Design and Development of a Rectifier Stage Topology for µgrid

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Abstract— Microgrids (µ-grids) are new way of electrical systems consisting of distributed energy sources and sensitive loads. The subjective of operation is to distribute stable and quality electric power. As it is intricate for the use of a real µ-grid for laboratory project, development of a model that can be connected and utilized for nominal loads. The design and development of a new system configuration of the front-end rectifier stage for µ-grid is presented in this paper. First, the mathematical model of µ-grid is developed and this configuration allows the µ-grid to supply the load separately or simultaneously depending on the availability of the energy sources. Proposed hardware implementation involves Cuk-SEPIC fused converter, a cascaded multilevel inverter and a variable load. The inherent nature of this Cuk-SEPIC fused converter, additional input filters are not necessary to filter out high frequency harmonics. For extraction of maximum power from the Solar PV and wind an adaptive MPPT is used specifically a standard perturb and observe method is used for Solar PV Hardware and Simulation results will given the scope for the use of proposed Rectifier Stage Topology.

Index Terms— Microgrid (µ-grid), Cuk converter, SEPIC converter, MLCI

1 INTRODUCTION

The electrical grid is tending to be more distributed, intelligent, and flexible. The trend of this new grid is to become more and more distributed, and hence the energy generation and consumption areas cannot be conceived separately. Nowadays electrical and energy engineering have to face a new scenario in which small distributed power generators and dispersed energy storage devices have to be integrate together into the grid. A trend for the change in the performance of existing distributed generations from backup to immediate energy supply and to have a malleable contact approach which sets up for the concept of Microgrid have become incipient. Microgrids (µ-grids) have becoming an important concept to integrating distributed renewable sources and energy storage systems.

Managerial and technology, variation for power generation, environmental and economical enticements and the expansion of smaller generating systems like solar, wind, microturbine power generators have opened new goal for on-site power generation by electricity consumers [1-4]. Among all sources of µ-grid Solar PV and Wind energy holds the most potential to meet our demands. Specifically Wind energy has a high potential in supplying large amount of power but it depends on the velocity of wind at particular location. Similarly, Solar PV is also having high potential in severing load but it mostly serves potentially in the day light. By considering the drawbacks and their inherent natures a common maximum power point tracking (MPPT) algorithms is made for coupled source for improving the output power, power transfer efficiency and reliability significantly.

When an individual input source is insufficient in convention the local load demands, the alternate energy source can satisfy for the change.

Many scholars have been suggested a simpler multi-input structure by integrating renewable sources from the DC-end with MPPT for each renewable source and many have proposed a fusion of the buck and buck-boost converter and given a scope for further development [5-7]. With the literature a passive input filters are required to remove passive input remove the hike in current harmonics frequencies squeeze into generators of wind turbine [8-9]. The increase in power loss and decrease in lifespan of generators can be reduced by reducing harmonic content in generator.

In this paper, an alternative multi-input rectifier topology is proposed for µ-grid (hybrid Solar/Wind system). Hardware design is a blend of the Cuk and SEPIC converters [10-12]. The proposed topology will give a scope for the use of µ-grid with MPPT for individual source and rectification circuits. Hardware and Simulation results are lend to check with the utility of the proposed system.

![Fig.1: Hybrid system with multi-connected boost converter](image)

2 MICROGRID (µ-GRID)

2.1 Solar PV:

Photo Voltaic module basically in build with solar cell and it is the element in charge of transforming the sun rays or photons directly into power. For a Solar system, the voltage output is a constant DC whose magnitude depends on the composition in which the solar cells/ modules are connected [14]. The process of regulating the voltage and current output of the array must be upgraded based on the weather conditions such as irradiation.

