ROBUST MULTI-OBJECTIVE SCHEME TO IMPROVE TRANSMISSION LINE PERFORMANCE CONSIDERING CUSTOMER INTERRUPTION COST AND VOLTAGE STABILITY INDEX

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Abstract: *The main contribution of this paper is to present an optimal solution of under voltage load shedding problem using Hybrid Genetic algorithm and Particle Swarm Optimization (HGAPSO). The effectiveness of the proposed scheme for optimal procedure is investigated. The above-mentioned problem is converted to an optimization problem with the multi-objective function including the minimum active power losses, the maximum voltage stability, the minimum customer interruption cost and the desired alleviating transmission line under over loading conditions, in which the customer interruption cost is modeled as a quadratic function in five major load classifications on each bus. The effectiveness of the proposed approach is confirmed on three different IEEE test systems called 30, 57 and 118 buses as small, medium and large scale power systems under different operating conditions. The comparative analysis is made between other evolutionary methods like PSO through some performance indices to demonstrate its flexibility and strong performance.*

Key words: *Customer Interruption Cost, Multi Objective Optimization, Under Voltage Load Shedding, Voltage Stability, HGAPSO.*

1. Introduction

In recent years, power system black outs around the world resulting from voltage collapse have become more repetitive because of some operational factors like system deficiencies, persistent load growing. Load shedding is the latest countermeasure to save a voltage unstable power system before pervasive blackout, when there is no control action to stop an approaching voltage collapse [1, 2]. In operation planning studies of power systems, the state of the power system analyzed by system beneficiary and performs in advance appropriate control actions to safeguard the security criteria. These control actions may be consists of voltage control resources such as transformer taps, shunt reactors or adjustments and modification of the generation dispatch such as decrease and increase of generation in several generators, and connection of off-line units [3].

In on-line voltage stability analysis, when the network is close to the load ability margin, the available control actions are ineffectual or there may not be fast enough to prevent the voltage collapse in power system. Therefore, in alarm conditions, emergency load shedding measures may be required. However, implementing of load shedding must be considered as last resort.

To be effective counter measure versus voltage instability, the two main categories consideration in load shedding as the amount of load to be shed and the location where load shed is to be shed [4,5,6,7]. The amount of load to shed is calculated by purporst which is load to be shed has to be optimum. Load shedding in power system less than necessary will obviously not to be efficient in arresting voltage collapse. Also, determining the location where load to be shed is the second important factor. Some researchers are using the OPF (Optimal Power Flow) methodologies in the dynamic simulation [4, 6,7]. In this approach, based on voltage stability viewpoint, the load buses are ranked in order of the strongest to the weakest. The weakest bus tends to be most capable to voltage instability given the practically large reactive power consumption for small reduction in bus voltage. Hence, often it is this bus that is the most appropriate candidate which is selected by load shedding initially [6].

Several works have been previously conducted on load shedding against voltage collapse .In [3], an LP-based optimization load shedding algorithm is introduced to load margin improvement. The objective function of problem consists of minimizing the total system load decrease. The load shedding algorithm selects both the optimal location of generation and load buses, and their corresponding power reduction based on first order sensitivities of the load margin with respect to the load to be shed. In [8], a load shedding versus long-term voltage instability is proposed. A distributed load shedding scheme has been introduced in that approach tends to act first where voltages drop the most. In [9], the optimum load shedding problem is formulated to purpose of minimization the sum of the squares of the variance between the connected load demands and the generated power. The supplied power based on bus voltage magnitudes is defined as a function. An approach to the load shedding scheme is introduced by increasing the number of participants in [10]. This load control mechanism is possible to divide every customer’s load into interruptible and uninterruptible parts, and load shedding implemented in the interruptible part only. The optimal load reduction request is defined by minimizing the expected value of a cost function, thus taking the uncertainty about the active power absorbed by each load into account. Analytical explanation of the design of several load shedding schemes for the protection of the Hellenic Interconnected System versus the risk of voltage stability is presented in [11]. In [12], a concept of soft load shedding (SLS) for residential consumers is proposed. It takes solely a fraction of the consumers' power, even if the effort is spread over a larger number. It therefore seeks to prevent the plunge into darkness.

