A NEW TECHNIQUE OF LOAD SHEDDING TO STABILIZE VOLTAGE MAGNITUDE AND FAST VOLTAGE STABILITY INDEX BY USING HYBRID OPTIMIZATION

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ABSTRACT

The boundary limitation of power systems in terms of generation and network growth, Owing to lack of generation or transmission capacity, due to this a power system operates near to its stability boundaries. The growing complexity of heavily loaded power systems stuck through disturbances and outages makes the problem of voltage uncertainty even worse, a blackout is usually the result of increasing load beyond the transmission capacity of the power system. Therefore, under voltage load shedding (UVLS) is performed as a final remedy to avoid larger scale voltage collapse, restore reactive power balance and finally re-establish the operating conditions, so it is considered, as state of the art to achieve voltage stability. Weak buses are identified using the Fast Voltage Stability Index (FVSI). Moreover, it is capable for identification of critical areas in a large power system; determine the point of voltage collapse, maximum permissible load, and the most critical line in an interconnected system. It is highlighted that if load shed is conducted at the location with high FVSI index value, the system would become more voltage stable. This paper focuses on optimal load shed as well as enhancing the system voltage profile this results to stabilize fast voltage stability index values by using a hybrid optimization algorithm based on the well-known Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). GA has traditionally been known for its accuracy while the PSO algorithm is popular for its fast convergence time. The GAPSO algorithm is utilized to minimize the total amount of load shed on the weak buses under the constraint of maintaining the minimum system voltage profile. The performance of the proposed technique was assessed by simulations in MATLAB/SIMULINK under the IEEE-30 bus meshed networks. Thus, the proposed technique is not only robust against system failures but is also efficient enough for real time applications in power systems.

Keywords: fast voltage stability index, voltage collapse, voltage stability, under voltage load shedding.

1. INTRODUCTION

Modern power systems are very complex, non linear, heavily stressed and have plentiful arrangements of operating situations. The number of disturbances that need to be inspected has raised massively. One of the main causes for power blackouts is voltage instability which is attributed to insufficient generation as well as transmission capacities. The increasing demand for electric power has put a lot of pressure on the systems responsible for the operation and control of the highly complex power networks that exists today. The load is considered the driving force for voltage stability, e.g. When the system voltage magnitude declines, motors are used to improve its voltage magnitude by rising the amount of reactive power. However, in the extreme contingency conditions the existing reactive power sources are not sufficient to stabilize the decreasing system voltage and increasing FVSI values. Furthermore, factors such as unexpected load increments or component outage causes a voltage collapse resulting in blackout state.

The major challenges faced by power system operators include change in the nature of loads, performance of the on load tap changer transformer, the dependency on generation positioned remotely away from load centers, natural load growth, and the influence of protection and control systems. Contingency condition may be created by overloading the power system up to a certain limit leading to an outage of transmission line or a generator. Similarly, a sudden change in load value or generations may also give rise to a contingency situation. Contingency analysis gives tools for building, analysing, and managing records of contingencies and related violations [1].

The success of UVLS in stabilizing a system depends on determining the optimal amount, time and location for load shedding. Shedding lesser or more than required amount of load does not arrest voltage instability and may even lead to a voltage collapse or over frequency problems, respectively. Similarly, shedding load at the wrong place may cause unnecessary interruption, loss of customer trust, and the utility revenue. The time instant at which load shedding needs to perform is also very crucial as discussed in [2]. The UVLS scheme has been proven to be robust tool in stabilizing systems suffering from low voltage magnitudes and increasing FVSI values[3-5], note that voltage instability does not only influence the local load area but may also spread to the adjacent area in an interconnected power system, commonly known as cascading failures.

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The decreasing magnitude of voltage and increasing values of FVSI index are the sign of power system instability and if remedial action not taken timely power system may falls in a blackout condition very quickly. To restore power flow solvability and improve voltage magnitudes, the load buses are chosen based on (FVSI) value, high values of FVSI indicate weak buses, which are the most suitable candidate for load shed. Therefore, this paper focuses on finding the optimal amount of load shed which stabilize the decreasing magnitude of voltage and increasing values of FVSI. In order to achieve this hybrid technique based on the GA and PSO algorithms is proposed. The proposed technique converts UVLS into an optimization problem with a multi-objective function including minimum amount of load shed, at selected weak buses and minimum voltage drop in order to achieve voltage stability at all buses, In addition it also stabilize the increasing FVSI values. Thus the proposed technique has the ability to stabilize the voltage profile and FVSI values.

This paper is structured as follows section 2 provides a review of the existing literature relevant to this research. Section 3 explains problem formulation while section 4 introduces some preliminary background. The proposed UVLS technique is presented in section 5 whereas section 6 gives the simulation studies and results. Finally the conclusion is given in section 7.

2. LITERATURE REVIEW

A concrete approach offering the least amount and finest location of load shedding was presented in [6]. The proposed technique uses a multi-stage and non-linear approach to find the minimum load shed at each stage. Genetic Algorithms were executed in the Hydro-Quebec system to estimate the amount of load shed in[7, 8],but the approach is unable to grip a broader range of load behavior, different scenarios and short-term voltage instability problems. GA was utilized to investigatefor optimal supply restoration approach in the network of distribution system [9]. Likewisealternativestudy [10] showedan optimization tool builton GA to estimate and perform load shed. To solve steady State load shedding problem a novel application of the GA presented in [11]. A new adaptive load shedding technique using GA is proposed in [12]. The load buses are ranked from the strongest to the weakest. The weakest bus is considered the best option for load shedding. The voltage stability margin is highly influence by the weakest buses in an interconnected power system. Therefore, the identification of weak buses is necessary for planning and operation of power systems in long-term studies.

