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Unified Power Flow Controller: Operation, Modelling and Applications

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Abstract— **This paper focuses on implementing the unified power flow controller (UPFC) in the optimal power flow approach, a critical aspect of power and control system operations. Optimal power flow minimizes operating costs and maintains safety margins for control variables, making it an indispensable tool for energy management. The flexible AC transmission system (FACTS) is a fundamental component of this approach, with the UPFC playing a crucial role. This versatile device provides various types of energy system compensation, enabling the independent control of reactive and active electrical power in transmission lines and bus voltages simultaneously. Previous studies have explored a wide range of engineering applications for UPFC using diverse techniques. This paper reviews these applications, specifically examining how UPFC can increase power system flexibility and controllability. Additionally, this paper explores utilizing artificial intelligence (AI) in the placement of UPFC in power systems. By incorporating AI techniques such as machine learning and optimization algorithms, power system operators can optimize the placement of UPFC to achieve optimal energy management. This approach enhances the efficiency and reliability of energy systems, resulting in significant cost savings and improved power system performance.**

Keywords—Power Flow Controller, power flow, transmission system, big data, soft computing, mathematics, mathematical modeling, artificial intelligence, energy consumption, voltage source converter.

I. INTRODUCTION

The expansion of the industrial sector, coupled with the rise in energy consumption and the need to maintain dynamic stability, while ensuring acceptable voltage levels, has resulted in power transmission constraints in the power system [1,2]. To increase the transfer capacity of modern power systems, transmission lines must be built, leading to higher operating costs for these energy systems. Compensators are used to improve the status of existing lines and supply the network with the necessary load [3,4]. High-voltage flexible AC transmission systems are essential for maintaining appropriate voltage levels and quality. Without proper evaluation and accumulation of Flexible AC Transmission Systems (FACTS), the complex power system may be unable to regulate voltage or adjust the level of electrical power injected into or absorbed by the power system. The utilization of FACTS leads to an overall improvement in grid capacity and performance [5]. Moreover, FACTS devices play a critical role in enhancing the efficiency and reliability of large-scale energy systems. They provide a greater degree of control over electrical energy, enabling the damping of power oscillations. As a result, these devices are instrumental in achieving the flexibility of the power system [6]. A considerable amount of research has been conducted in the field of FACTS devices [7], and they are now a crucial part of interconnected large-scale electrical networks [8]. FACTS devices are classified into three main categories, as illustrated in Fig. 1 [9]. The first category comprises mechanical switches such as thyristor-controlled series compensator (TCSC) [10]. The second category includes hybrid devices such as static synchronous compensator (STATCOM) [11], and the third category includes voltage source converters such as interline power flow controller (IPFC) [12]. By utilizing these FACTS devices, power system operators can efficiently manage power flow and maintain a reliable, stable, and flexible power system.

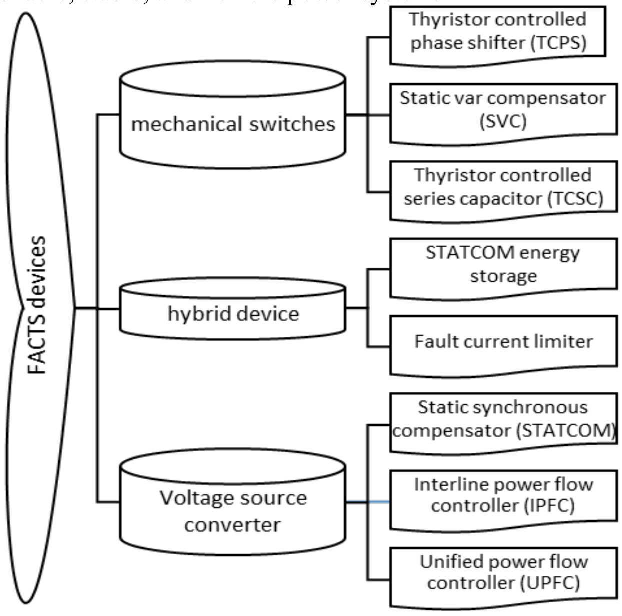

Fig. 1. Classification of FACTS devices

To address the need for reactive power compensation on high-voltage transmission grids, an electrical device called a

