ISSN: 1934--9955 www.ijise.net
Vol-20 Issue-01 Mar 2025

Digital Simulation of an Interline Power Flow Controller System Using Artificial Intelligence Techniques

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Abstract— The Interline Power Flow Controller (IPFC) is a controller that can govern the flow of power among a substation's several transmission lines. It uses voltage source converters to make up for series losses and is based on the FACTS system. To manage the active power flow in each line, one may modify the reactive voltage injected by each Voltage Source Converter (VSC). The reactive power fluxes in the lines are controlled by injecting a series active voltage, while the DC voltage is regulated by a single VSC. The creation of an IPFC circuit model and its application to the interline power flow controller model are detailed in this work. We use MATLAB Simulink to do the simulations. The outcomes produced using MATLAB**.**

Index Terms— Voltage Source Converter (VSC), Interline Power Flow Controller (IPFC), and Flexible AC Transmission System (FACTS).

1. INTRODUCTION

Over the last several years, Electrical Power Quality has achieved more Modern power systems have mechanical controls, which do not allow for rapid control. Furthermore, since mechanical gadgets break down significantly more quickly than static electrical ones, such controls cannot be activated very often. As a result of FACTS technology, utilities may maximise the use of their transmission infrastructure and improve grid dependability, which helps with some of these problems but not all of them. With the ability to control line current at a reasonable cost, there is a great deal of hope for expanding the limit of existing lines utilizing bigger guides and using one of the Realities regulators to permit comparing ability to move through these lines in both typical and emergency situations. The use of FACTS controllers brings the power carrying capacity of a line closer to its thermal rating. An improved version of the static created series compensator is the interline power stream regulator, or IPFC for short. At steady state functioning, the IPFC may be represented mathematically in [1]. Simulation findings indicate that the IPFC can achieve power balancing across transmission frameworks with two indistinguishable equal lines, and the fundamental premise is explained in depth in [2]. To achieve power flow management, the authors of [3] go over the IPFC's fundamental features and suggest two primary control methods for the device.
In [4], controllers based on thyristors are mentioned as part of the Flexible AC Transmission System (FACTS). In IPFC, several VSCs are connected at a single DC terminal; each VSC is capable of compensating in series for its own line. Transferring the right amount of power from overloaded to underloaded lines via the common DC connection is one approach to achieve system-wide power optimization [2]–[4]. The effectiveness of a Generalized Interline Power Flow Controller (GIPFC) in managing two separate yet balanced AC systems is assessed and examined in reference [5]. Nonlinear regulation of Thyristor Controlled Series Capacitors (TCSCs) and IPFCs is described in literature [6] using a mix of fuzzy schemes and Radial Basis Function Neural Networks.
In [7], the authors present a power stream control design for IPFC and dissect move capabilities. A robust tool with two integrated power flow controllers (IPFCs), one loop, and an optimum power flow approach is proposed in paper [8] for use on a three-machine, nine-bus test system. This paper presents the numerical models of IPFC and Summed up UPFC, as well as their applications to drive stream, in reference [9]. The features of sub synchronous resonance are investigated in paper [10], which provides IPFC with 12 pulse three level converters. From [1] to [10], the IPFC circuit model is absent from the aforementioned literature. In this study, we try to simulate a four-bus system using IPFC circuit.

2. BASIC PRINCIPLE OF INTERLINE POWER FLOW CONTROLLER

The interline power stream regulator, as displayed in Figure 1, works by compensating for individual lines in sequence using various DC to AC inverters. Vital to the plan of IPFC as a power stream regulator are at least two static coordinated series compensators (SSSCs), which are solid state voltage source converters that imbue a practically sinusoidal voltage at variable plentifulness and are coupled by means of a typical DC capacitor.
A transmission network may benefit from SSSC by having its load distributed more evenly and by increasing the adaptable dynamic power on a solitary line. Also, IPFC's common DC connection may be used to exchange active power using these series converters. Dismissing misfortunes in the converter circuits, the complete dynamic power that VSCs should be able to output to transmission lines is zero. By connecting VSCs in series, we may keep the DC connect voltage at a consistent, wanted level and infuse a voltage at the central recurrence with a size and stage point that we control. As a bidirectional link, the common DC connection represents the dynamic power trade between voltage sources.

