Optimal Operation of Microgrid Employing Predictive Control

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***Abstract*—The purpose of the present paper is to build a predictive algorithm based on the output voltage of the LC filter in order to achieve the AC Microgrids operation in the maximum power point tracking of the captured solar energy. Methods of regulating the microgrids input voltage are conventionally achieved by linear control loops. This type of control presents limitations like high sensitivity to parameter variations and slow transient response. The operation of the microgrids at the maximum power point is analyzed. The inverter's the optimal power values are determined based on the simulated data. The simulations were carried out in the MATLAB/Simulink simulation environment. Based on the vector control, the voltage drops on the inverter transistors are calculated in advanced for the next step, based on the phase diagram. A predictive algorithm is designed to ensure a stable operation in the maximum power point area, MPP, (i.e. the optimal area from the energy point of view).**

Keywords—predictive algorithm, solar power plant; energy efficiency; maximum power point; variable solar power.

I. Introduction

In order to benefit of a maximum efficiency from the solar energy production systems, they must be operated at the maximum power points (MPPT). Therefore, the MPPT control is mandatory in today's world. In essence, it empowers low efficiency microgrids to always deliver maximum power [1], [2], [3], [4]. There is a wide variety of control algorithms for MPPT, based on space vector modulation (SVM), using closed-loop control. Most control methods are based on the generation of pulse width modulation (PWM) [5], [6], [7], [8].

This paper proposes a more dynamic control based on the measured current data to calculate the next future value at the inverter output. There is a wide variety of predictive control methods, but they are all based on three fundamental principles: the prediction model, the optimization of the result (rolling optimization) and the correction of the feedback [23]. The prediction model is the basis of an optimized control. The prediction model must be able to predict the future states or outputs of the system based on previous information. The optimization of the result refers to the minimization of control errors and to the minimization of the energy necessary for controlling the system. Predictive control needs to compensate for the influences of various external factors, thus a closed loop control mechanism must be introduced [23]. This paper uses a predictive model based on hysteresis. This procedure involves keeping the output value within the limits of a hysteresis area [11]. The predictive model is applied to a microgrid network to maintain the output power at maximum value. Among the advantages of the predictive control is the advance knowledge of the necessary output values . The main disadvantage is that the errors that occurred when purchasing the output values can be corrected during the next sampling interval. The predictive control presented in this paper is based on the classical six step commutation.

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II. Description of the Method

The model of the system used in this paper is shown in Figure 1. The vector that minimizes the load current error is applied during the next sampling interval. The possible voltage vectors generated by the inverter are shown in Figure 2. The switching state could be changed only once at each sampling instant.

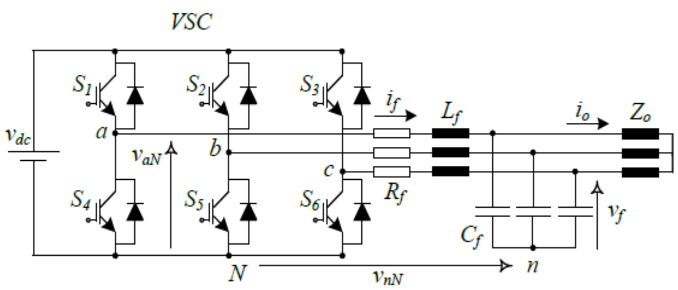

Fig. 1. Inverter model

Between the output voltage $\vec{v}$ and the switching state vector $\vec{S}$ there is a proportional relationship:

$$\vec{v} = V_{dc} * \vec{S} \quad (1)$$

Where:

$$\vec{S} = \frac{2}{3}(S_a + \vec{a}S_b + \vec{a}^2 S_c) \quad (2)$$

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V_{dc} – is the DC link voltage

$\vec{a}$ – is the angle $(e^{j\frac{2\pi}{3}})$

S_a, S_b, S_c are the switching state of the inverter and they can be described as:

$$S_a = \begin{cases} 1, & S_1\text{-on} \quad S_4\text{- off} \\ 0, & S_1\text{-off} \quad S_4\text{-on} \end{cases} \tag{3}$$

$$S_b = \begin{cases} 1, & S_2\text{-on} \quad S_5\text{-off} \\ 0, & S_2\text{-off} \quad S_5\text{-on} \end{cases} \tag{4}$$

$$S_c = \begin{cases} 1, & S_3\text{-on} \quad S_6\text{-off} \\ 0, & S_3\text{-off} \quad S_6\text{-on} \end{cases} \tag{5}$$

With the above defined states, eight possible voltage vectors generated by the inverter can be obtained. The voltage values are presented in the below table:

