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Contingency Planning And Analysis In Deregulated Power Systems- Novel Method

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Abstract:
The aim of the study presented in the paper is to propose a systematic simple method of Contingency Planning and Analysis. Contingency analysis is one of the basic power system studies. It refers to the security of the system operation under the loss of one or more of the major system components due to a random failure. The present day competitive market scenario demands zero tolerance for even single contingency. Therefore, there is great need to develop systematic plans which can be implemented to give fast and efficient results. The Novel Method proposed is tested on 9-Bus IEEE Test System and the results analyzed.

Keywords: *Contingency, Single Contingency, Multiple Contingency, Remedial Action Scheme*

Introduction

Electrical Energy is a vital commodity and an important resource for one and all, in all walks of life and all areas of application. Electrical Power Generation Industry is a major industry. It is a long-term plan for the Government involving not only huge amounts of money, men, time and various major resources but also social and political decision factors. Thus, maintenance of the existing Power-Systems is very important. Economic prosperity, national security, and public health and safety cannot be achieved without it. Communities that lack electric power, even for short periods, have trouble meeting basic needs for food, shelter, water, law, and order[1].Due to the increase in demand for power and technology advancements a large and varied restructuring of the Electrical Industry has been effected. The various strategies adopted by the countries world-wide are – Privatization and De-Regulation[2] of electricity markets. This has resulted in the arising of Independent System Operators(ISO) in the Electric Industry and Market. These new strategies have a very large impact on almost all the power systems around the world and have resulted in a competitive market. Privatization has resulted in the arising of several parties some who may be only sellers, buyers or buyer and seller. Hence, there is a need to develop procedures for selling and buying of power. Contingency is an outage of a component. The outage of a component even for a fraction of a second is not acceptable in the present day scenario of the Electrical Industry. The customers demand quality service with continuous power supply maintained with good voltage profile so as not to damage their equipment and operation of their production or services. So also for the ISO to be successful they have to ensure Quality of Service(QoS), reliability, security and efficiency. Contigency management is one of the prime objectives of ISOs'. Therefore there is need to identify the various likely contingencies, the effect of the contingency in the operation of the system and means and methods to prevent functional, safety and monetary damage.

The present day technology is sophisticated, integrated with automatic equipment which are programmed. The availability of various Electrical Power System simulation softwares such as MATLAB, Power World and on-line monitoring systems provided by Supervisory Control and Data Acquisition(SCADA)[3] enable us to plan for effective handling of contingency. On-Line Contingency Analysis can be conducted by Intelligent Systems[4][5] which makes the Contingency Planning dynamic.The paper aims to study the aspect of contingency, its effect, and propose a simple systematic approach for Contingency Planning and Analysis with IEEE 9Bus System as a Case Study. The paper is organized as follows: Section 1 is Introduction, Section 2 Contingency, Section 3. Contingency Plan – Proposed Approach with Case Study System with analysis of the Results and Discussion. Section 4. Remedial Action Scheme, Section 5. Results and Section 6. Conclusion is presented.

Contingency

A contingency is defined by North American Electrical Reliability Council(NEERC) as the unexpected failure or outage of a system component , such as Generator, Transmission Line, circuit breaker or switch. Systems are designed to withstand one contingency, i.e (N-1) criterion. However, some events trigger others and cascading failures might occur. Therefore not all contingencies are equal, and the number of components in a given system makes it prohibitive to evaluate all(single) contingencies. The system is considered (N-1) secure when a single contingency will not cause any system limits to be violated.Contingencies are relevant events anticipated by a planner, including low-probability events that would have major impacts. Contingency planning is a "What if?" skill important in all types of planning domains, but especially in contested and competitive domains. The objective of contingency planning is not to identify and develop a plan for every possible contingency, which could be exhaustive. Rather, the objective is to encourage one to think about major contingencies and possible responses. Vital few situations actually unfold according to the assumptions of a plan.

Line contingency and generator contingency are generally most common type of contingencies. These contingencies mainly cause two types of violations – Low Voltage Violations and Line MVA Limits Violations.

Low Voltage Violations

This type of violation occurs at the buses. This suggests that the voltage at the bus is less than the specified value. The operating range of voltage at any bus is generally 0.95-1.05 p.u. Thus if the voltage falls below 0.95 p.u then the bus is said to have low voltage. If the voltage rises above the 1.05 p.u then the bus is said to have a high voltage problem. It is known that in the power system network generally reactive power is the reason for the voltage problems. Hence in the case of low voltage problems reactive power is supplied to the bus to increase the voltage profile at the bus. In the case of the high voltage reactive power is absorbed at the buses to maintain the system normal voltage.

