# AN ADAPTIVE CONTROL STRATEGY FOR A WIND ENERGY CONVERSION SYSTEM BASED ON PWM-CSC AND PMSG

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**Abstract**

*This project proposes a new adaptive control strategy for a wind energy conversion system based on a permanent magnet synchronous generator and a pulse-width modulated current source converter. Electrolytic capacitors are not required in this type of converter and the voltage in the DC-link as well as the generated reactive power can be dynamically modified according to the wind velocity, being even negative if required. However, it is challenging from the control and stability standpoint. Capacitive filters placed on the AC side, which are required for safe commutation, can create resonances with the power grid. Reactive power is generated according to the capacity of the converter, the wind velocity and the load profile. The adaptive control strategy uses an adaptive PI which is self-tuned based on a linear approximation of the power system calculated at each sample time. A model reference is also proposed in order to reduce the post-fault voltages. Simulation results demonstrate the advantages of the proposed control.*

**Key Words:** *Wind Energy, PMSG, PWM-CSC, Adaptive Control.*

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## 1. INTRODUCTION

While DC-based systems are not a new technology—at the advent of the electrical era, Thomas Edison envisioned that they would become the predominant choice—the ability to incorporate them with the existing AC grid is a relatively new development. Absence of excitation losses in permanent magnet generators allows much higher efficiency to be achieved than with wounded rotor machines. The other classification divides the generators to low-speed machines with direct drive and high-speed machines with a gearbox. Direct drive generators that are used in WTs are large, heavy and expensive as compared to the genera-tors used in WTs with transmission. In general, transmitting electricity from the generator to the consumer at a higher voltage reduces the amount of power lost in the process. However, there are functional limitations that make transmitting across high-voltage AC lines an ineffective option. HVAC lines lose large amounts of power due to induction, capacitance, the "skin effect" (wherein the current moves to the outside of the cable, forming a "skin" and thus failing to utilize the cable in its entirety), and the ionization of the air around the cable, which draws electrons away from the path of transmission. HVDC, by eliminating the alternating current, eliminates these problems, but introduces a new challenge: switching to an HVDC grid necessitates either the construction of DC generators to replace the AC generators currently in use, or the systematic conversion of AC to DC at the point of transmission. As AC generators are generally understood to be less expensive and easier to maintain than DC generators, the second option is more desirable.

## 2. WIND ENERGY CONVERSION SYSTEM

In the proposed system, a permanent magnet synchronous generator is used instead of a doubly fed induction generator because of various advantages such as high power density and soft start due to magnetization provided by the permanent magnets, also because of insignificant losses in the rotor and less reactive power compensation. Most often, thyristors are arranged in a series to form thyristor valves, in a type of system known as natural commutated conversion. This basic system can be improved with the addition of commutation capacitors, which, inserted between the converter transformers and the thyristor valves, increase the accuracy with which the valves "fire" in synchronicity to control the direction and magnitude of power. This kind of system is known as a capacitor commutated converter. A third kind of converter station, the voltage source converter, is built with semiconductors which can turn off or on via remote control almost instantaneously, allowing for an even greater degree of load control, as well as the ability to control active and reactive power independently of one another. This allows the converter station to act as a mechanism to control reactive power, further regulating the voltage of the system.

