Control System for Wind Energy Conversion Using Neuro-Fuzzy Logic

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Abstract:

In this study, we suggest a new adaptive control technique for wind energy conversion systems utilising permanent magnet synchronous generators. When the characteristics of the system being managed change over time or are originally unknown, the controller must employ a type of control known as adaptive control. These types of generators can only be integrated into the grid with the help of a full-rated AC/AC converter, which is often based on voltage source converter technology (VSC). To regulate both active and reactive power, voltage source converters are available. At the heart of the adaptive control technique is a self-tuning adaptive PI that is informed by a linear approximation of the power system at each sampling interval. Wind resources may be easily plugged into existing electrical grids with the use of adaptive control. In order to lower the voltages after a problem, a model reference is also provided. The benefits of the suggested control are shown through simulation.

Keywords: wind energy, converter, voltage, electrical grids and simulation

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1. Introduction

Wind power, often known as wind energy, is the electricity generated by turning wind turbines. Many individual wind turbines may be found in large wind farms, and all of them are wired into the electrical grid. Wind power is a viable fossil fuel alternative since it is cheap, abundant, widely available, renewable, clean, generates zero greenhouse gas emissions during operation, and necessitates minimal land usage. When compared to other forms of energy production, wind power has a highly stable output from one year to the next, but substantial variance on shorter time periods. It's possible that as a region's reliance on wind power grows, there will be a corresponding rise in grid upgrades needed and a decrease in its capacity to completely replace conventional output. Maximum power production (or rated power) of a wind turbine is obtained at a specific wind speed. Power output increases according to the cube of the wind speed if a turbine is allowed to operate uncontrolled in situations when the wind speed is over the rated wind speed, which can cause the generator and the power electronics system to overheat.

Furthermore, increased aerodynamic forces on the machine at high wind speeds might eventually cause system stress and failure. For this reason, wind turbine controllers must maintain a steady power output even when the wind speed exceeds the turbine's rated wind speed. There are two types of generators that may be utilised in wind turbine installations: induction and synchronous. Cage rotor, wrapped rotor with slip control, and doubly fed induction rotor induction generators are the three most common types of induction generators used in wind power conversion systems. Since it allows for a great deal of speed fluctuation, the third is rarely used in wind speed creation. When it comes to wind power generation, however, the variable-speed directly-driven multi-pole permanent magnet synchronous generator (PMSG) is the preferred architecture due to its superior performance, lower operating costs, and absence of rotor current. In addition, PMSG doesn't require a gearbox, which means the nacelle may be lighter and the overall system can be cheaper. When the characteristics of the system being managed change over time or are originally unknown, the controller must adopt a control strategy known as adaptive control in order to maintain stability. Adaptive control techniques are useful for solving the control challenges associated with wind turbines because they work well with nonlinear applications that have uncertain modelling parameters and insufficient knowledge of operational circumstances. The nonlinear aerodynamic loads on a wind turbine are the primary source of nonlinearity in a wind turbine model. It is exceedingly challenging, if not impossible, to create an exact model of the dynamic properties of a wind turbine. Wind turbines, in addition, must work in situations that are both extreme and unpredictably turbulent. Since wind turbines are so intricate, they are prime targets for adaptive control strategies. Due to the complexity of modelling wind turbines' dynamic characteristics and the turbulence in which they operate, there are several obstacles in the way of their efficient and safe functioning. The application of adaptive control techniques, which are ideally adapted to challenges where the plant model is not well known and the plant operating circumstances are uncertain, is a potential new field of wind turbine research.

