BENDER DECOMPOSITION FOR TRANSMISSION NETWORK PLANNING WITH SECURITY AND CORRECTIVE CONTROLS

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Abstract: - Bender decomposition approach is used to solve power transmission network expansion planning problems. A novel filtering technique is used for efficient elimination of redundant outages, presented and successfully tested. The same technique is used for selecting relevant contingencies. The transmission network needs to be flexibly and economically robust against all uncertainties. Corrective control operation strategy, however, can be alternatively used to boost the flexibility, to expedite the integration of the new generators and to decrease the overall cost. The growth in application of corrective actions to enhance network utilization will require a probabilistic treatment of network security for determining efficient levels of investment in network reinforcement. Within the developed Benders decomposition based investment model, we proposed a new algorithm that can efficiently identify relevant outages and filter out those that do not contribute to finding the optimum operating solution. For selecting relevant contingencies, a novel filtering technique for efficient elimination of redundant outages is presented and successfully tested. In numerical examples we compare efficiency of network reinforcement propositions under both deterministic and probabilistic frameworks, while optimizing available preventive and corrective control actions, and in particular focusing on the application of generation reserve in combination with special protection schemes (SPS) for network congestion management purposes. We highlight the inadequacies of the deterministic approach with respect to its inherent inability to optimize accurately the portfolio of pre-fault post-fault actions since the impacts of corrective actions (in the form of SPS, demand response) and occurrence of “non-credible” events require explicit consideration of the likelihood of various outages.

Keywords: - Corrective control, bandwidth utilization, network utilization.

I. INTRODUCTION

Benders’ Decomposition is a popular technique in solving certain classes of difficult problems such as stochastic programming problems and mixed-integer nonlinear programming problems. It is a technique in mathematical programming that allows the solution of very large linear programming problems that have a special block structure. This structure often occurs in applications such as stochastic programming. In what follows we are going to show two applications of Benders decompositions: the first one for a stochastic programming problem and the second for a multi-commodity network flow problem. The algorithm adds new constraints as it progress towards the solution and is therefore referred to as a row generation approach, in accordance with its counterpart, Danzig–Wolfe decomposition, which is referred to as a column generation approach. Also security is one of the most critical aspects of any network and provides authentication and access control for resources.

Network security involves the authorization of access to data in a network. Users choose or are assigned an ID and password or other authenticating information that allows them access to information and programs within their authority. Network security has been historically based on deterministic criteria: electricity system should be able to withstand the occurrence of any defined set of credible outages without causing overloads or inadequate voltages on any remaining circuits, and without violating system stability limits. Securing a computer network infrastructure is a specialized field in a computer network. Network security is typically handled by a network administrator who implements the policy, network and hardware needed to protect a network and the resources accessed through the network from unauthorized access and also ensure that employees have adequate access to the network and resources to work. This means that a well-implemented network security blocks viruses, malware, hackers, etc. from accessing or altering secure information.

The underlying principle of the deterministic framework is that the system operation in a particular condition is considered to be exposed to no risk at all if the occurrence of any selected credible contingency does not violate the operational limits, while the system is considered to operate at an unacceptable level of risk if the occurrence of a credible contingency would cause some violations of operating limits. Neither of these is correct, as the system is indeed exposed to risks of failure and outages even if no credible network outage leads to violations of operating constraints and the risk of some violations may be acceptable if these can be minimized by using further post-fault corrective action. To tackle these problems, probabilistic frameworks for network security have been discussed and a number of novel approaches that assess
risk profiles and balance security and economics have been proposed like that in [1].

