Blackout Prevention by an Effective Forced Islanding Scheme

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***Abstract*— Abnormal cascading outages developing in large interconnected systems may result in blackout. Such blackouts imply damages to equipment of power plants, interruption of production cycles, and great economic losses. In order to avoid system wide instabilities, cascading outages and blackouts, an effective forced islanding scheme can be used. Numerous models and algorithms are available to predict hazards that subsequently results in loss of energy services to customers. But very few studies have assessed forced islanding in response to the risk of outages in the system. This paper proposes an algorithm that integrates the risk analysis and risk management by forced islanding to prevent the propagation of cascading failures across a transmission network while experiencing major disturbances and thereby reducing the possibility of a large-scale blackout. The scheme makes use of DC load flow studies and contingency analysis for its smooth operation. Contingency Analysis is done by using sensitivity factors, such as Line Outage Distribution Factor (LODF) and Generation Shift Factors (GSF), to calculate the overloads occurring due to the outage. For each outage, the forced islands to be formed are predefined. After forming forced islands, the islands are analyzed for stability. The proposed work is carried out on a sample 6 bus system using MATLAB program.**

Keywords*— Contingency Analysis; forced islanding; sensitivity factors; MATLAB

I. INTRODUCTION

Electric power is vital to the economy of a nation. Providing continuous supply of electric energy to meet the load demand is a complex technical challenge. It involves real-time estimation of the system state together with the control and coordination of generating units aimed at delivering electric power to the load in a secure manner. Consequently, power system network security is a major concern worldwide. However, due to deregulation, power systems are being operated closer to their maximum loadability. In addition, environmental constraints hinder the expansion of the electric transmission networks from meeting future demand growth. As a result, power systems are more vulnerable to severe disturbances like faults on major pieces of equipment. Large interconnected power systems may be seriously affected by severe occurrences that could lead to a cascade of automatic actions resulting in large-scale blackouts. Such blackouts imply damage to equipments of power plants, interruption in production cycles, chaos in the conditions of peoples' lives, and great economic losses. Therefore, there is a need for a new protection scheme aimed at reducing this risk.

Contingency analysis presents a method that addresses the details of the possible risks related to a respective contingency on a power system. It explores the effect of change in the power system operations on the alternatives, based on a 'what-if' type of analysis. Scheduled services, transmission line outages and generators outages are among the contingency events addressed in the contingency analysis of the power system.

As often seen, sometimes, during a disturbance, the system tends to break up into islands. This occurs on account of the tripping measures adopted by the grid's protective systems. Unintentional or natural islanding has the potential to damage equipment and compromise system security. On the other hand, to prevent system failure during extreme emergencies, it is sometimes recommended to execute controlled splitting of the system into stable islands with generation and/or load shedding using special protection schemes. Such forced islands are more stable than the unintentionally formed islands. They are also less prone to collapse and do not aggravate existing conditions that lead to blackouts.

Power system contingency events affect the reliability of power services. If not well managed, the entire system may be driven into a disastrous state. The system security may be jeopardized and their consequences may become severe and harsh to the system operations. Security of the power system operations is the main aspect in this thesis. This is done by adopting a suitable forced islanding technique to avoid the risks related to each contingency case.

Both contingency analysis and forced islanding procedure are time consuming; therefore an approach should be able to minimize this time when addressing the large system networks which is composed of many buses. Challenges intended to be addressed in this thesis include: optimize computation time for the contingency analysis and appropriate selection of possible islands such that it avoids the risk of each contingency.

A risk assessment application of a newly developed concept for finding accurate boundary values of load flow solutions is discussed in [2]. The uncertainty considered is of non-statistical nature and best modeled using fuzzy set theory. The paper [3] formulates detection of a set of severer contingencies in power systems as a combinatorial optimization problem and proposes a Tabu Search (TS) based method to solve it. A contingency analysis of power system to predict the line outage, generator outage and to keep the system secure and reliable by using full Newton's method is presented in [6]. Use of full Newton's method takes more time to perform the contingency analysis on a system. In paper [4], predetermined islanding scenarios along with automated load shedding schemes are applied once a prospective cascading outage condition is predicted. Paper [5] proposes a methodology to split the power system across the weak areas of the network affected by a large disturbance, by opening the transmission lines with minimum power exchanged.

The main outcome of this paper is the development of a new and effective power system forced islanding aimed at preventing cascading events from propagating further across a transmission network, thereby reducing the possibility of large-scale blackout. This is done in response to major contingencies in power system.

To detect the state of the system, continuous load flow analysis is done on the base system. As soon as a contingency occurs in the system, a contingency analysis is performed to determine the risk involved. As contingency analysis is a time consuming process, we use an approximate linear model of the power system such as a DC power flow model to perform the analysis utilizing minimum time. One of the easiest ways to provide a quick calculation of possible overloads during a contingency is to use linear sensitivity factors. These factors show the approximate change in line flows for changes in generation or line flows on the network configuration.

