

# Teaching-Learning Based Optimal Load Shedding for Enhancing Voltage Stability of Transmission Systems

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**ABSTRACT:** This paper presents a teaching-learning based optimization (TLO) methodology for enhancing voltage stability of transmission systems. The TLO, inspired from the behavior of the students in improving their performance through gaining the knowledge from the teacher and interacting with other students, explores the problem space for finding the global best solution of the given optimization problem. The methodology optimizes the bus locations for load shedding and the amount of shedding at each bus. The proposed design methodology is applied on a standard test system and the results are presented in this paper.

**KEYWORDS:** voltage stability; load shedding; teaching-learning based optimization

## I. INTRODUCTION

Present day transmission systems are operating in a stressed condition due to excessive load demand, and one of the major issues to such systems are voltage collapse (VC). During voltage collapse (VC), the voltage magnitude (VM) gradually falls initially and then all of a sudden, it abruptly becomes very low. This voltage collapse is in general triggered by a disturbance in the load [1]. A number of voltage stability indices are suggested by the researchers to assess the nearness of current operating point to the VC point [2].

Usually, generation shifting, VAR support at appropriate buses, adjusting transformer tap setting and switching the standby generators are done for avoiding VC. If the systems remains nearer to the VC point, even after implementing all these enhancement strategies, the only option available with the system engineer is the load shedding at appropriate buses. Several load shedding methods were suggested in recent decades, but many of them addresses under-frequency load shedding [3-6] and a few intends to avoid VC [7-9]. Sadati et al suggested a hybrid method, combining PSO and SA, for solving under-voltage load shedding problem in order to avoid VC [7]. Bogdan Otomega et al. developed a load shedding methodology involving first order sensitivity factors at various buses for avoiding long-term VC in [8]. Echavarren et al. proposed a load shedding methodology involving LP for avoiding VC with a goal of lowering the sheddable load [18].

Recently, teaching learning based optimization (TLO), inspired from teaching-learning process in class rooms, was suggested for solving optimization problems by Rao et al. [10]. It mimics the behaviour of the students in improving their performance through gaining the knowledge from the teacher and interacting with other students. This paper attempts to apply TLO in optimally finding the bus locations load shedding and the optimal amount of sheddable load with an objective of avoiding VC.

## II. PROBLEM FORMULATION

The load shedding problem can be formulated as an optimization problem involving the VSI, suggested in [2]. The VSI assesses the operating state of the distribution network and varies between zero at no load and one at VC point. The bus

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locations and amount of sheddable load are considered as the problem variables and optimized to bring the largest VSI of the transmission system to lie below a level of a critical threshold value. The problem can be formulated as

$$\text{Maximize } \Phi(x) = \left\{ VSI^{th} - \max(VSI_m) \right\} + w \left\{ 1 - \sum_{j=1}^{nsn} sP_j \right\} \quad (1)$$

Subject to

$$P_{Gm} - P_{Dm} - P_m(V, \delta) = 0 \quad (2)$$

$$Q_{Gm} - Q_{Dm} - Q_m(V, \delta) = 0 \quad (3)$$

$$V_m^{\min} \leq V_m \leq V_m^{\max} \quad (4)$$

Where  $VSI_m$  represents the VSI at bus- $m$  and is calculated by

$$VSI_m = \left| 1 - \frac{\sum_{n \in \alpha G} F_{mn} V_n}{V_m} \right| \quad m \in \alpha L \quad (5)$$

- $VSI_m$  : VSI at bus- $m$
- $P_{Gm} + jQ_{Gm}$  : real and reactive power generation at bus- $m$
- $P_{Dm} + jQ_{Dm}$  : real and reactive power demand at bus- $m$
- $sP_j + jsQ_j$  : sheddable real and reactive power load at chosen bus location- $j$
- $nsn$  : number of sheddable buses
- $\alpha L$  : set of load buses
- $\alpha G$  : set of generator buses
- $V_m$  : complex voltage at load bus- $m$
- $V_n$  : complex voltage at generator bus- $n$
- $F_{mn} = |F_{mn}| \angle \theta_{mn}$  : elements of hybrid-F matrix

The  $[F]$  is computed using

$$[F] = -[Y_{LL}]^{-1}[Y_{LG}] \quad (6)$$

where  $[Y_{LL}]$  and  $[Y_{LG}]$  are sub matrices of the Y-bus matrix.

