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CONTENTS

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Title

POWER QUALITY ENHANCEMENT IN MICROGRID (ISLANDING MODE) BY USING ND – MLI DSTATCOM

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Abstract:

Microgrids are systems with clusters of micro generators, which are installed for distributed power generation. When interfaced to the utility grid, microgrids are exposed to common utility power-quality disturbances. The paper focuses on the combination of wind, FC and MT for sustained power generation. We propose herein a dynamic model, design and simulation of a wind/FC/MT hybrid power generation system with power flow controllers.

The general function of the multilevel inverter is to synthesize a desired AC voltage from several levels of DC voltages. As the number of voltage levels increases the harmonic content decreases significantly. The modulating technique is modified reference modulating techniques. i.e., third harmonic injected reference and offset line voltage injected reference with triangular carrier waves. The main objective of this study is to reduce total harmonic distortion. A novel technique for the selection of switching states to synthesize the desire vector is proposed. This paper realizes the implementation of five-level diode clamped MLI

Keywords: Microgrid, DG, Wind turbine, PEM Fuel cell, ND - MLI DSTATCOM.

Introduction:

This white paper proposes the significant potentials of smaller DER (< 100 kW/unit) to ‘meet customer utilities’ needs can be best captured by organizing these resources into MicroGrids. MicroGrids are envisioned as clusters of generators (including heat recovery), storage, and loads that are operated as single controllable systems. MicroGrids can operate both connected to and synchronized with the utility distribution grid and in isolation from the utility distribution grid (as an “island”).

Power quality problems like voltage sag, voltage swell and harmonic are major concern of the industrial & commercial electrical consumers due to enormous loss in terms of time and money. Due to the increasing complexity in the power system, voltage sags are now becoming one of the most significant power quality problems and deserves attention. Voltage sag is defined as a momentary decrease in voltage rmsvalue between 10% to 90% of the nominal voltage level for duration of half a cycle to one minute. A power quality study done recently indicates that 92 % of all disturbances in a power system, caused by voltage sags [1].

This is due to the advantage of a large numbers of sophisticated electrical and electronic equipment, such as computers, programmable logic controllers, variable speed drives, and so forth. Some special equipmentare sensitive to voltage disturbances, especially if these take up to several periods, the circuit does not work. Therefore, these adverse effects of voltage changes necessitate the existence of effective mitigating devices. There are various solutions to these problems. According to efficiency, the most reliable DERs are PEM Fuel cell, Wind Turbine.

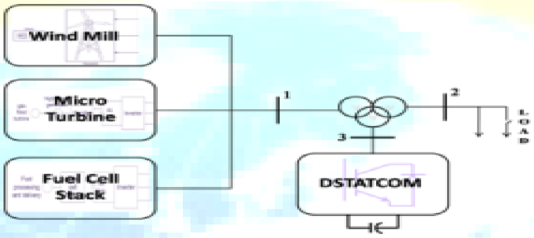

Figure 1: Block diagram of the µgrid with ND - MLI DSTATCOM to Load

A) Wind Turbine:

In this paper the modelling of wind turbine is described. The three bladed rotor is the most important and most visible part of the wind turbine[8]. It is through the rotor that the energy of the wind is transformed into mechanical energy that turns the main shaft of the wind turbine.

B) PEM Fuel Cell

Fuel cells convert the chemical energy of a fuel and an oxidant directly into electrical energy and heat using electrochemical processes—not combustion[3].Perhaps the simplest system, a Proton Exchange Membrane Fuel Cell (PEMFC), combines hydrogen fuel with oxygen from the air to produce electricity, water, and heat. A Basic Proton Exchange Membrane Fuel Cell consists of 3 components: an anode (a negative electrode that repels electrons), an electrolyte in the center, and a cathode (a positive electrode that attracts electrons)[4].As hydrogen flows into the fuel cell anode, a catalyst, often a platinum coating on the anode helps to separate the gas into protons (hydrogen ions) and electrons.

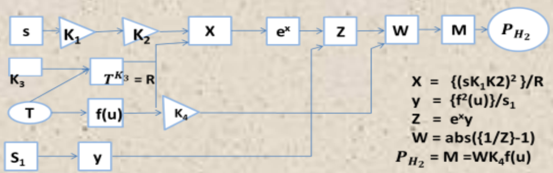

Figure2: Block Diagram of formation of Anode(H_2) of PEMFC

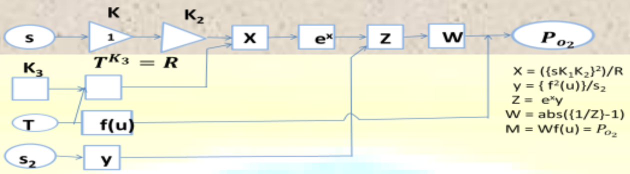

Figure 3: Block diagram of formation of Cathode(O_2) of PEMFC

The PEMFC has a high power density and a relatively low operating temperature (ranging from 60 to 80 degrees Celsius, or 140 to 176 degrees Fahrenheit)[5,6]. The low operating temperature means that it doesn't take very long for the fuel cell to warm up and begin generating electricity.

