are DC link reduction control algorithms proposed with controlled rectifier and inverter circuits with a DC link. But these controllers are proposed for DC link reduction alone without any MPP tracking ability. Since the wind power systems operate in the range of MW, the power loss without incorporating a MPP tracker is not affordable. There are many maximum power point tracking (MPPT) algorithms proposed and compared. The MPPT algorithms are broadly classified as tip speed ratio control (TSR), power signal feedback (PSF) and hill climb search (HCS) algorithm. The TSR method is simple to implement but it needs an additional anemometer for the wind speed measurement increasing the cost. Modifications for the TSR method have been developed named as adaptive TSR which can estimate the wind speed instead of actually measuring it removing the anemometer. But, the wind estimation cannot be accurate, and the controller complexity has been increased resulting in higher computation time and cost of the controller. The lookup table based techniques require a pre-programmed 2D look table with stored values of optimal generator speed and corresponding maximum power at various wind velocities. But due to the non-negligible inertia of WECS, the generator speed does not change relatively as compared to the change in wind. The most widely used one is the hill climbing search algorithm (HCS) and its modifications. These algorithms provide good results for stable and very slow wind changes. But there are always the disadvantages like perturbation step size and speed efficiency trade off, oscillations at the steady state.

The method proposed in this paper is an attempt to avoid the constraints or disadvantages posed by the earlier discussed MPPT methods and incorporate the DC link reduction control, making the system more economical and reliable. The proposed MPPT controller is system independent and does not require any additional equipment like anemometer or lookup tables. This is achieved with a simple boost converter circuit without adding any complexity to the system.

II. PROPOSED WIND ENERGY CONVERSION SYSTEM

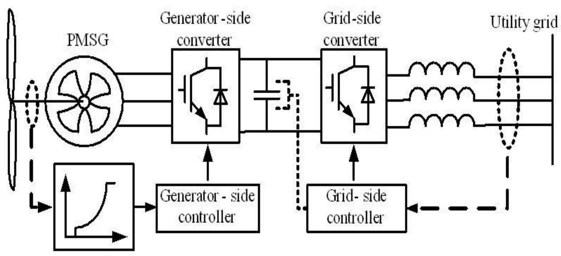

Fig.1 A Simple Schematic block - WECS

The block diagram of the proposed WECS is illustrated in Fig. 1. The proposed system consists of the rectification, boost and inverter stages connected to the grid with the help of a LC filter. The rectification stage consists of an uncontrolled rectifier, producing a dc voltage V_{dc} proportional to the speed of the generator ω_m. The boost stage performs the MPPT and V_{dclink} link ripple reduction along with boosting the voltage. The inverter performs the phase locked loop technique and synchronizes the output of the inverter with the grid. The output is filtered with the help of an LC filter before connecting it to the grid. The measured and controlled quantities are V_{dc} and current I_{dc} from the rectification stage for MPPT and dc link ripple reduction.

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III. MPPT CONTROL

The permanent magnet synchronous generator (PMSG) is favored more and more in developing new designs because of higher efficiency, high power density, availability high energy material at reasonable price and possibility of smaller turbine diameter in direct drive applications. Presently a lot of research efforts are directed towards designing of WECS which is reliable having low wear and tear, compact, efficient, low noise and maintenance cost. WECS with all these properties is realizable in the form by using PMSG wind energy conversion system.

There are three commonly used configurations for WECS with these machines for converting variable voltage and variable frequency power to fixed voltage and fixed frequency power.

A. Tip Speed Ratio Control

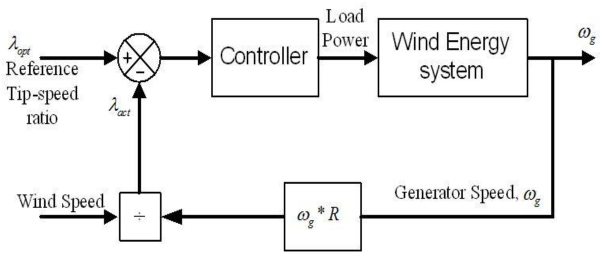

Fig. 2 TSR based MPPT control module

A wind speed estimation based TSR control is proposed which is used in tracking the peak power points. The wind speed is estimated using neural networks. By using the estimated wind speed and knowledge of optimal TSR, the optimal rotor speed command is computed. The generated optimal speed command is applied to the speed control loop of the WECS control system.

