

Research Article

Fast Screening Method for an Important Transmission Line in Electrical Power System Uniting Internet Thinking and Physical Features

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Received 22 January 2022; Revised 24 February 2022; Accepted 4 March 2022; Published 29 March 2022

Academic Editor: Chia-Huei Wu

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In the electrical power system, a few transmission lines may have cascading failures and even lead to severe blackout accidents. In order to further prevent the electrical power system from cascading failures and being enlightened by Internet thinking, based on the complex network theory, this paper proposes the TL-SALSA (transmission line-stochastic approach for link structure analysis) algorithm combining Internet thinking and physical characteristics of the electrical power system for screening the important transmission lines. The TL-SALSA algorithm not only retains the low-computational complexity advantage of the SALSA (stochastic approach for link structure analysis) algorithm but considers the impact relational among transmission lines and the electrical power system operation mode. The IEEE 39-bus power system and IEEE 118-bus power system are simulated and compared with the electric betweenness algorithm, and the results further evidence the effectiveness of the TL-SALSA algorithm. The results also show that the TL-SALSA algorithm can improve the screening efficiency by nearly three orders of magnitude compared with the electric betweenness algorithm, which proves the potential of the TL-SALSA algorithm for screening important transmission lines in large-scale electrical power systems.

1. Introduction

With the scale-up of the modern electrical power system, the probability of cascading failures increases significantly and its influence expands accordingly, resulting in severely adverse economic and social impact [1–3]. In a massive interconnection electrical power system, a cascading failure is universally elicited by one or a few failures of electrical power system components, such as transmission lines or buses [4]. It is critical to find out those crucial components in order to restrain the cascading failures' spread and ultimately prevent cascading failures. Based on the environment of screening important transmission lines and the inspiration of the Internet thinking, this paper intends to propose an algorithm for real-time screening to important transmission lines.

The research approaches can be roughly divided into two types in the available literature: algorithm based on simulation and algorithm based on graph theory. In terms of the former, the OPA (ORNL-Pserc-Alaska) algorithm was proposed to find out the vital transmission lines by simulating the evolution process of the electrical power system, including the power flow dynamics evaluation process and power grid growth dynamics evaluation process [5]. Subsequently, a modified OPA algorithm was proposed in [6], which improves the iteration and the development process of the electrical power system. Moreover, the classic investment risk assessment indexes (value at risk VaR) and CVaR (conditional value at risk) were considered to measure the importance of electrical power system transmission lines. There are advantages of calculation precision in the OPA series algorithm, while its further application is restricted

by extreme computation complexity [7]. The Monte-Carlo-based algorithm was proposed in [8] to screen the important transmission lines. Unfortunately, the similar problem-high computation complexity appears in the promotion of the Monte-Carlo-based algorithm. According to [9, 10], the random chemistry algorithm was put forward with a lower computation complexity. Conversely, it still cannot meet the demands of screening the critical transmission lines in real-time application.

Various algorithms based on graph theory have been proposed for screening the important transmission lines in the electrical power system. Abstracting the electrical power system to graph and analyzing it by graph theory indexes are the basic methods in this algorithm, and the original degree centrality [11] as well as the betweenness centrality [12] is also accepted when analyzing the electrical power system. However, those methods ignored the physical background of the electrical power system, just focusing on the graph theory to find important transmission lines. Based on the betweenness centrality theory of the graph theory, the electric betweenness algorithm was proposed [13, 14] and Kirchhoff's law has been considered in it. Hence, the electric betweenness algorithm can reflect the physical characteristics of electrical power systems strongly and screen important transmission lines effectively. Some algorithms based on K-core raised currently, which shows a better performance for screening the critical transmission lines than the new graph theory indexes [15, 16]. A second-order Kuramoto oscillator network model was proposed in [17], which analyzed the various situations causing blackout accidents in the low-frequency condition. Unfortunately, only several small-scale electrical power systems were considered in [17].

Due to the similarity and consistency between the Internet and electrical power system, both systems can be abstracted as complex networks [18, 19]. This characteristic laid the foundation for Internet ideas to solve the puzzling problems in the electrical power system. Nowadays, some algorithms have been proposed for screening the important nodes in the electrical power system, which combines the physical characteristics of the electrical power system and the ideas of the Internet system [20, 21]. So far, as is known to the authors, a few algorithms are inspired by Internet thinking to screen important transmission lines of the electrical power system [22, 23]. An important transmission line screening algorithm based on the PageRank algorithm was improved step by step in [22, 23]. Nevertheless, the PageRank algorithm's inherent weakness that computational process only considers the influence of indegree of the being evaluated node and ignores the influence of outdegree being evaluated node. This weakness causes the accuracy of screening important transmission line results to have congenital disabilities.