Line MVA Limits Violations

This type of contingency occurs in the system when the MVA rating of the line exceeds given rating. This is mainly due to the increase in the amplitude of the current flowing in that line. The lines are designed in such a way that they should be able to withstand 125% of their MVA limit. Based on utility practices, if the current crosses the 80-90 % of the limit, it is declared as an alarm situation.

Contingency Plan – Proposed Approach With Case Study System

The Proposed Approach for Contingency Planning is depicted by applying on the 9-Bus IEEE Power Case Study System. The stages of Contingency Planning are explained in sections 3.1. to 3.7.

Objective Statement

The Objective of the Contingency Planning should be clear and specific. The Inputs for the study, Algorithm and Method applied for Power Flow Study and the Output Data Collected would depend upon the Objective. In the present Case Study the Objective is to determine the effect of various contingencies on the State of the System. This is the process of preparing the cause-effect data depicted in the form of a table.

Collect Data Regarding The System And Prepare The System For Study

The data required for Contingency Management of the 9-Bus System is Bus Data, Generator Data and Line Data. These tables are the Inputs for the Plan. The data for the various Test – Systems is available in Matpower 4.1 Version[6] which is freely downloadable from the web-site cited in [7]. Matpower is a Power System Simulation Software that consists of a set of Data Files and Program Files. The Data files contain all the data of the various IEEE Power Systems such as 9-Bus,14-Bus,24-Bus,30-Bus and 118-Bus.The Program Files are for Optimal Power Flow(OPF), Y-Bus creation and so on. The Files can be executed on Matlab Software.

One-Line Diagram

Having obtained the System Data create the One-Line diagram using softwares such as Power World. The One-Line Diagram of 9-Bus System is shown in Fig. 1.

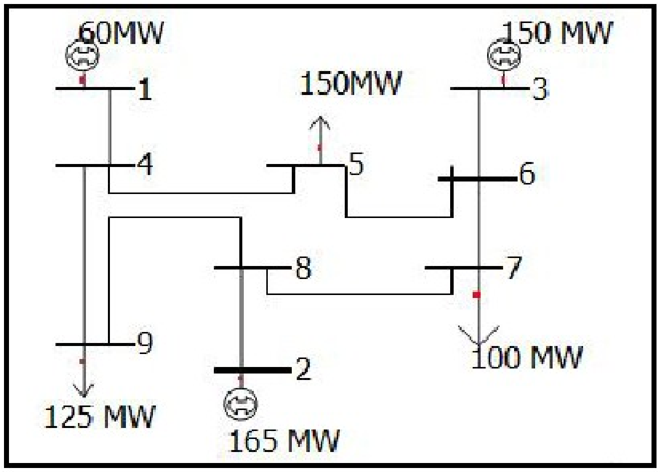

Figure 1: One Line Diagram of 9 – Bus System
Obtain the Base Case Results

Generator No.	Output(MW)
G1	60
G2	165
G3	150

Table 1: Generator Data

Run Optimal Power Flow program on the System to obtain the Base Case Results. The Base Case results are Generator Outputs , Line-Flow and Bus Voltage Profile. For the 9-Bus system under study the Generator Output data is given in Table 1, Line-Flow Data in Table 2. and Bus-Data in Table 3.

Line No	Bus From-To	Power Flow (MW)
1	1-4	60
2	4-5	40.2
3	4-9	19.8
4	6-5	109.8
5	3-6	150
6	6-7	40.2
7	8-7	59.8
8	2-8	165
9	8-9	105.2

Table 2: Line Flow Data

Bus No	Vol.(Mag.) p.u	Voltage Angle	Load (MW)	Generation (MW)
1	1.0	-7.94		60
2	1.0	4.72		165
3	1.0	3.7		150
4	1.0	-9.92		
5	1.0	-12.03	150	
6	1.0	-1.34		
7	1.0	-3.65	100	
8	1.0	-1.19		
9	1.0	-10.88	125	

Table 3: Bus Data

Conduct Contingency study

Contingency Study is conducted by running the Contingency Analysis Tool of the Power World Simulator Software. In this study only Generators, Buses and transmission lines have been taken into consideration for Contingency Studies. The 9-Bus System Consists of Nine Buses, three Generators, and Nine Lines. Total Number of contingencies studied are 94.

