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LOAD FREQUENCY CONTROL OF HVDC LINK INTERCONNECTED POWER SYSTEM USING GENETIC ALGORITHM

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Abstract

Advances in power electronics have improved grid support functions such as tie-line power control and frequency control, making renewable generation and High Voltage DC (HVDC) links more common in power system applications. Load Frequency Control (LFC) systems handle the complex interactions between the distributed generator and the control area with the HVDC link. In this work, LFC of a two-zone system including parallel AC/DC transmission links has been analysed. The parameters of this system are optimised using advanced genetic algorithm resulting in improved performance of system in terms of reduction in peak overshoots and settling time of frequency measurement, tie line power flow and area control error signals in an interconnected power system. The advantage of having parallel HVDC links is also demonstrated when performance is compared to system interconnected with only AC tie line.

1 Introduction

It is well known that the number of long-distance high capacity power exchanges between managed areas has increased significantly. The latest advances in integration of super grid and renewable energy interconnection in modern power systems have raised concerns about HVDC transmission, which is a new challenge for future power systems. This is due to the deregulation of the energy industry and the introduction of devices based on power electronics in the power grid [1]. The advantages of the HVDC system are to interconnect asynchronous networks and to transmit higher power over longer distances. These benefits have maintained interest for HVDC technology in industry and academia.

High voltage DC systems can also increase the reliability of large-scale interconnected system [2,3]. Communication, coordination, frequency control, and tie-line power control of the interconnected multi-zone system pose additional challenges in order to extend the application of HVDC control to interconnect system with wide area [4]. The interconnect power system has a plurality of control zones. Any mismatch between the demand and the generated power can cause a deviation of the link power flow or system frequency from their predetermined values. In order to eliminate deviations from each area, LFC is used to control the set points of the different generating units in these areas. Thus, the function of the LFC is to adjust the power generation from the various sources in each region so that the tie-line power and power system frequency are maintained within specified limits [5].

This paper is based on the use of previous concepts and traditional models, taking into account the new DC/AC combined scenario, and applications of DC interconnection to renewable energy system dissemination [8]. Power transmission and control has been improved by using the LFC scheme with existing transmission lines in parallel configuration, to function them as a DC-AC parallel link that interconnects two-control area of power system [6,7]. In the literature, to interconnect the LFC of a two-zone power system, DC/AC parallel links are used. LFC is implemented with various control schemes to improve the dynamic response. These systems are suitable for responding to the essential changes in the state of modern power systems. It is noteworthy that the LFC function can be used not only, for modern HVDC transmission and long-term dynamic control of Flexible AC Transmission System (FACTS) but also equipment for emergency control of frequency stability analysis [10,11].

As mentioned, grids are in high demand for related issues such as increasing long-distance transmission, high-capacity transmission, integrating large-scale renewable energy with multi-area interconnect systems reliably, and have greater adaptability and control over the power flow of transmission systems. Tapping remote energy far from the consumer centre is driving force behind development of new HVDC transmission

lines. Challenge usually involves the integration of solar energy, or integration of large offshore wind farms far from the coast. In these circumstances, DC transmission frames are actually considered to be advantageous and cheaper than AC [12]. In addition, power market consolidation is another driving force behind this new transmission line concept, which implies long-distance power transactions.

The fundamental challenge of power systems under separation is to develop communications and controllers to the appropriate level of operation and control of the various systems. Communication systems that is used to control the power systems operations leads to unwanted delays. Time delay system uses the LFC scheme for a given communication channel characteristic. Maximum delay is calculated to gain the knowledge about the stability analysis and control design [13]. Recently, time delays in load frequency controller design were considered in remote case studies. At the same time, there is not much to consider in case of complex DC/AC interconnection and LFC loop communication retransmissions [13,14]. A major application of HVDC transmission lines is that these lines can be operated in parallel with existing AC transmission lines and are designed to improve controllability. Therefore, they can be regarded as DC/AC parallel links connecting any two control areas. DC/AC parallel links are used in the literature to interconnect LFCs of two-zone power systems using various control methods to achieve a satisfactory dynamic response. However, none of them consider the complete DC link model for LFC applications. This feature is integrated into the DC link.