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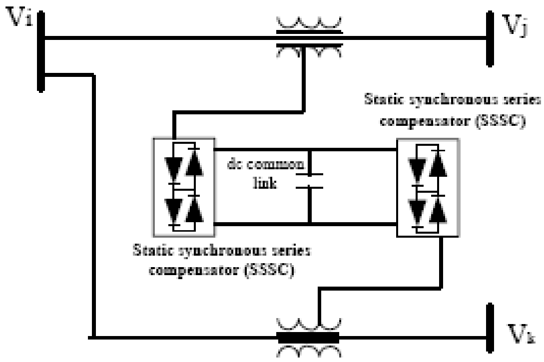

Figure 1: IPFC, a schematic representation

3. MATLAB SIMULATION

We report the findings of a computerized recreation of the IPFC framework that was led utilizing MATLAB Simulink.

Model for ipfc system

Figure 3 shows the single-stage model of a four -transport framework with an IPFC.In this diagram, a dependent voltage source stands in for the line transformer. One way to move reactive power from an underloaded line to an overloaded one is to install converters between the two transmission lines.

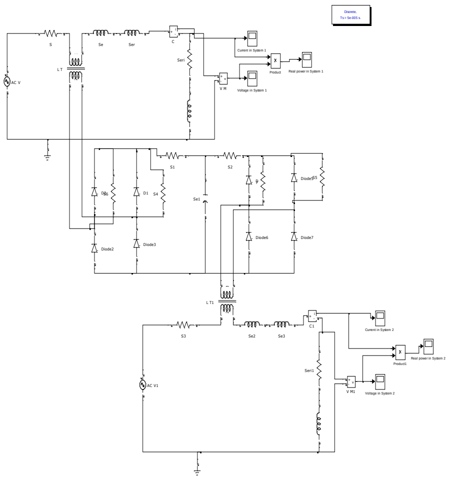

Fig 2: Simulation Model of IPFC

Figure 4 depicts the rectifier-inverter subsystem that is utilized in the IPFC model. Connected scopes allow for the measurement of loads' reactive and actual powers. For the simulation, we used a essential information source voltage with a stage point of 15 degrees and an optional info source voltage with a phase angle of 30 degrees, all of which were identical in voltage. Because of the phase angle difference, the secondary load's actual power is greater than the main load's.

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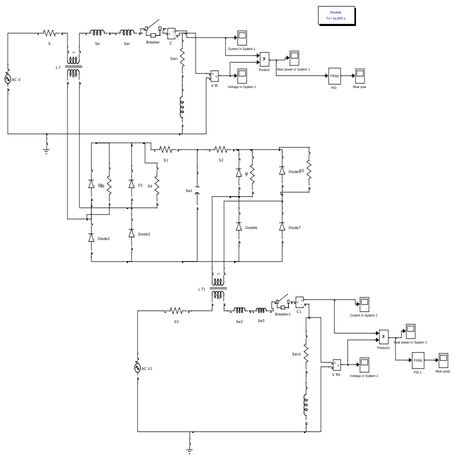

Fig 3: Simulation Model of IPFC with PID controller and with Switch closing from 0.2 to 0.3 secs

Figure 8 displays the MATLAB circuit model of a shut circle IPFC framework with primary and optional burdens. We rectify the load voltage after sensing it. It is comparable to a signal that serves as a reference. The pulse generator's output controls the inverter's switches. Part 2 detects the voltage across the optional burden. Module 3 distinguishes the voltage across the primary burden. The beat creating module is represented by Subsystem 4.