Unified Power Flow Controller (UPFC) is utilized [13]. What makes UPFCs unique is their reliance on the protection and control power system, setting them apart from traditional AC transmission technology [14]. Additionally, they are highly adaptable to accommodate the specific requirements of various functionalities, further enhancing their usefulness. In the power system, UPFCs serve different purposes in improving grid behavior, such as security enhancement [15], backup protection [16] and oscillation damping [17]. Due to their numerous advantageous characteristics, UPFCs have been extensively researched for their application in the power system [18,19]. As a member of the FACTS family, UPFCs are connected using a combination of shunt and series connections, making them more flexible in their usage. The aim of this research is to provide a comprehensive review of the various applications of UPFCs in the modern power system. The categorized information presented in Table I summarizes the operating fundamentals of the FACTS device family, including the various possible main control approaches and the local signals utilized for supplementary damping control [20,21]. This concise summary of published research on UPFCs serves as a valuable resource for practitioners and researchers in the field. In conclusion, UPFCs have become an essential component in addressing reactive power compensation in high-voltage transmission grids. Their unique characteristics and adaptability to specific functionalities have made them valuable assets in improving grid behavior.

This paper is structured as follows: Section II of this paper provides a thorough introduction to the principles of unified power flow controllers (UPFC), including their capabilities and limitations. Section III then presents a summary of the coordination design of UPFC and power system stabilizers (PSS), highlighting the key considerations that need to be considered to ensure optimal performance. Moving on to Section IV, this section briefly reviews the current state of research on the application of artificial intelligence (AI) in UPFC optimal placement studies. Specifically, the focus is on how AI can be used to identify the best locations for UPFC installations to mitigate congestion and other related issues. In Section V, this paper categorizes other flexible AC transmission systems (FACTS) devices that are used to address power system challenges, such as sub synchronous resonance (SSR) and congestion. Eventually, this paper is concluded in Section VII.

II. UNIFIED POWER FLOW CONTROLLER

A. Compensating Structure

As illustrated in Fig. 2, the UPFC is a combination of a static synchronous series compensator (SSSC) and a STATCOM that are paired using a prevalent DC voltage source [22]. The UPFC employs a series transformer to inject current into a power transmission line, using a pair of controllable three-phase bridges. This advanced control system allows for the precise management of both reactive and active power flows in the transmission system, providing a balanced sine wave source is applied. One of the key advantages of the UPFC is its ability to independently control the reactive and active power flows on the power line, as well as the bus voltages, thanks to the inverters that operate via a universal DC link and a DC storage capacitor. However, it's worth noting that internal reactive power interaction via a DC link between two inverters is not possible. The SSSC component of the UPFC is primarily used to regulate the capacity for the transfer of electrical energy in the line to which it is connected, while the STATCOM is typically employed to regulate the bus voltage at locations where typical connections are found [23].

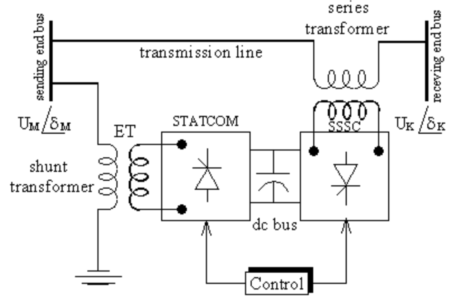

Fig. 2. Orbital structure of unified power flow controller

There are three distinct categories of techniques for controlling the active and reactive power flow: (*i*) is designed to inject the series voltage in phase shift with the power transmission line current, allowing it to function similarly to a variable sense capacitor [24], (*ii*) is according to injecting the series voltage in phase shift with the UPFC bus [25], and (*iii*) the D-Q axis current in the power transferring line is independently controlled, enabling individual control of the reactive and active power flow [26].

