RESEARCH ON GRID INSTABILITY CAUSED BY THE INTERACTIONS IN MICROGRID

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ABSTRACT

More and more power electronic (PE) converters are used in power systems, especially microgrids, due to the integration of new energy and controllable loads. The PE device brings harmonic pollution and adds inductive and capacitive components into power systems. When these PE devices interact with each other or with the power system, grid instability (oscillations) might occur. This paper introduces a modularized PE-integrated microgrid theoretical model and presents the reprehensive results of the overall evaluation on the microgrid instability issues caused by the interaction in both grid-connected and islanded microgrids by using this theoretical model.

INTRODUCTION

Nowadays, the characteristic of power systems is changing due to the integration of new energy and controllable loads. The interface between these power sources/loads and power systems is power electronics (PE) based converter/inverter. With the booming development of new energy, large amount of PE devices are used in the modern power systems. Compared with conventional equipment (transformer etc.) used in power systems, a PE device has individual controller, brings harmonic pollution and adds inductive and capacitive components into the power system. When these PE devices interact with each other or with the power system, grid instability (oscillations) might occur. Regarding the potential instability issues, many researchers have made small signal stability analysis on microgrids. However, most of them focus on the grid stabilities affected by the controller parameters of a specific control method, grid or load parameters etc. [1] – [4]. Their analysis are done based on a grid with one or two converters. Small signal stability issues caused by the interactions between different converters (same or different types) are not investigated.

As the frequency of the oscillations caused by the controller interactions between converters is normally low, e.g. few Hz up to several tens Hz. Thus, small signal stability theory is selected as the theory basis to develop a modularized microgrid theoretical model in our research. This paper introduces this model and presents the typical results of the evaluation on the microgrid instability issues caused by the interactions in both grid-connected and islanded microgrids by using this theoretical model. Fig.1 shows the system configuration of a typical microgrid studied in this paper.

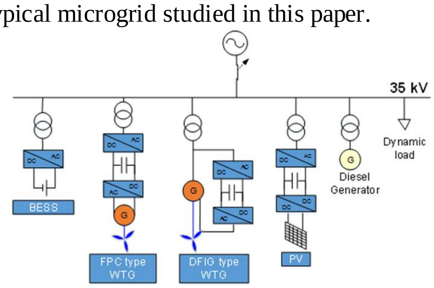

Fig.1 The system configuration of a typical microgrid

MODULARIZED THEORETICAL MODEL OF MICROGRID

The significant advantage of the modularized theoretical model is its easily extendable aspect, i.e. it is suitable for microgrids with any number of connected converters etc.. The detailed modelling method and model validation will be introduced in this section.

Modularized theoretical model

Each generator (including new energy sources and conventional generators) or load connected to a microgrid is written as nonlinear dynamic equations (it is differential algebraic equations) based on its physical working principle, i.e. the complete electromagnetic transient model. They are called components in Fig.2. Each component is interfaced with the grid through its terminal voltage and current, so that all the components can be conveniently joined together with the network in a modularized way, as shown in Fig.2. Therefore, this modularized model could be easily extended to larger power systems.

According to the small signal stability theory, the nonlinear dynamic models of different components (see Fig. 2) should be linearized around the equilibrium point of the grid to simplify the complete system model, so as to avoid the dimensionality disaster caused by the system complexity. By using the modularized modelling method, the linearization of each individual component are done first, then they are coupled together through a separate network model. Finally, the linearized MIMO (multiple input multiple output) models of all individual components are integrated together. The component models and the network MIMO models are coupled through the network constraints (i.e. KCL and KVL constraint), and hence a linearized closed-loop system is established for the microgrid and a modularized microgrid theoretical model is obtained.

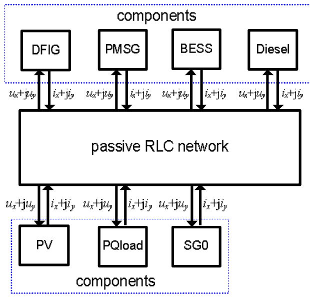

Fig.2 Modularized modelling of interconnected microgrid

As the new energy sources in our research are only considered as generators in our research, the control method used in DFIG, PMSG and PV inverter are typical PQ control. The control method used in BESS inverter is typical virtual synchronous generator control.

Validation of the theoretical model

After the modularized theoretical model is developed, it is important to make validation of the model before it is used for further theoretical analysis on the oscillation modes of the microgrid. Two types of validations are made for the developed theoretical model: 1) Validate the nonlinear dynamic model of individual component; 2) Validate the complete microgrid theoretical model.

