LATEST TRENDS IN CONTINGENCY ANALYSIS OF POWER SYSTEM

VinayP.Doshi
Department of Electrical Engineering
Fabtech College of Engineering and Research,
Sangola, INDIA

Sadanand A. Salgar
Department of Electrical Engineering
Fabtech College of Engineering and Research,
Sangola, INDIA

Prof.Shravan Kumar Akireddy
Department of Electrical Engineering
Fabtech College of Engineering and Research,
Sangola, INDIA

Abstract : Contingency plans based on N-1 and N-2 contingencies are already very much used by utilities. Artificial intelligent methods are new trends for analysing the contingency scenario along with state of art congestion management. This gives extra backup and boost to reliable operation under contingent scenario of power system. This paper envisages the summary of all those efforts. This paper will help utilities to put more thinking in terms of recent developments in fast and intelligent computing methods. The paper highlights classical research and modern trends in contingency analysis such as hybrid artificial intelligent methods. Steady state stability assessment of a power system pursues a twofold objective: first to appraise the system's capability to withstand major contingencies, and second to suggest remedial actions, i.e. means to enhance this capability, whenever needed. The first objective is the concern of analysis, the second is a matter of control.

Keywords: Contingency Analysis (CA), Artificial Neural Network (ANN).

Introduction

Contingency is the loss or failure of one or more components in the power system. Contingency can also be defined as a specified set of events occurring within a short duration of time [1]. Contingency in a system may be none, severe or critical. None: The system restores itself to pre-disturbed state after a contingency. Severe: The system element gets overloaded and collapses if the corrective action is not performed before the system moves towards instability. The system becomes unstable and collapses immediately. Contingencies such as unexpected line outage soften contribute to voltage collapse blackout [2]. Hence contingency assessment is necessary to check out the severity of the line .By contingency ranking the system operator can be cautioned about the vulnerable lines present in the system and he can preset the corrective measures in case of outage of that line. Contingency analysis is the simulation analysis that employs various contingencies associated with probable events, to come up with the most optimal responses under the circumstances. The objective of steady state contingency analysis is to investigate the effects of generation and transmission unit outages on MVA line flows and bus voltage magnitudes .Contingencies are ranked in an approximate order of a scalar performance index (PI) [3]. The PI should have essentially two aspects of functions:

1. Distinction of actual critical outages from non-critical ones,
2. Prediction of the relative severity of critical outages [4].

Electric utilities in today's market are facing many challenges and sometimes conflicting requirements. The task of maintaining reliability has been greatly complicated by the introduction of wholesale electricity markets. All players now depend on the reliability of the power grid, and all are at risk if the grid is not reliably operated. On the one hand, the planning and operation reliability criterion is still N − 1 (the system must be able to withstand any single contingency event) and on the other economic forces put pressure for providing higher standards of reliability.

Security constrained optimization applications at the current stage ensure that voltage magnitude and other state and control variables are under their operating limits after the first contingency.

It has been found that traditional N − 1 reliability criteria for transmission and operation planning is inadequate in new (deregulated) competitive energy markets. Not just engineering (planning and operation) reliability criteria should be revisited in order to go beyond N − 1butalso the economic implications of such criteria must be assessed accordingly. Following are areas coming up as modern challenge for contingency from application point of view.

Role of Visualization in Contingency Analysis

With the global trend toward deregulation in the power system industry, the volume and the complexity of the CA results in the daily operation and system studies have been increasing. Not only has deregulation resulted in much large system model sizes, but also CA is computed more frequently in the restructured power markets to monitor the states of the system under what if situations in order to accommodate the maximum number of power transfers. The net impact of these changes is a need for more effective and efficient visualizations for CA results to help with the comprehension of the essential security information, information which could be buried in the enormous and complex CA data sets. The traditional display for CA results in an EMS is often a tabular list showing the violated buses and transmission elements, along with the corresponding contingency name, element value, limit and perhaps the percentage violation. However, when the number of elements in the list becomes excessive it can be difficult to build a mental connection between the violated elements and the contingencies causing the violations, or to understand the underlying problems in the system.