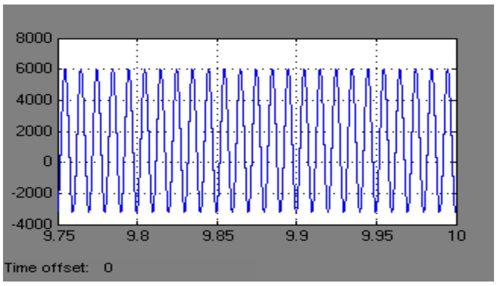

Fig 4: Real power for system load 1

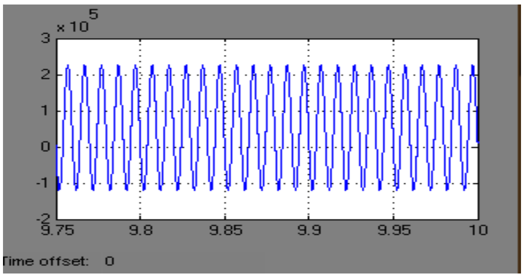

Fig 5: Real power for system load 2

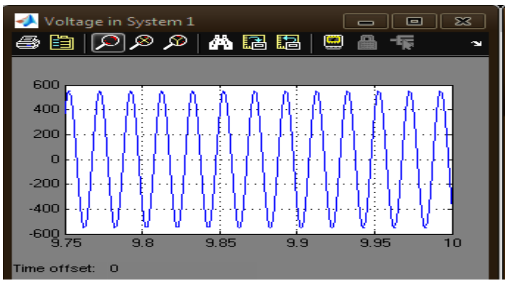

Fig 6: Voltage for system load 1

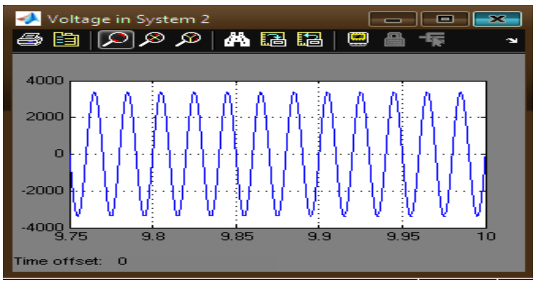

Fig 7: Voltage for system load 2

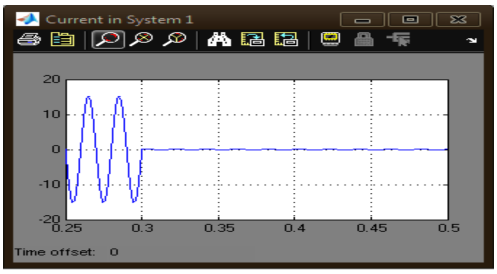

Fig 8: Current for system load 1

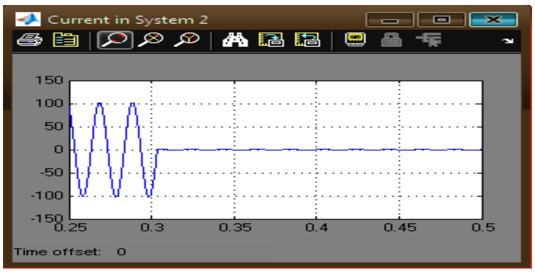

Fig 9: Current for system load 2

Table 1: Real Power measured at Load 2   Table 2: Reactive Power measured at Load 2

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S.No	Bus Angle at System 1	Bus Angle at System 2	Real power measured at Load 2
1	180^{0}	45^{0}	225KW
2	180^{0}	90^{0}	187KW
3	270^{0}	45^{0}	440KW
4	270^{0}	90^{0}	235KW
5	270^{0}	180^{0}	18KW
6	360^{0}	45^{0}	235KW
7	360^{0}	90^{0}	230KW
8	30^{0}	20^{0}	500KW
9	30^{0}	10^{0}	550KW

Table 3: Reactive Power of secondary Load

Primary line Voltage (KV)	Secondary line Voltage (KV)	Reactive power of secondary load (MVAR)	
		Open Loop	Closed Loop
110	110	6.486	6.535
120	120	6.482	6.532

S.No	Voltage rating of Line 1(KV)	Reactive power at line 1	Voltage rating of Line 2(KV)	Reactive power at line 2
1	6	130KVAR	6.6	176KVAR
2	10	410KVAR	11	510KVAR
3	32	3.5KVAR	33	4.2KVAR
4	64	16.5KVAR	66	20.9KVAR

Table 4: Real Power of secondary Load

Type of System	Real power (MW)	
	Primary Load	Secondary Load
Open Loop	7.8	8.37
Closed Loop	7.8	8.55551

Model reference adaptive controller

We take a look at a system that has two ties—AC and DC—that link two huge AC networks. Interaction between DC control and the more common AC area controls is a part of the system. Here, the topic of how to get the most out of classical controllers has sparked debate in respected academic publications. An innovative control approach called a Model Reference Adaptive Control method (MRAC) is introduced in this article and used to regulate the network stability in each of the sections.

