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Current control based power management strategy for distributed power generation system

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A B S T R A C T

The integration of renewable energy sources (RES) based distributed generation (DG) systems into electric grid has many challenges such as synchronization, control, power management (PM) and power quality problems. This paper proposes a references current generator (RCG) based PM strategy to control three phase inverter and manage power flow among the DG energy sources, electric grid and load demand under balanced and unbalanced grid conditions. The amplitudes of active and reactive power oscillations are also eliminated and controlled through only one flexible control parameter (FCP) under grid faults and harmonic distortions. Compared with previous similar studies, one of the important contributions is capable to inject maximum active power and minimum reactive power into electric grid and load at inverter power capacity under grid faults Another contribution is to extract the positive and negative sequence (PNS) voltage and current components with the improved fast and robust dual adaptive filters based phase locked loop (DAF-PLL). Fractional order proportional integral (FOPI) is selected as an attractive solution for AC current regulation to exhibit fast transient response and to achieve zero steady-state errors as compared with conventional current regulation controllers in synchronous or stationary frames.

1. Introduction

The conventional power systems have many problems such as using fossil fuels which result in very high costs; greenhouse gas emissions and pollution are exhaustible and limited in supply and have long transmission lines, large amount of technical and nontechnical losses (Amin & Wollenberg, 2005; Wu, Hu, Teng, et al., 2017). The modern power generation technologies have encouraged changes in the power system structure (Cau, Cocco, Petrollese, et al., 2014; Divshali & Choi, 2016). In order to overcome these limitations and problems, renewable energy sources (RES) based distributed generation (DG) power systems can cope with environmental issues, energy crises and remove the drawback of a single RES by taking the best possible use of each individual energy source. The main drawbacks of RES, such as wind turbines (WT) and photovoltaic cell (PV) have discontinuity for energy generation (Cau et al., 2014; Kamali, Rahim, & Mokhlis, 2014). To avoid overloading power converter, current controller limit power that fuel cell (FC) unit can supply power to grid. However, power limitation result in slow dynamic response the FC unit (Das, Padmanaban, Venkitusamy, et al., 2017). The various controllers such as model predictive controller and sliding mode controller can be used to deal with the slower dynamics of the FC. In particular, the purpose of control algorithms based power management (PM) strategy in DG power systems guarantees continuity of energy, optimum use of power capability of inverter and maximum utilization of renewable sources in all conditions. Key issues for grid connected DG power systems consist of control and PM strategy (Olatomiwa, Mekhilef, Ismail, et al., 2016). The control algorithm based PM strategy is also significantly important to supply maximum active power and minimum reactive power delivery capability under balanced and unbalanced conditions according to power demand.

Advanced control algorithms based PM strategy has been reported to achieve a balance active power in recent studies. Bayrak, Bayrak, Ozdemir, et al. (2016) focuses on low cost power management for hybrid power plant. Predictive control based PM is designed to coordinate power flow between various energy sources (Brka, Kothapalli, & Al-Abdeli, 2015). An energy management optimization is proposed to overcome power quality problems for power units and batteries (Li, Wang, Chen, et al., 2017; Panda & Patnaik, 2017). Coordinated control strategy is designed for PM of solid oxide fuel cell (FC) based microgrid. Power balance principle is used in coordinated control strategy of grid connected inverter systems (Sun, Wu, Xue, et al., 2018). Other control method is that positive and negative sequence (PNS) control based on the sliding mode control and Lyapunov function theory are designed for hybrid AC/DC WT/PV/FC microgrid (Baghaee, Mirsalim, Gharehpetian, et al., 2017). Dash, Samanta, and Ganesan (2016) and Yumurtaci (2013) have proposed two PM strategy to control standalone and grid connected hybrid system. The impact of weather conditions

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on WT and PV systems are analyzed and investigated. However, the impact of grid faults on control of inverter interfaced DG system and injected active–reactive power are not considered in these studies. The grid faults have been shown to be one of the greatest challenges for conventional inverter control to provide maximum power capability at inverter capacity. In order to ensure balanced current, constant active power and reduce active and reactive power oscillations, some researchers have investigated positive and negative sequence (PNS) based reference current generators (RCG) (Kabiri, Holmes, & McGrath, 2016; Wang, Duarte, & Hendrix, 2010). Active and reactive powers and their oscillations are independently controlled with two flexible control parameters (FCP) in stationary reference frame (STRF) by Wang, Duarte, and Hendrix (2011). Karimi-Ghartemani, Khajehoddin, Piya, et al. (2016) and Piya, Ebrahimi, Karimi-Ghartemani, et al. (2018) have been proposed a universal controller that achieve robust against uncertainties and change of the grid parameters. Embedded synchronization into controller provides agile and smooth responses without stability issues. Other interesting power control method is reported that a new vector transformation based instantaneous p-q power control is enhanced by Montanari and Gole (2017). However, the controllable of active–reactive power oscillations is difficult because of using two adjustable control parameters. Sosa, Castilla, Miret, et al. (2016) proposes maximum power capability of inverter and avoid only active power oscillation with using two FCP. Maximum power deliver allowed by inverter and active power oscillations are discussed under various scenarios by Lopez, De Vicuna, Miret, et al. (2018). The PM strategy and power flow between DG energy sources, grid and load demand are not taken into consideration in these studies. The PNS components are also obtained from slow (longer than two cycles) conventional sequence extractors to obtain the RCG.