The 2-D visualizations based on one-line diagrams have been relatively popular due to the familiarity of power operator's with one-line diagrams and the importance of geographic information in power system operation and control. Example scheme include encoding the width [5]–[8], color [6]–[8] and arrow size[6] of transmission lines according to line performance indices(PIs) or post contingency loadings, augmenting the one-lines with the thermometers [4], [5] showing bus PIs and the pie charts [12] for contingent voltage angles .In contrast to the one-line diagram based visualizations, the presentation of contingency data in a 2-D matrix [7]–[10] or bar charts [11] gives a clear overview of the system severity status ,but at the expense of the loss of geographic information. Other2-D visualizations not based on the geographical network can be found in [12] where high-level security risk levels were displayed by rectangular and oval meters and 2-D iso-risk curves displayed security level as a function of operating conditions. In addition to the 2-D visualization techniques listed, 3-Dvisualization without geographic background has been applied into power system CA results. In [7], a third

dimension was added to represent time, allowing the display to show the time variation in contingency severity. Similarly, in [13] a 3-D manifold was used to display the percentage overload of the monitored transmission lines under each contingency by scaling the z axis in terms of percentage overload, assigning each point on the y axis a contingency, and each point on the x axis a monitored line.
This literature review indicates that power system CA visualization is still in its infantry, with a pressing need for better techniques. This work first discusses possible 2-D visualization techniques for CA data and their drawbacks, and then presents a geographic 3-D approach.

Smart Grid Contingency

In future smart grids, with distribution networks having loops more frequently, current transmission contingency analysis (TCA) which usually neglects the distribution power flow variations after a contingency may leave out severe outages [14]. With more distribution management systems deployed on the distribution side, a new transmission CA method based on global power flow (GPF) analysis which integrates both the transmission and distribution power flow is proposed in this work (named as GTCA) to address the problem. The definition and new features of GTCA are first introduced. Then, the necessity of GTCA is physically illustrated. Difference in the results of GTCA and TCA is mathematically analyzed. A GPF-embedded algorithm of performing GTCA is then provided. The data exchange process and the performance with communication interruptions are discussed. As multiple contingencies are considered in GTCA, several approaches are proposed and discussed to reduce communication burdens and improve the computational efficiency. Plenty of numerical tests are performed in several systems to verify the theoretical analysis. With theoretical analysis and numerical verification, it is suggested that GTCA should be performed instead of TCA to avoid potential false alarms, especially in the condition that DNs are more frequently looped in the future smart grids.

Contingency Analysis and Identification of Dynamic Voltage Control Areas

Contingency analysis has been an integral part of power system planning and operations. Dynamic contingency analysis is often performed with offline simulation studies, due to its intense computational effort. Due to a large number of possible system variations, covering all combinations in planning studies is very challenging [15]. Contingencies must be chosen carefully to cover a wider group of possibilities, while ensuring system security. This work proposes a method to classify dynamic contingencies into different clusters, according to their behavioural patterns, in particular, with respect to voltage recovery patterns. The most severe contingency from each cluster becomes the representative of other contingencies in the corresponding cluster. Using the information of contingency clusters, a new concept called dynamic voltage control area (DVCA) is derived. The concept of DVCA will address the importance of the location of dynamic reactive reserves. Simulations have been completed on the modified IEEE 162-bus system to test and validate the proposed method.

