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Stability improvement of microgrids in the presence of constant power loads

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ABSTRACT

Renewable energy sources, the most reasonable fuel-shift taken over the naturally limited conventional fuels, necessarily deal with the self-sustainable microgrid system rather than the traditional grid distribution system. In practice, the microgrid system experiences the challenge of instability due to the Constant Power Load (CPL) from many electronic devices. In this paper, AC microgrid stability, besides the stability analysis and pole zero movement, is thoroughly investigated for each and every considerable parameter of the system in order to improve the stability scenario. After demonstrating all cases regarding the instability problem, the storage based virtual impedance power compensation method is introduced to retain the system stability and extend the loading limit of the microgrid system. Here, in this proposed method, both the active and reactive power compensation techniques are suggested for a potential solution. Besides this, a PID controller is implemented to maintain the constant terminal voltage of CPL via current injection method from storage. All the cases and results are rigorously scrutinized in the virtual platform such as MATLAB/Simulink with appreciable aftermaths. Hardware implementation of the proposed method is also conducted to find out its effectiveness.

1. Introduction

Today, the power industry faces many problems, including rising cost of energy, power quality and stability, aging infrastructure, mass electrification, climate change, and so on [1]. Moreover, fossil fuel availability and cost, quality of power, stability issues, and many more problems are arising in the power system industry. To reduce carbon emissions and make environmentally friendly power generation systems, there will be no choice but to adopt renewable energy. Hence, distributed power system is becoming popular nowadays and researchers have focused on this emerging technology. A microgrid is a compact organization of interconnected loads as well as distributed energy resources within specified electrical boundaries, functioning as a single controllable individual with respect to the grid. In this course, it can connect to and disconnect from the conventional grid to enable it to operate in both grid-connected and islanded modes [2,3]. However, managing distributed resources (renewables, conventional, storage) and loads within a microgrid in case of islanded and grid-tied modes and the transition between several phases is a challenge [4]. It requires both short-term and long-term stability analysis of the microgrid system for reliable operation. Furthermore, there are several key control concerns for the microgrid such as maintaining stability, regulating voltage and frequency, sharing active and reactive load, and handling various types of loads, for example inductive motor load and constant power load. The constant power load has a negative impedance effect on the system which causes huge stability concerns for the inverter-based power system. However, microgrids, a multi-converter cascaded system, are strictly regulated point-of-load (POLs) converters that exhibits negative incremental impedance and, in practice, act as CPLs. This behavior causes a serious stability concern for microgrid system since the overall system is poorly damped [5].

To improve the stability scenario of the microgrid system, a number of research works have been conducted around the world for recent decade [6–12]. For AC systems, an investigation of stability has been carried out [13]. Injection of reactive VAR to support voltage stability of AC grids by using a distributed static synchronous compensator (STATCOM) has been demonstrated. Feedback from output taken to modify reference levels and introduce virtual resistance for increased damping has also been shown to be an efficient method of improving AC microgrid stability [14]. The proposed controller modifies the system transfer function by adding a virtual resistor. The proportion of power between CPL and CVL for stability is changed to insure the desired stability conditions. In this way, virtual damping is used to improve stability without the cost of wasted energy. Though this improves the loading limit, the enhancement is not substantial and the upper limit of the amelioration remains quite unchanged. An observer-based

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nonlinear controller can also be used by adopting the input-output feedback linearization [15]. This offers the advantage of robustness analysis against the parametric uncertainties. The usual methods that can be applied to stabilize CPLs, especially in automotive systems, has been summarized in [16] with broad categorizations of converter-level analysis and control, large-signal phase plane analysis and system-level analysis. Vilathgamuwa et al. obtained the state space model from a physical microgrid system. From that, they accomplished the linearized plant stability analysis with constant power load by using PID control technique. Zeng Liu and Jinjun Liu at [17] proposed a technique to investigate the stability conditions for AC systems by using Nyquist Stability Criterion.

In [18], Santiago Sanchez Acevedo and Marta Molinas analyzed nonlinear tools to attain stability with interconnection of power electronics and distributed generation with loads behaving as CPL. Dq frame analysis is shown for three-phase AC system to investigate small signal stability at [19]. Besides that, the stability criterion for Distributed Power System (DPS) analysis is presented using infinite norms input-output impedance matrix by Zeng Liu et al. at [20]. In 2013, Nadeem Jelani et al. at [21] investigated how the voltage stability is affected with the rising proportion of the CPL loads to the system and proposed the static synchronous compensator to solve the CPL instability problem. After that, in [22], Dena Karimipour and Farzad R. Salmasi, based on Popov's Absolute Stability Criterion, introduced stability analysis of the AC microgrid system. At [23] of Yanjun Dong et al., developed a simulation model for constant power loads in AC system by using a Pulse Width Modulation rectifier. In the sequence of this research and developments, in [17], Zeng Liu et al., by using infinite-norm of the impedance (admittance) matrixes, investigated stability of the power system by adopting a boost rectifier as a Constant Power Load.

