Security Enhancement through the Allocation of a Unified Power Flow Controller (UPFC) in a Power Network for Congestion Management

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ABSTRACT

The electricity demand is continuously increasing, so a most efficient use of the current power system's capacity is desired. Flexible AC Transmission Systems (FACTSs), a recently developed transmission technology, are widely used to boost the power transfer ability of long-distance transmission line networks and to enhance the consistency of the transmission systems. The use of FACTS devices can lead to reduced flows on heavily loaded lines, targeted bus voltage levels, and better power network stability. In this study, an optimization method based on the optimal position of the Unified Power Flow Controller (UPFC) is suggested to boost system security. It is decided that the real power flow is the best place for the UPFC in this instance. The optimal placement during congestion has been determined using the Genetic Algorithm (GA) and the sensitivity to the useful power flow index. Congestion is produced on the network and system performance is evaluated. The proposed solutions are evaluated in the IEEE 30 bus network before being implemented in MATLAB. In the case of congestion, the security of the network is evaluated after connecting the UPFC. The effectiveness of the proposed solution was verified with the help of the Power World Simulator 16.0.

Keywords-UPFC; sensitivity to useful power flow index; genetic algorithm; location optimization; security

I. INTRODUCTION

Modern large and complex networks are delivering under stress as a result of the ongoing increase in demand. The utilities are forced to deal with continuous I^2R loss, line overloads, and variations in bus voltage. Power transmission systems require more capacity, flexibility, reliability, and security. Electric utility companies search for various strategies to effectively use the existing transmission lines up to their working capacity. However, this has the side effect of raising the possibility of system instability while security issues emerge. On improving the network security, techniques that relieve stress have received much attention. Line overloads have been addressed using load shedding and generation rescheduling methods. Load shedding is frequently regarded as the last choice because it will interrupt the power supply of some customers. The operational costs associated with generation rescheduling are fairly substantial. The use of FACTS devices to redistribute power is preferred in order to solve line overload problems since it offers a financially appealing technique of resolving line overloads without switching off power. FACTS devices are frequently applied in networks to ensure steady state and secure operation. FACTS devices can alter system settings such as useful power, MVAR power, and node voltage and are incorporated in the electrical networks to improve their flexibility, stability and security. UPFC is considered to be a part of the most recent generation of FACTS. The UPFC efficiently redistributes power within the power network. Additionally, an existing transmission line can have a UPFC built on it, something that requires less space than adding a new transmission corridor. Due to the extremely high power flow control speeds of UPFCs, overloads brought on by component failures or intermittent generation can potentially be immediately relieved. However, the number of UPFC devices and the complexity of the power system enhance combinatorically the viable zone and the constraints to be taken into consideration in optimization approaches. Authors in [1] explain that the line loading is tracked in real-time performance and can be kept under their thermal tolerance by a quick and effective dynamic response management of the UPFC. In [2], the authors describe the SCOPF simulation used to decide the appropriate place for UPFC in the standard network under higher load circumstances According to [3], the use of UPFC may effectively decrease the N-1 congestion issue of transmission channels running North to South and has a significant cost superiority over the old method. Authors in [4] suggest incorporating a UPFC into a Newton-Raphson load flow method. The created UPFC model is based on a power injection strategy that considers four control modes to manage the voltage amplitude of a given node, the useful and MVAR powers flow in a line concurrently or selectively. In [5], the best place of a DPFC in a network was suggested, followed by the optimum placement of two DPFCs in a system. The artificial algae method is used for the optimal placement of the DPFC in the electrical system. In [6], the authors present and execute a 161 kV UPFC model on an 11-bus network. The weakest bus is located by using FVSI, and the most vital line was identified using MLA. Authors in [7] examine dynamic stability, proposing a method that uses a hybrid strategy to identify the best placement and size of the UPFC. Authors in [8] utilized the conventional strategy to place the TCSC and UPFC in the best possible location for boosting system security under various operating situations and at the best FACTS parameter values. Authors in [9] discuss various methods for reducing congestion, such as load shedding, GA, PSO, MINLP, SFLA, and Fuzzy Logic Systems. The best location for DG, Nodal Pricing, and cost-free methods are also discussed. In [10], the authors suggested a full-featured, reliable and adaptable model for ESS and UPFC together after briefly reviewing the models that are now in use, including the decoupled, power injection, and voltage source models. In order to reduce total grid losses, authors in [11], use the Tabu search algorithm based on an improved HS method to represent an optimization challenge for an I grid. Authors in [12], discuss how FACTS devices can enhance a transmission line's ability to handle power and maintain Voltage. Numerous researches have discussed the ideal location for UPFC [13–16]. However, they are not concerned with the verification of the software-based congestion forecast.

