

SENSORLESS FUZZY-LOGIC-BASED MAXIMUM POWER POINT TRACKING CONTROL FOR A SMALL-SCALE WIND POWER GENERATION SYSTEMS WITH A SWITCHEDMODE RECTIFIER

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Abstract:

A fuzzy inference system (FIS) based sensor less maximum power point tracking (MPPT) algorithm has been proposed. The Fuzzy based controller has the ability to track the maximum power point (MPP) and the corresponding rotor speed of the wind generator by estimating wind speed with very little error compared to the conventional MPPT techniques. The algorithm developed is based on two series fuzzy networks, one for wind speed estimation and the other to determine the maximum power point and the corresponding rotor speed. The method demonstrates remarkable performance in estimating wind speed and to predict MPP accurately without undesired oscillations around maximum power point. The algorithm does not require any mechanical sensor for wind speed measurement. Nonlinear time domain simulations have been carried out to validate the effectiveness of the proposed controllers under different operating conditions. Simulation results confirm the effectiveness of the proposed MPPT controller in tracking the maximum power point under rapidly changing wind conditions.

Keywords: *Sensor less Fuzzy MPPT, Permanent magnet synchronous generator (PMSG), Switch mode rectifier*

I. Introduction

Zero net energy buildings which have its cumulative energy consumption being met by renewable energy sources installed within its precincts have become increasingly popular [1]. These distributed generators (DGs) require new power electronic interfaces and control strategies to improve the efficiency and quality [2, 3]. DG systems based on a single intermittent source, either photovoltaic (PV) or wind energy system are unreliable due to seasonal variations. DG systems consisting of two or more renewable sources have a higher reliability, due to the complementary nature of the resources [4, 5]. In such hybrid schemes, permanent magnet synchronous generators (PMSG) are generally employed, as they do not require any reactive power support. Further, PMSG can be driven directly by wind turbine, thereby avoiding a gear box arrangement which requires regular maintenance [6]. Moreover, PMSG can be operated in higher power factor and higher efficiency than other machines because of its self-excitation

property [7]. Various possible combinations of hybrid PMSG-PV systems are illustrated in the literature. Earlier, a six-arm converter topology was attempted, in which the outputs of a PV array and wind generator were subjected to a boost operation through individual switches to match the DC bus voltage [8]. In [9], a hybrid wind-PV system along with battery was explained, in which both the sources were connected to a common DC bus through individual power converters, then the DC bus was connected to the utility grid through an inverter. Grid connected PMSG-PV hybrid system with battery backup was described in [10], where the DC link voltage was fixed to battery voltage, but the maximum power extraction from wind-driven PMSG was not performed. A grid connected hybrid system where the PV array and wind-driven PMSG were connected to a common DC link through a multi-input DC-DC converter was proposed earlier in [11]. A PMSG – PV hybrid system with multi-input DC- DC converter and multi-input inverter was also brought out in [12].

II. Wind Generator Power Supply (PMSG)

a) Introduction

From all the generators that are used in wind turbines the PMSG's have the highest advantages because they are stable and secure during normal operation and they do not need an additional DC supply for the excitation circuit (winding) . Initially used only for small and medium powers the PMSG's are now used also for higher powers. With the developments in permanent magnetic materials in recent years, the performance of PMSG based wind turbine systems have been improved and they are widely used. These systems require neither slip rings nor an additional power supply for magnetic field excitation. They can also operate in a relatively wide range of wind speeds. Therefore, their efficiency is known to be higher than that of any of the aforementioned wind turbine systems. The power converter with wind turbine is shown below in figure1.

However, a PMSG based wind turbine system requires a full-scale power converter which directly connects the generator to the grid. The rating of the power converter is usually limited by available semiconductor technology. One effective way of reducing the power converter's rating requirement is to connect multiple power converters in parallel. If three power converters are connected in parallel, then the capacity of each power converter can be reduced to one third of the total capacity of the wind turbine system [15].

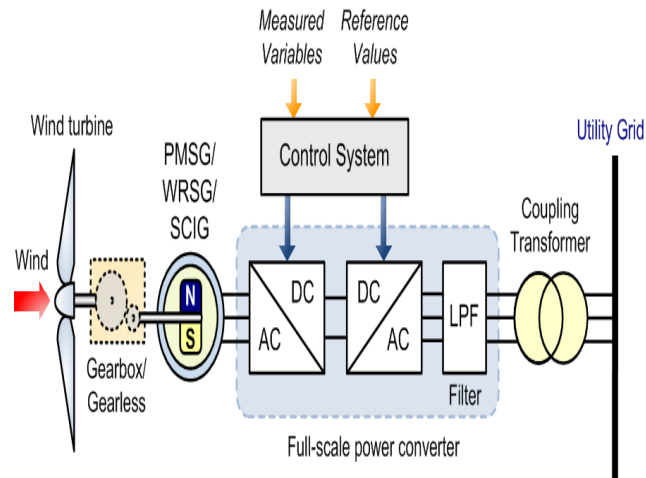


Fig 1 Conventional Wind Turbine with Power Converter

b) Permanent Magnet Synchronous Generator (PMSG)

