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A STRUCTURAL APPROACH STUDY OF MODEL PREDICTIVE CONTROL IN THE PERSPECTIVE OF PHOTOVOLTAIC SYSTEMS

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Abstract

Solar energy photovoltaic power is the direct solar energy utilization form with non-pollution, effective and easy power generation which can be either independent running or parallel running. The independent running of solar energy photovoltaic power generation system requires battery as the energy storage device, chiefly adopted in remote areas without power grid and dispersedly populated areas. But, the whole system is rather costly. Predictive control developments for applications in the field of renewable energy systems are still under investigation. In this article, the fundamentals of predictive control are studied with a focus on model predictive control (MPC). Based on this techniques, a control strategy for flexible power supply can be developed which could be implemented in renewable energy systems, such as solar photovoltaic (PV) systems.

I. Introduction

Nowdays, fossil fuel is the main energy supplier of the worldwide economy, but the recognition of it as being a major cause of environmental problems makes the mankind to look for alternative resources in power generation. Moreover, the day-by-day increasing demand for energy can create problems for the power distributors, like grid instability and even outages.

The necessity of producing more energy combined with the interest in clean technologies yields in an increased development of power distribution systems using renewable energy.

Among the renewable energy sources, the photovoltaic (PV) technology gains acceptance as a way of maintaining and improving living standards without harming the environment. The number of PV installations has an exponential growth, mainly due to the governments and utility companies that support programs that focus on grid-connected PV systems. Besides their low efficiency, the controllability of grid-connected PV systems is their main drawback. As a consequence, the current controller plays a major role. Therefore, the control strategies become of high interest [1].

Renewable energy power is an important solution to global warming. Solar energy generated from PV systems is one of the fastest and the most promising growing renewable energy types. Recently more power electronics converters have been used to integrate the energy sources into the AC and/or DC common buses in a distributed generation (DG) system. As the penetration and capacities of DG units increase, the power converters are required to operate more efficiently and effectively to maintain high power quality and dynamic stability. To fulfil these requirements, advanced control techniques have been intensively investigated in the last years.

The main characteristic of predictive control is the use of the system model for the prediction of the controlled variables. Next, predefined optimized criterion selects the appropriate control set.

The predictive controller aims for system-level control using control horizons of several minutes or even hours, but it fails to consider the discrete-time models and behaviours of power converters that act as power electronic interface between the renewable energy sources and the grid. In this paper we extend and explore the feasibility of predictive control by suggesting appropriate control strategies for renewable energy systems.

Model predictive control (MPC) ranks second after PID as the most widely-applied control methods in industry. Compared to PID controller, MPC has some significant advantages including fast response and stronger robustness against load disturbance and

parameters uncertainty. Especially, one prominent characteristics of MPC is predicting the future behavior of the desired control variables based on a minimization cost function until a predefined horizon in time. With the rapid development of high-speed microprocessors, MPC has been applied increasingly to "fast-process" systems such as power converters and power systems in the past years.

II. Principle of model predictive control

The basic principle of the MPC strategy is shown in Figure 1. Through switching state Si, with Si=1,…, n, the system can be evaluated with variable x(t) and the prediction function f(x(t), Si), for i=1,…,n. In t=tk , all the possible system prediction results xn(k+1), for n=1,…,n, can be obtained. This prediction function f is derived directly from the discrete time model. The behavior of the system at t_{k+1} can be obtained by the measured value x(k) and n switching control signal Si, it can generate n possible values x_0, x_1, …,x_n. As shown in Figure 1, the predicted value $x_1(k+1)$ is the closest to the reference x*. so S2 is selected and applied in following sample time in t=$t_{k.}$ Following the same criterion, the predicted value $x_1(k+2)$ is