This paper presents a new scheme for load shedding problem so as to improve the performance of transmission line. Herein, voltage stability index is used to maximize the security of power system against voltage collapse. The above-mentioned problem is converted to an optimization problem with the multi-objective function including the minimum active power losses, the maximum voltage stability, the minimum customer interruption cost and the desired alleviating transmission line under over loading conditions which is solved by HGAPSO. Load buses are ranked by interruption cost and load shedding tries to minimize the cost of interruption. Consequently, load which have a lowest interruption cost is selected by the proposed algorithm. The results are compared with PSO to reveal its effectiveness.

This paper is sets out as follows: Section 2 presents the problem formulation. Section 3 presents the proposed solution method for solving the problem. The application of the proposed model and simulation results are presented in Section 4 and 5 respectively, and finally, the conclusion is presented in Section 6.

2. Problem statement

The proposed under voltage load shedding is defined as an optimization problem which its objective function consist of four object. Three of them cover operational conditions and try to recovering normal operating in power system and the fourth one is economical object that try to reduce interruption costs by selecting the cheapest load from power system.

2.1. Elimination of transmission line under over loading condition

This factor can be stated as follow:

$$OF_1 = \begin{cases} \sum_{i=1}^{N_{line}} 10^{5\left(\frac{S_i - S_i^{\max}}{S_i^{\max}}\right)} & \text{if} \quad S_i^P > S_i^{\max} \\ 0 & \text{if} \quad S_i^P \le S_i^{\max} \end{cases} \tag{1}$$

Where S_i^P represent apparent power transmitted through the line in post contingency and $S_i^{\max}$ is its maximum apparent power. Exponential definition of this function allow to load shedding algorithm to pursue of alleviating transmission line over loadings effectively in compare of linear functions which debated in literatures such as [13].

2.2. Voltage stability index

Fast Voltage Stability Index (FVSI) [14, 15, 16] as voltage stability indicator in transmission line is proposed to utilize in under voltage load shedding. The FVSI is calculated from power flow concept in single line which consists of two bus system. Fig. 1 shows the two bus power system one line diagram.

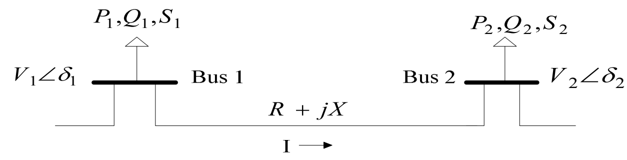

Fig. 1. Two bus power system model

Fast voltage stability index is equal to:

$$FVSI = \frac{4Z^2 Q_2 X}{V_1^2 (R\sin\delta + X\cos\delta)^2} \approx \frac{4Z^2 Q_2}{V_1^2 X} \tag{2}$$

Where V_1 is voltage on sending bus, Q_2 reactive power on receiving bus and X represent is line reactance. δ is angle difference between sending and receiving bus. This index varies between 0 and 1. The values close to 1 indicate instability conditions in transmission line and the values which are near to 0 indicate stability conditions. Also, this index has capability of on line voltage stability assessment which must be minimized to improvement transmission line performance. So, the second object of under voltage load shedding can be formulated as follows:

$$OF_2 = \sum_{i=1}^{N_{Line}} FVSI_i \tag{3}$$

Based on equation (3), a summation of voltage stability indexes is minimized by under voltage load shedding to betterment system stability in viewpoint of voltage.

2.3. Active power losses

The third operational object of proposed load shedding is minimization of active power loss in power system. Load shedding that proposed so far didn't consider active power loss whilst active power loss increased extremely by transmission line congestion due to contingency event. The equation (4) displayed the third object of load shedding scheme [17, 18].

$$OF_3 = \sum_{i=1}^{N_{Line}} R_i I_i^2 = \\ = \sum_{i,j=1,2,\ldots,N_{Bus}} \left[V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)\right] Y_{ij} \cos\varphi_{ij} \tag{4}$$

Where $V_i, V_j, \delta_i, \delta_j$ represent voltage and voltage angle on sending and receiving end of line respectively. Y_{ij}, φ_{ij} are magnitude and angle of i^{th} and j^{th} component of admittance matrix.