Single Contingency

It is the loss of one component .It corresponds to the N − 1 criterion.[4] i.e.the system should be able to support the load when one of the N basic transmission system components (transmission

lines, generators or transformers) is out of operation Only one Bus, or One Generator or One Line Failure For the 9-Bus System 21 Single Contingencies were studied.. The Results are Tabulated in Table 4.

Multiple – Contingencies

For the study two contingencies occurring at a time are considered. Any two Generators, any two Buses or Any Two Lines. 73Contingencies were studied. This is N-2 criterion[8][9][10].The results are tabulated in Tables 5,6 and 7. Thus a Total of 94 Contingencies were simulated, results obtained and Analyzed.

Contingency Number	Component	State	Effect of Contingency
C1	G1	Open	NV
C2	G2	Open	NV
C3	G3	Open	E1i.e1V,Branch 2-8 126% Loaded
C4	B1	Faulty	G1 Isolated
C5	B2	Faulty	G2 Isolated
C6	B3	Faulty	G3 Isolated & E1
C7	B4	Faulty	G1 Isolated
C8	B5	Faulty	L2 Isolated
C9	B6	Faulty	G3 Isolated & E1
C10	B7	Faulty	L7 Isolated
C11	B8	Faulty	G2 Isolated & E1
C12	B9	Faulty	L9 Isolated
C13	L1(1-4)	Open	NV
C14	L2(4-5)	Open	NV
C15	L3(4-9)	Open	NV
C16	L4(5-6)	Open	1V&E2i.e All loads and Gen. Islanded.L8-1056%loaded
C17	L5(3-6)	Open	G3 Islanded & E1
C18	L6(6-7)	Open	NV
C19	L7(7-8)	Open	NV
C20	L8(8-2)	Open	G2 Islanded
C21	L9(8-9)	Open	1V &E1

Notations:
Bn - Bus n
Cn – Contingency Number 1
CBn – Contingency effect at Bus n
En - Effect n
Gn -- Generator n
Ln(a-b) – Line n(From Bus – To Bus)
MCn - Multiple Contingency Number
NV – No Violation
O -- Open
1V – One Violation
En – Effect of Contingency

Table 4: Single Contingency Results

Contingency Analysis

Contingency Analysis is the analysis of the data obtained on creating a contingency. The two levels of Contingency analysis are i) off-line analysis which is used as a tool for planning to manage events that the planner has• Security is determined by the ability of the system to withstand equipment failure. Weak elements are those that present overloads in the contingency conditions (congestion) ii) online analysis collecting dynamic state of the system and taking preventive actions.. This allows operators to be better prepared to react to outages by using pre-planned recovery scenarios.

The Contingency Analysis Tool Box of Power World Simulator, provides tools for managing, creating, analyzing, and reporting lists of contingencies and associated violations. In general, the state of a power system is determined based on its ability to meet the expected demand under different contingency levels.

Contingency Number	Components	State	Effect of Contingency
MC1	G1 & G2	Open	NV
MC2	G1 & G3	Open	1V, & E1
MC3	G2 & G3	Open	1V & E1
MC4	B1 & B2	Faulty	CB1 & CB2
MC5	B1 & B3	Faulty	CB1 & CB3
MC6	B1&B4	Faulty	CB1 & CB4,
MC7	B1 & B5	Faulty	CB1 & CB5,
MC8	B1 & B6	Faulty	CB1 & CB6
MC9	B1 & B7	Faulty	CB1 & CB7
MC10	B1 & B8	Faulty	CB1 & C B8
MC11	B1 & B9	Faulty	CB1 & CB9
MC12	B2 & B3	Faulty	CB2 & CB3,1V
MC13	B2 & B4	Faulty	CB2 & CB4
MC14	B2 & B5	Faulty	CB2 & CB5
MC15	B2 & B6	Faulty	CB2 & CB6,1V
MC16	B2 & B7	Faulty	CB2 & C B7
MC17	B2 & B8	Faulty	CB2 & CB8,1V
MC18	B2 & B9	Faulty	B2 & B9,NV
MC19	B3 & B4	Faulty	C B3 & CB4,1V
MC20	B3 & B5	Faulty	CB3 & CB5,1V
MC21	B3 & B6	Faulty	CB3 & CB6,2V
MC22	B3 & B7	Faulty	CB3 & C B7,1V
MC23	B3 & B8	Faulty	CB3 & CB8,2V
MC24	B3 & B9	Faulty	CB3 & CB9,1V
MC25	B4 & B5	Faulty	CB4 & CB5
MC26	B4 & B6	Faulty	CB4 &C B6,1V
MC27	B4 & B7	Faulty	CB4 & CB7
MC28	B4 & B8	Faulty	CB4 & CB8,1V
MC29	B4 & B9	Faulty	CB4 & CB9
MC30	B5 & B6	Faulty	CB5 & CB6,1V
MC31	B5 & B7	Faulty	CB5 & CB7
MC32	B5 & B8	Faulty	CB5 & CB8
MC33	B5 & B9	Faulty	CB5 & CB9
MC34	B6 & B7	Faulty	CB6 & CB7,1V
MC35	B6 & B8	Faulty	CB6 & CB8,2V
MC36	B6 & B9	Faulty	CB6 & CB9,1V
MC37	B7 & B8	Faulty	CB7 & CB8,1V
MC38	B7 & B9	Faulty	CB7 & CB9
MC39	B8 & B9	Faulty	CB8 & CB9,1V

