Wind Energy AC-DC Converter Voltage Ripple Reduction in Hybrid Energy System

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Abstract:- **With the addition of a power converter, renewable energy systems must be extracted more efficiently. Renewable energy sources are obviously used to generate clean energy. This clean energy cannot be used directly on load due to fluctuating conditions; to address this, a modified AC to DC converter with a ripple-free output is introduced. This AC to DC converter is made up of a rectifier and an LC filter that run independently in their half cycles and share an input inductor. This AC to DC converter is both cheap and effective. The input current is precisely phase-locked to the source voltage, yielding a high input power factor. In addition, the source current voltage ripple was reduced to less than 5V. It was discovered that the converter with Capacitor has significantly lower ripple and far superior voltage regulation than the converter without Capacitor. The simulation was carried out in MATLAB/SIMULINK, and the experimental parameters were determined using a standard prototype.**

Keywords- *Voltage Ripple, Wind Turbine, Rectifier, LC Filter, Hybrid System.*

I. INTRODUCTION

The only practical way to reduce the rising energy demand that comes with sustainable development is through non-conventional energy sources[1][2].In recent years, the number of electric generators powered by solar, wind, fuel cell, hydro, and other renewable energy sources has increased significantly, indicating a growing demand for green energy. This trend is expected to continue in the coming years, with renewable energy meeting 30% to 60% of total needs from 2020 to 2050.The vast majority of India's total renewable energy production is accounted for by renewable electricity sources such as photovoltaic and wind power. A hybrid energy system connects multiple energy sources with efficient energy conversion technologies to supply electricity to a local load/grid. A number of interconnected generating units comprise the current complex power system network. This intricate network includes a renewable grid that primarily uses wind and solar energy. Because wind power is the most abundant renewable resource, there is an increasing amount of research being done on its efficient use. Because of features such as variable velocity running and decoupled active and reactive power control, among others, PMSM wind turbines have proven to be the most commonly used wind turbines in the production of variable velocity constant frequency wind power.The difficulty of implementing a converter of a three-phase PMSM wind power generation system is examined for the mechanical design constraints of PMSM used in wind power generation systems.By using defined control techniques for the power converter, the needed fixed values for the grid's frequency and voltage may be given while maximizing the amount of extracted power in variable speed operation[3][4].Because wind speed varies, connecting the wind turbine generator directly to the load may cause voltage and frequency fluctuations. This problem is exacerbated when variable speed generators, such as the Permanent Magnet Synchronous Machine, are used because their speed range is wider, resulting in a variable frequency and voltage of the alternating current output supply. However, for the electrical supply to be satisfactory, the voltage and frequency values must be acceptable. Power electronics components such as a rectifier, a boost rectifier, and a PWM inverter are used to construct it.The hybrid system is subjected to these setups' high frequency current harmonic injection[5].

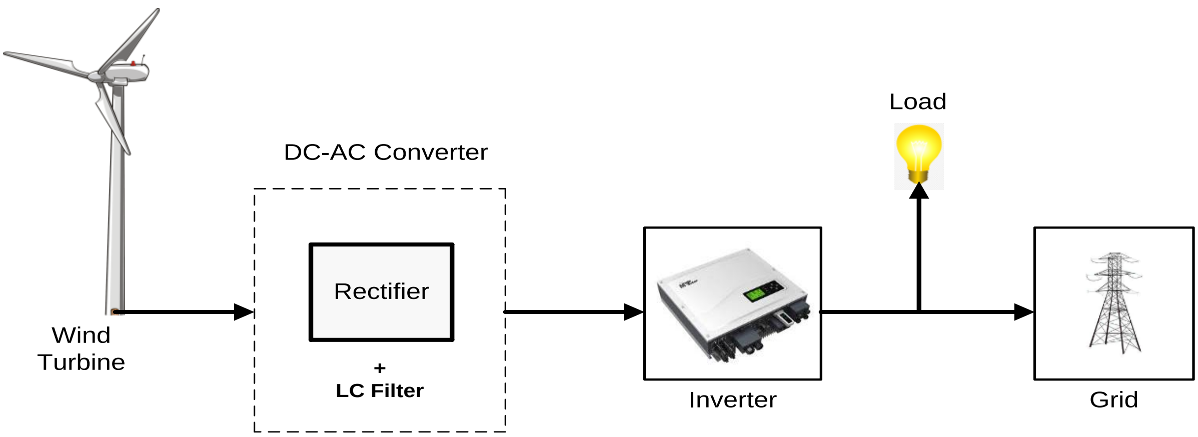

Fig. 1: Wind Energy Generation System Block Model.