the closest to the reference x* thus S3 is selected and applied in t=t_{k+1}. So that the control signals of the inverter switching tubes can be obtained [1]. According to Jiefing et al [6], active power P(k+1) and reactive power Q(k+1) at t_{k+1} can be predicted by t_k moment state. In order to predict instantaneous active power P(k+1) and reactive power Q(k+1) at tk+1, it needs to know grid current i_d, i_q , grid voltage e_d, e_q , sampling voltage $u_d(k)$,$u_q(k)$, three-phase inverter switching state Si and DC bus voltage U_{dc}. In order to select the optimal voltage vector $u_d(k)$, $u_q(k)$, it needs to establish a cost function g. Comparing all the predict power values, a voltage vector which makes the cost function minimum will be chosen and applied at the following moment. Figure 2 shows the algorithm for the direct MPC power control.

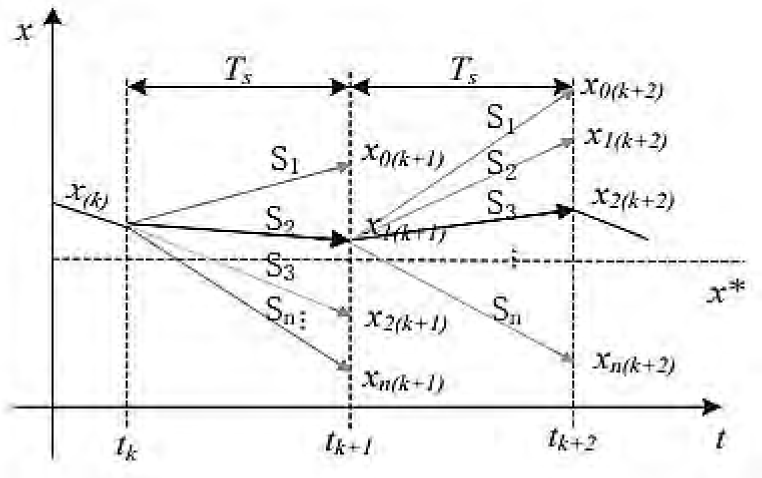

Figure 1. Principle of MPC

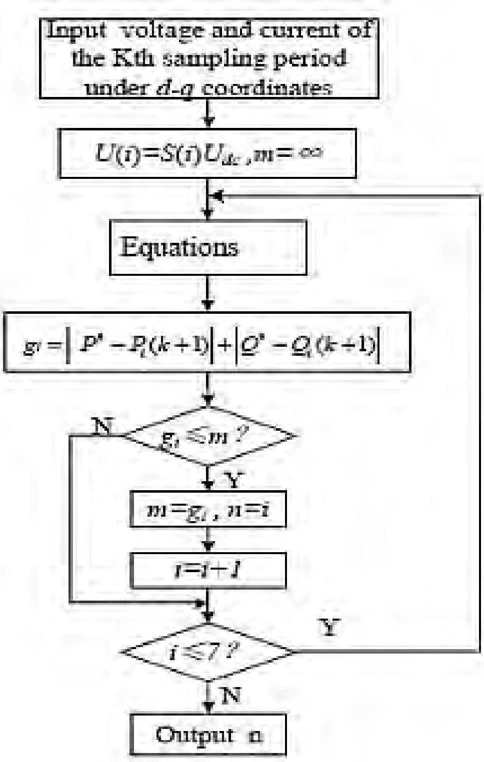

Figure 2. MPC flowchart for direct power control

III. Application of Predictive Control in Renewable Energy Systems

For PV system, several useful topologies have been studied and applied. Figure 3 shows a typical configuration of PV system where several strings are interfaced with their own DC-DC converter for voltage boosting and then connected to a common DC bus. After that, a common DC-AC inverter is used for grid interfacing. Usually the MPPT is implemented on the DC-DC converter, while the grid synchronization and power regulation are achieved by the grid-side inverter.

