Wind-Solar-Storage Hybrid Micro grid Control Strategy Based on SVPWM Converter

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Abstract—Distributed generator (DG) is an increasing interest in using not only to inject power into the grid, but also to enhance the power quality. In this paper, a space voltage pulse width modulation (SVPWM) control method and current double closed loop control strategy is proposed for DG converter in a wind-solar-storage hybrid micro grid system. This method is based on the proper topology of three-phase voltage controller. Power fluctuation is existed in among wind system, photovoltaic (PV) system and both side of the storage unit system when the wind-solar-storage hybrid micro grid is disconnected to the grid because of troubleshooting or repairing of hybrid micro grid system, it can make a big shock, it also affects the normal work of the other DG and power quality of important load, and it even makes the whole system paralysis seriously. So, the topological structure of DG controller and control method are discussed in detail and simulation results are presented. The results demonstrate the effectiveness of the proposed method in the wind-solar-storage hybrid micro grid.

Index Terms—Hybrid Micro Grid, Wind-Solar-Storage, SVPWM Converter, Simulation

I. INTRODUCTION

The distributed generation system is becoming an important development direction in many countries and regions along with our country economy development fleetly, electric power requirement advance year after year and energy sources & environment contradiction looming large. Connecting the micro grid system and smart grid is an effective approach to make the best of distributed generation [1-5]. However, the distributed renewable energy power generation intermittence and the random characteristics restrict its power generation capability and its running stabilization. The micro grid can join the distributed generation, burden, energy storage equipment together through advanced control system, and form a controllable cell. It not only run with distribution power system connection grid, but also run without grid [6-8]. The micro grid connection may dig well the distributed generation and bring remarkable value into the power supply department and user [9-11]. The converter as bridge of micro power supply and grid has a crucial role for the stable operation of the whole system and the effective using of the power.

In this paper, the wind-solar-storage hybrid micro grid system structure is established firstly. The hybrid micro grid is connected the medium voltage (MV) alternating current distribution network by ac/dc or dc/ac converters [12-19]. In order to prevent the power output fluctuation to wind power and photovoltaic of wind energy and solar energy fluctuate, the battery is installed the side of wind system and solar system respectively. Meantime, it is also avoided the voltage flicker caused by controlling more power source start and stop frequently. And this system will avoid the big power output volatility state caused by unit power deviation set point value is not matched with unit adjusting ability though combining the power prediction method. Then the principle of double closed loop control strategy is analyzed and control model is established.

SVPWM converter is an ideal method to content the needs of the wind power system of ac excitation converter power supply. The dynamic mathematical model is established of three-phase voltage source SVPWM converter based on the three-phase voltage source converter topological structure. The voltage space vector control method was applied to process the dynamic real-time simulation for the converter, and its performance was analyzed. The simulation results validated that SVPWM converter control is viable and effective for the wind-solar-storage micro grid system.

This study make the SVPWM converter apply to wind-solar-storage micro grid power system based on the principle of voltage and current double closed loop control strategy and voltage space vector pulse width modulation technology. The control strategy and the principle are deduced on the basis of the topological structure for three-phase voltage type converter structure. Solar and wind energy will be generated power complementary by this wind-solar-storage hybrid micro grid system structure. It is realized the peak load shaving between wind power and solar photovoltaic power generation unit, and the long-term fluctuations of the grid power is inhibited in a certain extent.

II. STRUCTURE OF THE WIND-SOLAR-STORAGE MICRO GRID SYSTEM

The wind-solar-storage hybrid micro grid system structure is shown as Fig. 1. In Fig. 1, Micro grid is
connected the medium voltage (MV) alternating current distribution network by ac/dc or dc/ac converters [20-23]. All of these converters are used SVPWM control. Batteries are disposed at wind turbine and photovoltaic (PV) array export outlet for the power to stabilize the grid and islanding operation using a given voltage and frequency control [24-27]. Meanwhile, the batteries can absorb or recharge the power shortfall of wind and solar in order to maintain the power balance of the entire system.Load1 and load2 are sensitivity load. It should guarantee the reliability of power supply when micro grid system operations. Load3 is the normal load, it can be removed when necessary.

