Available online at www.sciencedirect.com
ScienceDirect
IFAC Papers Online CONFERENCE PAPER ARCHIVE
IFAC-PapersOnLine 48-30 (2015) 578–582

Case Studies on Cascade Voltage Control of Islanded Microgrids Based on the Internal Model Control

Mehrdad Yazdanian and Ali Mehrizi-Sani

***Abstract*— Erratic variations of the load and step changes of the voltage reference value usually impose voltage transients to the microgrid. These transients prevent effective utilization of the electric power delivery infrastructure and cause violation of the limits. Furthermore, some industrial loads are very susceptible to these unpredictable variations of the voltage. This paper proposes an innovative approach to improve the transient behavior of the three-phase voltage of a distributed generation (DG) unit in an islanded microgrid. The proposed approach has a cascade control structure, which consists of an inner current control feedback loop and an outer voltage control feedback loop. Both control loops are developed based on the internal model control (IMC) approach. Several simulation case studies confirm that the proposed IMC-based approach has superior transient performance compared with the conventional PI-based voltage control approach.**

I. Introduction

The economical advantages and environmental considerations are increasing the penetration of distributed generation (DG) units such as wind turbines, photovoltaic (PV) units, and fuel cells in the grid. The utilization of distributed generation in the grid brings many potential benefits both to the utility and to the end user such as:

- reducing line losses;
- reducing carbon footprint; and
- increasing power quality and reliability.

However, capturing these benefits requires a shift in the control strategy from existing centralized schemes to more sophisticated hierarchical schemes [1], [2]. A promising way to interconnect and control these DG units based on a hierarchical structure is to form an autonomous microgrid, which is connected to the host grid through the point of common coupling (PCC) and can operate in both grid-connected and islanded modes. There are certain requirements that should be satisfied in both modes such as active and reactive power flow control, frequency and voltage stability, and black start operation. However, the voltage and frequency of the microgrid are imposed by the host grid in the grid-connected mode, while they should be regulated by local controller of the DG units in the islanded mode.

The voltage-sourced converters (VSCs) are being utilized as a key element in the structure of the trending power system infrastructures such as DG units, microgrid, and smartgrid. Therefore, the challenges associated with the voltage control of the VSC are attractive research areas, which have received more attention in recent years [3]–[12]. In [12], a multivariable digital control methodology is developed for voltage control of an islanded DG. This methodology simultaneously applies open-loop shaping and decoupling using convex optimization and guarantees satisfactory dynamic response and robust stability against load uncertainty and nonlinearity. This optimization-based loop shaping method is also applied on the outer loop of a cascade digital control strategy for voltage regulation in [13]. However, its design procedure is not straightforward. Reference [14] proposes a voltage/frequency control approach. This approach develops a dynamic model for the load and DG unit, and uses this model along with feedforward compensation to develop a controller for voltage and frequency. However, this control method does not obtain good results under unbalanced load conditions. More recently, [15] proposed a robust adaptive voltage control strategy. This method uses an adaptive control term, which compensates system uncertainties and a state feedback control term, which forces the error dynamics to converge to zero.

In recent years, internal model control (IMC) has been used for set point tracking and disturbance rejection in wide range of process control applications. IMC compares the predicted output (obtained from a feedforward path using an approximation of the plant) with the plant output, and utilizes the error as a feedback signal to adjust the set point. In this paper, an IMC-based cascade voltage control strategy is developed to improve the transient behavior of an electronically interfaced DG unit in an islanded microgrid. The inner control feedback loop is designed based on the IMC-based current control approach reported in [16] to compensate the input disturbances and phase delays caused by the RLC filter, and the outer control feedback loop is developed based on IMC to provide set point for the inner current control loop to maintain the desired voltage. The proposed method provides superior performances such as faster step response, shorter settling time, less overshoot, and more robustness against fault compared with the conventional PI-based controller [17].

The rest of this paper is structured as follows. Section II reviews the structure of the internal model control. Section III introduces the mathematical model of an islanded DG unit, and briefly presents the conventional PI-based voltage control approach. Section IV drives the mathematical formulation for the proposed IMC-based voltage controller. The performance of the proposed approach is compared with the conventional voltage control approach trough different simulation case studies in Section V, and Section VI concludes the paper.

II. Conventional Control of an Islanded DG Unit

Fig. 1 shows the typical configuration of an electronically interfaced DG unit. This DG unit consists of an ideal voltage source, a VSC which is connected in series to an RLC filter to attenuate voltage harmonics, a three-phase load, and a local cascade voltage controller. The DG unit can operate both in grid-connected mode and in islanded mode by closing and opening the switch S. However, the focus of this paper is on the voltage control of the DG unit in the islanded mode of

