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Active Power Regulation of Hydro Dominating Energy System using IDD optimized FPA

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Abstract

In this paper an attempt is made to propose the different models of control and design such as integral derivative (ID), proportional integral derivative (PID) and integral double derivative (IDD) effectively optimized through flower pollination algorithm (FPA) for active power regulation of modern energy system having hydro dominating areas. At first, the performance of FPA-ID, FPA-PID and FPA-IDD founded LFC are evaluated for standard load change in one control area and their performance for system model is judged on the basis of inverse time multiplied absolute error (ITAE). The results obtained show the advancement of FPA-IDD over other designs for hydro dominating energy system. The performance of the control lacks in minimizing system overshoot, oscillations and settling time due to large responding time of hydro turbines. Hence, the collective operation of unified power flow control (UPFC) in series with tie-line and active power support from redox flow battery is installed in the hydro dominating energy system. The significant improvement in system results are obtained by installing the UPFC and RFB in system model. Further enhancement in the system results are achieved by recalculating the gains of IDD with the help of FPA with positive support from RFB and UPFC. The application results are obtained for standard load change and results show the effectiveness of the proposed technique for the hydro dominating energy system.

Keywords: AGC; Flower pollination algoritm; FPA-ID; FPA-PID; FPA-IDD; RFB; UPFC

1. Introduction

The power system is expanding day by day to meet the demands of the modern customers with intention to limit the carbon dioxide emission with focusing towards energy generation via renewable

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energy technologies to meet the current and future system demand. Hence, it is estimated that future power system may have the energy generations from all hydro power plants having hydro turbines. As the energy generation shifts towards hydro power the active power regulation will become a challenge for the electric utilities as the response time of hydro turbines are much larger than thermal turbines resulting in the deteriorate performance and loss of system stability in the wake of quick load change in the system. The balance between system energy generation and demand are met through automatic generation control (AGC) scheme which tries to maintain the balance among these quantities and at the same time maintain system frequency to standard and tie-power exchange among control areas to defined value [1-2]. To achieve the standards of AGC, the design technique based on conventional architecture was primarily taken by the researchers and did not work well due to the gain selections through trial and error methodology. However, recently the soft computing techniques such as fuzzy logic, artificial neural network, genetic algorithm (GA), particle swarm optimization (PSO), bacteria foraging optimization algorithm (BFOA), hybrid BFOA are explored by the several researchers on timely basis in the AGC studies to select the gains of the controller. Hence, it is always welcome step in the AGC studies to come up with some strong optimization techniques such as flower pollination algorithm (FPA) to evaluate the gains of conventional controllers as well as to explore the different structures in order to achieve the standards of AGC [3]. Further, most of AGC studies are related to thermal power plants and very less efforts are made to study hydro dominating models due to large turbine time constants resulting in loss of system stability. On the other side. The enhancement in power electronics technology has led to the efficacious installation of FACTS devices in the modern power system. The redox flow battery (RFB) has almost zero time constant and capability to quickly inject the power in case of sudden change in system load. However, considering the system cost it is not advisable to install RFB in every hydro dominating areas. Unified power flow controller (UPFC) is also a member of FACTS family which is much cheaper in cost and installed in series with the tie-line to enhance the performance of hydro dominating power system [4]. In the light of above discussion this paper is set:

- To propose different conventional designs such as ID, PID and IDD with gains evaluated through powerful evolutionary algorithm i.e. FPA.
- To evaluate the FPA-ID, FPA-PID & FPA-IDD for AGC of hydro-hydro power system for step load change and to compare the AGC results in terms of achieved ITAE.
- The achieved ITAE obtained via FPA-IDD are quite promising in comparison to other designs. Still, the AGC performance lacks in reaching acceptable limits. Hence, the UPFC in series with tie-line and RFB in area-2 of the model is installed for further enhancement and dynamic performance is enhanced.
- Finally the gains of IDD are revaluated through FPA with support from UPFC and RFB for standard load change and the enhancement in AGC performance is presented.