2.4. Customer interruption cost

There are many studies of interruption cost in literatures [19-22]. These investigations show that the interruption cost generally increases proportionally to the magnitude of load and the r^{th} power of outage duration, and the rate of increase differs markedly from customer to customer. Table 1 show that the cost of an interruption load depends on its type, magnitude and the duration of customer interruption.

Table 1
Sector interruption cost [22]

User sector	Interruption Duration (min) & Cost ($/KW)				
	1	20	60	240	480
Larger users	1.005	1.508	2.225	3.968	8.240
Industrial	1.625	3.868	9.085	25.16	55.81
Commercial	0.381	2.969	8.552	31.32	83.01
Agricultural	0.060	0.343	0.649	2.064	4.120
Residential	0.001	0.093	0.482	4.914	15.69

This table gives the interruption cost for five discrete outage durations. In direction of load shedding purpose; the nonlinear curve between duration (minute) and costs ($) is fitted for each classes of load. Curve fitted on cost ($/kW) and time by:

$$Cost\left(\frac{\$}{kW}\right) = a\,t^2 + b\,t + c \tag{5}$$

Where a, b, c are constant coefficients and t is duration of load interruption. Equation (6) shows cost of interrupted load by load shedding scheme which depends on time of interruption. Load interruption cost for each classes of load is derived as:

$$IC\,(\$) = \left(a\,t^2 + b\,t + c\right)\left(P_D^0 - P_D^P\right) \tag{6}$$

Where, P_D^0, P_D^P are demand active powers in initial and post contingency conditions respectively. For the industrial customer as example, the first term of equation (6) $at^2(P_D^0 - P_D^P)$ is an approximated cost which is proportional to the r^{th} power of t and represents costs such as those required for plant restoration. The second term $bt(P_D^0 - P_D^P)$ is a term proportional to the interruption duration such as loss of production. The third term $c(P_D^0 - P_D^P)$ represents the fixed cost required for equipment maintenance etc.

It is supposed, which each bus includes five feeders with one class of load in each feeder. The load of each feeder is a part of total load on bus. So, this has a participation factor. Also cost of load in each bus can be formulated as:

$$\begin{aligned} Total\ Cost &= IC_L \times PF_L + IC_I \times PF_I \\ &+ IC_C \times PF_C + IC_A \times PF_A + IC_R \times PF_R \end{aligned} \tag{7}$$

Where PF is participation factor and L, I, C, A and R are abbreviation of load classifications. Equation (7) represents an economical weight factor for weighted load shedding. Hence, cheapest loads are selected by load shedding scheme. So, the next term of optimization problem is given as follows:

$$OF_4 = \min : \sum_{i=1}^{N_{Bus}} \left(Total\ Cost_i\,(P_{Di}^0 - P_{Di}^P)\right) \tag{8}$$

2.5. Constrains

Load shedding scheme has been implemented on power system under feasibility and solve ability of power flow equations. Hence, power flow equations are equality constraint of load shedding which expressed in equations (9) and (10).

$$\begin{aligned} P_{Gi}^0 - P_{Di}^0 + \Delta P_{Di} &= \\ \sum_{j=1}^{N} |V_i||V_j||Y_{ij}|&\cos(\delta_{ij} + \delta_j - \delta_i) \end{aligned} \tag{9}$$

$$\begin{aligned} Q_{Gi}^0 - Q_{Di}^0 + \Delta Q_{Di} &= \\ -\sum_{j=1}^{N} |V_i||V_j||Y_{ij}|&\sin(\delta_{ij} + \delta_j - \delta_i) \end{aligned} \tag{10}$$