M-file Program:

```
clc
 %%%%%%%%%USER DEFINED PARAMETERS%%%%%%%%%
gamma=.0001;   %Value of gamma
Ts  = 3;       %Desired settling time for reference model
z   = .707;    %Desired damping ratio for reference model
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
omega=4/(Ts*z);
am=[2*z*omega omega^2]
```

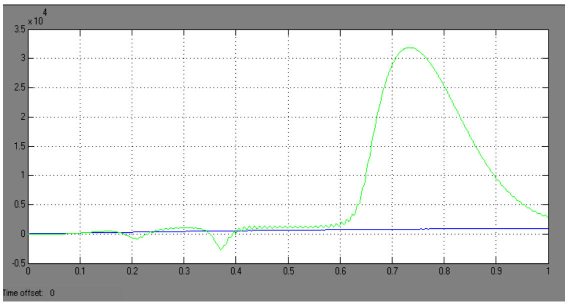

Fig 10: Real power for system Load 2 with MRAS

Artificial Intelligence techniques:

IEEE 30-Bus System

In December 1961, the American Electric Power System (in the Midwest US) was represented by the IEEE 30 Bus Test Case. One thousand volts and eleven thousand volts are the starting points. Depending on the model, these buses may be found operating at 132 or 33 kV. No line limitations are present in the 30-bus test scenario. This information came from the IEEE power systems test case that was downloaded.

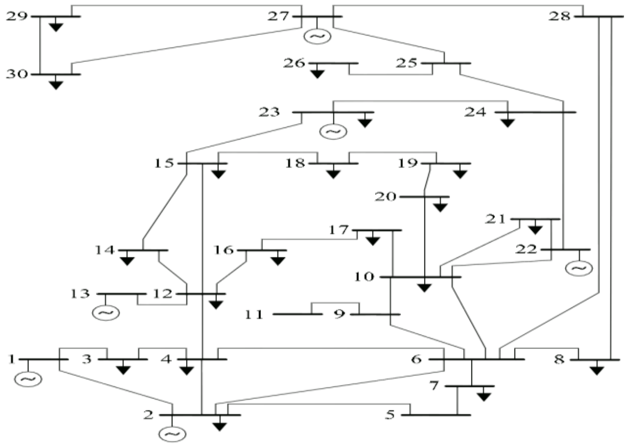

Fig 11: The 30-bus test system according to the IEEE

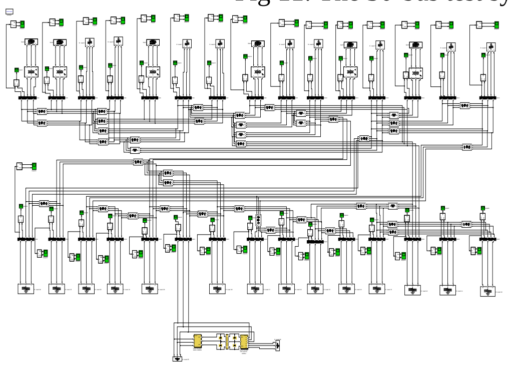

Fig 12 The 30-bus test system as a single line diagram.

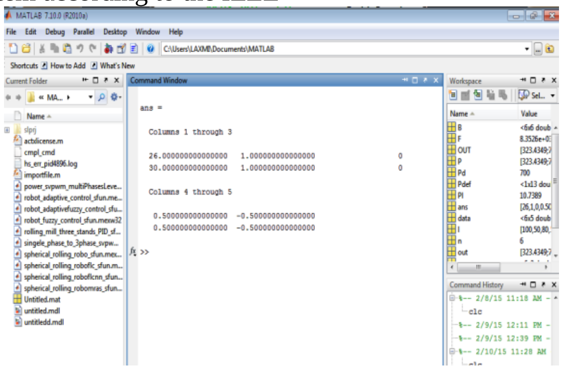

Fig 13 The 30-bus test system as a single line diagram

STATCOM Bus	Vsh pu	Thst Degree	Qsh pu
26	1.0014	-16.7872	-0.0137
30	1.0020	-18.0321	-0.0202

