AUT Journal of Electrical Engineering

AUT J. Elec. Eng., 54(2) (2022) 225-234
DOI: 10.22060/eej.2022.21061.5454

Optimal Locating and Sizing of Unified Power Quality Conditioner for Multi-Objective Congestion Management by Hybrid Fuzzy- Harmony Search Algorithm

A. Moradi[1*], S. M. R. Hashemi[2], S. M. Mirrezaei[3]

[1] Department of Electrical Engineering, Mahdishahr Branch, Islamic Azad University, Mahdishahr, Iran.
[2] Faculty of Computer Engineering, Shahrood University of Technology, Semnan, Iran.
[3] Faculty of Electrical Engineering, Shahrood University of Technology, Semnan, Iran.

ABSTRACT: Flexible AC transmission system devices can function efficiently, powerfully, and economically in congestion management through the control of the lines transmission power and the voltage of the power systems buses. However, the congestion management of power systems may affect the transient stability or network voltage stability, and also reduce the system security. Therefore, constructing congestion management requires the consideration of power system stability. In this paper, a multi-objective Fuzzy structure is employed to obtain the optimal locating and sizing of the Unified Power Quality Conditioner -phase angle control for the congestion management, so that it optimizes total operating cost, voltage, and transient security. In order to achieve the above goals, Unified Power Quality Conditioner-phase angle control placement has been performed using the Fuzzy method. Using Fuzzy inference system, triple objective functions are expressed in terms of a single objective function and optimized with the Harmony Search Algorithm. To illustrate the effectiveness of the proposed approach, this method is implemented in MATLAB software for the congestion management of England's new network with 39 buses. The results indicate that using the proposed method, congestion management is done optimally, which not only does not reduce system security, but also increases its security margin.

Review History:

Received: Feb. 06, 2022
Revised: Mar. 25, 2022
Accepted: May, 15, 2022
Available Online: Dec. 01, 2022

Keywords:

Congestion management
Fuzzy inference system
Harmony Search Algorithm (HSA)
Power system stability margin
Unified Power Quality Conditioner-phase angle control (UPQC-PAC)

1- Introduction

Today, with increasing demand for power and restrictions on the construction of new lines, the congestion of network lines and network power losses are increasing. Therefore, with the available facilities on the network as much as possible, the power losses and congestion of the network lines should be reduced. The congestion of the lines is a challenge in transferring power from generators to load centers. The congestion of the lines occurs when the transmission system is not able to meet a specific pattern of production, consumption and transmission and finally the system security is compromised [1]. Hence, it is necessary to relieve the congestion of the transmission system before violating the system constraints [2]. In [3], the congestion management is done with consideration of voltage stability. In [4], the stochastic multi-objective congestion management is done with considering voltage and transient stabilities. An optimal reorganization of the transmission network using the transmission line keys is presented in [5] as a method for the congestion management. In [6], a method based on Optimal Power Flow (OPF) with the lowest cost of congestion as the target function is presented. In [7], the optimal location of series FACTS device TCSC is done to remove congestion with minimum cost of installation in a deregulated power system. In [8], a new approach for optimal demand response program in the microgrid considering the high penetration of the solar energy and tidal units as significant and popular renewable sources in the system is proposed. The congestion management in restructured system using the OPF framework is widely discussed in [9]. The management of real-time congestion can be quickly generated by reprogramming and with the load elimination method, which is one of the most commonly used methods of using the sensitivity of the transmission lines to the change in production and load, which requires no duplication of the process and it is widely used to solve the congestion management problem [10]. The problem of managing real-time congestion has been solved [11] in order to minimize the cost of rescheduling of generators by choosing optimal participant generators. In [12], a new approach is proposed based on the flow-gate marginal prices to calculate and invest the congestion surplus. In [13], interior point-initialized particle swarm optimization approach has been presented to solve the congestion management in multiutility market. In [14], a new approach based on load curtailment/generator rescheduling is proposed for congestion management in a deregulated power network. In [15], a new method is introduced to reduce congestion cost by feeding needed reactive power of system in addition to load shedding and re-dispatching active power of generators. A multilayer feed forward neural network is presented for clearing line overloads in real time for restructured power system [16].

Since early 1970s, powerful thyristors, power capacitors, and large reactors have been employed in various circuit con-

*Corresponding author's email: alireza.moradi@msh-iau.ac.ir

figurations to control the exchange of reactive power. These devices actually provide variable parallel impedance with a switch that can be very effective in controlling the reactive power. Unbalanced voltage, overvoltage, and voltage drop are known as the most common problems of power quality [17]. These problems caused to be emerged disturbance in sensitive loads, significant financial losses, reduced Power Quality (PQ) and a decrease in system power factor. According to stringent standards [18], it is necessary to maintain the PQ of the source in modern power systems.

As efficient, cost-effective and powerful tools, FACTS devices can be employed as fundamental means in congestion management by controlling power flows of transmission lines without structure changes or generation re-dispatching [19].

