COMBINED LFC AND AVR OF MULTI AREA MULTI SOURCE POWER SYSTEM WITH ARTIFICIAL BEE COLONY ALGORITHM BASED PIDD CONTROLLER

Abstract

This paper investigates the load frequency control (LFC) and automatic voltage regulation (AVR) of multi area multi source power system (MAMSPS) in a combined manner. Investigation is performed by laying the step load disturbance (SLD) of 10% in area-1. In order to regulate the MAMSPS dynamic behaviour, this paper proposes an artificial bee colony (ABC) algorithm tuned proportional-integral-double derivative (PIDD) controller whose performance dominance is validated with other controllers. Further, the MAMSPS is integrated with the territorial control strategy of superconducting magnetic energy storage (SMES) and unified power flow controller (UPFC). Simulation analysis revealed that, an improvement in MAMFPS dynamical behaviour is noticed with the integration of UPFC-SMES devices.

Keywords: LFC-AVR analysis, artificial bee colony algorithm, 10%SLD, PIDD controller, UPFC-SMES devices.

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I. INTRODUCTION

The major aspect in the stability of the electric interconnected power system (IPS) is the LFC which affects the frequency directly. The intensity of the deviations in IPS frequency depends on the power full indicator called real power imbalance (RPI). The difference in real power demand and generation is the RPI having direct analogy with the frequency. The frequency of the Indian grid is 50Hz and however, the power grid frequency can be operated safely within the range of 49.8Hz to 50.2Hz. Suppose, if the generation of real power is less than the available load demand then the frequency might drop below 50Hz and vice-versa. The continuous fluctuation of load on the IPS, made the system frequency to vary. In order to compensate the deviations in the IPS frequency, the power system operators have to change the generation to meet the load demand continuously. The continuous change in generation can't be performed manually and requires an automatic control action. The LFC is an automatic action which pays attention to the RPI to maintain the frequency not to go beyond the specified range [1].

Several control strategies are reported in the literature regarding to the LFC of electrical IPS. The development of secondary controller is the heart of the LFC and most of the researchers are focusing on it. However, the developed regulator's performances are tested by the researchers on numerous IPS models as given in [2] detail. In a wide range, authors adopted the IPS models of one/two/three area systems with traditional and non-conventional generation units. The combination of thermal, hydro and a few works are even considered the gas unit along with the aforementioned are rigorously selected for investigation. The non-linearity features of governor dead band (GDB) and generation rate constraints (GRC) are considered by the researchers for conducting research close to the real time environment. Though majority of the researchers are not considered the practical constraints, this work considered for investigation.

The controllers of fuzzy logic control (FLC) are widely enacted by the research scholars to the IPS as secondary controllers to various power generation sources. The FLC are one of the efficient control strategies [3] that the community of the research scholars are available with and its performance is more sensitive with the scaling parameters. Moreover, the rule based system, membership function selections, and the selection methods involved in Fuzzification and Defuzzification might degrade its performance. Further, the operation of the FLC requires the skilled technicians and its implementation is not simple with the real time environment. The FLC aided traditional and fractional order (FO) controllers based on algorithms of colonial search algorithm, sine-cosine optimization [4], squirrel search algorithm, imperialist competitive algorithm, Coyote optimizer, Harris Hawks optimization [5], golden eagle algorithm, backtracking search algorithm [6], donkey and smuggler optimization, bibliography algorithm, quasi-oppositional grey wolf algorithm, chaotic whale optimizer, big-bang big-crunch algorithm, lightning search algorithm, stochastic fractal search algorithm [7], JAYA optimization, symbiotic organisms search algorithm [8], gravitational search algorithm, marine predators algorithm, slap swarm optimization, COOT algorithm, water cycle algorithm, etc. are reported in the early studies.

The degree-of-freedom (DOF) controllers like 2DOFPID/3DOFPID, tilt-integral-derivative from the FO family, and the FO based conventional PI/PID are also extensively available in recent studies. However, the proper working of the above said controllers strongly relies on the optimization techniques. Algorithm's like JAYA algorithm, marine predators algorithm, seagull optimization, krill herd algorithm, fish schooling algorithm, differential search algorithm, path finder algorithm, multiverse optimizer, moth flame algorithm [9] Egyptian vulture optimization, wild horse algorithm, culinary chef algorithm, sooty tern algorithm, bacteria foraging algorithm, volley ball premier approach [10], sine-cosine algorithm, levy flight technique, water cycle algorithm, and doctor patient optimization etc. are available. The involvement of too many control loops in the DOF type controllers and the additional parametric knobs in the FO controllers laid the computation burden on the soft computing methods. This might lead to the degradation of the controller performance and there by the IPS stability.

Considering the above aspects, this work is going out with the classical controllers like PI/PID [11]. The test system deliberated in this work is considered with the non-linearity features and the performance of traditional controllers for these kinds of test systems might be ineffective. Thus, a modified traditional controller that is the PIDD is selected whose structure and functioning is same alike of the conventional PID. The DD parameter in the PIDD can handle the non-linear behaviour of the considered model effectively. ABC algorithm is selected for the PIDD tuning in this work owing to the advantages of derivative free operation, simple, ability to give global solutions, less parameters, adaptability and parallelisation.

