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# OPTIMAL UTILIZATION OF GENERATORS USING HARMONY SEARCH ALGORITHM FOR THE MANAGEMENT OF CONTINGENCY

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Abstract. *In the modern world totally dependent on electric power, stable operation of the electrical system is absolutely necessary. Hence, optimal utilization of the existing power resources has become absolutely necessary. In this work, a procedure of optimal tuning of generators with harmony search algorithm in the existence of UPFC has been presented. The UPFC has been placed based on an index which is a composition of L-index and LUF index. A multi objective function has been chosen for tuning the generators. The multi-objective function consists of voltage deviation, generation cost and power loss. The presented technique has been examined and implemented on an IEEE 30 bus system for normal and for contingency condition.*
**Keywords:** Optimal reallocation, UPFC, Harmony search algorithm, Voltage stability

1. **Introduction.** Optimal power flow or optimal reallocation of generators consists of optimizing an objective function in the presence of operational constraints. Many methods have been developed so far to solve the OPF problem. In [1], Zhang et al. have proposed a modified multi-objective evolutionary algorithm based decomposition (MOEA/D) method to solve OPF. A modified Tchebycheff decomposition method has been utilized to obtain uniformly distributed Pareto-optimal solution. A solution to the OPF problem of the power systems has been obtained using various methods like improved colliding bodies optimization algorithm [2], particle swarm optimization [3], adaptive group search optimization [4], gray wolf optimizer [5], quasi-oppositional teaching learning based optimization [6], differential evolution optimization algorithm [7], and improved harmony search method [8].

FACTS devices play a very important role in further enhancing the effect of the solution to OPF problem of the power systems. Mahdad and Srairi [9] used adaptive flower pollination algorithm in combination with SVC for solving the OPF problem in case of faults in the generating units. Rao and Vaisakh [10] presented a result to multi-objective optimal power flow (MOOPF) problem utilizing an adaptive clonal selection algorithm

(ACSA) to reduce generation cost, transmission loss and voltage stability index (L-index) with multi-type FACTS devices. Different voltage source converter (VSC) based multi-type FACTS devices like UPFC, IPFC and GUPFC are studied and inserted as power injection models in multi-objective optimization problem formulation. Huang and Huang [11] propose a hybrid optimization method for optimal power flow utilizing a flexible AC transmission system (FACTS). To determine the optimal solutions to the FACTS allocation problem, a hybrid optimization method that incorporates a harmony search algorithm and an ant system is presented. UPFC is one of the most powerful and flexible FACTS devices and has been used for various power system issues like minimization of transmission loss and operating cost of the system [12], system security [13], available transfer capability [14], total transfer capability [15], social welfare [16], power system loadability [17], multi-area economic dispatch performance utilizing swarm intelligence technique [18] and various other applications.

In this paper, UPFC is placed based on multiple index which is a combination of L-index as well as LUF index. UPFC sizing is done employing harmony search algorithm for optimal power flow. The optimal sizing of generators has been used for a multi-objective function, especially, minimization of voltage deviation, minimization of generation cost and minimization of transmission line loss. The results of optimal sizing without and with UPFC have been compared to prove the effectiveness of the proposed method. Results are also compared with genetic algorithm.

Optimal generation reallocation with optimal placement of UPFC using multiple index and optimal tuning of UPFC with HS algorithm are the advantages of the proposed method.

**Abbreviations**

| | |
|---|---|
| FACTS | Flexible AC transmission system |
| OPF | Optimal power flow |
| UPFC | Unified power flow controller |
| HS | Harmony search |
| GA | Genetic algorithm |
| $P_L$ | active power loss |
| $P_{Gi}$ | active power generated at bus $i$ |
| $P_{Di}$ | power demand at bus $i$ |

## 2. Method of Placement and Algorithm for Sizing.

### 2.1. L-index.

$$L\text{-}index = \left| 1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j} \right| \tag{1}$$

L-index lies between 0 and 1. Lesser the value of index remains system stable. $V_i$ indicates magnitude of voltage at bus $i$, $V_j$ indicates magnitude of voltage at bus $j$ and $F_{ji}$ indicates complex elements.