In [20], Fujita and Akagi introduced a Unified Power Quality Conditioner (UPQC) that has ability to improve PQ on both source and load side.

Since then UPQC has been recognized for its top-notch capability of reducing main PQ issues almost entirely, which makes it one of the most intriguing solutions for the improvement of PQ in the distribution system [21]. Lately, theoretical results of UPQC employment in smart grids have been vastly considered by scholars of the field [22]. As UPQC is under research for the time being, it has not found its application capacity yet. Additionally, the production and marketing costs of UPQC system is considerably high due to entailing two sets of power converters and transformers in its structure [17].

Consequently, it is necessary to reduce the size of the UPQC system without missing its offset capabilities to increase the experimental use of the UPQC.

In reference [23], Verma et al. employed sensitivity-based two-step optimization approach to accommodate Unified Power Flow Controller (UPFC) for the congestion management. According to this approach, UPFC should be installed in a line that has the most negative coefficient of sensitivity. However, there are no economic considerations in this reference. In [24], Chong et al. employed sensitivity-based three-step optimization approach to accommodate UPFC for the congestion management. In [25], the sensitivity analysis was used by an active power flow index for the Thyristor controlled series capacitor and Thyristor Controlled Phase Angle Regulator placement. In this reference, TCSC should be installed in a line that has the most negative coefficient of sensitivity and Thyristor Controlled Phase Angle Regulator should be installed in a line that has the highest sensitivity coefficient, considering the fact that FACTS installation on the mentioned line has the lowest cost while relieving the congestion. In 2004, Alomoush studied the role of SSSC in congestion relief in the electricity market. In 2005, Yao et al. investigated the effect of SSSC on the congestion management. In the same year, Glanzman and Andersson used the SVC and TCSC to relieve the congestion. Additionally, YAO and Al-Dabbagh studied on UPFC's role in removing the congestion of transmission lines [26-27]. In [28], Reddy and Padhy optimized TCSC and UPFC location for the congestion management in the restructured power system using genetic algorithm. In [29], Moradi et al. optimized TCSC location for the congestion management in the restructured power system, using components of nodal prices. In [30], a novel congestion management approach within an Optimal Power Flow framework in the context of restructured power markets is proposed. In [31], a novel congestion management approach is proposed by using the optimal transmission switching and demand response for a system with conventional thermal generators and renewable energy sources. In [32], congestion management is done using multi-objective hybrid differential evolution and particle swarm optimization with solar-energy storage system based distributed generation in deregulated power market. None of the mentioned references has considered power system security concerns.

Nevertheless, by removing congestion of power, systems can be achieved using a lower voltage and transient stability due to focusing on security restrictions. This is why the consideration of power system stability in the congestion management construction is essential.

The employment of a multi-objective structure, which simultaneously optimizes three goals of reducing the operating costs in the congestion management, improving the voltage stability, and the transient stability is presented in this paper using UPQC-PAC. In order to achieve these goals, UPQC-PAC placement has been performed using the Fuzzy method. To illustrate the effectiveness of the proposed approach, this method is implemented in MATLAB software for the congestion management of England's new network with 39 buses. The contents of this paper are organized as follows: Sections 2 and 3 present the mathematical modeling of UPQC-PAC and problem formulation, respectively. The proposed Fuzzy method for finding the optimal location and size of UPQC-PAC is described in section 4. Section 5 deals with simulation results, and section 6 presents the conclusions.

2- UPQC-PAC Modeling

In this research, Phase Angle Control (PAC), an integrated optimizer of power quality, is used which contains two series and shunt inverters, as seen in Fig. 1. In common usage, they employ the series inverter for the supply voltage mitigation sag or swell. and also utilize the shunt inverter for compensation if there are load current and harmonics as reactive components. In the case of normal condition and voltage sag, series voltage V_{Se} and shunt compensating current I_{Sh} would be injected by series inverters and shunt inverters, respectively. While the operating condition is healthy, the series inverter injects to create a load end voltage shift in the phase angle δ in the UPQC-PAC model, as demonstrated in Fig. 2(a). In the case of reactive power provision, this aspect (i.e. the shift of phase angle) boosts the series inverter that lead to rate reduction of shunt inverters and a UPQC overall rating. In other words, if phase angle δ is controlled suitably, load reactive power could be divided between shunt and series active filters without influencing on nominal amounts of UPQC. While there is voltage sag, v injection can provide a constant situation for load end voltage, as seen in Fig. 2(b). Maximum rating of series inverter is the key element to indicate the amount of V_{Se}. Mathematical details and formulation of UPQC-PAC can be found in [33-34].

