Lecture Notes in Electrical Engineering 365

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Editors

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Introduction

This book includes the original, peer-reviewed research papers from the 2nd International Conference on Electrical Systems, Technology and Information (ICESTI 2015), held during 9–12 September 2015, at Patra Jasa Resort & Villas Bali, Indonesia.

The primary objective of this book is to provide references for dissemination and discussion of the topics that have been presented in the conference. This volume is unique in that it includes work related to Electrical Engineering, Technology and Information towards their sustainable development. Engineers, researchers as well as lecturers from universities and professionals in industry and government will gain valuable insights into interdisciplinary solutions in the field of Electrical Systems, Technology and Information, and its applications.

The topics of ICESTI 2015 provide a forum for accessing the most up-to-date and authoritative knowledge and the best practices in the field of Electrical Engineering, Technology and Information towards their sustainable development. The editors selected high quality papers from the conference that passed through a minimum of three reviewers, with an acceptance rate of 50.6 %.

In the conference there were three invited papers from keynote speakers, whose papers are also included in this book, entitled: “Computational Intelligence based Regulation of the DC bus in the On-Grid Photovoltaic System”, “Virtual Prototyping of a Compliant Spindle for Robotic Deburring” and “A Concept of Multi Rough Sets Defined on Multi-Contextual Information Systems”.

The conference also classified the technology innovation topics into five parts: “Technology Innovation in Robotics, Image Recognition and Computational Intelligence Applications”, “Technology Innovation in Electrical Engineering, Electric Vehicle and Energy Management”, “Technology Innovation in Electronic, Manufacturing, Instrumentation and Material Engineering”, “Technology Innovation in Internet of Things and Its Applications” and “Technology Innovation in Information, Modeling and Mobile Applications”.

In addition, we are really thankful for the contributions and for the valuable time spent in the review process by our Advisory Boards, Committee Members and Reviewers. Also, we appreciate our collaboration partners (Petra Christian

University, Surabaya; Gunadarma University, Jakarta; UBAYA, Surabaya, University of Ciputra, Surabaya, Institute of National Technology, Malang and LNEE Springer, Germany), our supporting institution (Oulu University, Finland, Widya Mandala Catholic University, Surabaya and Dongseo University, Korea) and our sponsors (Continuing Education Centre, Petra Christian University, Surabaya and Patrajasa Resort Hotel, Bali).

On behalf of the editors Felix Pasila

Part I
Invited Speaker

Chapter 1
Computational Intelligence Based Regulation of the DC Bus in the On-grid Photovoltaic System

Mauridhi Hery Purnomo, Iwan Setiawan and Ardyono Priyadi

Abstract This paper presents a bidirectional DC/AC converter control system based on the vector control method for regulating the DC bus in On-grid photovoltaic systems. In this control scheme, the main task of the DC/AC converter is to control the power flow between the DC bus and the electrical grid. To avoid conventional controller parameter tuning problems and in addition to enhance transient performances of the DC bus voltage response that caused by abrupt changes of local DC loads that directly connected to DC bus system, in this work, the DC/AC converter control system is designed by utilizing radial basis function neural networks, that is a kind of the computational intelligence method. By combining with simple proportional control, the overshoot and undershoot of the DC bus voltage that caused by sudden connections and disconnections of the local DC loads can be damped more quickly and better than the standard optimal PI control system, so the overvoltage condition of the DC bus capacitor could be avoided. The effectiveness of the proposed control system is proved by simulation results.

Keywords Bidirectional DC/AC converter · Computational intelligence · Radial basis function neural networks · Vector control

1.1 Introduction

In the last decades, the development of distributed power generation systems based on renewable distributed generators like Photovoltaic, wind turbine, and fuel cell have grown rapidly [1–4]. To efficiently supply electrical power to local DC loads,

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the combination of the On grid DG system with DC microgrid recently also has attract a lot of attention [5].

In the control system point of view, there are at least two independent controlled converters in On-grid renewable power systems that connected via DC link: (1) an AC/DC or a DC/DC renewable power source side converter and (2) a bidirectional DC/AC grid side converter. The major task of the renewable power source side converter generally is to extract maximum power from green power source, i.e. by using Maximum Power Point Tracking (MPPT) algorithm, whereas the DC/AC grid side converter is to regulate DC bus voltage in a certain reference such that the flow of the electrical power between the DC link and the grid could be guaranteed.