It is remarkable that the reactive power generation constraint is considered in power flow algorithm and it is not required to considering in load shedding modeling. The other constraint is specified in equations (11), (12) and (13):

$$V_i^{\min} \le V_i^P \le V_i^{\max} \tag{11}$$

$$P_{Di}^{\min} \le P_{Di}^P \le P_{Di}^{\max} \tag{12}$$

$$\frac{\Delta P_{Di}}{P_{Di}^0} = \frac{\Delta Q_{Di}}{Q_{Di}^0} \quad \text{fixed power factor} \tag{13}$$

Where $V_i^P, V_i^{\min}$ and $V_i^{\max}$ are bus voltage in post contingency, minimum and maximum allowable bus voltage respectively. Also the control variable that enable us to obtain an optimal solution are P_{Di} and Q_{Di}. Considering that during the implementation of load shedding the power factor is maintained constant, simplifies the modeling. There are less variables, because the relation between active and reactive power in constant power factor.

3. Hybrid genetic algorithm and particle optimization

The optimal load shedding problem is formulated and defined as multi objective constrained problem. This paper uses a novel hybrid Genetic Algorithm and Particle Swarm Optimization for solving problems of optimal under voltage load shedding and the results were compared to PSO.

3.1. Particle swarm optimization

Particle Swarm Optimization is a new evolutionary computation technique first introduced by Kennedy and Eberhart in 1995 [24]. In PSO, the swarm has NP particles that each of them is a candidate solution. Each particle is an NL dimensional value vector where NL is the number of load buses which are optimized parameters. Hence, each parameter shows a dimension of the problem space.

- The first step: in this step the Iteration counter $Iter = 0$ and generates randomly NP particles and initialize the PSO. $[P_j(0),\ j = 1,2,...,NP]$, where $p_j(0) = [p_{j1}(0), p_{j2}(0),..., p_{jNL}(0)]$, $p_{jK}(0)$ is generated in range of $[p_K^{\min}, p_K^{\max}]$ randomly. $V_j(0)$ is randomly produced for calculation of the objective function. Then, set $x'_j(0) = x_j(0)$ for each particle and $j'_j = j_j$, $j = 1,2,...,NP$. Search for the minimum amount of the objective function g_{best}. Also, set the best evaluated particle associated with g_{best} as the global best position, $p''(0)$ with an objective function of j''. The initial value of the w is set to $w(0) = 0.98$.
- The second step: update the iteration counter $Iter = Iter + 1$.
- The third step: update the inertia weight factor as weight updating step.
- The fourth step: the global best position and individual best position are utilized to change the particle velocity with the following equation [25,26]:

$$\begin{aligned} v_{jk}(Iter) = & w(Iter) v_{jk}(Iter-1) \\ & + c_1 r_1 (p'_{jk}(Iter-1) - p_{jk}(Iter-1) \\ & + c_2 r_2 (p''_{best} - p_{jk}(Iter-1))) \end{aligned} \tag{14}$$

- The fifth step: each particle updates its position based on updated velocity, according to the equation 15:

$$P_{jk}(Iter) = P_{jk}(Iter-1) + v_{jk}(Iter) \tag{15}$$

- The sixth step: all of the particles are evaluated according $Iter$ the updated position. In this situation, if $j_{\min} < j'$ then updates each individual best as:

$$p'_j(Iter) = p_j(Iter) \quad , j_i = j'_i \tag{16}$$

- The seventh step: search for the minimum value of objective function, if $j_{\min} < j''$ then updates global best position as $j'' = j_{\min}$ and $p'' = p_{\min}(Iter)$.
- The eighth step: the algorithm if one of the stopping criteria is met, else go to step two.