After that, in [24], researchers Nadeem Jelani et al. have shown a phase margin analysis of a AC distribution system by using vector control techniques where a voltage source converter used as a constant power load. On another occasion, Ali Emadi at [25], in his paper, using the generalized state-space averaging method, modeled negatively incremental CPL loads and presented a comprehensive assessment in case of AC distribution systems. Besides that, in [26], Mohd Fakhizan Romlie et al., using simulation in PSCAD, investigated the stability as a function of system parameters in application of constant power loads (CPL) in DPS. Furthermore, Heskes, Myrzik, and Kling discussed the effect of negative differential impedance loads on voltage stability in the local power grid at [27]. Apart from that, in [28], Nadeem Jelani et al., in

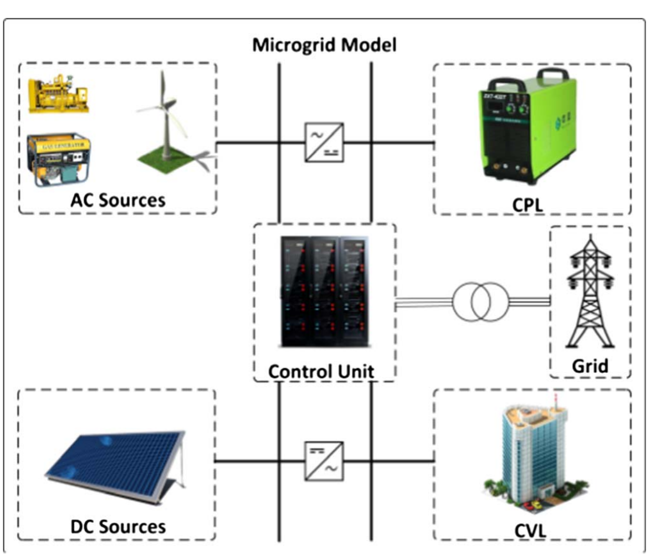

Fig. 1. Typical model of grid-connected microgrid with different distributed generations and loads.

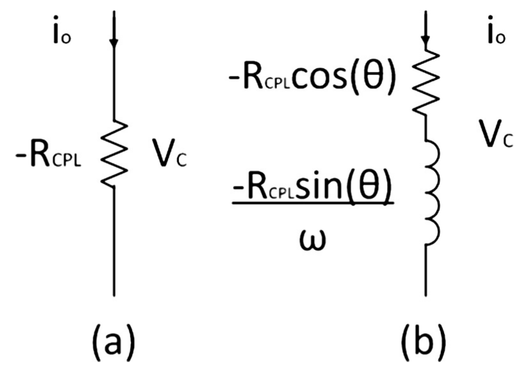

Fig. 2. Small signal representation of a CPL (a) with unity power factor regulation (b) and with lagging power factor [7].

their article, used a shunt filter as a CPL load compensator by using vector control techniques and discrete Fourier transformation. After that, Immersion and Invariance control technique, at [29], and single-phase matrix control (SPMC) technique, at [30], is introduced for analyzing CPL instability.

With the advancement of technology, the power electronic interfaced renewable resources and loads are increasing dramatically in power system/microgrid application. So, the necessity to stabilize continually increasing CPL-based system is getting intensified day by day. Hence, more research is required in the area of AC distributed systems in detail. A detail parameter sensitivity analysis will help the researchers to improve the stability of the system using active and reactive power compensation. Therefore, this paper proposes a storage-based virtual impedance method to improve the stability margin in the incidence of CPL and CVL loads in AC microgrid system. The proposed controller produces current command based on virtual impedance to improve stability limit and ensure system stability with the variation of system parameter, uncertainty, and disturbance. The terminal voltage of CPL has been compensated by using two different methods: real

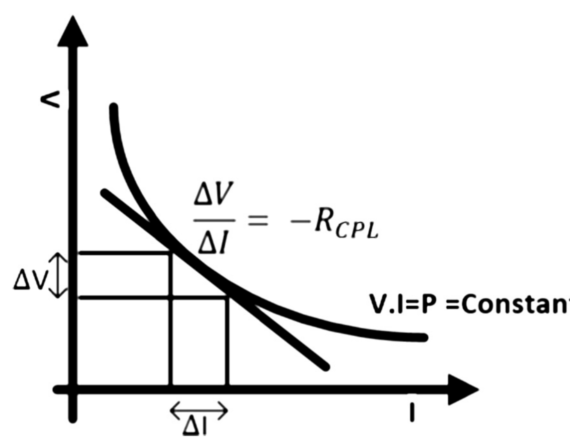

Fig. 3. Negative impedance characteristic of CPL [16].

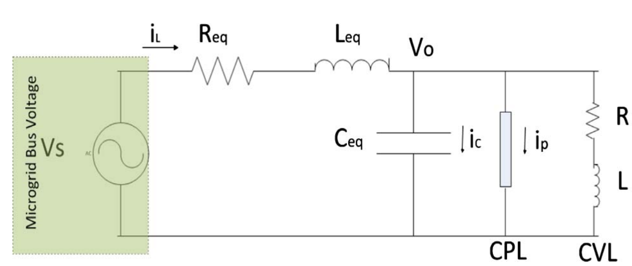

Fig. 4. Equivalent circuit of AC microgrid with CPL & CVL [14].

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