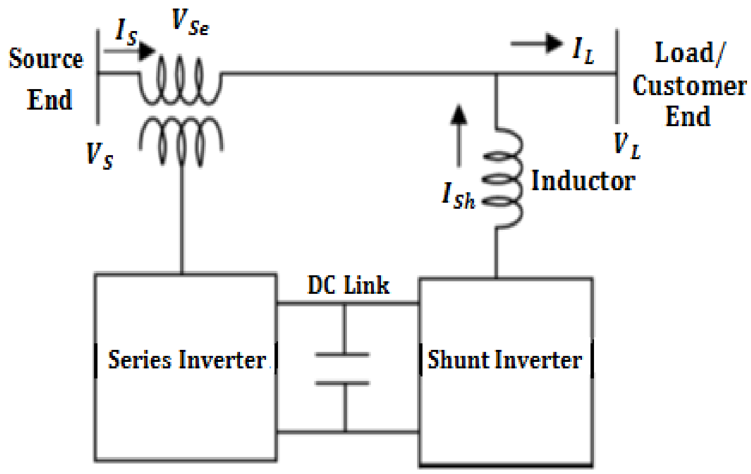

Fig. 1. General Schematic of UPQC [33]

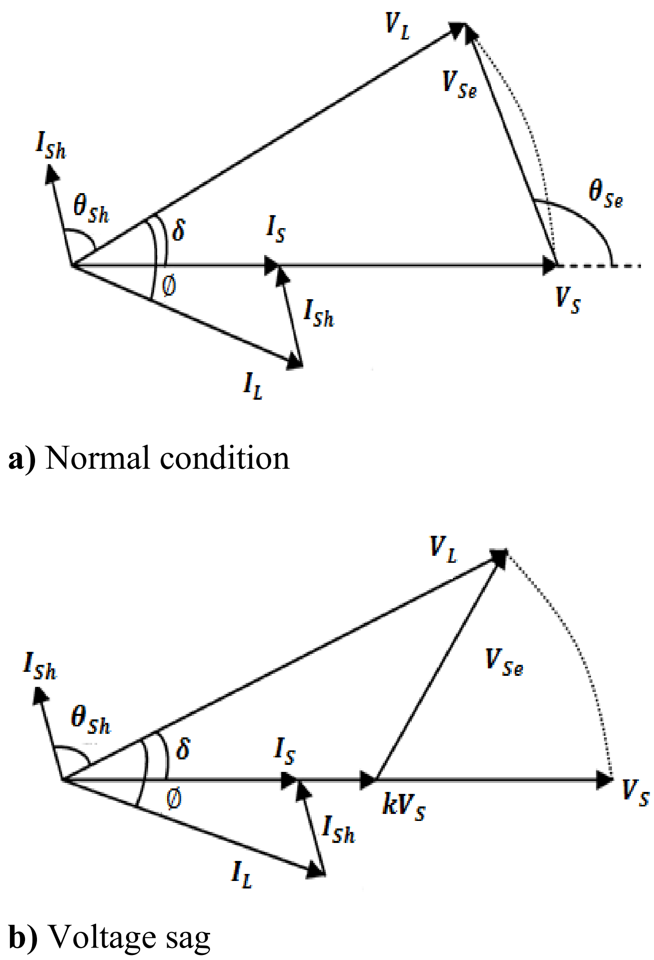

Fig. 2. Phasor Diagram of UPQC [33]

3- Problem Formulation

In this paper, a multi-objective congestion management structure is formulated to determine the optimal location and size of UPQC-PAC. The proposed structure minimizes the total operating cost and maximizes Voltage Stability Margin (VSM) and Corrected Transient Energy Margin (CTEM) to improve the power system stability. The phrases for these goals are given as follows:

3- 1- Minimize f_1: Total Operating Cost

$$\text{Minimize} f_1 = \left(\sum_{k \in SG} C_{Gk}\left(P_{Gk}\right) - \sum_{k \in SD} B_{Dk}\left(P_{Dk}\right) \right) \quad (1)$$

where SD is the set of participating demands, and SG is the set of generators in the market. Additionally, B_{Dk} and C_{Gk} are the benefit curve of P_{Dk} demand and bid curve of P_{Gk} generator, respectively. It is noteworthy that the benefit demands curve and generators bid curve are regarded as quadratic functions [35].

3- 2- Maximize f_2: Voltage Stability Margin (VSM)

In this paper, VSM [36] is an index used for voltage security measurement and Continuation Power Flow (CPF) is used to define the maximum load ability limit.

After using the congestion management, the final VSM is given below:

$$\text{Maximize} f_2 = VSM = VSM_0 + \Delta VSM \quad (2)$$

where VSM_0 is VSM value before using congestion management, and the phrase for ΔVSM is given as follows [37]:

$$\Delta VSM \cong -\frac{\partial VSM}{\partial Q_{Di}} Q_{ic} - \frac{\partial VSM}{\partial Q_{Dj}} Q_{jc} + \sum_{k \in SD} \frac{\partial VSM}{\partial Q_{Dk}} \Delta Q_{Dk} \quad (3)$$

where i and j are two buses related to the branch where the UPQC-PAC is installed. Q_{ic} and Q_{jc} are reactive power injected to buses for installing UPQC-PAC. Q_{Dk} is the reactive power consumption in bus k, and SD is the set of demands participating in the market.

