Adaptive control of a voltage source converter for power factor correction

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Abstract: In this paper an adaptive control is designed for a three-phase voltage source converter (VSC) acting as a static synchronous compensator to provide power factor compensation. The proposed method relies on an approximate third-order nonlinear model of the VSC that accounts for uncertainty in three system parameters. The design ensures asymptotic tracking of q-axis current and dc-voltage reference trajectories.

Keywords: Adaptive control, Voltage source converters (VSC), Power factor, PFC (Power Factor Correction), SPWM, Phase lock loop, THD, PCC

1. Introduction

A passivity based controller is proposed in those copies with unbalanced current and parameter uncertainties. The VSC model is developed using negative and positive sequence dynamics. Unlike the method proposed in this paper, none of the previous work involves an adaptive control for a third-order model with three unknown parameters. Hence, the proposed design accounts for a more precise VSC model and statements regarding its performance are improved in that regard. This paper improves on work by providing experimental validation and an explanation of how the controller achieves robust tracking performance. The paper is organized as follows: first, two third-order VSC models based on different power balances are presented. After a simple nonlinear state transformation, a linear model is obtained and its adaptive control derived. Simulation and experimental validation demonstrate the method’s performance. A PI control is cascaded with the d-axis current control to achieve robust tracking of constant dc voltage. A control method is proposed for a third-order VSC model. uses Lyapunov’s stability results and assumes a constant dc load current so the controller is independent of circuit parameters. A nonlinear sliding mode control provides robustness to parameter uncertainty and disturbance inputs. Another approach exploits the differential flatness of the system and takes energy stored in the VSC and q-axis current as linearizing output.

2. Techniques description

2.1 Three-Phase VSC Modeling

A typical application of power factor correction using a VSC. The VSC is connected at a point of common coupling (PCC) to a balanced three-phase source and inductive load through filter inductors. The inductive load introduces a phase shift between the ac source current and voltage, and this leads to a lagging power factor seen from the ac source. The VSC is in parallel with the load to improve power factor. The three-phase VSC contains six insulated gate bipolar transistors (IGBTs) each with an ant parallel diode to
provide a path for current when the transistor is off. The impedance of each filter inductor, which also includes IGBT conduction losses, is assumed balanced and equal to \( R + j\omega L \), where \( \omega \) is the angular frequency of the ac source.

![Circuit Diagram](image.png)

**Figure 1:** Circuit diagram

The ac source voltages are denoted \( v_a, v_b, v_c \), the ac source currents are \( i_a, i_b, i_c \), the currents flowing into the converter are \( i_a, i_b, i_c \), and the VSC terminal voltages are \( e_a, e_b, e_c \). The VSC gating signals \( g_1, \ldots, g_6 \) are binary valued and generated by sinusoidal pulse width modulation (SPWM). SPWM is based on comparing a triangular carrier wave with three-phase modulation signals. The phases of the modulation signals are shifted by \( 2\pi/3 \) and by \( \delta \) relative to the ac source. The SPWM amplitude modulation index is denoted by \( m_a \) and is determined by the ratio of the amplitudes of the modulation and carrier signals. Other choices of modulation are possible, e.g., space vector modulation, with straightforward modification.

### 2.2 Adaptive Control

Adaptive control is the control method used by a controller which must adapt to a controlled system with parameters which vary, or are initially uncertain. For example, as an aircraft flies, its mass will slowly decrease as a result of fuel consumption; a control law is needed that adapts itself to such changing conditions. Adaptive control is different from robust control in that it does not need a priori information about the bounds on these uncertain or time-varying parameters; robust control guarantees that if the changes are within given bounds the control law need not be changed, while adaptive control is concerned with control law changing them.

![Circuit Diagram](image.png)

**Figure 2:** Circuit
3. Simulation design without modulation

A simulation design modulation technique as shown in Figure 3 is 13 level symmetric MLI and figure 4 & 5 is corresponding voltage waveform & current distortion. Figure 6 & 8 is the proposed 13 & 31 levels Asymmetric MLI. Figure 7 is corresponding voltage waveform. The THD analysis is also compared for all the three simulations which is shown below in Figure 5, 8 & 9.