TABLE I. Overview of FACTS controller

Type	**Devices**	**Device's principle**	**Basic control**	**Local modulation signal**
Serie	TCSC	varying reactance	line compensation	synthesized frequencies synthesized voltages active power, current
	SSSC	reactive source	line compensation	
Shunt	SVC	varying reactance	bus voltage	
	STATCOM	reactive source	bus voltage	
Shunt-series	UPFC	series compensation and reactive source	active power flow compensation of bus voltage line	
Shunt-shunt	BTBL	reactive source and phase compensation	bus voltage active power flow	

B. Compensation Model

The UPFC operates by injecting voltage in series or in shunt with the transmission line. This results in the ability to control both the magnitude and phase angle of the voltage at the point of injection. By controlling these parameters, the UPFC can adjust the flow of power through the transmission line in real-time. This makes it a valuable tool for managing power transmission networks, particularly in situations where the network is under stress or there are variations in demand. The ability to adjust node voltages, line impedances, and phase angle using the UPFC allows for greater flexibility in managing power transmission systems. Additionally, the UPFC can provide voltage support, improve system stability, and mitigate the impact of disturbances on the power network [27]. Since UPFC is a multi-variable power controller in a large-scale energy system, it is essential to investigate the impact of the various power system operating conditions. Fig. 3

illustrates the UPFC model with a regulated voltage source. With the electric grid serving as a representation of the shunt and series voltage source inverters, this model is comprised of two power supplies, one of which is associated with series and the other in shunt. By transforming DC voltage to AC voltage, the power sources are established. The schematic representation of a UPFC with a controlled flow supplier can be found in Fig. 4 [28]. Fig. 5 depicts the model of the UPFC as a transformer with a shunt branch. In this model, the variable shunt susceptance and the turn ratio of the transformer are unaffected by the voltages and currents that are measured at the input and output of UPFC [29]. A dynamic model of UPFC was developed in [30], to boost the power transfer capability through the power transmission network. Series and shunt controllers were structured with fuzzy logic controllers in this approach. In [31], a comparative study on different techniques used to incorporate UPFC in load flow algorithms, such as the decoupled technique, load injection technique, matrix partitioning technique, and indirect technique, is presented. In [32], a reconfigurable cascaded multi-level inverter with a full-bridge converter is suggested. Each phase foot shunt has one end linked to the electrical power line and the other ends linked in parallel to the primary terminals of the series line transmitter and the alternating current (AC) inverter's output terminals.

