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Microgrid Frequency Regulation by Using of Electric Vehicles Controlled by Fuzzy Controller with Optimized Rules and Membership Functions

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Abstract. The growing use of electric power on one hand and environmental pollutions due to using of fossil fuels on another hand, have made it necessary to find new sources of energy to produce electric power. Renewable energies such as wind and solar resources can be employed to produce electric power but they suffer from uncertainties in their output powers due to stochastic environmental situations. These changes lead to frequency deviations in power grid and may make it unstable. This problem can be more challenging in standalone microgrids due to their low inertia. To overcome this problem, energy storage systems (ESSs) can be used. However using of ESSs needs to investments and may be not economical. Electric vehicles (EVs) can help power systems to balance generation and consumption and compensate the changes of renewable energy outputs. This can be done by EVs batteries so that they can be charged when grid frequency is high and discharged when frequency is low. This concept is introduced by Vehicle to Grid (V2G) phrase. In this paper a new method for control of EVs in a microgrid is proposed in order to decrease frequency deviations. For this purpose, fuzzy controller with optimized membership functions and rules has been introduced. Moreover in proposed method, state of charge (SOC) of EV battery can be control along with frequency regulation. Simulations have been carried out in MATLAB environment and results of simulations illustrate appropriate performance of proposed method.

Keywords: Optimized fuzzy controller, Vehicle to grid, Frequency regulation, State of charge, Microgrid

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1- Introduction

Renewable energies such as wind and solar energies can be alternatives for producing electric power. To better control of these renewable sources, they are usually employed in microgrids. A microgrid can operate in grid connected and standalone modes. When it is in grid connected mode, voltage and frequency are controlled by main grid but when it operates in standalone mode, voltage and frequency should be controlled by itself. Renewable energy sources (RESs) such as wind and solar energies suffer from uncertainties in their output power due to stochastic environmental situations which can lead to frequency deviations in grids. This problem can be more challenging in standalone microgrids due to their low inertias.

Nowadays using of electric vehicles is increasing. According to [1], the number of EVs in the United States in 2030, and 2050 will reach 51%, and 62%, respectively. It is possible to use electric vehicles batteries to balance generation and consumptions in microgrids so that they can be charged when grid frequency is high and discharged when frequency is low. This concept is introduced by Vehicle to Grid (V2G) phrase. By using of EVs batteries for frequency regulation, need to investment can be reduced. Using of electric vehicles for frequency regulation and control has been employed in several literatures [2-11].

In [2] power management scheme has been presented to leverage the participation of EVs for secondary frequency regulation. This paper has considered multiple objectives and using these objectives the problem of frequency support has been formulated as a “Mixed Integer Linear Programming (MILP)” problem. Ref. [3] has employed small-signal analysis to investigate which droop or virtual inertia method is more suitable for cooperation between wind generators and plugin hybrid electric vehicles (PHEVs) in order to participate in primary frequency regulations in power grids. Ref. [4] has proposed a novel frequency control strategy for EVs to participate in the primary and secondary frequency regulations of microgrids. In this paper virtual inertia and virtual damping are introduced using a virtual synchronous generator through AC/DC control. In Ref. [5] a novel strategy has been described to properly design the frequency-droop controller of plugin electric vehicles (PEVs) for primary frequency control (PFC). It is demonstrated that PEVs using the well-design droop controller significantly improve the PFC response while successfully preserving the frequency stability. In this paper a new control technique is suggested to alternate some portion of PEV’s reserve after a certain time by the reserve of conventional units during PFC and a method is proposed to evaluate the positive economic impact of PEV’s participation in PFC. Ref. [6] proposes the participation of EVs for load frequency control (LFC) under deregulated environment along with other conventional sources. In this article a new fractional order (FO) controller is suggested in all the areas for robust LFC considering bilateral transactions. Using of EVs for frequency regulation during grid restoration has been mentioned in Ref. [7]. This paper has been employed an adaptive optimal controller for this aim. In Ref. [8] an “aggregator-based hierarchical control mechanism” for secondary frequency regulation (SFR) using a fleet of EVs has been presented. In this article, EVs’ scheduling problem has been formulated to provide optimal SFR, while satisfying EVs’ energy demands under battery degradation constraints. In Ref. [9] a new coordination of EV, wind farm (WF), and photovoltaic (PV) for microgrid frequency regulation has been proposed. In this paper in the control design, an adaptive PI controller incorporating with a small delay consideration in the control loop is used to regulate frequency at various operating points. In Ref. [10], two controllers has been suggested by considering different charging profiles, state of charge (SOC) of electric vehicle batteries, and a varying number of electric vehicles in an electric vehicle fleet. These controllers provide bidirectional power flow, which can provide primary frequency control during different contingencies that an industrial microgrid may face during a 24-hour period. Ref. [11] proposes a hierarchical framework for control of governor/turbine and EVs in order to provide primary frequency support. The work has two layers. One layer dispatches the primary reserve references and another dispatches the aggregated EV power change.