Figure 2 & 3 represents the simulation results of solar with and without MPPT and I-V and P-V characteristics using
Guide. Maximum power point tracking (MPPT) algorithm is developed to constantly extract the maximum amount of power from the array under varying conditions. The ideal equations determining the I-V characteristics of the PV cell is.

\[ I = I_{ll} - I_{diode} \]  

(1)

Where \( I_{diode} = I_{Lc} \cdot \exp \left( \frac{qV}{\alpha L_{T}} \right) - 1 \)

\[ I = I_{ll} - I_{Lc} \cdot \exp \left( \frac{qV}{\alpha L_{T}} \right) - 1 \]  

(2)

Where, \( I_{ll} \) is the current generated by the sun irradiation, \( I_{diode} \) is the diode equation, \( I_{Lc} \) is the leakage current of the diode.

Electron charge \( q = 1.60217664 \times 10^{-19} \) C, \( k \) is the Boltzmann constant and \( T \) is the temperature, and \( 'a_d' \) is the diode ideally constant.

2.2 Wind:

The main components of a wind energy conversion system, including turbine blade, a gearbox, Converters, Inverters, Control circuits etc along with cables, filters, ground support equipment and interconnection equipment [13,15]. Wind turbine captures power from wind by means of turbine blades and converts it into mechanical power and Fig.2 represents the simulation output of Wind. The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time as follows

\[ P_w = \frac{1}{2} (\text{Mass of air per unit time}) \times (\text{Wind velocity})^2 \]

\[ = \frac{1}{2} \rho A_w V_w^2 \]  

(3)

Where, \( P_w \) : Power contained in wind (in watts), 
\( \rho \) : Air density,

\( A_w \) : Rotor area in (square meter)

\( V_w \) : Wind velocity without rotor interference,

Fig.4: Simulation Output of Wind

3 PROPOSED RECIFIER STAGE TOPOLOGY

The Power electronics research community and industry have reacted to this demand in two different ways: developing semiconductor technology to reach higher nominal voltages and currents. A system diagram of the proposed rectifier stage of a hybrid energy system is shown in Figure 5. The fusion of the two converters is achieved by reconfiguring the two existing diodes from each converter and the shared utilization of the Cuk output inductor by the SEPIC converter. This configuration allows each converter to operate normally individually in the event that one source is unavailable. Figure 5 illustrates the case when only the wind source is available. In this case, \( D_1 \) turns off and \( D_2 \) turns on; the proposed circuit becomes a SEPIC converter and the input to output voltage relationship is given by (4). On the other hand, if only the PV source is available, then \( D_2 \) turns off and \( D_1 \) will always be on and the circuit becomes a Cuk converter as shown in Figure 6. The input to output voltage relationship is given by (5). In both cases, both converters have step-up/down capability, which provide more design flexibility in the system if duty ratio control is utilized to perform MPPT control.

\[ V_{dc} = \frac{d_1}{d_2} \]  

(4)

\[ V_{dc} = \frac{d_2}{d_1} \]  

(5)

The mathematical expression that relates the total output voltage and the two input sources are been illustrated

To find an expression for the output DC bus voltage, \( V_{dc} \), the volt-balance of the output inductor, according to Figure 8. It is observed that \( V_{dc} \) is simply the sum of the two output voltages of the Cuk and SEPIC converter. This further implies that \( V_{dc} \) can be controlled by \( d_1 \) and \( d_2 \) individually or simultaneously.

Table1: Modes of switching states
As for the current stress, it is observed from Figure 8 which is the peak current always occurs at the end of the on-time of the MOSFET.

The PV output current, which is also equal to the average input current of the Cuk converter, is given in (10). It can be observed that the average inductor current is a function of its respective duty cycle \(d_1\)

\[
V_{ds1} = V_{PV}(1 + \frac{u_1}{u_2})
\]

\[
V_{ds2} = V_{W}(1 + \frac{u_1}{u_2})
\]

Therefore by adjusting the respective duty cycles for each energy source, maximum power point tracking can be achieved.

\[
i_{ds1,nk} = i_{PV} + i_{dc,av} + \frac{u_{PV}}{u_{1}}
\]

\[
i_{ds2,nk} = i_{W} + i_{dc,av} + \frac{u_{W}}{u_{2}}
\]

\[
L_{ds1} = \frac{u_1 - u_2}{r_1}
\]

\[
L_{ds2} = \frac{u_2 - u_1}{r_2}
\]

\[
i_{PV} = \frac{r_1}{r_2} \frac{u_2}{u_1}
\]

4 **MPPT CONTROL OF PROPOSED CIRCUIT**

A common inherent drawback of wind and PV systems is the intermittent nature of their energy sources.