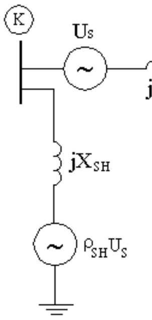

Fig. 3. Equivalent compensation circuit with controlled voltage source

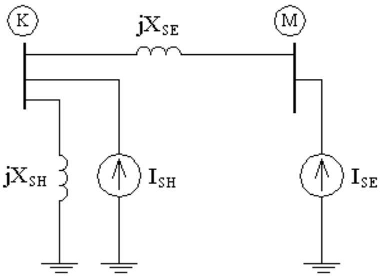

Fig. 4. Equivalent compensation circuit with controlled flow source

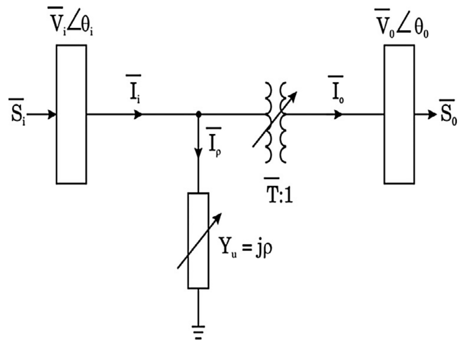

Fig. 5. UPFC Model as a transformer with a shunt branch

III. COORDINATION DESIGN OF UPFC AND PSS

Various techniques have been used for the coordinated design of Power System Stabilizers (PSS) and UPFC controllers. Some of the commonly used techniques include: (i) Classical control design: This applies to developing separate controllers for PSS and UPFC and then combining them using feedback signals. The design is based on linearized models of the power system. (ii) Optimal control design: This involves formulating an optimization problem that aims to minimize a certain cost function while satisfying system constraints. The optimal control design can lead to better performance than the classical control design. (iii) Robust control design: This applies to organizing controllers that can handle uncertainties and disturbances in the power system. Robust control design can improve system stability and performance under varying operating conditions. (iv) adaptive control design: This involves developing controllers that can adapt to changes in the power system. Adaptive control design can improve system performance under changing operating conditions. (v) Artificial intelligence (AI) based control design: This concerns utilizing machine learning and other AI techniques to design controllers for PSS and UPFC. AI-based control design can lead to better performance than traditional control design methods [33,34]. A strategy for coordinating UPFC with PSS to suppress oscillations generated by a small signal disturbance is presented in [35]. This procedure is used to determine the eigenvalue of the greatest real segment and then minimize it as a nonlinear optimization challenge. This model aims to suppress oscillations caused by small signal disturbances. In [36], genetic algorithms are used in a coordinated configuration among a power system stabilizer and a UPFC to optimize the damping proportion of electro-mechanical states by correlating various characteristics of PSSs with a UPFC. An optimal combination for simultaneously locating UPFC and PSS to augment the stability of the power system is addressed in [37], and a mixed integer nonlinear problem is developed for the analysis and design as a result of this presentation research. This architecture aims to boost the transient stability of the large-scale energy system.

IV. USE OF ARTIFICIAL INTELLIGENCE IN UPFC PLACEMENT

Finding the ideal positions and configurations for UPFC devices in power systems is very challenging, and a lot of data is frequently required. Three categories— conventional optimization (CO), sensitivity analysis (SA)-based, and Artificial Intelligence (AI)-based—can be used to categorize the techniques and approaches used in earlier research studies to determine the best locations and settings for the system equipped with UPFC. The most widely used techniques are those based on artificial intelligence, and these are also considered to be the best strategies. Power flow restrictions like reactive and active power, voltage, and power loss are all impacted by the generator failure. The ideal placement of the Facts devices as well as the selection of the appropriate signals in the power system are essential to its effective performance [38]. The best location for the FACTS controllers is extremely important to find the ideal location for UPFC controller placement in multiple applications [39]. Due to its ease of implementation in solving numerous challenging engineering optimization problems, AI is widely used [40]. To prove the practicability of the suggested method for choosing where the

UPFC interface should be in distribution or transmission networks, critical features should be investigated.

The parameters assessed include the phase angle, voltage profile, and proportion of power quality improvement, as well as the cost of the UPFC device during setup and operation, the cost of power generation, the location, number, and parameter of the UPFC device, the deviation of the voltage, the severity index, the voltage stability, and the mitigation of harmonics [41]. These analyses should be carried out in a specific power network, preferably the regular network of the IEEE bus system, under specific contingency conditions. The approach to UPFC placement based on evolutionary programming and various sensitivity analyses is described in [42]. Note that, in the field of optimization, this problem was solved utilizing evolutionary algorithms. To increase dynamic stability, a hybrid strategy based on optimal planning and sizing of UPFC using the combination of the Gravitational Search Algorithm (GSA) and artificial bee colony (ABC) algorithms is developed in [43]. The cuckoo search (CS) and firefly algorithm (FA) are suggested in [44], where the FA strategy optimizes the maximum power loss line as the suitable location of the UPFC, utilizing the best location and the UPFC's capacity to boost the multimachine power system's transient and dynamic stability. To achieve optimal power flow and optimal placement of UPFC, a new gray wolf with a population-based update evaluation algorithm is demonstrated [45]. Furthermore, there are a number of strong approaches, such as [46,47], that can be utilized in the field of planning the location of FACTS devices in the modern power system.

V. CONGESTION MITIGATION AND SSR

There is an extensive power flow approach for the UPFC that is delivered in [48]. This strategy has the capacity to manage both reactive and active electrical powers as well as the voltage amplitude simultaneously. In [49], eigenvalue computation and fast Fourier transform (FFT) investigation against operating point deviations and uncertainties in the system are also analyzed, along with a suggestion for mitigating sub-synchronous resonance (SSR) by employing fractional-order PI (FOPI)-based UPFC. A comprehensive optimization framework according to sequential interpretation to optimally distribute the UPFC and TCSC with wind power generators under deregulated large-scale energy system is furnished in [50], in which the suggested strategy for optimal planning of UPFC and TCSC has been experimented with, and verified on customized IEEE 14-bus and IEEE 118-bus multi-machine energy systems.