Line utilization factor (LUF) is an index used for determining the congestion of the transmission lines as given in Equation (2).

$$LUF = \frac{MVAij}{MVAij^{\max}} \tag{2}$$

LUF is the ratio of apparent power flow in the line to the maximum LUF of the line. When the power flow in the line is within its maximum limits, the system is said to be stable and the value of LUF is less than 1. $MVAij^{\max}$ is the highest MVA rating of the line linking bus $i$ and bus $j$, and $MVAij$ is actual MVA rating of the line linking bus $i$ and bus $j$.

The UPFC has been positioned on the basis of an index which is a combination of L-index and LUF index. A multi-objective function given in Equation (3) including fuel cost, real power loss and voltage deviation is utilized for the optimal tuning of generators.

$$Min\, F = Min(W_1 * F_1 + W_2 * F_2 + W_3 * F_3) \tag{3}$$

where $F_1$ is the generation cost given by

$$F_1 = Min\left(\sum_{i=1}^{ng}\left[ai + biP_{Gi} + ciP_{Gi}^2\right]\right) \tag{4}$$

The fuel cost coefficients are $a$, $b$, $c$ and the number of generators in the power system is $ng$.

$F_2$ is the real power loss

$$F_2 = Min\left(\sum_{i=1}^{ntl} real\left(S_{jk}^i + S_{kj}^i\right)\right) \tag{5}$$

where $S_{jk}$ gives the complex power flows from bus $j$ to bus $k$ in line $i$ and no. of transmission lines is $ntl$.

$F_3$ is the voltage deviation

$$F_3 = Min(VD) = Min\left(\sum_{k=1}^{Nbus}\left|V_k - V_k^{\text{ref}}\right|^2\right) \tag{6}$$

The actual value of voltage at bus $k$ is $V_k$ and the reference value of voltage at the bus is $V_k^{\text{ref}}$.

Power balance constraint

$$\sum_{i=1}^{N} P_{Gi} = \sum_{i=1}^{N} P_{Di} + P_L \tag{7}$$

where $i = 1, 2, \ldots, N$ and $N$ = number of buses.

Voltage balance constraint

$$V_{Gi}^{minimum} \leq V_{Gi} \leq V_{Gi}^{maximum} \tag{8}$$

where $Gi = 1, 2, \ldots, ng$ and $ng$ = number of generator buses.

Real power generation limit

$$P_{Gi}^{minimum} \leq P_{Gi} \leq P_{Gi}^{maximum} \tag{9}$$

where $Gi = 1, 2, 3, \ldots, ng$.

Number of generators is $ng$.

Generator buses voltage limits lie between 0.9 p.u. and 1.1 p.u.

2.2. **Algorithm.** Harmony search (HS) is a population based algorithm influenced from the musical procedure of searching for an ideal state of harmony, presented by Geem et al. in 2001 [19]. In the HS algorithm,

- musician is equivalent to decision variable.
- plays is equivalent to global optimum.
- pitch is considered as fitness value.

2.3. **HS algorithm parameters.** HMS is the harmonic memory size, HMCR (Harmony Memory Considering Rate) is rate of electing a value against the harmony memory, PAR (Pitch Adjustment Rate) = rate of selecting a neighboring value, $\delta$ = amount linking two neighboring values in discrete candidate set and fw (fret width) = maximum change in pitch adjustment.

TABLE 1. Harmony search algorithm parameters

| Parameters | Optimal range |
|---|---|
| Pitch adjustment rate (PAR) | 0.1-0.5 |
| Harmony memory size (HMS) | 1-100 |
| Harmony memory considering rate (HMCR) | 0.7-0.99 |
| Fret width (fw) | 0.1 |

3. **Results and Discussion.** The presented technique is examined on an IEEE 30 bus system. The NR load flow analysis for the IEEE 30 bus system is done. It is identified from Figure 1 that bus no. 30 has the highest L-index value of 0.0895 p.u. and hence is considered to be the feeble bus of the system. Two lines have been connected to bus number 30, namely, 27-30 and 29-30. It is identified from Figure 2, that the line 27-30 has the highest LUF value of 0.0367 p.u. Therefore, UPFC positioned at bus 30 and line 27-30 in the IEEE 30 bus system.