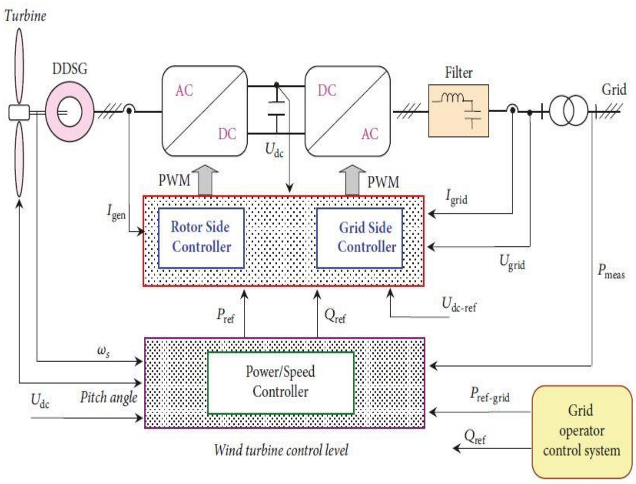


**Fig – 1 Configuration of a VS-WPGS based DDSG**

## 2.1 Adaptive PI Control Strategy

The new controlling technique can be adapted to integrate the PMSG based wind turbine into the grid as depicted in Fig. 5 includes an adaptive control strategy which is as, extraction of maximum tracking point using a suitable algorithm. It produces IDC dynamically according to the variations in wind velocity Most often, thyristors are arranged in a series to form thyristor valves, in a type of system known as natural commutated conversion. This basic system can be improved with the addition of commutation capacitors, which, inserted between the converter transformers and the thyristor valves, increase the accuracy with which the valves "fire" in synchronicity to control the direction and magnitude of power. This kind of system is known as a capacitor commutated converter. A third kind of converter station, the voltage source converter, is built with semiconductors which can turn off or on via remote control almost instantaneously, allowing for an even greater degree of load control, as well as the ability to control active and reactive power independently of one another. This allows the converter station to act as a mechanism to control reactive power, further regulating the voltage of the system.

## 2.2 PMSG-Based Wind Turbines

To choose the proper construction of the generator, the user must make sure that the generator suits for the use in WTs and meets the following design requirements: simple construction, light weight, slow rotational speed, high output power, changeable rotational speed, small starting torque, and low cost. Generally, the synchronous generators used with WTs can be divided into two general categories: generators with wounded rotor and superficial permanent magnet genera-tors. Absence of excitation losses in permanent magnet generators allows much higher efficiency to be achieved than with wounded rotor machines. The other classification divides the generators to low-speed machines with direct drive and high-speed machines with a gearbox. Direct drive generators that are used in WTs are large, heavy and expensive as compared to the genera-tors used in WTs with transmission. On the other hand, direct drive WTs offer significantly higher reliability as less mechanically wearing parts are used. When choosing the generator topology, one of the goals is to construct a generator as lightweight as possible, which would be suita-ble for use in direct drive WTs? Therefore, the energy efficient PM machine was chosen for use in WTs. Absence of excitation losses in permanent magnet generators allows much higher efficiency to be achieved than with wounded rotor machines. The other classification divides the generators to low-speed machines with direct drive and high-speed machines with a gearbox. Direct drive generators that are used in WTs are large, heavy and expensive as compared to the genera-tors used in WTs with transmission. One of the most important parameters of the generator is the power. To find the needed power of the generator, one must rely on a generator's potential use and its peculiarities. The power that a WT can achieve depends on different aspects. Those are, for example, climatic aspects – both the wind speed and the wind density affect wind power. The kinetic energy of the wind per second Pwind can be found according to the flowing equation of fluids and gases,However, this equation does not describe directly the power that the WT is Various types of generators are in use in wind turbines (WTs). The oldest and the most common type of generators in wind applications is the induction machine. Such solutions generally need some type of transmission to be used, which decreases the reliability of the machine. To increase the reliability, directly driven WTs are gaining popularity. Permanent magnet (PM) machines are mainly used in such WTs.