VI. IMPROVE POWER OSCILLATION DAMPING

Low-frequency oscillations are one of the primary problems that must be solved to guarantee the reliable operation of the power system [51,52]. Power oscillations can be triggered by a variety of factors, including faults in the transmission lines, power line switching, or a sudden change in the output of the generator [53]. Local plant mode oscillations, interplant mode oscillations, and inter-area mode oscillations are some of the different types of power system oscillations. The important advantage of increased energy transmission capability over the current interconnector is achieved through oscillation dampening. To reduce power system oscillations, several investigations have been carried out [54,55]. To identify the optimal control input parameters of a unified power flow controller (UPFC) for damping power system oscillations, a comparative analysis with the direct component of torque (DCT), minimum singular value (MSV), Hankel singular value (HSV), and residue has been proposed [56]. A damping control system, which is based on a generalized power-incorporated current controller, is a third-generation FACTS device that is presented in [57], to investigate its effect on reducing low-frequency oscillation.

VII. CONCLUSIONS

The implementation of Flexible AC Transmission System (FACTS) devices, such as the UPFC, has emerged as a promising solution for improving the utilization of existing power in modern power systems. UPFC, with its ability to control active and reactive power flows, regulate bus voltage and current flow, and manage up to three transmission power system parameters simultaneously, has attracted significant attention in recent years. This paper has highlighted the integration of artificial intelligence (AI) techniques into the placement of UPFC, which can optimize energy management using machine learning and optimization algorithms. The proposed method ensures the optimal placement of UPFC, leading to enhanced power transfer capabilities and improved power quality, resulting in substantial cost savings. The use of AI in the placement of UPFC is a novel and exciting approach with great potential for the future of energy systems, and its scalability makes it a widely applicable solution. Overall, this technique can significantly enhance the performance and reliability of energy systems, which is crucial in today's world.

REFERENCES

[1] X. Wu, R. Wang, Y. Wang, and L. Wang, "A Novel UPFC Model and its Convexification for Security-Constrained Economic Dispatch," IEEE Transactions on Power Systems, vol. 37, no. 6, pp. 4202-4213, 2022, doi: 10.1109/TPWRS.2022.3148090..

[2] S. Abrazeh et al., "Virtual Hardware-in-the-Loop FMU Co-Simulation Based Digital Twins for Heating, Ventilation, and Air-Conditioning (HVAC) Systems," IEEE Transactions on Emerging Topics in Computational Intelligence, 2022.

[3] S. Li, T. Hu, and Y. Li, "Reliability Improvement to UPFC With Routine Test to the Abnormal State," *IEEE Transactions on Power Delivery,* vol. 37, no. 6, pp. 4612-4622, 2022.

[4] A. Fathollahi, A. Kargar, S.Y. Derakhshandeh, "Enhancement of power system transient stability and voltage regulation performance with decentralized synergetic TCSC controller", Int. J. of Electrical Power and Energy Systems, Vol. 135,pp. 107533, Feb. 2022.

[5] G. Zhang et al., "A Novel Data-Driven Self-Tuning SVC Additional Fractional-Order Sliding Mode Controller for Transient Voltage Stability with Wind Generations," IEEE Transactions on Power Systems, pp. 1-12, 2023.

[6] Y. Bi et al., "Modified Deadbeat Predictive Current Control Method for Single-Phase AC–DC PFC Converter in EV Charging System," IEEE Transactions on Industrial Electronics, vol. 70, no. 1, pp. 286-297, 2023.

[7] Z. Azimi, G. Shahgholian, "Power system transient stability enhancement with TCSC controller using genetic algorithm optimization", Int. J. of Natural and Engineering Sciences, Vol. 10, No. 3, pp. 9-14, 2016.

[8] M. Yan, M. Shahidehpour, A. Paaso, L. Zhang, A. Alabdulwahab, and A. Abusorrah, "A Convex Three-Stage SCOPF Approach to Power System Flexibility With Unified Power Flow Controllers," *IEEE Transactions on Power Systems,* vol. 36, no. 3, pp. 1947-1960, 2021.

[9] T. Fetouh, M.S. Zaky, "New approach to design SVC-based stabiliser using genetic algorithm and rough set theory", IET Generation, Transmission and Distribution, Vol. 11, No. 2, pp. 372-382, Jan. 2017.