In the On-grid green power systems combined with local DC loads, the dynamic of the DC bus capacitor voltage basically is not only influenced by power dynamic generated using the green power sources but also the change of the load that directly connected to DC bus. If the DC/AC grid side converter is not controlled properly, the sudden connection and disconnection of the local DC loads could make overvoltage in the DC link capacitor.

Based on the type of the controller, up until now, Proportional Integral (PI) based controller is one of the most popular techniques generally utilized for DC/AC converter to regulate DC bus capacitor. However to get the optimal parameter of the control system, the parameter of the plant model practically should be known accurately. Several papers proposed intelligence techniques such as Fuzzy logic control and Sliding Mode Controller [6–8] to avoid conventional controller parameter tuning problems and to enhance the control performances.

The main focus of this work is to design a controller of bidirectional DC/AC converters for regulating DC bus voltage in On-grid photovoltaic system combined with DC micro grid by using Radial Basis Function Neural Networks (RBFNN). RBFFNN is one of the intelligence computation technique that has been widely adopted and implemented for off-line and on-line modelling and control application [9, 10]. The utilizing of the RBFNN as a control component in this case is to dampen overshoot and undershoot of the DC bus voltage that caused by sudden connections and disconnections of the local DC loads so the overvoltage condition of the DC bus capacitor could be avoided. Some simulations using Matlab Simulink software have been drawn to show the effectiveness of the proposed controller. Based on the simulation results, the performance of the RBFNN is better than the optimum PI controller.

The remainder of this paper is organized as follows. Section 1.2 describes the system model of the On-grid photovoltaic system combined with DC micro grid and the short theories of the RBFNN. The proposed control design is discussed in Sect. 1.3. Section 1.4 discusses some RBFNN simulation results, and finally, the conclusions are drawn in Sect. 1.5.

1.2 System Model

Figure 1.1 shows the topology of the On-Grid photovoltaic power system combined with DC microgrid under study. As shown in Fig. 1.1, there are two converters and its associated controller that operated independently.

The DC/DC buck-boost converter connected to the PV module is used to pump maximum electric power generated from the PV panel to the intermediate storage of the DC bus capacitor. Whereas the DC/AC converter injects surplus energy from the DC bus capacitor to the electrical grid. In this case, the PV power production is lower than the DC load consumption. The converter is able to transfer energy from the electrical grid to supply power shortages to the local DC load.

1.2.1 Photovoltaic Module and Its Converter

The main tasks of the DC/DC buck-boost converter as shown at Fig. 1.2 are to extract maximum electrical power from the PV module by means of the MPPT algorithm and at the same time the converter amplify the output voltage of the PV module to the DC bus voltage level. The PV module itself basically can be modeled as a circuit that contains current source parallel with diode. The typical characteristic of the V-I and V-P relations of the PV module is shown in Fig. 1.3. For the detail model of the PV module, the readers could refer to [11].