In order to prevent the power output fluctuation to wind power and photovoltaic of wind energy and solar energy fluctuate, the battery is installed the side of wind system and solar system respectively. Meantime, it is also avoided the voltage flicker caused by controlling more power source start and stop frequently. And this system will avoid the big power output volatility state caused by unit power deviation set point value is not matched with unit adjusting ability though combining the power prediction method, double closed loop control strategy and SVPWM Technology. Solar and wind energy will be generated power complementary by this wind-solar-storage micro grid system structure. It is realized the peak load shaving between wind power and solar photovoltaic power generation unit, and the long-term fluctuations of the grid power is inhibited in a certain extent.

According to the definition, instantaneous active and reactive power grid voltage is orientation $d,q$ coordinates SVPWM converter input active power $P$ and reactive power $Q$ shown as

$$
\begin{align*}
\Delta P &= u_d i_d + u_q i_q \\
\Delta Q &= u_d i_q - u_q i_d
\end{align*}
$$

(1)

According to the equation (1), the input active power of converter can be controlled by adjusting the $d$ axis current, and the input reactive power of converter can be controlled by adjusting the $q$ axis current when converter grid voltage constant. That id to say, it is realize the converter decoupling control of active and reactive power component.

When $P > 0$, converter is worked in rectifier state, and absorbed the energy from the grid. When $P < 0$, converter is worked in the state of inverter, energy is back to the power grid from the dc side. When $Q > 0$, the converter exported inductive reactive power. When $Q < 0$, capacitive reactive power is outputted via the converter.

**B. Space Vector Pulse Width Modulation Control Principle**

The main circuit structure of three-phase voltage SVPWM converter shown as Fig. 3. The power switch operated according to the modulation method, inductance L plays a filter role, and makes the input current approximating for sine wave of converter ac side. Dc bus voltage remains constant when converter steady state because having big capacitors in dc side.

Space voltage vector control is used in motor system has been widely, and used in new energy power generation and new type converter in recent years. It is
applied to parallel synchronous grid-connected controller in this paper.

In Fig. 3, \( V_a, V_b, V_c \) is the output three phase voltage value of the converter controlled by SVPWM method. The \( Q_1 \) to \( Q_6 \) is the six power transistor, which are controlled by the six control signal \( a, a', b, b', c, c' \). The upper part of a power transistor of inverter bridge is opened, \( a, b \) or \( c \) is equal to 1, the lower part of relative power transistor is shut down, that is to say the \( a' = b' = c' = 0 \). \( Q_1, Q_2 \) and \( Q_3 \) is the state of power transistor switch, which decided the value of output voltage \( V_a, V_b, V_c \). The relationship of the line voltage vector is \( [V_{ab}, V_{bc}, V_{ca}]^T \), \( [V_a, V_b, V_c]^T \) is the phase voltage vector, switch variable vector \( [a \ b \ c]^T \) and dc power supply voltage \( V_{dc} \) can be described as

\[
\begin{bmatrix}
V_{ab} \\
V_{bc} \\
V_{ca}
\end{bmatrix} = V_{dc} \begin{bmatrix}
1 & -1 & 0 \\
0 & 1 & -1 \\
-1 & 0 & 1
\end{bmatrix} \begin{bmatrix}
a \\
b \\
c
\end{bmatrix}
\] (2)

\[
\begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix} = \frac{1}{3} V_{dc} \begin{bmatrix}
2 & -1 & -1 \\
-1 & 2 & -1 \\
-1 & -1 & 2
\end{bmatrix} \begin{bmatrix}
a \\
b \\
c
\end{bmatrix}
\] (3)

According to the equation (2) and equation (3), the switch has eight possible combination models when the inverter is working. Relationship between switching states and voltage of inverter is described on the base of the \( V_{dc} \) value. As shown in Table I.