[10] G. Shahgholian, M. Maghsoodi, A. Movahedi, "Fuzzy proportional integral controller desin for thyristor controlled series capcitor and power system stabilizer to improve power system stability", Revue Roumaine Des Sciences Techniques, Vol. 61, No. 4, pp. 418-423, 2016.

[11] E. Jafari et al., “Designing an emotional intelligent controller for IPFC to improve the transient stability based on energy function”, Journal of Electrical Engineering and Technology, Vol. 8, pp. 478-489, 2013.

[12] G. Shahgholian, B. Bayat, "A new control technique for improving the oscillations and decreasing the harmonic components of voltage in STATCOM", Int. Review of Electrical Engineering, Vol. 6, No. 6, pp. 3163-3174, 2011.

[13] S.R. Samantaray, L.N. Tripathy, P.K. Dash, "Differential equation-based fault locator for unified power flow controller-based transmission line using synchronised phasor measurements", IET Generation, Transmission and Distribution, Vol. 3, pp. 86-98, Jan. 2009.

[14] A.A. Hossam-Eldin, H. Elrefaie, G.K. Mohamed, "Study and simulation of the unified power flow controller effect on power systems", Proceeding of the IEEE/EIMEPSC, pp. 461-467, Dec. 2006.

[15] M. M. Haque, M. S. Ali, P. Wolfs, and F. Blaabjerg, "A UPFC for Voltage Regulation in LV Distribution Feeders With a DC-Link Ripple Voltage Suppression Technique," IEEE Transactions on Industry Applications, vol. 56, no. 6, pp. 6857-6870, 2020.

[16] P. Song, Z. Xu, H. Dong, "UPFC-based line overload control for power system security enhancement", IET Generation, Transmission and Distribution, Vol. 11, No. 13, pp. 3310-3317, Oct. 2017.

[17] S. Ravindra, C.V. Suresh, S. Sivanagaraju, V.C.V. Reddy, "Power system security enhancement with unified power flow controller under multi-event contingency conditions", Ain Shams Engineering Journal, vol. 8, no. 1, pp. 9-28, March 2017.

[18] B. Kumar, A. Yadav, "Backup protection scheme for transmission line compensated with UPFC during high impedance faults and dynamic situations", IET Science, Measurement and Technology, Vol. 11, No. 6, pp. 703-712, Sep. 2017.

[19] J. Guo, M.L. Crow, J. Sarangapani, "An improved UPFC control for oscillation damping", IEEE Trans. on Power Systems, Vol. 24, No. 1, Feb. 2009.

[20] S. Dutta, P. Mukhopadhyay, P.K. Roy, D. Nandi, "Unified power flow controller based reactive power dispatch using oppositional krill herd algorithm", Int. J. of Electrical Power and Energy Systems, Vol. 80, pp. 10–25, Sep. 2016.

[21] B. Rathore, O. P. Mahela, B. Khan, and S. Padmanaban, "Protection Scheme using Wavelet-Alienation-Neural Technique for UPFC Compensated Transmission Line," IEEE Access, vol. 9, pp. 13737-13753, 2021.

[22] I. Bhawoorjar and P. Jagtap, "Grid-connected Hybrid PV Power System Performance evaluation by employing a Unified Power Flow Controller," in 2022 2nd Asian Conference on Innovation in Technology (ASIANCON), 26-28 Aug. 2022 2022, pp. 1-5.

[23] E. A. Cano-Plata, A. J. Ustariz-Farfán, and C. Arango-Lemoine, "EAF Arc Stability Through the Use of UPFCs," *IEEE Transactions on Industry Applications,* vol. 55, no. 6, pp. 6624-6632, 2019.

[24] K. Sreenivasachar, "Unified power flow controller: Modeling, stability analysis, control strategy and control system design", Ph.D. Thesis, University of Waterloo, Ontario, Canada, 2001.

[25] K.K. Sen, E.J.Stacey, "UPFC-unified power flow controller: Theory, modeiing and applications", IEEE Trans. on Puwer Delivery, Vol. 13, No.4, pp. 1453-1459, Oct. 1998.