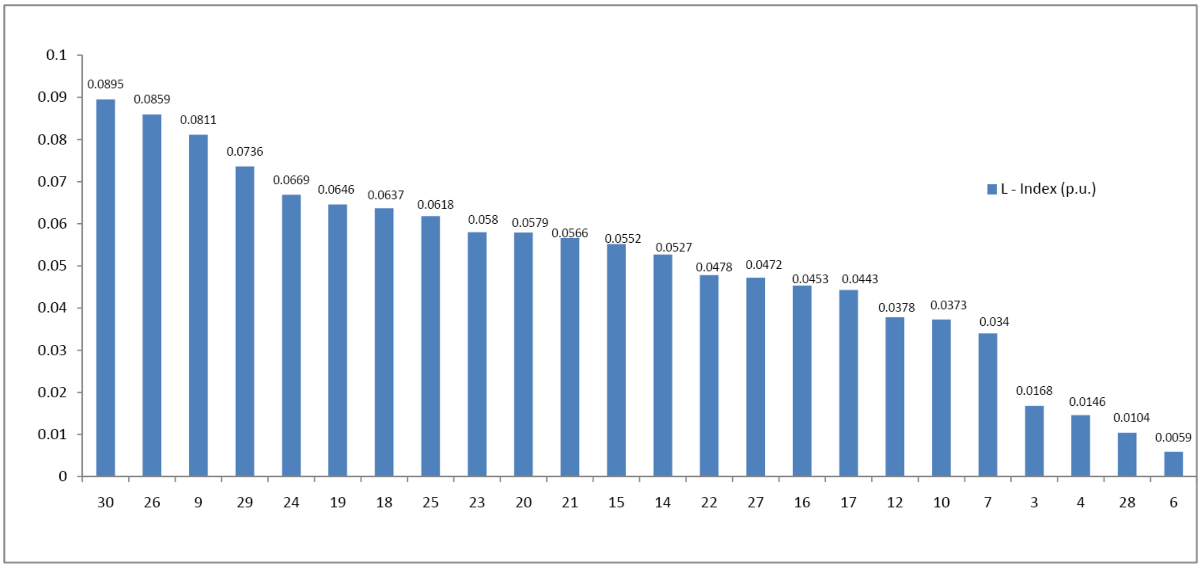


FIGURE 1. Weak bus in IEEE 30 bus system

Various combinations of HMCR and PAR are employed as well as fitness function values secured are furnished in Figure 3. It is identified: PAR = 0.35 & HMCR = 0.7 that is employed to study, extends the lowest objective function value. Various mixes of the objective function weights are employed as well as objective function values are identified and organized in Table 2. It is identified that $W_1 = 0.7$, $W_2 = 0.15$, $W_3 = 0.15$ presents the lowest value of objective function. Therefore, it is being studied.

Voltage profile for OPF excluding as well as including UPFC is contrasted within Figure 4. OPF in the availability of UPFC along with HS algorithm enhances voltage profile.