The Contributions of this Paper are:

- LFC-AVR analysis of MAMSPS is carried in combined manner.
- The PIDD based on ABC algorithm is suggested for simultaneous voltage and frequency stabilisation.
- Efficacy of PIDD is showcased over the other controllers.
- The UPFC-SMES as territory controller is implemented and improvement in MAMSPS performance is noticed.

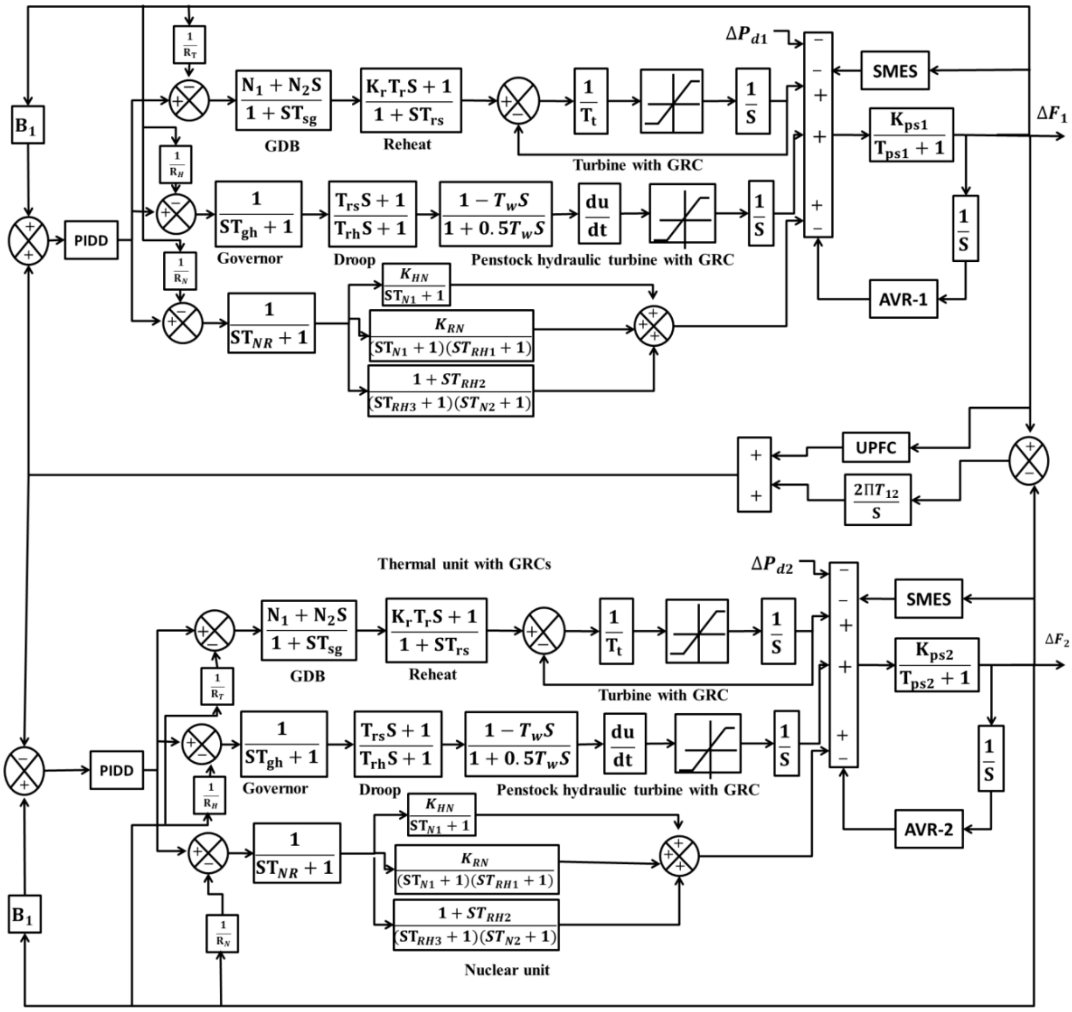


Figure 1: Model of MAMSPS with UPFC-SMES and AVR Coupling.

