History of Medicine Studies

ISSN:1300-669

Volume 18 Issue 2 July 2022

Using DC Current and Distribution Factor to Identify Potential Breakdown Sources in Power Systems

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Abstract

The brittleness hypothesis predicted the possibility of a chain reaction of failures in the electric power grid caused by brittle sources inside the system; hence, identifying these sources is essential for mitigating brittle risk. This book proposes a technique for identifying fragile sources using a mixture of DC flow and distribution factor, and demonstrates the approach's efficacy and feasibility using the IEEE-5 node system.

Keywords:

DC flow, distribution factor, brittle risk, and identifying brittle sources

Introduction

People's attention has been drawn to global blackouts of electricity systems in recent years [1–5]. Theoretically, the fragility of the electricity grid is to blame for the devastating outages that have occurred in the past. When a system is stressed from inside or outside, the brittleness hypothesis may pinpoint which component is the weakest link in the system and set off a domino effect that brings down the rest of the components. It causes a total failure of the system in the end. This article examines the fragility of electrical grids and pinpoints the weak link in the IEEE-5 node system via the use of a DC power flow and distribution factor.

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The Fragile Power Infrastructure's Danger

Both the internal structure and the brittle environment system contribute to the fragility risk of a complex system. The subsystems' organizational structure is what we mean by "internal structure," whereas the events and circumstances outside the system that contribute to its fragility are what we mean by "external brittle environment." Furthermore, as illustrated in Figure 1, the brittle risk model's complicated system structure may be broken down into four phases.

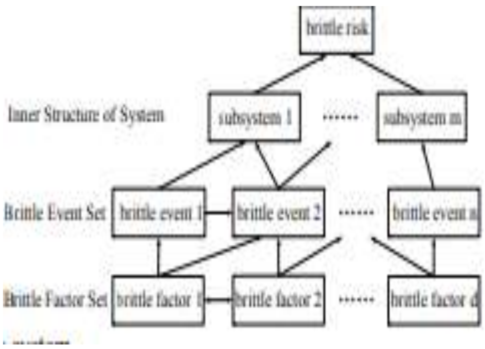

Figure.1: brittle risk model of complex system

It can be seen that the brittle model of complex system is composed by the brittle input, system structure and the brittle risk of the three fundamentals of brittle composition actually, which is shown in Figure 2.

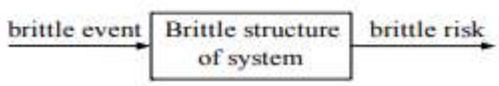

Figure.2: the upper brittle structure of complex system

Brittle structure of the system contains two aspects: First, the brittle state of each subsystem assume complex system S contains m subsystems, expressed as

$$: S=\{S_1, S_2, \ldots, S_m\}, \text{ so } S'_i \ (i = 1,2, \ldots,m)$$

represents that the brittle state of the corresponding subsystem

$$S_i, S'_i \text{ can be written: } S'_i \ \{a'_1, a'_2, \ldots, a'_r\}, \{a'_1, a'_2, \ldots, a'_r\}$$

is used to characterize Si's fragile state variables. The structure of the brittle risk for that section of the system is described by the brittle states of those subsystems. Second, the link of the brittle risk structure to the system, which includes the brittle relationship between subsystems and the proliferating ways of brittle inside the system. A subsystem Si(t) is a brittle source and a subsystem Sj(t) is a brittle receiver if and only if, whenever a state variable S′i'(t) characterizing the brittle character of a subsystem Si(t) changes, the other brittle state characteristic quantities S′j'(t) of the corrective subsystems Sj(t) also change.