Validation of the nonlinear dynamic model of individual component

In this validation, the dynamic performance of the individual component theoretical model (nonlinear dynamic model) and the corresponding Simulink model are compared. To simplify the research, each component is connected with a synchronous generator, which represents a utility grid, as shown in Fig. 3. G and SG represent a component (e.g. DFIG type WTG, PMSG type WTG etc.) and the utility grid, respectively. A voltage dip of 0.1p.u. is implemented at the terminal of the utility grid to create a disturbance to the grid. The dynamic performance of this component, obtained from its theoretical and Simulink model, are compared. Fig. 4 shows one example of the comparison results of DFIG type WTG.

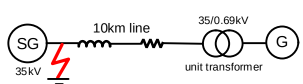

Fig.3 The grid configuration for validation of the nonlinear dynamic model of individual component

All components' theoretical models are validated and the results showed that the theoretical models of all individual components (see Fig.2) are accurate enough for further linearization and development of a complete microgrid theoretical model.

Validation of the microgrid theoretical model

To validate the complete microgrid theoretical model, several validation cases are studied by checking if the oscillation frequency obtained from the eigenvalue of theoretical model is consistent with the one obtained from Simulink model. The oscillations are trigged by varying the value of one of the converter's controller parameters until the eigenvalues of the microgrid theoretical model traverses the y axis. The oscillation frequency will be measured in the simulation results and compared with the corresponding one obtained from the theoretical model. The validation are done for 4 typical cases, including both grid-connected and islanded microgrid. The system configuration of a validation case example (a grid-connected microgrid with 4 DFIGs and 1 dynamic load) is showed in Fig.5. The detailed validation cases and validation results are presented in table 1. The error rate in table 1 shows the difference in percentage between the oscillation frequencies obtained from the theoretical model and the Simulink model. They indicated that the developed microgrid theoretical model is accurate enough for the further research.

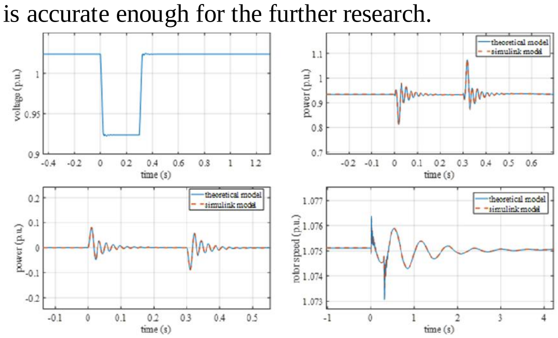

Fig.4 Comparison between dynamic responses of theoretical DFIG model (blue line) and Simulink DFIG model (red dash line): (a) terminal voltage magnitude of DFIG, (b) active power, (c) reactive power, and (d) rotor angular speed

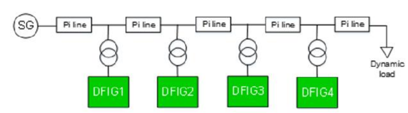

Fig.5 The system configuration of a validation case example (a grid-connected 4-DFIG microgrid)

Table 1 Theoretical model validation results obtained from four validation cases

Validation cases		Varied controller parameters	Typical oscillation frequency (Hz)		Error rate (%)
			Theoretical model	Simulink model	
Grid-connected Microgrid	Case 1 (4 DFIGs + 1 dynamic load)	Kp_cur (proportional gain of inner current loop of rotor side converter)	13.637	13.457	**1.32**
	Case 2 (4 PMSGs + 1 dynamic load)	Kp_g (proportional gain of inner current loop of grid side converter)	674.185	678.288	**0.61**
	Case 3 (4 PVs + 1 dynamic load)	Ki_g (Integral gain of inner current loop of grid side converter)	247.551	248.197	**0.26**
		Kp_g (proportional gain of inner current loop of grid side converter)	678.298	678.319	**0**
Islanded microgrid	Case 4 (4 BESSs + 1 dynamic load)	Ki_v (integral gain of AVR controller)	1.605	1.610	**0.31**

THEORETICAL EVALUATION ON THE MICROGRID STABILITY

By using the microgrid theoretical model introduced above, the evaluation on the grid stability is done for both grid-connected and islanded microgrid. Some typical results are presented in the following text.

Impact of controller parameters

The controller parameters of four type of converters (37 in total) are scanned with using the system configuration showed in Fig. 6.