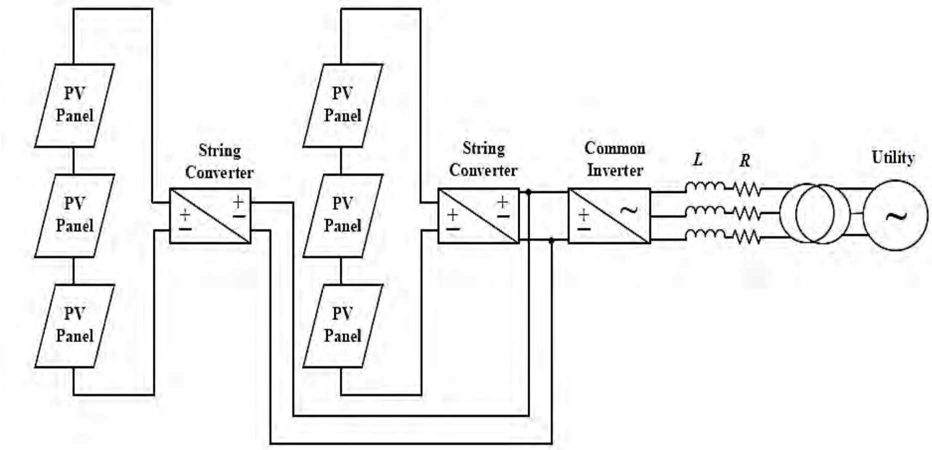

Figure 3. A typical configuration of PV system.

In this paper we concentrate on the control of the grid-side common inverter of the PV system (figure 1). Grid-connected PV systems should be controlled to regulate active and reactive powers flexibly for voltage support and power quality improvement. In this sense, flexible power regulation capability for a DG unit becomes more and more significant. For two-level inverters, there are eight possible voltage vectors generated by the inverter (six active vectors and two null vectors), and the α-β plane is divided into six sectors, as shown in Figure 4 [2,3].

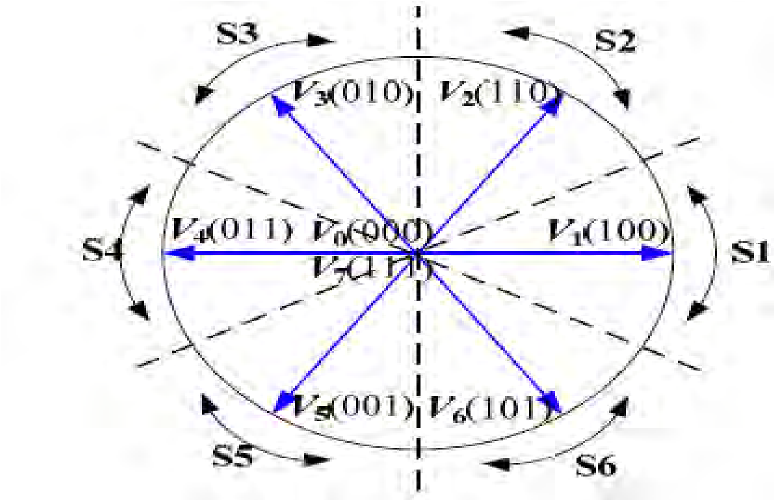

Figure 4. Possible voltage vectors generated by the inverter and sector division

According to the equivalent circuit in figure 1, the system mathematical model can be expressed as:

$$Vi = Vg + IR + L\frac{di}{dt} \qquad (1)$$

Where Vi and Vg are the inverter output voltage vector and grid voltage vector, respectively; I the line current vector; L the filter inductance; R the filter resistance. The instantaneous active and reactive powers exchanged between the PV and the utility grid can be expressed as:

$$P = \frac{3}{2}Re\{VgI^*\} = \frac{3}{2}\,(V_{g\propto}I_{\propto} + V_{g\beta}\,I_{\beta}) \qquad (2)$$

$$Q = \frac{3}{2}\,Im\{VgI^*\} = \frac{3}{2}\,(V_{g\beta}I_{\propto} + V_{g\propto}\,I_{\beta}) \qquad (3)$$