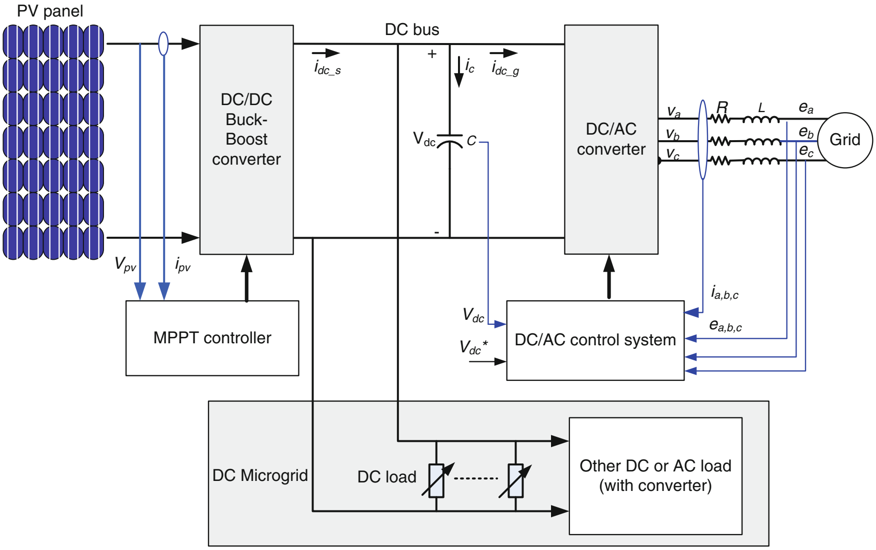

Fig. 1.1 Topology of the On Grid PV system combined with DC loads

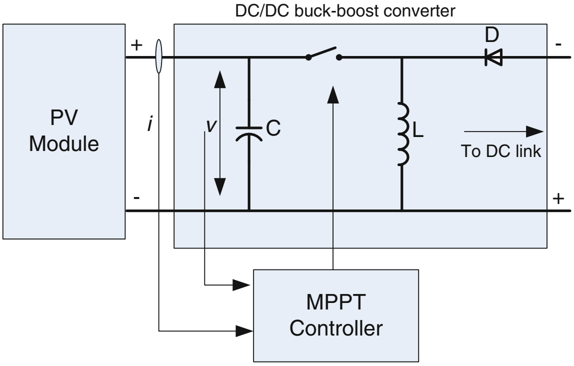

Fig. 1.2 DC-DC buck-boost converter circuit model

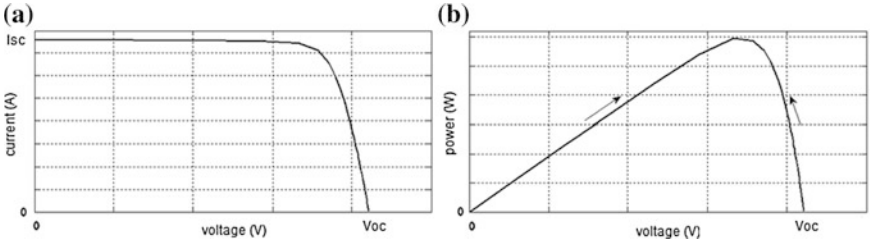

Fig. 1.3 The typical characteristic of V-I and V-P of a PV module

Although there several sophisticated MPPT algorithms proposed in the literature [12], in this works, the Perturb and observe (P&O) algorithm is used to extract maximum power from PV module. P&O basically, due to the dynamic of the solar irradiation, is far slower compared to the dynamic of the DC load connected to DC bus.

1.2.2 The Bidirectional DC/AC Converter Control Model

The main task of the DC/AC converter control system (Fig. 1.4) is to control the flow of the active power between DC bus and the electrical grid bidirectionally. This bidirectional control of the electrical power is accomplished indirectly by regulating the DC link voltage at a certain level.

In this proposed scheme there are two main factors that determine the direction of the power flow in the DC/AC converter: (1) The power generated from the PV module and (2) The total DC loads connected to DC bus. If the total DC loads

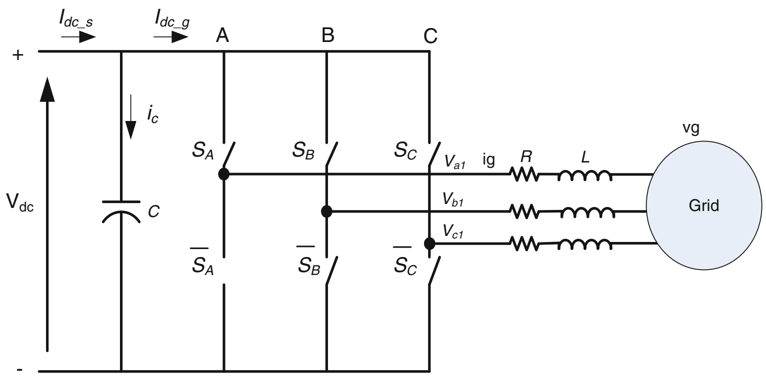

Fig. 1.4 The DC/AC Converter Model

power is less than the power of the PV module, the DC/AC converter will inject the surplus energy to the electrical grid (inverter mode), and conversely if consumption of the DC load power is higher than the power production of the PV module, the DC/AC converter will transfer some power from the electrical grid (rectifier mode). So in this case, the balance of the power will be maintained.