A Supplementary Power Modulation Controller (SPMC) is used to control power flow through the DC Link [11]. This controller is displayed during LFC operation. In this controller we are taking three signal frequency in area i, area j, and ac tie line power and given to the HVDC transfer function which is given in Fig 1. It is necessary to propose more detailed HVDC station dynamic model for LFC research as the application and importance of HVDC link is increasing [14-18].

2 Two-Area AC/DC Interconnected System

The Load frequency control issues are discussed in detail in the literature on power system control [1-4]. For implementing LFC in a multi-area system, the concept of Area Control Error (ACE) was introduced. In the dual regional power system model, the ACE for the ith region is given by below equation.

$$\text{ACE}_i = \beta_i \Delta f_i + \Delta P_{ij}. \tag{1}$$

Where f is the systems frequency ΔP_{ij} is the total tie-line power flow between two deferent areas $(\Delta P_{ij} = -\Delta P_{ij})$. β_i is the frequency bias, it is usually referred to the tie-line bias control. The state space representation of ith area can be given as follows:

$$\Delta w_i = \frac{K_{pi}}{1 + sT_{pi}} + [\Delta P_{mi} - \Delta P_{Li} - \Delta P_{tieAC}], \tag{2}$$

$$\Delta P_{mi} = \sum_{k=1}^{n} \Delta P_{m,ik}, \tag{3}$$

where local load deviation for $i = 1, 2$ is represented by ΔP_{Li} and $\Delta P_{m,ik}$ $(i = 1, 2)$ is output of generation company (GENCO) k in area i. Power system gain and time constant is K_{pi} and T_{pi} respectively. Power system gain can be given by:

$$K_{pi} = \frac{1}{D_{sys-i}}, \; T_{pi} = \frac{M_{sys-i}}{D_{sys-i}}, \tag{4}$$

where D_{sys-i} and M_{sys-i} are damping and inertia constants respectively. The other variables defined as follows:

$$\Delta P_{m,ik} = \frac{1}{1 + sT_{tg,ik}} \left[\frac{1}{2\pi R_k} - K_{li}\Delta P_{r\,efi} \right]. \tag{5}$$

Where T_{tg} the total time constants of governor and turbine in each generator and which is equal to $(T_{tik} + T_{gik})$ [5] and R_k is droop characteristics for each GENCO. The reference power of generation in ith area will be

$$\Delta P_{r\,efi} = \frac{ACE_i}{s} = \frac{1}{s} \left[\frac{\beta_i}{2\pi} \Delta w_i + \Delta P_{tieAC} \right], \tag{6}$$

$$\Delta P_{tieAC} = \frac{T_{ij}}{s}\left[\Delta w_i - \Delta w_j\right], \tag{7}$$

where T_{ij} is synchronization power coefficient of AC tie line connecting area i to j

$$\mathrm{X_{DC}} = \mathrm{K_{fi}}\Delta w_i + K_{AC}\Delta P_{tieAC} + K_{fj}\Delta w_j, \tag{8}$$

where $\mathrm{X_{DC}}$ is the dc link control signal, $\mathrm{K_{fi}}$, K_{AC} and K_{fj} are control gain so DC tie line power written as:
$$\Delta P_{DC} = G_p X_{DC}, \tag{9}$$

here G_p is HVDC link transfer function which is equal to

$$\mathrm{G_p} = \frac{1}{1 + \mathrm{sT_{DC}}}. \tag{10}$$

The actual DC power flowing through the system gives the time constant of the HVDC unit. Due to the frequency offset of each interconnection area and the AC link power deviation (for any parallel AC line with an HVDC transmission link) the total cable power in AC/DC system will be:

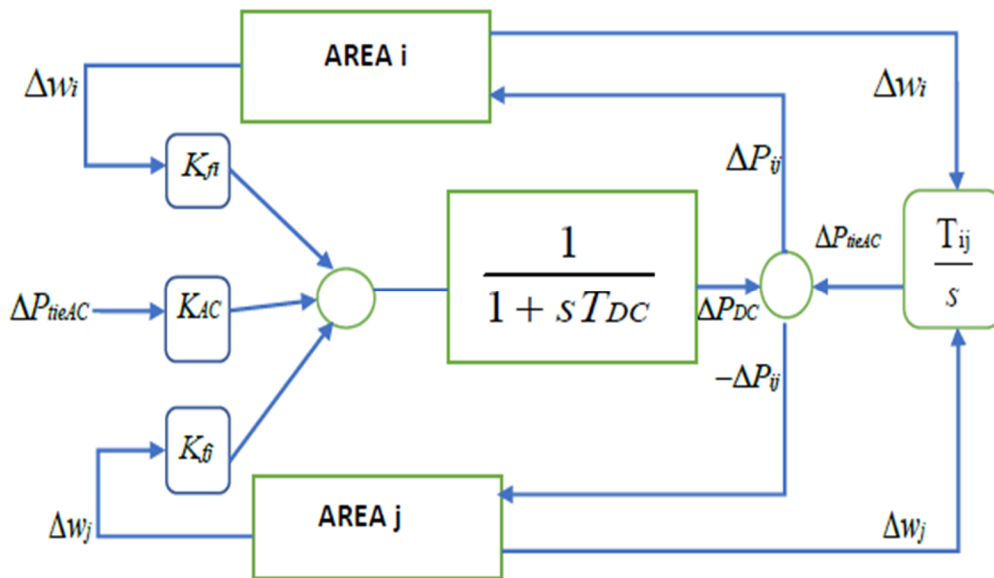$$\Delta P_{ij} = \Delta P_{DC} \ + \ \Delta P_{tieAC}. \tag{11}$$

Figure 1: Model of SPMC for HVDC link interconnected system

3 Optimization of LFC Parameters

In the model of a two-area parallel DC/AC interconnected system shown in Fig. 2 there are three controllers which need to coordinate to give a desirable result that is stabilization of grid frequency and normalcy in tie line power flows. There is a requirement to tune the integral controller gains if respective areas K_{Ii} and K_{Ij}. Further the three gains in SPMC viz. K_{f1}, K_{f2} and K_{AC} also need to set at value to give optimal response. In this work we have utilized the Genetic Algorithm to optimize these five parameters.

Genetic Algorithm (GA) is a metaheuristic developed by Holland in 1960s. It is inspired by the method of selection in nature. The decision variables to be found are binary coded in the form of strings of 0s and 1s. The candidate solution is having a set of properties which can be altered. The starting point of evolution is a population having randomly generated individuals. GA is an iterative process, where the set of candidate solutions in each iteration called a generation. In one iteration, the fitness of individuals in the population is evaluated which usually amounts to the value of the objective function in the optimization problem being solved. The fit individuals are randomly selected from the current generation, and each individual's properties are modified (recombined and possibly randomly mutated) to form a new generation. The next iteration uses

these new generation of candidate solutions. Usually, the algorithm terminates when either a maximum number of generations has been produced or no further improvement is achieved in the fitness function.

In this work, the integral of the squares of errors (ISE) for the three controllers in the system is taken as the fitness function.

$$\text{ISE} = \int_0^{t_{\min}} [\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tieline}^2]$$

The steps of genetic algorithm used for finding optimal control parameters in this problem are underlined below.

Step 1: Initialisation.
The algorithm begins by creating a random initial population. In this work, the initial population contains 20 individuals.

Step 2: Creating Next Generation.
At each step, the algorithm uses the individuals in the current generation to create the next population. To create the new population, the algorithm performs the following steps.
- Scores each member of the current population by computing its fitness value as given above. These values are called the raw fitness scores.
- Scales the raw fitness scores to convert them into a more usable range of values. These scaled values are called expectation values.
- Selects members, called parents, based on their expectation.
- Some of the individuals in the current population that have lower fitness are chosen as elite. These elite individuals are passed to the next population.
- Produces children from the parents. Children are produced either by making random changes to a single parent—mutation—or by combining the vector entries of a pair of parents—crossover.
- Replaces the current population with the children to form the next generation. This type of replay is performed randomly in different places. As a result, new chromosome groups are generated in which the selection process can be resumed again.

