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Energy Procedia 158 (2019) 6321–6327

Energy Procedia

www.elsevier.com/locate/procedia

10th International Conference on Applied Energy (ICAE2018), 22-25 August 2018, Hong Kong, China

Frequency Regulation of Wind Integrated Power System using Dual Mode Fuzzy

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Abstract

Owing to the increase in electrical load demand the dimension of interconnected energy system is increasing day by day and getting more complex with power injection from renewable technologies such as wind energy in order to supply and meet rising energy demands as well as to limit the dependency on conventional sources of power generation. However, the rising trends towards power generation via wind power will cause the challenging task to maintain the equilibrium between the power generation and load demand and hence to keep the power system frequency to standard value. Hence, in this work a new control design based on switching logic having additional fuzzy intelligence is proposed for wind integrated energy system. In addition, it is also tried to reduce the rule base for proposed design and hence to reduce the complexity of fuzzy based design. The proposed design is tested for standard load change and the results are matched with fuzzy PI and with natural response of the system to show the power of the proposed design. Further, it is also shown that doubly fed induction generator (DFIG) wind integrated system with proposed control design have the capability to improve the standard frequency profile in case of sudden change in the power demand of the energy system and hence it helps to deliver the required power to the modern clients.

Peer-review under responsibility of the scientific committee of ICAE2018 – The 10th International Conference on Applied Energy.

Keywords: LFC; DFIG; Fuzzy logic; Area control error; Dual mode with fuzzy tuning

1. Introduction

The complexity of power delivery structure is increasing day by day with growing trends towards the penetration of wind energy in conventional system. In addition to it, the large contribution of wind energy

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10.1016/j.egypro.2019.01.381

generations will have an effect on standard frequency profile of energy delivery system due to non-contribution of wind energy generators in frequency regulations i.e. load frequency control (LFC) scheme. However, the promising movement and advancement in wind power technology has led to the development of doubly fed induction generator (DFIG) based wind generation as it has the ability to work on asynchronous speeds. Further, its speed can be controlled as required by the system operator and may have significant effect in near future in frequency regulation of modern and interconnected energy delivery system [1-4]. Furthermore, the modern energy delivery structure is extremely non-linear and its operational points alter continuously as the power requirement of the modern customers shifts and for this reason the conventional approach based on hit and trial is extremely time consuming and no more usable for the current and future energy delivery system [5]. The intelligent LFC designs depend on genetic algorithm (GA), artificial neural networks (ANNs) and fuzzy logic (FL) concepts are proposed by the several researchers on timely basis. The FL have the power to handle various types of uncertainties and non-linearities of energy delivery system and hence appear to be a promising LFC design for current and future energy delivery system. In [6], the FL structure highly depend on adaptiveness in order to evaluate the PI controller gains as per the available area control error (ACE) was discussed. The FL design based on gain scheduling approach was identified and discussed in [7]. The FL design based on type-2 theory for LFC was developed in [8]. Therefore, it is observed from the literature that FL based LFC designs are gaining momentum worldwide and hence in this work an attempt is made to propose an LFC design based on dual mode structure. The proposed design first operates as proportional control (PC) and after few seconds it works as integral control (IC) for standard load change in power delivery system. Further, PC and IC both have the capability of fuzzy intelligence with changing structure and may prove to be an efficient LFC design for the proposed system [9]. In addition, the rule base for PC action is reduced to four and for IC action it is reduced to six and hence the designed control works effectively with four as well as six rules in comparison to twenty five rules required by the conventional fuzzy to provide the required results.

1.1. System Model used for Investigations

It is a two-area system with power generation from conventional thermal plants having synchronous generator in each area of interconnected energy delivery system. Two areas are connected via AC tie-line. The DFIG based wind turbines are integrated in each area of the two-area system. The detailed structure and DFIG modeling used for LFC studies is available in [3-4] and hence not included here due to space limitation. However, the two-area system having synchronous generators in each area having generation via thermal plants with DFIG based wind integrated system included in each area used for present LFC studies is given in Figure 1.