Particle Swarm Optimization was combined with Simulated Annealing to form a hybrid, was implemented to tackle UVLS problem more efficiently in [13]. The technique was tested on the IEEE 14 and 118 bus test systems. However, this technique can only be used for long term voltage stability and is unsuitable for short term voltage stability. Another hybrid scheme consisting of Particle Swarm Optimisation (PSO) and Linear Programming (LP)was developed to resolve the issues of low convergence and eliminate transmission line overloading [14]. The technique was implemented on the IEEE 14 bus system and had a fast convergence time. However, it was unable to solve non-linear problems. Modal analysis and PSO were combined to achieve optimal load shedding and voltage stability in [15]. However, the proposed technique works well on Transmission networks only. For the distribution system, a Comprehensive Learning PSO (CLPSO) was developed to achieve an optimal partition, in case of upstream loss [16]. The proposed technique works successfully on an Egyptian 66kV, 45 bus meshed network and 33-radial bus system. The dynamics related by voltage stability are frequently slow [17], therefore, the use of static based approaches is considered as a good approximation [18-20].An adaptive under-voltage load shedding scheme using model predictive control and a technique for load shedding based on the consideration of voltage stability was proposed in [21, 22]. To prevent voltage instability a new integer value modelling of optimal load shedding was achieved through hybrid discrete particle swarm optimization by considering multi objectives, the proposed methodology was employed on IEEE 14 and 30 bus test systems[2]. Probabilistic under voltage load shedding using point estimate method was presented in [23].

Estebsari A, Pons [24] show that automatic UVLS is better to manual UVLS with the Techno-economic impacts of automatic Undervoltage load shedding under emergencies. A robust UVLS scheme proposed by combining GA and PSO to improve transmission line performance with the fitness of minimum customer interruption cost was presented in[25]. However, the proposed technique does not achieve fast convergence and optimum amount load shed. Another study combines GA and PSO to get optimal DG sizing and location in distribution networks[26].It is observed that hybrid techniques perform well for large and complex power systems and produce more optimal and quality solutions than individual techniques [27].

3. PROBLEM FORMULATION

The objective function is the sum of the weighed difference between the pre-contingency and post-contingency for the active power demands and may be formulated to minimize the total load shed at selected buses and minimization of voltage drop at all buses so that the voltage stability is maximized. The objective function is given as follows:

$$\sum_{i=1}^{N_{BUS}} \left(P_{Di}^{b} - P_{Di}^{a} \right) \tag{1}$$

$$\min\{ \sum_{i=NLS} (P_{Li} - f_i(x_{\min}) - f_i x_{\max})) \} \tag{2}$$

$$V_2 - V_1$$

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Subject to

$$V_i - 0.9 \geq 0 \tag{3}$$

where P_{Li} is the ith load shedding bus, $f_i(x_{\min})$ and $f_i(x_{\max})$ are the limits of minimum and maximum load shedding limits at ith load bus and V_i is the ith bus voltage which should not be less than 0.9.Equality constraints of the networks are the power flow equations.

$$P(V) = P_{Gi} - P_{di}(V) - P_i(V,\delta) = 0 \tag{4}$$

$$Q(V) = Q_{Gi} - Q_{di}(V) - Q_i(V,\delta) = 0 \tag{5}$$

$$P_i(V,\delta) = V_i \sum_{i=1}^{NB} V_j Y_{ij} \cos(\delta_i - \delta_{j-} \theta_{ij}) \tag{6}$$

$$Q_i(V,\delta) = V_i \sum_{i=1}^{NB} V_j Y_{ij} \sin(\delta_i - \delta_{j-} \theta_{ij}) \tag{7}$$

Likewise, the change in active and reactive power generation value under the base condition and for loading condition are considered as inequality constraint.

$$P_{Gi}^{\min} \leq P_{Gi} \leq P_{Gi}^{\max} i = 1,2,.........NG \tag{8}$$

$$\Delta P_{Gi}^{\min} \leq \Delta P_{Gi} \leq \Delta P_{Gi}^{\max} \tag{9}$$

$$Q_{Gi}^{\min} \leq Q_{Gi} \leq Q_{Gi}^{\max} i = 1,2,.........NG \tag{10}$$

$$\Delta Q_{Gi}^{\min} \leq \Delta Q_{Gi} \leq \Delta Q_{Gi}^{\max} \tag{11}$$

The magnitude of all bus voltages is selected as an inequality constraint which is in the current state as well as the load shed condition.

$$V_i^{\min} \leq V_i \leq V_i^{\max}, i \in N_L \tag{12}$$

Notations used in above mathematical equations are explained in Table-1.

