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Integrating ARM Based Controller for a Single Area Deregulated LFC Modeled in LabVIEW

R.R. Lekshmi, B. Suresh, C. Vineel Sreya Sujith and Shrishti

Department of Electrical and Electronics Engineering Amrita Vishwa Vidyapeetham, India

Abstract: Deregulation in power system results in separate entities like generating company, distribution company, transmission company and independent system operator. The reliability and stability of the system is the responsibility of the independent system operator that provides many ancillary services, one of which is load frequency control. In a deregulated power system, the GENCOs generate to meet the contracted demand of the distribution companies via load frequency control. This paper presents a hardware development of control strategy and its integration with the single area deregulated load frequency control model in LabVIEW. The transfer function model of the deregulated single area system is modeled in LABVIEW. The secondary controller (Integral controller), responsible for maintaining the frequency at nominal value is developed in ARM processor and is interfaced with LABVIEW. The proposed system is tested for the effectiveness of the developed controller during contracted condition and demand violation.

Key words: Deregulated power system · Load frequency control · Bilateral market

INTRODUCTION

The conventional electric power industry is vertically integrated where the functions of generation, transmission and distribution are under the monopoly that supplies power to customers at regulated rates [1]. Initially the conventional system was preferred owing to many reasons that include low per unit cost of generation, disinterest among private players to invest [2]. However, technological advancements improved the efficiency of smaller plants that made the smaller plants possible to produce power at economical rates [2]. Hence, to provide electricity at lower price, to meet high demands and provide more options to the customers the electrical power system has accepted the world wide trend of restructuring [3]. Restructuring involves unbundling the electrical industry into separate units that include generation company (GENCO), transmission company (TRANSCO), distribution company (DISCO) and Independent System Operator (ISO) [4]. Each DISCO gets the power from any of the GENCOs depending on the contract made between them [5]. The operation of the entire system is tracked by the ISO [6].

The main characteristic of the *restructured* system to provide supply at low rates reliably is possible only with efficient system. Efficient system can be incorporated only with innovations. One of the strategies to accept innovation is to introduce competition among all the GENCOs and DISCOs. This introduces the market [7], a platform to perform power trading among the participating GENCOs and DISCOs.

The market can be poolco based [8], bilateral based [9] or hybrid [10]. In a poolco based market transaction, the GENCOs and DISCOs are players and give the offer and bids to the market. The offer and bids includes the amount of power and the price the players are willing to sell or buy. The ISO sketches the supply-demand curve and determine the Market Clearing Price (MCP) [11] which is the intersection of two curves. The GENCOs and DISCOs to the left of MCP are the winning players and are allowed to do trading at MCP. In a bilateral based market transaction, each DISCO makes contract with any of the GENCO in the same or other control area. The percentage of participation of each GENCO on each DISCO is given by the contract participation factor (cpf) [12]. The contracted value and amount is informed to the ISO. A hybrid system involves both bilateral contract as well as bidding.

ISO is responsible for maintaining the stability and reliability of the system. This is achieved by providing many ancillary services, one of which is Load Frequency Control (LFC) [13-16]. The goal of LFC in a conventional

Corresponding Author: R.R. Lekshmi, Department of Electrical and Electronics Engineering Amrita Vishwa Vidyapeetham, India.

system is to minimise the frequency deviation and tie line power [1]. Hence, a secondary controller is incorporated with the input as the sum of change in area frequency and tile line power change, so called Area Control Error (*ACE*) [17]. However, in a deregulated power system, LFC aims at minimising the frequency deviation and maintain the tie line power at scheduled value [18].

Under contract condition in a single area, the GENCOs share the demand contracted by the DISCOs based on the cpf values. During contract violation, the willing GENCOs are made to compensate for the unscheduled power demand. This is done by making ACE as change in area frequency. Many researches [19-24] have performed to get the best results by selecting suitable controller. However, all these researches include modeling of the transfer function model of LFC in MATLAB/Simulink. Microprocessors offer best solutions to real time problems and hence can be incorporated under practical case for the development of LFC. This paper presents the ARM based implementation of control strategy for a single area deregulated system modeled in LABVIEW.