**TABLE I. RELATIONSHIP BETWEEN SWITCHING STATES AND VOLTAGE OF CONVERTER**

<table>
<thead>
<tr>
<th>Switch state</th>
<th>Phase voltage</th>
<th>Line voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>a b c</td>
<td>( V_a ) ( V_{ca} ) ( V_c )</td>
<td>( V_{ab} ) ( V_{bc} ) ( V_{ca} )</td>
</tr>
<tr>
<td>0 0 0</td>
<td>0 0 0</td>
<td>0 0 0</td>
</tr>
<tr>
<td>0 0 1</td>
<td>-1/3 -1/3 2/3</td>
<td>0 -1 1</td>
</tr>
<tr>
<td>0 1 0</td>
<td>-1/3 2/3 -1/3</td>
<td>1 0 -1</td>
</tr>
<tr>
<td>1 1 0</td>
<td>-2/3 1/3 -1/3</td>
<td>-1 0 1</td>
</tr>
<tr>
<td>1 0 1</td>
<td>1/3 -1/3 -2/3</td>
<td>-1 -1 -1</td>
</tr>
<tr>
<td>1 1 1</td>
<td>0 0 0</td>
<td>0 0 0</td>
</tr>
</tbody>
</table>

**Figure 3. Three-phase SVPWM converter structure**

In the \( d, q \) axis coordinate system, the three phase voltage corresponding to the output variables can be expressed in the following equation

\[
\begin{bmatrix}
V_d \\
V_q
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \\
0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2}
\end{bmatrix} \begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix}
\] (4)

According to the equation (4), the eight kinds of switch state combination is mapped to the \( d, q \) axis coordinate system, \( U_1, U_2, U_3, U_4, U_5, U_6, U_7, U_8 \) the eight vectors are called the basic space vector. And the space is divided into six sectors, shown as in Fig. 4.

**Figure 4. Basic voltage space vector**

The purpose of SVPWM method control is described one given voltage with the eight kinds of basic voltage vectors. That is to say, a given reference voltage vector \( u_{ref} \) is expressed through a combination of corresponding basic space vector. As a result of the converter can produce only eight basic voltage vector expressions, so after a known reference voltage vector can be according to the principle of volt-second characteristics is equal to the output voltage vector approximation to the reference voltage vector.

**Figure 5. First sector voltage vector composite**

In the following content, the first sector is analyzed as an example for processing decomposition. The synthesized voltage vector \( u_{ref} \) is decomposed in the first sector of all the space, shown as in Fig. 5. \( u_{ref} \) is expressed with \( U_1 \) and \( U_2 \), as shown in

\[
\begin{bmatrix}
T \\
U_{ref}
\end{bmatrix} = U_1 T_1 + U_2 T_2
\] (5)

The voltage and action time relationship in the \( d, q \) coordinate system can be described as

\[
\begin{bmatrix}
V_d \\
V_q
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \\
0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2}
\end{bmatrix} \begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix}
\]
\[ \begin{align*}
\left[ U_1 \right] T_1 + \left[ U_2 \right] T_2 \cdot \cos 60^\circ &= V_c T \\
\left[ U_4 \right] T_4 \cdot \sin 60^\circ &= V_c T 
\end{align*} \]  
(6)

In the equation, \( T \) is the switching period, \( T_1 \), \( T_2 \) is the action time of \( U_1 \) and \( U_2 \), \( T_0 \) is the zero vector function time. All the amplitude of \( U_1 \) and \( U_2 \) is \( 2/3 V_{dc} \). Where the equation passed series of mathematical calculations, can be expressed as expressed in

\[ \begin{align*}
T_1 &= T \left( \frac{3}{2} V_d - \frac{\sqrt{3}}{2} V_q \right) / V_{dc} \\
T_2 &= \frac{\sqrt{3} V_q T}{V_{dc}} 
\end{align*} \]  
(7)

The other sectors basic space voltage vector function time was calculated similarly. And it must be saturated judgment, that is, if \( T_1 + T_2 > T \), that pick up

\[ \begin{align*}
T_1 &= T \cdot \frac{3}{2} \left( V_d - \frac{\sqrt{3}}{2} V_q \right) / V_{dc} \\
T_2 &= T \cdot \frac{\sqrt{3} V_q T}{V_{dc}} 
\end{align*} \]  
(8)