The controller controls the actual rotor speed to the desired value by varying the TSR of the system proposed. The mechanical output power at a given wind speed is drastically affected by the turbine's tip speed ratio (TSR).The TSR is defined as the ratio of turbine rotor speed to the wind speed. At a given wind speed the maximum turbine conversion efficiency occurs at an optimal TSR. Therefore as the wind speed changes, accordingly in order to maintain the optimal TSR the rotor speed is controlled by the controller.

In the given module, the TSR is given as the reference to the controller which produces the optimum power accordingly. The generator speed and the wind speed are compared and the difference is applied to the comparator which compares it with the TSR . The control target of the controller is the output power delivered to the load. Thus, the optimum power is obtained from the TSR that is given as the input to the activating system.

B. Hill Climbing Search Control

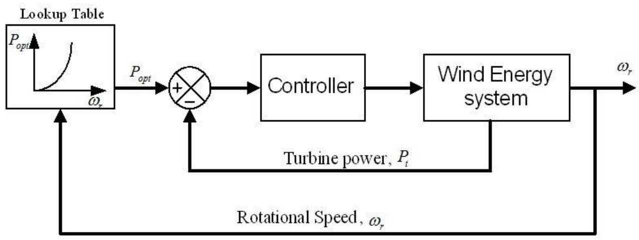

Fig. 3 HCS based MPPT control module

The control algorithm for the hill climb search module uses the principle of search-remember-reuse technique. The method uses memory for storing the peak power points, obtained during the experimenting process, which are later used for tracking maximum peak power points. The optimum speed and its corresponding peak power is tracked & stored in a format called as the look up table. The rotational speed of the turbine is noted down in the lookup table. The corresponding power is tracked from the look up table and is generated. The controller controls the peak power and maintains it upto the limiting value in bringing out an optimum power output. The HCS module is proposed in such a way that it continuously searches for the corresponding peak output power of the wind turbine. It can overcome some of the common problems that is faced by other methods of MPPT tracking. The tracking algorithm, depending upon the location of the operating point and relation between the changes in power and speed, computes the desired optimum signal to derive the system to the point of maximum power.

C. *Power Signal Feedback Method*

The turbine power equation is used for obtaining reference power for PSF based MPPT control of PMSG WECS. The PSF control block generates the reference power command P_{ref} which is then applied to the grid side converter control system. The wind speed is used as the input in order to generate the reference power signal. The actual power output of the rectifier P_r is compared to the reference power

P_{ref} and the required maximum peak power is generated.

$$P_{opt} = K_{opt}\omega_r^3$$

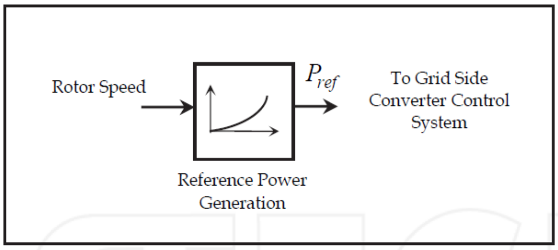

Fig. 4 PSF based MPPT control module

D. Wind Prediction Control Scheme

In controlling the PMSG load line so that it matches closely to the maximum power of the turbine generator, it is essential to know the wind speed. For the sensor less control strategy, here no anemometer is required to provide the controller with the wind speed conditions; therefore, it is essential to forecast the wind speed. To predict the wind speed from the earlier data, various techniques are available. A method called Autoregressive statistical models are commonly used for the wind speed prediction. In this prediction method, the control strategy required details of the WECS mathematical model in the control systems. A block diagram of the wind prediction for the sensor less WECS-controlled system is shown. The prediction control system considers the previous set of time frame energy captured from the WECS to predict the wind speed value for the next time frame set. Since the wind prediction system requires previous data, time frame sets were investigated, namely, the 30-s and 60-s wind prediction. The accuracy of the wind speed prediction depends on the coefficient index, linear prediction coefficient, and sampling time of the past value of the wind speed inferred from the turbine output. A higher degree of wind speed prediction accuracy may be achieved by using higher order statistical models and the WECS mathematical model in the control system. This, however, demands complex computation and adds to an increase in the cost of the controller. An acceptable level of performance can be obtained by using set ranges of wind speed. Using this methodology, calculation of wind speed can be carried out independently and the result used to correct the inverter input in a small number of ranges. In this paper, two such scenarios are considered, that is, having either three-wind-speed or five-wind speed ranges. The operating voltage of the CCI is targeted at three or five ranges optimum wind speed, depending on the 30-s and 60-s wind speed prediction. So when comparing all the methods of tracking power there is some disadvantages in each case, here by the introduction of some new techniques named adaptive MPPT, capacity of tracking power increases to some extent.