3.2. Combination of genetic algorithm and particle swarm optimization

Hybrid PSO has the advantages of both PSO and GA. Here in the PSO algorithm, the reproduction technique of Genetic is used to produce the best child from the worst parent [27]. The positions of the children are updated using the following equations:

$$\begin{aligned} child1(p_{id}^{(Iter)}) = & pi \times parent1(p_{id}^{(Iter)}) \\ & + (1-pi) \times parent2(p_{id}^{(Iter)}) \end{aligned} \tag{17}$$

$$\begin{aligned} child2(p_{id}^{(Iter)}) = & pi \times parent2(p_{id}^{(Iter)}) \\ & + (1-pi) \times parent1(p_{id}^{(Iter)}) \end{aligned} \tag{18}$$

The velocity vectors of the children calculated as follows:

$$\begin{aligned} child1(v_{id}^{(Iter)}) = & (parent1(v_{id}^{(Iter)}) + parent2(v_{id}^{(Iter)})) \\ & \times \frac{\left|parent1(v_{id}^{(Iter)})\right|}{\left|parent1(v_{id}^{(Iter)}) + parent2(v_{id}^{(Iter)})\right|} \end{aligned} \tag{19}$$

$$\begin{aligned} child2(v_{id}^{(Iter)}) = & (parent1(v_{id}^{(Iter)}) + parent2(v_{id}^{(Iter)})) \\ & \times \frac{\left|parent2(v_{id}^{(Iter)})\right|}{\left|parent1(v_{id}^{(Iter)}) + parent2(v_{id}^{(Iter)})\right|} \end{aligned} \tag{20}$$

Where pi is a uniformly distributed random number between $[0,1]$.

$parent1(p_{id}^{(Iter)})$: Position vector of a randomly chosen particle to take part in the reproduction process.

$parent2(p_{id}^{(Iter)})$: Position vector of randomly chosen particle to be the other parent in the reproduction process.

$child1(p_{id}^{(Iter)})$: Position vector of the first offspring.

$child2(x_{id}^{(Iter)})$: Position vector of the second offspring.

$parent1(v_{id}^{(Iter)})$: Velocity vector of the first parent.

$parent2(v_{id}^{(Iter)})$: Velocity vector of the second parent

4. Implementation of the proposed technique

The HGAPSO tries to find optimum load shedding pattern. The flowchart of under voltage load shedding is displayed by Fig. 2.

4.1. Initialization

It is supposed that $P_{Di}^{\min} = 0.5P_{Di}^{0}$ for all buses. This equation means that, load shedding in bus *i*, cannot be greater than 50 percent of load demand in this bus. Also in this paper, the interruption time for each classes of load is 30 minutes. Toolbox has been developed for any durations of load interruption with MATLAB software.

4.2. Fitness evaluation

The fitness function is calculated using equation (1)-(13). Also, it is considered that following equation is a multi-objective function with its constraints:

$$\min(f_1(x), f_2(x), ..., f_M(x))$$
$$subject\ to: \begin{cases} h_k = b \\ x^{(L)} \le x \le x^{(U)} \end{cases} \tag{21}$$

Where $x^{(U)}$ and $x^{(L)}$ are boundaries of x.