Sectors is judged via set \( N = A + 2B + 4C \), the definition as follow

\begin{align*}
X &= \sqrt{3} V_q T / V_{dc} \\
Y &= \left( \frac{\sqrt{3}}{2} V_q + \frac{3}{2} V_d \right) T / V_{dc} \\
Z &= \left( \frac{\sqrt{3}}{2} V_q - \frac{3}{2} V_d \right) T / V_{dc} 
\end{align*}  
(9)

if \( V_q > 0 \), the A=1, otherwise A = 0; if \( \sqrt{3} V_d - V_q > 0 \), the B=1, otherwise B = 0; if \( \sqrt{3} V_d + V_q < 0 \), the C=1, otherwise C = 0. The relationship of \( N \), sector number and vector effect time and is available such as table II through the above analysis.

**TABLE II. RELATIONSHIP BETWEEN N, SECTORS, T1, AND T2**

<table>
<thead>
<tr>
<th>( N )</th>
<th>3</th>
<th>1</th>
<th>3</th>
<th>4</th>
<th>6</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector 1</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
<td>( Y )</td>
</tr>
<tr>
<td>Sector 2</td>
<td>( T_2 )</td>
<td>( T_2 )</td>
<td>( T_2 )</td>
<td>( T_2 )</td>
<td>( T_2 )</td>
<td>( T_2 )</td>
</tr>
</tbody>
</table>

According to the 000, 100, 110, 111, 110, 100, 110 worked order, there is only one switch is changed every time, as shown in Fig. 6.

Define the time of switch point distance zero point is \( T_v \), \( T_u \), \( T_w \)

\[ \begin{align*}
T_v &= (T - T_1 - T_2) / 4 \\
T_u &= (T_v + T_1 / 2) \\
T_w &= (T_v + T_2 / 2) 
\end{align*} \]  
(10)

\( T_1 \) is corresponded to the first vector role time value, \( T_2 \) is corresponded to another nonzero vector role time value. So, \( T_v, T_u, T_w \) is assigned with each sector of the waveform in one switching cycle.

\( T_v \) is distributed to the duty ratio maximum phase, and \( T_w \) is distributed to the minimum phase. The switch points \( T_{cm1}, T_{cm2}, T_{cm3} \) can be got through the various sectors worked waveform, such as table III.

**TABLE III. VALUE OF THE POINTS FOR SWITCHING**

<table>
<thead>
<tr>
<th>( N )</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_{cm1} )</td>
<td>( T_v )</td>
<td>( T_u )</td>
<td>( T_u )</td>
<td>( T_u )</td>
<td>( T_u )</td>
<td>( T_u )</td>
</tr>
<tr>
<td>( T_{cm2} )</td>
<td>( T_v )</td>
<td>( T_v )</td>
<td>( T_v )</td>
<td>( T_v )</td>
<td>( T_v )</td>
<td>( T_v )</td>
</tr>
<tr>
<td>( T_{cm3} )</td>
<td>( T_v )</td>
<td>( T_v )</td>
<td>( T_v )</td>
<td>( T_v )</td>
<td>( T_v )</td>
<td>( T_v )</td>
</tr>
</tbody>
</table>

**C. The Simulation Result of SVPWM**

Fig. 7 is sector judgment waveform. The sector No. of synthesized voltage is judged according to the \( N = A + 2B + 4C \). The purpose is the reference voltage vector expression by the corresponding basic space voltage vector and action times.

**Figure 6. The vector action of sector NO.1**

In sector 1, for example, the active time of zero vector 000 and 111 are equality in a switching cycle assumed, the symmetric PWM waveform is generated, each basic space vector effect time is divided into two parts.
Fig. 8 is the A phase bridge arm switching function waveform. The standard saddle waveform verified that the rapid SVPWM is validity.

IV. STUDY SYSTEM AND SIMULATION RESULTS

A. Simulation Parameter

In the example, the wind power rating is $P_w = 21K \text{w}$.