[26] Z.Y.Huang, Y.X.Ni, C.M.Shen, F.F.Wu, S.S.Chen, B.L.Zhang, "Application of unified power flow controller in interconnected power systems modeling, interface, control strategy, and case study", IEEE Trans. on Power Systems, Vol. 15, No. 2, pp. 817–824, May 2000.

[27] C.D. Schauder, L. Gyugyi, M.R. Lund, D.M. Hamai, T.R. Rietman, D.R. Torgerson, A. Edris, "Operation of the unified power flow controller (UPFC) under practical constraints", IEEE Trans. on Power Deiivery, Vo1.13, No.2, pp. 630-639, April 1998.

[28] M. Pereira, L.C. Zanetta, "A current based model for load flow studies with UPFC", IEEE Trans. on Power Systems, Vol. 28, No. 2, pp. 677-682, May 2013.

[29] S.A. Nabavi-Niaki, M.R. Iravani, "Steady state and dynamic models of unified power flow controller (UPFC) for power system studies", IEEE Tran. on *Power Systems*, Vol. 11, No. 4, pp. 1937-19436, Nov. 1996.

[30] S. Alamelu, S. Baskar, C.K. Babulal, S. Jeyadevi, "Optimal siting and sizing of UPFC using evolutionary algorithms", Int. J. of Electrical Power and Energy Systems, Vol. 69, pp. 222–231, 2015.

[31] S. Ahmad, F.M. Albatsh, S. Mekhilef, H. Mokhlis, "Fuzzy based controller for dynamic unified power flow controller to enhance power transfer capability", Energy Conversion and Management, Vol.7 9, pp. 652–665, March 2014.

[32] S. Kamel, F. Jurado, J.A. PeçasLopes, "Comparison of various UPFC models for power flow control", Electric Power Systems Research, Vol. 121, pp. 243-251, April 2015.

[33] A. Fattollahi, "Simultaneous design and simulation of synergetic power system stabilizers and a thyristor-controller series capacitor in multi-machine power systems", Journal of Intelligent Procedures in Electrical Technology, vol. 8, no. 30, pp. 3-14, Sept. 2017.

[34] A. Siddique, Y. Xu, W. Aslam, M. Rasheed, and M. Fatima, "Analysis of Transient Stability with SSSC and UPFC with Multi-Band PSS in Two Area Multi-Machine System," in 2018 IEEE 3rd International Conference on Integrated Circuits and Microsystems (ICICM), 24-26 Nov. 2018 2018, pp. 226-230.

[35] G. Shahgholian and A. Fattollahi, "Improving power system stability using transfer function: A comparative analysis," Engineering, Technology & Applied Science Research, vol. 7, no. 5, pp. 1946-1952, 2017.

[36] H. Huang, L. Zhang, O. Oghorada and M. Mao, "Analysis and control of a modular multilevel cascaded converter-based unified power flow controller", IEEE Trans. on Industry Applications, vol. 57, no. 3, pp. 3202-3213, May/June 2021.

[37] L.H. Hassan, M. Moghavvemi, H.A.F. Almurib, K.M. Muttaqi, "A coordinated design of PSSs and UPFC-based stabilizer using genetic algorithm", IEEE Trans. on Industry Applications, Vol. 50, No. 5, pp. 2957-2966, Feb. 2014.

[38] D. Wang and K. Cai, "Multi-objective crashworthiness optimization of vehicle body using particle swarm algorithm coupled with bacterial foraging algorithm," Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, vol. 232, no. 8, pp. 1003-1018, 2018.

[39] B. V. Kumar and N. Srikanth, "A hybrid approach for optimal location and capacity of UPFC to improve the dynamic stability of the power system," Applied Soft Computing, vol. 52, pp. 974-986, 2017.

[40] K. Kavitha and R. Neela, "Optimal allocation of multi-type FACTS devices and its effect in enhancing system security using BBO, WIPSO & PSO," Journal of Electrical Systems and Information Technology, vol. 5, no. 3, pp. 777-793, 2018.

