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Voltage-base Frequency Control of Diesel Base Isolated Microgrids

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Abstract—**This paper present a voltage base frequency control (VBFC) for isolated microgrids The proposed controller attempts to control the frequency of the microgrid via the AVR. Frequency feedback to AVR changes voltage, consequently loads change due to the load sensitivity to the voltage, and finally load change provides positive damping or virtual capacity for reducing frequency deviation. The advantages of this method in comparison with others methods are 1) it does not need extra communication, 2) it helps increasing integration of renewable resources, 3) it provides fast and smooth frequency control, 4) it is based only on local frequency feedback, and 5) it can easily be used in any kind of microgrids. The test system model is based on a modified CIGRE benchmark and loads are voltage and frequency dependent. The performance of this method is simulated in PSCAD/EMTDC on the modified CIGRE model.**

Keywords— frequency control, microgrid, smart grid, distributed energy resource.

I. INTRODUCTION

In recent years, the microgrid, a small power grid with renewable energy sources, has attracted a lot of attention and actively studied around the world to combat fossil fuels and global warming. The main advantage of microgrids is to reduce transmission losses, the cost of construction of transmission lines, improving the supply stability prevent power changes with respect to renewable energies. In addition, with the IEEE 1547 standard permitting the islanded operation of distribution networks [1], isolated/islanded microgrids will become more prevalent, improving the reliability of electricity supply and allowing better integration of renewable energy sources[2]. However, it's difficult to keep the voltage and frequency constant and reduce the harmonics due to the small size of the system, low inertia and fast changes in the islands mode. Due to these problems, one of our most serious challenges in the isolated microgrid to control the frequency around the nominal operating point[3].

As we know, the most important feature of the microgrid is the ability to isolate when an error occurs in the power grid. In this case, the microgrid must be able to supply his loads continuously and reliable. Several books and papers discuss control techniques for operation of microgrids[4],[5]. From these resources, some of the most important control frameworks for the microgrids are:

1) Sustainability
2) Voltage and frequency regulation
3) Accurate distribution of active and reactive power
4) Fast and easy islanding and reconnection

The frequency control methods of isolated microgrid have been discussed in many papers. The droop control method is one of the most appropriate ways to control the frequency of the island's microgrid for using local signals without the need for communications[6]. Despite the advantages, this method is not suitable when the microgrid has nonlinear loads and all the microgrid resources who involved in providing the load act autonomously and, as a result, adversely affects the overall system stability[7].

Due to the problems of conventional droop method, different methods based on conventional droop method were presented to improve the power sharing and frequency response. To improve system stability, in Articles [8] and [9], the supplementary control loop was added to the main loop, but this loop caused the steady-state frequency response error. To reduce the steady-state frequency response error, [10], [11] and [12] proposed the angle droop control method. In this method, the voltage angle was used instead of the frequency for power sharing however, angle measurements with common reference and rapid communication were required for this method and as a result the power sharing and system stability limit get worse.

In [13], a virtual droop control method is proposed and introduced to manage microgrids in various operating modes. It regulates the microgrid voltage and frequency more tightly than the natural droop based control techniques. It also operates the fossil based generators at near rated power to increase their operating efficiency. The proposed technique operates the microgrid at a constant voltage and frequency, and uses communication for power sharing. With all these features, it needs powerful

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communication band and if the communication system lost microgird get problems.

In paper [14], a frequency control method for island microgrid base on voltage regulation is presented. In this paper, the frequency response is performed by using the load sensitivity to the voltage. This method gives us advantages include increasing integration of renewable resources and it does not need extra communication but In spite of all the advantages of this method, this article also has some disadvantages:

1) Absence of generalizability
2) A special case study
3) lack of checking different loads
4) not considering the load dependence to the frequency
5) complex model

In this paper, a frequency control method is proposed for low inertia migrogrids. The proposed method controls frequency of microgrid using frequency feedback to AVR. The proposed controller is a PID controller that its gains are adjusted using the Ziegler-Nichols method. The proposed controller is simple, considers voltage and frequency dependent loads, improves system damping, and depends only on local frequency signal and does not require PMU and communications devices.