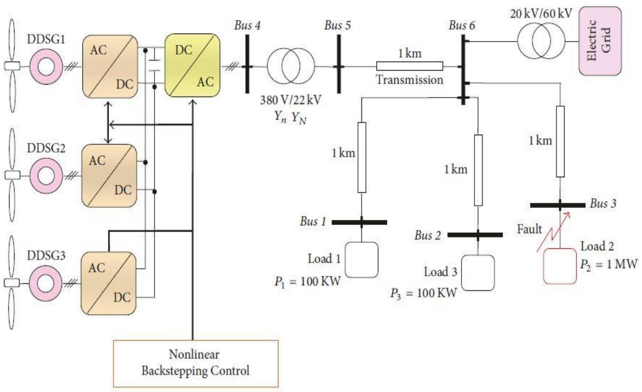


**Fig – 2 Configuration of the VS-W**

## 3. SYSTEM DESIGN

The proposed hybrid HVDC consists of a pulse width modulated current source converter (PWM-CSC) and a line-commutated converter (LCC). The PWM-CSC is connected to the offshore wind farm and the LCC connects the onshore grid. The hybrid topology takes advantages from self-commutated converters as well as LCCs. On the one hand, LCC-based HVdc is the most mature technology with the lowest power losses and lowest cost. Thus methods for tuning of fuzzy logic controllers are needed. In this paper, neural networks are used in a novel way to solve the problem of tuning a fuzzy logic controller. The neuro fuzzy controller uses neural network learning techniques to tune the membership functions while keeping the semantics of the fuzzy logic controller intact. This paper proposes a new adaptive control strategy Classical control theory is based on the mathematical models that describe the physical plant under consideration. The essence of fuzzy control is to build a model of human expert who is capable of controlling the plant without thinking in terms of mathematical model. The transformation of expert's knowledge in terms of control rules to fuzzy frame work has not been formalized and arbitrary choices concerning, for example, the shape of membership functions have to be made. The quality of fuzzy controller can be drastically affected by the choice of membership functions. Thus, methods for tuning the fuzzy logic controllers are needed. In this paper, neural networks are used in a novel way to solve the problem of tuning a fuzzy logic controller.

### 3.1 Proposed Work

The proposed energy conversion system is based on PMSG. This type of machine has three main features which are relevant for wind power applications: there are no significant losses generated in the rotor; magnetization provided by the permanent magnets allows soft start; and there is no consumption of reactive power. The first characteristic implies an improvement in efficiency while the second and third effect the power electronic converter which does not require bidirectional power capability. Hence, a full bridge diode rectifier is enough for the AC/DC conversion. In addition, PMSGs allow smaller, flexible and lighter designs as well as lower maintenance and operating costs. A gear box is not required if it is designed appropriately with a high number of poles.

A PMSG requires a full rated converter which is usually a back-to-back configuration with voltage source converters. Earlier the wind power generation was limited to few hundreds of kilowatts, supplying to an isolated area/load with permissive power quality issues. With the growth of Wind turbines and farms in size and ratio from the few hundred kilowatts to megawatts size, endures them to integrate with the grid which leads to the new problems such as interface of wind farms with the grid. In general most of the wind energy systems employ induction generators because of high efficiency & good controllability. In this paper the permanent magnet synchronous generators are employed due to their high power density & enables the grid integration by means of pulse width modulated current source converter(PWM-CSC) which has advantage of controlling the DC current according to the wind velocity irrespective of DC voltage rather than a conventional voltage source converter. Most of the contribution made in the area of wind energy conversion system control is by using conventional regulators which has certain limitations such as, the system identification and the calculation of the controller parameters have to be done offline, which leads to uncertainties in model.

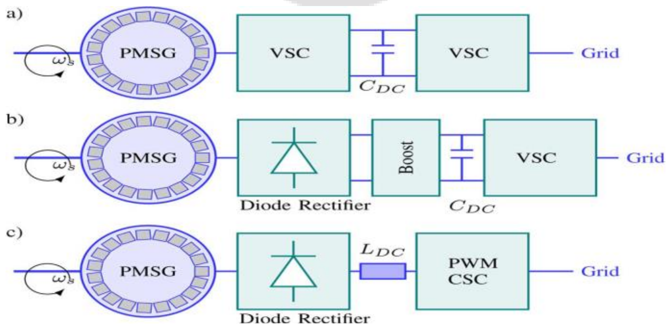


**Fig. – 3 The proposed conversion system**

Conduction losses depend mainly on the collector current while switching losses are mainly related to the switching frequency. Earlier the wind power generation was limited to few hundreds of kilowatts, supplying to an isolated area/load with permissive power quality issues. With the growth of Wind turbines and farms in size and ratio from the few hundred kilowatts to megawatts size, endures them to integrate with the grid which leads to the new problems such as interface of wind farms with the grid. In general most of the wind energy systems employ induction generators because of high efficiency & good controllability. In this paper the permanent magnet synchronous generators are employed due to their high power density & enables the grid integration by means of pulse width modulated current source converter(PWM-CSC) which has advantage of controlling the DC current according to the wind velocity irrespective of DC voltage rather than a conventional voltage source converter. Most of the contribution made in the area of wind energy conversion system control is by using conventional regulators which has certain limitations such as, the system identification and the calculation of the controller parameters have to be done offline, which leads to uncertainties in model prediction & may cause poor dynamic response. Usually converters are designed in such a way that conduction and switching losses are equal. A full-bridge can be considered as a device with only conduction losses since switching occurs only once during each cycle. A third option is to integrate the PMSG to the main grid through a diode rectifier and a PWM-CSC as given. Variation on the DC voltage is not a limitation on the PWMCSC; hence the power can be controlled directly by the inverter. In addition, a PWM-CSC does not require an electrolytic capacitor as the VSC. This impacts the reliability of the systems since 30% of failures on AC converters are related to the electrolytic capacitor.