The real power generation regarding the system as well as at each single generator, real and reactive power deprivation, voltage divergence and real power production cost

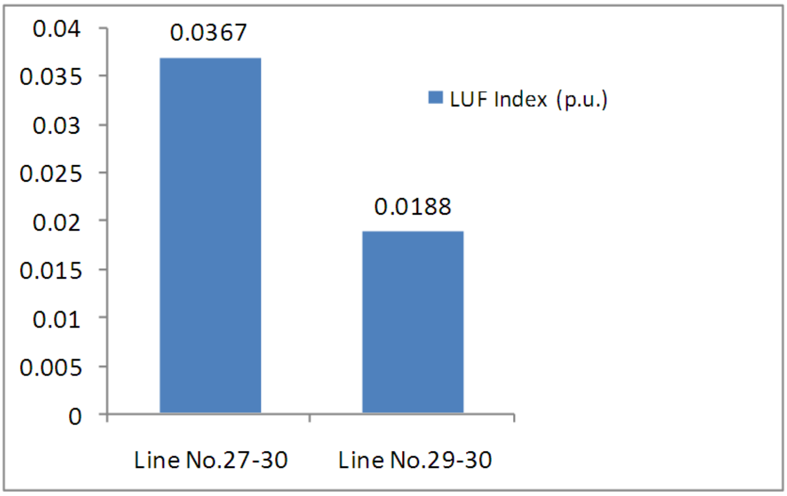


FIGURE 2. Severe line in IEEE 30 bus system is 27-30.

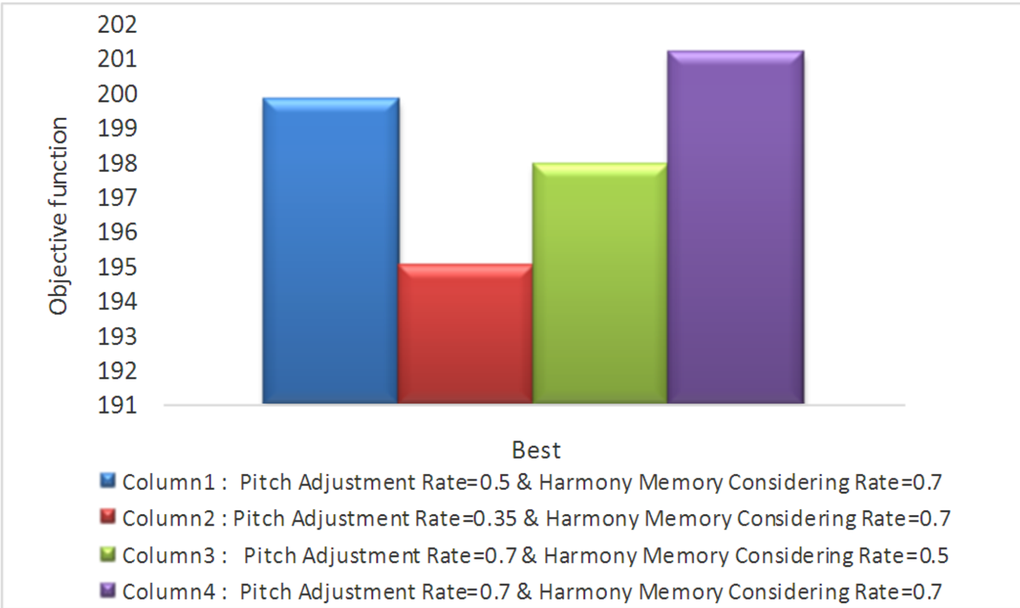


FIGURE 3. Multi-objective function value with change in HS algorithm parameters: PAR – pitch adjustment rate & HMCR – harmony memory considering rate

TABLE 2. Non dominant solutions for cost, losses and voltage deviation objectives

| **Solution number** | **Weight** | | | |
|---|---|---|---|---|
| | $W_1$ | $W_2$ | $W_3$ | $F_1$ **(Objective function value)** |
| 1 | 0.7 | 0.15 | 0.15 | 192.3 |
| 2 | 0.55 | 0.3 | 0.15 | 379.52 |
| 3 | 0.4 | 0.45 | 0.15 | 567 |
| 4 | 0.25 | 0.6 | 0.15 | 773.56 |
| 5 | 0.1 | 0.75 | 0.15 | 958.9 |
| 6 | 0.3 | 0.4 | 0.3 | 509.2 |