2. Literature Review

Utilizing a permanent magnet synchronous generator and a pulse-width modulated current source converter, this novel adaptive control approach converts wind energy into DC power. The double fed induction technique is used in the majority of wind farm studies. In spite of this, the suggested conversion system is a viable option because of its high efficiency and dependability. This sort of converter eliminates the need for electrolytic capacitors, and it allows for the reactive power generated and the voltage in the DC-link to be dynamically adjusted in response to changes in wind speed (the latter of which can even be negative). The new method of controlling permanent-magnet synchronous generators, which use current-source converters to connect to the power grid from the wind turbines themselves. Current-source converters provide certain advantages when used in medium voltage (2.3-13.8 kV) applications, although the dc link choke and filter capacitors can be a bit of a pain when it comes to designing the controller. Improved performance and dynamic reaction are the goals of the control plan development. This three-phase current source converter uses a pulse width modulation (PWM) technique with soft commutation. During current commutations, the collector-to-emitter voltage of the incoming switch is positive and the collector-to-emitter voltage of the outgoing switch is negative in the PWM scheme shown here.

Wind energy conversion systems (WECSs) that use permanent magnet synchronous generators are intended to share a single power control technique regardless of the type of grid they are connected to. The technique involves a pair of converters, one on the generator side to regulate the dc-link voltage and the other on the grid side to manage the power injection. Torsional oscillations resulting from the features of the drive train can be dampened by the c controller installed on the generator side. As a complement to and replacement for big traditional central power stations, the utilisation of distributed energy resources is becoming increasingly sought. Where the intermittent energy source accounts for a sizable portion of the overall system capacity, the definition of a power electronic interface is subject to requirements linked not only to the renewable energy source but also to its impacts on the power-system operation.

3. Materials and Methods

In order to facilitate the study of three-phase circuits, the direct-quadrature-zero (dq0 or dqo) transformation is a rotation of the reference frame of such systems. By applying the dqo transform on a balanced three-phase circuit, we may convert the three AC values to two DC ones. First, the DC variables are transformed into the equivalent three-phase AC values, and then the inverse transformation is performed to retrieve the real three-phase AC results from the simplified calculations. It's commonly used to streamline processes like controlling three-phase inverters and analysing three-phase synchronous machines. To account for time-varying inductances, the park transformation is applied to the stator and rotor quantities of a three-phase synchronous machine in order to analyse it. All three-phase values (voltages, currents, flux links, etc.) are shown as a matrix under the power-invariant, right-handed dqo transform:

$$x_{dqo} = Kx_{abc} = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos(\theta) & \cos(\theta-\frac{2\pi}{3}) & \cos(\theta+\frac{2\pi}{3}) \\ -\sin(\theta) & -\sin(\theta-\frac{2\pi}{3}) & -\sin(\theta+\frac{2\pi}{3}) \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix}\begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix}$$

$$x_{abc} = K^{-1}x_{dqo} = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos(\theta) & -\sin(\theta) & \frac{\sqrt{2}}{2} \\ \cos(\theta-\frac{2\pi}{3}) & -\sin(\theta-\frac{2\pi}{3}) & \frac{\sqrt{2}}{2} \\ \cos(\theta+\frac{2\pi}{3}) & -\sin(\theta+\frac{2\pi}{3}) & \frac{\sqrt{2}}{2} \end{bmatrix}\begin{bmatrix} x_d \\ x_q \\ x_o \end{bmatrix}$$

In order to properly connect the wind turbine to the power grid, it is suggested that a hierarchical control system be used. To begin, the DC current in the PWM-CSC is taken into account while modifying the maximum tracking point method. It follows that this current's standard is dynamically adjusted in relation to the speed of the wind. The next step is to create an adaptive PI control that can follow this benchmark. At last, an integrated model reference control helps mitigate grid fault-induced voltage surges. Modulating the current of the converter is accomplished by space vector modulation (SVM).

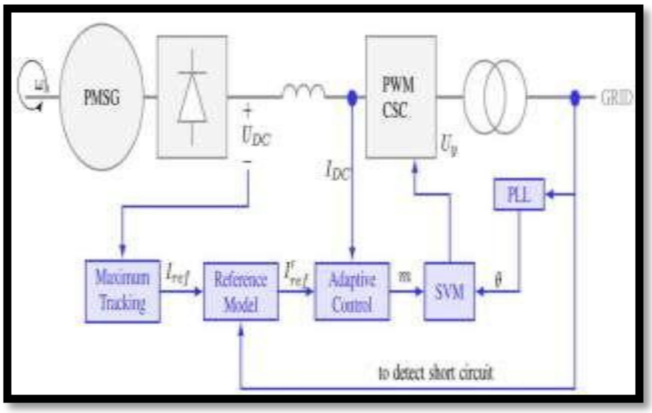

Fig.1. An adaptive control hierarchy for a pulse-width-modulated current source converter is proposed for energy conversion systems.