The location of UPFC based on congestion management by using sensitivity based methods and GA in order to relive the congestion and to enhance the power system security and reliability is discussed in this paper. The results are validated by using Power World Simulator (PWS). This investigation offers the ideal positioning for UPFC based on the useful power flow performance index approach. The fact that the active power flow assessment index is a reliable indication of useful power security, a decrease in Performance Indicator (PI) caused by the placement of the FACTS controller will improve network security. The location of these devices in the network was determined using the sensitivity of PI with regard to the FACTS control variables which is comparable to UPFC location determined by GA, for strengthening the security of system during congestion management. The decision on the placement of the UPFC is made in accordance with the results, and verified was with the PWS,

II. UPFC DESIGN

For steady state conditions, UPFC static modeling was created. Series and shunt converters were combined to create UPFC. Voltage (V_S), Insertion angle in a series with line (ϕ_s), and an element of shunt current (Iq), which is in quadrature with voltage Vi at the UPFC's i^{th} bus, are the three control parameters for UPFC [8]. The equivalent circuit of the line incorporating the UPFC is described in Figure. 1. When a line includes UPFC, its apparent powers are expressed as:

$$P_{is} = -V_s^2 g_{ij} - 2V_i V_s g_{ij} \cos(\emptyset_s - \delta_i) + V_j V_s\left[g_{ij} \cos(\emptyset_s - \delta_j) + b_{ij} \sin(\emptyset_s - \delta_j)\right] \quad (1)$$

$$Q_{is} = V_i I_q + V_i V_s\left[g_{ij} \sin(\emptyset_s - \delta_i) + b_{ij} \cos(\emptyset_s - \delta_i)\right] \quad (2)$$

$$P_{js} = V_j V_s\left[g_{ij} \cos(\emptyset_s - \delta_j) - b_{ij} \sin(\emptyset_s - \delta_j)\right] \quad (3)$$

$$Q_{js} = -V_j V_s\left[g_{ij} \sin(\emptyset_s - \delta_j) + b_{ij} \cos(\emptyset_s - \delta_j)\right] \quad (4)$$

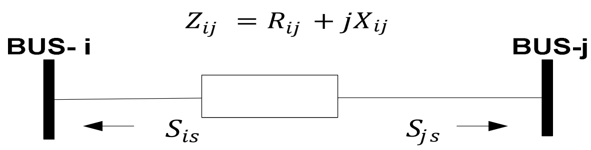

Fig. 1. FACTS controller model.

A. *Power World Simulator Software based UPFC Model*

A systematic approach is developed to simultaneously control real power, MVAR power, and bus voltages [10]. The useful power, MVAR power, or the voltage of each node can be used to secure the network. If the bus element is neutral to the bus parameters, the power flow solution is constant. UPFC is connected in the line and always maintains the voltage (V_{Et}) in sending bus i and injects P_{Bt}-Q_{Bt} at the receiving end to bus j as illustrated in Figure 2. Under loss-free UPFC, the power values for bus i and bus j would be equal as indicated in Figure 3. The UPFC sending end's known values are PEt and VEt. When UPFC is implemented at the sending, according to the design, an additional bus must be added to the network in the PWS [10]. If a UPFC is developed in the center of the line, the network will need to add two buses.

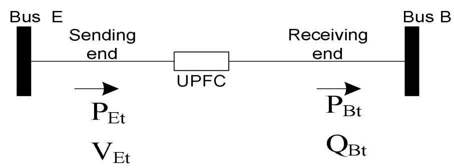

Fig. 2. UPFC power flow model.

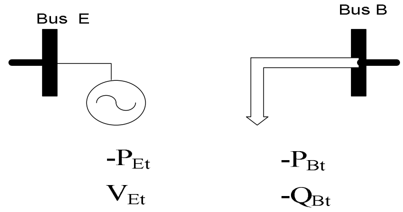

Fig. 3. UPFC static model.