The rest of the paper is organized as follows:

Section 2 gives an introduction to deregulated power system. Transfer function model of the LFC is developed in Section 3. Section 4 explains the proposed implementation with the control strategy algorithm. Results and discussions are explained in Section 5 followed by the conclusion.

Deregulated Power System: With the motive of improved customer focus, innovation, lower cost and more options for the user, electric power system has accepted the worldwide trend of transition in electric power system from vertically integrated to restructured structure. The first step in deregulation involves disaggregation of the traditional regulated power industry into separate utility that includes GENeration (GENCO), TRANSmission (TRANSCO), DIStribution Company (DISCO) and Independent System Operator (ISO) [3]. It also involves restructuring of the rules and regulations set up by government in the regulated power industry.

One of the main features of restructured system, to provide power to customers at low rates, is made possible by having a high efficient system. This is achieved with new innovations made incorporating new technology. Innovations are brought by enabling competition within the system. This creates the power market in deregulated environment, a platform to perform power trading. Under bilateral model, a DISCO and GENCO undergo negotiations and fix the contract power and price. This information has to be finally submitted to the ISO before trading. This is shown in Fig. 1.

The ISO keeps track of the system so as to maintain stability and reliability by incorporating many ancillary services. LFC is one of such ancillary services. The model of the deregulated single area LFC system is shown in Fig. 2.

The system under study consists of two GENCOs and two DISCOs [21].

LFC in a Deregulated Power System: The basic role of LFC in a deregulated power system is to assist in minimizing the frequency deviation by rescheduling the generation to match the contracted demand and to maintain tie line power at predetermined values [13].

The transfer function model of the system [25] shown in Fig. 2 has been developed and shown in Fig. 3. Under bilateral model, each DISCO may contract with one or more GENCOs to meet its demand. The selected system assumes to have contract between all GENCOs and DISCOs. cpfij represents the fraction of total load required by jth DISCO which is supplied by ith GENCO, with the sum unity. The cpf forms the elements of DISCO Participation Matrix (DPM) [6]. The rows represent the GENCOs and the columns represent the DISCOs participating for LFC. The DPM matrix for the system considered is shown in equation (1).

(1)

The power generated by each GENCO to meet the contract made by each DISCO is calculated using *cpf* and is shown in equation (2).

(2)

During contract violation, the unscheduled power demand is compensated by the willing GENCOs. Thus, the ACE of the participating GENCO is made equal to the change in area frequency. The participating GENCOs compensate for the uncontracted power based on the economic participation factor (epf) [24]. Hardware has to be developed for the secondary controller that achieves the goal of LFC modeled in LabVIEW.

