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Two degrees of freedom dc voltage controller of grid interfaced PV system with optimized gains

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ABSTRACT

This paper proposes the application of fictitious reference iterative tuning (FRIT) method to optimize the gains of dc voltage controller of grid connected photo-voltaic (PV) system. It may be difficult to achieve good control of dc voltage using conventional PI controller having only one-degree-of-freedom (1-DOF) due to the trade-off between overshoot (in step response) and disturbance response. In this paper, the optimal control of dc voltage is proposed with improved disturbance response by implementing 2-DOF PI controller structure. FRIT method has been programmed in MATLAB based upon the particle swarm optimization (PSO) algorithm. The fundamental idea related to FRIT method is the extraction of input and output data, reference model setting and range of controller gains. The performance of dc voltage control for the optimized 2-DOF PI controller is also compared with the fuzzy logic controller (FLC) response.

1. Introduction

The use of renewable energy sources have been motivated to use as distributed energy source for the generation of environmental friendly energy. In the distributed energy source, photovoltaic (PV), wind, biomass, tidal and geothermal are getting attention in the last decades. The technological advancement and research leads to the more feasible and cheaper production of renewable energy but still it is costlier in comparison to conventional sources of energy [1,2]. The PV system is extensively popular due to wide range of power application and received much attention as distributed generating (DG) source in grid connected mode to cater energy demand problem with inherent propoerty of energy storage [3–7]. The PV power generating system as a DG in grid connected mode having better control operation to operate at maximum power point (MPP) which will help to evacuate maximum generated power and controlled by grid following power export control technique [2–6]. The power electronics interface is essential for interfacing of PV system as a DG to grid and it can be implemented using direct/indirect current controlled pulse width modulated (PWM) voltage source inverters (VSI) [2–11]. VSI as a power electronics interface supports to implement the grid interfacing and power conversion [12].

The capacitor dc voltage of VSI in a grid connected PV system can be regulated using various types of controllers like proportional plus integral type controller (PI/PID), Fuzzy-PI, fuzzy logic controller (FLC) etc. [2–15]. Generally, PI/PID controller is extensively used as single input-output system for dc voltage control and for process control in industrial applications due to ease of implementation. The conventional PI control structure deals with the limitation to obtain the optimal response for the system. So, the 2-DOF PI/PID control structure has been proposed and utilized under various control schemes for different type of application with significant advantage over 1-DOF PI control [16–20]. The DOF of a control system defines the number of independent closed loops in the control configuration [21–23]. The 2-DOF control structure can be design in various control configuration as feedforward, feedback, set point filter etc. [21–25].

The PI/PID control structure is designed to obtain the stability and good control with better transient responses. The performance of the designed control structure is dependent upon the controller gains. So, the gains of the controller need to be appropriately tuned and various tuning methods have been proposed and discussed like as iterative feedback tuning (IFT), virtual reference feedback tuning (VRFT) and fictitious reference iterative tuning (FRIT) by several researchers in [26–30]. These direct design approach only requires the input and output data of the controlled system and received significant attention. The IFT tuning requires the multiple experiment data for iterative tuning so as to achieve the desired optimal response while VRFT required only one-shot experimental

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data. FRIT is also used only one-shot experimental data for the optimal controller gain tuning. So, these tuning methods helps to achieve the optimal controller gains without any requirement of system/plant model information based upon the one-shot closed loop experimental data. The basic difference between VRFT and FRIT is that in case of the VRFT minimization of function emphasizes on the input while FRIT emphasizes on the output. So, the FRIT method may be more advantageous and establishing better understanding in practical sense. FRIT method implementation and approach is better for 1-DOF as well as 2-DOF controller in comparison to VRFT [29–33].

FRIT method was modified, studied and analyzed for different application and optimal performances in [28–35]. It can be implemented as both online and offline system for controller tuning. The FRIT method deals with the disadvantage that it may results in local minimum for PI/PID controller tuning due to the non-linear and non-convex problem consideration. So, the FRIT method should be combined with an optimization technique to mitigate the local minimum solution for non-linear and non-convex optimization problems.

The DOF based control with optimal tuning methods of controller gains was widely applied and implemented specially in motor control application and process industry. Sometime, numerical examples are considered to show the effectiveness of DOF controllers and tuning method. This is the first time that the optimal tuning method and DOF based controller is used for dc voltage control. In this paper, the application of 2-DOF controller is proposed for the dc voltage regulation of VSI. The data driven tuning method FRIT is used for optimal tuning of dc voltage controller of grid connected PV system. FRIT is implemented based upon the particle swarm optimization (PSO) algorithm to prevent the problem of local minimum solution. The proposed 2-DOF PI control configuration is implemented to mitigate the overshoot in the response of conventional PI control as well as to achieve the fast transient response using optimal controller gains. FRIT is used as off-line tuning method and tune the controller gains by minimizing performance index error function based upon the fictitious reference signal. The performance of the proposed controller is investigated for step response as wells as under varied ir-radiance as system response affected due to change in ir-radiance and transient response.

