Demand Response for Smart Microgrid: Initial Results

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***Abstract*—This study is an attempt to address the frequency and voltage regulation inside of an islanded microgrid. Central demand response along with an adaptive hill climbing methodology is applied to a small islanded microgrid powered by a diesel generator. All dynamic models are developed in MATLAB/Simulink®. Simulation results show that the proposed method has the potential to suppress the frequency variations and stabilize the voltage of the microgrid.**

***Index Terms*—Demand response, smart grid, microgrid.**

I. INTRODUCTION

ENABLING active participation by electricity customers in demand response has been identified by USDOE as an important feature of smart grid [1]. This feature can be effective in maintaining a balance between generation and demand, and as a result, keeping system frequency and voltage within desired limits. Demand response can especially be effective with increasing penetration of intermittent renewable power. In a power system, frequency drifts upwards or downwards, is the main indicator of excess or deficiency of generation, respectively [2]-[4]. This deviation in frequency can be controlled through demand response.

With the rapidly increased demand for electricity and interest in the use of distributed generation (DG), control of power systems are becoming increasingly harder. In isolated applications, adding a small- or medium-size DG to a distribution system may not have a significant impact on the power quality at the feeder level. However, adding a large number of DGs to the main grid can create a daunting new challenge for their safe and efficient operation, as well as the safe operation and control of the power network to which they are connected. To address this challenge, a collection of DGs, loads and storage at a given part of a distribution system are independently managed as a microgrid, which can operate in grid-connected or island mode.

Frequency and voltage control which are known as ancillary services, have always been an essential part of a power system to achieve the required power quality standards. Three different levels of frequency control (primary, secondary and tertiary control) are applied in the ancillary services. In this way, spinning and non-spinning reserves (i.e., generation, storage, and responsive load) have the primary role for controlling frequency in a short period of time between 30 seconds up to 15 minutes [2].

Typically in the conventional ancillary services, load is only controlled under severe stability conditions such as under-frequency load shedding [3]. However, in the smart grid environment and availability of more information, some customer loads with energy storage capability, such as electric water heaters (EWHs) are excellent candidates to participate in balancing generation and demand [5].

In grid-connected mode, the frequency and voltage of a microgrid is the same as that of the main grid, and frequency and voltage regulation are achieved as explained earlier, i.e., through the traditional ancillary services. However, frequency and voltage regulation of microgrids in island mode need to be addressed independently, particularly in the absence of conventional ancillary services (such as spinning and non-spinning reserves). Frequency and voltage regulation, and other power quality issues become even more important given the intermittent nature of renewable power generation sources which may be inside a microgrid.

This paper presents some initial results showing the potential of using demand response for frequency and voltage regulation at the output of an isolated diesel generator. Adaptive hill climbing (AHC) method is applied to regulate the frequency with responsive loads. Based on the frequency deviation, the amount of the responsive loads (which are assumed to be EWHs) that should be operating at any time, is determined to keep the frequency within a desired limit. Simulation results indicate that the proposed method can effectively improve the transient and steady-state frequency and voltage deviations.

II. SYSTEM DESCRIPTION

For proof of concept, a small islanded microgrid is considered in this study. It includes a 3.125-MW, 2.4-kV diesel generator, equipped with speed governor and exciter, as a DG, along with fixed and active dynamic (responsive) loads. The system configuration is shown in Fig. 1. In general, a storage device is also a part of a microgrid; however, since the purpose of this paper is to show the applicability of AHC for frequency and voltage stabilization, a storage device is not included in the simulation studies and not shown in Fig. 1.

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The controller takes the frequency deviation signal ($\Delta f = f - f_{ref}$) as input, and based on that signal, it determines the amount of the responsive load, which needs to be disabled or enabled to keep the frequency within the desired threshold limits. The approach will also be effective for voltage stabilization, as will be shown in Section IV. This is because the output voltage of the generator depends on the amount of power demanded from the generator. Thus, by controlling the active responsive load, both the frequency and output voltage of the microgrid are regulated at the same time.

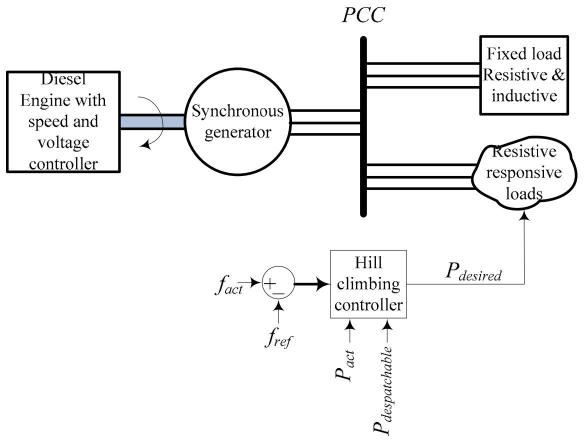

Fig. 1. Configuration of the proposed system.