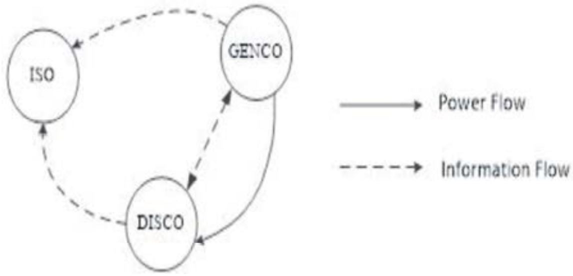

Fig. 1: Bilateral Power Trading

Fig. 2: Model of the deregulated single area LFC system

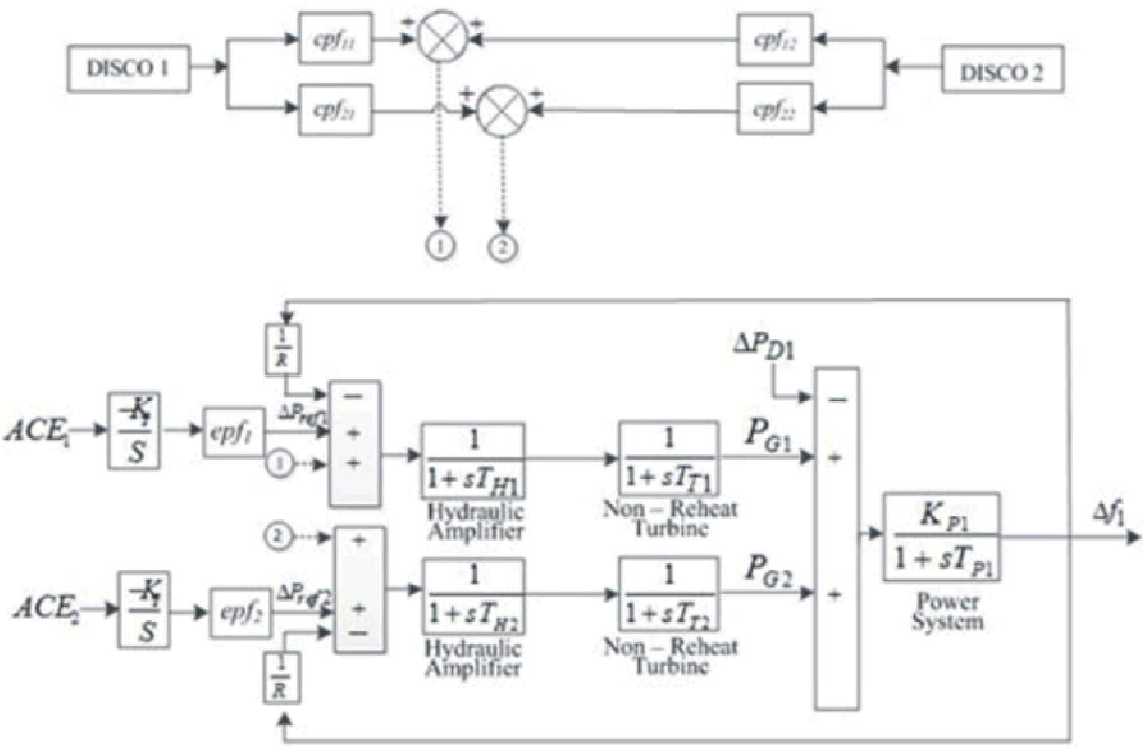

Fig. 3: Transfer function model of deregulated single area LFC system

Proposed System Design: The single area deregulate LFC discussed in section 3 is modeled in LabVIEW. During contract violation, the speed governor of the GENCOs takes action based on the frequency deviation. The primary controller of the speed governor operates so as to reschedule the GENCO power to meet the demand. However, the speed governor of the LFC exhibits drooping behavior that results in steady state frequency error. This error is minimized using a secondary controller that shifts the droop curve to make steady state frequency change to zero. The study focus on the steady state response, hence an integral controller is more suitable for the case. The integral controller minimize the error by adjusting the change in tie reference power, *ΔPref*. Thus, the input of the secondary controller is *Δf*.

$$ACE = \Delta f \quad (3)$$

In order to study the real time performance of the control strategy, the algorithm for the control action is implemented in micro processor. ARM processor due to its high speed is selected for the development of secondary controller. The ARM processor is coded to adjust ΔPref based on the frequency deviation. The flowchart for the computation to adjust ÄPref is shown in Fig. 4.

Using VISA, data is serially communicated to LPC2148 through Communication port. Communication port is connected to the UART 1 of LPC2148 via computer serial interface (Recommended Standard 232). The data fetched from LabVIEW is converted to string and is sent for communication. The data is processed in float type. Processor output is converted to string and is sent to LabVIEW.

RESULTS AND DISCUSSIONS

The transfer function model of deregulated single area power system explained in section 4 is developed in LABVIEW using the system parameters shown in Appendix.

Case A: GENCOs response under contract condition

In this study, 0.2 p.u. and 0.3 p.u. is demanded by DISCO 1 and DISCO 2 respectively. Each DISCO contracts with all GENCOs based on the DPM as shown in equation (4).

☻ (4)

From equation (2) it is clear that, DISCO 1 makes a contract of 10 % of the total demand on GENCO 1 and 90 % on GENCO 2 making a sum of 100 %. Similarly, DISCO 2 makes a contract of 30 % and 70 % with GENCO 1 and GENCO 2 respectively. The power generation of each GENCO is calculated using (2) and is furnished in Table 1.

From Table 1 it is clear that GENCO 1 has a total power generation of 0.11(0.02 + 0.09) p.u. Similarly GENCO 2 has a total power generation of 0.39 (0.18 + 0.21) p.u. Since the system is under contract condition change in area frequency, Δf =0. The condition is simulated and the results are shown in Fig. 5.