Step 3: Stopping Criterion.
The algorithm stops when one of the stopping criteria is met. The genetic algorithm uses the following conditions to determine when to stop:
- Generations: The algorithm stops when the number of generations reaches the value of Generations.
- Time limit: The algorithm stops after running for an amount of time in seconds equal to Time limit.
- Fitness limit: The algorithm stops when the value of the fitness function for the best point in the current population is less than or equal to Fitness limit.
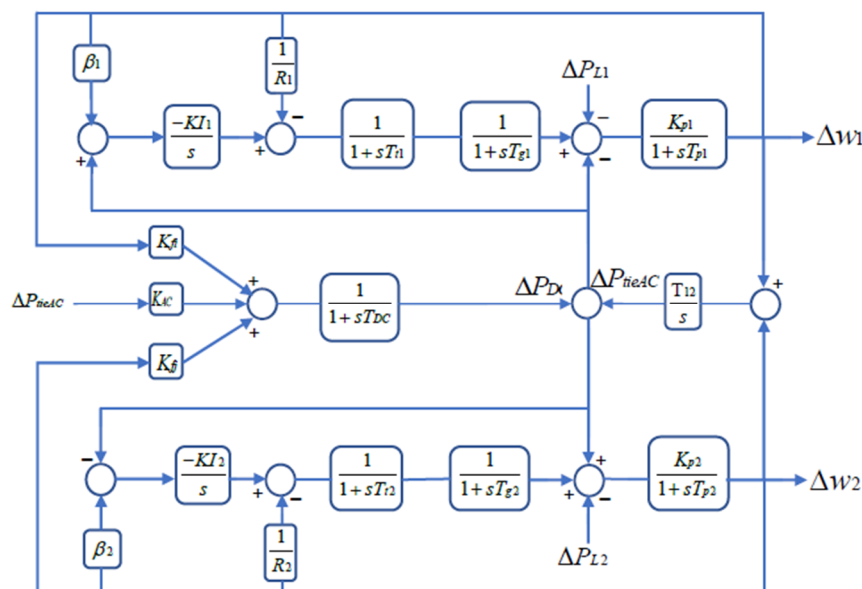

Figure 2: Two-area control model for HVDC link interconnected system with SPMC

4   Simulation Results

The layout of two area power system considered in this study is shown in Fig. 3. Data sheet of this HVDC link interconnected systems given in Table 1 and 2.
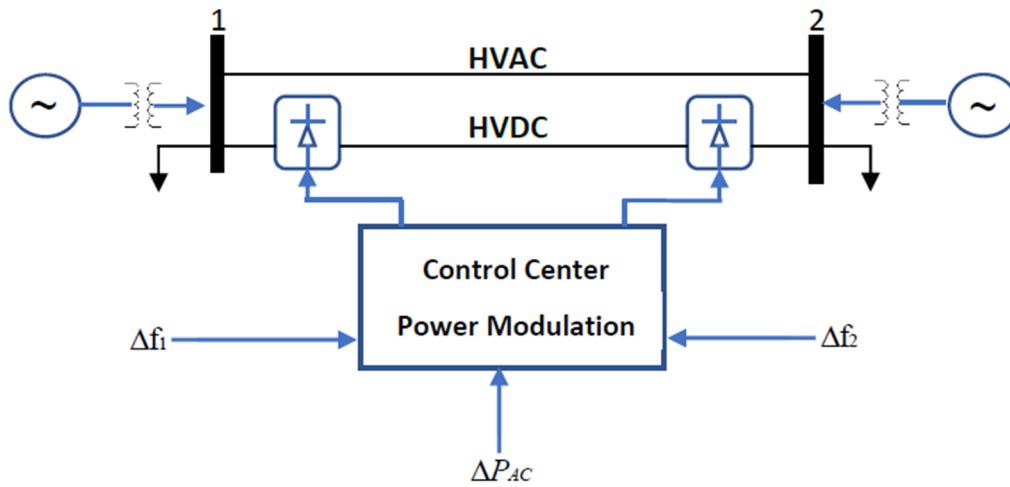