Table-1. Notations used in mathematical equations

P_{Di}^{b}	**Active power demand at bus i multiplying with loading factor before load shed** (in stresses condition)
P_{Di}^{a}	Active power demand at bus i after load shedding (unstressed condition)
P_{Gi}	Active power generated at'ith' bus
Q_{Gi}	Reactive power generated at'ith' bus
P_{di}	Active power demand at'ith' bus
Q_{di}	Reactive power demand at'ith' bus
V	Bus voltage magnitude
V_2	Voltage after load shedding (unstressed condition)
V_1	Voltage before load shedding (In stressed condition)
δ	Phase angle
V_i	Bus voltage magnitude atith bus
V_j	Bus voltage magnitude at bus j
Y_{ij}	Admittance of line ithjth (Ω)
δ_i	Voltage angle atith bus
δ_j	Voltage angle atjth bus
θ_{ij}	Admittance angle ofithjth line
NB	Number of buses
N_L	Number of lines
NG	Number of generators
$P_{Gi}^{\min}$	Minimum active power generation atith bus
$P_{Gi}^{\max}$	Maximum active power generation at ith bus
$Q_{Gi}^{\min}$	Minimum reactive power generation at ith bus
$Q_{Gi}^{\max}$	Maximum reactive power generation at ith bus
$\Delta P_{Gi}^{\min}$	Minimum change in active power at ith bus
$\Delta P_{Gi}^{\max}$	Maximum change in active power at ith bus
$\Delta Q_{Gi}^{\min}$	Minimum change in reactive power at ith bus
$\Delta Q_{Gi}^{\max}$	Maximum change in reactive power at ith bus
$V_i^{\min}$	Minimum voltage magnitude at ith bus
$V_i^{\max}$	Maximum voltage magnitude atith bus

4. PRELIMINARY BACKGROUND

4.1 Genetic algorithm

A non-linear, multi-objective problems require a global optimization GA which has obtained substantial

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attention as arobust stochastic search algorithm[28]. Developed algorithm is based on the biology of natural evolution; GA is performed on a set of the population with the application of "survival of the fittest" principle to yield superior estimates of the solution in a continuous cycle on the limit of predetermined constraints. Based on individual's level of fitness, each generation (solution) produces a new set of estimations and redevelops following the principle of operations as those of natural genetics. In this method, the development of populations of as et of individuals results, that are superior matched in terms of their adaptation to the given conditions [29]. Three types of operators are involved in the basic form of GA namely, selection, crossover, and mutation.

A population contains k chromosome representing candidate solution in GA algorithm, the dimension of each chromosome is m and the number of optimized parameters is real value vector. Consequently, the dimension of the space problem is indicated by every optimized parameter.

Step 1: Initialization stage: k number of chromosome is generated randomly and counter t = 0 is set. [$X_m(0)$, m= 1, . . . , k], where x_m (0) [$x_{m,1}(0)$, $x_{m,2}(0)$,……. $x_{m,j}$ (0)]. $X_{m,n}(0)$ is produced in search space [x_n^{min} x_n^{max}] randomly.

Step 2: Fitness: the objective function use m, the best value, m_{best} of the objective function, m is sought to evaluate each of the chromosomes in the initial population and then the chromosome associated with the global best set as m_{best}.

Step 3: Timing update: The time counter, t is updated to $t = t + 1$.

Step 4: Fresh population: The fresh population is created by following the succeeding steps until the fresh population is ended. Basically, the following steps are followed:

a) **Selection:** Based on their fitness, two parent chromosomes from the population are chosen.

b) **Crossover:** To form a new child, the parents are then crossed over using a crossover probability.

c) **Mutation:** New child is mutated at each chromosome using mutation probability

d) **Acceptance:** The new child is now placed in a fresh population

Step 5: Replacement: The Newly produced population is used to further run the algorithm.

Step 6: Stopping: Stop, if any of the stopping criteria for next step is fulfilled, otherwise go to step 2

4.2 Particle swarm optimization

In 1995, Kennedy and Eberhardt introduced PSO [30]. Inspired by the social behaviour of birds flocking and fish schooling, a swarm intelligence technique, PSO was establish to be fast and robust in resolving large-scale non-linear multi-objective optimization problems. It has been broadly employed in numerous engineering problems including UVLS. The main issue is to identify collapse point or maximum loading in the power system, PSO is suitable and fast to identify and it is successfully employed in UVLS problem.

In developing PSO algorithm, the population of k particles signifying candidate solutions with m being the representation of optimized parameter are defined. Every particle is an m dimensional real-valued vector indicating every optimized constraint gives a dimension of the problem space. The following steps explain the PSO technique.

Step 1: Initialization: Set the time counter,t = 0 and generate k chromosome randomly,[$x_m(0)$, m=1,………k], where $x_m(0)$ = [$x_{m,1}(0)$, $x_{m,2}(0)$,….. $x_{m,j}(0)$], $x_{m,n}(0)$ is randomly produced in search space, [x_n^{min}, x_n^{max}]. $V_m(0)$ is randomly produced for estimation of the objective function. For every particle set $x_m*(0) = x_m(0)$ and $m*m = m_m$, m = 1,…..n. Then, the best value of the objective function is sought m_{best}. The particle related with m_{best} is set as the global best, $x**$ (0) with an objective function $m**$. The initial value of the w (0) is set to 0.98.

Step 2: Timing update: The time counter, t is updated to$t = t + 1$

Step 3: Update of the weight: The inertia weight is updated.

Step 4: Update of the velocity: The individual best and the global best is now used to replace the particle velocity by the following equation:

$$v_{j,k}(t) = \omega(t) v_{j,k}(t-1) + c_1 r_1 (X^*_{j,k}(t-1) - x_{j,k}(t-1) + c_2 r_2 (x^*_{best} - x_{j,k}(t-1)))$$

Step 5: Position update: Every particle change its position based on the updated velocity, and may expressed by the following equation

$$X_{m.n}(t) = X_{m,n}(t\text{-}1) + V_{m,n}(t)$$

This helps to set any particle which violates its position bounds in any dimension to its appropriate limit.