After contingency analysis and determination of risks involved in each contingency case, we pre-define appropriate islands such that it eliminates the risks with minimal load-generation imbalance during the forced islanding technique. The islands must be self-sufficient and stable to supply the local loads.

II. Contingency Analysis

Contingency Analysis (CA) is used on a live network at regular intervals to evaluate new system conditions [1]. The basic methodology is to disable a particular part (branch) and evaluate network stability using power flow equation. The number of branches disabled, say x, determines the (N - x) contingency analysis. If only one branch is disabled we have (N - 1) contingency analysis. Based on this analysis, operators can device a ranking to prioritize transmission planning.

In this thesis, we will not be concerned with all the events that can cause trouble on a power system. Instead, we will be concentrating on the possible consequences and remedial actions required by two major types of failure events - 1) Transmission-line outages and 2) Generation-unit failures.

Transmission-line failures cause changes in the flows and voltages on the transmission equipment remaining connected to the system. Therefore, the analysis of transmission line failures requires methods to predict these flows and voltages so as to be sure they are within their respective limits. Generation failures can also cause flows and voltages to change in the transmission system. In this thesis, we have preferred to predict the change in flows alone, to analyze these failures.

One way to gain speed of solution in a contingency analysis procedure is to use an approximate model of the power system. For many systems, the use of DC load flow models provides adequate capability. In such systems, the voltage magnitudes may not be of great concern and the DC load flow provides sufficient accuracy with respect to the megawatt flows.

One of the easiest ways to provide a quick calculation of possible overloads during such failures is to use linear sensitivity factors. These factors show the approximate change in line flows for changes in generation on the network configuration.

These factors can be derived in a variety of ways and basically come down to two types:

1) Generation shift factors

2) Line outage distribution factor

A. *Generation Shift Factors (A_{1i})*

The generation shift factors are designated A1i and have the following definition

$$A_{li} = \frac{\Delta f_l}{\Delta P_i} \qquad (1)$$

where *l* is line index, *i* is bus index, Δf_l is change in megawatt power flow on line *l* when a change in generation, ΔP_i occurs at bus *i* and ΔP_i is change in generation at bus *i*.

The new power flow on each line in the network could be calculated using a pre-calculated set of '*A*' factors as follows:

$$\hat{f}_l = f_l^0 + A_{li}.\Delta P_i \; ; \qquad for\ l = 1, \dots L \qquad (2)$$

where f_l^0 is flow before the failure, $\hat{f}_l$ is flow on line *l* after the generator on bus *i* fails.

The "outage flow", $\hat{f}_l$ on each line can be compared to its limit.

B. *Line Outage Distribution Factor (D_{lk})*

The line outage distribution factors are used in a similar manner, only they apply to the testing for overloads when transmission circuits are lost. By defining the line outage distribution factor has the following meanings.

$$D_{lk} = \frac{\Delta f_l}{f_k^0} \qquad (3)$$

where D_{lk} is line outage distribution factor when monitoring line *l* after an outage on line *k*, Δf_l is the change in MW flow on line *l*, and f_k^0 is the original flow on line *k* before it was outaged (opened).

If one knows the power on line *l* and line *k*, the flow on line *l* with line *k* out can be determined using '*D*' factors.

$$\hat{f}_l = f_l^0 + D_{lk} . f_k^0 \qquad (4)$$

III. Proposed Algorithm

The test system used for formulating the algorithm is a sample 6-bus system [1] with bus data and line data as shown in tables I and II, respectively. There are 2 generator buses and 11 lines in the system as shown in figure 1.

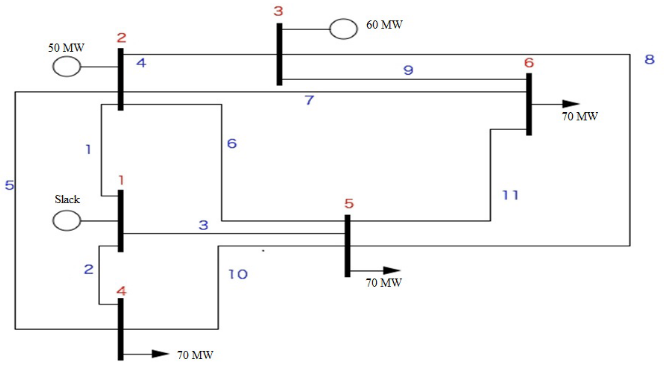

Fig. 1. Sample 6-bus system

TABLE I. Bus Data For 6-Bus System

Bus No.	Bus Code	Voltage Magnitude	Angle Degree	Generator MW	Generator MVAR	Load MW	Load MVAR	Qmax MVAR	Qmin MVAR
1	1	1.05	0	0	0	0	0	100	-20
2	2	1.05	0	50	0	0	0	100	-20
3	2	1.07	0	60	0	0	0	100	-15
4	3	1	0	0	0	70	70	0	0
5	3	1	0	0	0	70	70	0	0
6	3	1	0	0	0	70	70	0	0