Based on the network theory and the combination of physical features of the electrical power system and Internet thinking, notably the eminent SALSA algorithm [24], we propose the TL-SALSA (transmission line-SALSA) algorithm for screening the important transmission lines in this paper. The TL-SALSA algorithm comprehensively considers the influence relationship among each transmission line in

the period of building the adjacent matrix. Also, the electrical power system operation mode and electrical power system topology structure have been considered in the TL-SALSA algorithm. Besides, the advantage of it reserved from the SALSA algorithm is the calculation based on Markov chains without relying on massive cascading failure simulations, which endows the TL-SALSA algorithm with low computation complexity when screening important transmission lines in real time.

The remainder of this paper is organized as follows. It starts by expounding fundamental concepts and evaluation indexes in Section 2. The TL-SALSA algorithm is exhaustively then presented in Section 3. In Section 4, the study case based on the IEEE 39-bus system and the IEEE 118-bus system is analyzed and discussed in detail. Finally, the conclusion of this paper on a whole is given.

2. Fundamental Concepts & Evaluation Indexes

2.1. Bipartite Graph. Nodes and edges constitute a graph, which is the foundation of the complex system [25]. Many scientific fields can be abstracted as a graph to solve puzzling problems, like the Internet and electrical power system. There are various types of graphs, like the oriented graph, regular graph, and so forth. The bipartite graph is one of the critical types of the graph. On the strict definition, there are two node sets V_a and V_h form the bipartite graph's nodes. Also, the two node sets are disjoint and independent [26]. Moreover, all of the edges for connecting two nodes can be divided into two categories, one belonging to V_a and the other one belonging to V_h . In the bipartite graph, that union set of V_a and V_h includes all the nodes and the intersection is an empty set. At the same time as the SALSA algorithm proposed in [23], a loose definition for the bipartite graph is proposed. In this loose definition, V_a and V_h can be calculated as formulas (1) and (2) shown, respectively. Here, S denotes each nonisolated node.

$$V_a = c_a | c \in S \text{ and } \text{indegree}(c) > 0, \quad (1)$$

$$V_h = c_h | c \in S \text{ and } \text{outdegree}(c) > 0. \quad (2)$$

For most nodes in a relatively complex graph, the indegree and outdegree are more than zero. Hence, those nodes belong to V_a and V_h synchronously. The union set of V_a and V_h contains every node except the isolated node. Moreover, the intersection set of V_a and V_h maybe not an empty set.

2.2. Authority Score & Hub Score. As one of the key components, the authority score was proposed along with the PageRank algorithm [27]. Based on the authority score, the definition of the hub score was proposed in the HITS algorithm [28]. Node's authority score is affected directly by the quantity and quality of the in-degree nodes. With this correspondence, the one node's hub score is affected directly by the quantity and quality of the outdegree nodes, which is one of the advantages of the HITS algorithm compared with the PageRank algorithm. The PageRank algorithm can only

calculate the authority score, which reflects the influence of indegree. However, although the HITS algorithm considers both the indegree and outdegree, its calculation progress is mutually reinforced, which brings the risk of inaccurate calculation results.

2.3. VaR & CvaR. The VaR index is one of the classical indexes in the finance field, which has guided numerous economic investments. Furthermore, the VaR index is most commonly used to determine the extent and occurrence ratio of potential losses in the investment. The VaR index definition is the most significant possible load loss with the confidence level σ that the system will face in a particular future [29]. Moreover, the VaR index can be calculated as formula (3) shows. The bigger the VaR score calculated, the larger the loss will be. Here, x is the loss scale and $p(x)$ is the probability density function.

$$\sigma = \int_{-\infty}^{\text{VaR}} p(x) dx. \quad (3)$$

Although the VaR is a mature index, it also has a shortcoming: the tail-loss measurement is not sufficient. Hence, the application of the VaR index should be combined with the CVaR index.

The CVaR index was proposed to solve the shortcoming of the VaR index. It is a risk assessment index that predicts the quantity of tail-loss risk. The CVaR index's definition is that the conditional mean value of the loss is more than the VaR index under a certain confidence level [30]. The bigger the CVaR score is, the more excessive the loss. The CVaR index can be calculated as formula (4) shows.

$$\text{CVaR} = \int_{\text{VaR}}^{\infty} xp(x) dx. \quad (4)$$

2.4. Important Transmission Line Screening Algorithm

2.4.1. Original SALSA Algorithm. The original SALSA algorithm was initially proposed on the Internet area [24]. Just like the PageRank algorithm, the SALSA algorithm also ranks the significant web pages through the hyperlink structure. However, there has a big difference between the SALSA algorithm and the PageRank algorithm. Because of having one Markov chain, the PageRank algorithm considers the influence of indegree. The more the hyperlinks pointed by other important web pages in the PageRank algorithm, the more critical this web page is [28]. Unlike the PageRank algorithm, the SALSA algorithm has two independent Markov chains and further considers the influence of indegree and outdegree.