Step 6: Evaluation of Particle: Based on updated position every particle is now evaluated. If $m_{min} < m*$ then updates individual best as $x*_m(t) = x_j(t)$, $m_l = m_l*$

Step 7: The minimum value is now sought for; if $min<m**$,then the global best is updated by $m** = m_{min}$ and $x** = x_{min}(t)$.

Step 8: Stopping: On the satisfaction of stopping criteria then stop, otherwise go to step 2.

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4.3 Fast voltage stability index

Originating from the equation of two bus network shown in Figure-1, the Fast Voltage Stability Index can be formulated as

$$FVSI_{ij} = \frac{4Z_{ij}^2 Q_j}{V_i^2 X_{ij}} \tag{13}$$

Where X_{ij}, is line reactance between line i and j, Z_{ij} is the impedance between line i and j,Q_j is the reactive power flow at the receiving end and V_i is the sending end voltage

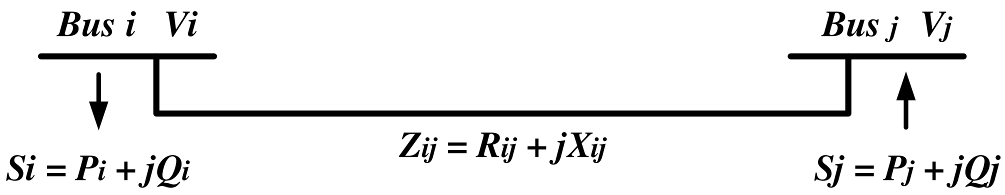

Figure-1. Model of two bus power system.[31].

The $FVSI_{ij}$ index can be estimated for any of the lines of the network and depends, basically on the reactive power. In power systems, FVSI is considered a strong index for analysing the voltage stability condition [32]. FVSI is also useful in determining power system's maximum loadability, on-line voltage stability assessment and identification of weak buses. This shows that FVSI provides essential information to correctly indicate the weak buses for load shedding. Let us consider the IEEE 30 bus system. Figure-2 shows the trend of voltage and FVSI plotted against enhancing values of reactive power for the 30th bus. It is found that the correlation between the voltage magnitude and FVSI is negative i.e. increasing the reactive power demand at Bus 30, results in a decrease in bus voltage magnitude while the corresponding FVSI values increase as evident in Figure-2.

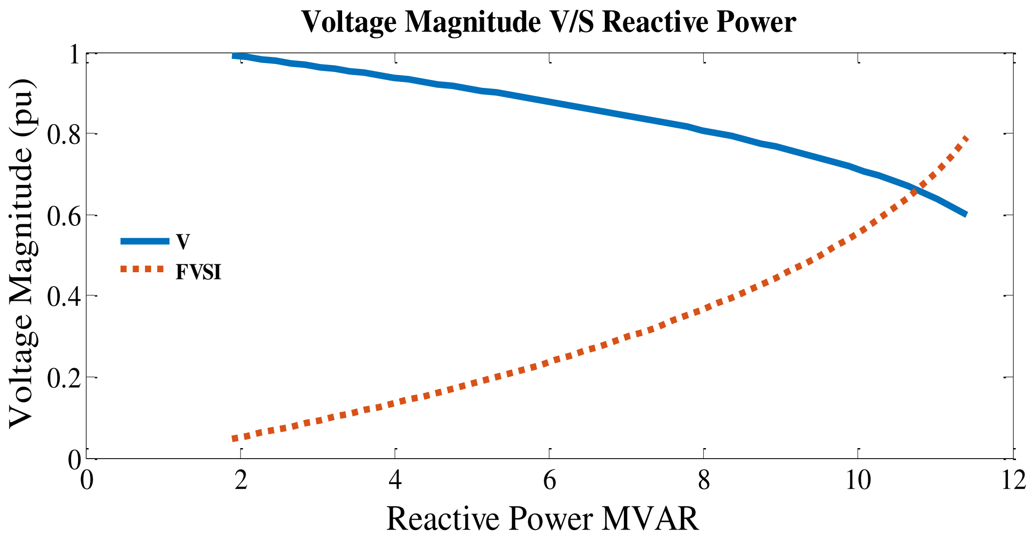

Figure-2. Bus voltage and FVSI index against increasing reactive power demand at bus 30.

5. PROPOSED LOAD SHEDDING METHOD

In the field of optimization hybrid metaheuristics have emerged with superior results in terms of best fitness and computation time. The proposed scheme is based on a hybrid approach by combining GA and PSO. However, both suffer from their own individual drawbacks for example although GA is popular for producing accurate results but takes a long time to converge. Similarly PSO is popular for its short convergence time but may not always converge to the best solution. GA and PSO have been proven to be well suited for generator and line outage cases[33]. Therefore, by proposing a hybrid scheme based on GA and PSO in this work, it is expected to combine the strengths of these techniques and produce a better algorithm than either of the algorithms deployed alone.

The proposed algorithm to obtain the optimal amount of load shed for a power system under stress is given in algorithm 1.