Figure 3: The layout of two area power system with HVDC link

Table 1: Parameters of GENCOs

Parameters	Area 1	Area 2
T_g (s)	0.06	0.06
T_t (s)	0.32	0.30
R (Hz/p·u)	2.4	2.5

Table 2: Control area parameters

Parameters	Area 1	Area 2
T_p (s)	20	25
K_p (Hz/p·u)	102	102
β (p·u/Hz)	.425	.39
T_{12} (p·u/Hz)	.245	___

This paper considers three cases for simulation studies to examine the performance of AC system, AC/DC system with standard controller gains [11] and AC/DC system in which parameters are optimized by genetic algorithm:

- Case-I; It is the case when we connect only AC tie line in the system.

- Case-II; It is the case when we use AC/DC system and we are taking standard controller parameters [11].

- Case-III; It is the case when we use AC/DC system and in this control, parameters are optimized by genetic algorithm, which is given by Table 3.

Table 3: GA optimized control parameters

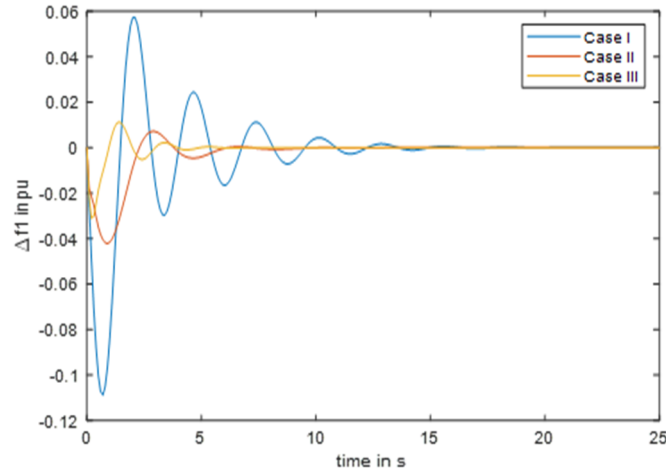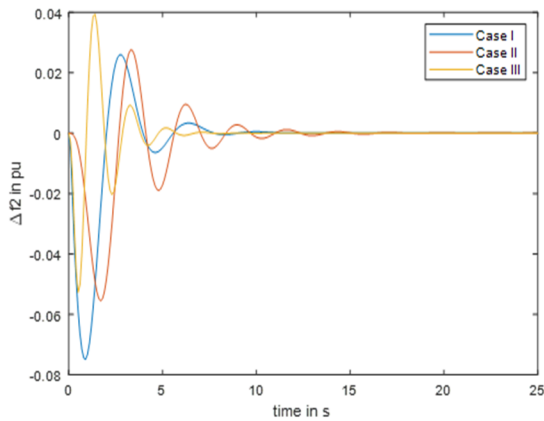| Parameter	Minimum Bound	Maximum bound	Optimum Value
K_{f1}	-5	5	1.712
K_{f2}	-5	5	-0.711
K_{AC}	-20	20	10.48
K_{I1}	-10	10	-5.379
K_{I2}	-10	10	-0.126