where a and b represent the real and imaginary components of the space vector expressed in the stationary frame. According to Equations (2) and (3), the active and reactive power derivatives can be calculated as:

$$\frac{dp}{dt} = \frac{3}{2}(\frac{dVga}{dt}I \propto +Vga\ \frac{DI\propto}{dt} + \frac{dVg\beta}{dt}I\beta + Vg\beta\ \frac{dI\beta}{dt} \quad (4)$$

$$\frac{dQ}{dt} = \frac{3}{2}(\frac{dVg\beta}{dt}I \propto +Vg\beta\ \frac{DI\propto}{dt} - \frac{dVg}{dt}I\beta - Vg \propto\ \frac{dI\beta}{dt} \quad (5)$$

Considering sinusoidal and balanced line voltage, one can obtain:

$$\frac{dVg\propto}{dt} = -wg.Vg\beta \qquad (6)$$

$$\frac{dVg\beta}{dt} = wg.Vg \propto \qquad (7)$$

Thus, the inverter output active and reactive power derivatives can be obtained by substituting Equations (1), (6) and (7) into Equations (4) and (5) as:

$$\frac{dp}{dt} = -\frac{R}{L}P - wgQ + \frac{3}{2L}(Re(VgVi^*) - |Vg|^2) \quad (8)$$

$$\frac{dQ}{dt} = wgP - \frac{R}{L}Q + \frac{3}{2L}Im\big((VgVi^*)\big) \quad (9)$$

$$P^{k+1} = Ts[-\frac{R}{L}P - wgQ + \frac{3}{2L}(Re(VgVi^*) - \ |Vg|^2)] + P^k \quad (10)$$

$$Q^{k+1} = Ts\left[wgP - \frac{R}{L}Q + \frac{3}{2L}Im(VgVi^*)\right] + Q^k \quad (11)$$

Now the predictive model has been obtained mathematically with Equations (10) and (11). Figure 5 depicts the block diagram of the proposed MPC strategy for grid-connected PV systems [4,5]. After the power is predicted, the next step is to evaluate the effects of each voltage vector on active and reactive powers and then select the one producing the least power ripple according to a specific cost function. Here, the cost function is defined as follows considering the same weighting priority for P and Q:

$$J = (P^* - P^{K+1})^2 + (Q^* - Q^{K+1})^2 \quad (12)$$

Once the optimal voltage vector is determined, it will be applied during the next sampling period to control the inverter.

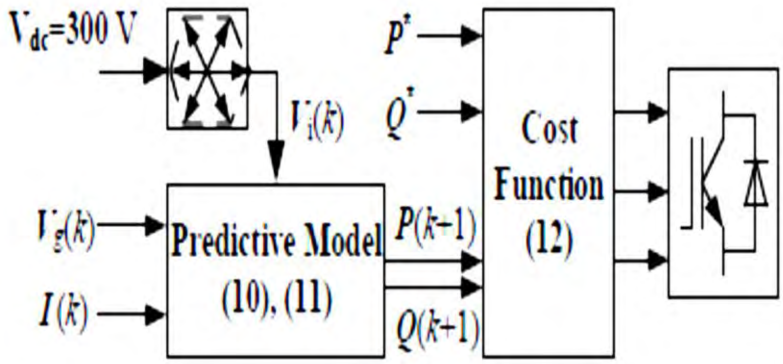

Figure 5. Block diagram of MPC strategy of PV systems.

IV. Conclusion

This paper has reviewed the most important type of predictive control approaches, namely model predictive control which can be employed in renewable energy systems such as PV power generation. Application example has been described. With the increasing level of renewable energy sources penetration in existing power system, new challenges have been posted to the control of these distributed generation units (DGs). The DGs are not only controlled to injected power into the main grid, also required to participate in grid support by flexible power regulation.

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