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# Corrective action planning using RBF neural network

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**Abstract**

In recent years, voltage limit violation and power system load-generation imbalance, i.e., line loading limit violation have been responsible for several incidents of major network collapses leading to partial or even complete blackouts. Alleviation of line overloads is the suitable corrective action in this regard. The control action strategies to limit the line loading to the security limits are generation rescheduling/load shedding. In this paper, an approach based on radial basis function neural network (RBFN) is presented for corrective action planning to alleviate line overloading in an efficient manner. Effectiveness of the proposed method is demonstrated for overloading alleviation under different loading/contingency conditions in 6-bus system and 24-bus RTS system.


*Keywords:* Line loading limit; Line-overloading alleviation; Conjugate gradient method; Local optimization; Generation rescheduling; Load shedding; Radial basis function neural network

## 1. Introduction

As power systems have become more heavily loaded due to increased load and large interconnections, there will be an increase in cases of voltage limit violation and line loading limit violation, particularly during contingencies like line outage, etc. Electric power systems operate under the influence of various parameters, which may vary with time and circumstances. In fact, the performance of power system operation is affected by the change experienced by parameters when some major disturbance, such as loss of transmission line or generation failure or a sudden deviation in load occurs.

Under emergency conditions of line overloading, operator has to make quick decisions for corrective action without caring much for the optimality of the operating point. In this condition, a direct approach could be line-overloading alleviation with minimum number of control actions, i.e., rescheduling of generators/load shedding.

The experience of several incidents of major network collapses has concluded a strong motivation to alleviate line-overloading and voltage limit violation [1], so that a secure state may be recovered. Kheddache et al. [2] presented a review of optimal load shedding techniques and the importance of relay setting for this purpose. In Ref. [3], conjugate gradient search technique has been used to minimise line overloads in conjunction with the concept of local optimization. The concept of local optimization is effective in the way that only buses in the vicinity of the overloaded line are processed for optimization process. This reduces the problem size drastically.

The control action can be performed within the security limits in a minimum time by generation rescheduling and/or load shedding, neglecting the economy consideration. These are several methods based on optimal load flow for the corrective and preventive control action along with economy and security functions on the basis of system planning. These optimization methods include a large number of variables and constraints. Hence, these methods are unsuitable for on-line implementation, due to their large computer storage and time requirements.

A number of methods like hybrid-decoupled approach, mean field theory, new dual method, etc., are developed in Refs. [4–6] for solving optimal load flow problem. A cyclic security analysis is presented for security constrained optimal power flow (SCOPF) giving the application of a new contingency screening model in Ref. [7]. An interior point quadratic-programming algorithm for solving power system optimization

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**Nomenclature**

$A_i$ — $[a_i(X_1), a_i(X_2), \ldots, a_i(X_{p^{\max}})]^T$ for $i = 1, 2, \ldots, H + 1$.
$AP_{mk}$ — active power flow through line $mk$, from $m$ to $k$
$AP_{mk}^{\max}$ — rating of line $mk$
$H$ — number of hidden layer (RBF) nodes
NO — number of neurons in output layer
$O_q$ — $\lfloor o_{q1}, o_{q2}, \ldots, o_{qp^{\max}} \rfloor$
$o_{qp}$ — output value of $q$th node in output layer for $p$th incoming pattern
OL — set of overloaded lines
$P_i$ — real power load at $i$th bus
$Q_i$ — reactive power load at $i$th bus
$r$ — dimension of input vector
$S_f$ — factor of safety (0.95)
$t_{qp}$ — target value at $q$th neuron of output layer for $p$th pattern
$T_q$ — $\lfloor t_{q1}, t_{q2}, \ldots, t_{qp^{\max}} \rfloor$
$U$ — Vector of the control variables available to the operator, i.e., bus power injections (generation rescheduling and load shedding)
$w_{qi}$ — weight between $i$th RBF unit and $q$th output node
$w_{qi}(K)$ — weights connecting the hidden and output layers nodes at $K$th iteration
$w_{qo}$ — biasing term at $q$th output node
$Wq$ — $w_{q1}, w_{q2}, \ldots, w_{qH}, w_{qo}$
$\bar{x}_{ji}$ — centre of $i$th RBF unit for input variable $j$
$x_{jp}$ — $j$th variable of input pattern $p$
$X$ — State vector of the power system consisting of bus voltage magnitudes and phase angles
$\propto$ — momentum term