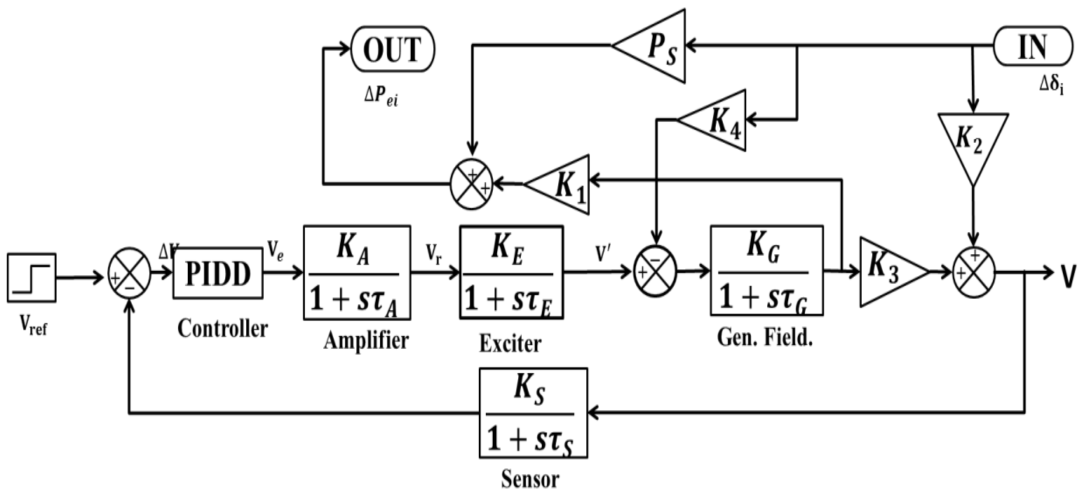


Figure 2: AVR with Coupling Coefficients.

II. POWER SYSTEM UNDER STUDY

The investigative MAMSPS for LFC-AVR in combined has two control areas as shown in Fig.1, and each area is having the generation sources of nuclear, hydro and thermal. The area 1 and 2 area having the generation capacity of 1:1 and area-1 is targeted with 10%SLD for the assessment of MAMSPS dynamical analysis. To carry out the research analysis near to real time environment, the thermal and hydro units are deliberated with GRC and GDB. The GRC and GDB indicate the non-linearity features to the generation units of thermal and hydro to attain the practical features. Moreover, the LFC is coupled with the AVR system as shown in Fig.2. The AVR have the K_1, K_2, K_3 and K_4 as coupling coefficients and these coefficients facilitates the coupling with LFC loop. Literature survey disclosed that, majority of the reported work neglected the AVR consideration. But in realistic practice, the generation units are usually coupled with the voltage regulators and in this work it has been considered.

1. **Controller and Objective Function:** The modified PID regulators are gaining momentum in the domain of IPS stability. As the traditional controllers resulting in to the inferior performance for the non-linearized systems, thus this work is carried out with some modifications to the conventional PID for the considered non-linear MAMFPS. By adding the DD parameter to the traditional PID, it might gains the ability to deal the behaviour of non-linearized systems effectively. In total the PIDD have three parameters such as K_P, K_I and K_{DD} named as proportional, integral and double derivative gains. The best suitable values of the above gains for the MAMSPS have to be found with ABC algorithm in this work subjected to integral time square error (ITSE). The ITSE is given in Equation (1), framed with the deviations in frequency at area-1 (Δf_1) and area-2 (Δf_2) and tie-line power (ΔP_{tie12}).

$$J_{ITSE} = \int_0^{T_{Sim}} \left(\Delta f_1^2 + \Delta P_{tie12}^2 + \Delta f_2^2\right) T\, dt \quad (1)$$

2. **Artificial Bee Colony Algorithm:** ABC algorithm was proposed by (Karaboga in 2005) [12] which come under the strategy of swarm intelligence based meta-heuristic optimizations. It mimics the behavior of honey bees foraging on finding the nectar (food source) and sharing food sources information to the bees in nest. In order to solve the constrained optimization problems, a constraint handling mechanism is incorporated in the algorithm. A minimal model of intelligent swarm selection in bee colony has been adopted in ABC algorithm. The selection of bees in bee colony consists of three kinds; they are employed bees, onlooker bees and scout bees. In bee colony, half of the bees are the employed bees and the remaining half is the onlooker bees. The responsibility of the employed bees is to explore the sources of nectar and to share the information regarding the quality of food source to the onlooker bees. Depending on the information given by the employed bees, the onlooker bees decides to exploit the food source. While, the scout bees exploit the food sources randomly in the environment depending on internal or external possible clues.

   In this ABC algorithm, the artificial bee's moves in a multidimensional search space. The entire searching procedure of nectar in flowers by honey bees can be remarked as optimization process. The food source quality relies on many factors like food concentration, proximity to hive and easiness to extract. The profitability of food source in this algorithm is represented with a numerical value named as fitness. Few employed and onlooker bees select the food source based on their own experience or experience shared by their mates and adjusts their positions. Employed bees are always associated with a food source which is previously exploited by them. Information regarding profitability and food source location will be shared by the employed bees with the rest of the colony. Unemployed bees continuously strive for finding the food sources. These unemployed bees are divided into scout and on looking bees. The employed becomes unemployed bees up on depletion of the food source. Decision has to be taken by the bees themselves whether to become the scout bees or onlooker bees. The solution quality in ABC algorithm is represented as food source fitness, which can be calculated by using problem objective function.