Assuming that an Internet has N web pages, the SALSA algorithm can be operated as follows. Firstly, the Internet system's web pages can be abstracted as nodes and the hyperlinks among web pages can be abstracted as edges. Thus, a directed and unweighted graph in the complex network theory can be obtained. Secondly, on the basis of the graph connection relationship, the adjacency matrix W can be captured.

After the nonzero entry of W is divided by the sum of the entries in its row, the matrix W_r can be obtained. Similarly, the W_c can be obtained after the nonzero entry divided by the number of entries in its column. This progress can be described as formula (5) where the $e = [1, 1, \dots, 1]^T$.

$$W_c = \left\{ [\text{diag}(W^T e)]^{-1} W^T \right\}^T, \quad (5)$$

$$W_r = [\text{diag}(We)]^{-1} W. \quad (6)$$

Thirdly, the matrices \tilde{A} and \tilde{H} can be obtained by deleting the full zero rows and columns of matrices $W_c W_r^T$ and $W_r W_c^T$, respectively. Formula (7) are designed to describe this process. Here, φ means deleting the full zero rows and columns of $W_c W_r^T$ and $W_r W_c^T$.

$$\tilde{A} = \varphi(W_c W_r^T), \quad (7)$$

$$\tilde{H} = \varphi(W_r W_c^T). \quad (8)$$

Fourthly, vector x can be calculated by formula (9). Similarly, vector y can be calculated by (10).

$$x = \tilde{A}x_0, \quad (9)$$

$$y = \tilde{H}y_0. \quad (10)$$

As shown in formulas (11) and (12), the two vectors can be calculated, respectively. L_a and L_h are the edge numbers of the bipartite graph, respectively.

$$x_0 = \left[\frac{1}{\sqrt{L_a}} \quad \frac{1}{\sqrt{L_a}} \quad \frac{1}{\sqrt{L_a}} \quad \dots \quad \frac{1}{\sqrt{L_a}} \right]^T, \quad (11)$$

$$y_0 = \left[\frac{1}{\sqrt{L_h}} \quad \frac{1}{\sqrt{L_h}} \quad \frac{1}{\sqrt{L_h}} \quad \dots \quad \frac{1}{\sqrt{L_h}} \right]^T. \quad (12)$$

In terms of the Internet, the importance of a web page is usually determined by the authority score and the Hub score typically serves as a reference. Because of considering not only the indegree but also the outdegree, the SALSA algorithm has better precision than the PageRank algorithm.

3. TL-SALSA Algorithm

Although the SALSA algorithm has an excellent performance in the Internet area, there is much difference between the Internet system and the electrical power system, like different topological structures and different influence modes among nodes. Hence, the original SALSA algorithm cannot be applied to screen the vital transmission lines for an electrical power system. In this context, according to the electrical power system's physical characteristics, the TL-SALSA algorithm is proposed for screening important transmission lines.

3.1. Adjacent Matrix. The adjacent matrix reflects the topological structure of the graph and the interaction effect

among each node. In order to screen important transmission lines, a new correspondence relationship between electrical power systems and a complex network should be designed. The SALS algorithm's primary analysis subjects are nodes, but our research targets are screening transmission lines. Hence, in the TL-SALS algorithm, the transmission lines should be abstracted as nodes in the graph and the adjacent matrix has been designed and constructed by an N-1 check. Because the N-1 check of transmission lines can reflect the relation among each line and the current variation. The TL-SALS algorithm chooses each transmission line's influence relationship as the edge, which is calculated by the N-1 check, because majority of transmission lines cascading failures result from power flow transferring. Also, the current variation value reflects the change of power flow intuitively. Hence, the transmission line's current variation value has been determined as the graph edge weight in the TL-SALS algorithm, which can be calculated by the N-1 check. The correspondence relationship among Internet system, complex networks, and electrical power system is shown in Table 1.