[41] A. Khodabakhshian, M.R. Esmaili, M. Bornapour, "Optimal coordinated design of UPFC and PSS for improving power system performance by using multi-objective water cycle algorithm", Int. J. of Electrical Power and Energy Systems, Vol. 83, pp. 124–133, Dec. 2016.

[42] J.G. Singh, H.W. Qazi, M. Ghandhari, "Load curtailment minimization by optimal placement of unified power flow controller", Int. Transactions on Electrical Energy Systems, Vol. 26, No. 10, pp. 2272–2284,

[43] S.M.Alamelu, R.P.K.Devi, "Novel optimal placement of UPFC based on sensitivity analysis and evolutionary programming", J. of Engineering and Applied Sciences, Vol. 3, No. 1, pp.59-63, 2008.

[44] B.V. Kumar, N.V. Srikanth, "Optimal location and sizing of Unified Power Flow Controller (UPFC) to improve dynamic stability: A hybrid technique", Int. J. of Electrical Power and Energy Systems, Vol. 64, pp. 429-438, Jan. 2015.

[45] B. Vijay Kumar, N.V. Srikanth, "A hybrid approach for optimal location and capacity of UPFC to improve the dynamic stability of the power system", Applied Soft Computing, Vol. 52, pp. 974–986, March 2017.

[46] L. Horváth and I. J. Rudas, "Active knowledge for the situation-driven control of product definition," *Acta Polytechnica Hungarica,* vol. 10, no. 2, pp. 217-234, 2013.

[47] S. Mousavi, et al., "Dynamic resource allocation in cloud computing," *Acta Polytechnica Hungarica,* vol. 14, no. 4, pp. 83-104, 2017.

[48] K.M. Kumar Reddy, A.K. Rao, R.S. Rao, "An improved Grey Wolf algorithm for optimal placement of unified power flow controller", Advances in Engineering Software, vol. 173, Article Number: 103187, Nov. 2022.

[49] K.A.K. Reddy, S.P. Singh, "Congestion mitigation using UPFC", IET Generation, Transmission and Distribution, Vol. 10, No. 10, pp. 2433-2442, July 2016.

[50] D. Koteswara Raju, Bhimrao S. Umre, Anjali S. Junghare, B. Chitti Babu, "Mitigation of subsynchronous resonance with fractional-order PI based UPFC controller", Mechanical Systems and Signal Processing, Vol. 85, pp. 698–715, Feb. 2017.

[51] S. Dawn, P.K. Tiwari, "Improvement of economic profit by optimal allocation of TCSC & UPFC with wind power generators in double auction competitive power market", Int. J. of Electrical Power and Energy Systems, Vol. 80, pp. 190-201, Sep. 2016.

[52] A. Fattollahi, M. Dehghani, and M. R. Yousefi, "Analysis and Simulation Dynamic Behavior of Power System Equipped with PSS and Excitation System Stabilizer," Signal Processing and Renewable Energy, vol. 6, no. 1, pp. 99-111, 2022.

[53] N. Taheri, H. Orojlo, F. Ebrahimi, "Damping controller design in offshore wind power plants to improve power system stability using fractional order PID controllers based on optimized exchange market algorithm", Journal of Intelligent Procedures in Electrical Technology, vol. 13, no. 51, pp. 91-110, Dec. 2022.

[54] A. Fattollahi-Dehkordi et al., "Decentralized synergistic control of multi-machine power system using power system stabilizer," Signal Processing and Renewable Energy, vol. 4, no. 4, pp. 1-21, 2020.

[55] M. Nayeripour, M.R. Narimani, T. Niknam, S. Jam, "Design of sliding mode controller for UPFC to improve power oscillation damping", Applied Soft Computing, Vol. 11, No. 8, pp. 4766-4772, Dec. 2011.

[56] R.K.Pandey, N.K. Singh, "UPFC control parameter identification for effective power oscillation damping", Int. J. of Electrical Power and Energy Systems, Vol. 31, No. 6, pp. 269-276, July 2009.

[57] M.M. Rahman, A. Ahmed, M.M.H. Galib, M. Moniruzzaman, "Optimal damping for generalized unified power flow controller equipped single machine infinite bus system for addressing low frequency oscillation", ISA Transactions, vol. 116, pp. 97-112, Oct. 2021.