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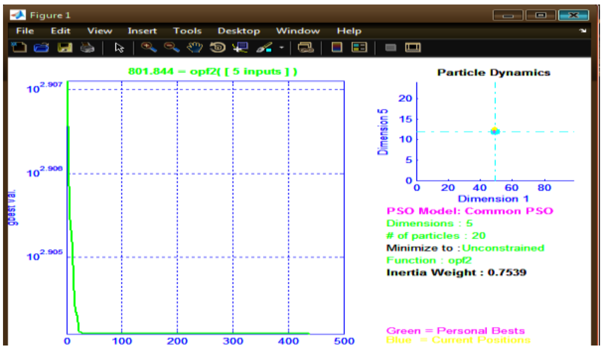

Fig 14: PSO of the 30-bus test system for the IEEE

```
TL =

    9.375732955765159
```

With the use of the PSO approach, this study determines, for both single- and multi-type FACTS devices, the best places to put them in order to save installation costs while simultaneously increasing system load ability.

Table 5: Values of control variables after optimization

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Bus	Control variables	Optimized values (xmin)
1	Vg1 (pu)	1.082
2	Vg2	1.043
5	Vg5	1.044
8	Vg8	1.041
11	Vg11	1.090
13	Vg13	1.056
6-9	T1	0.969
6-10	T2	1.015
4-12	T3	1.033
27-28	T4	0.982
3	QC3 (MVAR)	10.778
10	QC10	7.549
24	QC24	11.750

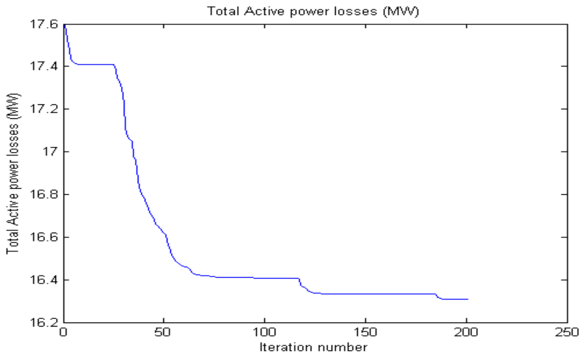

Fig. 15: Convergence characteristic of PSO

1	Population size	50
2	Acceleration constant (C1, C2)	1.4 and 1.4
3	Constriction factor	0.729
4	Max. and Min. inertia weights	0.9 and 0.4
5	Max. and Min. velocity of particles	0.003 and -0.003
6	Convergence criterion	200 iterations

Table 6: Selected parameters of PSO

PI Controller:

	Without Controller	With PI Controller
Model 1	28	18
Model 2	21	15.2
Model 3	23	12

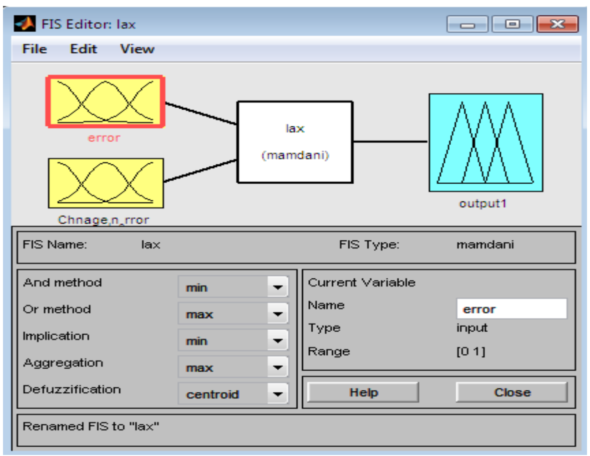

Fig 19: Fuzzy Inference Editor

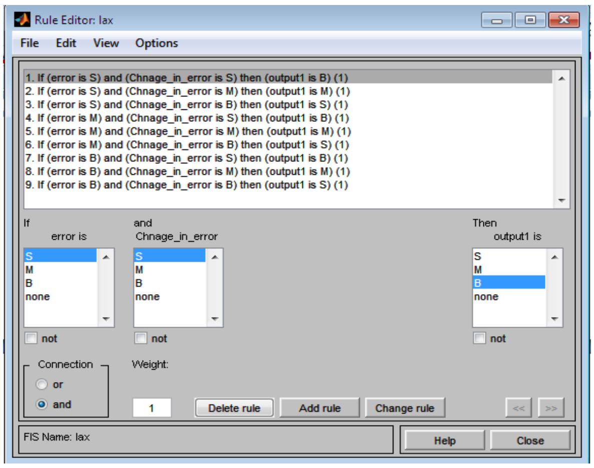

Fig 20: FIS rule editor

FLC Controller:

	Without Controller	With FLC Controller
Model 1	28	16.87
Model 2	21	14.42
Model 3	23	10.65

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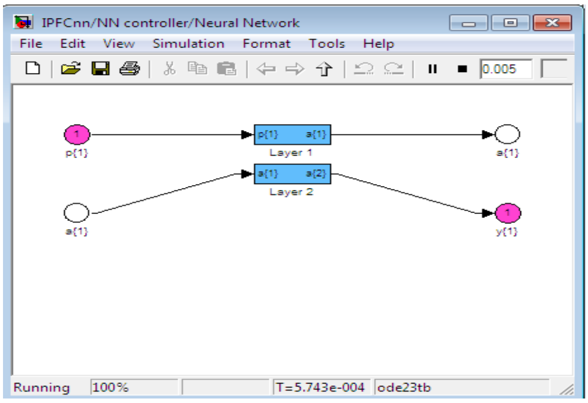

Fig 21: Subsystem of Neural Network Hidden Layers

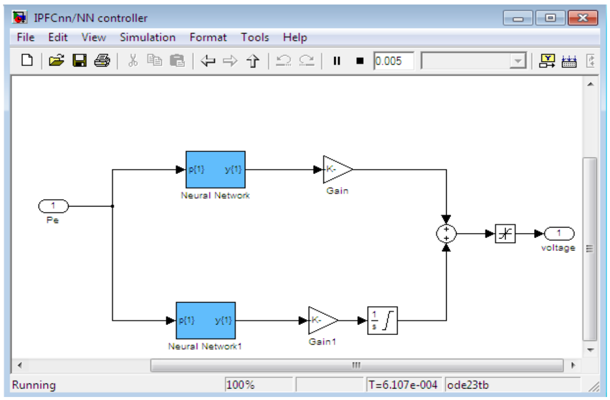

Fig 22: Subsystem of Neural Network

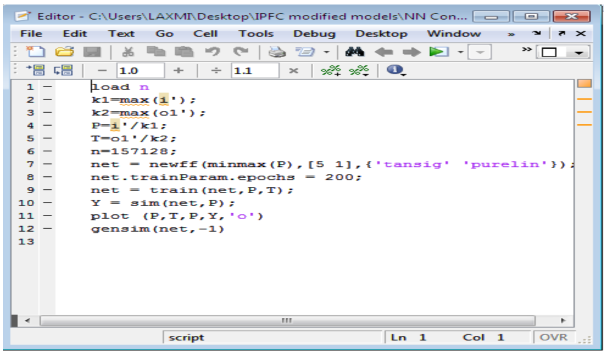

Fig 23: M-File Program of Neural Network

NN Controller:

	Without Controller	With NN Controller
Model 1	28	19.5
Model 2	21	7.48
Model 3	23	23.76

4. CONCLUSIONS:

The purpose of this thesis was to evaluate three Simulink models of a FACTS-based multi-machine power system, one with and one without Fuzzy-POD-IPFC controllers. In MATLAB 7.10, Simulink models were created for the multi-machine model under consideration, with and without the Fuzzy-POD-IPFC controllers, to reduce oscillations. Three models were created.A problem occurs close to generator 1 in the first model. A problem occurs close to generator 2 in the second model. The third model shows that the problem occurs close to generator 3. Additionally, a set of fuzzy rules was written to build the control approach. The standard POD-IPFC controller served as the basis for the fuzzy control approach, which was then implemented the voltage across the optional burden. Module 3 distinguishes the voltage across the primary burden. The beat creating module in the modelling process is that it enhances power system stability by modifying the conventional controller's amplification section.The outcomes of the simulations were visible on the scope after they were conducted in MATLAB 7.10 Version. With and without the controller, all three models showed power angle vs. time graphs. The simulation results show that the nine-bus system would have higher disturbances without the Fuzzy-POD-IPFC controller. In model 1, second, and third, we measure the power angle on the first, second, and third generators, respectively. According to the simulation findings, there are several ringing oscillations (overshoots and undershoots) and the output stabilizes after a long period of time. Better results were obtained by lowering aggravations in the power point and post shortcoming settling time by remembering the Fuzzy Case IPFC coordination framework for circle with the plant in each of the three models. Shortly after the problem occurs, the system stabilizes, which reduces the settling period and dampens the local mode oscillations. Not only is the control approach that has been devised straightforward and dependable, but it may also be easy to use in real-time scenarios.Thus, this thesis's designed technique's performance proves that power system oscillations may be dampened by using the Fuzzy-POD-IPFC coordination scheme, as opposed to a method without this scheme. As a result of the lack of IPFC activity nearby, it was resolved that generator 2 (model 2) is less steady and calls for greater investment to settle. In contrast with the other two models, Generator 1 stabilizes much more rapidly, whilst Generators 2 and 3 need somewhat more time.