3.1 Maximum Power Point Tracking

The wind speed used as a comparison in MPPT can be determined in a number of ways. Having anemometers provide data on wind speed to a central computer is the quickest and easiest method. But there are a few problems with how wind speeds are measured. In a vast wind system, there is typically some lag when trying to measure the wind speed at a faraway location. Anemometers, which are placed nearby, are provided in smaller VAWTs. Due to the fact that tiny VAWTs are typically positioned in places with turbulent winds, a delay in reaction time might have an impact on dependability.

No sensors In contrast to other methods of control, the MPPT doesn't require constant monitoring of wind speed. Constant output power, fixed voltage, and the wind speed forecast are only a few examples of possible implementations of such a control mechanism. Predictions of wind speed are typically made using auto regressive statistical models, which take into account past data to better predict future results. Predictions of wind speed at a later time interval may be made using the energy stored in each data set. The duration of the sample time period is just one of several parameters that affect the precision of wind speed forecasts. Predictions of wind speed improve as the interval between samples decreases. The ease of implementation is an important factor to think about while choosing a control technique. Advantages include a low sensitivity to changing input parameters and a short computation time. Where is the output current's angle. In order to have a power factor of 1, this angle needs to be identical to the angle of the grid voltage..

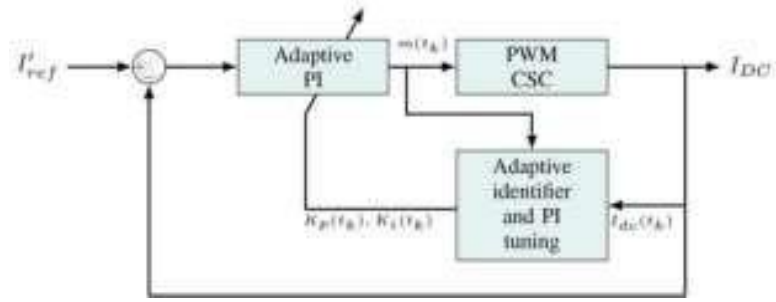

Fig.2 Adaptive identifier and control

Above the capacitive filter, the output power is around Px. To regulate the active power and the AC voltage separately in current source converters is standard practise. In this method, the active power is managed directly, while the reactive power is kept constant by the modulation. This new nonlinear system need adaptive control.

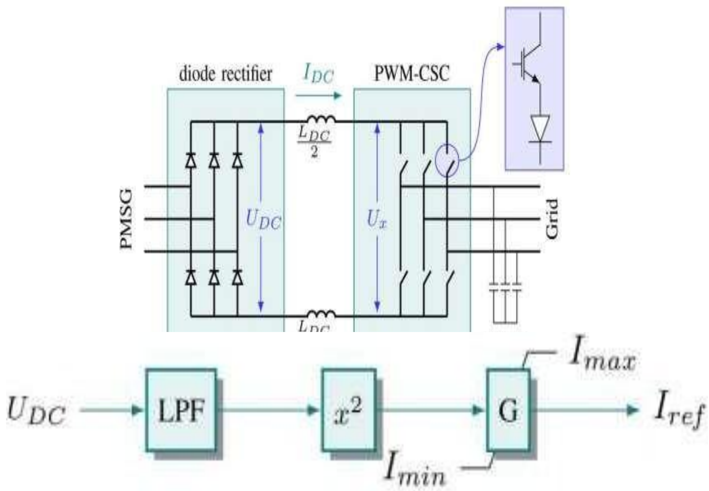

Fig. 3 converter for pulse-width modulated current

Fig.4. For the optimal tracking point algorithm, see the corresponding IDC reference.