The transmission expansion planning (TEP) problem in modern power systems is a large-scale, mixed-integer, non-linear and non-convex problem. TEP is a rather complicated process which requires extensive studies to determine when, where and how many transmission facilities are needed. A well planned power system will not only enhance the system reliability, but also tend to contribute positively to the overall system operating efficiency. Although remarkable advances have been made in optimization techniques, finding an optimal solution to a problem of this nature can still be extremely challenging. Based on the literalized power flow model and presents a mixed-integer linear programming (MILP) approach that considers losses, generator costs and the $N-1$ security constraints for the multi-stage TEP problem [3]. Although the probabilistic framework is in principle superior, in practice its additional value with respect to the deterministic approach is particularly material in the presence of significant application of corrective control. This could include, for example, generation re-dispatch, topology re-configuration and use of flexible AC transmission systems (FACTS), use of special protection systems (SPS), and application of flexible demand. SPS have been widely used to increase the transfer capability of the network by assisting system operators in administering fast corrective actions. Compared with constructing new transmission facilities, SPS can be placed in service relatively quickly and inexpensively. However, increased reliance on SPS results in additional risks to system security.

Furthermore, the probabilistic framework is particularly relevant when exercising corrective actions that involve cost. These effects cannot be taken into account, sufficiently accurately, within a deterministic approach as the cost of exercising corrective actions need to be balanced against the associated pre-fault cost. We present a novel transmission network investment model within the probabilistic framework that optimally balances preventive and corrective controls while determining efficient transmission network reinforcements. Transmission switching (TS) is introduced to add flexibility to the transmission and generation capacity expansion planning problem. TS could improve the performance of the capacity expansion planning model and reduce the total planning cost. The capacity expansion planning problem is decomposed into a master problem and two sub problems as presented in [5].

Specifically, the presented model couples network operation and investment by means of a Benders Algorithm, but rather than using a deterministic security constrained optimum power flow (SC-OPF) method to assess the effect of operational preventive and corrective control on network investment our model considers the probabilistic realization of a set of outages and permits balancing a larger portfolio of pre and post-fault operational actions such as network congestion, pre-fault commitment of generation reserve, post-fault generation re-dispatch or reserve utilization, and SPS over demand and generation. It is important to mention that current probabilistic models that are able to determine network investment have a limited consideration of the impact of corrective control on network investment as presented by [1, 2].

II. DESCRIPTION OF BENDERS ALGORITHM

Benders decomposition is a solution method for solving certain large-scale optimization problems. Instead of considering all decision variables and constraints of a large-scale problem simultaneously, Benders decomposition partitions the problem into multiple smaller problems. The main idea is the is to add one cut per realization of uncertainty of the master problem in each iteration, that is, a many Benders cuts as the number of scenarios added to the master problem in each iteration

Figure 1: General Bender algorithm with 3 modules

In Benders Algorithm, the network investment model plan the optimization model that give thought to various pre-fault operational measures and post-fault corrective actions to support operation and investment. The model is combination of operational, investment and filtering modules presented in the above figure 1.
**A. Operational Module**

In the operational module, the maximum probabilistic dispatch and so the maximum network utilization over a given operating condition is find out when considering the use of corrective control. The module find out the optimum power transfers across transmission network by balancing the cost of transmission hurdles against the cost of applying pre-fault operational measures and post-fault corrective actions. The optimization can be done under single Operating condition under a set of outages that are slant according to their properties, depend on whether. The benefits of the probabilistic framework are the pre-fault operational measures and post-fault corrective actions.

1) **System balancing**

Power flows can be controlled via generation balancing actions in order to mitigate circuit overloading while maintaining the supply and demand balance at all times.

2) **Allocation and utilization of generation reserve**

Different levels of generation reserve can be allocated in the pre-fault condition (via balancing actions) to efficiently deal with outage events in a post-fault condition. In this model, generation reserves are allocated and utilized in order to deal with outages not only of generating plants but also of transmission circuits. Consequently, the reserve is spatially optimized to facilitate the application of SPS. The reserve can be provided by synchronized generators and/or through units providing standing reserve of appropriate dynamic characteristics.

3) **Exercise of SPS to curtail generation and/or demand**

Following an outage of a circuit, SPS automatically disconnects (or instigate rapid reduction of) generation and demand in exporting and importing areas respectively, to avoid post-fault network overloads. This allows increased levels of power transfers in the pre-fault condition and hence results in reduced levels of network constraints.

**B. Investment Module**

The investment module supported by multiple executions of the operational module over a variety of operating conditions, determines:

1) The optimum network investment in a year.
2) The optimum generation commitments in each operating condition, and
3) The utilization of SPS in each operating state.