TABLE I. VOLTAGE VALUE BASED ON STATE

S_a	S_b	S_c	Voltage vector $\vec{v_i}$
0	0	0	$\vec{v_0}=0$
1	0	0	$\vec{v_1}=\frac{2}{3}v_{dc}$
1	1	0	$\vec{v_2}=\frac{2}{3}v_{dc}+j\frac{\sqrt{3}}{3}v_{dc}$
0	1	0	$\vec{v_3}=-\frac{1}{3}v_{dc}+j\frac{\sqrt{3}}{3}v_{dc}$
0	1	1	$\vec{v_4}=-\frac{2}{3}v_{dc}$
0	0	1	$\vec{v_5}=-\frac{1}{3}v_{dc}-j\frac{\sqrt{3}}{3}v_{dc}$
1	0	1	$\vec{v_6}=\frac{1}{3}v_{dc}-j\frac{\sqrt{3}}{3}v_{dc}$
1	1	1	$\vec{v_7}=0$

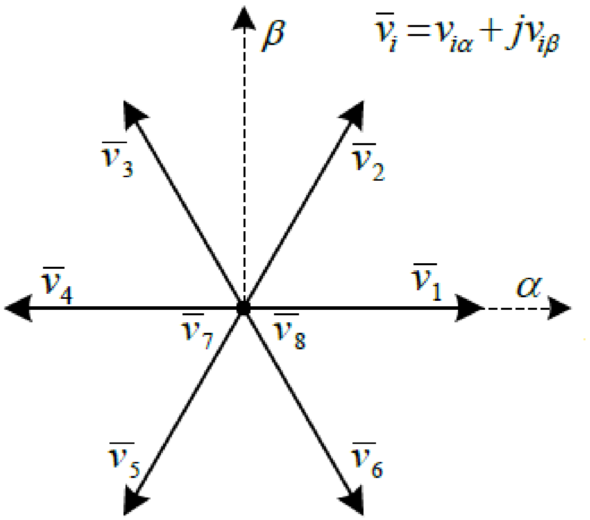

Fig. 2. Vectors generated by the inverters

III. PREDICTIVE CONTROL

Based on what was previously presented, a predictive algorithm was developed by measuring the phase voltage,the phase current before the LC filter and the phase current after the LC filter. For simplification, the measurements in phase coordinates were transformed into αβ coordinates. The control loop has the following schematic (figure 3):

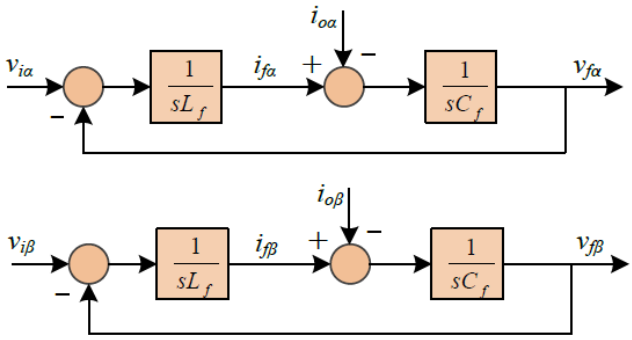

Fig. 3. The control loop

From the above schematic the transfer matrix in the time domain can be derived.

$$\frac{d}{dt}\begin{bmatrix} if \\ vf \end{bmatrix} = A \begin{bmatrix} if \\ vf \end{bmatrix} + B \begin{bmatrix} vi \\ io \end{bmatrix} \tag{6}$$

$$A = \begin{bmatrix} \frac{-Rf}{Lf} & \frac{-1}{Lf} \\ \frac{-Rf}{Cf} & 0 \end{bmatrix} \tag{7}$$

$$B = \begin{bmatrix} \frac{1}{Lf} & 0 \\ 0 & \frac{-1}{Cf} \end{bmatrix} \tag{8}$$

In order to simulate the results and to transfer them inside of a microcontroller, it is necessary to convert them into:

- Laplace domain

$$H\alpha(s) = \frac{1.333*10^7}{s^2 + 1.333*10^7} \tag{9}$$

$$H\beta(s) = \frac{-6.667*10^4*s}{s^2 + 1.333*10^7} \tag{10}$$

- Discrete domain

$$H\alpha(z) = \frac{0.06593*z+0.06593}{z^2-1.868*z+1} \tag{11}$$

$$H\beta(z)=\frac{-6.52*z+6.52}{z^2-1.868*z+1} \qquad (12)$$

Having all the measured data ready, one more step is needed in order to finish the prediction the state determination. This consists in the using two reference signals: a sinusoidal signal and its phase-shifted one with a phase of 90°.