The power coefficient \(C_p\) is a nonlinear function that represents the efficiency of the wind turbine to convert wind energy into mechanical energy. It is dependent on two variables, the tip speed ratio (TSR) and the pitch angle. The TSR, \(\lambda\), refers to a ratio of the turbine angular speed over the wind speed.

Radius of turbine blade \(r\)

Wind velocity \(V_w\)

Blade Pitch angle \(\beta\)

Angular velocity \(\omega\)

Blade tip speed \(\lambda\)

Turbine Power Coefficient \(C_p\)

Maximum value of \(C_p\) is 59.3% = 0.59
\[ c_0(\lambda, \beta) = c_1(\frac{\beta^2}{c_6} - c_2 \beta^4 - c_4) e^{-\frac{\beta}{c_3}} + c_6 \lambda \]

\[ x = \text{different for various turbine design} \]

\[ c_1 = 0.5176, c_2, 116, c_3 = 0.4, c_4 = 5, c_5 = 21, c_6 = 0.0068 \]

\[ \lambda = \text{different for various turbine design} \]

\[ \lambda = 1000 \text{ m/s} \]

\[ \alpha = \text{different for various turbine design} \]

\[ \alpha = 45 \text{ degrees} \]

\[ x = \text{different for various turbine design} \]

**5 CASCADED MULTILEVEL INVERTER**

The Cascade multilevel inverter subsists of a series of the H-bridge inverter units. The number of output phase voltage levels is 2S+1, where S is the number of DC sources and ‘s’ is the number of H-bridges connected in cascade per phase. Among ‘s’ number of switching angles, generally one switching angle is used for fundamental voltage selection and the remaining (s-1) switching angles are used to eliminate certain predominating lower order harmonics. In a three-phase system with isolated neutral, triplen harmonics are cancelled out automatically, and only non-triplen odd harmonics are present [17]. The fundamental voltage is obtained from the calculated switching angles \( \alpha_1, \alpha_2, \alpha_3 \ldots \alpha_n \) and ‘n’ represents the order of the harmonics and the switching angles are identical to the number of DC-sources. It is required to find the switching angles in the range of 0 to \( \pi/2 \) considering 3rd, 5th and 7th order phase voltage to zero.

The sum of all the individual inverter outputs \( (V_1+V_2+V_3=V_{out}) \) is represented in Figure 5, is voltage waveform of series H-bridge inverter which are proficient by connecting the DC source to AC output by using multiple combinations of switches.

The Fourier series of the quarter-wave symmetric for the above staircase waveform is written as follows:

\[ v_{out}(t) = \sum_{n=1}^{n} \sum_{k=1}^{n} \cos(n\alpha_k) \sin(n\alpha) \]

(11)

For seven level cascade inverter the fundamental voltage in terms of switching angles is given in equation (12).

\[ V_1 = \frac{\pi}{s} \sum_{k=1}^{s} \cos(\alpha_k) \]

When all the switching angles are zero

Maximum fundamental voltage \( (V_{1,\text{max}}) = 3 \times \frac{\pi}{4} \frac{\pi}{4} \)

Modulation index \( (M) = \frac{V_{1,\text{max}}}{V_{DC}} \)

(13)
The general function of the cascade multilevel inverter is to incorporate a desired voltage from several separate DC sources as shown in Fig.4. Each DC Source is connected to an H-bridge inverter and can generate three different voltage outputs, +Vdc, 0 and –Vdc [18]. The sum of all of the individual inverter outputs \( V_1+V_2+V_3=V_{out} \) are represented in Figure.5, is voltage waveform of series H-bridge inverter which are proficient by connecting the DC source to AC output by using multiple combinations of switches. Cascade multilevel inverter generally incorporated with different voltage sources and in these proposed cascade multilevel inverter DC sources as shown in figure 6 are replaced by µgrid (Solar, wind and Fuel Cell).