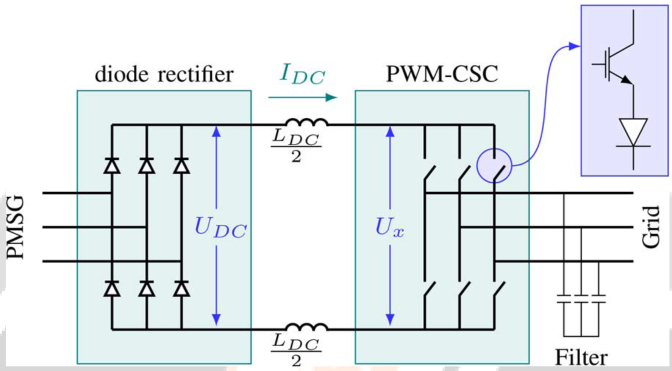


**Fig.- 4 Proposed strategy for adaptive control of energy conversion system based on PWM-CSC**

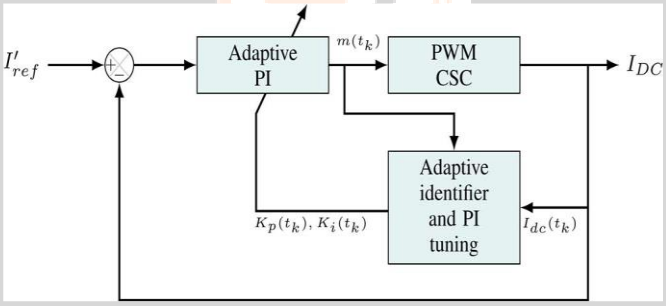


**Fig.5 - Adaptive control and identifier**

## 4. SIMULATION DIAGRAM

Simulink® is a block diagram environment for multidomain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink is widely used in automatic control and digital signal processing for multidomain simulation and model-based design. One of the main advantages of using Simulink blocks is that they are easy to understand and manipulate. You can drag and drop blocks from various libraries, configure their parameters, and connect them with wires to form your system. You can also create custom blocks using MATLAB functions or other Simulink models. Simulink is a block diagram environment used to design systems with multidomain models, simulate before moving to hardware, and deploy without writing code.

Simulink® is a graphical modeling and simulation environment for dynamic systems. Create block diagrams, where blocks represent parts of a system. A block can represent a physical component, a small system, or a function. An input/output relationship fully characterizes a block. Simulink model components include Subsystem blocks, Model blocks, Stateflow charts, and Simulink to Simscape™ converter blocks. To display units on a model, in the Debug tab, select Information Overlays > Units. It includes simulation, baseline, and equivalence test templates that let you perform functional, unit, regression, and back-to-back testing using software-in-the-loop (SIL), processor-in-the-loop (PIL), and real-time hardware-in-the-loop (HIL) modes. When you want to run a simulation one step at a time from the beginning, you can start the simulation by clicking Step Forward. In the Simulink Toolstrip, on the Simulation tab.