1.1. Study Model

In order to check the ability of the FPA-ID, FPA-PID and FPA-IDD, a two-area system having hydro power generation in area-1 and 2 is considered for the present study. The dynamics of RFB in area-2 and UPFC is incorporated in series with tie-line in transfer function form and incorporated in the system model. The model is given in Figure 1. The detailed mathematical modeling of UPFC and RFB is not included due to space limitation.

1.2. Flower Pollination Optimized AGC Designs

In the present study, the objective function (OF) is designed on the basis of area control error (ACE) which is the combination of frequency and tie-power deviation in linear form.

The inverse time multiplied absolute error (ITAE) is used as OF for the present study as it has the capability to reduce the settling time with reduction in peak overshoot which is difficult to obtain by means of other error criterions such as integral of squared error (ISE), integral of absolute error (IAE), etc. The OF (J_n) for the nth control areas is expressed as follows:

$$J_n = \int_0^{Tsim} (ACE).\, t.\, dt \tag{1}$$

The problem of optimization is to find the minimum value of ITAE subject to the following constraints:

$$K_{Pn}^{\min} \le K_{pn} \le K_{pn}^{\max}$$
$$K_{in}^{\min} \le K_{in} \le K_{in}^{\max}$$
$$K_{dn}^{\min} \le K_{dn} \le K_{dn}^{\max}$$

The K_{pn}, K_{in} *and* K_{dn} signify the proportional, integral and derivative gains. The maximum and minimum limits of these parameters is chosen between -2.0 to 2.0. The FPA algorithm is chosen to evaluate these parameters. The execution methodology of FPA is given in Figure 2 which is used to evaluate the parameters of ID, PID & IDD for AGC of hydro-hydro power generation [3]. The FPA was run continually 50 times and the optimal solution among the 50 trials are chosen as the parameters of the various AGC designs.