The DC Power Flow and Distribution Factor Mathematical Model

DC power flow mathematical model

Under certain conditions, the AC power flow equation may be simplified into the DC power flow equation [6]. Electric power system's alternating current power flow equation expression is :

$$P_i = V_i \sum_{j \in i} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij})$$

Branch power flow expression is:

$$P_{ij} = V_i V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) - t_{ij} G_{ij} V_i^2$$

In it, N is the number of nodes, Pi is the active power flow injected into the node i, Vi and Vj are voltage amplitude of the node i and j, j∈i means all nodes connected to the node i directly, tij means branch transformer non-standard ratio unit value,θ ij means the phase angle difference of the branch node voltage, Gij and Bij mean the corresponding real and imaginary parts of the node admittance matrix respectively.

$$G_{ij} + jB_{ij} = \frac{-1}{r_{ij} + jx_{ij}} = \frac{-r_{ij}}{r_{ij}^2 + x_{ij}^2} + j\frac{x_{ij}}{r_{ij}^2 + x_{ij}^2}$$

The application of DC power flow is based on the following assumptions in actual running of the high-voltage power systems. 1) The resistance R is much smaller than its reactance X in branch: rij=0, the susceptance

$$b_{ij} = -1/x_{ij}.$$

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ISSN:1300-669

Volume 18 Issue 2 July 2022

The voltage phase angle difference between two nodes of branch is very small: sin

$$\theta_{ij} = \theta_i - \theta_j \quad = \theta_{ij}, \cos\theta_{ij} = 1.0.$$

3) The susceptance of node to the ground is negligible:

bi0=bj0=0.

4) The voltage of each node is close to the rated voltage: Vi=Vj=1.0.

5) The relative transformers' ratio tij=1.

Then the equation (1) can be simplified :

$$P_i = \sum_{j \in i} B_{ij}\theta_{ij}$$

The matrix form: $P = B\theta$

The equation (2) can be simplified:

$$P_{ij} = -B_{ij}\theta_{ij} = \frac{\theta_i - \theta_j}{x_{ij}}$$

Modeling the Distribution Factor Approach Mathematically

In the power system analysis, the distribution factor technique [7] may be used to characterize active power flow changes of branches, which may be induced by the failure of one or more branches. It is shown that if branch l is broken, the power flow in branch k will shift since the active power flow in branch l is Pl. The vector matrix of order (n-1) associated with the node l is denoted by Ml, and the intermediate variable is denoted by l=XMl.

$$M_l^T = [\ldots \overset{i}{1} \ldots \overset{j}{-1} \ldots]$$

The self-impedance and mutual impedance of branch k after branch l breaking:

$$X_{l-l} = M_l^T \eta_l$$
$$X_{k-l} = M_k^T \eta_l$$

The power flow distribution factor of branch k (k≠l) to the branch l which broken off :

$$D_{k-l} = \frac{X_{k-l}/x_k}{1 - X_{l-l}/x_l}$$

The power flow of k:

$$P_k^l = P_k + D_{k-l}P_l$$

Power System Identifier with Fragile Power Source Fault simulation of breaking all of the components is used as the way of identifying the fragile power source. When the failure of one part of a system leads to the failure of other parts of the system and so on until all of the lines have snapped, it is clear that this part is the weak link in the system as a whole[8]. The computation of power flow allows for the detection of a fragile source. If one or more branches are severed, the power flow distribution of the original system must be promptly and accurately calculated using the DC power flow technique, and the power flow redistribution of lines must be quickly and accurately calculated using the distribution factor method. If the re-allocation causes power flow to be redistributed beyond the transmission boundary, the branch will be severed. This process repeats itself until either all of the lines have been severed or all of the flow has been reduced down below the limiting value.

The following are the stages of identifying a fragile source using DC flow and distribution factor:

1) Select one node as the reference node and its voltage phase angle: θ = 0 ;

2) Form the nodal admittance matrix B0 except for reference node:

$$\begin{cases} B_0(i,i) = \sum_{j \in i, j \neq i} 1/x_{ij} \\ B_0(i,j) = -1/x_{ij} \end{cases}$$

3) Calculate matrix X of B0: X= B0 -1 ;

4) The node voltage phase angle matrix

$$\theta = XP_i^{SP}$$

The active power flow Pij ;

6) Break off the branch l (l = 1, 2,K , m) one by one calculate self-impedance and mutual impedance of other branches to the branch l;

7) Calculate the flow distribution factor Dk-l of each branch k (k≠l) to the broken one l ;

8) Calculate the flow Pk l of other branches after branch l broken;

9) If the branch's flow of the re-distribution over the transmission border, this branch must be broken and come back to step (6) or end

Example

The IEEE-5 node system[6] is shown below in this paper. The numbers of node and branch are also marked in Figure 3.