The rest of this paper is organized as follows: Section II describes the principles of voltage control in synchronous machine. In Section III the proposed VBFC is presented. In Section IV, the proposed VBFC is implemented to the modified CIGRE microgird and the performance of the control techniques are compared via time domain simulations in PSCAD/EMTDC. Finally, the concluding remarks are presented in Section V.

II. BACKGROUND

A. *Voltage control in synchronous machines*

The primary voltage controller of a synchronous generator is referred to as an Automatic Voltage Regulator (AVR). An AVR manipulates the generator excitation level in order to keep the output terminal voltage within specific limits. A typical AVR consists of an amplifier, excitation controller, and a sensor.

A simple model of a synchronous generator can be provided by a linear relationship between the generator terminal voltage and its field voltage, with a gain K_G and a time constant T_G, which can be represented with the following transfer function:

$$\frac{V_t(s)}{V_f(s)} = \frac{K_G}{1+TG\ S} \tag{1}$$

Where K_G is around 1 and T_G is in order of a few seconds.

A sensor will measure the terminal voltage via a transformer and send the measured signal to the AVR through an amplifier. The sensor can be modelled by a simple first order transfer function as follows:

$$\frac{V_S(s)}{V_t(s)} = \frac{K_R}{1+TR\ S} \tag{2}$$

Where T_R has a very small value, in the range of a few milliseconds. The amplifier can also be modelled in a similar way as follows:

$$\frac{V_R(s)}{V_e(s)} = \frac{K_A}{1+TA\ S} \tag{3}$$

Where K_A is in the range of hundreds, while T_A can be in the order of tens of milliseconds.

There are several different excitation system model types for a synchronous generator [15]. Modeling a realistic excitation system in detail is a complicated task and requires various aspects, such as the magnetic circuit saturation, to be taken into consideration [16]. However, the following adequate linear model of the excitation system presented by a first-order transfer function can be used for small generators of the kind found in isolated microgrids:

$$\frac{\mathrm{V_F(s)}}{\mathrm{V_R(s)}} = \frac{\mathrm{K_E}}{\mathrm{1+TE\ S}} \tag{4}$$

Modern exciters have a very low T_E, typically in the range of hundreds of milliseconds.

Considering the models provided for various components of the system, it is possible to obtain the simplified block diagram of an AVR shown in Figure. 1. From the figure, it is possible to calculate the closed-loop transfer function of the terminal voltage $V_t(s)$ to the reference voltage V_{ref} (s), as follows:

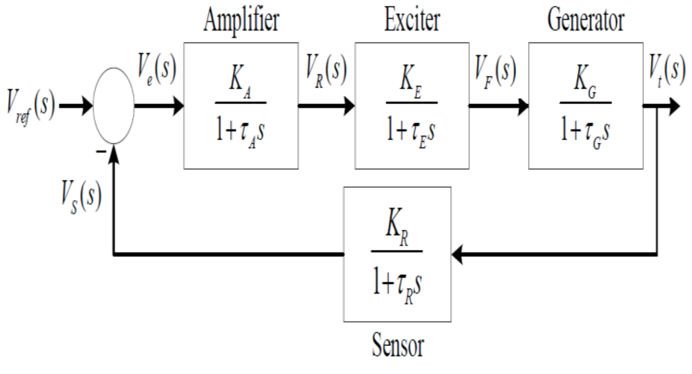


Fig. 1. Block diagram of an AVR[17].

B. *Frequency and voltage dependency of loads*

Loads in microgrid usually modelled by following equation [18]:

$$\mathrm{P} = \mathrm{P}_0 \left(\frac{\mathrm{V}}{\mathrm{V}_0}\right)^{n_p} \cdot (1 + \mathrm{K}_{\mathrm{PF}}.\mathrm{dF}) \tag{5}$$

Which can be viewed equivalently as a ZIP load:

$$P_L = P_{L0}\left[Z_P \left(\frac{V_L}{V_{L0}}\right)^2 + I_P \left(\frac{V_L}{V_{L0}}\right) + P_p\right] \tag{6}$$

$$n_p \approx \frac{2\times Z_P + 1\times I_P + 0\times P_P}{Z_P + I_P + P_P} \tag{7}$$