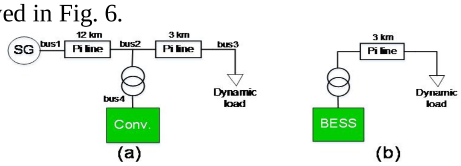

Fig.6 The system configuration used for controller parameter scan: (a) grid-connected microgrid, conv. means DFIG, PMSG and PV inverter respectively; (b) islanded microgrid

For each test case, only one type of converter is connected to the microgrid. The scanned controller parameters of different converter types are showed in table 2. The theoretical analysis results show that the controller parameters do affect the grid stability. However, only some controller parameters of each converter type impact grid stability, see the controller parameters marked in red in table 2. More detailed information about these controller parameters are given in table 3.

Table 2 Scanned controller parameters of different converter types

No.	DFIG	PMSG	PV	BESS
1	Kp_P	Kp_cur	Kp_dc	Kp_V
2	Ki_P	Ki_cur	Ki_dc	Ki_V
3	Kp_Q	Kp_dc	Kp_g	Kp_vol
4	Ki_Q	Ki_dc	Ki_g	Ki_vol
5	Kp_cur	Kp_g	Kp_PLL	Kp_cur
6	Ki_cur	Ki_g		Ki_cur
7	Kp_dc	Kp_PLL		Kp_PLL
8	Ki_dc	Kpw		Ki_PLL
9	Kp_g	Kiw		H
10	Ki_g			D
11	Kp_PLL			
12	Kpw			
13	Kiw			

Controller gain impacts grid stability (red)

Controller gain does not impact grid stability (green)

Table 3 More detailed information about the controller parameters marked in red in table 2

Converter type	Controller parameter	Implication
DFIG	Kp_P	Proportional parameter of active power controller of rotor side converter
	Kp_cur	Proportional parameter of inner current controller of rotor side converter
PMSG	Kp_g	Proportional parameter of inner current controller of grid side converter
PV	Kp_g	Proportional parameter of inner current controller of the inverter
	Ki_g	Integral parameter of inner current controller of the inverter
BESS	Ki_V	Integral parameter of the AVR of the BESS inverter
	Ki_vol	Integral parameter of the outer voltage controller of the BESS inverter
	D	Virtual mechanical damping

It is also observed that one controller parameter, which impacts the microgrid stability, is always related to one oscillation frequency (it might slightly change with the variation of parameter value). The detailed information is showed in table 4. For example, the frequency of the oscillations related to the controller parameter Kp_P (proportional parameter of active power controller of rotor side converter) of DFIG is around 46 Hz in our studied microgrid. Furthermore, the microgrid stability become worse as Kp_P decreases.

Table 4 Detailed information about controller parameters impact the grid stability

	Gain impacts grid stability	Variation trend of gain	Grid stability	Related oscillation frequency (Hz)
DFIG	Kp_P	Decrease	Worse	around 46 Hz
	Kp_cur	Decrease	worse	Around 14 Hz
PMSG	Kp_g	increase	worse	Around 680Hz
PV	Kp_g	increase	worse	Around 680Hz
	Ki_g	Increase	worse	Around 248Hz
BESS	Ki_v	increase	worse	Around 1.6Hz
	D	decrease	worse	Around 1.6Hz

Impact of converter type

The typical oscillation frequencies in the microgrid with different converter types are different. In a microgrid only with DFIG type WTG, the oscillation frequency is around 14 Hz and 46 Hz In a microgrid only with PMSG type WTG, the oscillation frequency is around 680Hz. Oscillations of 248 Hz might occur in a microgrid with solar inverter, oscillation around 1.6 Hz and 0.3 Hz might occur in a microgrid with BESS (islanded microgrid).

To further evaluate if there are different interaction phenomena between different types of converter, a comparison was made between a grid-connected microgrid with 5 DFIG type WTGs and a grid-connected microgrid with four different types of converters (1 DFIG, 1 PMSG, 1 solar inverter, 1 BESS) and one diesel generator, which is called as 'hybrid microgrid' in later text. The theoretical analysis results showed that the grid stability of a grid-connected microgrid with 5 DFIG type WTGs is almost the same as the one of a hybrid grid-connected microgrid, except that there are more oscillation modes. Typical oscillation frequencies of PMSG type WTG and solar inverter are found in the hybrid microgrid, as showed in the left top graph of Fig. 7 (X axis is the oscillation damping of the microgrid and eigenvalues on the right side of the red vertical line indicate the grid is not stable. Y axis the oscillation frequency.)

Similarly, theoretical analysis and comparison were made for two islanded microgrids: one is with 5 BESS inverters; another is with four different types of converters (1DFIG type WTG, 1PMSG type WTG, 1 solar inverter, 1BESS) and one diesel generator, which is called 'hybrid islanded microgrid' in later text. No instability issue is found in the islanded microgrid with 5 BESS inverters, however, the instability issue with the typical oscillation mode of DFIG is found in the hybrid islanded microgrid. From this observation, it also could be concluded that the grid stability issue is more critical for the microgrid with DFIG type WTG. Fig. 8 shows the grid stability scan results with two variable controller parameters (Ki_V and D).