For the converter circuit model in Fig. 1.4, the mathematical relations in the standard rotated *dq* model is represented in (1.1) and (1.2) [13].

$$v_{df} = Ri_{df} + L\frac{di_{df}}{dt} + v_{dg} - \omega_s Li_{qf} \tag{1.1}$$

$$v_{qf} = Ri_{qf} + L\frac{di_{qf}}{dt} + v_{qg} + \omega_s Li_{df} \tag{1.2}$$

where R and L are a resistance and an inductance of the filter, whereas i_{df}, i_{qf}, v_{df}, v_{qf}, v_{dg}, v_{qg} respectively are currents and voltages of the inverter and the grid in *dq*-axes model. and ω_s is a grid frequency. For ease of the design of feedback controllers, the two relations could be represented in the standard differential equation below [14]:

$$\frac{di_{df}}{dt} = -\frac{R}{L}i_{df} + \frac{1}{L}v_{df} + \frac{1}{L}d_{df} \tag{1.3}$$

$$\frac{di_{qf}}{dt} = -\frac{R}{L}i_{qf} + \frac{1}{L}v_{qf} + \frac{1}{L}d_{qf} \tag{1.4}$$

where:

$$d_{df} = (-v_{dg} + \omega_s L i_{qf}) \tag{1.5}$$

$$d_{qf} = (-\omega_s L i_{df}) \tag{1.6}$$

In this case, d_{df} and d_{qf} could be regard as measurable disturbances that can be easily compensated by its negation. If the rotated dq-axes perfectly aligned with the rotated grid voltage vector, the grid active and reactive power respectively could be represented in (1.7) and (1.8).

$$P_g = \frac{3}{2}(v_{dg} i_{df}) \tag{1.7}$$

$$Q_g = \frac{3}{2}(-v_{dg} i_{qf}) \tag{1.8}$$

From (1.7) to (1.8), it is clear that the active and the reactive grid power respectively could be controlled by the regulation of the d-axis and the q-axis current component independently. In the DC/AC control system, the reference of the d-axis current component is derived from the output of the DC bus voltage loop control.

By using SPWM with 3th harmonic injection, The dynamic capacitor voltage itself is represented by (1.9) [14].

$$\frac{V_{dc}}{dt} = -\frac{3}{2}\frac{m_a}{\sqrt{3}C} i_{df} + \frac{1}{C} i_{dc\_s} \tag{1.9}$$

1.2.3 The RBFNN Model

The RBFNN basically can be categorized as associative memory network that is fit used for on-line adaptive controller. This attribute basically come from the RBFNN properties: local generalization, simple learning rule and just have three-layer networks architecture [15]. Mathematically, The output of the RBFNN could be formulated as:

$$y = \sum_{i=1}^{p} G_i(\|c_i - X\|) w_i \tag{1.10}$$

where X, $G_i(.)$, w_i and c_i are input vector, Gaussian function weight and centers respectively. The RBFNN Weight updating can be computed easily by using least mean square algorithm that is showed in (1.11).

$$w(k+1) = w(k) + \alpha e(k) G(k) \tag{1.11}$$

1.3 Control Design

By using vector control technique, there are two loop controls that should be to designed: (1) The inner current loop control that related with the grid active and reactive power injection/absorption, and (2) the outer DC bus voltage loop control that related with regulation of the capacitor voltage.

Due to the capacitor voltage level is directly determined by active power that flow via DC bus, then the control output of the DC bus control in this case is used as reference of the *d*-axis current component. Figure 1.5 shows the complete block diagram of the proposed DC/AC converter control system.

1.3.1 Current Loop Control Design

As shown by (1.3) and (1.4), the dynamic of the *dq*-axis current component of the converter circuit basically is coupled first order system. To control of those current, in this work, we just utilize PI control plus Feedfoward control:

$$u_{d(q)} = u_{PI} - d_{d(q)f} \tag{1.12}$$

where u_{dq} and u_{PI} respectively are total control output and PI control output, whereas d_{dqf} is current coupling terms as represented by (1.5) and (1.6). By using