3- 3- Maximize f_3: Corrected Transient Energy Margin (CTEM)

In this paper, CTEM [38] is the index used to measure transient security. CTEM is defined as a function of generators active power generation.

After using congestion management, the final CTEM is given as follows:

$$\text{Maximize} f_3 = CTEM = CTEM_0 + \Delta CTEM \quad (4)$$

where $CTEM_0$ is the $CTEM$ value before using congestion management, and the phrase for $\Delta CTEM$ is given as follows [37]:

$$\Delta CTEM \cong \sum_{k \in SG} \frac{\partial CTEM}{\partial P_{Gk}} \Delta P_{Gk} \quad (5)$$

where P_{Gk} is active power production in bus k and SG is the set of generators participating in the market.

The optimization is performed under the following equality and inequality constraints.

3- 3- 1- Equality Constraints

- Power balance equation

$$P_{GK} - P_{DK} = |V_K| \sum_{m \in SN} |Y_{KM}||V_M| \cos(\delta_K - \delta_m - \theta_{km}) \quad K \epsilon \overline{SN} \quad (6)$$

$$Q_{GK} - Q_{DK} = |V_K| \sum_{m \in SN} |Y_{KM}||V_M| \sin(\delta_K - \delta_m - \theta_{km}) \quad K \epsilon \overline{SN} \quad (7)$$

where P_{GK} and Q_{GK} are the active and reactive power production in bus K, P_{DK}, and Q_{DK} are the active and reactive power consumption in bus K, and SN is the number of buses in the system.

3- 3- 2- Inequality Constraints

- Apparent line flow limit

$$\left|S_{ij}\left(V, \delta\right)\right| \le S_{ij}^{max} \quad (8)$$

- Power generation

$$P_{GK}^{min} \le P_{GK} \le P_{GK}^{max} \quad K \in SG \quad (9)$$

$$Q_{GK}^{min} \le Q_{GK} \le Q_{GK}^{max} \quad K \in SG \quad (10)$$

- Demand limit

$$P_{DK}^{min} \le P_{DK} \le P_{DK}^{max} \quad (11)$$

$$Q_{DK}^{min} \le Q_{DK} \le Q_{DK}^{max} \quad (12)$$

- Bus voltage limit

$$V_K^{min} \leq |V_K| \leq V_K^{max} \quad (13)$$

- VSM limit

$$VSM \geq VSM_0 \quad (14)$$

- CTEM limit

$$CTEM \geq CTEM_0 \quad (15)$$

where P_{GK}^{min} and P_{GK}^{max} are minimum and maximum active power production in bus K, Q_{GK}^{min} and Q_{GK}^{max} are minimum and maximum reactive power production in bus K, and are minimum and maximum active power consumption in bus K, and are minimum and maximum reactive power consumption in bus K, V_K^{min} and V_K^{max} are minimum and maximum voltage in bus K, S_{ij} is the apparent power in transmission line connecting buses i and j and S_{ij}^{max} is its maximum limit.

4- Proposed Fuzzy Method

In this paper, the optimal locating and sizing of the UPQC-PAC for multi-objective congestion management is presented, which includes three goals of reducing the system operating costs, improving the transient stability and voltage stability. In this paper, the triple objective functions have been transformed into a single objective function by the Fuzzy inference system and finally the obtained objective function is optimized with the Harmony Search Algorithm. Fuzzy sets are characterized by certain membership functions that represent the degree of membership in a fuzzy set (valued between 0 and 1). The membership function indicates how much a solution is satisfactory. The Fuzzy method framework is as follows:

Step 1: First, the network is checked in a basic state without the presence of UPQC-PAC. The three objective functions corresponding to the basic state are respectively f_1^{Base}, f_2^{Base} and f_3^{Base}.

Step 2: Subsequently, single-objective congestion management is performed with the aim of minimizing the operational cost of the system (function) with HS algorithm. In this case, X_1^{Best} is the optimized solution, and the three objective functions corresponding to this state are respectively f_1^1,f_2^1 and f_3^1.

Step 3: Next, single-objective congestion management is performed with the aim of improving the voltage stability (function) with HS algorithm. In this case, X_2^{Best} is the optimized solution and the three objective functions corresponding to this state are respectively f_1^2,f_2^2 and f_3^2.

Step 4: Afterwards, single-objective congestion management is performed with the aim of improving the transient stability (function f_3 with the HS algorithm. In this case, X_3^{Best} is the optimized solution, and the three objective functions corresponding to this state are respectively f_1^3,f_2^3 and f_3^3.