III. UPFC CONTROLLER PLACEMENT METHODOLOGY

The reserve capacity of the transmission system has a partial representation in load ratio. Additionally, the reserve capacity increases as the load rate decreases. Therefore, increasing the transmission capacity of overloaded lines could meet the needs of increasing load. Regarding accident prevention, both the stability state and the typical power flow of the system are examined. After that, the system starts to use congestion management. Here, the real power flow performance index and GA are used to calculate the maximum power flow and the most suitable position for placing the UPFC is selected. The system returns to regular operation and security is enhanced after attaching the UPFC.

A. Sensitivity-Based Method

The performance of the line under routine and emergency circumstances affects the active power flow Performance Indicator (PI). The active power flow PI [8] technique can be used to describe the loadability of the system's functionality:

$$PI = \sum_{m=1}^{N_l} \frac{w_m}{2n}\left(\frac{P_{lm}}{P_{lm}^{max}}\right)^{2n} \tag{5}$$

where, $w_m = 1$, N_l is the total number of lines in the system, w_m is a real non-negative weighting coefficient, P_{lm}^{max} is the maximum load capacity of the line, P_{lm} is the actual power flow in the line, and $n = 2$.

The degree of severity is determined by the system's loading circumstances in both normal and emergency situations. The sensitivity technique is used to analyze the system's performance. Low PI value means an operation within thermal limits under steady state conditions. The value of PI rises when an overloaded condition is reached. In this article, the active power flow performance indicator approach is used to decide where to allocate UPFC in relation to series insertion angle (ϕs) as shown below:

$$C_2^k = \frac{\partial PI}{V_S \partial \emptyset_s} = \sum_{m=1}^{N_l} w_m P_{lm}^3 \left(\frac{1}{P_{lm}^{max}}\right)^4 \frac{\partial P_{lm}}{V_S \partial \emptyset_s} \tag{6}$$

The real power injection in the line is taken into consideration when computing DC power flow equation [8] :

$$P_{lm} = \begin{cases} \sum_{\substack{n=1 \\ n\neq s}}^{N} S_{mn} P_n & for\ m \neq k, \\ \sum_{\substack{n=1 \\ n\neq s}}^{N} S_{mn} P_n + P_j & for\ m = k \end{cases} \tag{7}$$

According to Figure 1, the UPFC is situated in line k, which connects buses i and j. Pj is the additional electrical power that UPFC in the system injects into the line. The network has N buses, and S_{mn} is the mn^{th} part of the power flow matrix [S]. The following equation can be created by combining (6) and (7):

$$\frac{\partial P_{lm}}{V_s \partial \emptyset_s} = \begin{cases} \left(S_{mi}\frac{\partial P_{is}}{V_s \partial \emptyset_s} + S_{mj}\frac{\partial P_{js}}{V_s \partial \emptyset_s}\right) & for\ m \neq k \\ \left(S_{mi}\frac{\partial P_{is}}{V_s \partial \emptyset_s} + S_{mj}\frac{\partial P_{js}}{V_s \partial \emptyset_s}\right) + \frac{\partial P_{js}}{V_s \partial \emptyset_s} & for\ m = k \end{cases} \tag{8}$$

where:

$$\left.\frac{\partial P_{is}}{V_s \partial \emptyset_s}\right|_{\emptyset s=0} = -2V_i g_{ij}\cos(\emptyset_s - \delta_i) + V_j\left(g_{ij}\cos(\emptyset_s - \delta_j) + b_{ij}\sin(\emptyset_s - \delta_j)\right)$$

$$\left.\frac{\partial P_{js}}{V_s \partial \emptyset_s}\right|_{\emptyset_s=0} = V_j\left(g_{ij} cos\delta_j + b_{ij} sin\delta_j\right)$$

Due to its cost effectiveness, the useful power flow PI is derived using the aforementioned equation with regard to the series insertion angle as an installed UPFC control variable in each line individually. It should be put in an ideal position. The optimum allocation for UPFC placement is in the line with the most negative sensitivity index to improve system security, but other criteria may also be used to decide that UPFC should not be situated close to a producing transformer, despite the most negative sensitivity index.

B. Genetic Algorithm

GAs are methods for conducting a global search that are based on natural selection and genetics. They don't need any specialized knowledge or characteristics of the goal function and they can look for multiple potential solutions simultaneously. They are also excellent techniques for finding an effective answer to a complex problem since they consistently deliver high-quality solutions. Furthermore, they are useful algorithms that are simple to apply to the analysis of power systems.