Contingency-Risk

We consider the problem of designing (or augmenting) an electric power system at a minimum cost such that it satisfies the N-k-ε survivability criterion [16]. This survivability criterion is a generalization of the well-known N-k criterion, and it requires that at least (1-ε_j) fraction of the steady-state demand be met after failures of j components, for j=0,1,...,k. The network design problem adds another level of complexity to the notoriously hard contingency analysis problem, since the contingency analysis is only one of the requirements for the design optimization problem. We present a mixed-integer programming formulation of this problem that takes into account both transmission and generation expansion. We propose an algorithm that can avoid combinatorial explosion in the number of contingencies, by seeking vulnerabilities in intermediary solutions and constraining the design space accordingly. Our approach is built on our ability to identify such system vulnerabilities quickly. Our empirical studies on modified instances of the IEEE 30-bus and IEEE 57-bus systems show the effectiveness of our methods. We were able to solve the transmission and generation expansion problems for k=4 in approximately 30 min, while other approaches failed to provide a solution at the end of 2 h.

Computation of Worst Operation Scenarios Under Uncertainty for Static Security Management

This work deals with day-ahead static security assessment with respect to a postulated set of contingencies while taking into account uncertainties about the next day system conditions [17]. We propose a heuristic approach to compute the worst-case under operation uncertainty for a contingency with respect to overloads. We formulate this problem as a non-convex nonlinear bi level program that we solve approximately by a heuristic approach which relies on the solution of successive optimal power flow (OPF) and security-constrained optimal power flow (SCOPF) problems of a special type. The method aims at revealing those combinations of uncertainties and contingencies for which the best combination of preventive and corrective actions would not suffice to ensure security. Extensive numerical results on a small, a medium, and a very large system prove the interest of the approach.

ANN Efforts in Contingency Analysis

Fast and accurate contingency selection and ranking method has become a key issue to ensure the secure operation of power systems. In this work multi-layer feed forward artificial neural network (MLFFN) and radial basis function network (RBFN) are proposed to implement the online module for power system static security assessment [18]. The security classification, contingency selection and ranking are done based on the composite security index which is capable of accurately differentiating the secure and non-secure cases. For each contingency case as well as for base case condition, the composite security index is computed using the full Newton Raphson load flow analysis. The proposed artificial neural network (ANN) models take loading condition and the probable contingencies as the input and assess the system security by screening the credible contingencies and ranking them in the order of severity based on composite security index. The numerical results of applying the proposed approach to IEEE 118-bus test system demonstrate its effectiveness for online power system static security assessment. The comparison of the ANN models with the model based on Newton Raphson load flow analysis in terms of accuracy and computational speed indicate that the proposed model is effective and reliable in the fast evaluation of the security level of power systems. The proposed online static security assessment (OSSA) module realized using the ANN models are found to be suited for online application.

A Multi-Stage Stochastic Non-Linear Model for Reactive Power Planning Under Contingencies

This work presents a model for long-term reactive power planning where a deterministic nonlinear model is expanded into a multi-stage stochastic model under load uncertainty and an N-k contingency analysis [19]. Reactive load shedding is introduced in the objective function to measure the reactive power deficit after the planning process. The objective is to minimize the sum of investment costs (IC), expected operation costs (EOC) and reactive load shedding costs optimizing the sizes and locations of new reactive compensation equipment to ensure powersystem security in each stage along the planning horizon. An efficient scenario generation and reduction methodology is used for modelling uncertainty. Expected benefits are calculated to establish the performance of the expected value with perfect information (EVPI) and the value of the stochastic solution (VSS) methodologies. The efficacy of the proposed model is tested and justified by the simulation results using the Ward-Hale 6-bus and the IEEE 14-bus systems.

Optimisation in Contingency Analysis

In power system operation, transmission congestion can drastically limit more economical generation units from being dispatched. In this work, optimal transmission switching as a congestion management tool is utilized to change network topology which, in turn, would lead to higher electricity market efficiency [20]. Transmission switching (TS) is formulated as an optimization problem to determine the most influential lines as candidates for disconnection. In order to relieve congestion without violating voltage security, TS is embedded in an optimal power flow (OPF) problem with AC constraints and binary variables, i.e., a mixed-integer nonlinear programming (MINLP) problem, solved using Benders decomposition. Also, a methodology is presented which provides a guideline to the system operator showing the order of switching manoeuvres that have to be followed in order to relieve congestion. It is also shown that TS based on DC optimal power flow (DCOPF) formulation as used in the literature may jeopardize system security and in some cases result in voltage collapse due to the shortcomings in its simplified models. In order to evaluate the applicability and effectiveness of the proposed method, the IEEE 57-bus and IEEE 300-bus test systems are used.