Similarly:

$$Q = Q_0 \left(\frac{V}{V_0}\right)^{n_Q} \cdot (1 + K_{QF}.dF) \tag{8}$$

$$Q_L = Q_{L0}\left[Z_P \left(\frac{V_L}{V_{L0}}\right)^2 + I_q \left(\frac{V_L}{V_{L0}}\right) + P_q\right] \tag{9}$$

$$n_Q \approx \frac{2\times Z_q + 1\times I_q + 0\times P_q}{Z_q + I_q + P_q} \tag{10}$$

where P is the active power demand; Q is the reactive power demand; P_{L0} is the rated active power, and Q_{L0} is the rated reactive power at nominal operating voltage V_{L0}; and n_P and n_Q are voltage indexes for the active power and reactive power; K_{PF} and K_{QF} are Frequency index for active power and reactive power, respectively; Z_p, I_p, and P_p, and Z_q, I_q, and P_q are the constant impedance, constant current, and constant power coefficients for active and reactive power respectively.

III. VBFC CONTROLLER

A. *VBFC*

Figure. 2. shows the proposed VBFC for an isolated microgrid. The input signal to the controller is the system frequency deviation from the nominal set-point Δf. The frequency error is passed through a Proportional-Integral-derivative (PID) controller to ensure that the steady-state error is zero, and determines the damping factor provided by the VBFC.

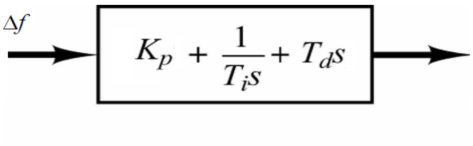


Figure. 2. Proposed VBFC

The output signal of the VBFC is then added to the reference set-point signal of the voltage regulator Vref. In a diesel-based system, the voltage regulator is the synchronous machine excitation system, as shown in Figure. 3.

The controller attempts to control the frequency of the microgrid via the AVR. Frequency feedback to AVR changes voltage, consequently loads change due to the load sensitivity to the voltage, and finally load change provides positive damping or virtual capacity for reducing frequency deviation.

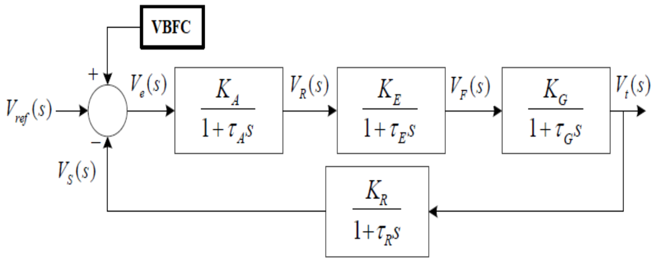


Figure. 3. Adding VBFC to Synchronous machine

B. *VBFC vs PSS*

It can be observed in Figure. 3. that the VFC control structure is similar to that of a Power System Stabilizer (PSS). However, there are fundamental differences in the application domain and performance of VFC and PSS. First, PSS acts on the derivative of rotor speed of a synchronous machine, and is designed to damp the low frequency electromechanical oscillations in power systems in the range of 1-2 Hz, such as inter area oscillations. Such phenomena may occur in power systems with large transmission networks. However, low frequency electromechanical oscillations are not a major concern in isolated microgrids due to relatively short feeders. Second, PSS is not designed to address large frequency deviations and/or eliminate steady-state frequency error. On the other hand, since VFC reacts to large frequency changes, it provides virtual reserves for the system that compensates for the active power mismatch and can potentially prevent frequency instabilities in isolated microgrids [19].

IV. RESULT AND ANALYSIS

In this section the proposed VBFC is applied to the modified CIGRE test system that is shown in Fig. 4 [20]. The performance of the proposed controller is compared with the conventional controller. The test system is simulated in PSCAD/EMTDC. The total load of the system is about 9 MVA, distributed among different phases to have an unbalanced load. Feeders are modeled as coupled π sections.

The synchronous machines nominal rating is 5.4 MVA. In the cases discussed here, the two synchronous machines are in charge of regulating the voltage, and the VBFC is implanted on the exciters of these machines. The standard IEEE AC1A excitation systems are used [21]. The parameters of the VBFC are tuned by Ziegler-Nichols to obtain the best performance. The tuned parameters of the VBFC are given in Table I.