The ratio of a line's actual power flow to its maximum power flow is known as the line's sensitivity factor. It is helpful in figuring out the severity of the line, where high severity indicates the line has a significant chance of collapsing soon. The fitness function to be maximized [16] is:

$$\sum_{ij=1}^{NL}\left(\frac{P_{ij}}{P_{ij}^{max}}\right) \tag{9}$$

where P_{ij} is the flow of power on line ij, P_{ij}^{max} is the maximum flow of power in line ij, and NL is the number of lines.

For the best allocation of UPFC, the line with the highest fitness value is taken into account.

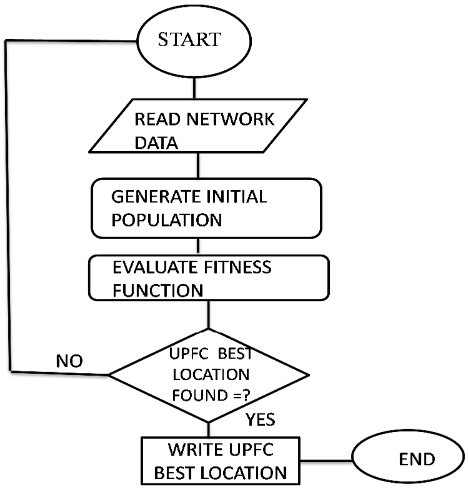

Fig. 4. Flowchart of the UPFC device optimal allocation process.

The GA begins with the initial population being generated at random and continues with selection, crossover, and mutation before the maximum generation is attained. Each string that relates to a location is used to construct the initial population, which is the transmission line's number where the FACTS is supposed to be placed. The position value differs for each string. Every member of the population will then have its objective function (fitness) evaluated. GAs have limitations to finding the objective function's largest positive value. In the process of reproduction, an individual is chosen to become part of a new generation based on its fitness. The primary goal of crossover is to combine the knowledge of two distinct individuals to create a new one. To prevent an early convergence to a local optimum, mutation is used to inject some type of artificial diversification into the population. Figure 4 summarizes the suggested optimization method. The "Arrangement of the FACTS locations" procedure is required to guarantee that each line has only one FACTS device.

IV. SIMULATION RESULTS

On a modified IEEE 30 bus network [11], the suggested technique for using UPFC in the most effective way was employed using MATLAB. Bus no. 1 was used as a reference. According to load flow analysis, line 4-6 has reached its maximum thermal limit.

A. Sensitivity Approach

The most suitable allocation of the UPFC was computed based on active power flow. With regard to the insertion angle in series with line as a control variable, the UPFC was put in each line for similar operational circumstances in order to decrease system's overloads without modifying the network's topology or without rescheduling generation. Table I shows the PI sensitivity indicator in relation to UPFC. According to Table I, line 5-7 has the largest negative sensitivity index with respect to ϕs. Therefore, it is appropriate to install the UPFC in line 5-7 to prevent overloading and improve system security.

TABLE I. SENSITIVITY BASED ON PI ON AN IEEE 30 BUS NETWORK WITH OVERLOAD AT LINE 4-6

Line no	$C_2^k = \frac{\partial PI}{V_s \partial \phi_s}$
1-3	-1.149867577
2-4	-1.378312267
2-5	-2.943605844
2-6	-4.151895176
3-4	-2.198711769
5-7	-7.896648528

B. Genetic Algorithm

In this paper, we try to discover the optimal location for the UPFC using GA. The best fitness function findings for UPFC are displayed in Table II. Table II shows that the fitness values in lines 2-4 and 2-5 are the highest, however the installation for UPFC location in lines 2-4 and 2-5 does not relieve the congestion. So, line 5-7 is the optimum location for the placement of UPFC because it can control the useful power flow in line and enhance the security of the network.

