Voltage Instability Detection Using Neural Networks

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INTRODUCTION

The explosive growth in decision-support systems over the past 30 years has yielded numerous "intelligent" systems that have often produced less-than-stellar results (Michalewicz Z. et al., 2005). The increasing trend in developing intelligent systems based on neural networks is attributed to their capability of learning nonlinear problems offline with selective training, which can lead to sufficiently accurate online response. Artificial neural networks have been used to solve many problems obtaining outstanding results in various application areas such as power systems. Power systems applications can benefit from such intelligent systems; particularly for voltage stabilization, where voltage instability in power distribution systems could lead to voltage collapse and thus power blackouts.

This article presents an intelligent system which detects voltage instability and classifies voltage output of an assumed power distribution system (PDS) as: stable, unstable or overload. The novelty of our work is the use of voltage output images as the input patterns to the neural network for training and generalizing purposes, thus providing a faster instability detection system that simulates a trained operator controlling and monitoring the 3-phase voltage output of the simulated PDS.

BACKGROUND

Artificial Neural Networks have been used to solve many problems obtaining outstanding results in various applications such as classification, clustering, pattern recognition and forecasting among many other applications corresponding to different areas.

Power system stability is the property of a power system which enables it to remain in a state of equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after a disturbance. Beyond a certain level, the decrease of power system stability margins can lead to unacceptable operating conditions and/or to frequent power system collapses (Sjostrom M. et al., 1999) (Ernst D. et al., 2004). In 2003 and within less than two months, a number of blackouts happened around the world, affecting millions of people. These blackouts include (Novosel D. et al., 2004):

- The 14th of August blackout in Northeast United States and Canada, which is considered one of the worst blackouts in the history of these countries, affecting approximately 50 million people.
- The 28th of August blackout in London, which affected commuters during the rush hour.
- The 23rd of September blackout in Sweden and Denmark, which affected approximately 5 million people.
- The 28th of September blackout in Italy, which is considered the worst blackout in Europe ever, affecting approximately 57 million people.

In recent years voltage instability has been one of the major reasons for blackouts, and it is the root cause of the 14 August blackout. Voltage stability is threatened when a disturbance increases the reactive power demand beyond the sustainable capacity of the available reactive power resources. Although, progress in the areas of communication and digital technology has increased the amount of information available at the efficient supervisory control and data acquisition

(SCADA) systems, however, during events that cause outages, an operator may be overwhelmed by the excessive number of simultaneously operating alarms, which increases the time required for identifying the main outage cause and then starting the restoration process (De Souza A.C.Z. et al., 1997) (Lukomski R. & Wilkosz K., 2003). Additionally, factors such as stress and human error can affect the operator's performance; thus, the need for an additional tool to support the real-time decision-making process which currently exists. This tool can be in the form of an intelligent voltage instability detector.

The implementation of neural networks for stabilizing power systems in general has been recently suggested (Wenxin L. et al., 2003) (Cardoso G. et al., 2004) (Keyhani A. et al., 2005) (Alcántara F.J. & Salmerón P., 2005) (Mishra, 2006). Research on different approaches to the assessment and improvement of voltage stabilization in particular has proposed different solutions to voltage instability using neural networks (Bansilal et al., 2003) (Kamalasadan S., 2006) (Lin H.C., 2007). However, none of the existing intelligent system solutions to detecting voltage instability in power distribution systems addresses the possibility of providing an artificial intelligent detector that simulates a human operator whose task is to detect voltage instability via monitoring the voltage output.

This article suggests a novel method for detecting voltage instability in power distribution systems. The proposed system uses 3-phase voltage output images as its database for training and generalizing a supervised neural network based on the back propagation learning algorithm. The intelligent system comprises two phases: the image processing phase, where voltage output images are pre-processed and meaningful features are obtained as the input patterns for the next phase which is the neural network implementation. Here, the supervised neural network learns to associate the voltage output patterns with three possible classifications; namely, Stable, Unstable or Overload.

The main objective of the proposed intelligent system is to provide earlier detection of voltage instability thus aiding a human operator. The intelligent system can be operated concurrently with SCADA systems thus enhancing the stability of the power distribution system. Upon the detection of voltage instability by the intelligent system, further measures can be taken to quickly sustain stability or clean voltage drop of the power distribution system.

THE INTELLIGENT DETECTION SYSTEM

The intelligent voltage instability detection system comprises two phases. Firstly, the image processing phase; where the PDS voltage output graph images are processed and feature vectors are extracted to be used for training and/or testing the neural network. Secondly, the neural network implementation phase, where the extracted features from the first phase are used as input vectors to a neural network. Our neural network is based on the back propagation learning algorithm due to its implementation simplicity, and the availability of sufficient database for training this supervised learner.

Voltage Output Image Processing

Training and generalizing a neural network using images requires sufficient number of images and meaningful input patterns. Our database contains voltage output images that correspond to a MATLAB-simulated power system. Our concern is with the transient stability of one distribution power substation whose voltage readings are taken as outputs of the circuit after simulation for 20 seconds, which is considered sufficient time to assure the simulation of the three output cases; in particular the overload case. These outputs are graphs of the sinusoidal waves of voltage during the 20 seconds of simulation. For every second on the graph there are 50 full waves, which make them concentrated and appear like a block.

The intelligent voltage instability detection system has three possible output classifications (*Stable*, *Unstable* or *Overload*). The image database has to account for the three cases. For each case there are three voltage output graphs representing three voltage phases (a, b, c). A total number of 54 cases (18 stable, 18 unstable and 18 overload) are simulated, thus resulting in 162 voltage output graph images which form our database. Figure 1 shows examples of the image database representing the voltage output cases (stable, unstable and overload).

The objective of the image processing phase is the extraction of meaningful patterns which form the input to the neural network within the intelligent system. The extracted patterns should distinctly represent the different voltage output cases, while keeping their size to a minimum, in order to reduce the computational cost.

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