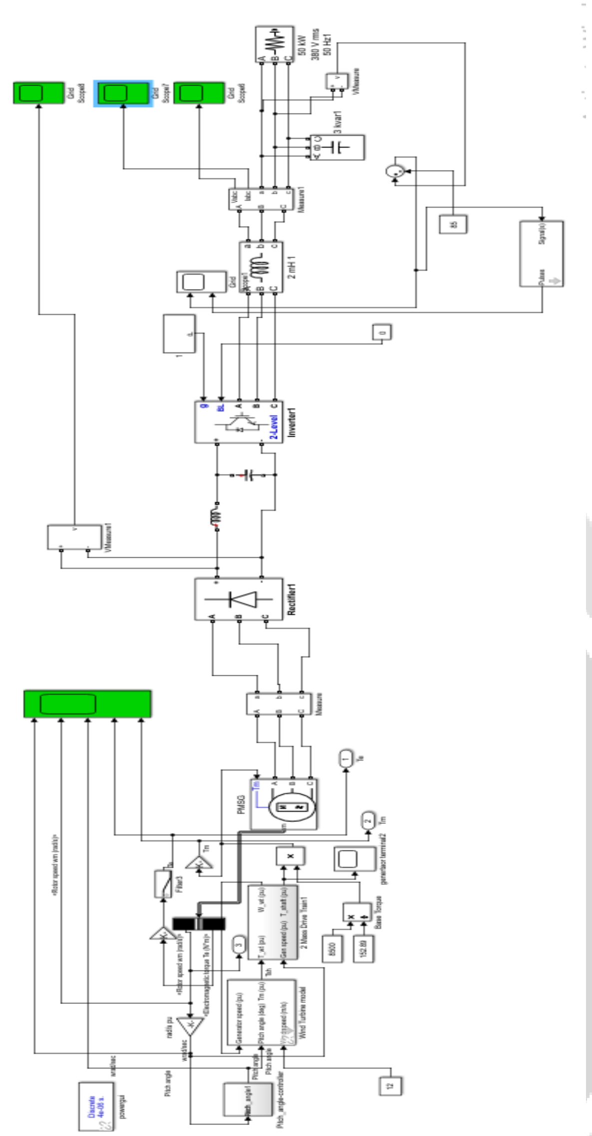

**Fig.6 - Simulation Diagram**

### 4.1 Result and Discussion

Model Reference Adaptive Control The objective of MRAC is to find the feedback control law that changes the structure and dynamics of the plant so that its I/O properties are exactly the same as those of the reference model.Reference current is modified during a short circuit in order to improve the short circuit behavior of the converter. A slightly different current in which the desired output is generated by a linear reference model is proposed. The reference model can be selected with an order less than or equal to the order of the process. In this work, a zero order model is used in pre-fault, no control during the fault and a first order model after the fault as follows: An adaptive controller is a fixed structure controller with adjustable parameters and a mechanism to automatically adjust those parameters. In this sense an adaptive controller is one way of dealing with parametric uncertainty Adaptive control theory essentially deals with finding parameter adjustment algorithms that guarantee global stability & convergence. This paper means that any control strategy which uses parameter estimation of the plant in real time utilizes recursive identification approach.

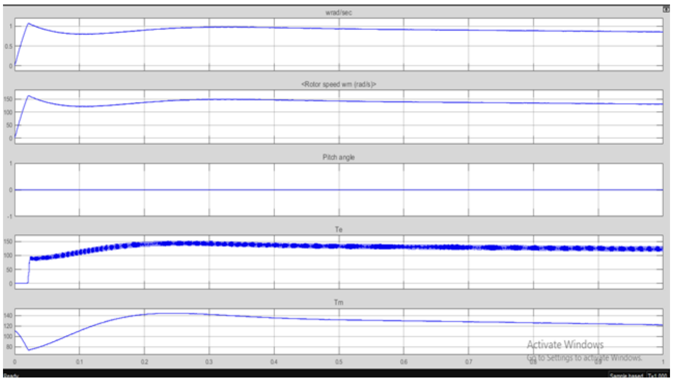

**Fig.7 - PMSG Generator Output**

The adaptive controller to be designed is based on the certainty equivalence principle: design the controller as long as the plant parameters are known. However, since these are unknown at time, they are replaced by an estimate given by an online identifier. An adaptive controller will contain characterization of desired closed-loop performance (reference model or design specification. A controlled plant requires only the output signal for its feedback, which makes the design of the adaptive controller easy. The plant parameters are estimated by using an online identifier. The dynamic performance of wind system is improved by a self-tuned control strategy at the transmission side. A new technology for tracking are adapted to extract the maximum power from the available wind by considering the uncertainties occurring in wind speed. A detailed switching model of the proposed energy conversion system was simulated using Matlab-Simulink. The system consists of a 13.2-kV distribution feeder with a 2-MWwind turbines are used in this project. Parameters of this system. Velocity for 15-s simulation is depicted above Fig.4.8. Base wind velocity is 12 m/s. A gust is simulated in order to demonstrate the maximum tracking point capability of the proposed Control. Wind velocity profile was created using a detailed model which considers stochastic Behavior. Rotational speed and voltage are plotted above. These two variables are Proportional as expected. shows voltage Udc with respect to rotational speed for the aforementioned simulation. The linear approximation given in is more accurate for low wind Velocities