According to formula (13), the adjacent matrix of an electrical power system can be obtained.

$$W_{ij} = \begin{cases} \frac{\Delta C_{i \rightarrow j}}{C_j^i}, & \text{apply } N-1 \text{ check on line } i, \\ & \text{current of line } j, \\ & \text{been influenced,} \\ 0, & \text{apply } N-1 \text{ check on line } i, \\ & \text{current of line } j, \\ & \text{not been influenced.} \end{cases} \quad (13)$$

Here, the $\Delta C_{i \rightarrow j}$ can be calculated by formula (14).

$$\Delta C_{i \rightarrow j} = \begin{cases} |C_j^i| - |C_j|, & |C_j^i| > |C_j|, \\ 0, & \text{other situations.} \end{cases} \quad (14)$$

$\Delta C_{i \rightarrow j}$ and C_j^i denote the current variation value and the corresponding transmission line j , respectively, when applying N-1 check on transmission line i . Moreover, i indicates the current value of transmission line j before any N-1 check.

3.2. Topological Structure. According to the above improvements to the adjacent matrix, a whole new topology structure has been established for screening important transmission lines, which relies on the relation among transmission lines, not only the electrical power system physical connection. Most of all, the topological structure contains many implicit features of an electrical power system, which has a decisive influence on screening important transmission lines. In the original SALS algorithm, formulas ((9)) and ((10)) only be calculated once, the authority score and Hub score can be calculated, In this calculation process, the authority score and Hub score just consider the effect of

TABLE 1: The comparison among the Internet system, complex networks, and electrical power system.

Internet system	Electrical power system	Complex networks
Web page	Transmission line	Node
Hyperlink	Influence relationship of N-1 check	Edge
No weight	Current variation value	Weight of edge

the near nodes toward the target node. Consequently, this calculation should be the set iteration until the authority score and hub score convergence. This calculation process can take a full account of the topological structure. The iteration process is shown in formulas (15) and (16). Here, k is the iteration.

$$x^k = \tilde{A}x^{k-1}, \quad (15)$$

$$y^k = \tilde{H}y^{k-1}. \quad (16)$$

3.3. Power Flow. Power flow is one of the critical characteristics of an electrical power system, which has a pivotal impact on transmission lines. Moreover, it reflects the operating state of the target electrical power system. To embody the influence of power flow, power flow has been designed as the initial iterative value of each transmission line for calculating importance. The calculation process is shown in formulas (17) and (18)

$$x'_0 = \left[\frac{PF(1)}{PF_a} \quad \frac{PF(2)}{PF_a} \quad \frac{PF(3)}{PF_a} \quad \dots \quad \frac{PF(L_a)}{PF_a} \right], \quad (17)$$

$$y'_0 = \left[\frac{PF(1)}{PF_h} \quad \frac{PF(2)}{PF_h} \quad \frac{PF(3)}{PF_h} \quad \dots \quad \frac{PF(L_h)}{PF_h} \right], \quad (18)$$

where $PF(i)$ is the power flow value of transmission line i , L_a and L_h are the numbers of transmission lines in the bipartite graph, and PF_a and PF_h denote the sum of power flow in a bipartite graph.

3.4. Important Transmission Lines Score. Because the electrical power system's physical characteristics are different from the Internet system, the idea that determines the score of the important transmission lines is also different. Based on the fact that transmission lines can influence other transmission lines and other transmission lines also can influence them, both of the two aspects should be considered in the calculation. Moreover, in the electrical power system, these two aspects can be approximated as equally important. Hence, the TL-SALS algorithm determining the important transmission line score is the sum of the authority score and hub score.

$$T_i = a_i + h_i. \quad (19)$$

The convergent authority score and hub score of transmission line i are a_i and h_i , respectively. T_i denotes the results of the importance score of transmission line i .

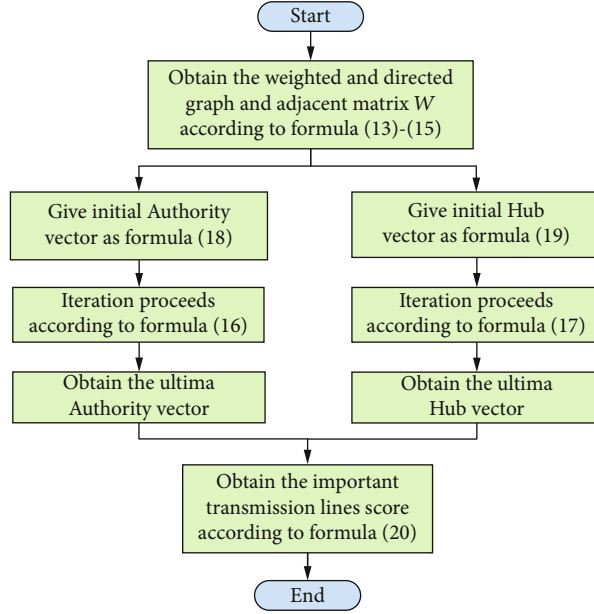


FIGURE 1: Flowchart for screening important transmission lines of electrical power system.