The PMSG is a regular Synchronous Machine, where the DC excitation circuit is replaced by permanent magnets, by this eliminating the brushes. Without the brushes and the slip rings, and because of the permanent magnets, the PMSG has a smaller physical size, a low moment of inertia which means a higher reliability and power density per volume ratio [6]. Also by having permanent magnets in the rotor circuit, the electrical losses in the rotor are eliminated. Due to the mentioned advantages, the PMSG are becoming an interesting solution for wind turbine applications. The construction of PMSG is shown below in figure2.

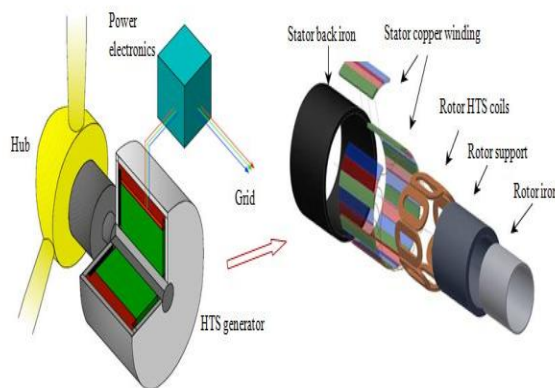


Fig.2 Construction of Permanent Magnet Synchronous Generator

However, the disadvantages of the permanent magnet excitation are high costs for permanent magnet materials and a fixed excitation, which cannot be changed according to the operational point.

C) Maximum power point tracking

Maximum power point tracking (MPPT) is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels, though optical power transmission systems can benefit from similar technology. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. The waveform of MPPT is shown figure 3. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

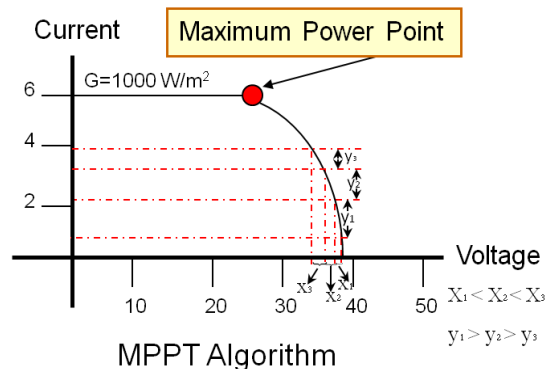


Fig.3 Maximum power point tracking waveform

- Solar inverter converts the DC power to AC power by performing MPPT process: Solar inverters sample the output Power (I-V curve) from the solar cell and apply the proper resistance (load) to solar cells to obtain maximum power.
- MPP (Maximum power point) consist MPP voltage (V mpp) and MPP current (I mpp). It is the capacity of the solar panel and higher value can make higher MPP.

Classification of MPPT

a) Perturb and Observe

In this method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. This is called the perturb and observe method and is most common, although this method can result in oscillations of power output. It is referred to as a *hill climbing* method, because it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

b) Sensor less Fuzzy MPPT

By assuming that the synchronous reactance and the DC-link voltage are almost constant, the back EMF (E) and the terminal voltage (V_g) of the PMSG are changed by the duty-ratio control of the SMR. If the back EMF (E) and the terminal voltage (V_g) are changed to the E' and $V' g$ by the control of the SMR, stator current (I_g) of the generator is also changed to $I' g$. Thus, power of the generator can be controlled by the duty-ratio control of the SMR. Consequently, the generator can be operated at the optimal operating point using the proposed MPPT control under the given wind speed condition.

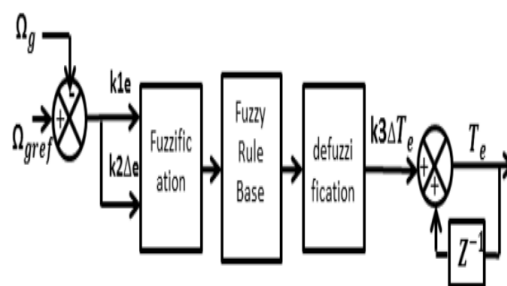


Fig4. Block Diagram FIS

$k_1 e$ / $k_2 \Delta e$	NB	NS	EZ	PS	PB
NB	NB	NB	NS	NS	EZ
NS	NB	NS	NS	EZ	PS
EZ	NB	NS	NS	EZ	PS
PS	NS	EZ	PS	PS	PB
PB	EZ	PS	PS	PB	PB