From Fig. 5 it is seen that the GENCO 1 and GENCO 2 power is increased from 0.11 p.u. and 0.39 p.u. respectively and is well matched with the calculated values shown in Table 1.

Table 1: Genco Output for Case a (P.U.)

DISCO	DISCO 1	DISCO 2
GENCO	(p.u.)	(p.u.)
GENCO 1	0.02	0.09
GENCO 2	0.18	0.21

Adjustmint Problem

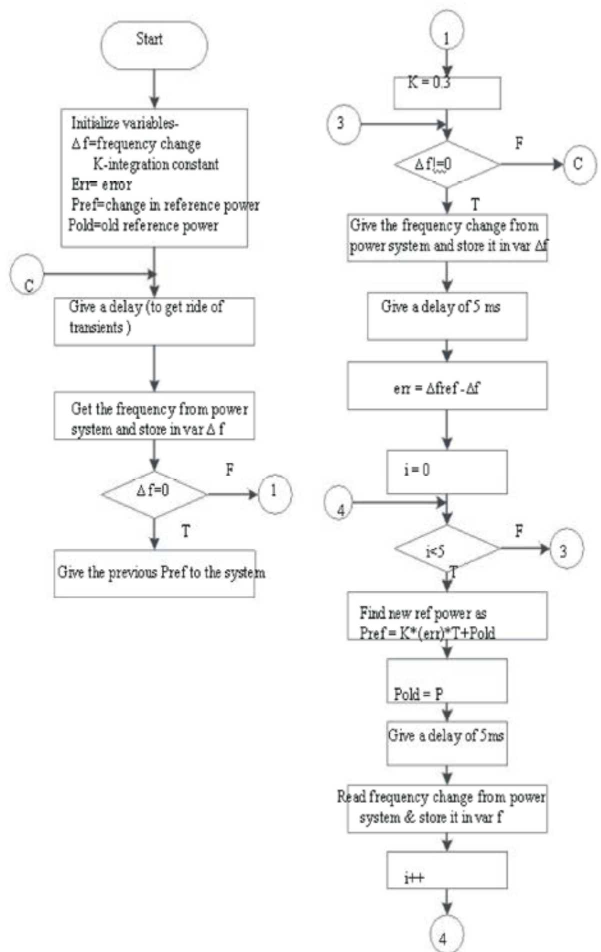

Fig. 4: Flowchart for compute change in reference power

Case 2: GENCOs responses for contract violation without secondary controller.

During contract violation of 0.01 p.u., all the GENCOs are made to participate by making ACE equal to Δf. Each GENCO meets the un-contracted demand based on the epf value equal to 0.5. In this case, power generated by the GENCO 1 and GENCO 2 is increased from 0.11 p.u. and 0.39 p.u. to 0.115 p.u. and 0.395 p.u. respectively. The absence of secondary controller exhibits a non zero value to the steady state frequency error. The case is simulated for a contract violation of 0.01 p.u. given in the LabVIEW model and the results are furnished in Fig. 6.