3.5. *Calculation Process.* According to the foregoing introduction, the calculation process of the TL-SALSA algorithm is shown in Figure 1.

The IEEE 9-bus system is selected to show the calculation progress of the TL-SALSA algorithm. Figure 2 shows the IEEE 9-bus electrical power system, which is formed from 9 buses and 9 transmission lines [30]. Also, Figure 2 can be abstracted as a graph, as Figure 3 shows. Under the

guidance of Figure 1, the important transmission lines can be screened by the TL-SALSA algorithm as the following steps.

Step 1

According to formulas (13) and (14), the adjacent matrix of the IEEE 9-bus system can be obtained. And just for simplicity, the adjacent matrix only considers the influence that W_{ij} is more than 100% in this example.

$$W = \begin{bmatrix} 0 & 2.237 & 0.873 & 0 & 0 & 2.115 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1.127 & 1.053 & 0 & 1.323 & 1.542 & 0.796 & 0 & 0 & 0 \\ 0 & 1.532 & 0.643 & 0 & 0 & 1.766 & 0 & 0 & 0 \\ 0 & 1.302 & 0.577 & 0 & 0 & 1.234 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.638 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.668 & 0.591 & 0 & 0 & 0 & 0.519 & 0 \\ 0 & 1.517 & 0 & 0 & 1.564 & 1.575 & 2.114 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1.347 & 1.054 & 0 & 0 \end{bmatrix}. \quad (20)$$

Step 2

Depending on adjacent matrix W , Figure 3 can be abstracted as another graph, as Figure 4 shows. In Figure 4, nodes represent transmission lines in Figure 3 and edges represent buses in Figure 3. Table 2 displays the node and transmission line correspondence relation between Figures 3 and 4. Then, the authority vector and hub vector before iteration of the IEEE 9-bus system can be calculated by formulas (18) and (19).

$$\begin{aligned} x'_0 &= [0.134 \quad 0.043 \quad 0.153 \quad 0.112 \quad 0.083 \quad 0.054 \quad 0.135 \quad 0.287], \\ y'_0 &= [0.121 \quad 0.1382 \quad 0.101 \quad 0.074 \quad 0.049 \quad 0.122 \quad 0.259 \quad 0.136]. \end{aligned} \quad (21)$$

Step 3

As formulas (15) and (16) show, the finally convergent authority vector and hub vector of the IEEE 9-bus system can be obtained, which are shown in formula (22).

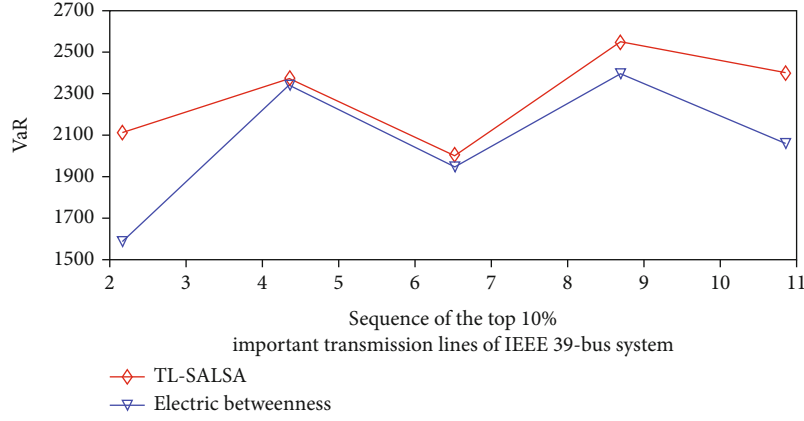


FIGURE 8: VaR relative change of the top 10% important transmission lines in the IEEE 39-bus system screened by electric betweenness algorithm and TL-SALSA algorithm.