Fuel Cell Performance Parameters:-Fuel cell performance is affected by design parameters such as cell size, power level, cost and by operating variables such as temperature, pressure, fuel composition andcurrent density[6]. The change in Gibbs free energy due to pressure can be studied by the Nernst equation [14]. It shows the effect of pressure on cell voltage as follows.

$$E = E^{o} + \frac{RT}{2F} \ln\{\frac{\alpha \cdot \beta^{\frac{1}{2}}}{\delta} . P^{\frac{1}{2}}\} \quad ...(1)$$

Modelling of fuel cell & wind turbine:

A) Mathematical Model of Fuel Cell

The experimental voltage-current data of the 500W Polymer exchange membrane fuel cell (PEMFC) built by Fuel Cell Technologies, Ltd,.Fig.4 shows the data points that are curve-fitted using quadratic, cubic, and fourth order polynomials.In addition, the relation between output power and current (P-I curve) is also shown.

$$V = -2.547 \times 10^{-6} I^3 + 1187 \times 10^{-3} I^2 - 0.1967 I + 39.2082 \quad ...(2)$$

Where V is the fuel cell terminal voltage and I is the current.

The minimum least squares error method is used to obtain the closest approximation.

$$V * I \quad = \quad I^2 * Z$$

$$V = I * Z \qquad \text{...(3)}$$

Where Z is the load impedance. Equations (2) and (3) are solved simultaneously to obtain an equation in terms of the current and the load impedance as follows

$$f(I) = -2.547 \times 10^{-6} I^3 + 1.187 \times 10^{-3} I^2 - (0.1967 \propto +Z) I + 39.2082 = 0 \qquad \text{...(4)}$$

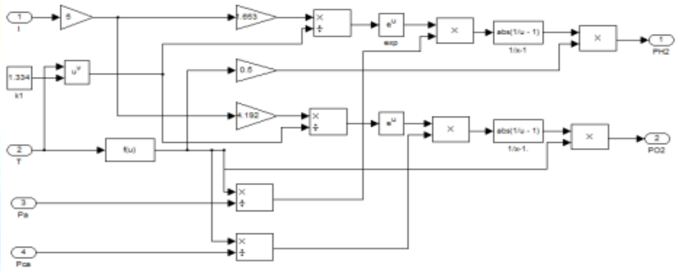

Figure 4: Simulink diagram of Fuel Cell Reaction

The Newton-Raphson iterative method is employed to solve the non-linear equation (2) and determine the fuel cell current. The method for solving an equation f(x) = 0 is outlined as follows [7]

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \qquad \text{... (5)}$$

Wherex_n is the estimate at the nth iteration and x_{n+1} is the updated estimate. The iteration process is terminated when $f(x_{n+1}) <= \epsilon \approx 0$, where $\epsilon$is the tolerance limit and x_{n+1} is the required solution. The method is terminated if $f^1(x_n) = 0$, load impedance is not negative for a fuel cell power system being simulated [6,7].

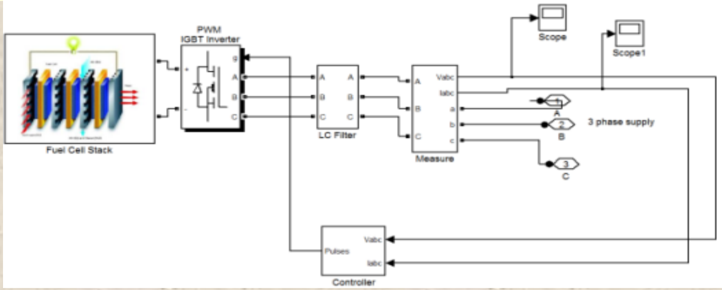

Figure 5: Simulink diagram of the Fuel Cell connected to µ-gird

B) Mathematical Model of Wind Turbine

Under constant acceleration, the kinetic energy of an object having mass m and velocity v is equal to the work done W in displacing that object from rest to a distance s under a force F,

$$\text{i.e., } E=W=Fs \qquad \text{…(6)}$$

According to Newton's law we have, $F = ma$

$$\text{Hence } E = mas \qquad \text{...(7)}$$

Using Newton's third equation of motion[8,9] $v^2 = u^2 + 2as$

We can get $a = \left(\frac{v^2-u^2}{2s}\right)$

Since the initial velocity of the object is zero, i.e. u=0, we get $a = \frac{v^2}{2s}$