Step 5: After performing these steps, four solutions are obtained for each objective function. The best value for each objective is named with f_i^{Best} as follows:

$$f_i^{Best} = \min(f_i^1, f_i^2, f_i^3, f_i^{Base}) = f_i^i \neq f_i^{Base} \quad i = 1,2,3 \quad (16)$$

In equation (16), it is assumed that the installation of the UPQC-PAC improves the desired objective function. Therefore, it is assumed that $f_i^{Base} > f_i^{Best}$ and $f_i^{Base} \neq f_i^{Best}$ For instance, in step 2, the operating cost of the system after installing UPQC-PAC (that means f_1^1 is lower than the basic operating cost of f_1^{Base}

Step 6:A linear membership function for each objective (f_i) is determined as follows:

$$\mu_i(f_i) = \frac{f_i - f_i^{Best}}{f_i^{Base} - f_i^{Best}} \quad (17)$$

Step 7: Finally, the objective function $F(x)$(is defined as follows:

$$Minimize \quad F(x) = \sum_{i=1}^{3} \mu_i(f_i(x)) \quad (18)$$

Thus, by using the Fuzzy method presented in this article, the problem of congestion management which is multi-objective, became a a single-objective problem with the goal of minimizing the function . $F(x)$, which is solvable using the HS algorithm.

The variable X is the independent variable of the problem, which shows the location of the installation, the active and reactive power of the UPQC.

The variable X has three members; the first member represents the branch where the UPQC-PAC should be installed in it. The second member is the active power of the UPQC-PAC, and the third member shows the reactive power of UPQC-PAC.

4- 1- Harmony Search Algorithm (HSA)

The Harmony Search Algorithm (HSA) is based on the natural process of music performance. As the composer seeks to find the most beautiful song in the process of optimization, we are also looking for the best answer to the problem.

The suitability of the answer in the optimization process is determined by examining the objective function. In making a song, the beauty of the track determines the pitch of each musical instrument, and in optimization, the value of the objective function is determined by the variables of the problem. More comprehensive description of the HSA is given in [39].

Table 1. HSA parameters

	Without UPQC	With UPQC
UPQC branch	-	6
K_{se} (pu)	-	0.73
S_{UPQC} (MVA)	-	195.54
VSM (%)	42.26	42.26
CTEM (%)	10.21	9.1954
Cost ($)	9595.34	8819.33

Table 2. Optimal solution based on the first scenario

	Without UPQC	With UPQC
UPQC branch	-	6
K_{se} (pu)	-	0.73
S_{UPQC} (MVA)	-	195.54
VSM (%)	42.26	42.26
CTEM (%)	10.21	9.1954
Cost ($)	9595.34	8819.33

5- Simulation Results

In this section, in order to evaluate the efficiency of the proposed Fuzzy method, the simulation was carried out on England's 39 buses new network in MATLAB software.

The suggested network consists of 39 buses, 46 transmission lines, 10 generators, and 21 loads, including 18 fixed loads and 3 dynamic loads that are sensitive to price. The network information is derived from [40].

5- 1- Single-Objective Congestion Management with the Aim of Decreasing the Total Operating Cost

In this scenario, single-objective congestion management is performed with the aim of minimizing the operational cost of the system (function f_1 with HS algorithm. In all simulations, the HSA settings are fixed and its parameters are given in Table 1.

The optimized results of this scenario can be observed in Table 2.

According to Table 2, in this scenario, the total operating cost decreases about 8% compared to the basic case (without UPQC), but CTEM index worsens and VSM index does not change.

5- 2- Single-Objective Congestion Management with the Aim of Improving the VSM Index

The optimized results of this scenario are illustrated in Table 3.

According to Table 3, the VSM index improves by 5.33%, but CTEM index and total operating cost worsen.

5.3. Single-Objective Congestion Management with the

Table 3. Optimal solution based on the second scenario

	Without UPQC	With UPQC
UPQC branch	-	37
K_{se} (pu)	-	0.62
S_{UPQC} (MVA)	-	150.54
VSM (%)	42.26	44.64
CTEM (%)	10.21	9.88
Cost ($)	9595.34	9780.21

Table 4. Optimal solution based on the third scenario

	Without UPQC	With UPQC
UPQC branch	-	7
K_{se} (pu)	-	0.83
S_{UPQC} (MVA)	-	180.54
VSM (%)	42.26	42.26
CTEM (%)	10.21	10.5082
Cost ($)	9595.34	9599.50

Aim of Improving the CTEM Index

The optimized results for this scenario are illustrated in Table 4.

According to Table 4, the CTEM index is about 3% better than the basic case (without UPQC), but the total operating cost worsened and the VSM index has not changed.

5.4. Multi-Objective Congestion Management with Proposed Fuzzy Method

In this section, the proposed Fuzzy method is used for multi-objective congestion management. The suggested method reaches the optimization of the targets such as the operating cost, the voltage stability, and the transient stability.