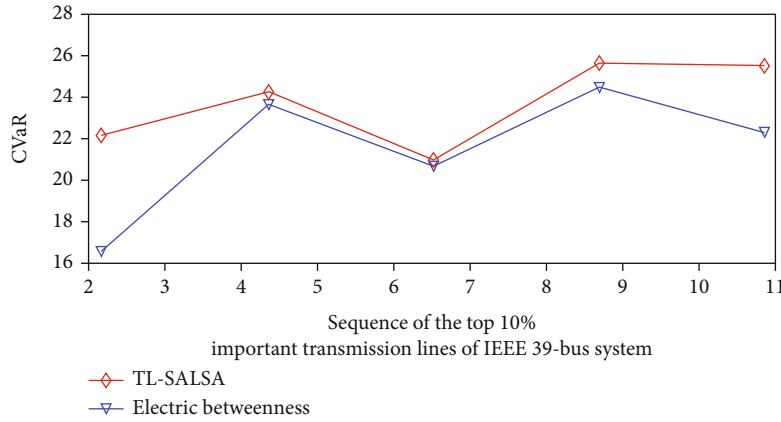


FIGURE 9: CVaR relative change of the top 10% important transmission lines in the IEEE 39-bus system screened by electric betweenness algorithm and TL-SALSA algorithm.

transmission line is. Figure 6 also shows the evaluation result in the IEEE 9-bus system structure graph by different node colors.

$$T = [0.225 \quad 0.313 \quad 0.207 \quad 0.189 \quad 0.231 \quad 0.329 \quad 0.130 \quad 0.277 \quad 0.098]. \quad (24)$$

4. Study Case

In this section, the IEEE 39-bus system and IEEE 118-bus system have been used as the environment to demonstrate the efficacy and practicality of the TL-SALSA algorithm.

4.1. IEEE 39-Bus System. There are 39 buses and 46 transmission lines in the IEEE 39-bus system [30]. The topological structure of the IEEE 39-bus system is displayed in Figure 7. Table 3 shows the top 10% important transmission lines (5 lines) screened by algorithm and the TL-SALSA algorithm.

Figure 8 illustrates the IEEE 39-bus system’s VaR score top 10% important transmission lines calculated by the electric betweenness algorithm and the TL-SALSA algorithm,

respectively. In Figure 8, the VaR indexes corresponding with important transmission lines screened by the electric betweenness algorithm are lower than the ones screened by the TL-SALSA algorithm. It means that the top 10% important transmission lines screened by the TL-SALSA algorithm has excellent possibilities of causing more extensive loss failures than the electric betweenness algorithm screened 10% of important transmission lines. Figure 9 shows a comparison between the electric betweenness algorithm and the TL-SALSA algorithm in the CVaR index. Without exception, all the positions are the electric betweenness algorithm lower than the TL-SALSA algorithm in Figure 9. According to the CVaR index definition, the result shown in Figure 9 demonstrates that the top 10% important transmission lines screened by the TL-SALSA algorithm are more likely to cause extreme failures. Hence, in the VaR index and the CVaR index, the TL-SALSA algorithm has better validity and accurate performance in the IEEE 39-bus system.

4.2. IEEE 118-Bus System. The IEEE 118-bus system has 118 buses and 186 transmission lines [30]. The topological structure of the IEEE 118-bus system is exhibited in Figure 10. The consequences of the top 5% important transmission