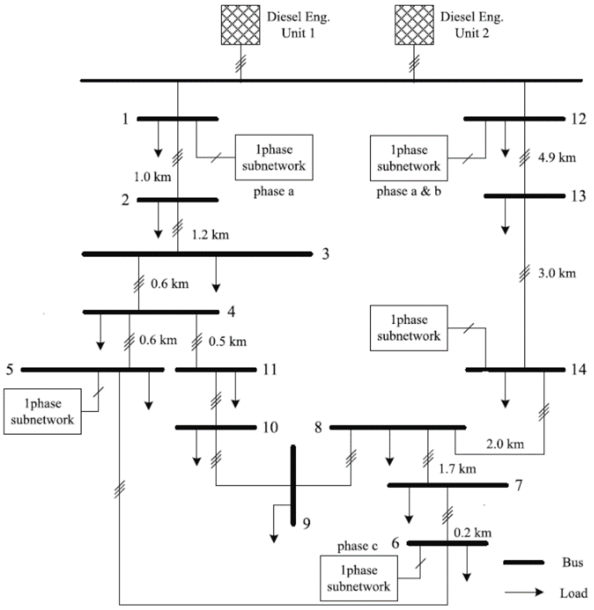


Fig. 4. Test microgrid based on CIGRE benchmark.[20]

Table I
VBFC parameter

Parameter	Value
K_p	15
T_i	6
T_d	1.5

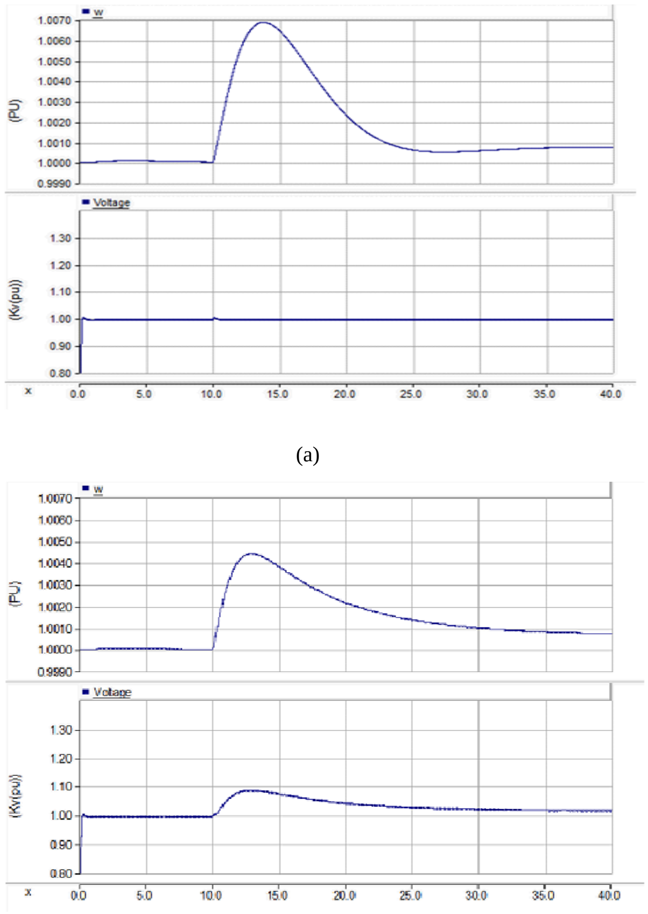
To evaluate the propose VBFC, an 800 kw per phase and 600 kvar per phase load at bus 2 is disconnected in time 10 sec. The frequency and voltage deviations under conventional frequency control and VBFC are assessed and are compared.

This experiment is repeated for four cases of load including residential and commercial loads in summer and winter. The parameters of these loads are given in table II for four different cases.