2. Modeling and Logic of Dual Mode Fuzzy

The system performance can be improved with the concept of dual mode [7]. Modules A and B work as proportional control and integral control with fuzzy tuned approach in order to bring the system frequency and tie-power to nominal value. Hence, control design changes dynamically based on the current ACE of the system. The dual mode with fuzzy tuning methodology depends upon the switching limit of the controller. With gains tuned through intelligent fuzzy systems; the performance of two-area system is improved significantly. The block diagram of dual mode with fuzzy tuning is shown in Figure 2. The proposed strategy is divided into three areas of operation;

(2.1) Allocation of control areas inputs

(2.2) Development of fuzzy rules for PC and IC action

(2.3) Defuzzification of fuzzy values into real values

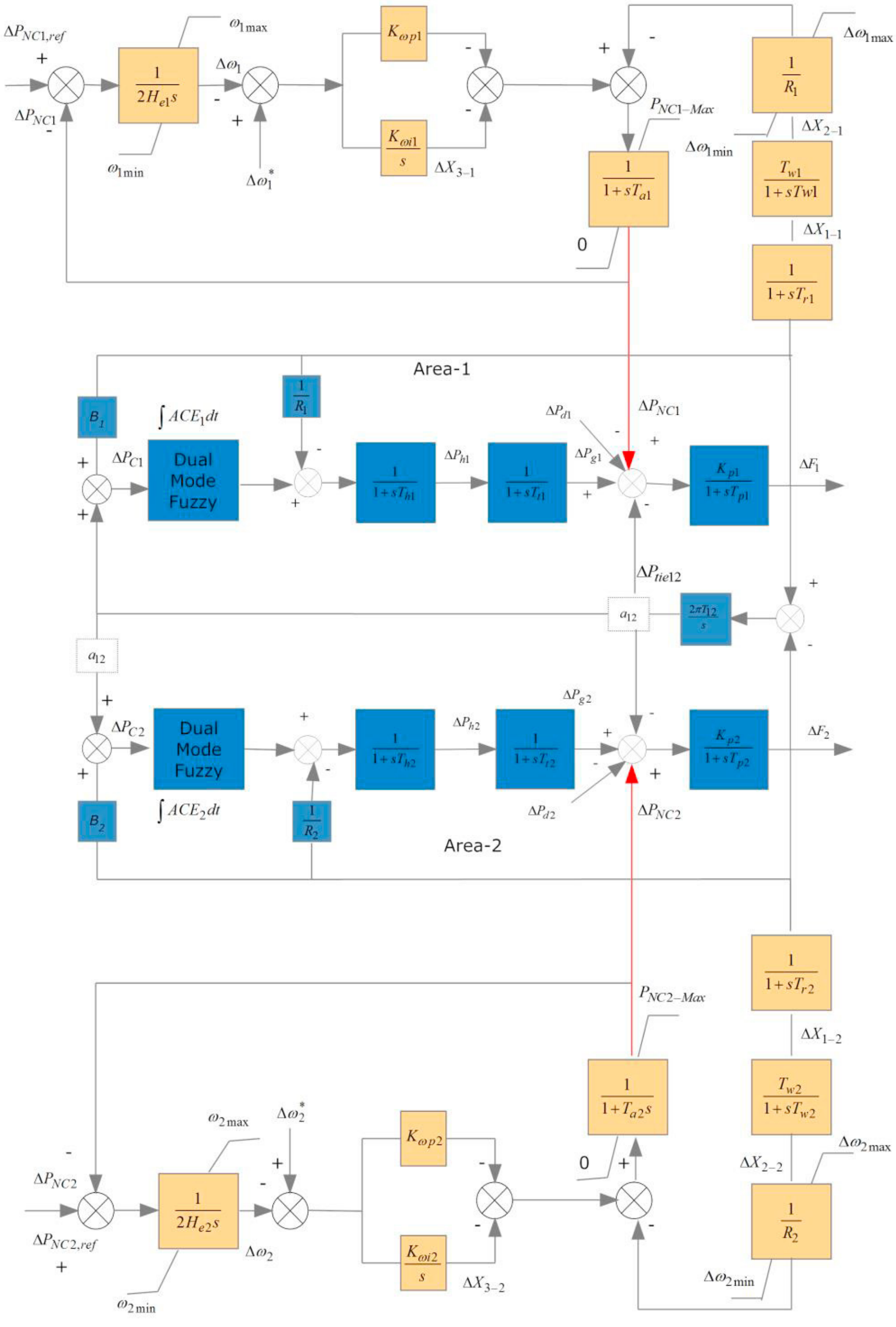

Figure 1: System Model

2.1. Allocation of Areas of Inputs

In order to achieve proportional action (Kp) by the proposed control design, the ACE is distributed into four parts which are positive large (PL), positive small (PS), negative large (NL) and negative small (NS). For obtaining integral operation (Ki) the ACE is distributed into negative big (NB), negative medium (NM), negative small (NS), positive small (PS), positive medium (PM) and positive big (PB). The formed rules for PC and IC action are shown in Table 1(a-b).