In ABC algorithm, the number of employed bees or on looker bees is equal to the number of solutions in the swarm. Initially, the population in D-dimensional search space is initialized as follows for SN solutions:

$$X_i = \{x_{i1}, x_{i2} \ldots\ldots, x_{iD}\} \quad (2)$$

At current position, the new solution V_i generated by each employee bee X_i in the neighborhood is given by Equation (3).

$$V_{i,j} = x_{i,j} + \varphi_{i,j} * (x_{i,j} - x_{k,j}) \quad (3)$$

Upon receiving the information regarding the food source by the onlooker bees from the employee bees, the onlooker bees perform the selection food process based on quality and quantity. The selection is done in probabilistic fashion which closely resembles the roulette wheel selection process indicated as follows:

$$P_i = \frac{fit_j}{\sum_{j=1}^{SN} fit_j} \quad (4)$$

If the bee's position is not improved for predefined number of cycles, then food source is abandoned. Then the food source is replaced with X_i discovered by the scout bees as follows:

$$x_{i,j} = ll_j + rand(0,1) * (ul_j - ll_j) \quad (5)$$

Where,

SN =swarm size

$\varphi_{i,j}$ = random number between [1,-1]

fit_i = fitness of i^{th} solution

ll_j =lower limit of j^{th} dimension

ul_j =upper limit of j^{th} dimension

3. **Unified Power Flow Controller:** One of the effective flexible AC transmission devices that the electrical operators are available with is the UPFC devices. It offers the regulation over the voltage profile, power flow control, enhancement in transmission line capability, and flexibility. Overall, it is crucial in handling the system stability, enhancement in line available transfer capability and network reliability. The components of UPFC involve the shunt inverter, DC link and the series transformer. The damping control structure of UPFC is shown in Fig.3 and is connected with the tie-line in this work to obtain the performance improvement.

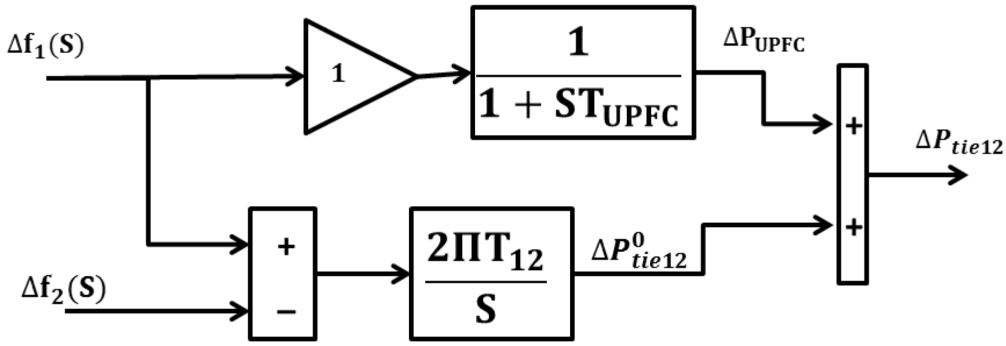


Figure 3: Structure of UPFC Device as Damping Controller

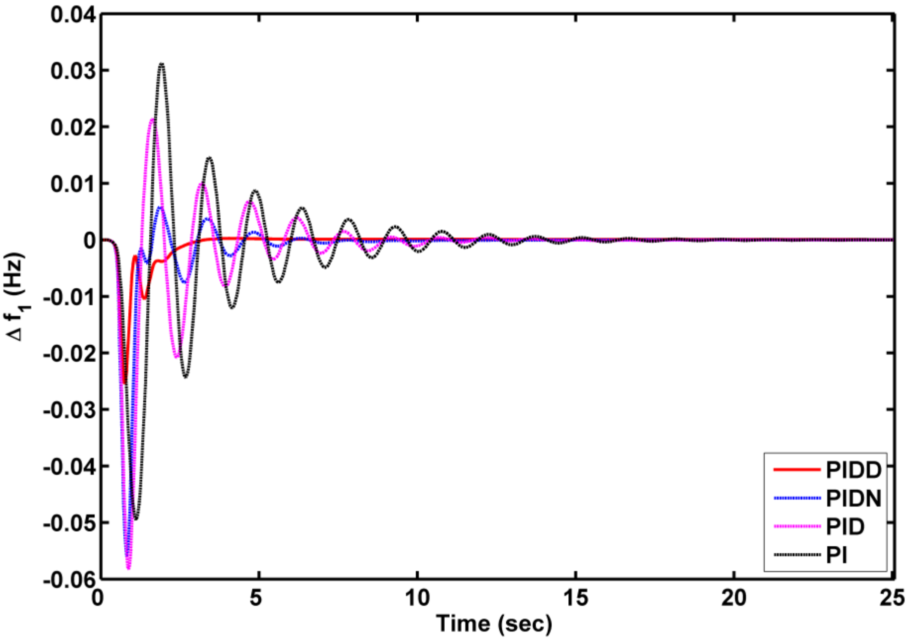
4. **Superconducting Magnetic Energy Storage:** The key components of the SMES involve the cryogenic system, power conversion unit, superconducting coil and the protection control system. The superconducting coil is placed in cryogenic system and the energy is stored in the coil as DC form. The power conversion unit plays a crucial role in the SMES while charging and discharging the DC coil. The protection control system monitors the charging and discharging process and offers protection against overheating and over currents. The modelling of SMES is given in Equation (6) and the gain and time parameters are considered as K_{SMES}=0.976, and T_{SMES}=0.997 as given in [13].