TABLE II. OVERLOAD IN LINE 4-6: GA BASED LOCATION FOR UPFC ON IEEE 30 BUS NETWORK

Line no	Best fitness value
1-3	0.933
2-4	1.0453
2-5	1.0443
2-6	0.9674
3-4	0.9304
5-7	0.9515

C. Power World Simulator

Despite having certain UPFC properties that increase power system effectiveness, there is a limitation related to active power injection. This capability's implementation greatly improves UPFC steady-state performance. The simple UPFC parameters calculation and steady state UPFC model simulation clearly demonstrate its superiority to other models. UPFC parameters can be simply calculated without the need for initial values and their limits may be easily altered. The results would be more reliable if these investigations were conducted using the provided model in a real network rather than a simplified one as shown in Table III. Figure 5 illustrates the system's congestion situation under steady state conditions. According to Figure 6, adding a UPFC to line 1-3 reduces overloading from 104% to 101% on line 4-6. Figure 6 depicts the line loading limit of 101%. According to Figure 7, even though overloading decreased after installing UPFC in lines 2–6, from 104% to 97%, according to PWS, the situation is still dangerous because the power flow in lines 4-6 is indicated by a red arrow, indicating that the thermal limit has not yet been obeyed. The power flow illustrated by the green arrows in Figure 8 shows that it runs within its thermal limit and decreases line 4-6 overloading from 104% to 97%. Therefore, line 5-7 is an excellent location for UPFC insertion according to the sensitivity indicator, GA, and the PWS has verified this location for improving system security.

TABLE III. LOCATION FOR UPFC ON THE IEEE 30 BUS NETWORK USING PWS. LINE 4-6 IS OVERLOADED BY 104%

UPFC placement in line no	% loading reduces in line 4-6 after UPFC placement
1-3	101
2-4	101
2-5	100
2-6	97 (congestion not relieved completely)
3-4	101
5-7	97 (completely relieved)

V. DISCUSSION

On a large power network, congestion is the most frequently occurring problem. Such problems can be avoided using UPFC. Simulation results indicate that the conventional sensitivity approach, based on coding methods, for determining the best location of UPFC is line 5-7 in an IEEE 30 bus network. The derived location is verified by the result of GA. The validation of the result is done by PWS. The network security is significantly enhanced by UPFC optimal location at line 5-7.

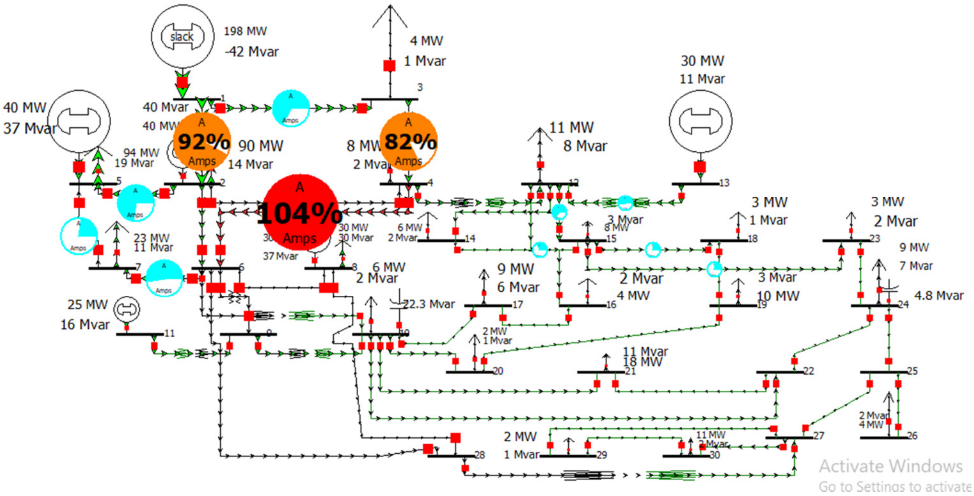

Fig. 5. System overload on line 4-6 of a modified IEEE 30 bus.