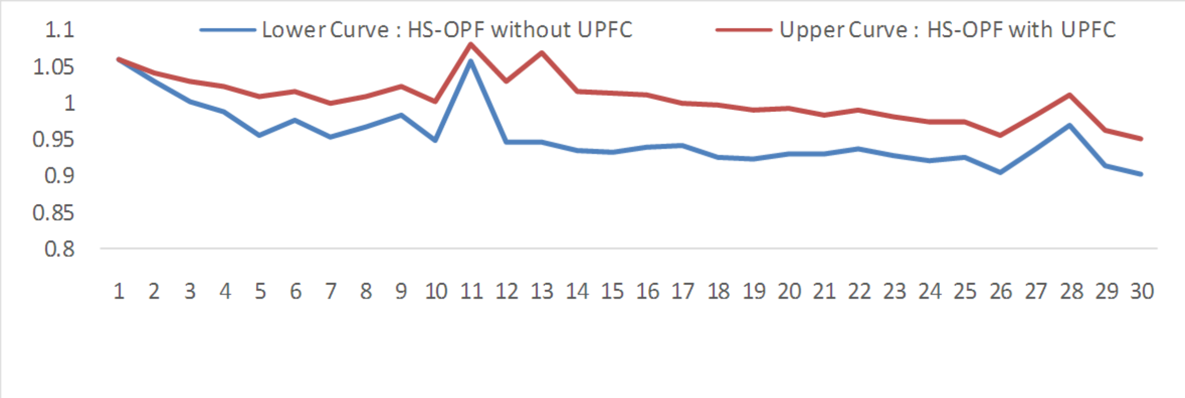


FIGURE 4. Comparison of voltage magnitude of optimal power flow without and with UPFC

TABLE 3. Comparison of OPF solution for 30 bus system employing HS-OPF without and with UPFC

| Specification | | HS without UPFC | GA without UPFC | HS with UPFC | GA with UPFC |
|---|---|---|---|---|---|
| Real power generation (MW) | $P_{G1}$ | 135.55 | 126.6 | 133.833 | 131.398 |
| | $P_{G2}$ | 32.689 | 27.33 | 32.6893 | 12.9481 |
| | $P_{G5}$ | 29.415 | 27.33 | 29.415 | 23.945 |
| | $P_{G8}$ | 42.808 | 21.32 | 42.8081 | 19.1834 |
| | $P_{G11}$ | 40.558 | 84.82 | 40.5583 | 96.9945 |
| | $P_{G13}$ | 10 | 3.992 | 10 | 5.0686 |
| Total power generation-Real (MW) | | 291.0275 | 291.4713 | 289.303 | 289.538 |
| Power loss-Real (MW) | | 7.627 | 8.071 | 5.9039 | 6.138 |
| Power loss-Reactive (MVAR) | | 19.38 | 35.35 | 7.74 | 25.14 |
| Voltage deviation (p.u.) | | 1.9507 | 2.501 | 0.2851 | 0.2859 |
| Real power generation cost ($/hr) | | 1360 | 1366 | 1254.2 | 1260 |
| Value of objective function (p.u.) | | 209.7 | 211 | 192.301 | 193.34 |

for HS-OPF excluding UPFC, GA-OPF excluding UPFC, HS-OPF alongside UPFC and GA-OPF alongside UPFC are contrasted within Table 3. It has been identified – harmony search algorithm stands far apt in regards to multi-objective optimization problem selected in contrast to GA. And it is identified that OPF in the availability of UPFC stands far efficient in contrast to without UPFC. In this way, the device stands highly efficient in regards to optimization of generators.

Contingency examination for IEEE 30 bus system is executed as well as it is discovered that omission of line 27-28 leads to the highest pressure on bus 30 pointed out by the highest L-index of 0.4522 p.u. in Table 4. It is indicated from Table 5 that line 27-30 is the severe-most line for line 27-28 contingency. Therefore, $n-1$ contingency for line 27-28 and UPFC at bus 30 and line 27-30 is taken for examination and observation.