$$G_{SMES} = \frac{K_{SMES}}{1 + sT_{SMES}} \qquad (6)$$

5. **Simulation Results**

- **Case-1**: **Analysis of MAMSPS with Various Controllers**

The different controllers like PIDD, PIDN, PID, and PI are placed in the LFC-AVR loops of MAMSPS independently in both the control regions and to get the comparative assessment all the controllers are fine-tuned with ABC algorithm. The dynamic behaviour of MAMSPS for 10%SLD in area-1 under different controllers are shown in Fig.4 and further the responses are interpolated numerically in terms of settling time noted in Table 1. Noticing the Fig.4 responses it is clear that the responses deviations are effectively dampened by the PIDD controller over the other regulators. The dominance of PIDD can be noticed in every control area frequency and terminal voltage as well as the tie-line power. Moreover the PIDD outperforms the others in bringing the responses to steady state position as noted from Table 1. Further, the ITSE objective function is effectively handled by the PIDD as shown in Fig.5 and is enhanced by 43.018%, 67.869%, and 85.185% with PIDN, PID, and PI. The optimal parameters of PI, PID, PIDN and PIDD that are found using the ABC algorithm are noted in Table 2.



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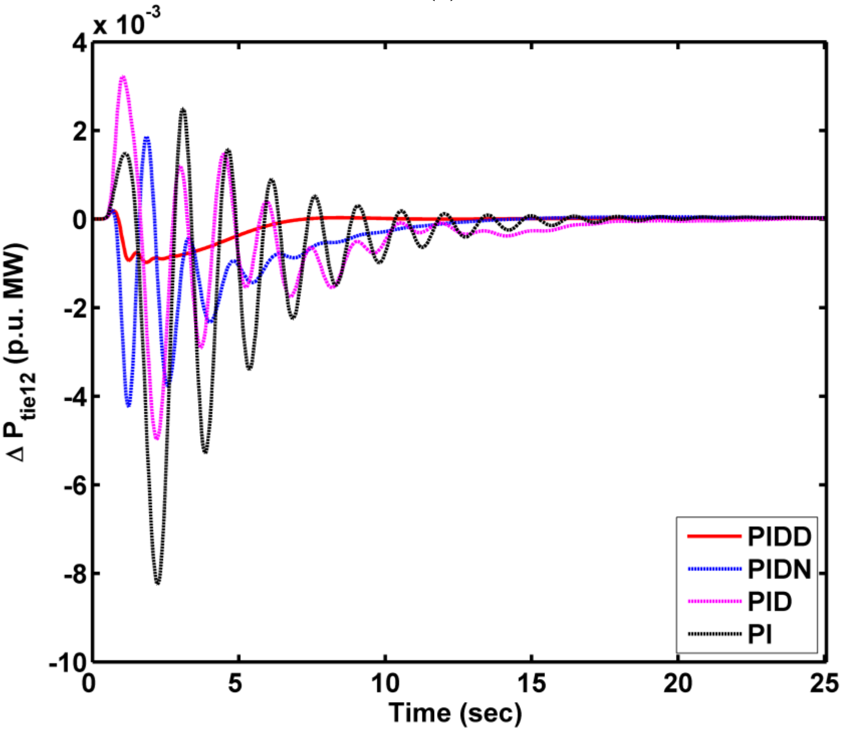

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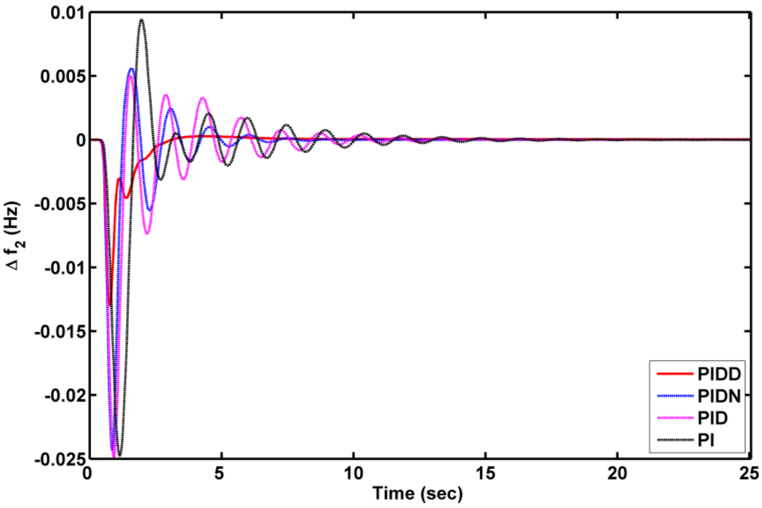

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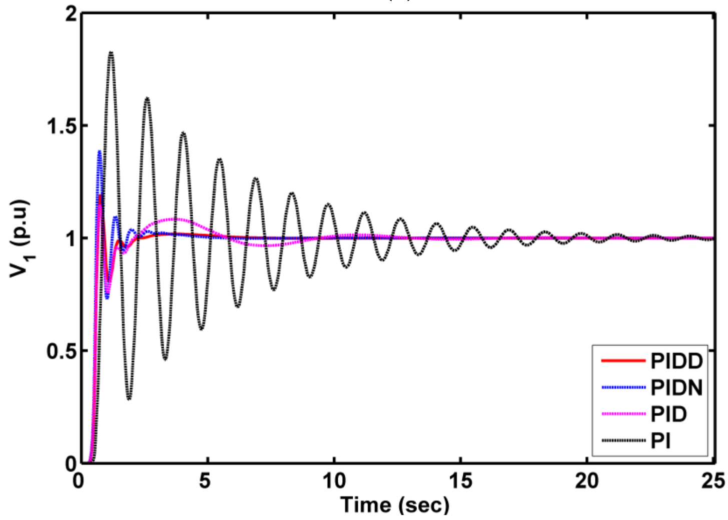