Fig5. Fuzzy Decision making rules

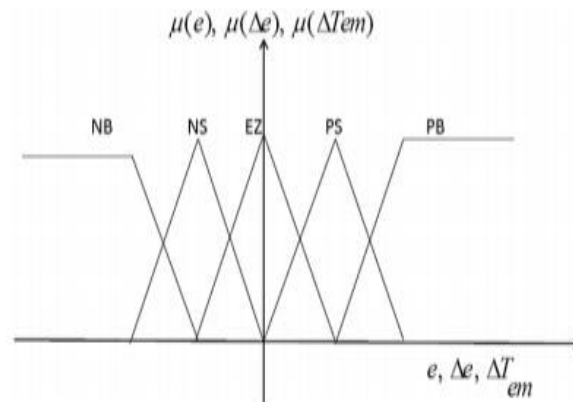


Fig6. Fuzzy membership functions

III. Proposed Wind energy system

The proposed SMR system is composed of a three-phase diode bridge rectifier, a single diode, and a power switch. This system is similar to a system with a boost converter; however, in comparison with the conventional system, the proposed system is much more economical and efficient because the large inductance of the PMSG can be used as the input inductor of the boost converter, as shown in Fig. 4a. The voltage magnitude and frequency of the generated power are determined by changes in the wind speed. If the wind power generator is directly connected to a grid, various problems can occur. Thus, a GSC is required for efficient power transfer and economic power generation. This GSC performs phase-angle detection, unity power-factor control, and DC-link voltage control. To perform the proposed MPPT control, power of the GSC

is used. The FLC for the MPPT control operates on the same principle as the P&O controller, conducting constant perturbations of the duty cycle to track the MPP. To implement sensor less MPPT control, the voltage and current measurement of the GSC are used to calculate power. Using the difference between the current and past values of the measured power, the duty ratio of the SMR is controlled by the variable step size, and the generator is driven at a speed determined by the output of the optimal duty ratio. In this paper, the fuzzy membership functions are selected in the form of a triangle for simplicity because they are simple and do not require many computational resources.

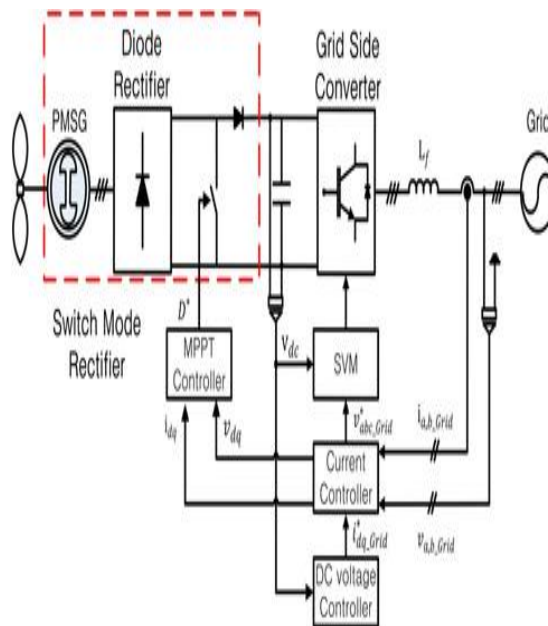


Fig 7 Proposed WECS with switch mode rectifier and sensor less fuzzy MPPT

IV. Simulation Results and Discussion

Simulation result of a sensor less fuzzy based MPPT for PMSG wind power generation using single switch mode rectifier for voltage boosting and inverter for grid interface is verified with R-load performance. The sensor less MPPT scheme with single switch mode rectifier and simulation results is shown below in figure 8 to 13.