Figure 4: Frequency Deviation in Area 1

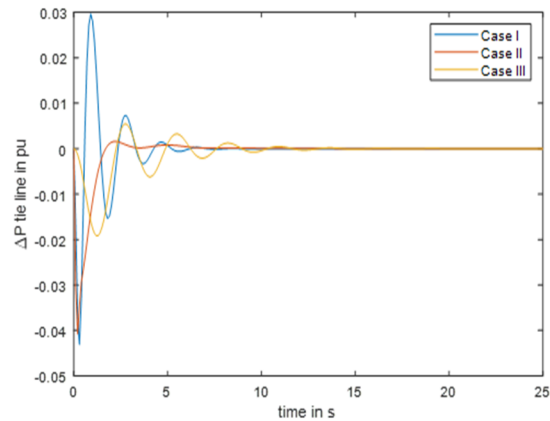Figure 5: Frequency Deviation in Area 2
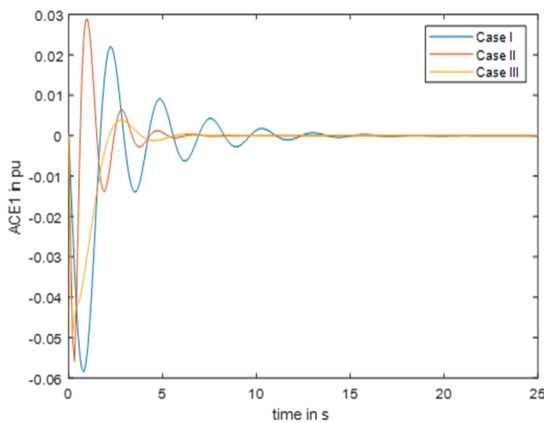

Figure 6: Tie Line Power Deviation

Figure 7: Area Control Error in Area 1

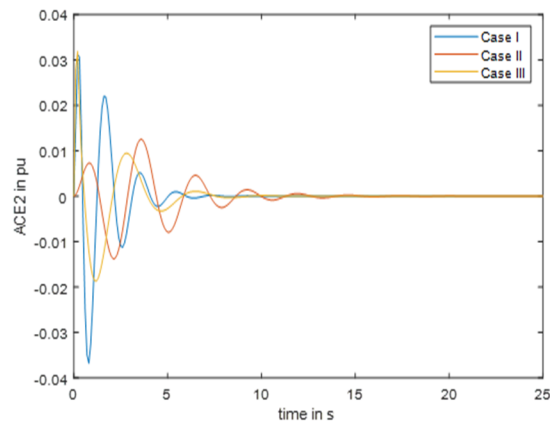Figure 8: Area Control Error in Area 2

Table 4: Overshoot (OS) [in p·u] and Settling Time (ST) [in s] of system response for different systems

	Δf_1		Δf_2		ΔP_{tie}		ACE_1		ACE_2		*ISE*
	OS	ST	OS	ST	OS	ST	OS	ST	OS	ST	
CASE I	-0.108	15	-0.074	11	-0.043	7	-0.586	14	-0.013	8	0.1634
CASE II	-0.042	7	-0.055	13	-0.041	14	-0.559	7.5	-0.018	12.5	0.0867
CASE III	-0.031	5	-0.052	6	-0.020	12	-0.05	7	-0.036	6.5	0.035

A comparison of response obtained from system in all three case has been depicted in Fig. 4 and 5 shown in deviation in frequency of area 1 and area 2 respectively for 5% deviation in load. Fig 6 shown the deviation in AC tie line power in control area 1 and area 2. From the Fig it is obtain that in Case II we get improved response as compared to Case I when HVDC interconnection is not utilize. This shown the utilities of parallel HVDC interconnection in LFC of 2 area system. In case III when control parameters of SPMC and LFC are optimized using genetic algorithm a further improvement in response is observed. These improvements are better utilized therefore data seen in table IV which show peak overshoot (in p·u), settling time (in s) for frequency error, tie line power error and area control error in both areas. The last column also shown the improvement in performance index ISE. The ISE reduce from 0.1634 in Case I to 0.0861 in Case II and further to 0.035 in Case III which shows considerable improvement in performance index.

5   Conclusion

This paper proposes an improved control strategy for multi-region interconnection linked through parallel AC/DC Link. The LFC of interconnected power system considering detailed dynamic models of HVDC links is presented due to its importance in future modern power systems. These simulation results distinguish between AC only interconnected systems and AC/DC interconnect systems. Using HVDC interconnect system, frequency errors, Tie line power deviations and ACEs have shorter settling times and smaller overshoots than traditional systems. Further the LFC and SPMC parameter are optimized using GA resulting in significant improvement over performance reported in literature earlier.

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