Table 5:Multiple Contingency Results

Analysis of Case Study

The effect of the various Contingencies in the 9-Bus study system have been classified into three categories. The first category is Highly Critical(HC) if there are two violations. This indicates that all preventive measures and precautions should be taken to ensure that the probability of occurrence of such contingency is zero. The second category is Medium Critical(MC) if there is one violation. this also indicates that all preventive measures and precautions should be taken to ensure that the propbability of occurrence of such contingency is very low below 0.1. The third category is Less Critical(LC) if there no violations but there is a reduction in the System Capacity such as load or generator isolated. Though the effect of such contingency is that it does not cause damage to existing performance of the system, it mitigates further increase of Power Supply which would hamper the market. Hence, steps should be taken to pevent Low Critical Contingencies.

The Analysis of the Single and Multiple Contingency results in Table 4. and Table 5. respectively, of the 9-Bus Study Test System is Tabulated in Table 6.

Level of Contingency Effect	Contingency Number
Highly Critical(HC)	C6,C9,C11,C16,C17,C21, MC2 To MC28
Medium Critical(MC)	C3
Less Critical(LC)	C1,C2,C4,C5,C7,C8,C10,C12,C13,C14,C15,C18,C19,C20,MC1

Table 6: Analysis of Single and Multiple Contingency Results

It can be observed from the above result analysis that branch 2-8 is a critical branch.The classification as HC,MC AND LC enables to prepare a preventive and rectification or remedial action table so as to clear the contingency as early as possible.

Output

The CA application provides several outputs, such as[8]:

displays for users to set up and control the application

execution status and problem displays, showing progress and non-convergence situations

results – in the form of many types of contingency violation lists, according to severity, type of equipment, loss of generation or load, equipment affected by multiple contingencies, creation of islands, etc.

results – in the form of many types of graphical displays, showing the overloads on one-line diagrams with color codes for severity, flags for types of problems, graphs, and even 3D representations of groups of analyses, etc.

visible warnings and audible alarms for operations staff and dispatchers, and sometimes for study users, to alert them about potential problems if certain contingencies should occur in the future.

Remedial Action Scheme

Remedial Action Schemes (RAS)[6][12] are the key components for any power system utility planning. These are the steps which the utilities need to take in order to get the system back to its normal operation. Remedial Action Scheme (RAS) as the name suggests are the necessary actions which need to be taken to solve the violations caused by a contingency. Remedial Action Schemes are also defined as Special Protection Schemes (SPS) or System Integration Schemes (SIS). The RAS is designed to mitigate specific critical contingencies that initiate the actual system problems. There may be a single critical outage or there may be several critical single contingency outages for which remedial action is needed. There may also be credible double or other multiple contingencies for which remedial action is needed. Each critical contingency may require a separate arming level and different remedial actions. The terms SPS and RAS are often used interchangeably, but WECC generally and this document specifically uses the term RAS.

Automatic single-phase or three-phase reclosing following temporary faults during stressed operating conditions may avoid the need to take remedial action. Appropriate RAS action may still be required if reclosing is unsuccessful [6].

Types Of Remedial Action[11]

Shunt capacitor switching

Generation Re-dispatch

Load shedding

Under load tap changing (ULTC) Transformer

Distributed Generation

Islanding

Phase Angle Regulators

Results

The results of the contingency analysis on 9 – Bus System is presented in the Tables 1 – 6. The contingencies are classified into three categories Highly Critical, Medium Critical and Less Critical. It is observed that branch 2-8 is the Highly Critical Branch.

Conclusion

The Novel Method of Contingency Planning and Analysis , demonstrated on the 9-Bus System is very systematic, simple and efficient. It enables to extensively study all types of contingencies.

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