The Fourier series of the quarter-wave symmetric for the above staircase waveform is written as follows:

\[
v_{out}(ot) = \sum_{n=1}^{\infty} \frac{2Vdc}{n\pi} \sin(not) \sum_{k=1}^{n} \cos(n_k \alpha_k)\]

(14)

For seven level cascade inverter the fundamental voltage in terms of switching angles is given in equation (15).

\[
V_1 = \frac{2Vdc}{\pi} \sum_{k=1}^{7} \cos(\alpha_k)
\]

(15)

When all the switching angles are zero

Maximum fundamental voltage \( V_{1_{max}} = 3 \times \frac{2Vdc}{\pi} \)

Modulation index \( (M) = \frac{V_{1_{max}}}{V_{dc}} \)

(16)

The 7-level cascaded inverter requires three H-bridges. The non linear equations which are used to finding the switching angles and desired fundamental voltage of 7-level inverter are equations (17), (18), (19) and (20).

\[
[\cos(\alpha_1) + \cos(\alpha_2) + \ldots + \cos(\alpha_7)] = \frac{2Vdc}{\pi}
\]

(17)

\[
[\cos(3\alpha_1) + \cos(3\alpha_2) + \ldots + \cos(3\alpha_7)] = 0
\]

(18)

\[
[\cos(5\alpha_1) + \cos(5\alpha_2) + \ldots + \cos(5\alpha_7)] = 0
\]

(19)

\[
[\cos(7\alpha_1) + \cos(7\alpha_2) + \ldots + \cos(7\alpha_7)] = 0
\]

(20)

6 HARDWARE AND SIMULATION RESULTS

<table>
<thead>
<tr>
<th>NR Method</th>
<th>α1</th>
<th>α2</th>
<th>α3</th>
<th>α4</th>
<th>THD%</th>
</tr>
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<tr>
<td>ITR1</td>
<td>18.113</td>
<td>47.755</td>
<td>76.420</td>
<td>89.9</td>
<td>16.47%</td>
</tr>
<tr>
<td>ITR2</td>
<td>10.536</td>
<td>35.286</td>
<td>65.172</td>
<td>89.358</td>
<td>16.18%</td>
</tr>
<tr>
<td>ITR3</td>
<td>10.222</td>
<td>34.287</td>
<td>61.170</td>
<td>88.682</td>
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<tr>
<td>ITR4</td>
<td>13.291</td>
<td>35.605</td>
<td>65.702</td>
<td>89.499</td>
<td>15.19%</td>
</tr>
<tr>
<td>ITR5</td>
<td>16.818</td>
<td>38.241</td>
<td>69.090</td>
<td>89.8</td>
<td>14.27%</td>
</tr>
<tr>
<td>ITR6</td>
<td>16.414</td>
<td>38.147</td>
<td>65.921</td>
<td>89.785</td>
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</tr>
<tr>
<td>ITR7</td>
<td>16.102</td>
<td>36.213</td>
<td>65.919</td>
<td>89.710</td>
<td>13.27%</td>
</tr>
</tbody>
</table>
7 Conclusion

Now-a-days, the Microgrid is aggregations of resources are-connected to the different application as DC source. In this paper, an alternative multi-input rectifier topology is proposed for μ-grid (hybrid Solar/Wind system). Hardware de-sign is a blend of the Cuk and SEPIC converters. The proposed topology will give a scope for the use of μ-grid with MPPT for individual source and rectification circuits. Hardware and Simulation results are lend to check with the utility of the proposed system.

References


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