*Greek symbols*
$\delta_q$ — $[\delta_{q1}, \delta_{q2}, \ldots, \delta_{qp^{\max}}]$
$\eta(K)$ — learning rate or adaptive size at $K$th iteration
$\sigma_I$ — width of $i$th RBF unit

problem with significantly less computational efforts is also presented in Ref. [8].

Mohamed et al. proposed a range of feasible corrective actions for security control, which included phase shifter control; generation rescheduling and/or load shedding to alleviate the line overload problem and transformer taps to adjust the bus voltage deviations [9]. In Ref. [10], an algorithm has been proposed for the alleviation of line overloads and voltage violations by corrective rescheduling that utilizes the decoupling of real and reactive power and the decomposition between optimization without security constraints and optimization to satisfy security constraints. Arya et al. [11] proposed an interactive line-switching algorithm for overload alleviation under line outage condition. In case, overload elimination was not possible, the overload rotation amongst two disjoint sets of overloaded lines after line switching was also suggested. A corrective switching algorithm has been proposed which relieves overloads and voltage violations as well [13]. Ioannis et al. [14] present a model and some initial results of a dynamical model for blackouts in power transmission systems. The traditional form of load control (shedding) is quite disruptive to consumers and so often avoided. In [15], a non-disruptive load control method has been developed to switch small pieces of load, so that interruptions are effectively unnoticed by consumers. These conventional methods for power system optimization and security analysis [1–15] are too slow for real-time applications in modern energy management system.

With the advent of artificial intelligence, in recent years, expert systems, pattern recognition, decision tree, neural networks and fuzzy logic methodologies have been applied to different power system problems [16–26]. Bansilal et al. [20] proposed an expert system for alleviation of network overloads using phase shifting transformers and also by rescheduling generation and/or load curtailment. For overload alleviation, fuzzy controls are suggested in Refs. [21,22], while a neural network based approach has been proposed in Refs. [23,26]. The application of artificial neural network (ANN) has shown great promise in power system engineering due to their ability to synthesize complex mappings accurately and rapidly.

Artificial neural network is the functional imitation of a human brain which simulates the human intuition in making decisions and drawing conclusions even when presented with complex, noisy, irrelevant/partial information. The information going to the input layer neurons (units) of artificial neural network is recoded into an internal representation and the outputs are generated by the internal representation rather than by the input pattern. It can model any non-linear function without knowledge of the actual model structure and during testing phase it gives the result in very short time.

A neural network consists of a number of neurons, which are the elementary processing units that are connected together according to some pattern of connectivity. The development of artificial neural network involves into two phases, training or learning phase and testing phase. Developing a neural network is unlike developing software, because the network is trained, not programmed. Most of the published work in power system area utilizes multi-layer perceptron (MLP) model based on back propagation (BP) algorithm, which usually suffers from local minima and over fitting problems.

In this paper, an approach based on radial basis neural network [26–28] is proposed to alleviate line overloading under different loading/contingency conditions in an efficient manner. The RBFN has many advantageous features such as optimised system complexity, minimised learning and recall times. RBF model has an input layer, one hidden layer and output layer [33]. The input variables are directly fed to the hidden units without weights. The approach developed here is successfully applied to 6-bus system and 24-bus RTS system.

## 2. Methodology

The general block diagram of the work carried out in this paper is presented in Fig. 1. A large number of patterns are