Risk and N-1 Criteria Coordination for Real-Time Operations

This letter describes a new perspective on coordinating system N-1 criteria and risk for real-time operations, where risk is modelled to capture the system's overall security level [21]. A risk-based security-constrained optimal power flow (RB-SCOPF), considering N-1 criteria and risk together, is compared with the traditional SCOPF. The IEEE 30-bussystem is tested to illustrate the coordination between risk and N-1 criteria in RB-SCOPF.

Two-stage robust optimization for N-k contingency-constrained unit commitment

This work proposes a two-stage robust optimization approach to solve the N- k contingency-constrained unit commitment (CCUC) problem [22]. In our approach, both generator and transmission line contingencies are considered. Compared to the traditional approach using a given set of components as candidates for possible failures, our approach considers all possible component failure scenarios. We consider the objectives of minimizing the total generation cost under the worst-case contingency scenario and/or the total pre-contingency cost. We formulate CCUC as a two-stage robust optimization problem and develop a decomposition framework to enable tractable computation. In our framework, the master problem makes unit commitment decisions and the sub-problem discovers the worst-case contingency scenarios. By using linearization techniques and duality theory, we transform the sub problem into a mixed-integer linear program (MILP). The most violated inequalities generated from the sub problem are fed back into the master problem during each iteration. Our approach guarantees a globally optimal solution in a finite number of iterations. In reported computational experiments, we test both primal and dual decomposition approaches. Our computational results verify the effectiveness of our proposed approach.

A Progressive Contingency Incorporation Approach for Stochastic Optimization Problems

Reliability is a key objective in many optimal design problems. Very often this criterion is incorporated into stochastic optimization problems by introducing contingency evaluation scenarios [23]. These results in a special problem structure where the stochastic scenarios used to describe reliability are linked to the failure of specific individual elements. This work presents a progressive contingency incorporation (PCI) approach that takes advantage of this structure to increase efficiency. The algorithm is applied to the design of an offshore wind farm, where the electrical layout is decided, as representative of the possible advantages of PCI within power systems. The problem must determine the placement and type of cables in a collector system. Results show that time savings achieved by the PCI approach can be remarkable, reaching two orders of magnitude for the case study.

Automated Handling of Arbitrary Switching Device Topologies in planning Contingency Analysis: Towards Temporal Interoperability in Network Security Assessment

Existing power system planning software is not capable of simulating large numbers of contingencies that involve bus mergers and bus splits without cumbersome modifications to planning models either manually or through scripting [24]. This means that some of the events that can occur in a bulk power system are not studied in detail prior to real-time operation. This work proposes the use of a unified network applications framework for planning contingency analysis capable of incorporating contingencies that involve arbitrary configurations of switching devices. The method handles any type of bus split or bus merger events automatically without requiring case conversion or modification. This drastically simplifies the tabulation of results of complex contingencies and makes potential unsecure system conditions visible during the planning stage. The efficiency of the algorithm is demonstrated in large-scale ISO models that incorporate full-topology switching modelling, and it is shown to be at least ten times faster than scripting. The proposed method hence supports direct comparison of planning and real-time grid security assessment evaluation, providing full temporal interoperability between offline contingency analysis and real-time security assessment.