TABLE II. Line Data For 6-Bus System

Line No.	Sending End Bus	Receiving End Bus	Resistance p.u.	Reactance p.u.	Half Susceptance p.u.	Power Limit
1	1	2	0.1	0.2	0.02	30
2	1	4	0.05	0.2	0.02	50
3	1	5	0.08	0.3	0.03	40
4	2	3	0.05	0.25	0.03	20
5	2	4	0.05	0.1	0.01	40
6	2	5	0.1	0.3	0.02	20
7	2	6	0.07	0.2	0.025	30
8	3	5	0.12	0.26	0.025	20
9	3	6	0.02	0.1	0.01	60
10	4	5	0..2	0.4	0.04	20
11	5	6	0.1	0.3	0.03	20

A. *Contingency Analysis*

An algorithm is formulated for contingency analysis on the test system using sensitivity factors and implemented using MATLAB program. The flow chart for the algorithm is shown in figure 2. Here, 100 MVA is selected as the base for the sample 6-bus system. First, we calculate the dc power flow of the complete 6-bus system, which is used as the base case power flow. The sensitivity factors are then pre-calculated. Next, we intentionally impart an outage into the system, which can either be a generator outage or a line outage. We then find out the contingency power flow using the pre-calculated sensitivity factors and base case power flow. This contingency power flow is compared to the thermal limits of lines to find out the overloads in the system. The results of the contingency analysis are shown in tables IV and V.

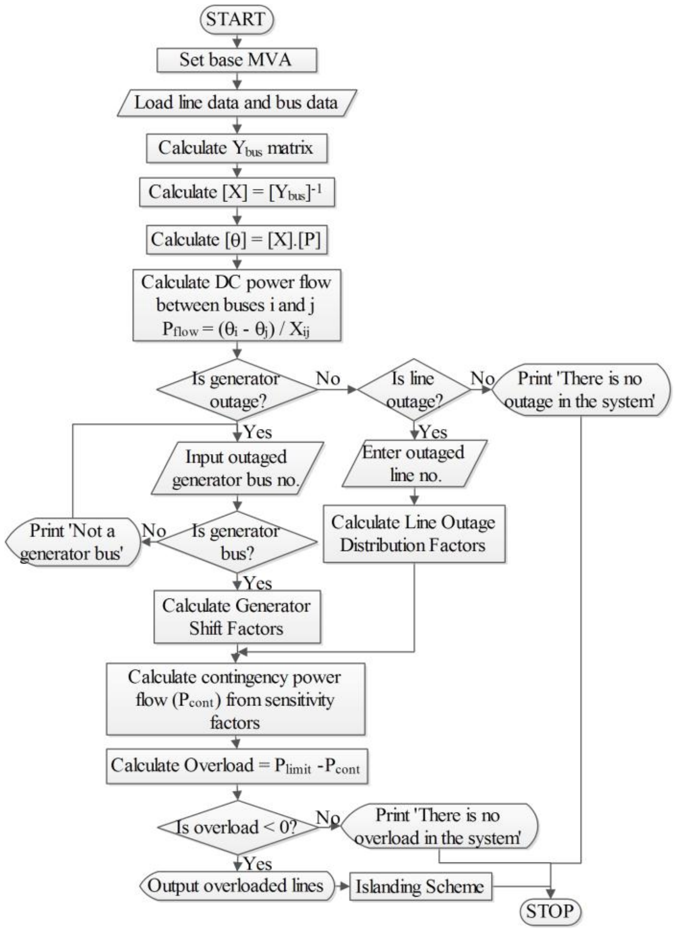

Fig. 2. Contingency analysis procedure

B. *Forced Islanding*

An algorithm is developed for forced islanding, the flow chart of which is shown in figure 3.