III. FIRING PULSE GENERATION

In this section the determination of duty cycle to reduce the DC link ripple and track the MPP of the WECS by following the optimum cubic curve is shown. Initially the duty cycle D1 is set to an arbitrary value within the limits of 0<D1<1.Here V_r and I_r are the voltage and current drawn from the rectifier and P_r is obtained as the product of these values. P_r is calculated along with its corresponding ω_{opt1} to follow the optimal cubic curve. The boost converter output voltage is always greater than the input voltages. The output voltage (V_{dc}) can be varied from the input voltage (V_r) upto several times the input voltage. The duty cycle of the boost converter is calculated as follows:

Let V_{dc} be the output voltage of the boost converter, then

$$\frac{(Vdc - Vr)Toff - VrTon}{T} = 0 \quad (1)$$

Where,

T_{off} is off time period of the switch S

T_{on} is on time period of the switch S

T is the time period ($T = T_{on} + T_{off}$)

$$V_{dc} = V_r * \frac{T}{Toff} \quad (2)$$

The duty cycle is given as

$$D = \frac{Ton}{T} = 1 - \frac{Toff}{T} \quad (3)$$

$$\frac{T}{Toff} = \frac{1}{1-D} \quad (4)$$

$$V_o = V_{dc} = V_r * \frac{1}{1-D} \quad (5)$$

When the duty cycle changes, the slope of the load also changes according to the changes seen in the turbine and the new operating point is obtained.

Also consider duty cycle is unity i.e $T = T_{on}$ corresponding to the new input or rectification proportional to the rectification or the input voltage Value from the above equation is voltage say V(i + 1).

Now the operating point of the system will be new instead of as that is just a virtual point measured and the operating point can only be on the P-ω curve. As the slope of the load line is adjusted with the help of the new duty cycle to be coinciding with rotor speed ω_{opt1} the operating point will be the intersection of the load line with new slope and the P-ω curve. This process continues till the rotor speed coincides with the optimum curve rotor speed. While the duty cycle is operating at duty cycle d(i) , the next iterative duty cycle d(i + 1) is calculated during the i^{th} iteration taking the reference of ω_{opt} (i + 1).

IV. IMPLEMENTATION, RESULTS AND DISCUSSIONS

The proposed work is implemented in MATLAB/SIMULINK and its simulation diagram is shown in figure 5. For tracking the maximum power from the wind, an adaptive controller is presented. The controller tracks the maximum power with respect to the speed of the wind generation system. The simulation diagram for the main wind generation system with PMSG is shown in figure 6 as result.

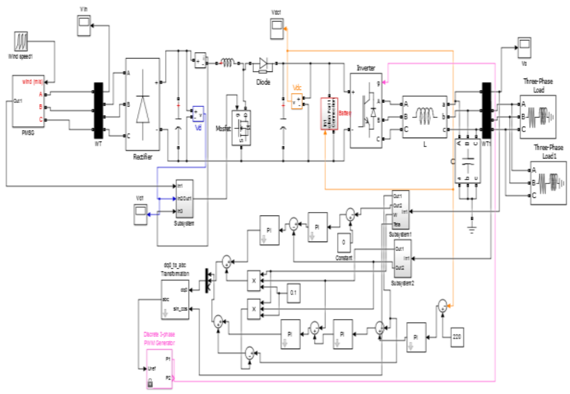

Fig. 5 MATLAB Implementation Circuit

The diagram for the estimation of rotor speed is shown in the subsystem. The various results obtained from the simulation diagram are shown below. Corresponding to source (wind power) the output of wind speed, rotor speed, pitch angle and torque in the wind turbine model will varies accordingly. The output from the PMSG is represented as generator terminal and generator terminal 2 respectively. In figure shown below the overall output of the wind generation system is given. Figure also shows the output voltage of uncontrolled rectifier and the voltage source inverter. The maximum power tracked from the wind using new adaptive MPPT controller is shown in the result. The maximum output power from the wind is evaluated using MPPT controller. Turbine and generator torque also shown in the below figures.