Substituting above equation in equation (9), we get that the kinetic energy of a mass in motions is

$$E = \frac{1}{2}mv^2 \qquad \text{...(8)}$$

The power in the wind is given by the rate of change of energy [9,10]

$$P = \frac{dE}{dt} = \frac{1}{2}v^2\frac{dm}{dt} \qquad \text{...(9)}$$

As mass flow rate is given by $\frac{dm}{dt} = \rho A\frac{dX}{dt}$

And the rate of change of distance is given by

$$\frac{dX}{dt} = v$$

We get $\frac{dm}{dt} = \rho Av$

Hence from equation (9) the power can be defined as

$$P = \frac{1}{2}\rho Av^3 \qquad \text{...(10)}$$

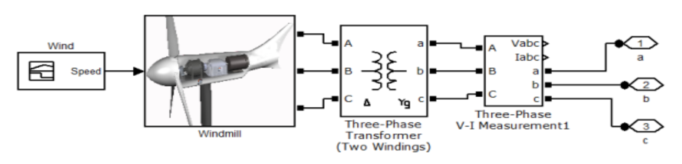

Figure 6: Simulink diagram of the Wind Turbine connected to μ-gird

The swept area of the turbine can be calculated from the length of the turbine blades using the equation for the area of a circle:

$$A = \pi r^2 \qquad ...(11)$$

Where the radius is equal to the blade length.

Modulation Strategy in Three phase five level DCMLI:

The diode-clamped multilevel inverter uses capacitors in series to divide up the dc bus voltage into a set of voltage levels. To produce m levels of the phase voltage, an m level diode-clamp inverter needs (m-1) capacitors on the DC bus. A three-phase five-level diode-clamped inverter is shown in Figure-3. In this circuit, the dc bus voltage is split in to five levels by four series connected bulk capacitors C_1, C_2, C_3 and C_4.

For a dc bus voltage Vdc, the voltage across each capacitor is Vdc/4, and each device voltage stress will be limited to one capacitor voltage level, Vdc/4, through clamping diodes. For the general case of an m-level topology, one phase leg consists of 2(m-1) active switches and (m-1) (m-2) clamping diodes, where m is the number of voltage levels shown in Figure-4. The total dc bus voltage Vdc is distributed across the dc capacitors C_1, $C_{2 \ldots} C_{(m-1)}$. Hence, an output voltage of -Vdc / (m-1), Vdc / (m-1) is possible at the output.

The steps to synthesis the five level output voltage in this work are as follows:

1. For an output voltage of Van=0, two upper switches S3, S4 and two lower switches S1’ and S2’ are turned on.
2. For an output voltage of Van=Vdc/4, three upper switches S2, S3, S4 and one lower switch S1’ are turned on.
3. For an output voltage of Van=Vdc/2, all upper switches S1 through S4 are turned on.
4. To obtain the output voltage of Van= -Vdc/4, upper switch S4 and three lower switches S1’, S2’ and S3’ are turned on.
5. For an output voltage of Van = -Vdc/2, all lower switches S1’ through S4’ are turned on.

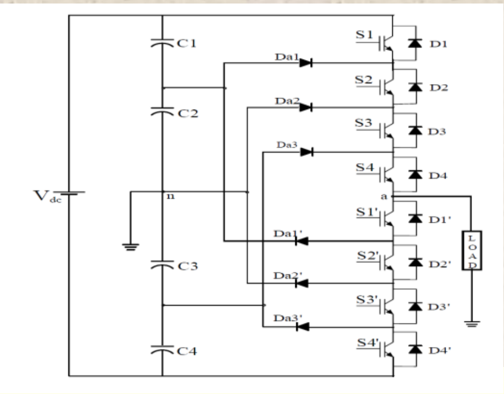

Figure 7. Five level DCMLI

TABLE 1. SWITCHING SCHEME FOR SINGLE PHASE FIVE LEVEL DIODE CLAMPED INVERTER.