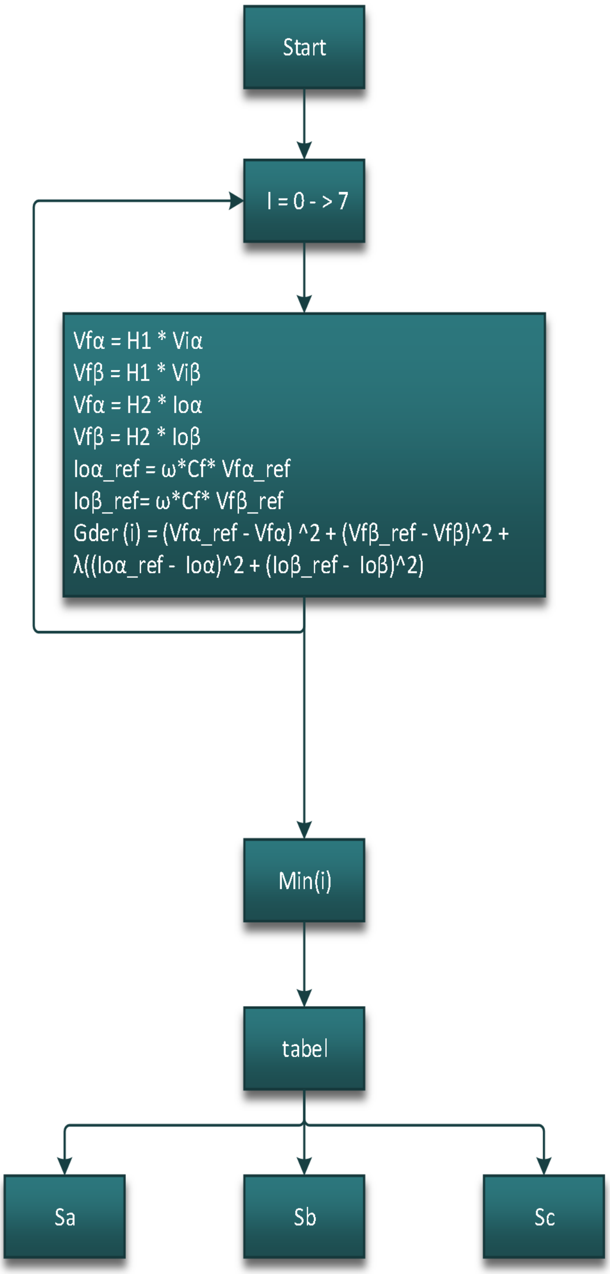

Fig. 4. Logic scheme of the predictive algorithm

The reference signal is then introduced together with the measured and converted signal into an equation that will provide the error between the two signals.

The voltage equation is described below:

$$g_{con}=(v^{*}_{f\alpha} - v_{f\alpha})^2 + (v^{*}_{f\beta} - v_{f\beta})^2 \qquad (13)$$

The current equation is as next depicted:

$$g_{der}=(Cf*\omega_{ref}*v^{*}_{f\alpha} - i_{f\alpha}+i_{o\alpha})^2 + (Cf*\omega_{ref}*v^{8}_{f\beta} - i_{f\beta}+i_{o\beta})^2 \qquad (14)$$

The above two equations will form one by summing them with a correction factor λ_d.

$$g_{predictive}=g_{con}+ \lambda_d*g_{der} \qquad (15)$$

From (15) a look-up table can be implemented that will trigger one of the seven possible states of the static converter. The implemented resulted predictive algorithm is next presented in figure 4.

IV. Simulation Results

By implementing the proposed predictive algorithm in MATLAB/Simulink environment, the following waveforms were obtained:

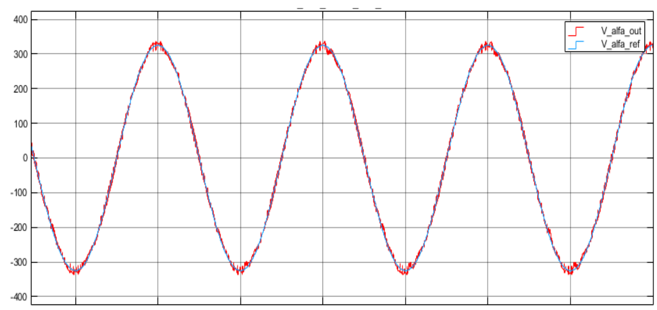

Fig. 5. Vα_out vs Vα_ref

Figure 5 presents two waveforms: Vα_out obtained from the predictive algorithm and Vα_ref that is mainly a cosine wave with a frequency of 50 Hz and an amplitude of 325 V. It can be observed that the two signals are overlapping with little ripples on the edges.