Thus, using the Fuzzy method suggested, the problem of congestion management which is a multi-objective became a single-objective problem with the goal of minimizing the equation (18), which is solvable using the HS algorithm.

The optimized results of this scenario are exhibited in Table 5.

According to Table 5, the total operating cost decreases about 5% compared to the basic case (without UPQC), and the CTEM index and the VSM index are about 3% better than the basic case (without UPQC). The results indicate that using the proposed method, congestion management is done optimally, which not only does not reduce system security but also increases the its security margin.

The convergence diagram of the HS algorithm based on the fourth scenario is shown in Fig. 3.

6- Conclusions

The major issues in utilization of power grids are congestion and overloading for lines. This leads to the deregulation of the mentioned systems as sharp increases in the costs of parts of power systems, increasing the market power and competition reduction. For the purpose of controlling flows of power via transmission lines, FACTS devices can be important tools for congestion management which enjoy a high

Table 5. Optimal solution based on the fourth scenario

	Without UPQC	With UPQC
UPQC branch	-	5
K_{se} (pu)	-	0.62
S_{UPQC} (MVA)	-	142.32
VSM (%)	42.26	43.62
CTEM (%)	10.21	10.53
Cost ($)	9595.34	9105.01

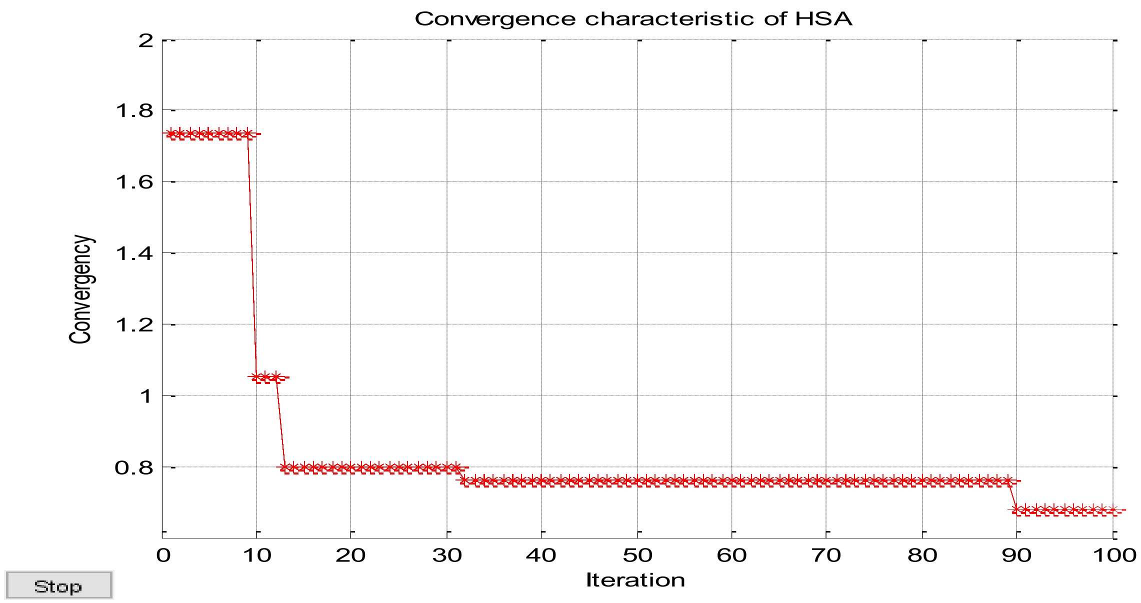

Fig. 3. The convergence diagram of the HS algorithm

efficiency, high power, and a good cost-effectiveness. Nevertheless, removing congestion of power systems can be achieved using a lower voltage and transient stability due to solving the security restrictions. This is the reason for consideration of power stability in the congestion management construction. A structure which is multi-objective for the management of congestion with UPQC-PAC is proposed in the present article which can optimize total transient security, voltage, and operating cost at the same time. For this purpose, the optimal sizing and locating of UPQC has been done using the Fuzzy method. The proposed Fuzzy method, is formulated in the form of a single-objective optimization problem for the multi-objective congestion management problem, and solved by HSA. In order to evaluate the reliability of the proposed method, simulation has been carried out on the England's new network with 39 buses. The results indicate that using the proposed method, congestion management is done optimally, which not only does not reduce system security, but also increases the its security margin.

References

[1] S. Barbulescu, P. Kilyeni, D. Cristian, D. Jigoria Oprea, "Congestion management using open power market environment electricity trading", 45th International on Engineering Conference (UPEC), pp. 1-6, September 2010 .

[2] M. M. Esfahani, G. R. Yousefi, "Real time congestion management in power systems considering quasi-dynamic thermal rating and congestion clearing time", IEEE Transactions on Industrial Informatics, Vol. 12, No. 2, pp.745-754, February 2016.