The real power generation of the system as well as at each single generator, real and reactive power deprivation, voltage divergence and real power production cost for HS-OPF excluding UPFC, GA-OPF excluding UPFC, HS-OPF alongside UPFC and GA-OPF alongside UPFC are contrasted within Tables 6 and 7. It has been identified – harmony search algorithm stands far apt in regards to multi-objective optimization problem selected in contrast to GA. And it is identified that OPF in the availability of UPFC stands far

Table 4. Severe bus identification in IEEE 30 bus system

| **Rank** | **Bus No** | **Line outage** | **L-index** |
|---|---|---|---|
| 1 | 30 | 27-28 | 0.4522 |
| 2 | 19 | 9-10 | 0.1918 |
| 3 | 30 | 27-30 | 0.1793 |
| 4 | 29 | 27-29 | 0.1613 |
| 5 | 14 | 4-12 | 0.1591 |
| 6 | 21 | 10-21 | 0.1416 |
| 7 | 26 | 25-27 | 0.1375 |
| 8 | 20 | 10-20 | 0.1341 |
| 9 | 30 | 6-28 | 0.1298 |
| 10 | 19 | 19-20 | 0.117 |
| 11 | 17 | 10-17 | 0.1167 |
| 12 | 30 | 29-30 | 0.1163 |
| 13 | 30 | 3-4 | 0.1151 |
| 14 | 30 | 4-6 | 0.1041 |
| 15 | 26 | 10-22 | 0.102 |
| 16 | 26 | 22-24 | 0.102 |
| 17 | 30 | 6-10 | 0.0938 |
| 18 | 30 | 12-15 | 0.0938 |
| 19 | 30 | 23-24 | 0.0934 |
| 20 | 30 | 21-23 | 0.0921 |
| 21 | 30 | 12-14 | 0.0907 |
| 22 | 30 | 12-16 | 0.0904 |
| 23 | 30 | 15-18 | 0.0902 |
| 24 | 30 | 14-15 | 0.0898 |
| 25 | 30 | 18-19 | 0.0898 |
| 26 | 30 | 15-23 | 0.0898 |
| 27 | 30 | 16-17 | 0.0894 |
| 28 | 30 | 6-7 | 0.0867 |
| 29 | 30 | 6-9 | 0.0857 |
| 30 | 30 | 24-25 | 0.0823 |

Table 5. Severe line in IEEE 30 bus system

| **Rank** | **Line connected** | | **LUF value** |
|---|---|---|---|
| | **FB** | **TB** | |
| 1 | 27 | 30 | 0.0379 |
| 2 | 29 | 30 | 0.0191 |

efficient in contrast to without UPFC. In this way, the device stands highly efficient in regards to optimization of generators.

Voltage profile for OPF excluding as well as including UPFC is contrasted within Figure 5. OPF in the availability of UPFC along with HS algorithm enhances voltage profile.

TABLE 6. Comparison of objective function parameters for 27-28 contingency with UPFC placed at 27-30

| System condition | System parameters | | HS algorithm-OPF without UPFC | HS algorithm-OPF with UPFC |
|---|---|---|---|---|
| With 27-28 contingency | Real power generation (MW) | $P_{G1}$ | 139.4716 | 135.9548 |
| | | $P_{G2}$ | 32.6893 | 32.6893 |
| | | $P_{G5}$ | 29.415 | 29.415 |
| | | $P_{G8}$ | 42.8081 | 42.8081 |
| | | $P_{G11}$ | 40.5583 | 40.5583 |
| | | $P_{G13}$ | 10 | 10 |
| | Total power generation-Real (MW) | | 294.9423 | 291.4255 |
| | Power loss-Real (MW) | | 11.5423 | 8.0255 |
| | Power loss-Reactive (MVAR) | | 31.84 | 13.06 |
| | Total generation cost ($/hr) | | 1275.7 | 1262.2 |
| | Deviation in voltage (p.u.) | | 3.5378 | 0.4166 |
| | Objective function value | | 199.9636 | 195 |