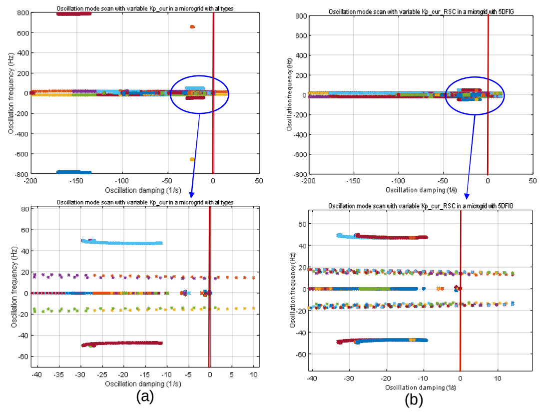

Fig.7 Grid stability scan with variable Kp_cur (DFIG controller parameter) in grid-connected microgrid. (a) microgrid with 5 DFIG type WTGs; (b) hybrid microgrid

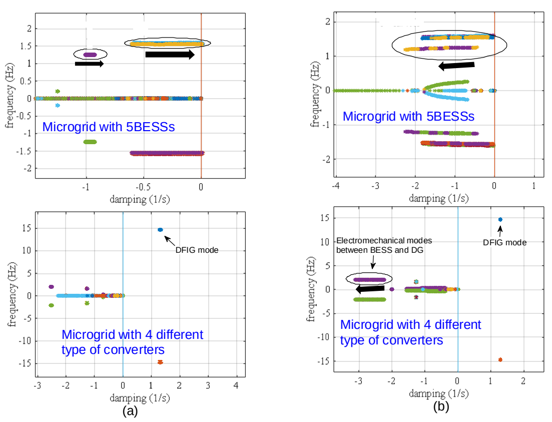

Fig. 8 Grid stability scan with variable Ki_v and D (BESS controller parameters) in an islanded microgrid (figures in top row) and a hybrid islanded microgrid (figures in bottom row). (a) Variable Ki_v; (b) Variable D

Impact of converter numbers

Theoretical analysis is also done for the microgrid with multiple converters (the same system configuration as showed in Fig. 5). The analysis results showed that the number of converters connected to the microgrid do affect the grid stability. By using the same controller parameters, the microgrid with single converter is stable, however, the microgrid with multiple converters is not stable. Fig.9 shows an example results obtained in the microgrid with DFIG. The X axis is the oscillation damping of the microgrid and eigenvalues on the right side of the red vertical line indicate the grid is not stable. The Y axis is the oscillation frequency of the microgrid. When the controller parameter Kp_cur of DFIG is varied from 0.03 to 0.5, the oscillation damping and frequency of different oscillation modes of two microgrid are calculated and presented in Fig.9. It can be observed that some oscillation damping of the microgrid with four DFIGs are positive values, i.e. the grid is not stable. However, the microgrid with a single DFIG is stable in the whole variation range of Kp_cur.

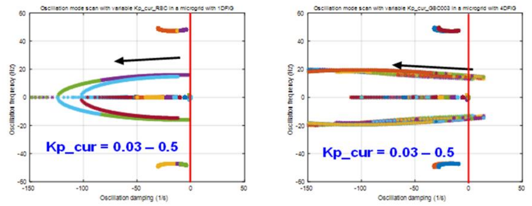

Fig. 7 The scan results of the proportional parameter of rotor current controller (Kp_cur) in the microgrid with DFIG: (a) microgrid with single DFIG; (b) microgrid with four DFIGs

The theoretical analysis results also show that some new oscillation mode occurs when the grid is connected with multiple PMSGs, PV inverters or BESSs. In a microgrid with two PMSGs, the oscillation mode with frequency around 680Hz is found. The oscillation mode with frequency around 680Hz is also found in a microgrid with multiple PV inverters. The oscillation mode with frequency around 1.6Hz is found in a microgrid with multiple BESSs. This observation proves that more oscillations might occur as the number of connected converters increases in the grid.

CONCLUSIONS

This paper presents the representative results of an overall evaluation and analysis on the grid instability caused by the interaction in both grid-connected and islanded microgrids. The results show that the controller parameters of the converters affect the grid stability. Furthermore, the interactions between converters do exist because the grid stability is affected by the number of converters connected to the grid. The inherent oscillation modes of different types of converters are not same. The modularized microgrid theoretical model introduced in this paper is a valuable and helpful tool for evaluating the grid instability issues in microgrids or other power system with large amount of power electronic devices.

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