ALGORITHM 1: GAPSO

Input: $Population_{size}$, $Problem_{size}$, $P_{crossover}$, $P_{mutation}$

Output: S_{best}

1 Population Initialize Population ($Population_{size}$, $Problem_{size}$); θ:⟸

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2 Pg-best θ ; ⟸
3  for each P ∈ Population do
4 Pvelocity Update Velocity (Pvelocity, Pl-best, Pp-best,); ⟸
5 Pposition Update Position (Pposition, Pvelocity); ⟸
6 if Cost(Pposition) ≤ Cost (Pp-best) then
7 Pp-best Pposition; ⟸
8 if Cost (Pp-best) ≤ Cost (Pl-best) then
9 Pl-best Pp-best; ⟸
10 Sbest Pl-best; ⟸
11 end if
12 end if
13 end for
14 Parents Select Parents (Population, Populationsize); ⟸
15 Children θ; ⟸
16 for each Parent1, Parent2 ∈ Parents do
17 Child1, Child2 Crossover (Parent1, Parent2, Pcrossover); ⟸
18 Children Mutate (Child1,Pmutation); ⟸
19 Children  Mutate (Child2,Pmutation); ⟸
20      end for
21 Evaluate Population (Children);
22 Sbest Get Best Solutions (Children) ⟸
23 Population Replace (Population, Children); ⟸
24 return Sbest;
25 end
```

The proposed algorithm replaces the local search mechanism of GA with the global search mechanism of PSO as shown in line 3 to 13 of Algorithm 1. After obtaining the global solutions using PSO, the resulting optimum values are employed by GA to obtain the optimum value of load shed.

6. SIMULATION RESULTS (IEEE 30 BUS)

The proposed hybrid GA-PSO algorithm was examined on the IEEE 30bus test system using the MATPOWER [34, 35] toolbox in MATLAB. The system includes 6 generators with buses located at 1, 2, 5,8,11 and 13 as shown in Figure-8. It is made of 41 lines, two Static VAR sources at buses 10 and 24, and 4 tap changing transformers. The base load of the system is 283.4MW and 126.20MVAR.