The ripples indicate the presence of an alternating current component, which is completely removed to obtain a pure direct current output. That is why we must design a circuit to convert the rectified output into a pure DC signal. The rectifier is connected to the LC filter to reduce residual harmonics on the DC side. Filter inductance is a constant inductor with low ripple that maintains current while improving output voltage load regulation, reducing harmonics in the input current, and improving power factor. The filter capacitor was chosen to reduce the output voltage ripple.

II. WIND ENERGY GENERATION SYSTEM

Wind turbines and power electronic converters are part of the WECS structure. Mechanical energy is converted into electrical energy by generators. In recent years, the multipole PMSM has proved to be the better choice due to the lack of gearboxes, which reduces the damage and maintenance requirement of WECS.The high speed shaft is then attached to a generator, which produces power[5][6][7].The generator converts mechanical wind energy into electrical energy, then the power electronic converters system converts AC to DC voltage. The output current and voltage of a permanent magnet wind generating system are proportional to the electromagnetic torque and rotor speed, respectively[8].The wind turbine's mechanical power is provided by:

$$P_m = \frac{1}{2}\rho \mathrm{A} C_p(\lambda,\beta) v_w^3$$

Where,

$$\rho = airdensity, \quad A = Rotorsweptarea, C_p(\lambda,\beta) = powercoefficientfunction,$$
$$\lambda = Tipspeedratio, \quad \beta = Pitchangle, \quad v_w = Windspeed$$

The efficiency of a wind turbine's conversion of wind energy into mechanical energy is determined by the power coefficient function, which is governed by the pitch angle and tip speed ratio. In the formula known as the "tip speed ratio," the ratio of the turbine's angular speed to the wind speed is represented.

$$\lambda = \frac{Rw_b}{v_b}$$

Where,

$$R = turbineratio, \quad w_b = angulorrotationalspeed$$

Depending on the wind speed, the rotation speed can be changed to maximize power. Pitch angle is the term used to describe how the turbine blades are oriented with respect to the longitudinal axis.Once the generator converts mechanical wind energy into electrical energy, the system will operate with power electronic converters. They have a role in converting AC to DC voltage.As a result, various converter topologies have been employed to perform this conversion with low cost and high efficiency. This paper focuses on the modified AC to DC converter that is most commonly found in the literature.

III. ANALYSIS OF AC TO DC CONVERTER

The converter is to be modified to connect the obtained lower input renewable input to a steady load. The actual experimental block diagram of the suggested system is shown in Figure.