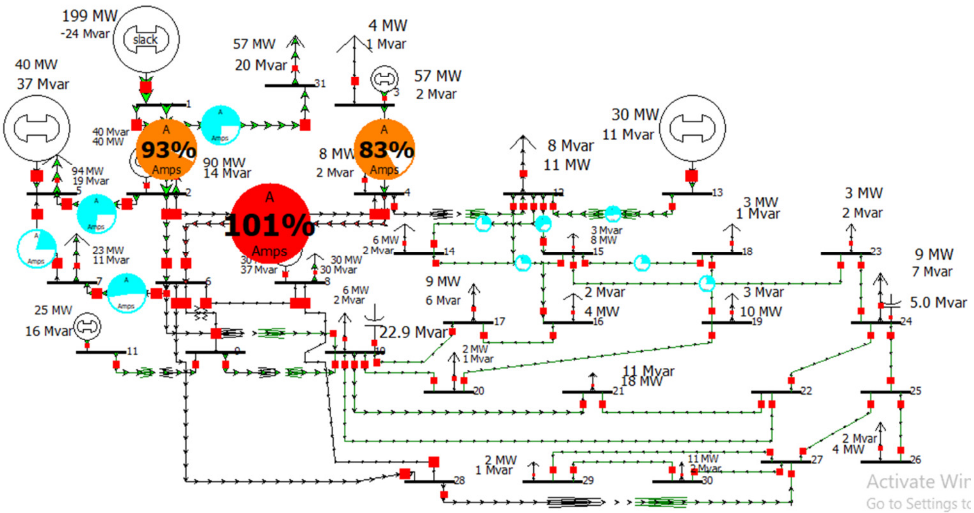

Fig. 6. UPFC located in line 1-3.

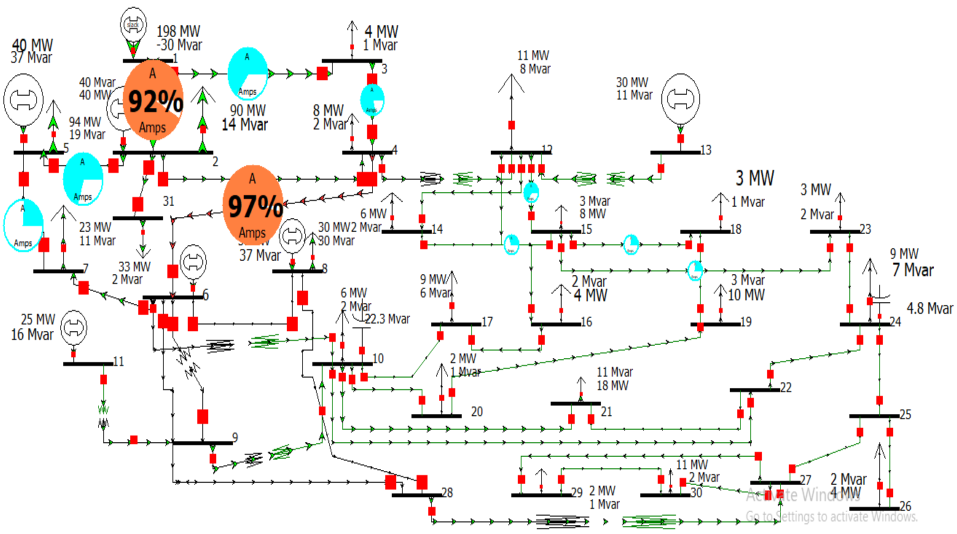

Fig. 7. UPFC located in line 2–6 (line 4-6 is shown in red despite 97% capacity).

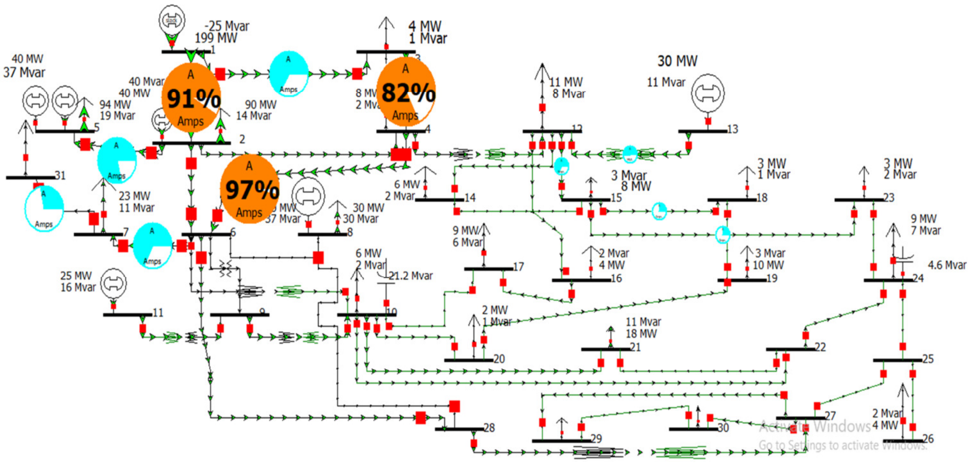

Fig. 8. UPFC located in line 5-7 (green indicates the flow in line 4-6 displays 97% loading).