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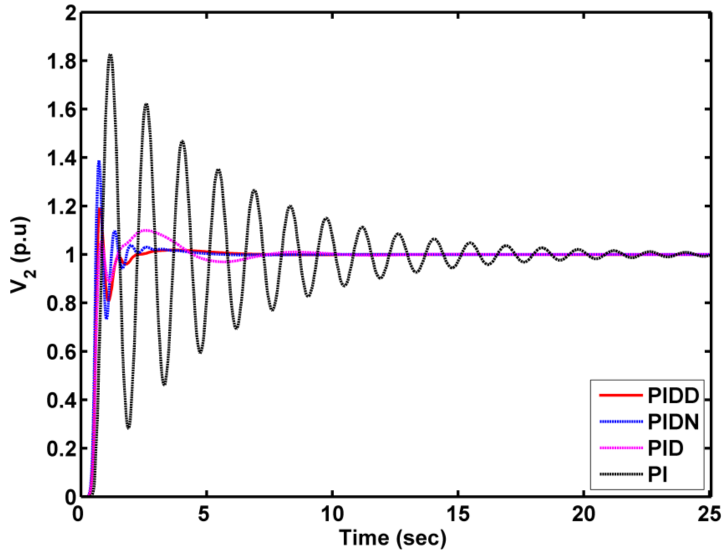

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Figure 4: Case-1 Responses.a.Δf_1 b.ΔP_{tie12} c.Δf_2 d.V_1 e.V_2.

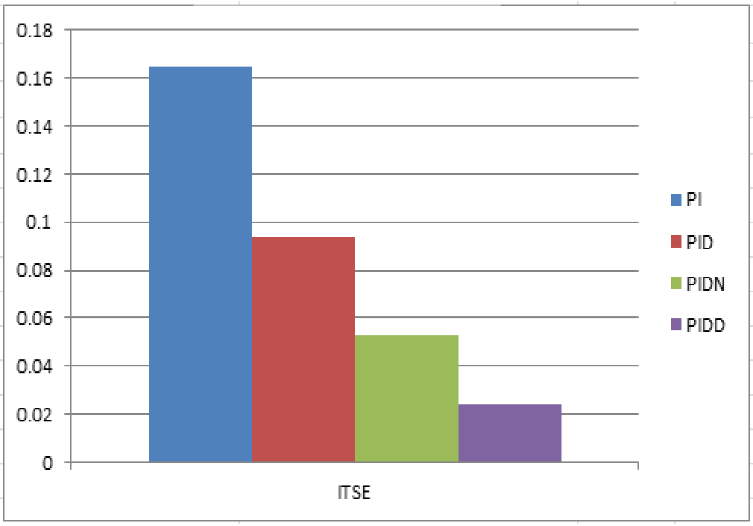


Figure 5: Bar Chart ITSE Index for Various Controllers.

Table 1: Responses Settling Time

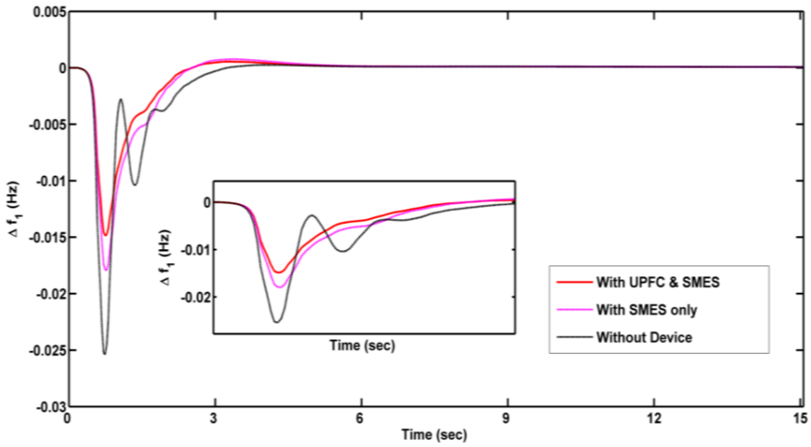
Settling time (Seconds)	**Case-1**				**Case-2**	
	PIDD	**PIDN**	**PID**	**PI**	**SMES**	**UPFC-SMES**
Δf_1	10.67	13.41	17.86	20.16	8.53	6.24
Δp_{tie12}	13.57	14.69	18.67	20.23	10.27	10.24
Δf_2	10.48	12.44	15.58	18.16	7.13	5.96
V_1	7.59	9.56	16.54	32.27	4.32	3.17
V_2	7.36	9.38	12.32	31.63	3.98	3.46
ITSE*10^{-3}	24.49	53.116	94.197	165.312	-	-