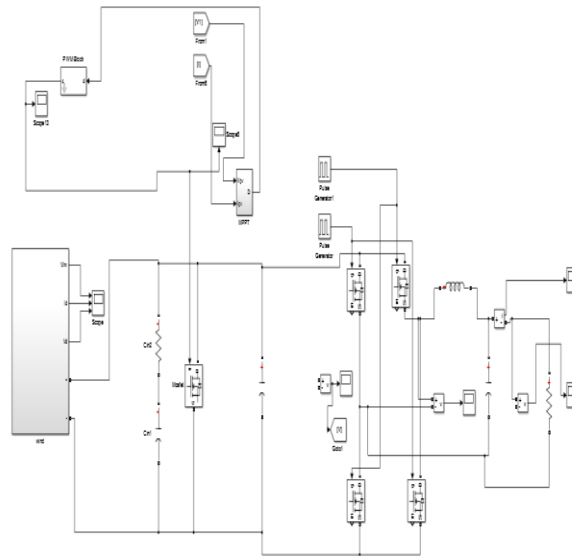


Fig8 Simulation circuit of proposed system

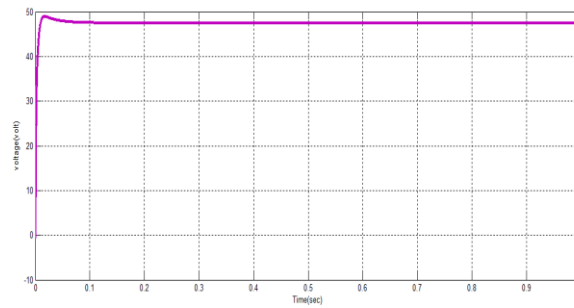


Fig 9 Dc link Voltage

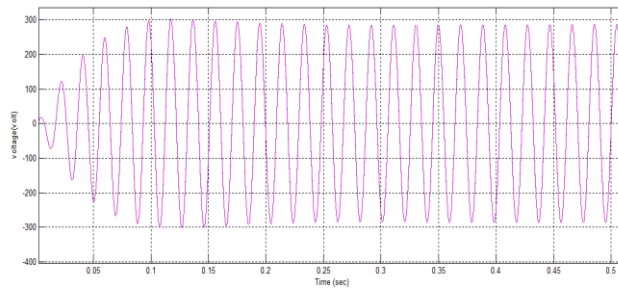


Fig 10 Proposed wind output

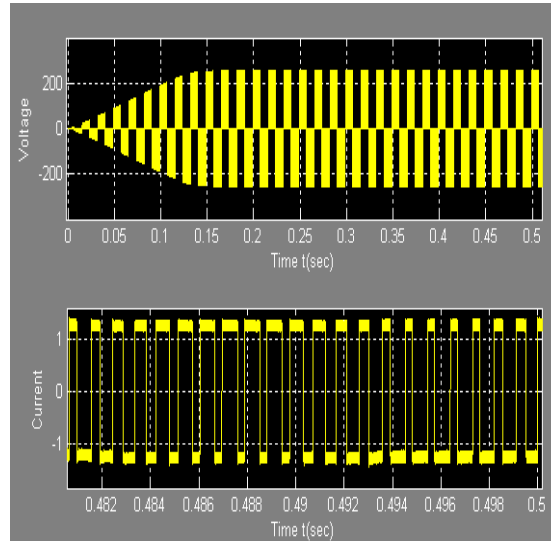


Fig 11 Inverter output voltage and current

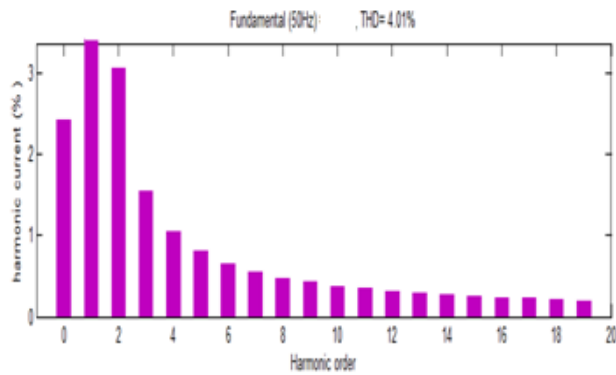


Fig 12 THD performance

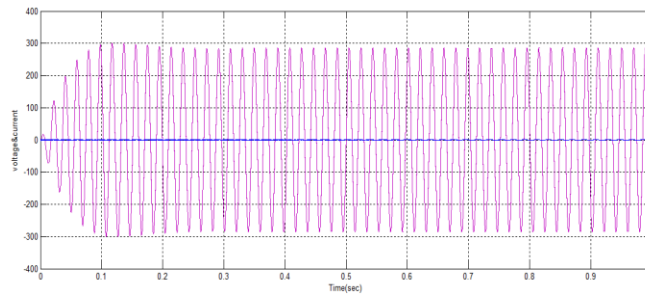


Fig 13 PFC performance

V. Conclusion

In this paper a sensor less fuzzy based MPPT was proposed for PMSG wind power generation. A conventional boost converter is replaced by a single switch mode rectifier which ensured improved performance with lesser passive components and sensor less MPPT system extracted high power even with low speed working condition of PMSG. The SSC has been controlled, using a speed fuzzy logic controller, in such a way to permit to the wind system to track its maximum power operating point for a wide range of wind speed and ensure the MPPT strategy. The GSC is controlled also by using another fuzzy logic regulator to ensure a smooth DC voltage between the two converters (SSC and GSC). As perspectives, a coordinated control, between the SSC and the GSC, can be proposed for MPPT active power production and power quality improvement, without any system over rating. Elsewhere, the WECS can be also controlled to operate in standalone mode.

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