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5. REFERENCES

[1] K. R. Padiyar, Nagesh Prabhu, "Analysis of SSR With Three-Level Twelve-Pulse VSC-Based Interline Power-Flow Controller," IEEE Transactions on Power Delivery, vol. 22, no. 3, July 2007.

[2] Yankui Zhang, Yan Zhang, and Chen Chen, "A Novel Power Injection Model of IPFC for Power Flow Analysis Inclusive of Practical Constraints," IEEE Transactions on Power Systems, vol. 21, no. 4, November 2006, pp. 1550-1556.

[3] Jianhong Chen, Tjing T. Lie, D. M. Vilathgamuwa, "Basic Control of Interline Power Flow Controller," IEEE, 2002, pp. 521-525.

[4] R. L. Vasquez Arnez, L. Cera Zanetta Jr., "Steady state Multi-Line Power Flow through the Generalized IPFC," IEEE/PES Transmission & Distribution conference, 2004, pp. 28-33.

[5] A. Kazemi, E. Karimi, "The Effect of Interline Power Flow Controller (IPFC) on Demanding Inter-area Oscillations in the Interconnected Power systems," IEEE ISIE 2006, July 9-12, 2006, Montreal, Quebec, Canada.

[6] S. Teerathana, A. Yokoyama, Y. Nakachi, M. Yasumatsu, "An Optimal Power Flow Control Method of Power System by Interline Power Flow Controller," IEEE, 2004, pp. 343-346.

[7] R. Leon Vasquez-Arnez, Lulz Cera Zanetta, "A Novel Approach for Modeling the Steady-State VSC-Based Multiline FACTS Controllers and Their Operational Constraints," IEEE Transactions on Power Delivery, 2007, pp. 1-8.

[8] Jun Zhang, Akihiko Yokoyama, "Optimal Power Flow Control for Congestion Management by Interline Power Flow Controller (IPFC)," International Conference on Power System Technology, 2006, pp. 1-6.

[9] V. Diez-Valencia, U. D. Annakage, D. Jacobson, "Interline Power Flow Controller (IPFC) Steady State Operation," IEEE Canadian Conference on Electrical & Computer Engineering, 2002, pp. 280-284.

[10] Power Engineers Handbook by Tamil Nadu Electricity Board Engineering Association, Sixth edition, 2002.

[11] Rani, R.U., Swarupa, M.L. (2023). Contribution Title High Accuracy Dataset Control from Solar Photovoltaic Arrays by Decision Tree-Based System. In: Sharma, H., Shrivastava, V., Bharti, K.K., Wang, L. (eds) Communication and Intelligent Systems. ICCIS 2022. Lecture Notes in Networks and Systems, vol 689. Springer, Singapore. https://doi.org/10.1007/978-981-99-2322-9_39.

[12] Rajeswaran, N., Swarupa, M.L., Maddula, R., Alhelou, H.H., Kesava Vamsi Krishna, V. (2023). A Study on Cyber-Physical System Architecture for Smart Grids and Its Cyber Vulnerability. In: Haes Alhelou, H., Hatziargyriou, N., Dong, Z.Y. (eds) Power Systems Cybersecurity. Power Systems. Springer, Cham. https://doi.org/10.1007/978-3-031-20360-2_17.