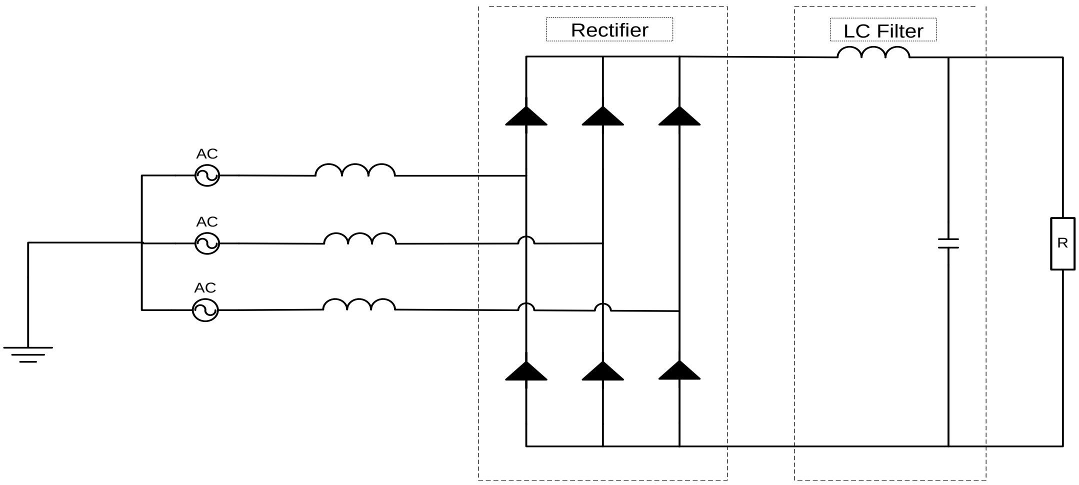

Fig. 2: Circuit Diagram of Modified Rectifier.

The control of a rectifier is described in this section of the paper, as is the definition of a DC voltage waveform. The sections that follow demonstrate how rectifier parameters affect the DC voltage waveform.

- **Control of Voltage-** DC side Inductance is connected in rectifier, there is a constant voltage across this inductance. DC voltage is not constant and fluctuates around the desired value, so LC filters are added.The DC voltage waveform is defined in the equation as the ration of the subtraction of the maximum and minimum DC voltage values when the maximum and minimum DC voltage values are added.

$$\sigma_{V_r} = \frac{V_{r(max)} - V_{r(min)}}{V_{r(max)} + V_{r(min)}}$$

- **Capacitor Effect-** This section discusses the effect of capacitor value on the DC voltage waveform. The capacitor values are changed, and the load current is set to nominal. DC voltage is produced when the capacitor value is less than the nominal value. The ripple in the DC voltage is visible. If the capacitor value is greater than the nominal value, DC voltage is produced. As the capacitor value increases, so does the DC voltage waveform increase with reduce voltage ripple.

- **Load Effect-** This section describes the DC voltage ripple dependence on the load current of the rectifier. If the current load and nominal load current are lower, the DC voltage ripple is reduced. The ripple in the DC voltage is obvious. The DC voltage ripple will be high if both the load current and the nominal current load are high. The ripples in the DC voltage are quite large.

IV. DESIGN OF LC FILTER

Out voltage ripple shows the presence of an AC component. To produce pure DC output, the whole AC component has been eliminated. For this reason, we created a circuit that transforms the rectified output into a pure DC signal. Rectifiers are always linked to an LC filter in order to lower residual harmonics on the DC side. To enhance load control of the inductance output voltage, lower harmonics in the input current, and boost power factor, filters are employed to maintain a steady inductor current with little ripple. To lessen the output voltage's ripple, filter capacitors are selected. This model generates output DC with 75V ripple voltage dependent on the system characteristics, including LC, three single phase sources at 50Hz, a resistive load at 120°, and amplitude 230V RMS. Filter output DC has been used to produce ripple voltages lower than 5V.

A. Formula for Filter Inductor

$$L = \frac{0.013V_{l(max)}}{2\pi f I_{cri}} = 23mH$$

$$V_{l(max)} = 565V, f = 50H_z, I_{cri} = 5A$$

The maximum three-phase line-to-line voltage is 400*1.414 = 565V, which is the load current as long as the inductor maintains constant conduction. The line frequency has also been set to 50 Hz. The load current for this current is 5.6A. I chose 5A as the critical current. When all of these values are entered into the L formula, the inductance value is 23mH. The inductor and the circuit must be connected in series.

This formula calculates the capacitance value by providing the cut off frequency. Wave attenuation affects filter capacitance:

$$\frac{\Delta V_0}{\Delta V_r} = \left(\frac{f_c}{f_r}\right)^2$$

$$f_c = 77.45H_z$$

$$\Delta V_0 = 5V, \Delta V_r = 75V, f_r = 6f = 300$$

The ripple in the output voltage here is determined by the load tolerance (5V). The unfiltered rectified voltage has a ripple of 75V. A six-pulse rectifier has a wave frequency of 6*f = 6*50 = 300. The cut-off frequency is found by substituting all of these values in this formula.