2.2. Tuning Rules for Proportional Action and Integral Action

Table 1(a). The rule base for PC

If ACE is	Then K_p is
PL	NL
PS	NS
NL	PL
NS	PS

Table 1(b). IC based on ACE values

If ACE is	Then K_i is
NB	PB
NM	PM
NS	PS
PS	NS
PM	NM
PB	NB

2.3. Defuzzifying the Output Value

The obtained crisp output is defuzzified by the famous method called centroid. This method is also identified as center of area or center of gravity.

3. Analysis of Results Obtained

The present work discusses the dual mode with fuzzy tuning methodology for a two-area system having thermal power generations via synchronous generators in area-1 & 2 with DFIG based wind generation in each control areas. The LFC design for the proposed system is implemented via developing the logic in such a way that after a sudden load change, the module 1, i.e. PC will be active and reduces the overshoot from frequency and tie-power deviation responses and once the system gets settle after few seconds the logic will shift to module 2, i.e. IC will be active and eliminates the steady state error as well as takes the system back to the original condition. Further both the modules i.e. Modules 1 and 2 have fuzzy tuning approach which will further improve the LFC performance significantly. Initially, the efficacy of the proposed LFC is checked for standard load change, i.e. 1% in area-1 without integrating wind power generators and the obtained LFC response is compared with natural response and with fuzzy PI under similar working conditions. The system responses, i.e. ΔF_1, ΔF_2 (frequency deviations of areas-1 & 2) and ΔP_{tie12} (tie-power deviations) are given in Figure 3.