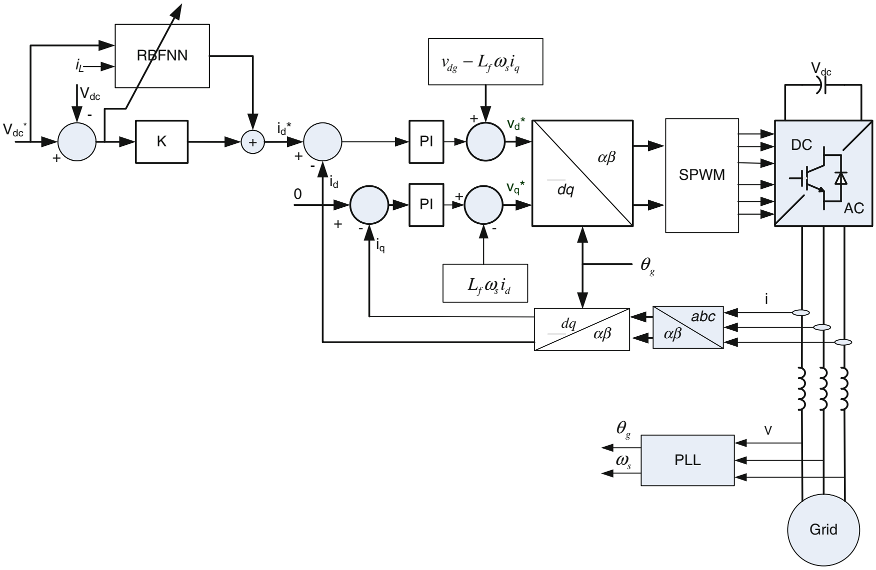

Fig. 1.5 Diagram block of the DC/AC Converter control system

the control strategy (1.12), the dynamic of the *dq*-axis current model dynamic could be simply represented by transfer function form:

$$H_{d(q)}(s) = \frac{I_{d(q)}(s)}{V_{d(q)f}(s)} = \frac{(1/R)}{(L/R)s + 1} \tag{1.13}$$

Utilizing pole placement technique, the PI control parameters can be obtained easily by using (1.14):

$$\begin{aligned} K_i &= R/T_{cl} \\ K_p &= \frac{L}{T_{cl}} \end{aligned} \tag{1.14}$$

where K_i, K_P and T_{cl} are the integrator gain, the proportional gain and the desired closed loop time constant, respectively. Equation (1.15) shows the final transfer function of the *dq*-axis current component closed loop system by using pole placement technique.

$$H_{d(q)cl}(s) = \frac{I_{d(q)}(s)}{I_{d(q)ref}(s)} = \frac{1}{T_{cl} + 1} \tag{1.15}$$

1.3.2 DC Bus Voltage Control Design

By substituting $I_d(s)$ from (1.15) to the transfer function $V_{dc}(\mathrm{s})/I_d(s)$ from (1.9), we can obtain dynamic the DC bus capacitor voltage to the change of the *d*-axis current component reference (1.16).

$$V_{dc}(s) = -\frac{3m_a}{s2\sqrt{3}C}\frac{1}{(T_{cl} + 1)}I_{d\_ref}(s) + \frac{1}{Cs}i_{dc\_s} \tag{1.16}$$

by referring to the DC/AC control topology in the Fig. 1.5 the *d*-axis current component reference $I_{d\_ref}(s)$ basically is the simple proportional gain output plus the RBFNN output:

$$I_{d\_ref} = K_P(V_{dc} - V_{dc\_ref}) + U_{RBFNN} \tag{1.17}$$

Substituting (1.17) to (1.16), we will derive (1.18)

$$V_{dc}(s) = \frac{HK_p}{(s + HK_p)}V_{dc\_ref}(s) + \frac{U_{RBFNN}}{(HK_P/s + 1)} + \frac{1}{(HK_P/s + 1)Cs}i_{dc\_s} \tag{1.18}$$

If the weight updating of the RBFNN in Eq. (1.11) is stable such that:

$$U_{RBFNN} = -\frac{1}{Cs} i_{dc\_s}(s) \tag{1.19}$$

Then (1.18) could be simplified as:

$$V_{dc}(s) = \frac{HK_p}{(s + HK_p)} V_{dc\_ref}(s) \tag{1.20}$$

by using the final limit teorema of the Laplace transform, it is clear that from (1.20), the output of DC bus capacitor voltage in the steady state will always equal to its reference.

1.4 Simulation Result and Discussion

In this Section, some simulations based on the Matlab Simulink software packet have been done to show the performance of the proposed control system and comparing the results with the PI base control system. For the simulation purpose, the parameter of the plant and the RBFNN model is chosen as shown in Table 1.1. Whereas Table 1.2 shows the PI control parameter for both the inner current loop and the DC bus voltage loop control. The PI parameter for the inner loop is obtained by using the pole placement technique, where the desired closed loop time constant is 0.001 s. The outer loop PI controller parameters is derived using the symmetrical optimum method. As shown in Tables 1.1 and 1.2, for fair comparison, the simple gain proportional at the RBFNN controller is the same with the proportional gain of the optimal PI controller.