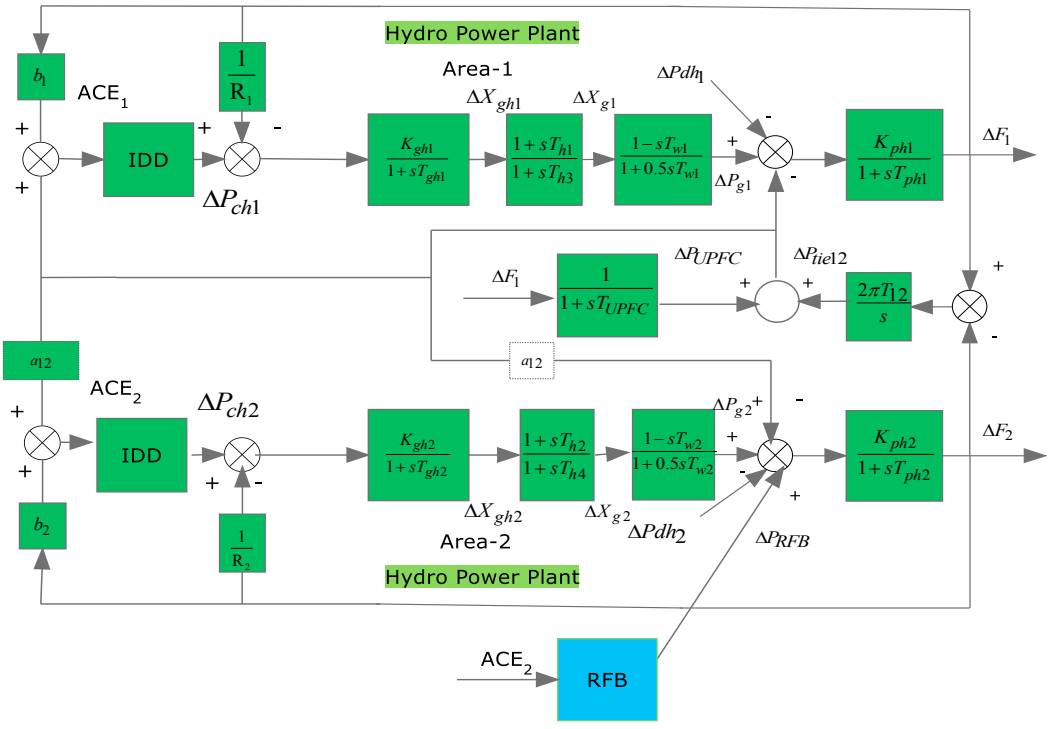

Fig. 1. System Model

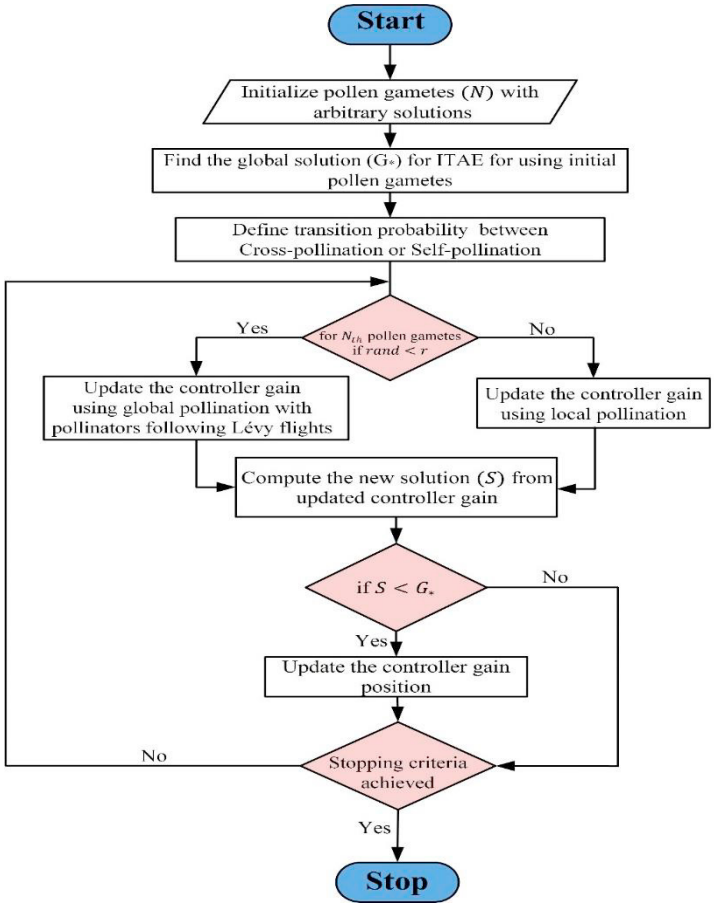

Fig. 2. Execution methodology of FPA

1.3. Analysis of Results

Due to modern trends towards renewable technology based energy generation and to limit the various harmful emissions in the environment from thermal based power plants an attempt is made to study the dynamics of hydro-hydro power generation model, i.e. AGC of hydro energy system as well as to propose the different AGC designs for this power system. Very limited AGC work on this model is present in the literature as responding time of hydro turbines are much larger resulting in sustained oscillations, higher overshoot and difficult to achieve steady state conditions for standard load change i.e. 1% change in power generation and load balance model. However, it is expected to have more and more power generation from hydro power in future and hence it is critical to investigate the performance of such types of models as well as to propose suitable control strategy. The various conventional designs such as ID, PID, IDD proposed in today's world are preferred choice of researchers and engineers due to its simplicity. Further, in present work the various conventional designs are combined with powerful evolutionary algorithms in order to be simple and promising for AGC. At first, the ID, PID and IDD AGC designs are evaluated for 1% load change in area-1 and FPA is used to find the optimal gains of AGC designs. The gains of FPA-ID, FPA-PID and FPA-IDD as well as value of ITAE are given in Table 1 for

various AGC designs. The reduction in ITAE (6.111587685) value obtained with IDD optimized FPA as compared to FPA-ID (6.275642512), FPA-PID (7.459889004) clearly shows the control and efficacy of the AGC design. The AGC responses of ΔF_1, ΔF_2 (frequency deviations of control areas-1 & 2) and ΔP_{tie12} (tie power deviation) is given in Figure 3. The results shows the advancement of FPA-IDD in terms of settling time with oscillations reduction in comparison to AGC response obtained via FPA-ID and FPA-PID. Still, the improvements in AGC responses are required. Hence, the dynamics of UPFC in series with tie-line and RFB at area-2 is added to the system model and the significant improvement in FPA-IDD performance is achieved. However, there is an increase in the value of ITAE. The obtained gains of IDD via FPA and ITAE value are shown in Table 2. The results of FPA-IDD are compared with FPA-IDD with UPFC+RFB. The appreciable overshoot reduction with improved settling time and no oscillations in AGC response is achieved via means of FPA-IDD with UPFC+RFB combination. This is due to fact that these energy storage technologies have lesser time constant which results in significant enhancement of AGC performance.