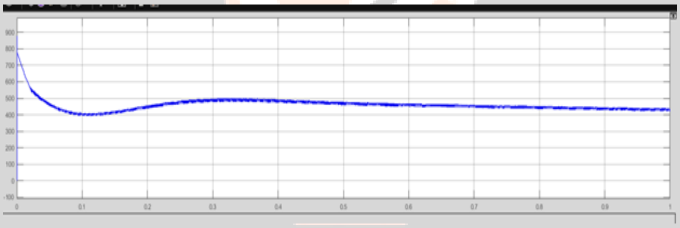

**Fig.8 - DC output of rectifier**

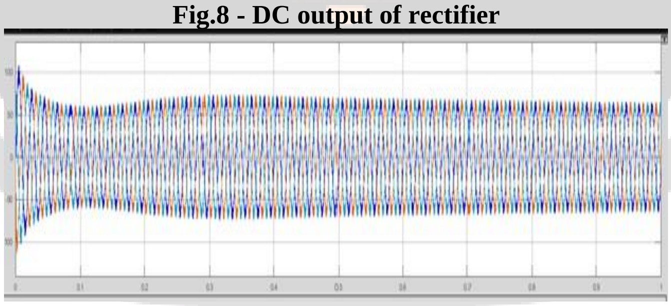

**Fig.9 - Output voltage**

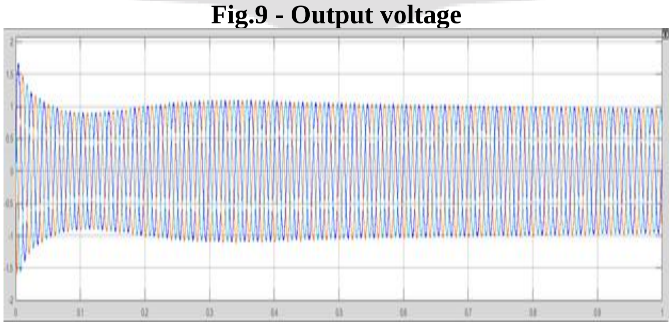

**Fig.10 - Output Current**

The modules X1 and X2 represent the input variables that describe the state of the system to be controlled. These modules deliver crisp input values to the respective membership modules (μ-modules) which contain definitions of membership functions and basically fuzzify the input. Now, both the inputs are in the form of linguistic variables and membership associated with the respective linguistic variables. The μ-modules are further connected to R-modules which represent the rule base of the controller, also known as the knowledge base. Each μ-module gives to its connected R-modules, the membership value μ(xi) of the input variable Xi associated with that particular linguistic variable or the input fuzzy set. The R-modules use either min-operation or product-operation to generate conjunction of their respective inputs and pass this calculated value forward to one of ν-modules. The ν-modules basically represent the output fuzzy sets or store the definition of output linguistic variables. If there are more than two rules affecting one output variable then either their sum or the max is taken and the fuzzy set is either clipped or multiplied by that resultant value. These ν-modules pass on the changed output fuzzy sets to C-module where the defuzzification process is used to get the final crisp value of the output. The control strategy changes dynamically according to the wind conditions

## 5. CONCLUSIONS

An adaptive control for a PWM-CSC-based energy conversion system particularly designed for wind power applications was presented. Both the control and the type of converter increase the flexibility of the wind turbine. They are able to operate in critical conditions such as short circuit and fast changes in wind velocity. Measurements of wind velocity or rotational speed are not required. A reference model is used to improve the transient behavior of the control after critical faults. For systems with time invariant behavior, the adaptive controller also behaves as a fixed controller. Therefore, it can be seen that the adaptive controller method can be used as a technique for self-tuning the controller based on the desired response.

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