Table II
Load model parameter [22] , [18]

Case	Type of load	N_P	N_Q	K_{PF}	K_{QF}
1	Residential (summer)	1.2	2.9	0.8	-2.2
2	Residential (winter)	1.5	3.2	1	-1.5
3	Commercial(summer)	0.99	3.5	1.2	-1.6
4	Commercial(winter)	1.3	3.1	1.5	-1.1

The frequency and voltage of bus 2 for Case 1 of table II are shown in Fig. 5. The frequency response of the system is compared with conventional controller. Fig. 5(a) shows that under the conventional control the peak of frequency is 1.007 pu. Fig. 5(b) shows that under the VBFC the peck decrees to 1.0045 Pu. In addition, the system transient response is enhanced under VBFC. Moreover, the voltage of bus 2 does not reach to its limits under VBFC and hence we have an acceptable voltage response.

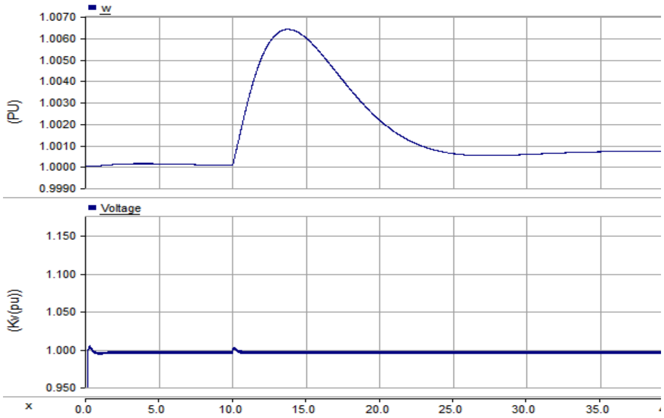


(a)

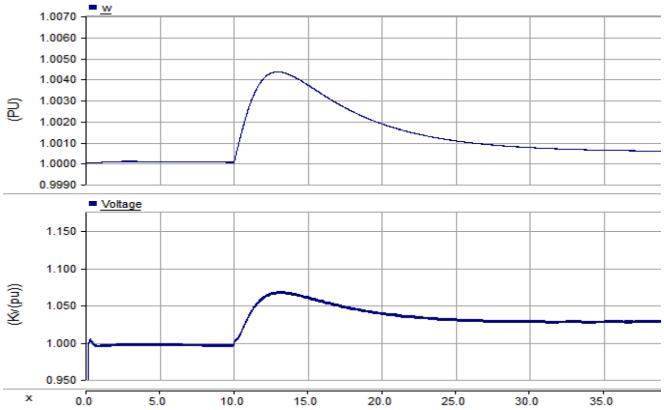
(b)

Fig. 5. Frequency and voltage in case 1: (a) with conventional controller; (b) with VBFC

Similar to the case1, cases 2, 3 and 4 are shown in figure 6, 7 and 8. By comparing the conventional controller with VFC in frequency response, it is found out that the frequency peak in these cases without using VBFC are 1.0065, 1.0073 and 1.0067 pu respectively. By using VBFC in these cases the frequency peak decreasing in all cases for example in case 3 it decrees to 1.0042. In addition, the system transient response is enhanced under VBFC in all cases. Moreover, the voltage of bus 2 does not reach to its limits under VBFC in any cases and hence we have an acceptable voltage response.

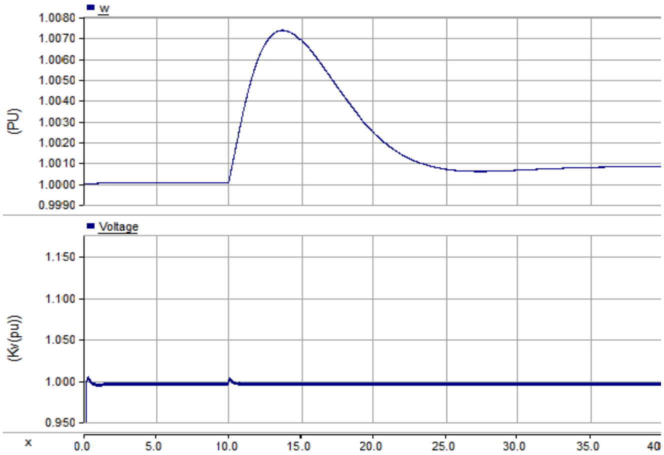


(a)