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2015.12.442

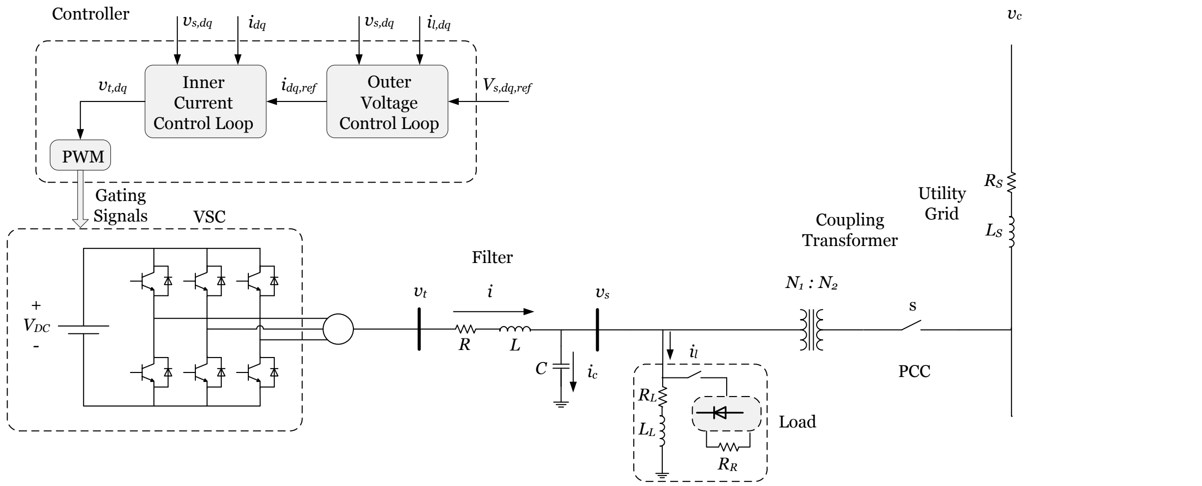

Fig. 1. Schematic diagram of the study system.

operation. In this case, the objective of the voltage controller is to regulate the load voltage v_s regardless of the load current i_l [14]. The conventional PI-based voltage controller of the DG unit consists of an inner loop for current regulation and an outer loop for voltage regulation [14], [18].

Inner and outer control loops have similar structure and both of them consist of a decoupling term and a PI controller in each axis. However, the decoupling term in the inner current control loop is ωL, while it is ωC for the outer voltage control loop.

The PI controller of the current control loop is

$$K_c(s) = \frac{k_p s + k_i}{s}. \tag{1}$$

The parameters of this PI controller generally are chosen as follow

$$\begin{cases} k_p = \dfrac{L}{\tau} \\ k_i = \dfrac{R}{\tau}, \end{cases} \tag{2}$$

where L and R are the parameters of the filter, and τ is the tuning parameter, which is equal to the time constant of the closed-loop system.

Once the inner control loop is designed, the symmetrical optimum approach [19] can be utilized to design the parameters of the PI controller of the outer control loop. Consider the PI controller of the outer control loop as

$$K_v(s) = k\frac{s + z}{s}, \tag{3}$$

where k is the gain and z is the zero of the controller. The phase margin δ_m is usually chosen between 30° and 75°. Therefore, z can be obtained as follows:

$$\delta_m = \sin^{-1}\left(\frac{1 - \tau z}{1 + \tau z}\right). \tag{4}$$

In the next step, the controller gain k can be obtained as follows

$$k = C\sqrt{z\tau^{-1}}. \tag{5}$$

More details about the design procedure of the inner and outer control loops can be found in [14], [18].

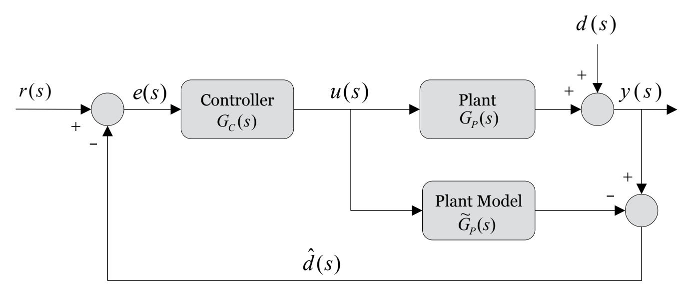

Fig. 2. Block diagram of internal model control (IMC).

III. Overview of IMC

Internal model control (IMC) was introduced for the first time by Garcia and Morari in [20]. The term "internal model control" comes from the fact that the plant model is utilized in the structure of the IMC controller. This characteristic makes IMC a suitable choice for reference set point tracking and disturbance rejection. Furthermore, it provides a simple and systematic design procedure. Fig. 2 depicts the structure of IMC, in which $G_P(s)$ is the plant to be controlled, $\tilde{G}_P(s)$ is a mathematical model of the plant, and $G_C(s)$ is the controller.

It can be seen that the IMC structure takes advantage of both feedback and feedforward control loop. The feedforward control loop predicts the output of the system by applying the manipulated control signal $u(s)$ into the $\tilde{G}_P(s)$. The feedback control loop adjusts the set point to compensate the effect of the model mismatch and output disturbance.

The output $y(s)$ is [16]:

$$y(s) = \frac{G_C(s)G_P(s)}{1 + \big(G_P(s) - \tilde{G}_P(s)\big)G_C(s)} r(s) + \frac{1 - G_C(s)\tilde{G}_P(s)}{1 + \big(G_P(s) - \tilde{G}_P(s)\big)G_C(s)} d(s). \tag{6}$$

Therefore, ideally perfect control and disturbance rejection can be achieved if $G_P(s) = \tilde{G}_P(s)$, and $G_C(s) = G_P^{-1}(s)$. However, these conditions are not realizable in practice because the plant model is an approximation, and the plant may has noninvertible components. Therefore, the plant model should be factorized into the invertible and noninvertible components