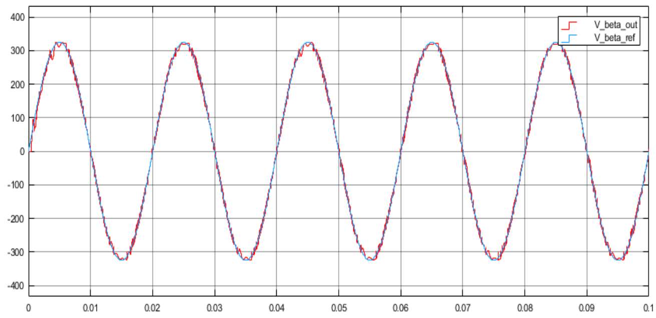

Fig. 6. Vβ_out vs Vβ_ref

Figure 6 presents two waveforms: Vβ_out obtained from the predictive algorithm and Vβ_ref that is mainly a sine wave with a frequency of 50 Hz and an amplitude of 325 V. In this case also, the two signals are overlapping too.

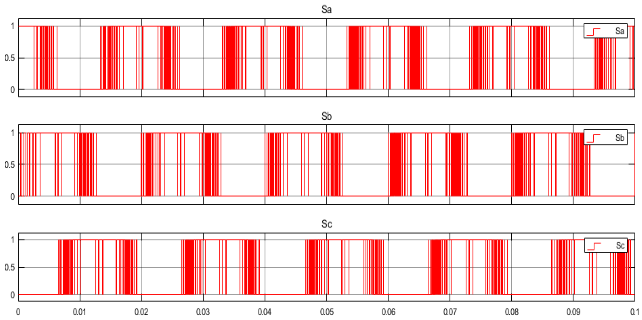

Fig. 7. Sa, Sb, Sc commutation

In the above figure 7, the states of the inverter's phases are presented, as stated by (3), (4) and (5) equations. The value of 1 means that the upper transistor is on (see Figure 1) and the lower one is off.

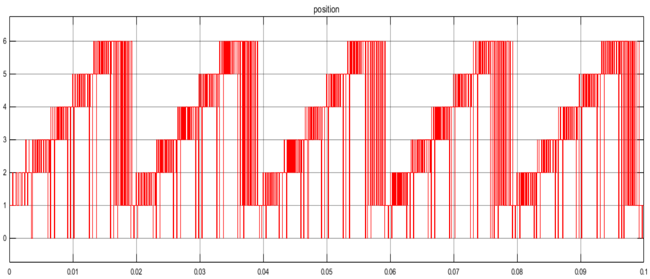

Fig. 8. Output voltage commutation vector

In a classical vector control algorithm each state is on for a certain amount of time and after that it will go to the next state from 0 to 6 and then reset. The proposed predictive algorithm does the same with some sudden changes in between as it can be seen in Figure 8. In the latter case, the applied vector is not that static and, based on the measurement data,depending on the error needed to be compensated and on the imposed sine-like waveform on the output, any other state based can be applied.

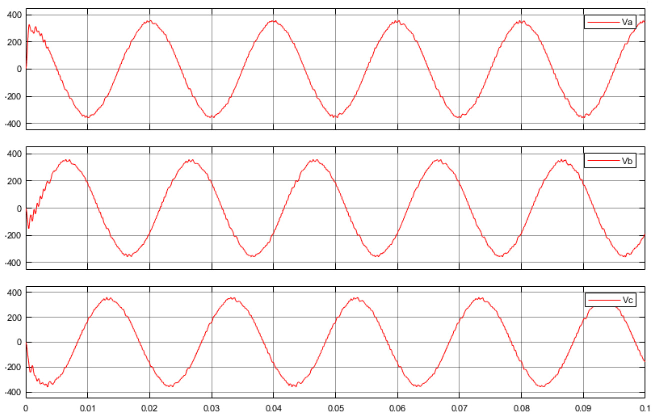

Fig. 9. Output voltage on each phase

Figure 9 displays the voltage on each phase in the phase (abc) coordinates. The only visible flaw is the starting point in which small ripples are visible, but they can be neglected depending on the application.

The parameters used in the simulation are presented in the below table.

TABLE II. PARAMETERS VALUE

Variable name	Value
Vdc	600 [V]
Lf	5 [mH]
Cf	15 [uF]
Z0	10 + 0.754j [Ω]
sample time	1 [us]
Vref amplitudee	325 [V]
output frequency	50 [Hz]
λ_d	5000
ω_{ref}	314 [rad/s]

V. CONCLUSION

A predictive control method was presented in this paper based on the classical vector control. The predictive control is far better than the vector control because it changes its states based on the input signals adapting the commutation sequence. One of its drawbacks is that a rather high frequency must be used, so a simple microcontroller might not be able to do that, therefore it needs a better hardware equipment like an FPGA or a DSP. Further fine tuning and improvements will take place when using the algorithm to control a real inverter.

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