The rated power of Photovoltaic is $WP_{pv} = 8KW$. All the capacity of the battery1 and battery2 is set 10KW.h. Sensitive load1 and sensitive load2 active power reference values are 11KW and 8KW respectively. The value of the grid voltage is 380V, 50HZ. Filtering inductance is set $L = 2mH$. The value of dc side capacitor is set $C = 220\mu F$. Dc side voltage is set $E = 600V$. Power supply equivalent resistance value $R = 0.1\Omega$. The parameter of line is set $R/X = 0.641/0.082\Omega/km$.

A. Simulation Result

Fig. 9 shows the wind speed change state of wind turbine in this micro grid system, the wind speed $v$ is changed up and down based on the rated wind speed value 12$m/s$.

![Figure 9. The diagram of wind speed change](image)

Fig. 10 is the light and temperature waveform of solar micro power supply.

![Figure 10. The light and temperature diagram of](image)

Wind-solar-storage hybrid micro grid system is operated the connected grid state before one second, then it is run island model after with the grid disconnection at one second time. Micro grid connected to the grid again at twenty second, the corresponding simulation results as shown in the figure below. Fig. 11 shows the output active power of four micro power sources, $P_{w}$ is the output active power of wind turbine, $P_{pv}$ is the photovoltaic output active power, $P_{b1}$ is the output active power of battery1 and $P_{b2}$ is the output active power of battery2. Fig. 11 shows the battery can stabilize the wind power and photovoltaic fluctuations very well. In Fig. 12, the output reactive power of four micro power sources is shown. $Q_w$ is the output reactive power of wind turbine system, $Q_{pv}$ is the photovoltaic output reactive power, $Q_{b1}$ is the output reactive power of battery1 and $Q_{b2}$ is the output active power of battery2.

![Figure 11. The output active power simulation waveform of micro source](image)

![Figure 12. The output reactive power simulation waveform of micro source](image)

Fig. 9-Fig. 11 shows that micro grid system got wind energy and light energy in the form of maximum power tracking as the change of wind speed and illumination, and dynamic response is rapidly. The micro grid operated in island model at 2s- 20s times. The power after the wind and light supplement is averaged via batteriy1 and batteriy2 with the increase or decrease of wind speed and illumination. The batteries charged and discharged is reasonable according to different situations in order to maintain the power balance of whole micro power grid. Meanwhile, the reactive power of load need is provided by the batteries overall. Because of the micro grid is disconnected with grid, the micro power grid is not provided reactive power by the power grid system, and the reactive power from the batteries are increased at this time. So, the reactive power from the wind and photovoltaic array are configured zero value for ensuring maximum utilization of wind and light energy, the simulation results as shown in Fig. 12.

The micro grid changed as connected grid operation again at 21s-35s times, and storage battery adopted constant power control at this time. Wind power $P_{w}$ and
photovoltaic power $P_{w/g}$ transmitted according to the power after filtering under the action of the battery, the waveform as shown in Fig. 13 and Fig. 14. That is to say the battery can stabilize the wind power and photovoltaic fluctuations very well. In the process of the whole model transformation, system power changes gently, without the big power rush impacted on power grid, shown the good transient characteristics.

![Wind power waveform after stabilizing](image1)

Figure 13. Wind power waveform after stabilizing

![PV power waveform after stabilizing](image2)

Figure 14. PV power waveform after stabilizing

V. CONCLUSIONS

This study make the SVPWM converter apply to wind-solar-storage micro grid power system based on the principle of voltage and current double closed loop control strategy and voltage space vector pulse width modulation technology. The control strategy and the principle are deduced on the basis of the topological structure for three-phase voltage type converter structure. The models of these methods are built for simulation research. The theoretical analysis and simulation research validate this converter control and the battery can stabilize the wind power and photovoltaic fluctuations very well. The SVPWM converter is applied in the wind-solar-storage micro grid power system used this controls strategy and the modulation technology let the system realize the real time control more conducive.

REFERENCES