In this paper a new method for control of electric vehicles (EVs) in a microgrid is proposed in order to decrease frequency deviations. For this purpose, a fuzzy controller with optimized membership functions and rules has been introduced. Moreover in proposed method, SOC of EV battery can be controlled along with frequency regulation. Imperialist Competitive Algorithm (ICA) has been employed for optimization. To the best knowledge of authors, this study has not been reported in the literatures. The rest of paper is organized as follows. In second part, understudy microgrid is introduced. Then suggested method is described in next part. In forth part, simulations are conducted and the results are discussed. At last in fifth part, conclusion is given.

2- Understudy Microgrid

The understudy microgrid has been shown in Fig. 1. The elements of this microgrid are PV system, wind energy system, BESS, diesel generator, EVs and loads. In following, modeling of systems is described [12-15].

- PV system model:

A lag transfer function is assumed for PV cells as follows:

$$G_{PV}(s) = \frac{\Delta P_{sol}}{\Delta \Phi} = \frac{K_{PV}}{1+sT_{PV}} \tag{1}$$

where $\Delta \Phi$ is intensity of radiation and ΔP_{sol} is output power of PV. T_{PV} shows time constant of PV system response and K_{PV} is PV system gain. In an AC microgrid, PV system is connected to microgrid by using of inverter and filter. Dynamic modeling of output inverter and filter according to input is as follows:

$$G_{inv}(s) = \frac{\Delta P_{PV,AC}}{\Delta P_{sol}} = \frac{1}{(1+sT_{IN})(1+sT_{I/C})} \tag{2}$$

where T_{IN} and $T_{I/C}$ are time constants of inverter and filter respectively. For intensity of radiation a random signal is produced by uniform random number block of MATLAB.

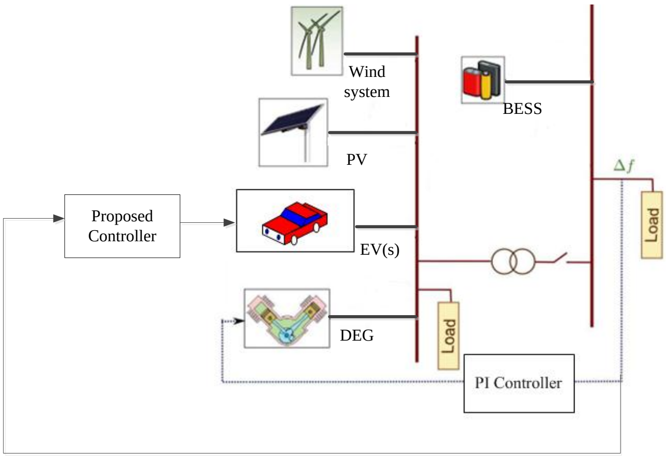

Fig. 1. Understudy microgrid

- Wind turbine generator:

For modeling of wind turbine generator, a lag transfer function is supposed as follows:

$$G_{wtg}(s) = \frac{\Delta P_{WTG}}{\Delta P_{W_m}} = \frac{K_{WTG}}{1 + sT_{WTG}} \tag{3}$$

where T_{WTG} and K_{WTG} show the time constant and gain of wind turbine generator system respectively. In this study, wind velocity changes are obtained by a method as same as intensity of radiation.

- Diesel Generator:

Relation between frequency changes and output power of synchronous generator is modeled as follows:

$$G_{\deg}(s) = \frac{\Delta P_{DEG}}{\Delta f} = \frac{K_{DEG}}{(1 + sT_G)(1 + sT_{DE})} \tag{4}$$

where K_{DEG} is final gain of diesel generator system to microgrid frequency changes and T_G and T_{DE} are time constants of synchronous generator and diesel respectively.

- Battery energy storage system:

Following transfer function is used to model the BESS in order to frequency analysis:

$$G_{BESS}(s) = \frac{\Delta P_{BESS}}{\Delta f} = \frac{K_{BESS}}{1 + sT_{BESS}} \tag{5}$$

where K_{BESS} is gain of BESS to microgrid frequency changes and T_{BESS} is time constant of it.

- EV model:

To model EV in order to frequency analysis, a first degree transfer function is used as follows:

$$G_{EV}(s) = \frac{\Delta P_{EV\_out}}{\Delta f} = \frac{1}{1 + sT_{EV}} \tag{6}$$

where T_{EV} is time constant of model.