The reduction in ITAE with improved system results are improved to great extent when IDD gains are recalculated via FPA in presence of UPFC+RFB. These recalculated gains of IDD as well as reduced ITAE value is given in Table 2 which shows the efficacy of AGC design. Further, the improved system performance can be clearly seen from the AGC responses as given in Figure 3.

Table 1. The gains of several AGC designs obtained via FPA

Controller	K_p	K_i	K_{d1}	K_{d2}	ITAE
ID	0	0.16503	-0.30014	0	6.275642512
PID	0.041029	0.21432	-0.21262	0	7.459889004
IDD	0	0.15649	1.1699	-1.4129	6.111587685

Table 2. The comparative analysis of earlier calculated and recalculated gains of IDD via FPA in presence of UPFC+RFB

Controller	K_p	K_i	K_{d1}	K_{d2}	ITAE
IDD	0	0.15649	1.1699	-1.4129	6.749695558
IDD+UPFC+RFB(retune)	0	2	-0. 79909	1.6394	2.349770563

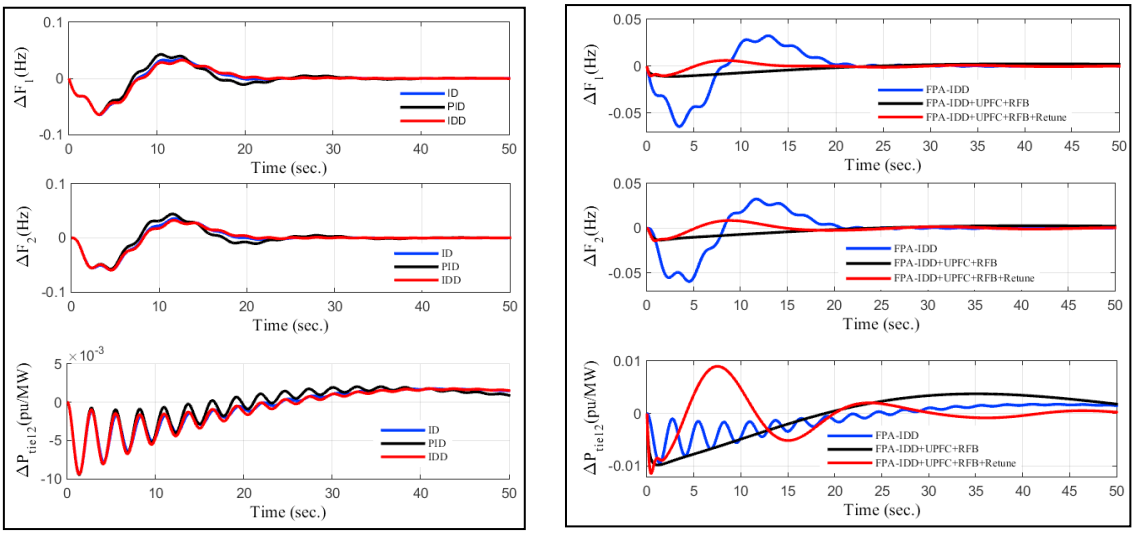

Fig. 3. The system responses obtained via several AGC optimized via FPA

2. Conclusions

This work designs FPA optimized IDD control to achieve the standards of AGC for hydro dominating power system for step power demand and compares its performance with other designs by achieving the acceptable value of ITAE. The further AGC enhancement is obtained by considering the dynamics of UPFC in series with tie-line with fast power injection capability of RFB. The overshoot reduction in system responses with faster settling time and zero steady state condition is guaranteed with the proposed AGC. Finally the gains of IDD are recalculated via FPA for step power demand considering joint support from UPFC and RFB and the noticeable enhancement in AGC is observed for hydro dominated power system. At last it can be said that proposed AGC is simple yet effective and provides acceptable performance.

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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.