S_1	S_2	S_3	S_4	S_1’	S_2’	S_3’	S_4’	V_{an}
1	1	1	1	0	0	0	0	$+V_{dc}/2$
0	1	1	1	1	0	0	0	$+V_{dc}/4$
0	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	$-V_{dc}/4$
0	0	0	0	1	1	1	1	$-V_{dc}/2$

Third harmonic injection PWM (THIPWM): A method to improve the gain of the pulse width modulator is to inject a third harmonic (THIPWM 1st and 3rd) [10]. This technique is derived from conventional sinusoidal PWM With the addition of a 17% third harmonic component to the sine reference waveform. The hardware implementation of this technique is straightforward. It should be noted that the 15% increase in gain over the SPWM technique is achieved at the expense of introducing third harmonics on the line to neutral waveforms. However for a balanced load with a floating neutral point, third harmonic current can not flow and therefore third harmonic voltages are not present on the line-to-line waveforms [l I]. Based on the same idea, an alternative pattern is the (HIPWM, and 9th). This technique is a variation of the previously presented (THIPWM 1st and 3rd). In particular, an addition harmonic component a multiple of 3 is also injected in the reference waveform. Although, the above mentioned switching patterns for PWM converters provide increased gain compared with the conventional SPWM technique, they also imply the reference or modulating waveforms have to be continuous regardless of their shape. As a result they do not provide any reduction in switching frequency compared with the SPWM [11]. For third harmonic injection PWM, the reference waveform is defined as [11].

$f(\omega_0 t) = 1.15\ M \sin(\omega_0 t) + 0.19\ M \sin(3\omega_0 t)\ \ 0 \le \omega_0 t \le 2\pi$, where M is the modulation index ratio, see Fig.3b.

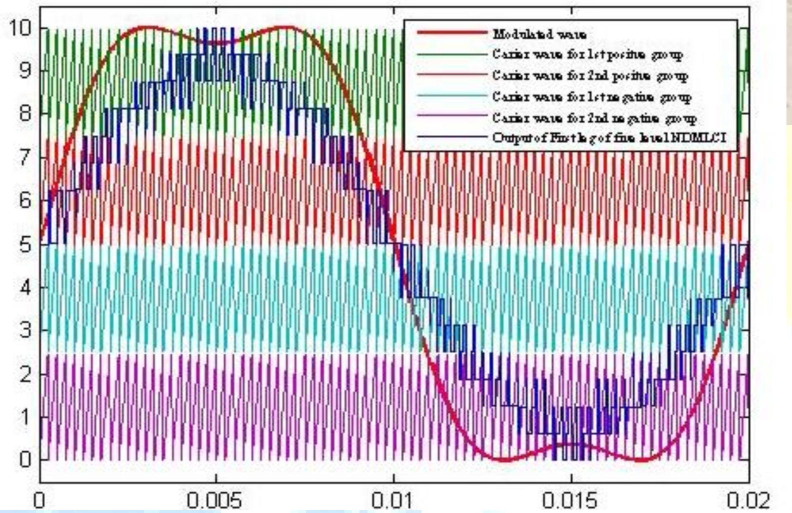

Figure 8: Third harmonic injected PWM

Simulation and Results:

Results of Wind Turbine:-Here we considered Wind turbine as rotate with constant speed i.e 19.4 rpm.

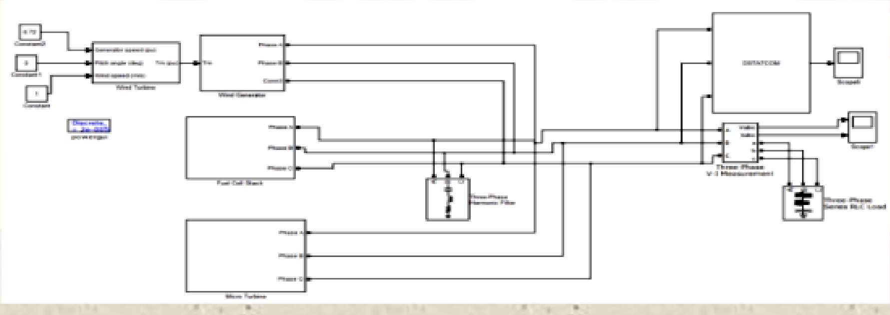

Figure 9: Simulink Diagram of the MicroGrid with ND - MLI DSTATCOM connected to Load