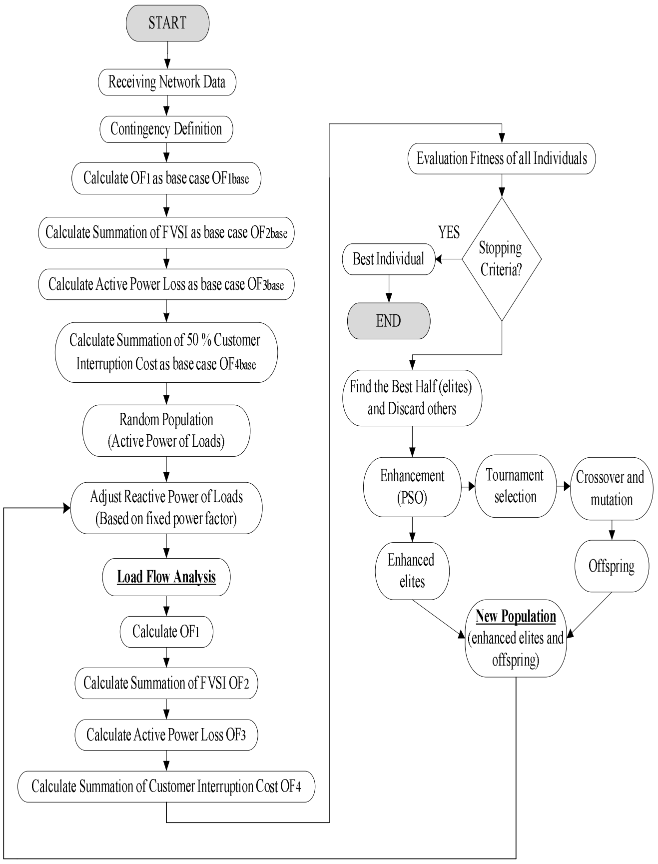

Fig. 2. The Flowchart of proposed under voltage load shedding

In order to solve multi objective problem, equation (21) is changed to no constraint function with penalty factors as follows [28, 29]:

$$\min\left[\left(f_1(x),f_2(x),\ldots,f_M(x)\right)+\lambda\left(b-h_k\right)+\lambda_x\sum_{N_x^{\lim}}(\Delta x)^2\right]$$
$$\Delta x=\begin{cases}x-x^{(U)} & if\ \ x>x^{(U)}\\ x^{(L)}-x & if\ \ x<x^{(L)}\end{cases} \tag{22}$$

Based on optimization methodology which is described above, the fitness function of under voltage load shedding is defined as equation (23).

$$Fitness=\text{minimize}\begin{bmatrix}k_1\dfrac{OF_1}{OF_{1base}}+k_2\dfrac{OF_2}{OF_{2base}}\\ +k_3\dfrac{OF_3}{OF_{3base}}+k_4\dfrac{OF_4}{OF_{4base}}\\ +\lambda f\,(V_i^P)\end{bmatrix} \tag{23}$$

Where k_1,k_2,k_3,k_4 are arbitrary gains factor of normalized objects and λ is penalty factor of constraint. Also, $f\,(V_i^P)$ represent defined penalty function and it described as equation (24).

$$F_V(V_i^P)=\begin{cases}V_i^P-V_i^{\max} & \text{if}\quad V_i^P>V_i^{\max}\\ V_i^{\min}-V_i^P & \text{if}\quad V_i^P<V_i^{\min}\\ 0 & \text{if}\quad V_i^{\min}<V_i^P<V_i^{\max}\end{cases} \tag{24}$$

5. Simulation result

The proposed methodology of under voltage load shedding is implemented over the IEEE 30 bus, 57 bus and 118 bus test system [30]. The optimization models are solved using two evolutionary methods. The first approach is based on HGAPSO and the second one is based on PSO. However, the HGAPSO heuristic optimization method has not been applied to the under voltage load shedding problem yet. The 30 bus test system is small power system and suitable to primary assessment of proposed load shedding. Also, the 57 bus and 118 bus test system is a relatively medium scale and large scale power system that is suitable to verify the computational efficiency and optimality of load shedding scheme.

5.1. IEEE 30 bus test system

The IEEE 30 bus network one line diagram, as well as data for generators, demands and transmission lines can be found in [30]. It is assumed that the system loading is in 10 percent increasing. In this situation, a disturbance causes the contingency and the outage of line 1-2. Following this disturbance, extreme over load in line 1-5 is occurred and its voltage stability index shows the instability conditions. Some of network condition in post and pre contingency before performs of load shedding scheme are shown with Table 2.

Table 2
IEEE 30 bus indexes in pre and post contingency conditions

Power System Indexes	Min. Bus Voltage (Bus No)	Max. FVSI (Line)	Line over loading (MVA)	Active power loss(MW)
Pre contingency	0.9435 (30)	0.2362 (2-5)	0	25.85
Post contingency	0.8578 (3)	1.1275 (1-3)	340.50	124.33

Voltage stability index show alarm conditions and there is no control action available, the collapse is inevitable ignoring that the extreme over loading causes to trip the over loaded line and beginning cascading outages in lines, if the load shedding did not applied to power system quickly. The optimal pattern of load shedding in load buses is tabulated in Table 3.
Based on results of load shedding, whole of transmission line over loadings is removed from network and the voltage stability index has been improved by 66.21% decreasing on this index.