Table 2: Controller Optimal Gains

	Area-1				Area-2			
	PIDD	PIDN	PID	PI	PIDD	PIDN	PID	PI
K_P	1.376	2.485	3.168	2.638	0.854	2.374	2.153	1.749
K_I	0.834	1.083	2.116	0.016	0.715	1.163	1.164	0.128
K_D	-	0.318	0.094	-	-	0.226	0.163	-
K_{DD}	0.994	-	-	-	0.891	-	-	-
N	-	227.34	-	-	-	221.23	-	-

- **Case-2: Analysis of MAMSPS under PIDD controller with UPFC-SMES**

In this subsection, the MAMSPS performance is going to be further investigated by incorporating the UPFC-SMES devices at the territory level. Initially, the LFC-AVR of MAMSPS is integrated with SMES in both the control regions and the dynamic responses are noticed as shown in Fig.6. Observing the Fig. it is found that a considerable improvement in frequency, tie-line power and terminal voltage at both the control regions are noticed. The quick response nature of SMES balances the real power imbalance rapidly which supports the system behaviour not to violate further. Later, the SMES devices are still continuing at area-1 and are-2, the UPFC device is laid with the tie-line and the corresponding responses are shown in Fig.6. From Fig.6, it is concluded that with the coordination of UPFC-SMES the dynamic behaviour of MAMSPS is predominantly improved. The responses settling time is more minimized with the suggested UPFC-SMES strategy at the control level as shown in the Fig.7.



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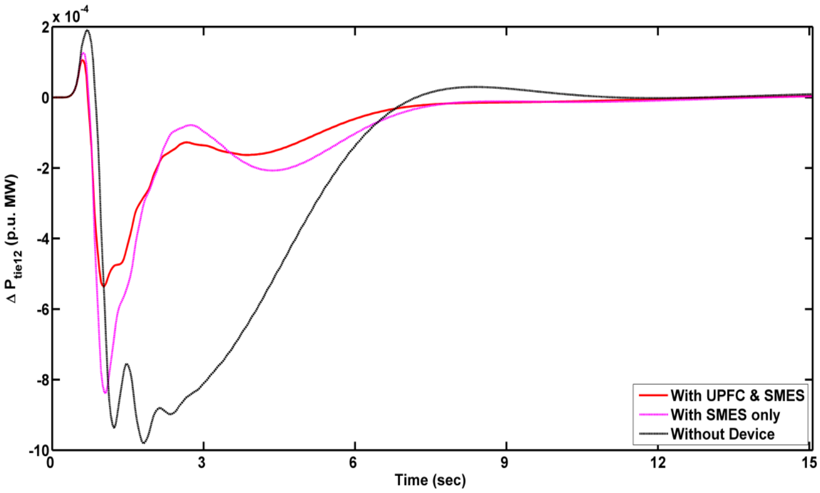

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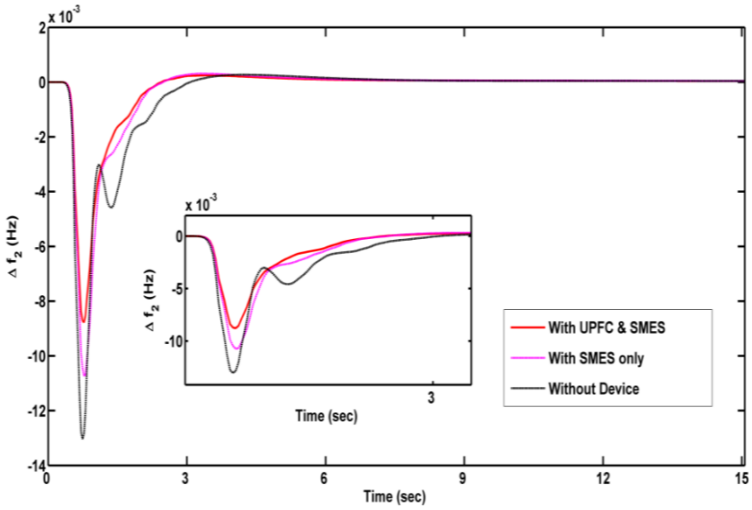

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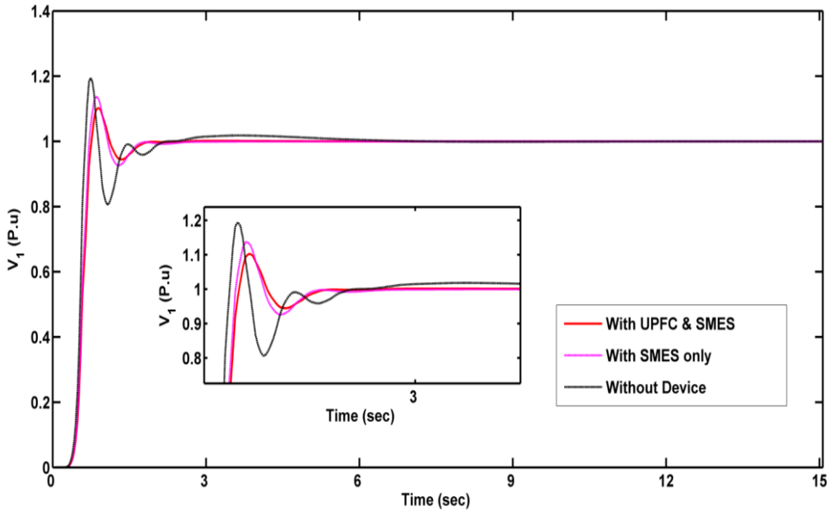