B. Filter Capacitance Formula-

$$C = \frac{1}{4\pi^2 f_c^2 L} = 180\mu F$$

$$f_c = 77.45H_z, L = 23mH$$

Both the cut-off frequency and the inductance value are substituted to obtain the capacitance value. Capacitors are connected in parallel to the circuit. The elements are designed for 5V wave voltage as well as monitored for 5V waveform.

- **Simulation Work:** The parameters of the suggested system model are as follows when using Simulink in MATLAB to reduce voltage ripple in a wind power conservation system with a redesigned AC-DC converter:

Parameters	Value 1	Value 2
Load Resistance	100mf	100mf
Inductance	23mH	23mH
Capacitor	90omh	180omh

Fig. 3: Model Simulation LC Filter Parameters

Specifications	Measurement 1	Measurement 2
Amplitude	326V	326V
Frequency	50Hz	50Hz
Output Voltage	565V	565V
RMS Voltage	400V	400V
Output Current	5.6A	5.6A
Voltage Ripple	10V	5V

Fig. 4: Model Simulation Specifications Output Observations.

V. RESULT & DISCUSSION

- **LC filter less converter-** In this Simulink model, the input voltage is 326V at each stage with a peak amplitude of 50Hz. The DC output voltage is 400*1.414 = 565V because the phase RMS voltage is 400V. This is a 5.6A output current. It produces a ripple voltage of about 75V, which has been removed with an LC filter.

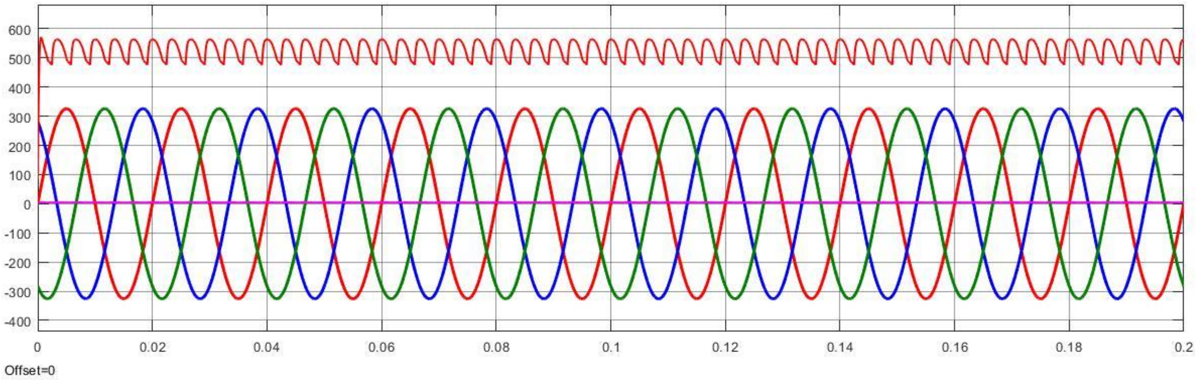

Fig. 5: Without Filter Rectifier Multi-meter Output waves result

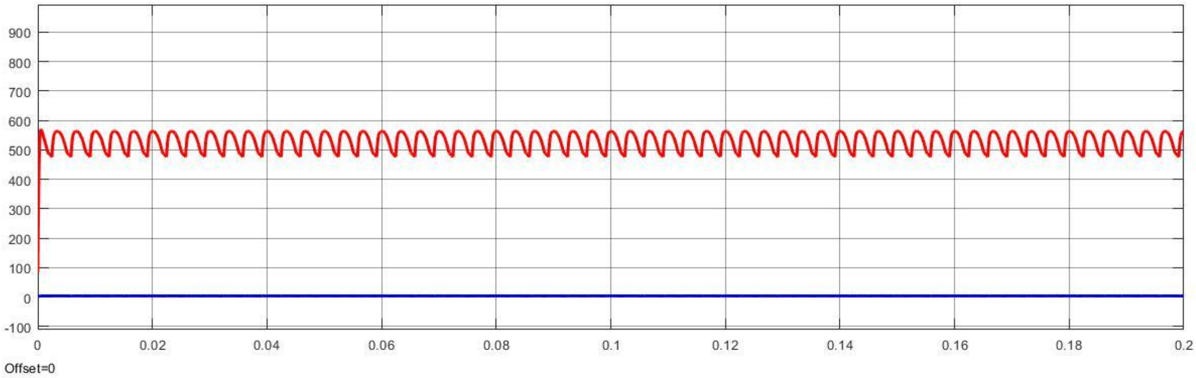

Fig. 6: Without Filter Rectifier Output voltage and current waves result.