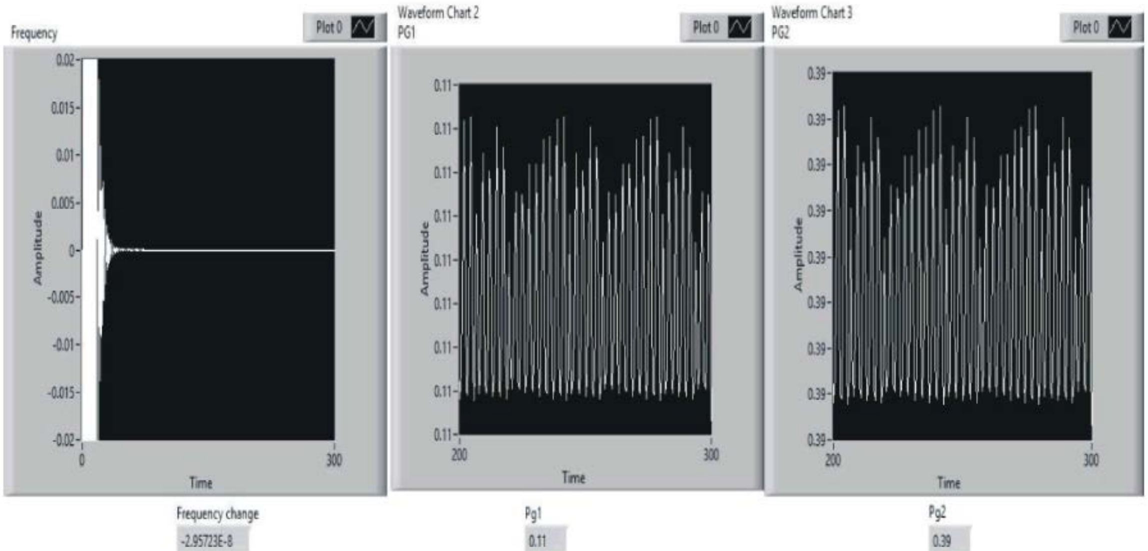

Fig. 5: The GENCOs and frequency responses without contract violation

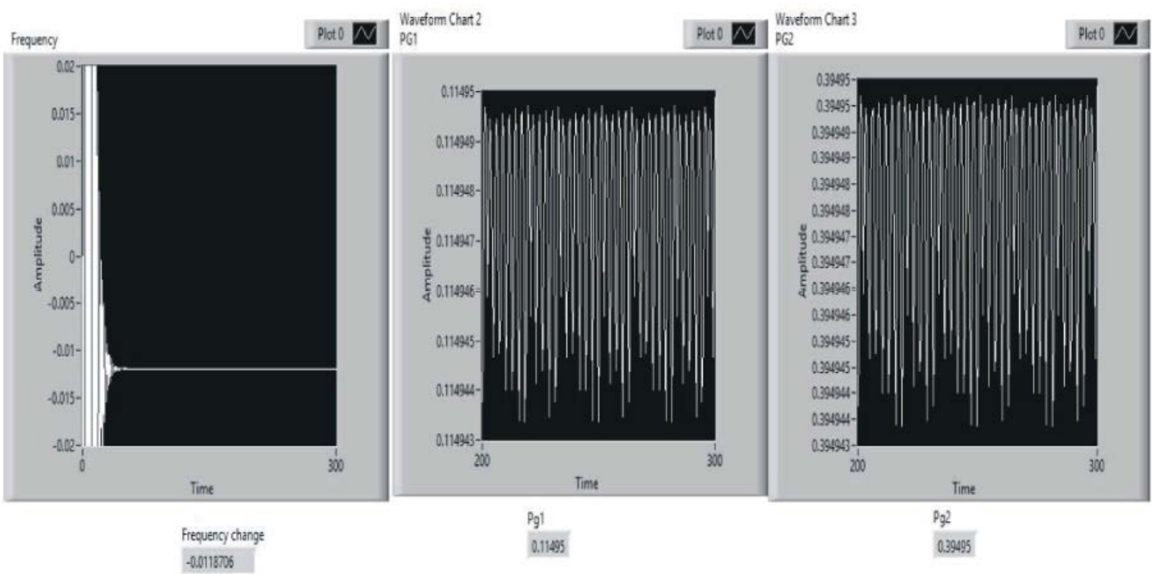

Fig. 6: The GENCOs and frequency responses without secondary controller during contract violation

Table 2: Gencos and Frequency Responses for the Cases Considered (P.U.)

		With contract violation	
	Contracted condition	Without Secondary Controller	With secondary controller
PG1(p.u.)	0.11	0.115	0.115
PG2(p.u.)	0.39	0.395	0.395
Δf (Hz)	0	-0.01187	0

From Fig. 6 it is seen that the GENCO 1 and GENCO 2 power is increased from 0.11 p.u. to 0.115 and 0.39 to 0.395 p.u. respectively. However, the change in frequency is non zero due to the drooping characteristics exhibited by the speed governor. This is achieved by incorporating a secondary controller. The transfer function model of the system with ARM based secondary controller is simulated during contract violation of 0.01 p.u. and the results are shown in Fig. 7.