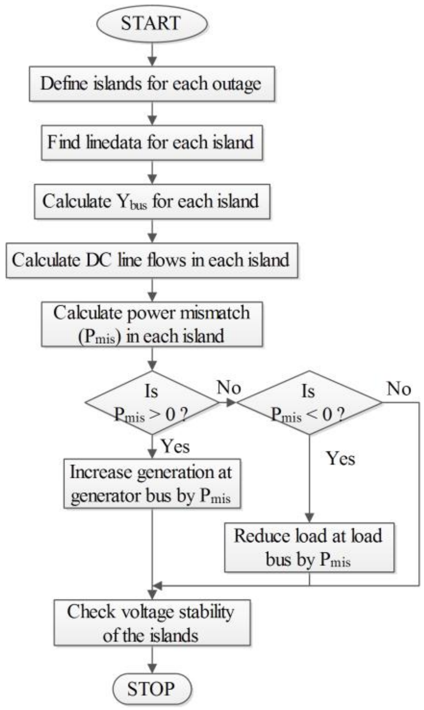

Fig. 3. Flow chart for Forced Islanding Scheme

TABLE III. PRE-DEFINED ISLANDS

Outage Case	Island 1	Island 2
Gen 2	2, 3, 6	1, 4, 5
Gen 3	2, 3, 6	1, 4, 5
Line 1	1, 2, 4, 5	3, 6
Line 2	1, 2, 3, 5	3, 6
Line 3	1, 2, 4, 6	3, 5
Line 4	No Island	
Line 5	2, 3, 6	1, 4, 5
Line 6	2, 3, 6	1, 4, 5
Line 7	2, 3, 6	1, 4, 5
Line 8	1, 2, 4, 5	3, 6
Line 9	2, 3, 4	1, 5, 6
Line 10	No Island	
Line 11	No Island	

For implementation of the forced islanding scheme, islands for each outage case are predefined. The islands are selected in such a way that load demand approximately equals generation in these islands. The predefined islands for each contingency case of the 6-bus system are given in table III.

After splitting the system into islands, load flow analysis is done on each island and power mismatch is calculated in each island, to warn for an increase of generation or a decrease of load in each island if the mismatch is positive or negative, respectively, by an amount equal to the mismatch. Also, voltage stability of the islands is analyzed considering a tolerance limit of ±10% for the voltage.

IV. RESULTS

A. Contingency Analysis

TABLE IV. RESULT FOR GENERATOR 2 OUTAGE

Line No.	Maximum Power flow	Base case Power flow	Sensitivity Factors	Contingency Power flow	Overload
1	30	25.3284	-0.4706	53.5658	-23.5658
2	50	41.5672	-0.3149	60.4605	-10.4605
3	40	33.1045	-0.2145	45.9737	-5.9737
4	20	1.8537	0.0544	-1.4132	21.4132
5	40	32.4776	0.3115	13.7895	26.2105
6	20	16.2189	0.0993	10.2631	9.7369
7	30	24.7781	0.0642	20.9264	9.0736
8	20	16.9317	0.0622	13.2010	6.7990
9	60	44.9220	-0.0077	45.3858	14.6142
10	20	4.0448	-0.0034	4.2500	15.7500
11	20	0.2999	-0.0565	3.6878	16.3122

TABLE V. SUMMARY OF CONTINGENCY ANALYSIS RESULTS

Outage Case	Overloaded Lines
Gen 2	1,2, 3
Gen 3	5, 8, 9
Line 1	2,3
Line 2	1, 3, 5
Line 3	1, 2, 6, 7, 8
Line 4	No Overload
Line 5	2, 6, 8
Line 6	8
Line 7	6, 9
Line 8	6
Line 9	7, 8
Line 10	No Overload
Line 11	No Overload

The sensitivity factors, contingency power flows and overloads in each line as calculated by the algorithm for generator 2 outage case are given in table IV. An outage on generator 2 causes overload in lines 1, 2 and 3 as indicated by the negative values for overload in these lines. Similarly, results can be obtained for each outage case which is summarized in table V.

B. Forced Islanding

The analysis result of the forced island formed during generator 2 outage case is briefly discussed below:

Island 1 (2, 3, 6):

Power Flow result -

From Bus	To Bus	Power Flow
2	3	25.4545
2	6	44.5455
3	6	25.4545

Voltage at buses -

$V_2 = 1$
$V_3 = 1.07$
$V_6 = 0.9863$

Bus voltages are within limits.

Island 2 (1, 4, 5):

Power Flow result -

From Bus	To Bus	Power Flow
1	4	77.77
1	5	62.22
4	5	7.77

Voltage at buses -

$V_1 = 1.05$
$V_4 = 0.7996$
$V_5 = 0.7227$

Bus voltage is below limit.

V. CONCLUSION

This paper has discussed an effective scheme integrating risk analysis with risk management by incorporating forced islanding scheme in response to the risk of outages occurring in the power system. With this scheme, we aim to reduce the risk of blackouts in the system. The method is incorporated by conducting a contingency analysis on the base system, utilizing sensitivity factors to determine the overloads in the lines during an outage. For each outage, the forced islands to be formed are predefined. After forming forced islands, the islands are analyzed for stability. The proposed work is carried out on a sample 6 bus system using MATLAB program.

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