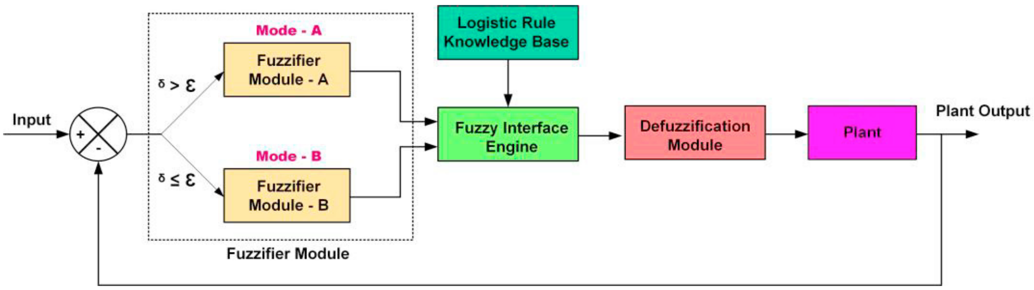

Figure 2: Dual mode with fuzzy tuning

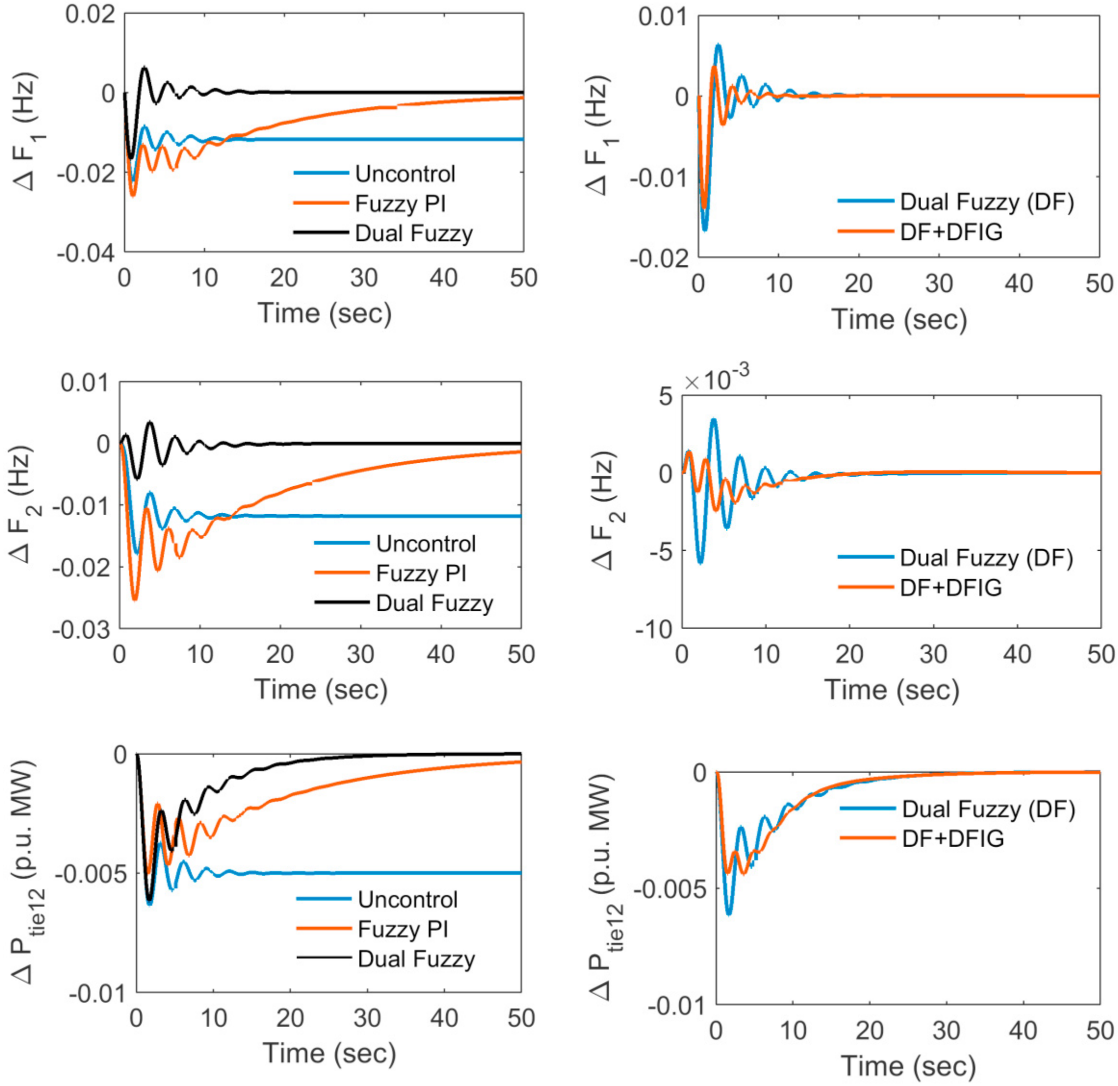

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Figure 3: The system responses obtained via dual mode fuzzy tuning approach

The LFC response shows that sufficient steady state error i.e. difference between actual and desired LFC exists in natural system responses. As compared to natural LFC, the fuzzy PI has lesser first peak overshoot but the settling time and movement towards steady state is quite slow. This is due to fact that for every disturbance the fuzzy PI have to evaluate complete 25 rules and hence the system gets slower to provide the required results for LFC. In comparison to both, the dual mode fuzzy response for LFC results in lowest first peak overshoot with reduced oscillations and faster actual condition, i.e. steady state error move towards zero. The trend towards settling is soft and faster for all LFC responses. The act of proposed LFC is ensured with four rules for PC action and 6 rules for IC action and hence the LFC results are enhanced. Hence, the studies are further extended to study the dual mode with fuzzy tuning technique with considering the impact of DFIG based wind generation in both areas. The LFC results for proposed LFC with and without DFIG are compared for various LFC responses i.e. ΔF_1, ΔF_2 (frequency deviations of areas-1 & 2) and ΔP_{tie12} (tie-power deviations) and shown in Figure 3. The look of LFC clearly reveals that DFIG has the ability to inject the quick active power in each area for load change in either of the area by reducing its speed and hence delivering the power to the grid which significantly enhances the proposed LFC. The of settling of all LFC responses are smooth and the system reaches to normal condition within couple of seconds after the load changes and the same is justified via LFC responses as shown in Figure 3.

4. Conclusions

In this research work a new control design based on switching logic having additional fuzzy intelligence is proposed for wind integrated conventional power system. In addition, it is also tried to reduce the rule base for proposed deign and hence to reduce the complexity of fuzzy based design. The proposed design is tested for standard load change and the results are match with fuzzy PI and with natural LFC response to show the validity of the proposed design. The obtained LFC response for frequency and tie-power deviations shows enhanced results in comparison to that obtained via fuzzy PI as well as from natural LFC. The obtained results for LFC are ensured with reduce rule base in comparison to obtain via fuzzy PI with twenty five rules and therefore there is significant great reduction in the design complexity. In addition to the above, the DFIG capability in reaching faster and smoother performance have shown remarkable improvements in LFC results with dual mode fuzzy tuning in comparison to no DFIG integration to conventional energy system. Hence, at this stage it can be said that wind integrated system may results in enhancing frequency profile of the interconnected power system and thus deliver quality power to the modern clients.

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Biography

Prof. Ramesh Bansal has over 25 years of experience and currently he is Professor and head of the department in the Department of Electrical and Computer Engineering at University of Sharjah. He has published over 300 papers. Prof. Bansal is an Editor/Associate editor of IEEE Systems Journal, IET-RPG & Electric Power Components and Systems. He is a Fellow and CEngg IET-UK, Fellow Engineers Australia and Institution of Engineers (India) and Senior Member-IEEE.