VI. CONCLUSION

In this study, a sensitivity-based technique and GA have been developed for determining the most appropriate location for placing a UPFC device. Test results demonstrate that the sensitivity factor or GA can be utilized to successfully deploy UPFCs in response to the desired objectives. The position of UPFC can be chosen if there is congestion. With the use of PWS, a comprehensive model of UPFC must be taken into consideration after choosing the appropriate location in order to relieve congestion and improve system security. Line 5-7 is the resulting suitable placement for UPFC by both GA and active power flow performance indicator methods and this result was validated by PWS software.

REFERENCES

[1] P. Song, Z. Xu, and H. Dong, "UPFC-based line overload control for power system security enhancement," *IET Generation, Transmission & Distribution*, vol. 11, no. 13, pp. 3310–3317, Jun. 2017, https://doi.org/10.1049/iet-gtd.2017.0022.

[2] S. Adhvaryyu, C. Mukherjee, and D. Seri, "Security Constrained Optimal Power Flow with Optimally Allocated UPFC Based on Technical and Economic Criteria," in *2017 International Conference on Computer, Electrical & Communication Engineering (ICCECE)*, Kolkata, India, Sep. 2017, https://doi.org/10.1109/ICCECE.2017.8526229.

[3] M. Li *et al.*, "Application of UPFC in Fujian 500 kV power grid," *The Journal of Engineering*, vol. 2019, no. 16, pp. 2510–2513, 2019, https://doi.org/10.1049/joe.2018.8576.

[4] M. Ebeed, S. Kamel, J. Yu, and F. Jurado, "Development of UPFC operating constraints enforcement approach for power flow control," *IET Generation, Transmission & Distribution*, vol. 13, no. 20, pp. 4579–4591, Aug. 2019, https://doi.org/10.1049/iet-gtd.2018.5609.

[5] J. Chakravorty and J. Saraswat, "Deciding Optimal Location of DPFC in Transmission Line Using Artificial Algae Algorithm," *Engineering, Technology & Applied Science Research*, vol. 9, no. 2, pp. 3978–3980, Apr. 2019, https://doi.org/10.48084/etasr.2667.

[6] W. D. Asihene, F. B. Effah, and E. Normanyo, "Utilizing Unified Power Flow Controller for Voltage Stability Improvement of the Electric Power Transmission System of Ghana," *Jurnal Nasional Teknik Elektro*, vol. 9, no. 1, pp. 51–60, May 2020, https://doi.org/10.25077/jnte.v9n1.760.2020.

[7] B. Vijay Kumar and N. V. Srikanth, "Optimal location and sizing of Unified Power Flow Controller (UPFC) to improve dynamic stability: A hybrid technique," *International Journal of Electrical Power & Energy Systems*, vol. 64, pp. 429–438, Jan. 2015, https://doi.org/10.1016/j.ijepes.2014.07.015.

[8] J. G. Singh, S. N. Singh, and S. C. Srivastava, "Enhancement of Power System Security through Optimal Placement of TCSC and UPFC," in *2007 IEEE Power Engineering Society General Meeting*, Tampa, FL, USA, Jun. 2007, https://doi.org/10.1109/PES.2007.385939.

[9] A. Pillay, S. Prabhakar Karthikeyan, and D. P. Kothari, "Congestion management in power systems – A review," *International Journal of Electrical Power & Energy Systems*, vol. 70, pp. 83–90, Sep. 2015, https://doi.org/10.1016/j.ijepes.2015.01.022.

[10] S. Kamel, M. Ebeed, J. Yu, and W. Li, "A comprehensive model of C-UPFC with innovative constraint enforcement techniques in load flow analysis," *International Journal of Electrical Power & Energy Systems*, vol. 101, pp. 289–300, Oct. 2018, https://doi.org/10.1016/j.ijepes.2018.03.034.

[11] Z. M. Zohrabad, "Application of Hybrid HS and Tabu Search Algorithm for Optimal Location of FACTS Devices to Reduce Power Losses in Power Systems," *Engineering, Technology & Applied Science Research*, vol. 6, no. 6, pp. 1217–1220, Dec. 2016, https://doi.org/10.48084/etasr.725.

[12] M. Y. A. Khan, U. Khalil, H. Khan, A. Uddin, and S. Ahmed, "Power Flow Control by Unified Power Flow Controller," *Engineering, Technology & Applied Science Research*, vol. 9, no. 2, pp. 3900–3904, Apr. 2019, https://doi.org/10.48084/etasr.2587.