[3] H. Ahmadi, M. Khanabadi, H. Ghasemi, "Transmission system reconfiguration for congestion management ensuring transient and voltage stability", 13th International Conference on Environment and Electrical Engineering (EEEIC), pp. 22-26, November 2013.

[4] M. Esmaili, N. Amjady, H. A. Shayanfar, "Stochastic multi-objective congestion management in power markets improving voltage and transient stabilities", Int. Trans. Electr. Energ. Syst, Vol. 21, No. 1, pp. 99-115, 21 January 2011.

[5] G. Granelli, M. Montagna, F. Zanellini, P. Bresesti, R. Vailati, M. Innorta, "Optimal network reconfiguration for congestion management by deterministic and genetic algorithms", Electric power systems research, Vol. 76, No. 6-7, pp. 549-556, April 2006.

[6] A. A. J. Basha, M. Anitha, "Transmission congestion management in restructured power system using firefly algorithm", International Journal of Computer Applications, Vol. 85, No. 1, pp. 39-43, January 2014.

[7] M. Khan, A. Siddiqui, "Congestion management in deregulated power system using FACTS device", International Journal of System Assurance Engineering and Management, Vol. 8, No. 1, pp. 1-7, 2017.

[8] M. Mobtahej, K. Esapour, S. Z. Tajalli, M. Mohammadi, "Effective demand response and GANs for optimal constraint unit commitment in solar-tidal based microgrids", IET Renewable Power Generation, DOI: 10.1049/rpg2.12331.

[9] K. Elango, S. Paranjothi, "Congestion management in restructured power systems by FACTS devices and load shedding using extended quadratic interior point method", International Journal of Applied Engineering Research, Vol. 57, No. 3, pp. 380-390, October 2011.

[10] B. Talukdar, A. Sinha, S. Mukhopadhyay, A. Bose, "A computationally simple method for cost-efficient generation rescheduling and load shedding for congestion management", International Journal of Electrical Power & Energy Systems, Vol. 27, No. 5-6, pp. 379-388, June 2005.

[11] S. Dutta, S. Singh, "Optimal rescheduling of generators for congestion management based on particle swarm optimization", IEEE Transactions on Power Systems, Vol. 23, No. 4, pp. 1560-1569, August 2008.

[12] R. Nematbakhsh, A. Hooshmand, R. Hemmati, "A new restructuring of centralized congestion management focusing on flow-gate and locational price impacts", Int. Trans. Electr. Energ. Syst, e2482, February 2018.

[13] B. Singh, R. Mahanty, S. P. Singh, "Social welfare maximization for congestion management in multiutility market using improved PSO incorporating transmission loss cost allocation", Int. Trans. Electr. Energ. Syst, e2593, September 2018.

[14] S. Saravanabalaji, R. Krishnathevar, H. Thilagar, D. Durairaj, "A novel approach for congestion management using improved differential evolution algorithm", Int. Trans. Electr. Energ. Syst, e2614, October 2018.

[15] M. Heydaripour, A. Akbari Foroud, "A New Framework for Congestion Management with Exact Modeling of Impacting Factors", Iranian Journal of Electrical & Electronic Engineering, Vol. 8, No. 4, pp. 329-340, September 2012.

[16] S. Balaraman, N. Kamaraj, "Real Time Congestion Management in Deregulated Electricity Market Using Artificial Neural Network", Iranian Journal of Electrical and Computer Engineering, Vol. 10, No. 1, pp. 34-40, November 2011.

[17] J. Ye, H. B. Gooi, "Optimization of the Size of UPQC System Based on Data-Driven Control Design", IEEE Transactions on Smart Grid, Vol. 9, No. 4, pp. 2999-3008, November 2016.

[18] S. Ali, K. Wu, K. Weston, D. Marinakis, "A machine learning approach to meter placement for power quality estimation in smart grid", IEEE Transactions on Smart Grid, Vol. 7, No. 3, pp. 1552-1561, July 2016.

[19] M. Gitizadeh, M. Kalantar, "FACTS devices allocation to congestion alleviation incorporating voltage dependence of loads", Iranian Journal of Electrical & Electronic Engineering, Vol. 4, No. 4, pp. 176-190, June 2008.

[20] H. Fujita, H. Akagi, "The Unified Power Quality Conditioner: the integration of series-and shunt-active filters", IEEE transactions on power electronics, Vol. 13, No.2, pp. 315-322, March 1998.

[21] V. Khadkikar, "Enhancing electric power quality using UPQC: A comprehensive overview", IEEE transactions on Power Electronics, Vol. 27, No. 5, pp. 2284-2297, December 2012.

[22] J. He, B. Liang, Y. W. Li, C. Wang, "Simultaneous Microgrid Voltage and Current Harmonics Compensation Using Coordinated Control of Dual-Interfacing Converters", IEEE Transactions on Power Electronics, Vol. 32, No. 4, pp. 2647-2660, June 2016.

