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# Multi-objective approach for load shedding based on voltage stability index consideration

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**Abstract** In voltage stability analysis, it is useful to assess voltage stability of power systems by means of scalar magnitudes, or indices. Operators can use voltage stability indices to know how close the system to voltage collapse. The voltage stability indices are a powerful tool to identify the weakest bus and critical line. This identification can be used to gain control over devices for voltage stability up to certain level and load shedding is possible if the load keeps on increasing. This paper presents a computationally simple index based load shedding algorithm using weighted sum genetic algorithm where an AC power flow solution cannot be found for the stressed conditions. Minimization of total load shed and sum of New Voltage Stability Index (NVSI) at the selected buses are considered as two objectives of this algorithm to restore the power flow solvability. This is validated in both IEEE 30 bus system and a practical system Tamil Nadu Electricity board (TNEB) 69 bus system in India for considering both heavy loading and $(N-1)$ contingency.

## 1. Introduction

Power systems, nowadays are operating under increased stresses because of the lack of proper planning for expansion. Due to economic and environmental restrictions, there is no expansion of transmission networks with the increase of loads. Interconnected power systems are operated with higher power transfers between areas but there is little coordination and exchange of on-line information between utilities. And hence, adequate voltage level monitoring system and data exchange is not in place, which becomes pivotal in case of blackouts. In essence, the direct cause for blackouts has been found to be voltage collapse. Enhancement of power system voltage stability has seen extensive research with proposals and successful implementation of some measures such as VAR (Volt Ampere Reactive) compensation, load shedding and active power control. Many earlier works are available for under frequency, under voltage with no solution for power flow equations being suggested.

Optimal steady state load shedding was formulated to minimize the sum of the squares of the differences between

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the connected loads and the generated power. The supplied power was treated as a dependent variable modeled as a function of the bus voltage magnitude [1].

A simple new technique was developed to define the optimum location and the optimum quantity of load to be shed in order to prevent the system voltage from going to the unstable zone using L-indicator index [2]. A method of load shedding was proposed with objective of minimize load shedding in the situation where total generation is less than the total demand by minimizing system loss with the constraints on generator limits and line flow limits [3]. Some of literatures were proposed corrective model or preventive model for load shedding incorporating dynamic analysis to increase loading margin [4]. A new methodology has been developed for optimum load shedding based on Hopfield neural network model for optimization. Minimum Eigen value was used as indicator. A threshold value of this indicator can be assumed for a specific system. Emergency load shedding required if this value fell below the threshold value [5].

Recently many of the researchers proposed many heuristic algorithms to improve for load shedding automation. An optimal load-shedding algorithm was developed for undervoltage load shedding using two heuristic methods such as Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) [6]. A computational algorithm for minimum load shedding at selected load buses was developed using Differential Evolution (DE), Self-adaptive Differential Evolution (SaDE) and Ensemble of Mutation and Crossover Strategies and Parameters in Differential Evolution (EPSDE). Developed algorithm accounts inequality constraints not only in present operating conditions (after load shedding) but also for predicted next interval load (with load shedding) [7]. The buses for load shedding were selected based on the sensitivity of minimum Eigen value of load flow Jacobian with respect to load shed. A computational algorithm for minimum load shedding was developed using DE [8]. Computational intelligence techniques, due to their robustness and flexibility in dealing with complex nonlinear systems, could be an option in addressing this problem. Computational intelligence includes techniques such as artificial neural networks, genetic algorithms, fuzzy logic control, adaptive neuro-fuzzy inference system, and particle swarm optimization. Research in these techniques is being undertaken in order to discover means for more efficient and reliable load shedding. Advantages and drawbacks of these intelligence techniques in load shedding were discussed briefly in [9].

The solution of the power flow problem has received much attention over the last several decades. This is due to its fundamental importance to power system analysis. However little attention has been focused on how to handle situations where the power flow equations have no real solution. As power systems become more heavily loaded, there will be an increase in the number of situations where the power flow equations have no real solution, particularly in contingency analysis and planning applications. Since these cases can represent the most severe threats to viable system operation, it is important that a computationally efficient technique be developed to both quantify the degree of unsolvability, and to provide optimal recommendations of the parameters to change to return to a solvable solution [10].

Analysis of the power flow feasibility boundary has received considerable attention in the literature. Very few literatures are available to load shed to restore power flow solution. A methodology was proposed for identifying the fewest network topological changes (removal of transmission lines) that result in operating point infeasibility, such that the amount of minimum load shedding required for feasible operation is greater than a user-defined threshold [11]. A computationally simple algorithm was developed for studying the load shedding problem in emergencies where an AC power flow solution cannot be found for the stressed system. This algorithm was divided into two sub-problems: restoring solvability sub-problem and improving voltage stability margin (VSM) sub-problem. Linear optimization (LP)-based optimal power flow (OPF) is applied to solve each sub-problem. In restoring solvability sub-problem, rather than taking restoring power flow solvability as direct objective function, the objective function of maximization of voltage magnitudes of weak buses was employed. In VSM sub-problem, the traditional load shedding objective was extended to incorporate both technical and economic effects of load shedding and the linearized VSM constraint was added into the LP based OPF [12].

The feasible region is the set of points where the power flow equations have a solution and all system values (e.g., line flows, bus voltages) are within their limits. Normally this is the desired operating region for the system. Let the infeasible region be the set of points where the power flow equations have a solution, but where one or more limit is violated. Usually it is possible to operate the system (at least for a while) in this region. Much progress has been made in the development of security enhancement tools to provide controller recommendations for moving from the infeasible region back into the feasible region. Denote the feasible and infeasible regions as the power flow solvable region. Lastly, let the unsolvable region be the set of points where the power flow equations have no real solution. In this paper, restoring power flow solvability is pursued through load shedding. The load shed buses are selected based on the NVSI value, i.e., high value of NVSI indicates the weak buses and it needs load shedding to restore power flow solvability and improve voltage magnitudes. The minimization of sum of NVSI and sum of load shed at selected buses are considered as objectives of this algorithm. This multi-objective optimization is implemented through the weighted-sum genetic algorithm.

## 2. Load shedding algorithm

Load shedding techniques are commonly classified as three types namely conventional, adaptive and computational intelligence based load shedding techniques. The drawbacks of the conventional method of load shed are as follows: (i) it does not provide optimum load shedding (ii) and does not deal efficiently with modern and complex power systems.

### *2.1. Genetic Algorithm (GA) application in load shedding*

The Genetic Algorithm (GA) is the global optimization technique for solving non-linear, multi-objective problems [13]. The GA is used for this work, due to its evolutionary nature, least mathematical requirement regarding the problems, capability to solve much more complex problems beyond the scope of conventional methods and suitable for solving multi-objective problems. Since the GA provides greater