Table 3
The result of implementing the proposed technique on 30 bus test system

	HGAPSO	PSO
Total load shedding (MW)	78.6988	77.8260
Agricultural load (MW)	7.8314	3.9858
Industrial load (MW)	0.3514	1.1189
Commercial load (MW)	0.3514	1.4819
Residential load (MW)	69.6373	70.0833
Large users load (MW)	0.5274	1.1560
Total customer interruption cost ($)	19095.0051	27946.5970
Maximum FVSI (Line)	0.5286 (1-3)	0.5299 (1-3)
Active power loss (MW)	38.5413	38.6900

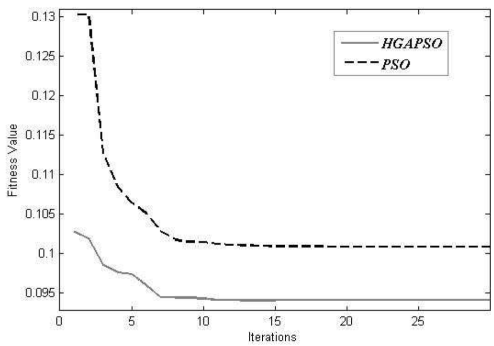

Fig. 3. HGAPSO and PSO convergence(30 bus)

In this situation, 91.4222 MW load curtailment causes to decreasing active power loss in presence of minimum customer interruption cost. The convergence of HGAPSO and PSO algorithms is shown in Fig. 3.

Table 4
IEEE 57 bus indexes in pre and post contingency conditions

Power System Indexes	Min. Bus Voltage (Bus No)	Max. FVSI (Line)	Line over loading (MVA)	Active power loss(MW)
Pre contingency	0.9377 (31)	0.2391 (13-49)	0	28.18
Post contingency	0.8774 (31)	0.6004 (2-3)	339.45	109.29

5.2. IEEE 57 bus test system

The IEEE 57 bus test system consists of 7 generators, 80 branches and 42 loads, the detailed characteristics of 57 bus test system are given in [30]. It is assumed that the power system loading is increased to 1.2 times the base case and the line 1-15 tripped in reason of disturbance occurrence. This contingency causes over load on lines 1-2, 2-3, 1-16, 3-15, 12-17 and 12-16 respectively. The indexes of 57 bus test system are shown by Table 4 in post and pre contingency occurrence.

In this situation, over load is divided into several transmission lines and because of this, the voltage stability index shows the better conditions in compare of 14 bus system. However, the amount of transmission line over loadings is high and it able to lead system to collapse. Also, Active power loss is increased and it may be produce pressure on power system components. In many states, the active power loss may causes to decrease thermal stability of transmission lines. The optimal pattern of load shedding in load buses is tabulated in Table 5.

Table 5
The result of implementing the proposed technique on 57 bus test system

	HGAPSO	PSO
Total load shedding (MW)	157.3018	157.9061
Agricultural load (MW)	27.9476	25.1415
Industrial load (MW)	11.4854	16.7912
Commercial load (MW)	24.8756	28.0118
Residential load (MW)	80.9576	77.9911
Large users load (MW)	12.0356	10.4020
Total customer interruption cost ($)	218286.2053	256641.8046
Maximum FVSI (Line)	0.3634 (2-3)	0.3634 (2-3)
Active power loss (MW)	55.1815	55.3245

Based on the results that tabulated on Table 4, proposed load shedding provides voltage stability by 45.63% decreasing in voltage stability index in presence of alleviating transmission line over loadings. Here, similar to previous study, the global convergence of HGAPSO is compared to the PSO method. This is shown in Fig. 4.