The paper is organized as follows. In Section 2, the DOF based controller configuration and design is considered. In Section 3 the optimization problem of FRIT method is considered and implementation in combination with PSO is explained with step by step procedure considered for 2-DOF PI controller. In Section 4 FLC is considered and membership function for dc voltage control is shown. In Section 5 the control algorithm of dc voltage control with VSI is considered. In Section 6 the performance of controllers have been discussed and analyzed considering disturbance in reference dc voltage. In Section 7 concluding remarks have been given for the paper.

2. dc voltage PI controller

The conventional PI control structure in Fig. 1 consists of controller and plant/system transfer function block where, $P(s)$: PI controller ($k_p + k_i/s$) and $G(s)$: transfer function of the plant/system. The 1-DOF PI controller may not achieve very satisfactory response considering multi-objective view point of the system control and therefore 2-DOF controller have natural advantage over conventional PI controller [21]. In this paper, the 2-DOF PI control has been instrumented first time for dc voltage control.

The number of independent closed loops in control structure decides the DOF of the system control and considered as

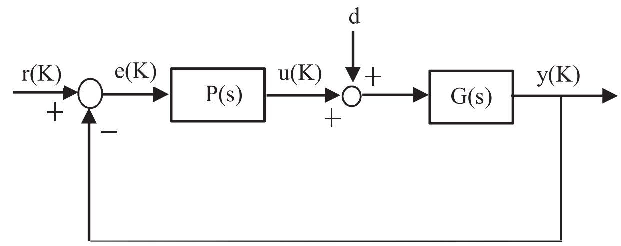

Fig. 1. Generalized 1-DOF PI controller configuration.

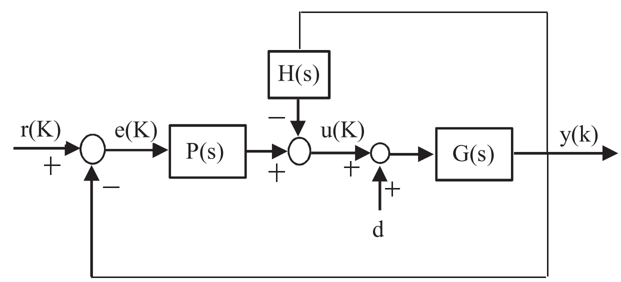

Fig. 2. Generalized 2-DOF FB type PI controller configuration.

two-input and one output system. The 2-DOF controller designed and discussed in [16,21] with various configuration stated as feed-forward type(FF), feedback type (FB), filter type, filter and preceded derivative type and component separated type depending upon the application and objective of system control. The 2-DOF feedback compensating (2-DOF FB) controller in Fig. 2 is implemented for dc voltage regulation. The 2-DOF PI control configuration used for dc voltage control consists of proportional gain (K_p) and integral gain (K_i) same as conventional PI controller and additional feedback proportional gain (K_{pfb}) as a feedback compensation. So, it is having two proportional control gain and one integral control gain and can be represented as PI-P (2-DOF PI) controller. The reference input signal (r) and controller output signal (y) are the input signal and the modified output signal (u) output signal. The closed loop transfer function of conventional PI control structure in Fig. 1, from reference input r to controlled output y and from disturbance d to y are given respectively as

$$M_{r1}(s) = \frac{G(s)P(s)}{1 + G(s)P(s)} \tag{1}$$

$$M_{d1}(s) = \frac{G(s)}{1 + G(s)P(s)} \tag{2}$$

The transfer function shown in Eqs. (1) and (2) is having only one tuning element as $P(s)$ for optimal system performance. As it includes only one tuning element it can-not be tuned independently. The closed loop transfer function of 2-DOF FB control structure in Fig. 2 from reference input r to controlled output y and from disturbance d to y are given respectively as

$$M_{r2}(s) = \frac{G(s)P(s)H(s)}{1 + G(s)H(s)(P(s) + 1)} \tag{3}$$

$$M_{d2}(s) = \frac{G(s)}{1 + G(s)(P(s) + H(s))} \tag{4}$$

Here, the transfer function shown in Eqs. (3) and (4) having two tuning element as $P(s)$ and $H(s)$. It helps to achieve the optimal performance for the system with feedback compensating terms.