[23] K. Verma, S. Singh, H. Gupta, "Location of unified power flow controller for congestion management", Electric Power Systems Research, Vol. 58, No. 2, pp. 89-96, June 2001.

[24] B. Chong, X. P. Zhang, K. R. Godfrey, L. Yao, M. Bazargan, "Optimal location of unified power flow controller for congestion management", Int. Trans. Electr. Energ. Syst, Vol. 20, No. 5, pp. 600-610, July 2010.

[25] N. M. G. Kumar, P. Venkatesh, P. S. Raju, "Modeling

and Analysis of SVC, TCSC, TCPAR in Power Flow Studies", International Journal of Emerging Technology and Advanced Engineering, Vol. 3, No. 1, pp. 418-425, January 2013.

[26] N. Ashokkumar, M. RathinaKumar and M. Yogesh,"Flexible AC Transmission Devices as a Means for Transmission Line Congestion Management-A Bibliographical Survey", International Journal of soft Computing and Engineering, Vol. 3, No. 1, pp. 229-234, July 2013.

[27] M. Zeraatzade, "Transmission congestion management by optimal placement of FACTS devices", Brunel University School of Engineering and Design PhD Theses, 2010.

[28] K. R. S. Reddy, N. P. Padhy, R. Patel, "Congestion management in deregulated power system using FACTS devices", In 2006 IEEE Power India Conference, 10April 2006.

[29] A. Moradi, Y. Alinejad-Beromi, K. Kiani, "Locating of Series FACTS Devices for Multi-Objective Congestion Management Using Components of Nodal Prices", Iranian Journal of Electrical & Electronic Engineering, Vol. 13, No. 1, pp. 32-46, March 2017.

[30] S. R. Salkuti, S-C. Kim, "Congestion Management Using Multi-Objective Glowworm Swarm Optimization Algorithm", Journal of Electrical Engineering & Technology, Vol. 14, No. 4, pp. 1565-1575, May 2019.

[31] S. R. Salkuti, "Multi-objective-based optimal transmission switching and demand response for managing congestion in hybrid power systems ", International Journal of Green Energy, Vol. 17, No. 8, pp. 457-466, May 2020.

[32] D. Asija, P. Choudekar, "Congestion management using multi-objective hybrid DE-PSO optimization with solar-ess based distributed generation in deregulated power Market", Renewable Energy Focus, Vol. 36, pp. 32-42, March 2021.

[33] A. R. Moradi, Y. Alinejad-Beromi, M. Parsa and M. Mohammadi," Optimal Locating and Sizing of Unified Power Quality Conditioner - phase Angle Control for Reactive Power Compensation in Radial Distribution Network with Wind Generation", International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications, Vol. 31, No. 2, pp. 299-306, February 2018.

[34] S. Ganguly, "Multi-objective planning for reactive power compensation of radial distribution networks with Unified Power Quality Conditioner allocation using particle swarm optimization", IEEE Transactions on Power Systems, Vol. 29, No. 4, pp. 1801-1810, January 2014.

[35] P. Kumar Tiwari, Y. Raj Sood, "An Approach for Optimal Placement, Rating and Investment Cost Recovery of a TCSC in Double Auction Power Market", Proceedings of International Conference on Power Systems, Energy, Environment, pp. 91-97, 22 February 2014.

[36] N. Amjady, M. Esmaili, "Improving voltage security assessment and ranking vulnerable buses with consideration of power system limits", International Journal of Electrical Power & Energy Systems, Vol. 25, No. 9, pp. 705-715, November 2003.

[37] M. Esmaili, H. A. Shayanfar, R. Moslemi, "Locating series FACTS devices for multi-objective congestion management improving voltage and transient stability", European Journal of Operational Research, Vol. 236, No. 2, pp. 763-773, July 2014.

[38] F. Da-Zhong, T. S. Chung, Z. Yao, S. Wennan,"Transient stability limit conditions analysis using a corrected transient energy function approach", IEEE Transactions on Power Systems, Vol. 15, No. 2, pp. 804-810, May 2000.

[39] K. S. Lee, Z. W. Geem, "A new meta-heuristic algorithm for continuous engineering optimization: harmony search theory and practice", Computer methods in applied mechanics and engineering, Vol. 194, No. 36, pp. 3902-3933, September 2005.

[40] G. Bills, "On-line stability analysis study, RP 90-1", North American Rockwell Information Systems Co., Anaheim, CA (USA) 1970.

HOW TO CITE THIS ARTICLE

A. Moradi, S. M. R. Hashemi, S. M. Mirrezaei, Optimal Locating and Sizing of Unified Power Quality Conditioner for Multi-Objective Congestion Management by Hybrid Fuzzy- Harmony Search Algorithm , AUT J. Elec. Eng., 54(2) (2022) 225-234.

DOI: 10.22060/eej.2022.21061.5454