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Dynamic available transfer capability determination in power system restructuring environment using support vector regression

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ABSTRACT

This paper presents dynamic available transfer capability (DATC) determination in power system restructuring environment using support vector regression (SVR). Dynamic available transfer capability is first determined based on the conventional method of potential energy boundary surface transient energy function. Simulations were carried out on a WSCC 3-machine 9-bus system and a Practical South Indian Grid test system by considering load increases as the contingency. The data collected from the conventional method is then used as an input training sample to the SVR in determining DATC. To reduce training time and improve accuracy of the SVR, the kernel function type and kernel parameter are considered. The proposed SVR based method, its performance is validated by comparing with the multilayer perceptron neural network (MLPNN). Studies show that the SVR gives faster and more accurate results for DATC determination compared with MLPNN.

Introduction

Electric power systems have become more and more complicated due to the rapid development of restructuring in electricity sector. Under power system restructuring environment, besides the system operator, certain real-time information of the transmission grid to be known by its market participant for their future power contract under secure operation.

Real-time available transfer capability (ATC) is one of the important information to be published on the open-access same-time information system for the market participants to arrange possible secure power transactions. Therefore, a fast and accurate evaluation of the available transfer capability has been more important to assure the secure, economic, stable and reliable operation of power systems. Available transfer capability of a transmission network quantifies the measure of unutilized transfer capability remaining in the transmission network for the further commercial activity over and above already committed usage [1]. In [2] available transfer capability is classified as static ATC (SATC) and dynamic ATC (DATC) based on the consideration of different power system constraints. SATC involves the line thermal limit, bus voltage limit and saddle node bifurcation limit. DATC involves the small signal stability limit and transient stability limit. In real time approach of ATC calculation, the effect of all the abnormal conditions has to be considered, hence transient stability constraints based DATC is more appropriate rather than SATC.

A number of methods have been reported to date in literature for DATC determination. An iterative algorithm based on the Gauss–Newton solution of a nonlinear least square problem for determining transient stability based DATC has been proposed in [3]. Optimization approach of incorporating transient stability constraint optimal power flow to determine DATC has been used by few researchers [4–6]. New optimization techniques proposed in [7] deals with available transfer capability calculation incorporating system dynamics to avoid exhaustive numerical simulations directed by energy margin (EM) and energy margin sensitivity. Hybrid approach of combining transient energy margin and eigenvalue analysis to screen critical contingencies for fast ATC assessment with stability constraints has been proposed in [8]. A fast and accurate dynamic method considering transient stability analysis and voltage stability analysis for computing ATC using potential energy boundary surface (PEBS) and point of maximum potential has been proposed in [9]. The structure preserving energy function method has been proposed in [10,11] for the determination of DATC and to enhance the DATC through optimal placement of FACTS controllers respectively.

In recent years, the application of artificial neural network for the determination of DATC has gained a lot of interest among researchers due to its ability to do parallel data processing with

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high accuracy and fast response in real time. In [12], the application of back propagation algorithm and radial basis function neural network is used for the computation of DATC. In [13], proposed an adaptive wavelet neural network to determine DATC having bilateral as well as multilateral transactions. The results of the proposed adaptive wavelet neural network model outperforms has been compared to the radial basis function neural network in determining DATC, in terms of accuracy. In [14,15] the drawback of the neural network is overcome by the pattern recognition approach such as support vector machine (SVM) and relevance vector machine (RVM).

This paper focuses the attention on the support vector regression (SVR) approach to determine the transient stability based dynamic available transfer capability. The PEBS transient energy function based on the computation of energy margin is used as the conventional method for determining DATC. The pre-screening of line outages using energy margin values is also carried out to reduce the computational burden in determining DATC. The conventional method consumes longer computational time since it repeats the transient stability analysis many times. To overcome the computational difficulty of conventional method, SVR technique for determining more reasonable accuracy of DATC with less computational time is proposed in this paper. The proposed SVR based DATC assessment is tested on a WSCC 3-machine 9-bus system and a practical South Indian Grid test system and its performance is validated by comparing with the multilayer perceptron neural network. It was developed using the MATLAB Neural Network Toolbox, whereas SVR was developed using the Spider, adopted from [16].

Transient energy function

Power system transient stability [17] is the ability of the power system to remain in synchronism when the system is subjected to large disturbances such as sudden change in load and three phase fault. When the system undergoes large disturbances, the system will go to unstable state after sometime if the fault is not cleared within its critical clearing time. Hence the objective of transient stability analysis is to find the critical clearing time of circuit breakers to clear the fault. Conventionally, transient stability assessment has been performed using time-domain simulation process. It is an off-line and more time consuming process so it does not match with the real time operating conditions. To overcome this, the more reliable transient energy function method is considered for the fast and accurate evaluation of transient stability assessment. In this paper, potential energy boundary surface method is used for calculating energy margin of the system.