Wide-Area Optimal Control of Electric Power Systems With Application to Transient Stability for Higher Order Contingencies

A real-time stabilizing control method for responding to N-K contingencies, with large K, is developed utilizing network and machine time-synchronized measurements [25]. The controls follow an optimality principle in driving rotor-angles to an acceptable equilibrium point, at minimum cost, by predicting state response trajectory to a collection of stepped structural changes, from an admissible set, according to a defined model. A cost metric suitable for mitigating rotor-angle instability is developed. Non-idealities in modelling, measurement latency, control availability, and actuation success are investigated. It is shown how control over system structure in a feedback formulation increases the capability to handle higher order contingencies. As an experimental example, a set of simultaneous N-3 transient stability related contingencies are stabilized for the IEEE 39-bus system. Furthermore, the response after control actuation failure is investigated and it is shown that the system remains driven to a valid stable equilibrium point.

Contingency filtering technique for transient stability constrained optimal power flow

Transient stability constrained optimal power flow (TSCOPF) is an important and difficult problem. When multiple contingencies are considered, a reliable contingency filtering technique should be used to reduce the scale of TSCOPF problem [26]. This study brings in the concepts of active contingency and critical contingency, and develops a novel contingency filtering strategy. Based on time-domain numerical simulations, the proposed contingency filtering strategy first screens all the considered contingencies and identifies active contingencies whose severe indices violate the pre-defined threshold of transient stability, then further finds out the critical contingencies in which some generators are most severely disturbed according to the severe indices trajectories. The severe indices can be such as maximal relative rotor angles, maximal transient generator voltage dips and so on. Taking only the critical contingencies into account, the scale of TSCOPF problem is reduced significantly. Interior point method is used to solve the reduced TSCOPF problem. Numerical results on several cases indicate that the proposed contingency filtering technique is reliable and efficient. Compared with the conventional TSCOPF approach, which involves all the contingencies, the proposed contingency filtering strategy possesses overwhelming advantages in CPU time and memory consumption, and is hopeful to solve TSCOPF problems with many contingencies.

Multiple Element Contingency Screening

This work presents a method for determining the double outage contingencies that threaten the system without solving the full contingency set [27]. Two methods for contingency screening with complementary properties are presented. The results of the algorithms are compared to the full double outage contingency analysis results for a large North American case. The results show that the screening algorithms are able to detect nearly all of the contingencies that will result in violations, while requiring only a small fraction of the contingencies to be solved.

Assessing the Vulnerability of a Power System through a Multiple Objective Contingency Screening Approach

This work introduces a new, alternative approach for the analysis of power systems vulnerability based on a hybrid model that combines elements of the classical Deterministic Network Interdiction Problem (DNIP) with the use of an efficient multi-objective optimization evolutionary algorithm (MOEA) [28]. From a power systems perspective, the traditional DNIP is implemented as a surrogate approach to understand the interaction between the power system's component incapacitation (due to random failures or external attacks), and the system load shedding. The work recognizes that, when analyzing power system vulnerability, it is possible to have multiple competing objectives and multiple prospective solutions that may change based on the preference of the decision-maker. This multi-objective view of the DNIP in the power systems context is solved using MOEA. As a result, the proposed approach could be used as an initial, straightforward screening approach to identify severe system disturbances. Several examples illustrate that the approach is able to reproduce and improve upon the results presented in previous studies.

Congestion Management

FACTS Devices Allocation With Control Coordination Considering Congestion Relief and Voltage Stability

This work presents an optimal allocation method for flexible ac transmission system (FACTS) devices for market-based power systems considering congestion relief and voltage stability[29]. The purpose of the FACTS devices installation is to provide benefit for all entities accomplished by both minimizing annual device investment cost and maximizing annual benefit defined as difference between expected security cost (ESC) with and without FACTS devices installation. Different from previous approaches, the proposed method accurately evaluates the annual cost and benefits obtainable by FACTS devices installation by formulating a large-scale optimization problem that contains power flow analyses for a large number of system states representing annual power system operations. In addition, dynamic state transitions caused by specified contingencies are also simulated in the optimization problem to evaluate the effect of FACTS control actions as well as the other coordinated controls. The expected cost consists of operating cost under normal and contingency states along with their related probabilities to occur. Maximizing social welfare is the objective for normal state while minimizing compensations for generations re-scheduling and load shedding as well as maximizing social welfare are the objectives in case of contingency. Although installation cost of FACTS devices is required, they are useful as cost free means, which can reduce effectively the annual costs for generations re-scheduling and load shedding.