In heavy loading condition when original real and reactive loads are multiplied by a loading factor of 1.58, the total load is increased to 447.772MW and 199.396MVAR. The power flow analysis is possible and the values are converged but when loading factor increased to 1.59 the power flow is not possible and the values did not converge. Total maximum possible increment of load is 450.606MW, so the total load increase at all buses by 2.834MW which is 0.01 % of the base load 283.4MW will lead to non-solvability so it is considered as total maximum possible load shedding for this case. To investigate the performance of the proposed method and its efficiency, only shedding of load on weak buses represents the best option for restoring solvability otherwise shedding on healthy buses creates unnecessary interruption and does not restore solvability.

We suppose that the system loading is increased by 1.58 times the base case, following this disruption the voltage profile of the overall system decreases as shown in Figure-6. Five weak buses are selected 30, 26, 29, 24 and 7 for load shedding based on the highest FVSI values as tabulated in Table-2. Different loading conditions at selected buses are listed in Table-3, which would give knowledge to generate their boundary. Table-4 and Figure-3 shows the voltage magnitudes of selected buses before and after load shed. It is clear from Figures 3, 6 and 9 that voltage profile is improved significantly by proposed technique.

Table-2. Top five weak buses selected for load shedding.

Line	Bus	FVSI	Rank
29-30	30	0.358	1
25-26	26	0.311	2
27-29	29	0.252	3
23-24	24	0.224	4
5-7	7	0.167	5

Table-3. Different loading values for weak buses.

Bus No.	Base loading P (MW)	loading factor =1.58 solvable	loading factor=1.59 Unsolvable
30	10.6	16.748	16.854
26	3.5	5.53	5.565
29	2.4	3.792	3.816
24	8.7	13.746	13.833
7	22.8	36.024	36.252