Mathematical formulation of transient energy function

For a classical model of n-generator system, the equation of the motion with respect to an arbitrary synchronous reference frame and neglecting the damping effect are given by

$$\left.\begin{aligned} \dot{\delta}_i &= \omega_i \\ M_i\dot{\omega}_i &= P_i - P_{ei} \quad i = 1,2,\ldots,n \end{aligned}\right\} \tag{1}$$

where

$$P_i = P_{mi} - E_i^2 G_{ii} \tag{2}$$

$$P_{ei} = \sum_{j=1}^{n}[C_{ij}\sin(\delta_i - \delta_j) + D_{ij}\cos(\delta_i - \delta_j)] \tag{3}$$

$$C_{ij} = E_iE_jB_{ij}; \quad D_{ij} = E_iE_jG_{ij} \tag{4}$$

where δ_i, ω_i are rotor angle and speed of the machine i with respect to synchronous reference frame respectively; M_i is inertia constant of the machine i; P_{mi} is the mechanical power input to machine i; P_{ei} is the electrical power output of i; E_i is the voltage magnitude behind transient reactance of machine i; G_{ij} is transfer conductance between nodes i and j of the reduced bus admittance matrix; G_{ii} is self conductance at i^{th} node of the reduced bus admittance matrix; and B_{ij} is transfer susceptance between nodes i and j of the reduced bus admittance matrix.

The transformation of above equations into the *Center of Inertia* (COI) coordinates not only offers physical insight to the transient stability problem formulation in general, but also provides a concise framework for the analysis with transfer conductance [18]. The COI frame of reference is defined as:

$$\delta_0 = \frac{1}{M_T}\sum_{i=1}^{n}M_i\delta_i; \quad \omega_0 = \frac{1}{M_T}\sum_{i=1}^{n}M_i\omega_i \tag{5}$$

where

$$M_T = \sum_{i=1}^{n}M_i \tag{6}$$

By defining new rotor angles and speeds relative to this reference,

$$\theta_0 = \delta_i - \delta_0; \quad \tilde{\omega}_i = \omega_i - \omega_0 \tag{7}$$

The equation of motion becomes

$$\left.\begin{aligned} \dot{\theta}_i &= \tilde{\omega}_i \\ M_i\dot{\tilde{\omega}}_i &= P_i - P_{ei} - \tfrac{M_i}{M_T}P_{COI} \cong f_i(\theta) \quad i = 1,2,\ldots,n \end{aligned}\right\} \tag{8}$$

where

$$P_{COI} = \sum_{i=1}^{n}P_i - 2\sum_{i=1}^{n+1}\sum_{j=i+1}^{n}D_{ij}\cos\delta_{ij} \tag{9}$$

We note that the centre of inertia variable satisfy the constraints

$$\sum_{i=1}^{n}M_i\theta_i = \sum_{i=1}^{n}M_i\tilde{\omega}_i = 0 \tag{10}$$

Therefore, the transient energy $V(\theta, \tilde{\omega})$ is defined for the post fault system at any instant can be illustrated by

$$V(\theta, \tilde{\omega}) = V_{KE}(\tilde{\omega}) + V_{PE}(\theta) \tag{11}$$

$$V_{KE}(\tilde{\omega}) = \sum_{i=1}^{n}\frac{1}{2}M_i\tilde{\omega}_i^2 \tag{12}$$

$$\begin{aligned} V_{PE}(\theta) = &-\sum_{i=1}^{n}P_i(\theta_i - \theta_i^s) \\ &-\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\left[C_{ij}(\cos\theta_{ij} - \cos\theta_{ij}^s) - D_{ij}\frac{\theta_i + \theta_j - \theta_i^s - \theta_j^s}{\theta_{ij} - \theta_{ij}^s}(\sin\theta_{ij} - \sin\theta_{ij}^s)\right] \end{aligned} \tag{13}$$

where $V_{KE}(\tilde{\omega})$ and $V_{PE}(\theta)$ are the total changes in kinetic and potential energy of the system relative to the COI. $\theta_{ij} = \theta_i - \theta_j$, $\theta_{ij}^s = \theta_i^s - \theta_j^s$ and θ^s is stable equilibrium point of the post fault system.

Computation of transient energy margin using PEBS method

The procedure for computing the energy margin consists of the following steps:

1. Read the power system dynamic data.
2. Run the base case power flow for the pre fault system.