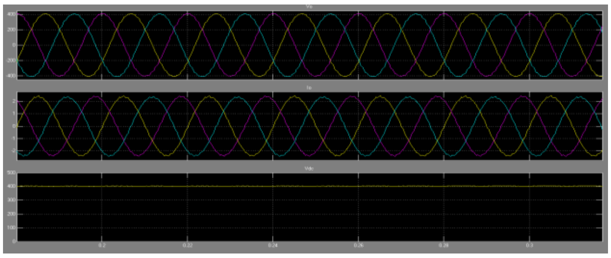

Fig. 6 Inverter and DC-DC converter output voltage

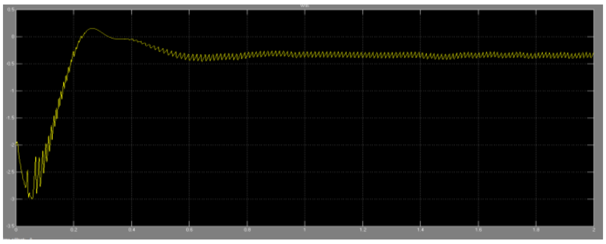

Fig. 7 Generator terminal speed

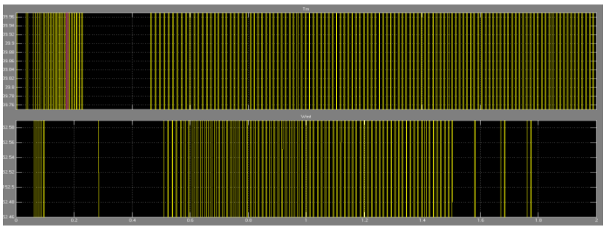

Fig. 8 Turbine and Generator torque

VII. CONCLUSION

In this paper a new Adaptive MPPT control and ripple reduction technique for a variable speed PMSG wind energy conversion systems has been presented. The controller follows a optimum algorithm to track the MPP. The ripple components with twice the fundamental frequency appear in the dc link also mitigated here. So, a controller is proposed to compensate any frequency on dc link, by taking the error information from the dc link which has to be corrected. From the detailed study of various algorithms, the regulation of the duty cycle is designed in such a way that it tracks the MPPT and reduces the ripple content simultaneously. The results show that the proposed algorithm is simple to implement and performs with high efficiency making the WECS more reliable and economical for usage.

APPENDIX

PARAMETERS OF TURBINE SYSTEM

Wind Turbine	
Air Density	1.23 Kg/m^3
Swept Area	1.450 m^2
Radius of Blade	0.55 m
Blade efficiency	0.35 to 0.40
Lift coefficient	0.70
Base speed of wind	10 m/s
Power Coefficient	Function of λ, β

PARAMETERS OF GENERATOR SYSTEM

Permanent magnet Synchronous Generator	
Number of Phases	3
Back EMF	Sinusoidal
Rotor	Round rotor
Stator resistance per phase	3 Ohm
Stator Inductance	0.0008 H
Flux linkage	0.206
Pole pairs	4
Rated Torque	1.2405 Nm

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BIOGRAPHIES

First author (corresponding author)

S.Pragaspathy* was born in September 21, 1985 in Tamilnadu, India. He received his B.E degree in Electrical & Electronics Engineering from Hindusthan college of Engineering and Technology, Coimbatore, Tamilnadu, India, in 2008, M.E degree in Power Electronics and drives from Anna University, Coimbatore, India, in 2011. He is currently working as Assistant Professor of Electrical and Electronics Engineering at Nehru Institute of Engineering and Technology, Coimbatore, Tamilnadu, India. He has presented his papers in more than 10 national and international conferences and published a research paper in a national level journal. His current area of research includes Renewable energy technology, Modeling of Wind turbine generators, Power converters, Electrical Machines and drives, Control systems.

B.Anand was born in March 10, 1979 in Tamilnadu, India. He received his B.E degree in Electrical Engineering from Government College of Engineering, Tirunelveli, Tamil Nadu, India, in 2001, M.E degree in Power Systems Engineering from Annamalai University, Tamilnadu, India, in 2002 and Ph.D. degree in Electrical Engineering in 2011 from Anna University, Chennai, India. He is member of IEEE and reviewer of Taylor and Francis journal. His research has been presented and published in more than 25 international conferences and journals.

Dr.B.Anand is having more than 12 years of teaching experience and currently working as Associate Professor of Electrical and Electronics Engineering, Hindusthan College of Engineering and Technology, Coimbatore, India. His research interests include the development of hybrid intelligent system algorithms and application to the power system control problems.

C.M Sibu was born in September 22, 1994 in Tamilnadu, India. He is Pursuing his final year B.E in Electrical and Electronics Engineering at Nehru Institute of Engineering and Technology, Coimbatore, Tamilnadu, India. He has Published 10 research papers in various National and International Journals. Presented Research articles and short research notes in NIT, Meghalaya and JNU, New Delhi. His area of research interests includes, Renewable Technology, Human Machine Interface and Power Networks.