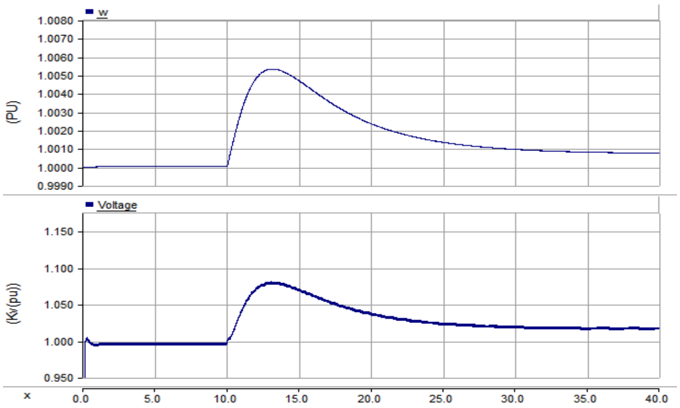


(b)

Fig. 6. Frequency and voltage in case 2: (a) with conventional controller; (b) with VBFC

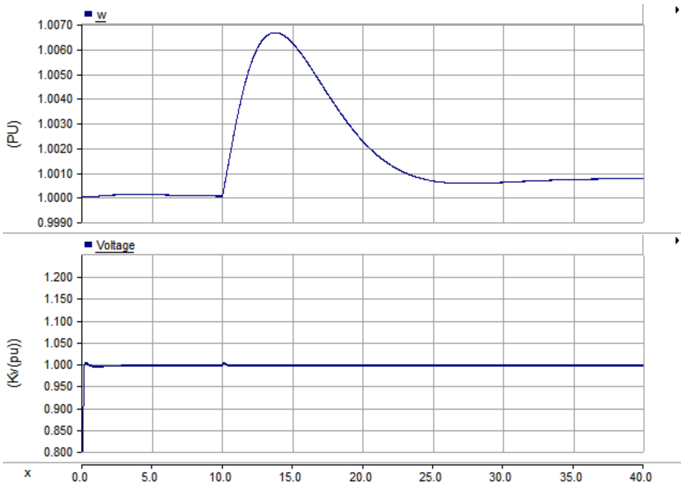


(a)

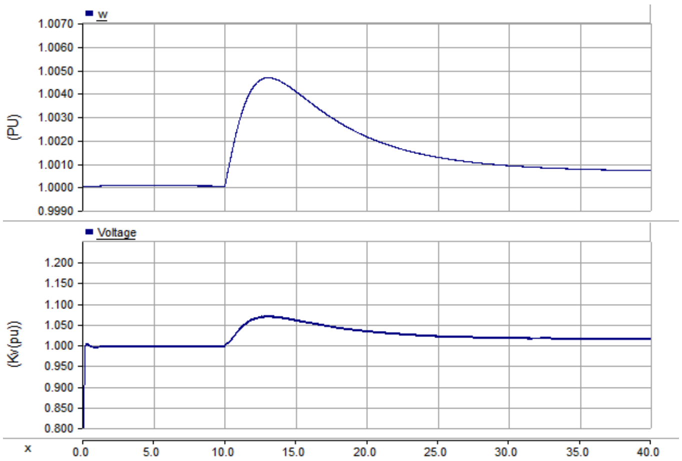


(b)

Fig. 7. Frequency and voltage in case 3: (a) with conventional controller; (b) with VBFC



(a)



(b)

Fig. 8. Frequency and voltage in case 4: (a) with conventional controller; (b) with VBFC

V. *CONCLUSION*

In this paper a VBFC control for isolated microgrid is proposed to improve the frequency response of the system. Based on results this controller is easily applicable to a variety of different type of microgrid. This method give us several advantages including frequency response improvement, Simplicity, communication device reduction, Only local feedback signals are required, works with any type of microgrid, Improves the system damping, and system flexibility for increasing penetration of renewable resource without need of extra energy storage system. Simulation results show that under conventional controller frequency goes out of it limits, but under the proposed VBFC frequency response improves and remains within its limits. Simulation results show that although performances of both conventional controller and VBFC are depended on the dependency of load to voltage and frequency, VBFC leads to better performance than conventional controller in all cases. Simulation results also show that although voltage is changed to control frequency it remains within its limits in all studied cases.

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