3.2 The Controller of Neuro-Fuzzy

The dynamic system with many inputs and a single output, whose states at any time are described by "n" variables X1, X2,..., Xn. Input variables are first translated into their relevant language variables (a process known as fuzzification) before the control action that derives the system to the target state can be stated. The inferencing procedure, which involves the combination of these principles, then establishes the linguistic worth of the result. A defuzzification strategy is used to transform the output's linguistic value, also known as the fuzzified output, into a crisp value. The crispoutput value is obtained by first defuzzifying the final output fuzzy set, which is generated when all rules in this architecture are assessed in parallel. We utilise the product function to join our fuzzified inputs, but the min or sum operation is more commonly employed. Our defuzzification strategy makes use of the simplified reasoning approach, sometimes called the modified centre of area method. Because of their versatility and ease of usage, triangular fuzzy sets will be employed for both input and output. Many implementations of

FLCs may be approximated by a linear function of the following restrictions on fuzzification, defuzzification, and the knowledge base.

- ✓ The triangle membership function is used in the fuzzification process.
- ✓ Every fuzzy set's width is the sum of the peaks of its neighbouring sets. Over the segment separating two neighbouring sets, the total of the membership values will equal one. Therefore, at any one time, the value of a control variable will be equal to the total of all membership values over the whole universe of conversation. Fuzzy partitioning is a term used to describe this limitation.
- ✓ The defuzzification technique employed here is the modified centre of area approach. A weighted average of all potential output values might be thought of as a close analogue to this approach. This structure can be simply described as "neural-like." On the other hand, it's not hard to see it as a fuzzy logic controller.

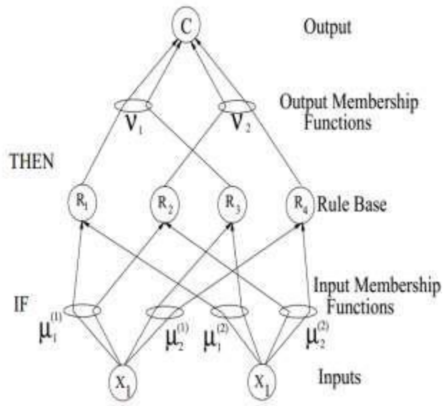

Fig. 5 Rule of four for architecture fuzzy controller from the perspective of a neural network

Figure 5 shows a very basic neural fuzzy controller with only four rules. It is simple to comprehend that this design is "neural-like." It is also simple to understand as a fuzzy logic controller at the same time. The input four variables that characterise the status of the system to be managed are represented by the modules X1 and X2. The relevant membership modules (- modules) get precise input values from these modules, which are then fuzzified by the definitions of the membership functions in the modules' definitions. Presently, both inputs take the form of memberships connected to certain language variables and linguistic variables themselves. The R-modules, which stand in for the controller's rule base or knowledge base, are further coupled to the -modules. Each -module provides the membership value (xi) of the input variable Xi associated with that specific linguistic variable or the input fuzzy set to its related R-modules.

4. Results and Discussion

A filter is an electrical network that modifies a signal's frequency-dependent amplitude and/or phase properties. In a perfect world, a filter would not modify the component frequencies of the incoming signal or add new frequencies to it. In electrical systems, filters are frequently employed to highlight and reject signals in different frequency bands. Combinations of resistors (R), inductors (L), and capacitors form the foundation of passive implementations of linear filters (C). Because they do not require an external power source and/or do not have active parts like transistors, these types are collectively referred to as passive filters. While capacitors conduct low-frequency impulses while blocking high-frequency ones, inductors do the opposite. Although they are used in conjunction with inductors and capacitors to control the circuit's time-constants and, consequently, the frequencies to which it reacts, resistors lack any frequency-selective characteristics on their own. The reactive components of the filter are inductors and capacitors.