This study focuses on resistive load regulation for frequency stabilization at the distribution level, where microgrids normally operate. AHC control (described in Section III) is applied to regulate the frequency by controlling the system responsive loads. Promising simulation results show the potential of the proposed demand response strategy for frequency and voltage regulation of an isolated diesel generator, which will eventually be applied to a microgrid. The responsive load is considered to be 15% of the total load, i.e., 15% of the total load is available to be controlled. Each responsive load is assumed to be a 4.5 kW electric water heater (EWH), which could be either in “ON” or “OFF” state.

The dynamic model for the diesel engine with governor and excitation controller and synchronous generator are extracted from MATLAB/Simulink SimPowerSystems toolbox [8], which are based on the IEEE standard 421.5 [9].

The dynamic load is modeled in the d-q frame as shown in Fig. 2. Based on the theory of d-q frame [10], the direct-and quadrature axis currents (i_d and i_q) can be expressed as follows:

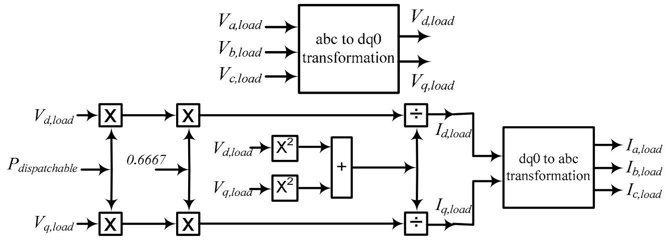

Fig. 2. Schematic of modeling of the active dynamic load.

$$i_d = \frac{2}{3}.\frac{v_d}{v_d^2 + v_q^2}.P + \frac{2}{3}.\frac{v_q}{v_d^2 + v_q^2}.Q \qquad (1)$$

$$i_q = \frac{2}{3}.\frac{v_q}{v_d^2 + v_q^2}.P - \frac{2}{3}.\frac{v_d}{v_d^2 + v_q^2}.Q \qquad (2)$$

where P and Q are the desired active and reactive power of the responsive load, respectively, and v_d , v_q (i_d , i_q) are the load voltage (current) in d-q frame. To transform the values from *abc* frame to d-q frame and vice versa, a phase locked-loop (PLL) is applied [10]. The voltage values in the d-q frame are extracted from the voltage across the load. The d- and q-axis of currents calculated are then transformed into the *abc* frame through the *dq0* to *abc* block.

III. THE PROPOSED CONTROL STRATEGY

The proposed control strategy regulates the frequency of the islanded microgrid by controlling the operation of the responsive EWHs to match the demand and generation at each instant in time. On the average, residential EWH electricity consumption accounts for about 11% of total electricity consumption and it increases to over 30% during peak demand hours [5], [6]. Therefore, there is a considerable potential for EWHs to be effective in demand response applications for frequency and voltage stabilization. When the frequency deviation, Δf, is negative (due to low generation or high demand), then a portion of the responsive loads that are operating will be turned OFF. On the other hand, when Δf is positive, a part of the responsive loads that are not operating will turn ON. Therefore, the percentage of the EWHs in the ON/OFF state is continuously adjusted, as shown in Fig. 3, to regulate the system frequency within the desired limit. Since EWHs have energy storage capability, turning them ON or OFF for a few minutes may not have a noticeable effect on the participating customers comfort level, and they may not even realize the control of their EWH. Moreover, the percentage of participating responsive load is kept to a minimum at each instant.

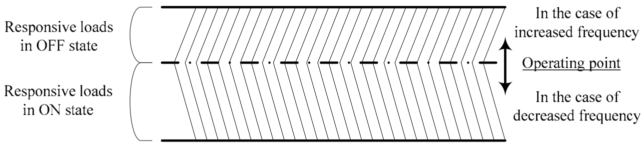

Fig. 3. The idea of responsive load control.

AHC is applied to determine the percentage of responsive loads which need to be operating at each instant in time for frequency stabilization. This technique was originally introduced for maximum power point tracking (MPPT) for photovoltaic (PV) systems [11], [12]. The original hill climbing involves a perturbation in the duty ratio of the power converter which perturbs the PV array current, which consequently perturbs the PV array voltage [11], [12]. This way, the operating point of the PV systems will move to its