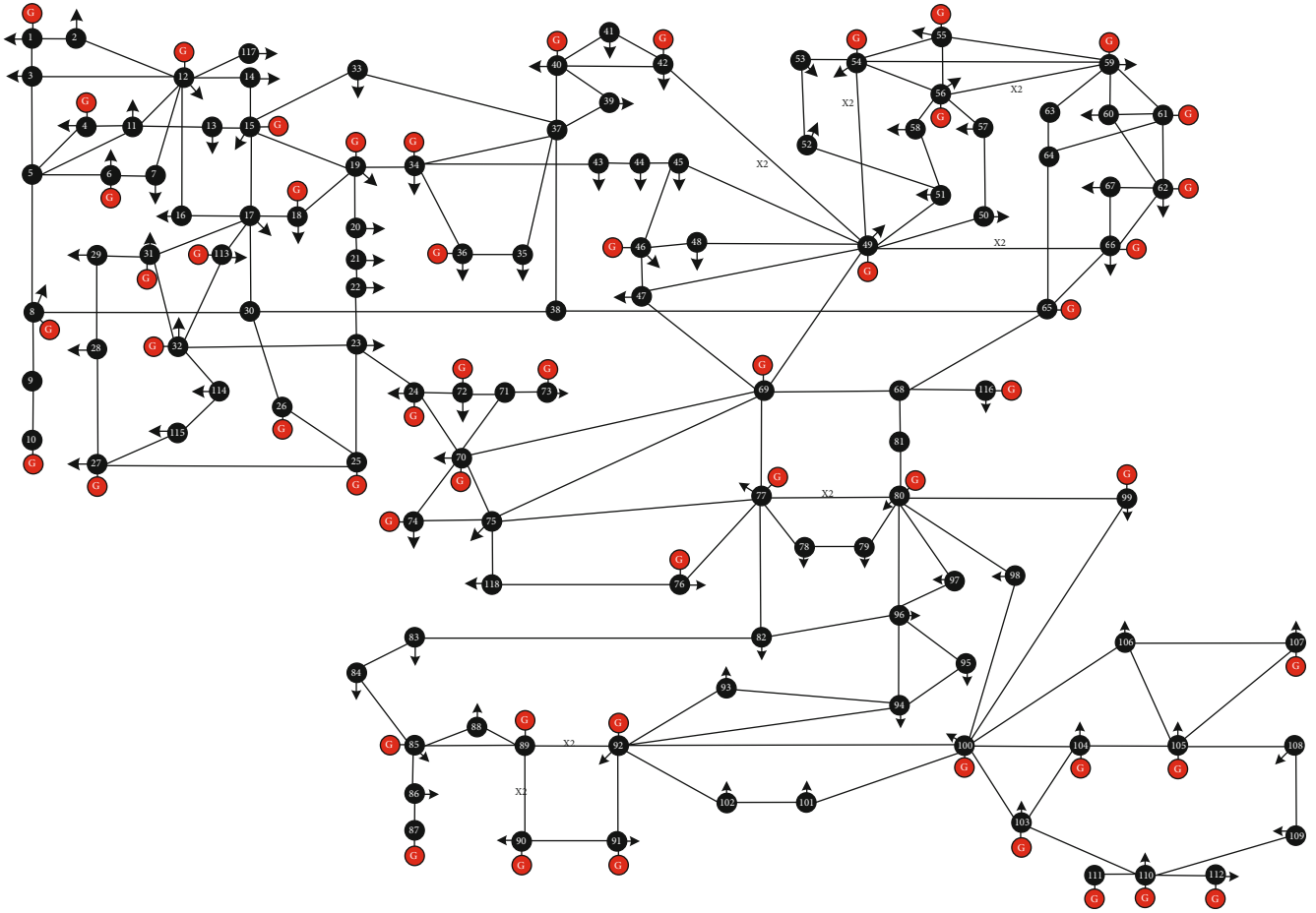


FIGURE 10: IEEE 118-bus system.

TABLE 4: The top 10% important transmission lines of the IEEE 118-bus system screened by the electric betweenness algorithm and the TL-SALSA algorithm.

Ranking	Electric betweenness	TL-SALSA
1	Bus 65-bus 68	Bus 5-bus 8
2	Bus 80-bus 81	Bus 9-bus 10
3	Bus 38-bus 65	Bus 8-bus 9
4	Bus 30-bus 38	Bus 13-bus 15
5	Bus 68-bus 81	Bus 37-bus 38
6	Bus 8-bus 30	Bus 38-bus 65
7	Bus 8-bus 9	Bus 49-bus 66
8	Bus 65-bus 66	Bus 49-bus 66A
9	Bus 23-bus 24	Bus 17-bus 30

lines (9 lines) in the IEEE 118-bus system screened by the electric betweenness algorithm and the TL-SALSA algorithm are depicted in Table 4.

Figure 11 shows the relative VaR score change of the 5% important transmission lines screened by the electric betweenness algorithm and the TL-SALSA algorithm, respectively. In Figure 11, there are 8 positions that the TL-SALSA algorithm has higher VaR score than the Electric betweenness and only the sixth position where VaR score of the TL-SALSA algorithm is lower than the Electric betweenness algorithm. At the same

time, Figure 12 shows the CVaR score of the IEEE 118-bus system top 5% important transmission lines calculated by the electric betweenness algorithm and the TL-SALSA algorithm. The tendency of results is similar to the VaR consequences shown in Figure 11. In Figure 12, there are 8 positions that the TL-SALSA algorithm have a higher CVaR score than the electric betweenness algorithm and only the sixth position that the TL-SALSA algorithm CVaR score lower than the electric betweenness algorithm CVaR score. This is because the TL-SALSA algorithm comprehensively considers the influence of

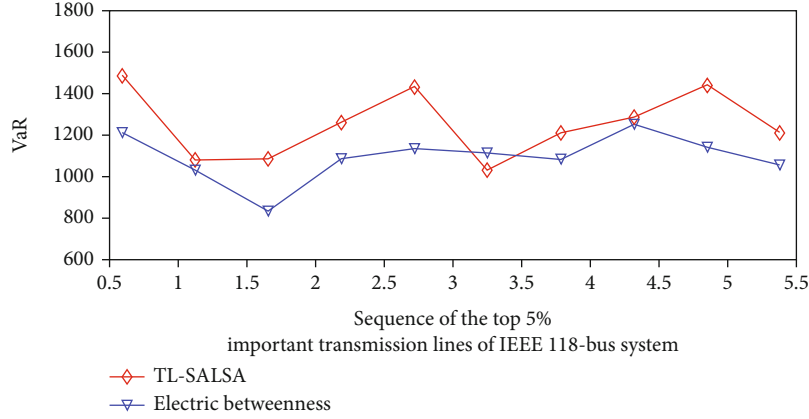


FIGURE 11: VaR relative change of the top 5% important transmission lines in the IEEE 118-bus system screened by the electric betweenness algorithm and TL-SALSA algorithm.