In this simulation, the power of the PV module is extracted using the simple P&O MPPT algorithm where the output of this algorithm is used directly to drive a semiconductor switch of the DC/DC buck-boost converter. Figure 1.6a shows the output power of the PV module in 1 s time duration for solar irradiance 1000 W/m^2 that is delivered to DC bus system that have reference 350 V.

Table 1.1 Plant and RBFNN control parameter

Plant parameter	Value	Plant parameter	Value
Pv nominal power (W)	2000	L DC/AC filter (H)	0.01
DC bus voltage ref. (V)	350	C- DC link (uF)	1200
Grid voltage (rms) (V)	110	SPWM frequency (KHz)	10
Grid frequency (Hz)	50	RBFNN MF number	6
Time sampling (s)	0.0001	Alpha	0.0000025
R DC/AC filter (ohm)	0.02	Simple gain	0.560

Table 1.2 The optimal PI parameters

Inner Loop Control parameter	Value	Outer Loop Control parameter (for comparison)	Value
Kp	10.0	Kp	0.560
Ki	20.0	Ki	62.22

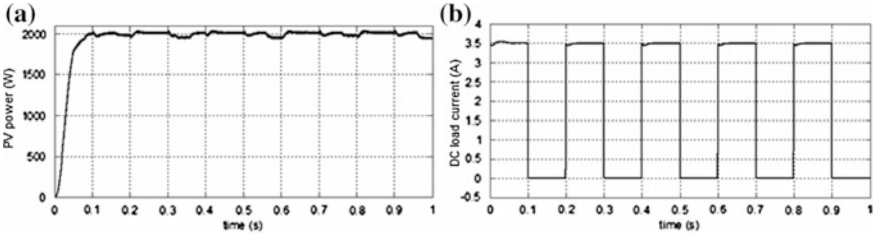

Fig. 1.6 The PV Power output delivered to DC bus (**a**) the change of DC load current caused by connection and disconnection DC load (**b**)

To test the transient performance of the DC/AC converter control system in the capability of the voltage regulation and the grid power injection in response to the abrupt changes of the DC load, in this work, we do by connecting/disconnecting 100 ohm resistor in the DC microgrid bus suddenly every 0.1 s. Figure 1.6b shows the current flowing into the microgrid caused by such action.

In view of the control system, this DC load changes can basically be considered as disturbance that cause the output control system deviates from the reference. Figure 1.7 shows the changes of some important variables in the on grid PV system in response to the DC load changes: (a) the DC bus voltage, (b) the grid active power, (c) the grid reactive power, and (d) the grid current.

For comparison purposes, the response of the RBFNN control system and the standard PI control system is plotted in the same axis as shown in Fig. 1.7. From Fig. 1.7a, we can see that in response to the changes of DC load current, the voltage of the DC bus in a while will deviate from its reference. However it is clear from Fig. 1.7a that at any time the DC load is changed, the output response of the RBFNN control system in the transient state is more damped compared to the response of the PI control system. The superiority of the RBFNN control system over the PI control can also be seen from performance indexes ITAE showed in Fig. 1.7a.

With the constant solar irradiance and the changing load, the profile of the surplus electrical power that is injected to the grid is shown in Fig. 1.7b. From Fig. 1.7b, it could be seen that the power injection resulted from the RBFNN control system has settling time faster compared to the response of the PI control system. We can also see the bidirectional nature of the DC/AC converter system at