With respect to above mentioned, frequency model of microgrid is shown in Fig. 2. In this figure, D and H show damping and inertia constant of microgrid respectively.

3- Proposed Controller

Structure of proposed controller has been shown in Fig. 3. As can be seen from figure 3, frequency deviation of microgrid and SOC of EV battery are considered as two inputs of the controller and with respect to values of them, output power of EV battery for charging and discharging is computed. Initial membership functions and rules of the controller have been shown in Fig. 4 and table. 1 respectively. In Fig. 4 points of A to F are optimized so that frequency deviation is become minimum. Moreover rules of table. 1 (excluding Zero rules) are optimized. It supposed that frequency deviation and SOC have symmetrical membership functions. In another word VL, NM, NS should be same as PL, PM and PS respectively and Zero membership function should be symmetrical respect to zero value. This subject is true for SOC and output membership functions too. So following relations should be established in Fig. 4:

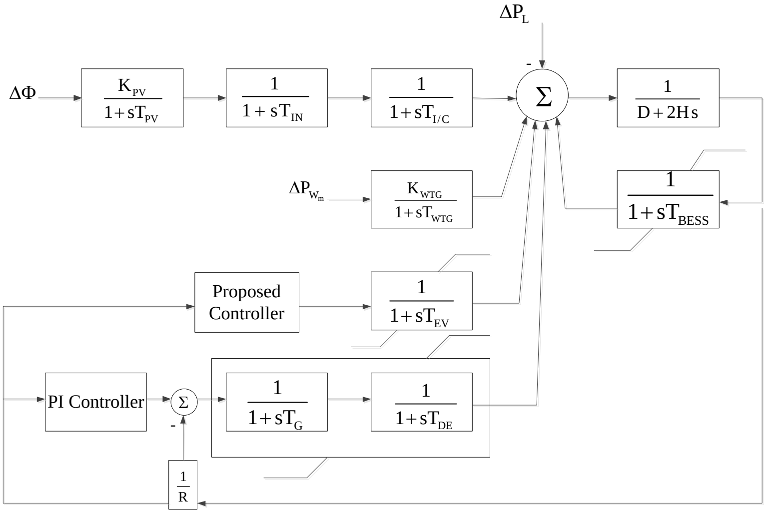

Fig. 2. Frequency model of microgrid

$$A' = -A \tag{7}$$
$$B' = -B \tag{8}$$
$$C' = 100 - C \tag{9}$$
$$D' = -D \tag{10}$$
$$E' = -E \tag{11}$$
$$F' = -F \tag{12}$$

Rules of table. 1 are optimized so that negative rules should be same as positive rules according to size. For example when frequency deviation is VL and SOC of EV is M and output is obtained as PM, then when frequency deviation is VH and SOC is M, output should be NM. In Table 1 intended rules for optimization are identified by a number. By specifying of positive outputs, negative outputs can be identified. It is supposed that 50% SOC is enough for EVs so membership functions of SOC are symmetrical than 50% and rules of fuzzy controller are symmetrical than to SOC equals to 50% and frequency deviation equals to zero.

Following fitness function has been considered for optimization:

$$F = \int_0^t |\Delta f| t\,dt \tag{13}$$

Imperialist competitive algorithm (ICA) has been employed for optimization. An explanation of the ICA has been given in [16] and not repeated here in order to abbreviation. Table.2 shows optimum rules. Values of A to F have been obtained as following by ICA:

A=-0.5 B=-0.1 C=40 D=-0.89 E=-0.4 F=-0.3

Fig. 3. Structure of proposed method

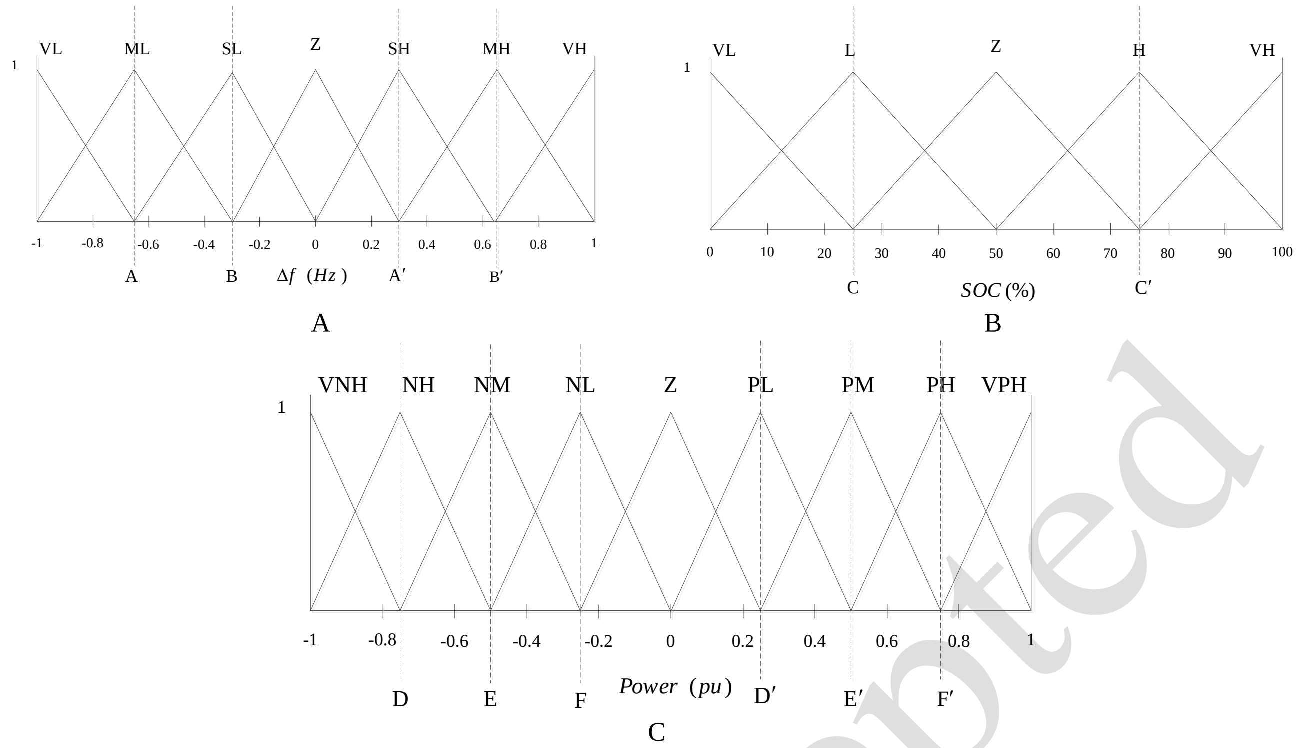

Fig. 4. Initial membership functions of proposed controller. A) Frequency deviation B) SOC C) Power

Table. 1: Initial rules of proposed controller

SOC \ Δf	***VL***	***ML***	***SL***	***Z***	***SH***	***MH***	***VH***
VL	Z	Z	Z	Z	NM	NH	VNH
L	Z	Z	Z	Z	NL	NM	NH
M	PM (1)	PL (2)	Z	Z	Z	NL	NM
H	PH (3)	PM (4)	PL (5)	Z	Z	Z	Z
VH	VPH (6)	PH (7)	PM (8)	Z	Z	Z	Z

Table. 2: Optimized rules of proposed controller

SOC \ Δf	***VL***	***ML***	***SL***	***Z***	***SH***	***MH***	***VH***
VL	Z	Z	Z	Z	NM	NH	VNH
L	Z	Z	Z	Z	NL	NH	Z
M	Z	VPH	Z	Z	Z	VNH	Z
H	Z	PH	PL	Z	Z	Z	Z
VH	VPH	PH	PM	Z	Z	Z	Z

4- Main results

4-1- Frequency deviation in presence of renewable energies

In this case study, frequency deviation of microgrid is evaluated in presence of changes of wind and solar power plants. It is assumed that there are no load changes in this study. Frequency deviation of microgrid is displayed in Fig. 5 by employing of proposed method and the fuzzy controller with initial rules and membership functions. It is illustrated that by proposed controller frequency deviation is decreased. Maximum of frequency deviation is -0.3375 Hz with initial fuzzy controller while it is -0.110 8Hz by proposed controller that shows frequency deviation of microgrid is decreased by 67% by proposed controller.