Table-4. Bus voltage magnitudes at weak buses before and after load shedding.

Bus No	Volts before load shed	Volts after load shed by GA	Volts after load shed by PSO	Volts after load shed by GAPSO
30	0.754536	0.950324	0.976690	1.002597

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26	0.788245	0.973748	0.989237	1.021846
29	0.825120	0.958589	0.990261	1.023539
24	0.858520	0.943492	0.981156	1.003706
7	0.858301	0.935944	0.969548	1.002235

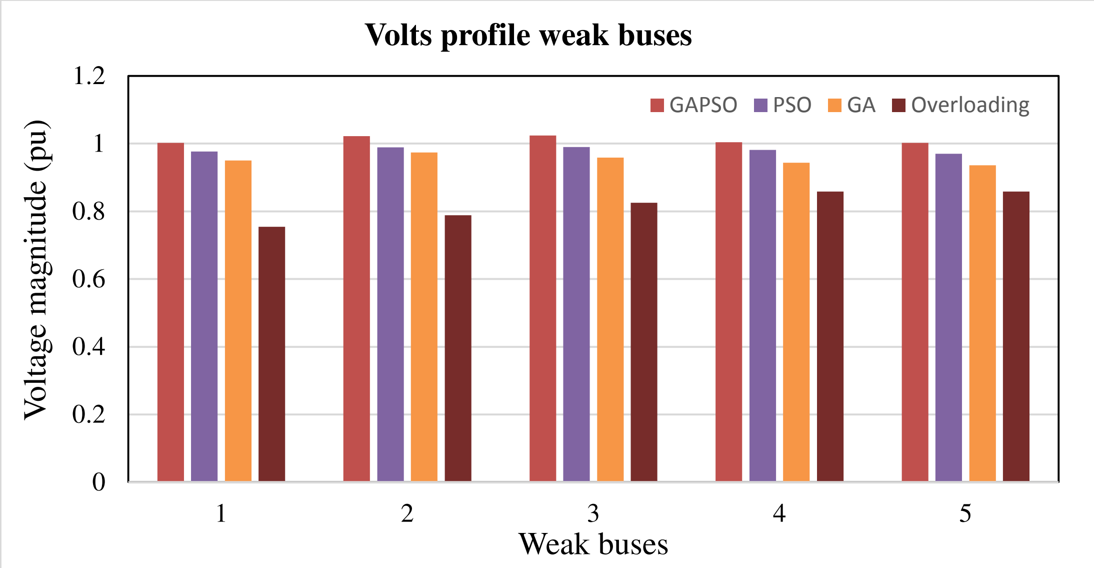

Figure-3. Volts magnitude weak buses.

The proposed method makes a significant improvement in the voltage profile of the system as shown in Figures 3, 6 and 7. It is also observed that when the system is overloaded the voltage of the buses falls below 0.9pu as shown in Figure-5. However, the proposed technique successfully stabilizes these buses and thus the overall system voltage profile as shown in Figures 3 and 6. Moreover, the proposed GAPSO technique also outperforms the GA and PSO in terms of the voltage profile as shown in Figures 3 and 6. The proposed technique have also the ability to stabilize the FVSI values and Voltage on increasing reactive power demand on bus 30 as shown in Figures 4 and 5 respectively. The voltage of bus 30 falls to a very dangerous level 0.6pu (Figure-5) if load shedding not perform than it may lead to a system collapse condition. Moreover, the FVSI values of bus 30 are stable at 0.1 as shown in Figure-4, while the Voltage magnitude is stable at 0.98pu as shown in Figure-5. These results show that the proposed technique gives the most accurate results in term of stabilize the voltage magnitude and FVSI index values. The power system returns back to a safe and normal operating condition after load shed. Therefore, the proposed method may be employed for real time applications in power systems.