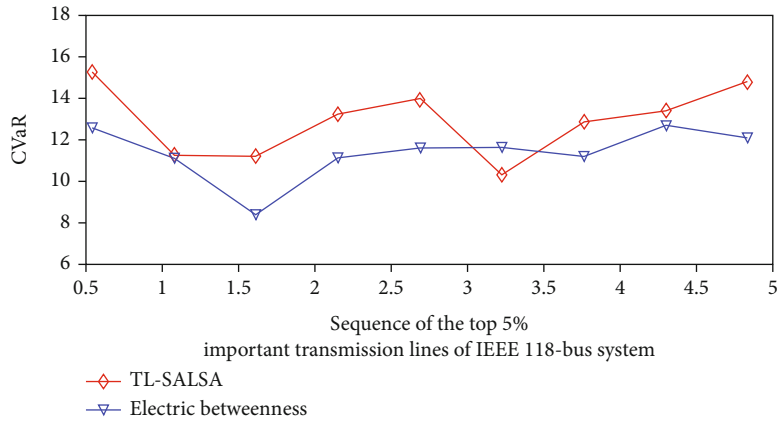


FIGURE 12: CVaR relative change of the top 5% important transmission lines in the IEEE 118-bus system screened by electric betweenness algorithm and TL-SALSA algorithm.

both the topological structure and the current variation value. On the one side, the transmission line bus 38-bus 65 induces a rocket rise (more than 200%) in the current of 20 transmission lines when calculating the N-1 check on the transmission line bus 38-bus 65. The more transmission lines influenced by the target transmission line, the more significant the target transmission line was playing in the cascading failure transport chains. On the other side, 2 transmission lines can cause the current of the transmission line, bus 3-bus 65 to have a rocket rise of more than 200% when calculating the N-1 check on the 2 transmission lines. The more transmission lines can seriously influence the target transmission line, the more significant the target transmission line is playing in the cascading failure transport chains. However, corresponding to the transmission line bus 38-bus 65, the numbers of the transmission line bus 8-bus 30 are 8 and 3. Due to the VaR index and the CVaR index calculated in terms of loss of load, the two indexes relatively leave out of consideration influence range in the failures' topological structure. Above all, a conclusion can be drawn that the TL-SALSA algorithm is more effective than the electric betweenness algorithm.

4.3. *Computation Complexity.* The consequences of the electric betweenness algorithm are related to the load, which is

variable with time. The calculation of both the PageRank algorithm and the TL-SALSA algorithm relies on the N-1 check. Furthermore, the N-1 check is also related to the load. The time complexity of electric betweenness algorithm and the TL-SALSA algorithm are $O(n^4)$ and $O(n)$, respectively. Hence, the TL-SALSA algorithm is more appropriate for screening important transmission lines in real-time screening.

5. Conclusion

Based on the complex network theory, this paper proposes the TL-SALSA algorithm for screening important transmission lines in an electrical power system by combining Internet thinking and physical characteristics of the electrical power system. In the TL-SALSA algorithm, it has the advantage of lower computational complexity because it adopts the core calculation process of the SALSA algorithm based on the Markov chain. The calculation process of the authority score and hub score of TL-SALSA depends on two independent Markov chains, which further ensures the screening accuracy. Then, this paper designs the N-1 check adjacency matrix of the TL-SALSA algorithm to reflect the relation among transmission lines. To better screen important transmission lines, the iterative process and power flow influence

have been devised in the TL-SALSA algorithm, reflecting the electrical power system topology structure and electrical power system operation mode, respectively. In the case study, the results show that the TL-SALSA algorithm can screen out the important transmission lines more accurately and effectively and verify the effectiveness and practicability of the algorithm. Another advantage of the TL-SALSA algorithm is its lower computation complexity characteristic, which is beneficial to real-time screening of important transmission lines.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Acknowledgments

This work is supported by the National Natural Science Foundation of China (no. 51907109).

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