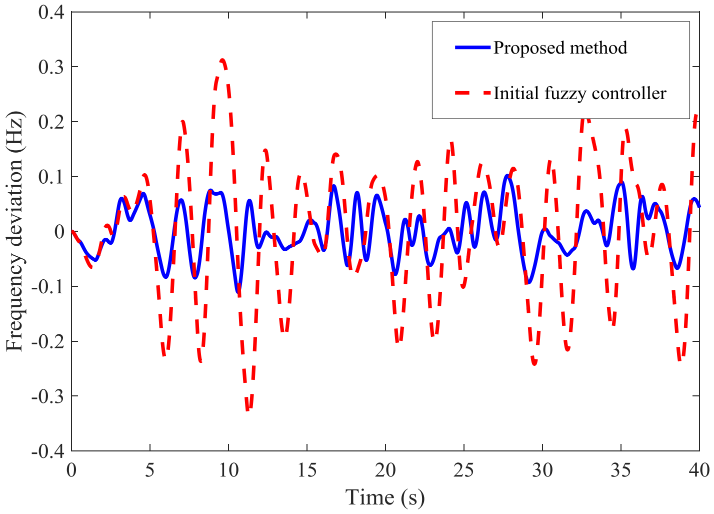

Fig. 5. Microgrid frequency deviation in presence of renewable energies

4-2- Loss of PV system

It is assumed in this case study that PV system loses 0.1 pu of its power at instant of 10 s. Changes of frequency deviation of microgrid is shown in Fig. 6. It illustrates that with initial fuzzy controller frequency deviation has high fluctuations but by using of proposed method, fluctuations of frequency deviation is decreased significantly. Moreover proposed controller could reduce maximum of frequency deviation by 42%.

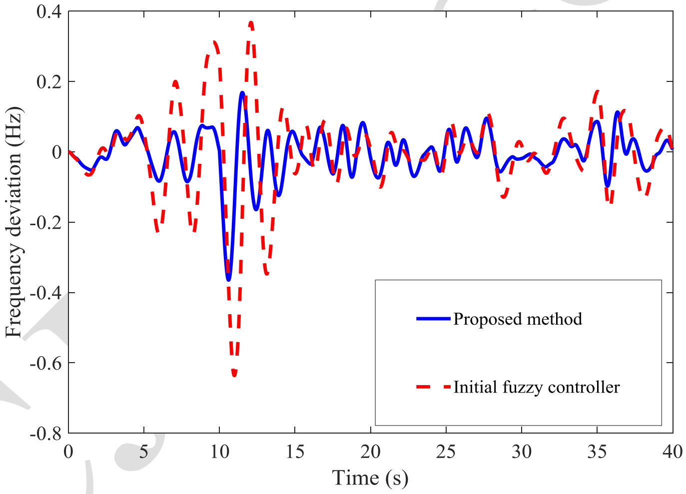

Fig. 6. Microgrid frequency deviation by decreasing of PV system power.

4-3- SOC evaluation

Performance of proposed controller in control of SOC of EVS batteries is carried out in this case study. For this reason it is supposed that there are three groups of EVs with different initial battery SOCs as 47%, 50% and 53% in microgrid. Load changes with zero mean is considered for this case study. Changes of SOCs of EVs have been shown in Fig. 7 for 3600 s. It can be seen that by proposed controller, SOC of EVs with 53% initial SOC is decreased toward 50% and SOC of EVs with 47% initial SOC is increased toward 50%. SOC of EVs with 50% initial SOC does not change.

5- Conclusion

In this research a new method has been introduced for frequency regulation in a microgrid. In this method a fuzzy controller with optimized rules and membership function has been employed. Frequency deviation of microgrid and SOC of EV battery have been considered as inputs of controller. Performance of proposed controller in reducing of microgrid frequency deviation has been verified in presence of renewable energies and load changes. Results of simulations show that proposed method could better decrease frequency deviation of microgrid than initial fuzzy controller. Moreover ability of proposed method to control of SOC of EV battery has been evaluated and result of simulations illustrates appropriate performance of proposed controller.

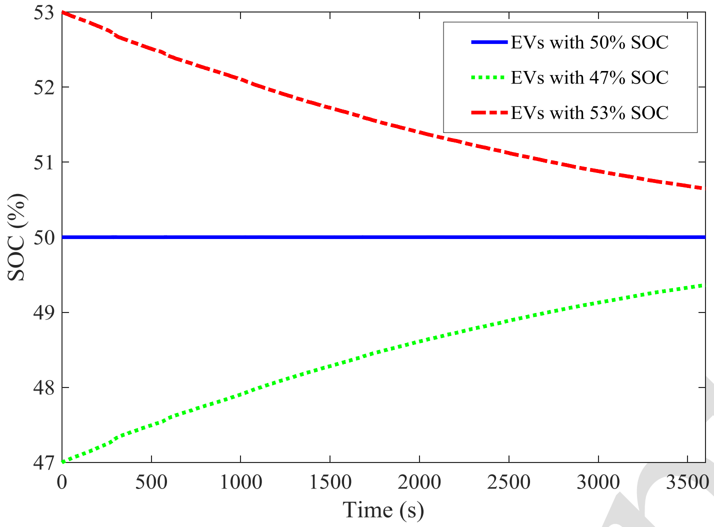

Fig. 7. Changes of SOCs of EVs.

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