Super component Contingency Modelling for Security Assessment in Power Systems

The utilization of the power systems to its maximum capacity is a condition that produces economic benefits to all agents involved in the chain of energy supply and thus to society [30]. However, under these conditions, operators can take risks that could cause the loss of system stability and, in the worst case, blackouts. Thus, operators require analysis tools that give them information in order to take preventive and corrective actions, to operate the system in a reliable way and to check the behaviour of the same. Generally, in this type of analysis, simple component's contingencies are used. However, the practice has shown that more than one component (generation unit, circuit line, single transformer, among others) of the system can fail, either by simultaneous outages, events in cascade or by a major outage that means a complete installation with several components gets out of service. So, a super component refers to complex electrical facilities as: substations, generation plants and multiple circuit transmission lines. An outage of the super component implies the multiple and simultaneous outages of many elements. These kinds of events are not, generally, considered in the mentioned analyses; however, it would be very important to keep them in mind in the security evaluation of power systems. This work presents a methodology to evaluate the severity of this kind of contingencies in the operative planning scenario. The super components that are taken into account are the multiple circuit lines (in the same structure), generation plants and substations. The impact of contingency on power system security is evaluated in a 24-hour day-ahead planning horizon through the computation of the energy not supplied, the number of overloaded lines and the percentage of load loss The Energy not supplied is computed as function of a load shedding based on operator's rules.

Two-Stage Stochastic Programming Model for Market Clearing With Contingencies

Planning for contingencies typically results in the use of more expensive facilities before disruptions. It leads to different prices and energy availability at various network locations depending on how the contingency analysis is performed [31]. In this work we present a two-stage stochastic programming model for incorporating contingencies. The model is computationally demanding, and made tractable by using an interior-point log-barrier method coupled with Benders decomposition. The second-stage optimal recourse function (RF) defines the most economically efficient actions in the post-contingency state for returning the system back to normal operating conditions. The approach is illustrated with for two examples: small (with 8 buses/11 branches) and IEEE medium-scale (with 300 buses/411 branches).

DC Power Flow Revisited

Linear MW-only network power flow models are in widespread and even increasing use, particularly in congestion-constrained market applications [32]. Many versions of these approximate models are possible. When their MW flows are reasonably correct (and this is by no means assured), they can often offer compelling advantages. Given their considerable importance in today's electric power industry, dc models merit closer scrutiny. This work attempts such a re-examination.

Severe Multiple Contingency Screening in Electric Power Systems

We propose a computationally efficient approach to detect severe multiple contingencies. We pose a contingency analysis problem using a nonlinear optimization framework, which enables us to detect the fewest possible transmission line outages resulting in a system failure of specified severity, and to identify the most severe system failure caused by removing a specified number of transmission lines from service [33]. Illustrations using a three-bus system and the IEEE 30-bus system aim to exhibit the effectiveness of the proposed approach.

CONCLUSION

So far though several works have proposed many techniques for contingency assessment, classical, intelligent and modern. All such efforts focus on improving the steady state performance of the system under the scenario of power snap due to line outages. Time frame of such events in India is fifteen minutes. During transition of power system from one state to other, various interpretation of same line outage situation usually causes confusion in assessment by experts. All the expert knowledge if included in fuzzy set theory with ANN backup will improve the decision making easy and technically viable. This paper gives a direction to researchers and utilities to follow technical intelligent gateway to various credible contingency scenarios on real time base. Several researchers are active in this area and their efforts are integrated in the paper and hence it will act as a good reference for the concerned investigation and development effort. This approach is suited for all the systems.

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