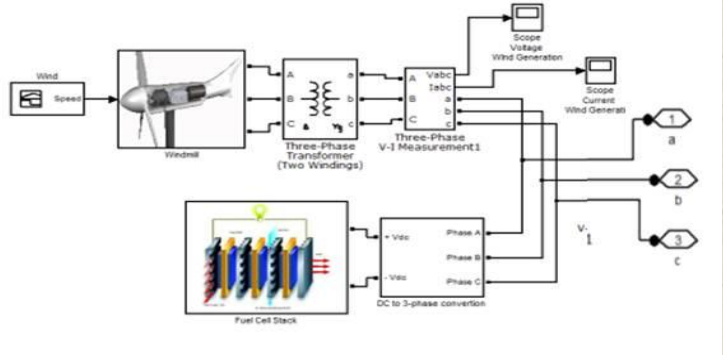

Figure 10: Internal Blok Diagram of the Micro Grid

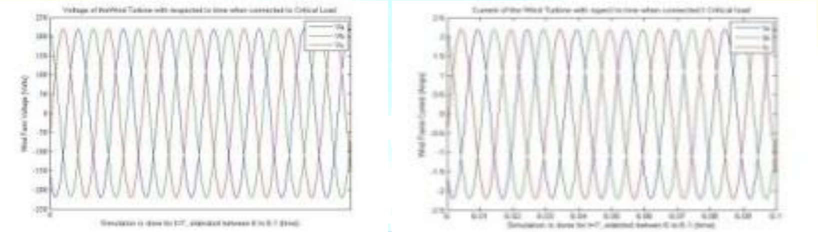

Figure 11: Voltage and Current shared by Wind Turbine

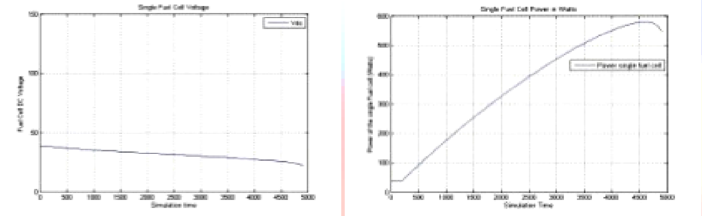

Figure 12: Voltage & Power shared by single Fuel Cell

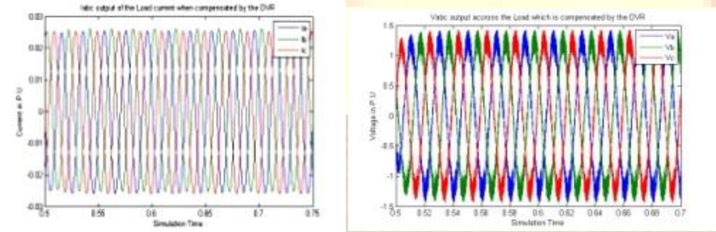

Figure 13: Currents &Voltages across the Load compensated by ND - MLI DSTATCOM

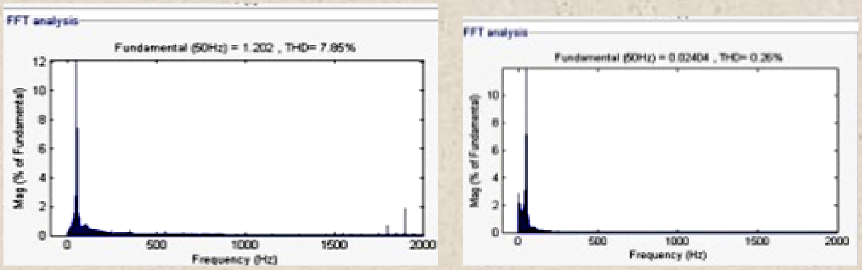

Figure 14: THD of the Voltage & Current at Load compensated by ND - MLI DSTATCOM

RESULT ANALYSIS:

The two developed models of the Wind Turbine and PEMFC are inserted in a complete MG system to deal with the system fast response.The simulation results show clearly the performance of a ND - MLI DSTATCOM in mitigating voltage sags under fault conditions with a low THD of 7.85% w.r.t Voltage and 0.26% w.r.t Current. The ND - MLI DSTATCOM handles both balanced and unbalanced situations without any difficulties and injects the appropriate voltage component to correct rapidly any anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value

CONCLUSION:

In this paper, MATLAB&SIMULINK dynamic models of Wind Turbine and PEMFC are developed. The obtained results prove that a Wind Turbine and fuel cell can deal with load changes in the micro grid.

The modeling and simulation of ND - MLI DSTATCOM using MATLAB/SIMULINK has been presented. The simulation shows that ND - MLI DSTATCOM performance is satisfactory in mitigating voltage sags/swells. The main advantage of this ND - MLI DSTATCOM is low cost and simple control. It can mitigate long duration voltage sags/swells efficiently during the fault. The impact of voltage sags on sensitive equipment is severe. Therefore, ND - MLI DSTATCOM is considered to be an efficient solution due to its low cost, small size, and fast dynamic response.

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