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ISSN:1300-669

Volume 18 Issue 2 July 2022

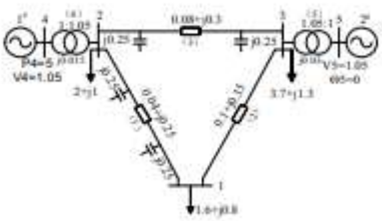

Figure.3: IEEE-5 node system

TABLE I. POWER TRANSMISSION BORDER OF LINES

Branch number	*Node of Beginning to end*	**Power transmission border**
(1)	1-2	2
(2)	1-3	0.65
(3)	2-3	2
(4)	2-4	6
(5)	3-5	5

Select node 5 as the reference node. The node admittance matrix B0:

$$B_0=\begin{bmatrix} 6.8571 & -4.0000 & -2.8571 & 0.0000 \\ -4.0000 & 74.0000 & -3.3333 & -66.6667 \\ -2.8571 & -3.3333 & 39.5238 & 0.0000 \\ 0.0000 & -66.6667 & 0.0000 & 66.6667 \end{bmatrix}$$

Calculate the impedance matrix X:

$$X=B_0^{-1}=\begin{bmatrix} 0.2439 & 0.1467 & 0.3000 & 0.1467 \\ 0.1467 & 0.2300 & 0.3000 & 0.2300 \\ 0.0300 & 0.0300 & 0.0300 & 0.0300 \\ 0.1467 & 0.2300 & 0.0300 & 0.2450 \end{bmatrix}$$

Calculate the phase angle vector matrix θ :

$$\theta=\begin{bmatrix} -0.0918 \\ 0.3129 \\ 0.0774 \\ 0.3879 \\ 0.0000 \end{bmatrix}$$

Calculate the flow of branches by substituting the matrix θ into flow equation:

$$P_1=P_{12}=-1.6189,\quad P_2=P_{13}=-0.0411$$
$$P_3=P_{23}=1.3011,\quad P_4=P_{24}-5.0000$$
$$P_5=P_{35}-2.5800$$

Discuss each branch whether the brittle source of power system is by breaking each branch respectively

The intermediate variable when branch (1) breaks off :

$$\eta_1=XM_1=\begin{bmatrix} -0.0972 \\ 0.0833 \\ 0.0000 \\ 0.0983 \end{bmatrix}$$

Obtain the self-impedance and mutual impedance to the branch (1) broken:

$$X_{1\text{-}1}=0.1956,\quad X_{2\text{-}1}=0.0972$$
$$X_{3\text{-}1}=-0.0833,\quad X_{4\text{-}1}=0.0833$$
$$X_{5\text{-}1}=0.0000$$

Obtain distribution factor of each branch:

$$D_{2\text{-}1}=1.2755,\quad D_{3\text{-}1}=-1.2755$$
$$D_{4\text{-}1}=-25.5102,\quad D_{5\text{-}1}=0.0000$$

Calculate the rest of the branches' flow:

$$P_2^1=-2.1060,\quad P_3^1=3.3660$$
$$P_4^1=36.2980,\quad P_5^1=-2.5800$$

As can be seen from the results, the breaking of branch (1) resulted in other branches exceeding the transmission borders and breaking, so branch (1) is the brittle source. The flowing table is the result of chain breaking calculated in the same way.

TABLE II. CHAIN BREAKING RESULTS

Breaking branch NO.	*Node of Beginning to end*	**Caused Broken branch NO.**
□	1-2	□, □, □
□	1-3	
□	2-3	□, □, □, □
□	2-4	
□	3-5	□, □, □, □

We can conclude that the branches (1), (3) and (5) is the brittle source of this system through the analysis. Any of their failure can cause the brittle risk and make system collapse.

Conclusion

According to the brittleness hypothesis, every system with a high degree of dependability also has a brittle risk, but this risk is limited by the variables and situations that may be aroused. Therefore, the tendency may be stopped in its tracks if the system's fragile source can be tracked and managed in real time. This study presents a simple and straightforward approach for identifying the brittle source of a system by combining DC flow and the distribution factor. The examination of the IEEE-5 node system provides conclusive evidence of the method's utility and efficacy.

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