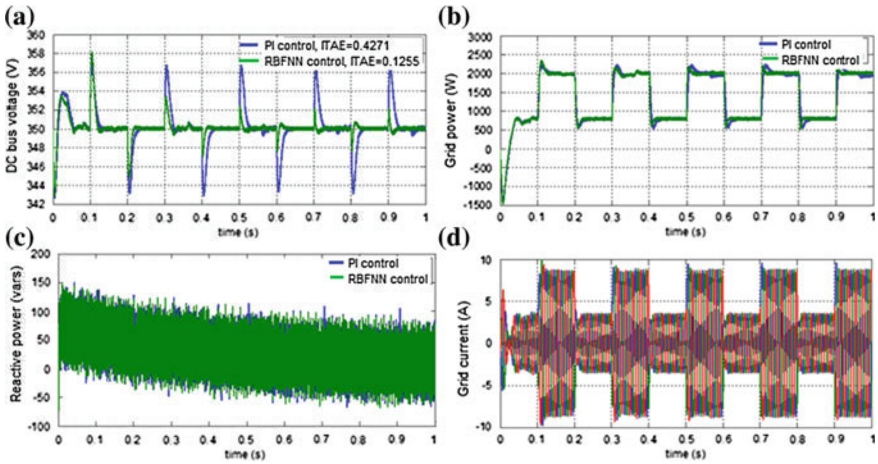

Fig. 1.7 The System response: The DC bus voltage (**a**) Active power injected to Grid (**b**) Reactive power (**c**) AC current (**d**)

that figure. The negative value of the grid power in the first 0.4 s of the simulation showed that the converters is in the rectifier mode, this is due to the PV power is still in transient state and the power that generated by the PV module is not sufficient to supply the DC load.

Due to the reactive power is directly controlled by q-axis current component, then the response of the RBFNN control system and the PI control system virtually the same as shown by Fig. 1.7c. While Fig. 1.7d shows the three phases current that injected to the electrical grid resulted from the RBFNN control system.

Finally, to guarantee the stability of the control system, we should determine the RBFNN parameters (i.e. Kp and α) appropriately. Figure 1.8 shows the influence of the chosen RBFNN parameter on the controlled output in response to the step change of the generated green power.

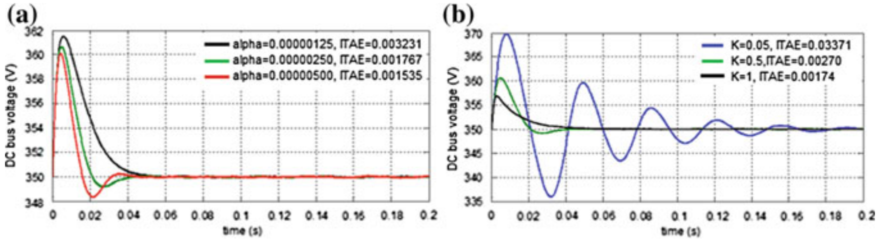

Fig. 1.8 The DC bus voltage response to the change of the DC load current change for several value of alpha (**a**) and proportional gain (**b**)

1.5 Conclusion

In this work, we present the RBFNN control system design for the DC bus voltage regulation in the on-grid PV system. The effectivity and the performance of the proposed controller in the response to the disturbance, i.e. response to the sudden connection and disconnection of the DC load is proved by the simulation study. The simulation results show that compared to the Optimal PI control system, the overshoot of DC bus voltage caused by the abrupt change of the DC load for the RBFNN control system is more damped and the controlled output is more quickly to settled.

In the future work, the investigation of the optimal RBFNN parameter, i.e. the proportional gain and the learning rate will be done further by utilizing optimization method such as PSO and Genetic Algorithm.

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Chapter 2
Virtual Prototyping of a Compliant Spindle for Robotic Deburring

Giovanni Berselli, Marcello Pellicciari, Gabriele Bigi and Angelo O. Andrisano

Abstract At the current state-of-the-art, Robotic Deburring (RD) has been successfully adopted in many industrial applications, but it still needs improvements in terms of final quality. In fact, the effectiveness of a RD process is highly influenced by the limited accuracyof the robot motions and by the unpredictable variety of burr size/shape. Tool compliance partially solves the problem, although dedicated engineering design tools are strictly needed, in order to identify those optimized parameters and RD strategies that allow achieving the best quality and cost-effectiveness. In this context, the present paper proposes a CAD-based Virtual Prototype (VP) of a pneumatic compliant spindle, suitable to assess the process efficiency in different case scenarios. The proposed VP is created by integrating a 3D multi-body model of the spindle mechanical structure with the behavioural model of the process forces, as adapted from previous literature. Numerical simulations are provided, concerning the prediction of both cutting forces and surface finishing accuracy.

Keywords CAD-based tools · Compliant spindle · Robotic deburring · Virtual prototyping

2.1 Introduction

The process of finishing mechanical parts with complex shapes and narrow tolerances generally involves the use of five axes CNC machines, namely extremely expensive devices that require large set-up times. As a potential alternative for the same task, industrial robots offer greater flexibility along with a lower initial

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