[13] N. G. Hingorani and L. Gyugyi, *Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems*, 1st ed. New York, NY, USA: Wiley-IEEE Press, 1999.

[14] E. Acha, C. R. Fuerte-Esquivel, H. Ambriz-Pérez, and C. Angeles-Camacho, *FACTS: Modelling and Simulation in Power Networks*, 1st ed. Hoboken, NJ, USA: Wiley, 2004.

[15] "Power Systems Test Case Archive - UWEE," *University of Washington*. http://labs.ece.uw.edu/pstca/.

[16] J. S. Amirtham and V. Uma, "Optimal location of unified power flow controller enhancing system security," in *2016 Second International Conference on Science Technology Engineering and Management (ICONSTEM)*, Chennai, India, Mar. 2016, pp. 326–331, https://doi.org/10.1109/ICONSTEM.2016.7560971.

[17] P. S. Vaidya and V. P. Rajderkar, "Optimal Location of Series FACTS Devices for Enhancing Power System Security," in *2011 Fourth International Conference on Emerging Trends in Engineering & Technology*, Port Louis, Mauritius, Aug. 2011, pp. 185–190, https://doi.org/10.1109/ICETET.2011.58.

[18] V. P. Rajderkar and V. K. Chandrakar, "Comparison of Series FACTS Devices Via Optimal Location in a Power System for Congestion Management," in *2009 Asia-Pacific Power and Energy Engineering Conference*, Wuhan, China, Mar. 2009, https://doi.org/10.1109/APPEEC.2009.4918227.

[19] A. V. Hardas, V. Rajderkar, V. K. Chandrakar, and V. D. Hardas, "Optimum Location of Thyristor Controlled Phase Angle Regulator Based on Performance Index," in *2018 International Conference on Smart Electric Drives and Power System (ICSEDPS)*, Nagpur, India, Jun. 2018, pp. 132–136, https://doi.org/10.1109/ICSEDPS.2018.8536084.

[20] V. K. Chandrakar and A. G. Kothari, "Optimal location for line compensation by shunt connected FACTS controller," in *The Fifth International Conference on Power Electronics and Drive Systems, 2003. PEDS 2003.*, Singapore, Aug. 2003, vol. 1, pp. 151–156, https://doi.org/10.1109/PEDS.2003.1282736.

[21] R. Dakhare and V. K. Chandrakar, "Congestion Management by Phase Shifting Transformer Using Fuzzy Logic Control," in *2021 6th International Conference for Convergence in Technology (I2CT)*, Maharashtra, India, Apr. 2021, https://doi.org/10.1109/I2CT51068.2021.9418190.

[22] S. S. S. Kapse, M. B. Daigavane, and P. M. Daigavane, "Optimal Localization and Sizing of UPFC to Solve the Reactive Power Dispatch Problem Under Unbalanced Conditions," *IETE Journal of Research*, vol. 66, no. 3, pp. 396–413, May 2020, https://doi.org/10.1080/03772063.2018.1491808.

[23] V. P. Rajderkar and V. K. Chandrakar, "Optimal location of thyristor controlled series compensator (TCSC) for congestion management," *Indian Institute (I) Journal-EL*, vol. 9, pp. 30–35, Dec. 2009.

[24] S. P. Nangrani and K. D. Joshi, "Trends in chaos and instability for understanding system complexity," *Journal of Intelligent & Fuzzy Systems*, vol. 38, no. 5, pp. 6727–6737, Jan. 2020, https://doi.org/10.3233/JIFS-179750.

[25] R. H. Adware, P. P. Jagtap, and J. B. Helonde, "Power System Oscillations Damping Using UPFC Damping Controller," in *2010 3rd International Conference on Emerging Trends in Engineering and Technology*, Goa, India, Aug. 2010, pp. 340–344, https://doi.org/10.1109/ICETET.2010.167.

[26] P. Jagtap and V. Chandrakar, "Comparative Study of UPFC Controllers to Improve Transient and Dynamic Stabilty of Power System," in *2021 IEEE 4th International Conference on Computing, Power and Communication Technologies (GUCON)*, Kuala Lumpur, Malaysia, Sep. 2021, https://doi.org/10.1109/GUCON50781.2021.9573804.