In investment timescales, the operating costs and risks associated with proposed transmission network reinforcement are measured and summed over the entire year which is represented by a set of operating conditions. This is required to determine the efficient levels of transmission investment that is balanced against the cost associated with pre-fault operational measures and post-fault corrective actions.

**C. Filtering Module**

The filtering module serves to limit the number of operating states considered in the optimization and is applied iteratively as follows:

1) Finding the relevant outages over the initial network for each operating condition (1st run in Fig.1),
2) Finding the relevant outages over the enhanced network for each operating condition, and adding these outages (if not included) to the previously found set of relevant outages (ith run in Fig.1).

The Benders algorithm (loop 1) stops according to the general criterion which is when the upper (Z upper) and lower (Z lower) estimations of the overall transmission cost function (i.e., investment (T) operation (O) unsupplied demand (X)) are nearly equal. Loop 2 stops if there are no more outages to be added to the set of relevant outages given the latest sets of transmission network capacities and generation outputs. To reduce the potentially substantial computational burden in larger networks, parallel threading is used (Fig.1 shows how different operating conditions can be run in parallel) together with a heuristic procedure that searches the (nearly) optimum solution of the mixed integer linear programming (MILP) problem within a given duality gap.

**III. IDENTIFICATION OF RESOURCE**

Understanding the current resource utilization for commercial cellular networks is the very first and necessary step towards optimizing them. To achieve this goal, we will collect cellular data of hundreds of thousands of users from the core network of large cellular carrier.

**IV. ROUTING OVER CHANNEL**

Routing is the process of selecting best paths in a network. In packet switching networks, routing directs packet forwarding through intermediate nodes. Routing regions are typically rectangular and are classified on the basis of number of sides that have terminals of nets to be routed. A two-sided routing region is called a channel and the associated routing problem is called a channel routing problem. The network layer is responsible for routing packets from the source to destination. To overcome the various problems occurred in networking we have to use the different kinds of routing algorithm such that link state routing algorithm (Dijkstra’s algorithm, Open Shortest Path First) or distance vector routing (Routing Information Protocol, Border Gateway Protocol).

**V. SECURITY AND CORRECTIVE CONTROLS**

To protect the network from various security threats, we have used the security mechanism and security services. Security controls are technical or administrative safeguards or counter measures to avoid, counteract or minimize loss or unavailability due to threats acting on their matching
vulnerability, i.e., security risk. Controls are referenced all the time in security.

VI. NETWORK UTILIZATION

Network end nodes provide computation capability by incorporating one or more processors, memory hierarchy and a network interface through which they communicate with other end nodes. As illustrated in Figure 2, interconnection networks are built with a set of communication links, routers (or switches), and network interfaces attached to end nodes. Communication links distribute packets among routers and network interfaces. End nodes use a network interface through which they gain access to one or more adjacent routers or other end nodes. Network interfaces usually provide buffer resources in order to temporarily hold input and output packets in the event of network congestion or delays in processing. The links connecting a network interface and a router are called injection channels and delivery channels, depending upon the direction of packet flow. Once injected, packets proceed toward their destinations via one or more routers which are responsible for assigning necessary output links to incoming packets based on their header information.

![Figure 2: Generalized architecture model for network](image)

Network utilization is the ratio of current network traffic to the maximum traffic that the port can handle. Through monitoring network utilization, we can understand whether the network is busy, normal or idle. Capsa Network Analyzer makes it easy for us to monitor the network utilization, so as to find out the bottleneck and improve network performance.

VI. CONCLUSION

The transmission network investment problem optimally balances preventive and corrective control within a probabilistic security model. Hence it is used as a benchmark to assess the performance characteristics of the conventional deterministic concept. We highlighted the inadequacies of the deterministic approach with respect to its inherent inability to optimize accurately the portfolio of pre-fault and post-fault actions since the impacts of corrective and occurrence of “non-credible” events require explicit consideration of the likelihood of various outages. In this paper, we concluded that deterministic approach drives less efficient and potentially more risky system operation that ultimately leads to inefficient network investment.

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