![Figure 3: Voltage Source converter without adaptive control](image)

![Figure 4: Line to neutral voltage waveform](image)
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4. Modulation technique types of adaptive control technique

In general one should distinguish between: 1. Feed forward Adaptive Control, 2. Feedback Adaptive Control as well as between 1. Direct Methods and 2. Indirect Methods. Direct methods are ones wherein the estimated parameters are those directly used in the adaptive controller. In contrast, indirect methods are those in which the estimated parameters are used to calculate required controller parameters. There are several broad categories of feedback adaptive control (classification can vary):

Dual Adaptive Controllers [based on Dual control theory]

1. Optimal Dual Controllers [difficult to design]
2. Suboptimal Dual Controllers
3. Nondual Adaptive Controllers

Figure 5: Line voltage waveform

Figure 6: Proposed VSC with adaptive control
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4. Adaptive Pole Placement
5. Extremum Seeking Controllers
6. Iterative learning control
7. Gain scheduling
8. Model Reference Adaptive Controllers (MRACs)

Figure 7: Shunt VSC

Figure 8: Voltage & Current with (out) injection

Figure 9: I/P Voltage & Current waveform
5. Conclusion

Various types of stability may be discussed for the solutions of differential equations describing dynamical systems. The most important type is that concerning the stability of solutions near to a point of equilibrium. This may be discussed by the theory of Lyapunov. In simple terms, if all solutions of the dynamical system that start out near an equilibrium point stay near forever, then is Lyapunov stable.

More strongly, if is Lyapunov stable and all solutions that start out near converge to, then is asymptotically stable. The notion of exponential stability guarantees a minimal rate of decay, i.e., an estimate of how quickly the solutions converge. The idea of Lyapunov stability can be extended to infinite-dimensional manifolds, where it is known as structural stability, which concerns the behavior of different but nearby solutions to differential equations. Input-to-state stability (ISS) applies Lyapunov notions to systems with input

Given I/P & Expected O/P

1. \(V_{in} = 440\text{Vac (ph to ph)}\)
2. \(V_{SAF} = 170-200\text{Vdc}\)

5.1 Applications

When designing adaptive control systems, special consideration is necessary of convergence and robustness issues. Lyapunov stability is typically used to derive control adaptation laws and show convergence.

Typical applications of adaptive control are (in general)

1. Self-tuning of subsequently fixed linear controllers during the implementation phase for one operating point;
2. Self-tuning of subsequently fixed robust controllers during the implementation phase for whole range of operating points;
3. Self-tuning of fixed controllers on request if the process behaviour changes due to ageing, drift, wear etc.;
4. Adaptive control of linear controllers for nonlinear or time-varying processes;
5. Adaptive control or self-tuning control of nonlinear controllers for nonlinear processes;
6. Adaptive control or self-tuning control of multivariable controllers for multivariable processes (MIMO systems);

Usually these methods adapt the controllers to both the process statics and dynamics. In special cases the adaptation can be limited to the static behavior alone, leading to adaptive control based on characteristic curves for the steady-states or to extremum value control, optimizing the steady state. Hence, there are several ways to apply adaptive control algorithms.

5.2 Advantages

1. For HVDC transmission. To reduce the complexity of the control design,
2. design accounts for a more precise VSC model and statements regarding its performance are improved
3. The dc voltage transient is indirectly controlled by \(d\)-axis current response.
4. Power factor correction is achieved almost unity
5. Increased voltage

A conclusion section must be included and should indicate clearly the advantages, limitations, and possible applications of the paper. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

Acknowledgements

Applications. Increased Grid capacity, HVDC-links, Industrial UPS, Marine UPS. Future scope-The control system can make simple than now used. In future we may have smart grid. At the time we may need the adaptive control to maintain constant voltage for different situation.

6. References