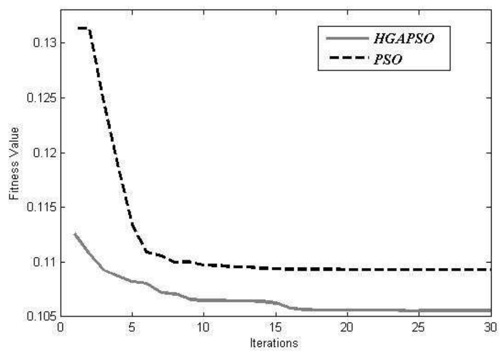

Fig. 4. HGAPSO and PSO convergence(57 bus)

5.3. IEEE 118 bus test system

The IEEE 118 bus test system represents a portion of American Electric Power System (in the Midwestern US) and consists of 54 generation unit, 99 customers and 186 interconnected lines, the detailed characteristics of which are given in [30]. The system is under 30% load increscent in compare of base case and the outage of line 5-8 is occurred by a disturbance. This contingency causes 407 MVA over loadings in under study power system that is tabulated in Table 6. This extreme amount of over load may cause to cascading transmission line outages and system lead to black out if load shedding not performed quickly. The voltage stability index represents small changes in this situation, but this index close to collapse after cascading faults in system.

Table 6
IEEE 118 bus indexes in pre and post contingency conditions

Power System Indexes	Min. Bus Voltage (Bus No)	Max. FVSI (Line)	Line over loading (MVA)	Active power loss(MW)
Pre contingency	0.9500 (38)	0.6246 (69-77)	0	392.59
Post contingency	0.9323 (38)	0.6674 (69-77)	407.33	550.45

The optimal pattern of load shedding is tabulated on Table 7. Transmission line over loadings is alleviated completely and the active power loss decreased effectively. Also, the total amount of load shedding is 8.7% of entire load of system.

Table 7
The result of implementing the proposed technique on 118 bus test system

	HGAPSO	PSO
Total load shedding (MW)	482.7462	522.3441
Agricultural load (MW)	172.8010	124.5926
Industrial load (MW)	0	30.5211
Commercial load (MW)	8.0275	56.3052
Residential load (MW)	285.2850	220.4987
Large users load (MW)	16.5425	90.4265
Total customer interruption cost ($)	179024.8504	655223.3300
Maximum FVSI (Line)	0.4216 (69-75)	0.3883 (69-75)
Active power loss (MW)	344.2254	349.4277

Based on Table 1, the agricultural and residential loads are inexpensive in compare of the other load classes such as industrial or commercial loads. Consequently, based on Table 7 the most amount of load curtailment is in agricultural and residential area. Also, the results represent minimum load interruption cost which is obtained from HGAPSO solver and PSO is not successful to obtain minimum interruption cost. Fig. 5 shows good convergence of HGAPSO in compare of PSO. So, HGAPSO is powerful to obtain better solution of load shedding that is applied by this paper firstly.

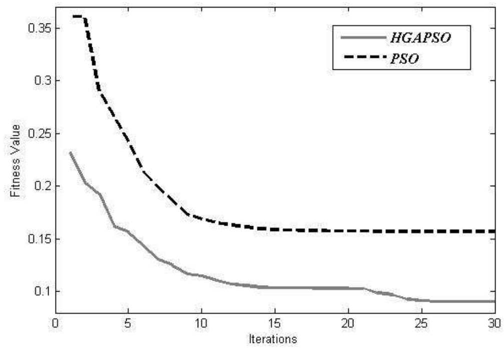

Fig. 5. HGAPSO and PSO convergence(118 bus)

6. Conclusion

In this paper a multi-objective load shedding approach to improve transmission line performance in contingency conditions based on Hybrid Genetic algorithm and Particle Swarm Optimization (HGAPSO) is presented. The under voltage load shedding problem is converted to an optimization problem with the multi-objective function including the minimum active power losses, the maximum voltage stability, the minimum customer interruption cost and the desired alleviating transmission line under over loading conditions. The proposed HGAPSO algorithm is easy to implement without additional computational complexity. Three different systems, 33-bus, 57-bus and 118-bus test systems, are applied to verify its robust performance. The effectiveness of proposed scheme Compared with other method can be summarized as follow:

- The faster convergence and less time consuming
- The ability to jump out the local optima
- Providing the correct answers with high accuracy in the initial iterations
- Superiority in computational simplicity, success rate and solution quality

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