The PNS components are significantly essential module to obtain the RCG under unbalanced conditions. Various researchers have been investigated PNS extractors to generate reference current in the literature. Dual second-order generalized integrator (DSOGI) (Sun, Chen, Wang, et al., 2016; Zhang, Rocabert, Candela, et al., 2017), delay signal cancelation based PLL (DSC-PLL) (Jin, Li, Li, et al., 2017; Meral, 2012), double synchronous reference (DSRF) or decoupled double synchronous reference (DDSRF) (Ali, Christofides, Hadjidemetriou, et al., 2017; Reyes, Rodriguez, Vazquez, et al., 2012; Rodriguez, Pou, Bergas and et al., 2007), moving average filter (MAF) (Mirhosseini, Pou, & Karanayil) and multivariable filter (MVF) (Meral & Çelik, 2018a; Wang et al., 2010) are presented for separation of PNS components in STRF or synchronous reference frame (SRF) under unbalanced conditions. Recently, another approaches have been emerged, multi complex coefficient filter (MCCF)-PLL (Guo, Wu, & Chen, 2011) and third order sinusoidal integrator (TOSSI) (Chilipi, Al Sayari, Al Hosani, et al., 2016, 2018). Two PNS extractors separate fast and more robust PNS components. However, the impact of voltage harmonics, including many sub-modules, dynamic response and computational burden still seem problems for signal processing in abovementioned PNS extractors.

This paper proposes a current control method based improved PM strategy to manage active power flow among DG units (PV, FC and WT), electric grid and various loads under balanced and unbalanced conditions. In particular, the PM strategy is not discussed under grid faults and discontinuity of energy sources in previous similar studies. Various PM scenarios have been performed to manage active power flow among DG units. This paper provides some advantages in fourfold: (1) in order to generate reference current, the PNS voltage–current components are separated by improved DAF-PLL, which provides fast dynamic response and is less affected by harmonic distortions and grid faults. Its performance is examined and compared with existing PNS extractors, (2) the proposed control algorithm based PM strategy increase the inverter power capability by injecting the maximum active current and minimum reactive current under grid faults, (3) the current tracking errors are minimized by fractional order proportional integral (FOPI), which exhibits fast dynamic response in compared with conventional current regulation controllers in SRF or STRF and (4) active–reactive power oscillations are regulated and controlled by only one FCP. Performance comparison of proposed solution is comprehensively tested and reviewed with some previous studies.

The outline of the paper is structured as follows. Following introduction, Section 2 briefly describes the DG energy sources based on mathematical computation. The performance comparisons of improved DAF-PLL based sequence extractor is presented and analyzed with existing PNS extractors in Section 3. Section 4 formulates problem statement for proposed solution. In Section 5, proposed RCG based control strategy is introduced for maximum power deliver and PM strategy. The implementation of proposed system is verified, compared and tested under various cases in Section 6. Section 7 summarized the conclusion derived from this study. All nomenclatures are given in Table 1.

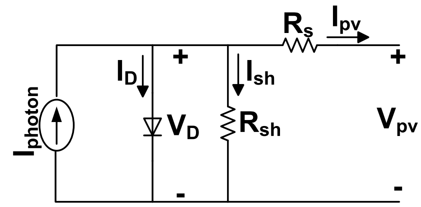

Fig. 1. Equivalent circuit for a PV cell.

2. Distributed generation (DG) energy sources

The DG power system consists of combination of PV cell, FC and WT at common DC bus. All local current/power controllers for PV cell, FC and WT are designed to control the power flow among the DG system, load demand and grid power. Fig. 2 shows the configuration of DG power system with control algorithm based proposed PM strategy. Proposed solutions (improved PNS extractor and existing PLLs, conventional control strategy, proposed RCG based control algorithm and various PM scenarios) are tested in grid connected DG based three phase inverter as shown in Fig. 2.

2.1. PV cell power generation

The measured power from single PV cell is relatively small. To generate more power, the various topologies of PV modules in series and parallel connection are required. The equivalent circuit of single PV cell is given in Fig. 1 (AbdelHady, 2017).

The PV has modeled and analyzed based on simple equivalent circuit. The characteristics of PV current and voltage are derived from Eq. (1) that depends on temperature and radiation. The PV power from boost converter output is calculated in (2) (AbdelHady, 2017; Bai, Abedi, & Lee, 2016).

$$\begin{aligned} I_{pv} &= I_{ph}\left(1 + C_0 (T - 273.15)\right) \\ &\quad - I_o\left(e^{\frac{q(V_{pv}+I.R_s)}{nkT}} - 1\right) - \frac{(V_{pv}+I.R_s)}{R_{sh}} \end{aligned} \tag{1}$$

$$P_{pv} = \eta_{boost\_conv} V_{pv} I_{pv} \tag{2}$$

where R_s is the series resistance, I_{ph} is the photon current, R_{sh} is shunt resistance, V_{pv} is open circuit voltage, T is temperature, k is Boltzmann's constant, I_o is reverse saturation current, q is the charge of an electron and η_{boost_conv} is efficiency of boost converter.