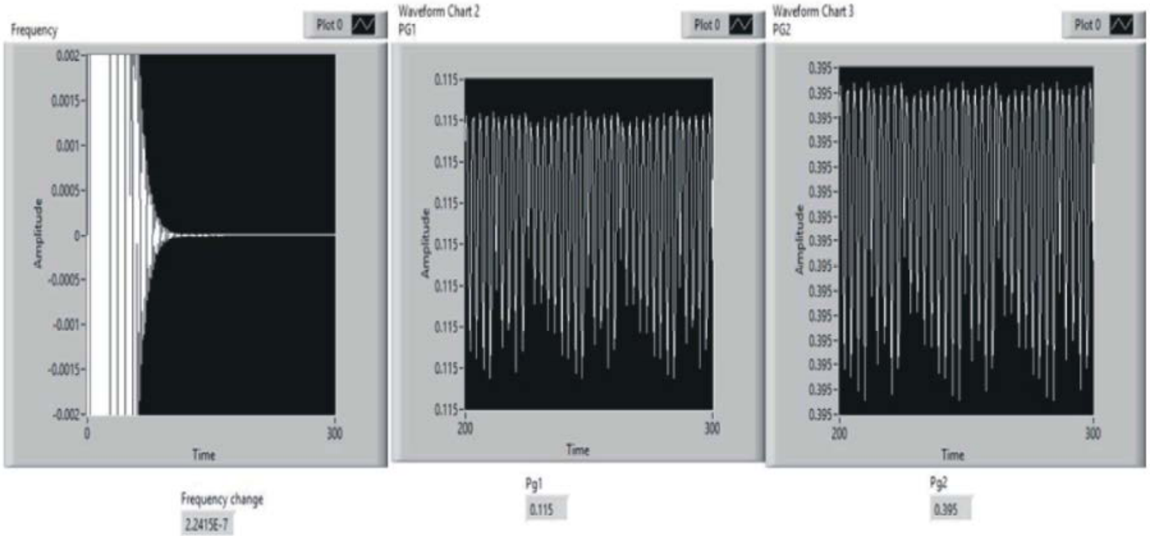

Fig. 7: The GENCOs and frequency responses with secondary controller during contract violation

Fig. 7 clearly shows that the frequency error of the deregulated system is minimized to zero. The GENCOs and the frequency responses for the cases considered are shown in Table 2.

From Table 2 it is clear that by using secondary controller the steady state frequency error becomes zero during contract violation. The secondary controller developed using the proposed algorithm for a single area deregulated load frequency control system gives the desired frequency response with zero steady state error.

CONCLUSIONS

This paper presented modeling of single area LFC in LabVIEW and integration of ARM based control strategy. The control action was based on tie line bias control. The single area LFC model having two GENCOs and DISCOs was considered for the study. Each DISCO is made to contract with all GENCOs in the area based on the cpf. The system was analyzed under contracted condition and the results were obtained as per the calculated values. During contract violation the compensation was made by the GENCOs based on epf. This was done by making *ACE* value of the participating GENCOs to be equal to Δf. However the absence of secondary controller gave a non-zero value to the steady state frequency change. This was eliminated by the introduction of integral controller developed in ARM. Analysis of the system under violation showed the effectiveness of the proposed ARM based controller for real time.

APPENDIX 1

ΔPGi Change in power output of i^{th} GENCO, p.u.
ΔPD Change in load, p.u.
Plj Local load of j^{th} DISCO, p.u.
THi Time constant of i^{th} governor, s
TTi Time constant of i^{th} turbine, s
KPk Equivalent gain of k^{th} Subsystem
TPk Equivalent time constant of k^{th} Subsystem, s
Ri Droop characteristics of i^{th} GENCO, Hz/p.u.

ΔPtie ij scheduled Scheduled tie line power deviation, p.u.

Δptie ij actual Actual tie line power deviation, p.u.
ΔPtie ij error Error in tie line power deviation, p.u.

APPENDIX 2:

PL	1000 MW
Pr	2000 MW
f	50 Hz
KPi	100
TPi	20 s
Ri	2 Hz/p.u. MW
âi	0.40333
THi	0.08 s
TTi	0.3 s
T	0.0707
a	-1

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