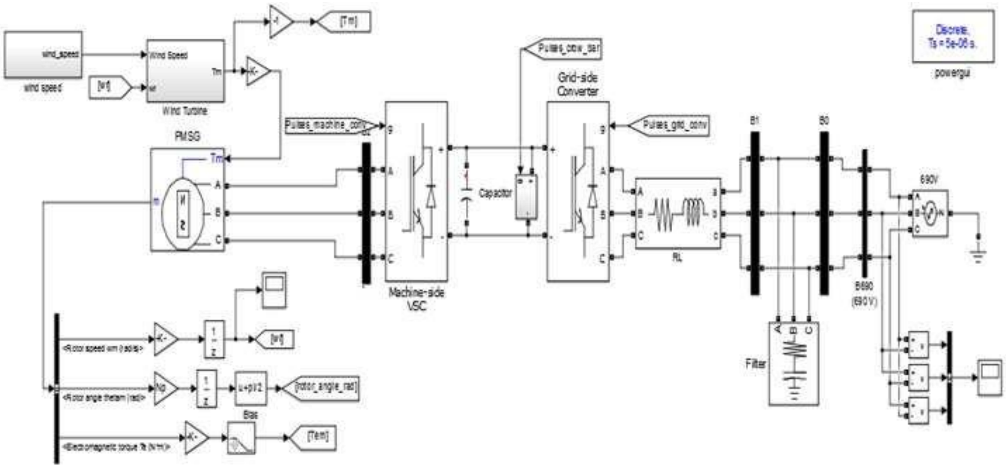

Fig. 6 Simulation Diagram

Phase locked loop

A control system that creates an output signal whose phase is correlated to the phase of an input signal is known as a phase-locked loop (PLL). Although there are many different kinds, it is simple to picture it as an electrical circuit made up of a variable frequency oscillator and a phase detector at first. A periodic Signal is created by the oscillator. The phase detector matches the phases of the two signals by comparing the phase of the input periodic signal with that of the received signal.

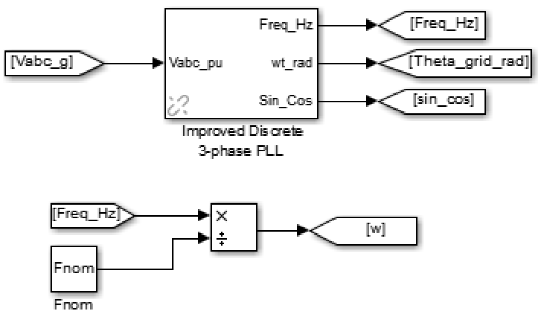

Fig.7 Phase locked loop

DQ0 transformation

The dq0 transform often called the Park transform is a space vector transformation of three-phase time-domain signals from a stationary phase coordinate system (ABC) to a rotating coordinate system (dq0). For three-phase balanced systems, the dq0 transform has the following advantageous characteristics:

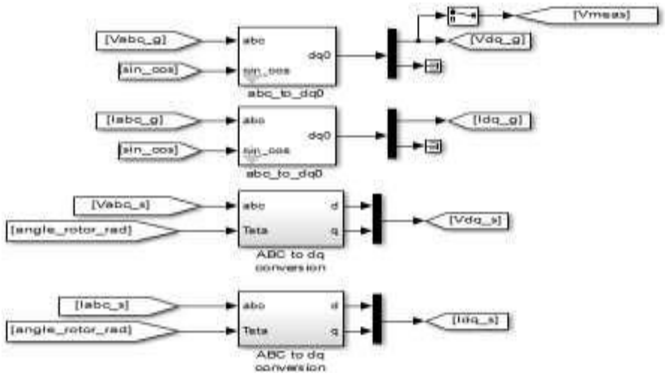

Fig.8 DQ0 transformation

Three-phase time-domain signals are transformed using the dq0 transform, also known as the Park transform, from a stationary phase coordinate system (ABC) to a rotational coordinate system (dq0).

5. Conclusion

An adaptive control for PWM-CSC based energy conversion system is particularly for wind energy conversion system is proposed. Both the adaptive control and the converter increase the flexibility of wind turbine. Since the control is adaptive wind speed need not be considered. A reference model is also proposed in order to improve the transient behavior of control after critical fault. The proposed adaptive control is self-tuned and increases the efficiency of the whole system.

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