TABLE 7. Parameters comparison employing HS & GA with 27-28 contingency

| OPF employed | Power flow | Power loss-Real (MW) | Voltage deviation (p.u.) | Real power generation cost ($/hr) |
|---|---|---|---|---|
| GA-OPF | Without UPFC | 14.1453 | 4.9205 | 1290.5 |
| | With UPFC | 9.9524 | 0.4194 | 1192 |
| HS-OPF | Without UPFC | 11.5423 | 3.5378 | 1275.7 |
| | With UPFC | 8.0255 | 0.4166 | 1262.2 |

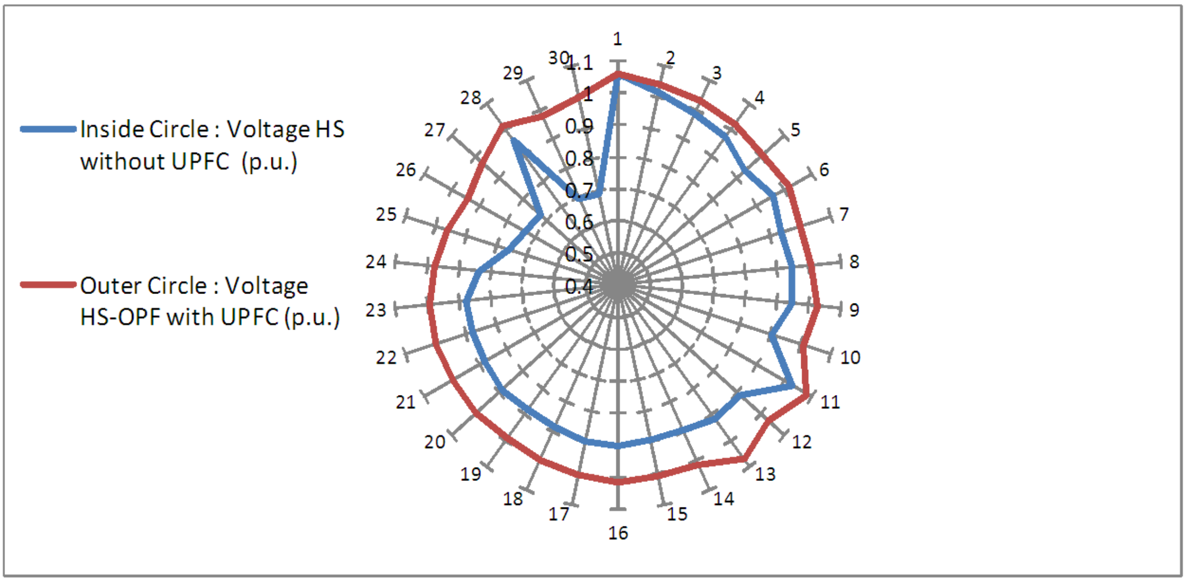


FIGURE 5. Comparison of bus voltages for 30 bus system using HS-OPF without and with UPFC

4. **Conclusions.** A correct strategy is the need of the current power systems for the optimal utilization of the power system resources and to provide stability to the systems as well. In this paper,

- OPF method in the existence of UPFC has been presented for controlling the instability in voltage issues and minimization of power losses.
- A multi-objective function, namely, reduction of real power loss, voltage deviation, and reduction of fuel cost has been considered for the purpose.
- The UPFC has been optimally placed in the system on the basis of L-index and LUF.
- HS algorithm has been presented for the optimization of the UPFC and generator parameters. The results obtained have been verified with that of GA to prove the efficacy of the proposed method.
- The presented technique has been examined for an IEEE 30 bus system for normal and network contingency condition.
- OPF in the existence of UPFC has been established to be an optimal technique for the power system performance improvement as depicted by the improvement in the values of the power system parameters.
- In this paper, all loads are assumed as constant power type. More practical load models, considering their voltage and frequency dependency may be considered in future study.
- In this paper, cost of the FACTS devices has not been included in the OPF formulation. This may be included, while studying its impact on the system performance.

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