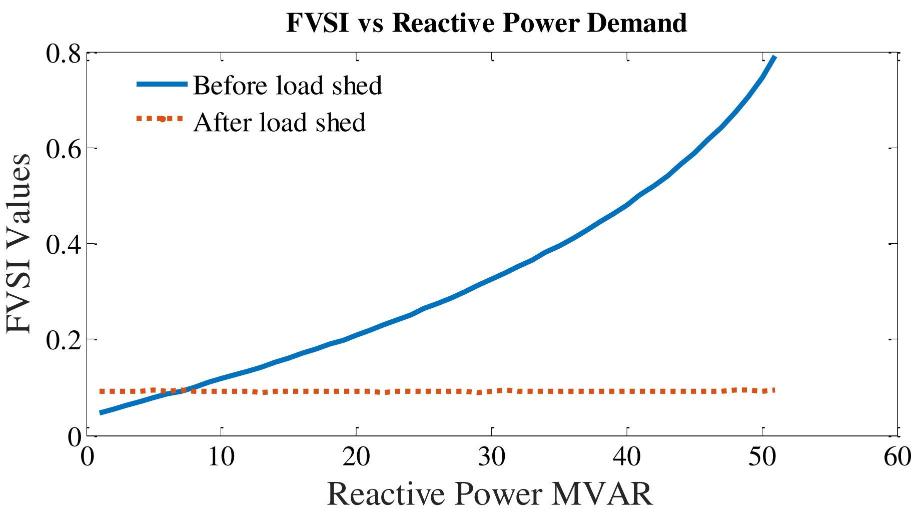

Figure-4. FVSI values before and after load shed.

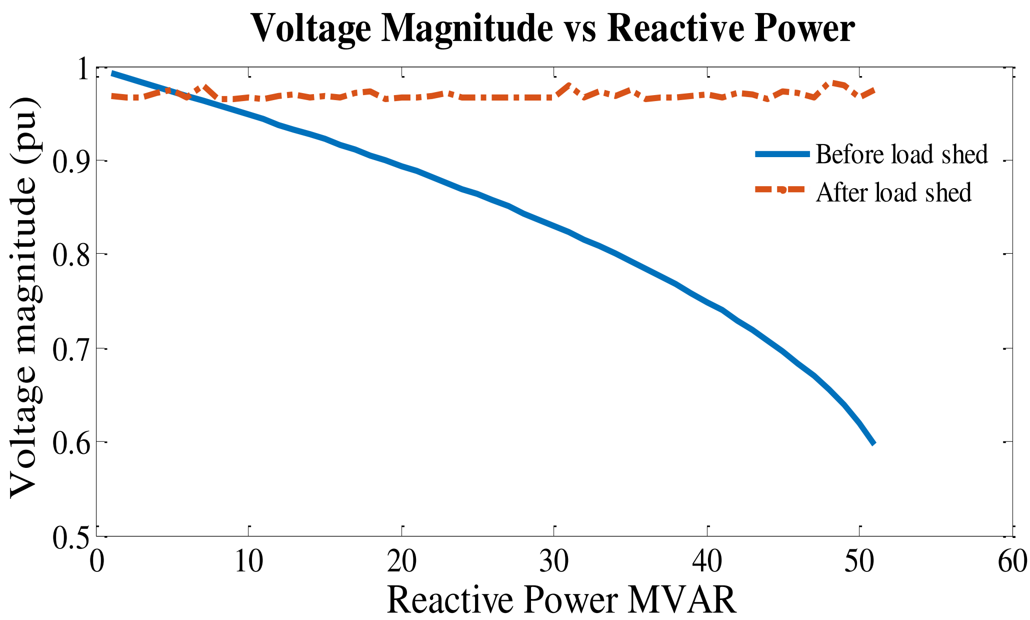

Figure-5. Voltage magnitude before and after load shed.

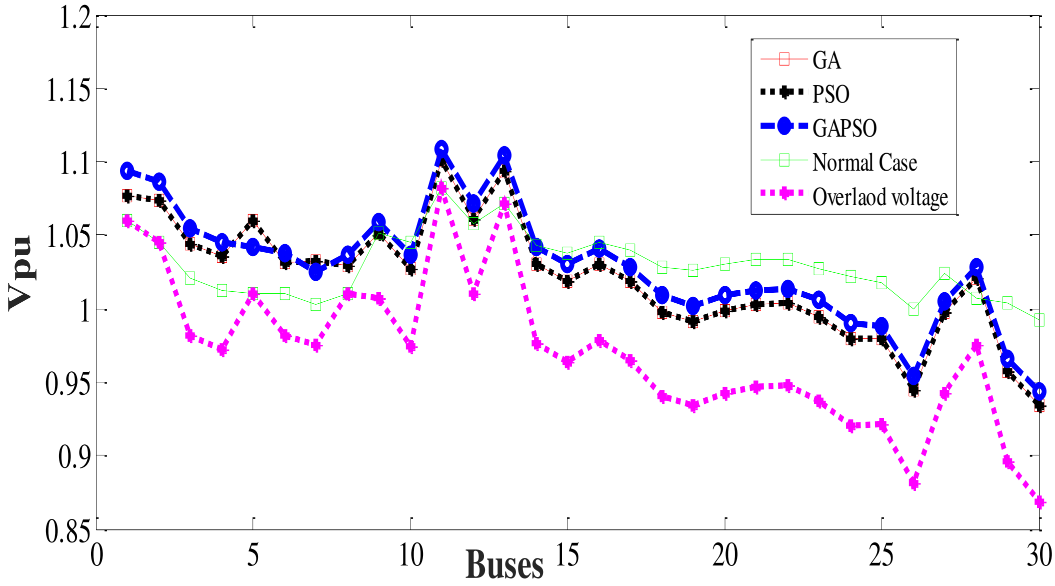

Figure-6. Voltage profile of IEEE 30 bus test system after load shedding.

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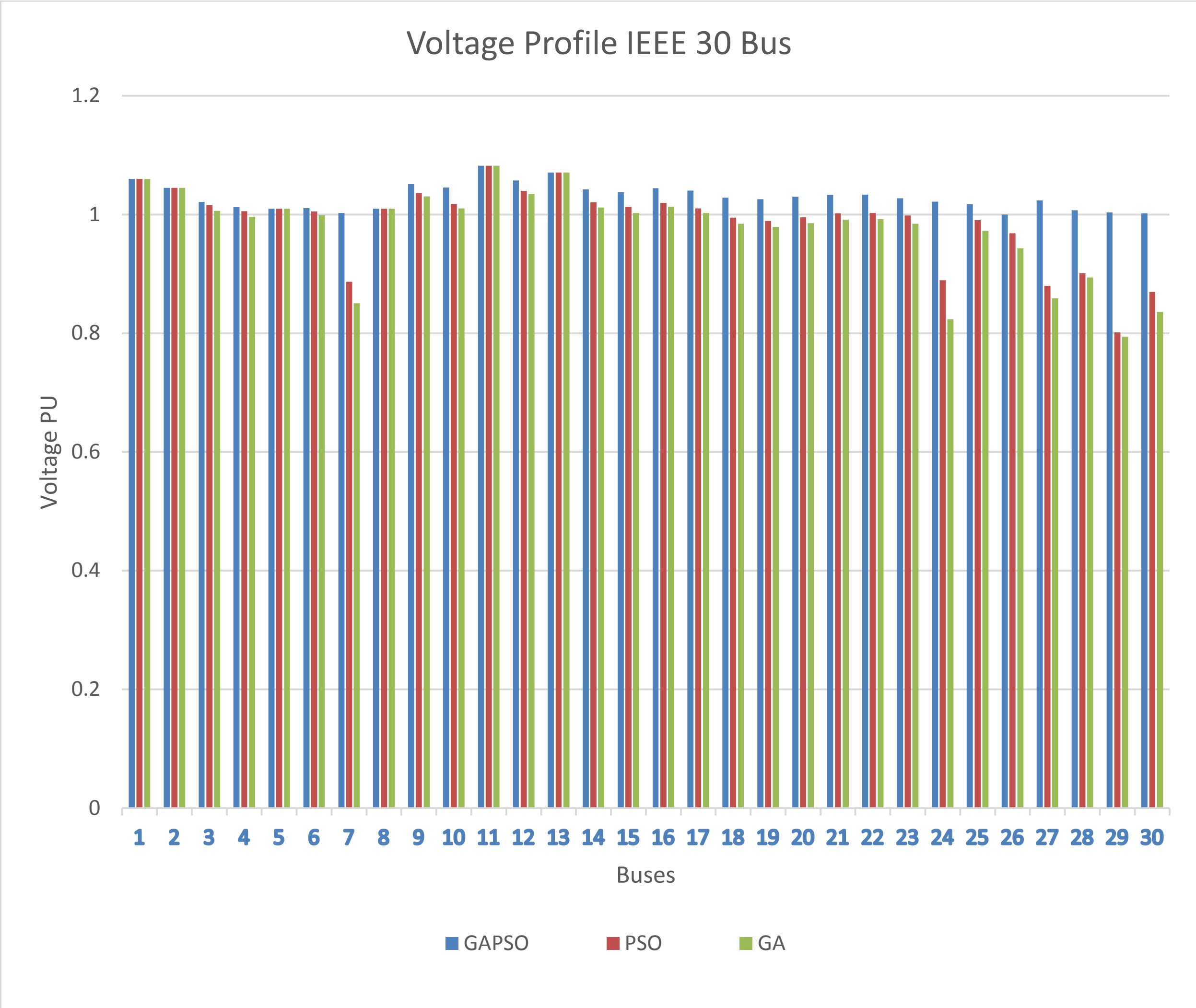

Figure-7. Volts profile of all algorithms.

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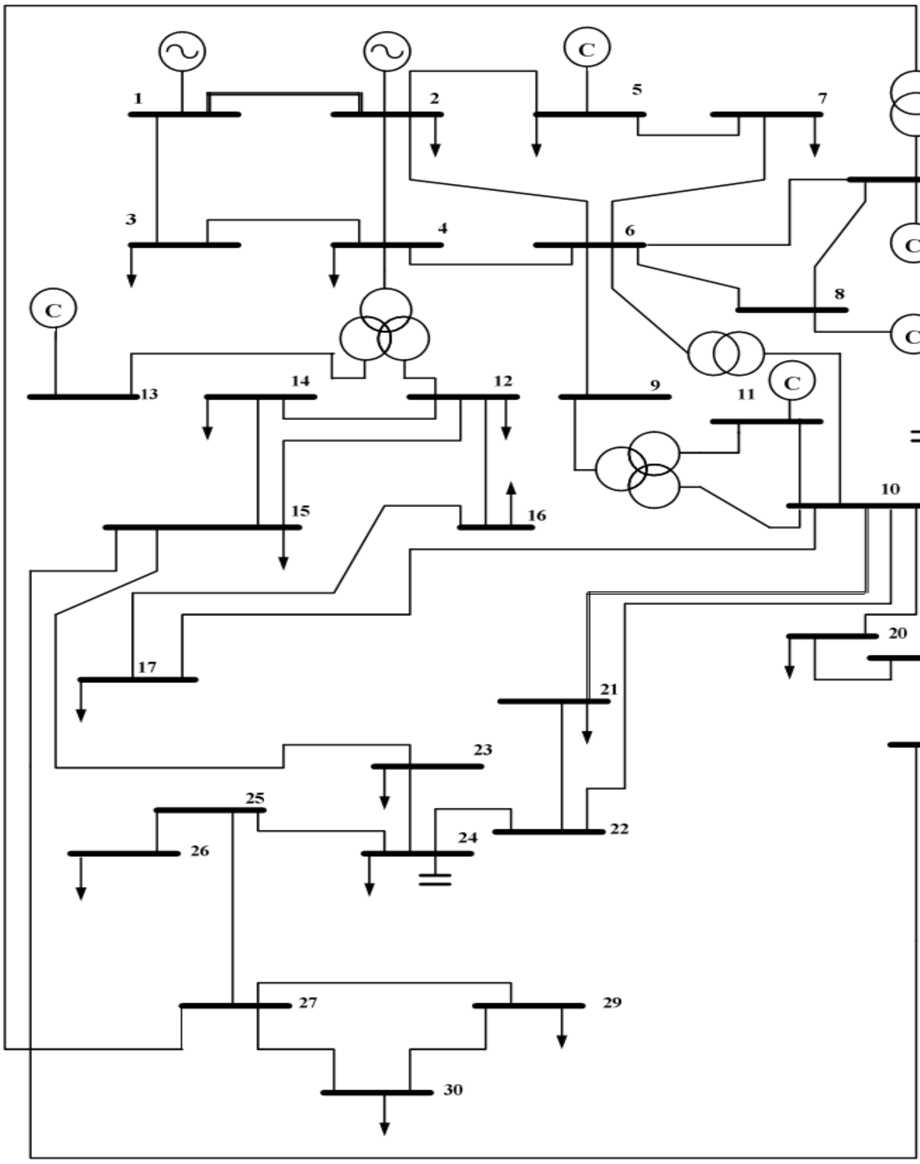

Figure-8. IEEE 30 bus test system [36, 37].

7. CONCLUSIONS

This paper proposed a hybrid GA-PSO based technique for load shedding in power systems. The proposed methodology exploits the advantages of GA and PSO techniques by combining them in a single algorithm. The proposed algorithm uses threshold values of FVSI to select the weak buses for load shedding. The performance was evaluated using the Matpower environment in MATLAB and compared with the performance of GA and PSO algorithms used individually for load shedding. The results show that the proposed algorithm was implemented on IEEE 30 bus test systems. The GAPSO algorithm sheds the minimum amount of load and brings a significant improvement in voltage profile along with stable FVSI values which guarantees a secure power system operation of the collapsing system. Moreover, the proposed algorithm also outperforms the GA and PSO algorithms. The results clearly indicate the effectiveness of proposed method. Thus it can be concluded that proposed technique for load shedding reduces the FVSI index hence reducing the probability of voltage instability, finally achieved stabilized voltages which ensures power system reliability.

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