### III. PROPOSED METHOD

The proposed method employs TLO in solving the load shedding problem. It requires representation of problem variables in the form of students and formation of a fitness function. Each student [10] in the load shedding problem is modelled to represent the sheddable bus locations ( $snL$ ) and the sheddable real load power ( $sP$ ) at each bus as

$$student_i = [snL_1, sPnL_2, \dots, nL_{nsn} \quad sP_1, sP_2, \dots, sP_{nsn}] \quad (7)$$

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The performance function is formed as

$$\text{Maximize } F = \{VSI^{th} - \max(VSI_m)\} + w \left\{ 1 / 1 + \sum_{j=1}^{nsn} sP_j \right\} \quad (8)$$

Initially a class room of students is randomly generated and the performance of each student is calculated using Eq. (8). The best among the student population is considered as teacher. The teaching and learning phases are performed with a view of altering the students grade points. The process of altering the grade points of the students is represented as an iteration, which is continued by considering the students obtained in the previous iteration as the initial student population for next iteration.. The TLO iterative process of generating new population can be terminated after a fixed number of iterations. The student having the best fitness function value is considered as the optimal solution. The pseudo code for TLO is available in [10].

## IV. SIMULATION RESULTS

The proposed method is tested on a modified 6 bus Ward and Hale system [11], where the base load is multiplied by a factor of 1.6 to move the operating point closer to the VC point. The threshold value for VSI is chosen as 0.315. The number of sheddable buses is chosen as three. The PM given the sheddable real power but assuming the power factor of the load is unchanged after load shedding, the sheddable reactive power can be calculated from the power factor and real power. The resulting sheddable powers are given in Table 1. The VSI values prior to load shedding are also included in the same table. It is very clear that all the VSI values are less than the threshold value of 0.315 after load shedding. Similarly all the bus voltage magnitudes are improved from very low range to an acceptable voltage range after load shedding. It is very clear that the PM is able to perform shedding to enhance voltage stability of the system.

Table 1 Results of PM

Bus No	Sheddable Load Power	VSI		VM	
		Before	After	Before	After
3	0.331 + j0.079	0.697	0.304	0.738	0.903
4	---	0.523	0.229	0.769	0.931
5	0.262 + j0.161	0.733	0.297	0.705	0.896
6	0.129 + j0.012	0.667	0.299	0.730	0.921

## V. CONCLUSION AND FUTURE WORK

The TLO, inspired from the teaching-learning process of students in class room, searches for optimal solution for multimodal optimization problems. An elegant methodology using TLO was developed for solving load shedding problem, which is a complex, mixed integer and non-linear optimization problem. The PM was applied on a 6-bus transmission network with increased load level and the results were found to improve both voltage stability and voltage profile. The load shedding problem can be modified to include the other objectives such as improving the voltage profile and reducing the network loss in future and solved using TLO.

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## REFERENCES

1. Taylor CW, Power System Voltage Stability, McGraw-Hill, Inc., 1994.
2. Kessel P and Glavitsch H, 'Estimating the voltage stability of a power system', IEEE Trans. Power Delivery, Vol. PWRD-I, No. 3, pp.346-54, 1986
3. Dong Mingchui, Lou Chinwang and Wong Chikong, 'Adaptive under-frequency load shedding', Tsinghua Science and Technology, Vol. 13, No. 6, pp.823-828, 2008.
4. Hsu C-T, Kang M-S and Chen C-S, 'Design of adaptive load shedding by artificial neural networks', IEE Proc. Gener. Transm. Distrib, Vol. 152, No. 3, pp. 823-828, 2005.
5. Huang SJ and Huang CC, 'An adoptive load shedding method with time-based design for isolated power systems', Electrical Power and Energy Systems, Vol. 22, No.1, pp.51-58, 2000.
6. Chuvychin VN, Gurov NS, Venkata SS and Brown RE, 'An adoptive approach to load shedding and spinning reserve control during underfrequency conditions', IEEE Trans. on Power Systems, Vol. 11, No.4, pp. 1805-1810, 1996.
7. Sadati N, Amraee T and Ranjbar AM, 'A global particle swarm-based simulated annealing optimization technique for under-voltage load shedding problem', Applied Soft Computing, Vol. 9, No. 2, pp. 652-657, 2009.
8. Bogdan O, Mevludin G and Thierry VC, 'Distributed undervoltage load shedding', IEEE Trans. on Power Systems, Vol. 22, No.4, 2283-2285, 2007.
9. Echavarren FM, Lobato E and Rouco L, 'A corrective load shedding scheme to mitigate voltage collapse', Electrical Power and Energy Systems, Vol. 28, No. 1, pp.58-64, 2006.
10. Rao RV, Savsani VJ and Vakharia DP, 'Teaching-learning-based optimization: A novel optimization method for continuous non-linear large scale problems', Information Sciences, Vol. 183, No. 1, pp. 1-15, 2012.
11. El-Sadek MZ, Mahmoud GA, Dessouky MM and Rashed WI, 'Optimum load shedding for avoiding steady state voltage instability', Elect. Power System Research, Vol. 50, No. 2, pp.119-123, 1999.