- **Converter with LC Filter** – In this simulation the inductance value 23mH and cut off frequency 77.45Hz have been substituted. Keeping the capacitance values 180 and 90 micro-farad, the ripple voltage decreases by 5V and 10Vrespectively.

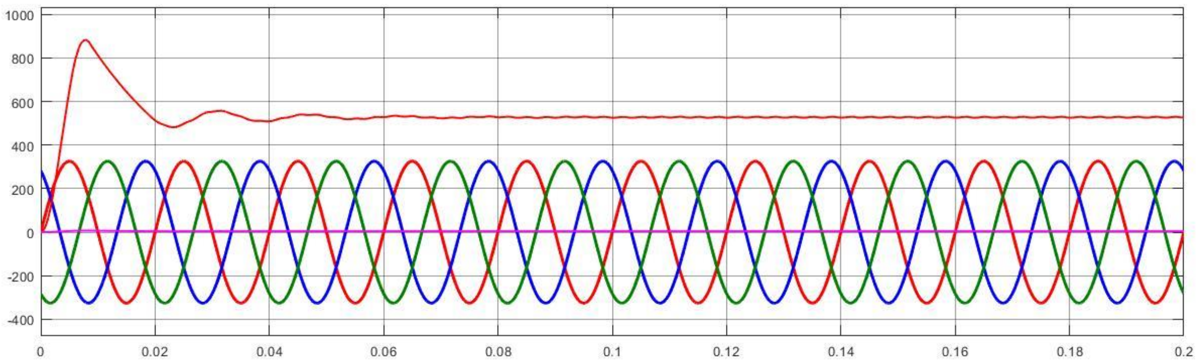

Fig. 7: Modified Rectifier Multi-meter Output waves result

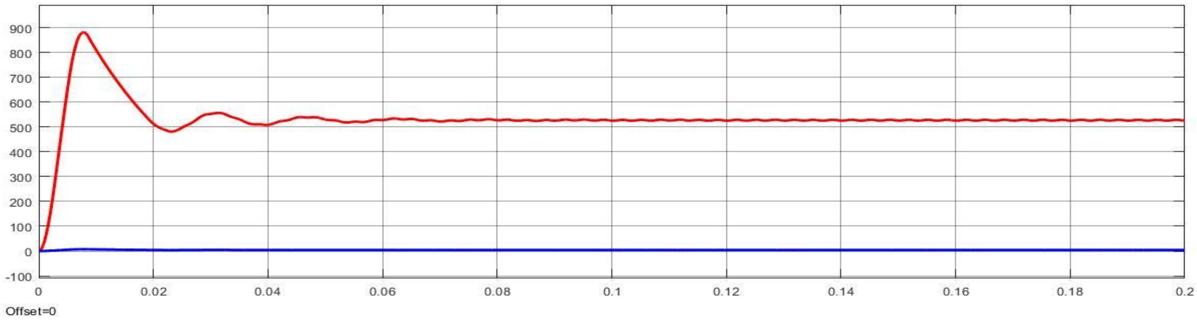

Fig. 8: Modified Rectifier Multi-meter Output Voltage and current result.

VI. CONCLUSION

This paper focuses on hybrid power generation technology, which combines a solar and wind turbine system. All renewable energy must be concentrated on a better extraction state with no distortion. For a less Ripple voltage output, we have suggested a Modified AC to DC converter topology. Future work on this development may include a thorough analysis of the best renewable energy source based on season and availability, as well as a suitable controller.

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