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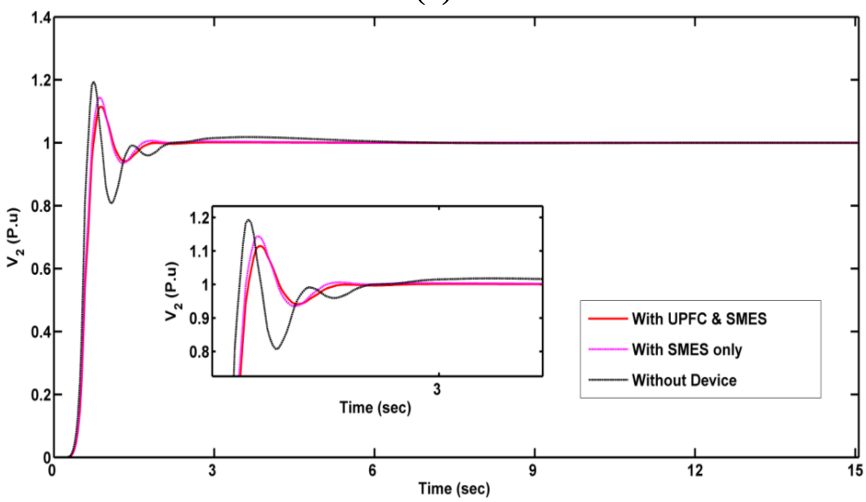

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Figure 6: Case-2 Responses.a.Δf_1 b.ΔP_{tie12} c.Δf_2 d.V_1 e.V_2.

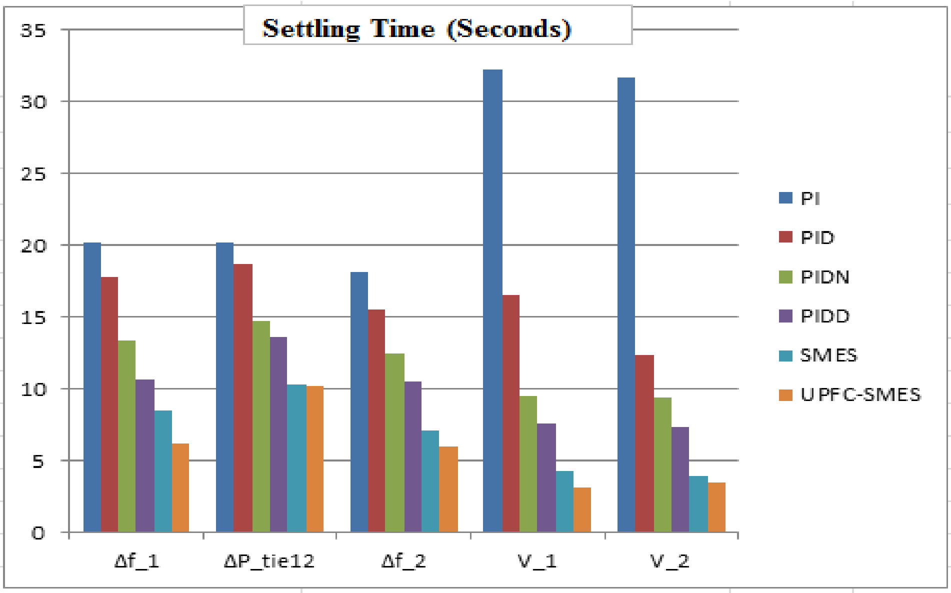

Figure 7: Bar Chart Represents the Responses Settling Time (in Seconds).

III. CONCLUSION

The combined LFC-AVR analysis is carried out in this work and for the investigation an MAMSPS model is deliberated. The MAMSPS is subjugated to 10%SLD for assessing the dynamical behaviour and the ABC algorithm based PIDD is suggested for LFC and AVR analysis. The efficacy of PIDD is demonstrated with the PIDN, PID and PI controllers optimized with the ABC algorithm. Simulation results clearly showcased the dominance of PIDD over the other controllers in terms of diminishing the deviations as well as in dealing with the time conceding to reach the steady condition. Moreover, the ITSE value is predominantly enhanced by the ITSE over the others. Further, the investigation is extended to the integration of UPFC-SMES as additional regulatory approach for attaining the improvement in MAMSPS dynamic performance. The UPFC-SMES integration with MAMSPS gave the considerable enhancement in system dynamic behaviour. Thus, this work strongly recommending to adopt the UPFC-SMES at the territorial level for obtaining the predominant enhancement in IPS dynamical behaviour during load perturbations.

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