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## Social impact based contingency screening and ranking

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**Abstract:** This paper develops a new index to rank the contingencies in different partitioned areas of networks. The new index considers the social and economic impacts of the contingencies and ranks them by using an overall index that combines these effects with technical factors. This overall index is implemented in the Western Systems Coordinating Council (WSCC) system. Load flow is run in different scenarios; and real power losses, Available Transmission Capability (ATC), and Expected Socially Unserved Energy (ESUE) are compared.

**Keywords:** contingency screening and ranking; public perception; index of social and economic factors; expected socially unserved energy.

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## 1 Introduction

The objective of contingency ranking is to determine critical contingencies from a large list of contingencies and rank them according to their severity. When there are a large number of contingencies, ranking contingencies effectively and accurately is difficult. Traditionally, limitations are associated with the problems of thermal loading and transient stability. Voltage instability has become the limiting constraint for many power systems.

The majority of papers attempt to use voltage stability margin as the index; in addition, they attempt to save the margin calculation time. First-order sensitivity analysis using the Traditional Power Flow (TPF) is a popular choice in contingency analysis (Kang and Meliopoulos, 2002). Tellegen's theorem has also been used to compute the first-order sensitivity based on adjoint network solutions. Chiang *et al.* (1997; 1998) discussed the issue of voltage security related with contingencies. Ejebe *et al.* (1996) uses two operating conditions to estimate the margin. Besides the voltage stability margin there are some other methods used to form an index for ranking. Barquin *et al.* (1995) uses structural indices derived from system models for contingency ranking. A novel framework for extending conventional probabilistic reliability analysis to account for system stability limits was developed in Momoh *et al.* (1999).<sup>1</sup>

In this paper a new index considering the social and economic impacts of contingencies beyond<sup>1</sup> (Momoh *et al.*, 1999) is introduced and implemented. The main difference in this method involves the integration of economic conditions and the incorporation of a measure of public perception ( $U_i$ ) into the model. A suitable threshold value will be used to isolate those contingencies that should be considered in the outage scenario. The value will be selected according to the numerical test results obtained for different systems.

This method does not require substantial load flow calculation, and can rank the contingencies selected based upon technical, economic and social factors. Therefore, it can be viewed as a comprehensive index. Moreover, our ranking of contingencies may be used for long-run decisions to improve the efficiency of the system.

Similar works by Orecchini *et al.* (2000) and Mili *et al.* (2004) have considered socio-economic influences. Orecchini *et al.* (2000) attempt to integrate technological and environmental factors ('human' and 'natural') in order to determine the best energy supply system solution. In measuring social and cultural factors, they used an interview process. Mili *et al.* (2004) proposes a risk analysis model of catastrophic failures incorporating socio-economic and technological factors. Specifically, they seek to calibrate social and economic impact of Hurricane Isabel-induced cascading electricity failures on Washington, DC metropolitan area.

The organisation of the paper is as follows. Section 2 presents an overview of contingency screening and ranking methods in power systems. Section 3 contains a discussion of a new contingency screening and ranking index based on social and economic factors. Section 4 estimates the indices to evaluate the selected contingencies. In Section 5, this method is applied to sample power systems and Section 6 concludes the paper.

## 2 Traditional methods of contingency screening and ranking

### 2.1 Indices based on coherency

The coherency is the measure of closeness of all generator rotor angles after fault clearing. Obviously stable cases are much closer to the Centre of Inertia (CI) than unstable cases. The index is defined from the concept of coherency and formed as following (Li and Bose, 1997):

$$I1 = \max(\max \theta_i(t) - \min \theta_i(t)) \quad i = 1, 2, \dots, NG \quad t_{cl} \leq t \leq t_{cl} + T \quad (1)$$

where:

- $\theta$  = the generator rotor angle relative to the centre of inertia
- $NG$  = the total number of generators
- $t_{cl}$  = the fault clearance time
- $T$  = the length of short period after fault clearing.

### 2.2 Indices based on transient energy conversion

Transient stability is a measure of whether generators in the system lose synchronism or not after the fault is cleared. The transient kinetic energy added to the system due to a fault contributes to the separation of the system. If the system has enough potential energy capability, then the excess kinetic energy injected into the system can be 'absorbed', and the system will not lose synchronism, but will reach a new stable equilibrium point. The index is defined from the concept of energy conversion and formed as following (Fouad and Vittal, 1992):

$$I2 = \max(|V_{ke}(t)| - |V_{pe}(t)|) \quad t_{cl} \leq t \leq t_{cl} + T \quad (2)$$

where:

- $V_{ke}$  = the transient kinetic energy
- $V_{pe}$  = the transient potential energy
- $t_{cl}$  = the fault clearance time
- $T$  = the length of short period after fault clearing.

We have pursued the early swing transient instability of generators in this paper. This is because we are interested in dynamics of generator changes for long-run decision-making. Voltage stability (over-voltage and under-voltage) is equally important methods of contingency screening and ranking. We cover these in some of our previous work (see Momoh *et al.*, 1999). In this paper, we focus on the indices that are instrumental to dynamic stability evaluation.

### 2.3 Indices based on dot products

A dot product is defined for detecting the exit point in the transient energy function method. The exit point is characterised by the first maximum of transient potential energy with respect to the post-fault network. It is computed by the dot product of the fault-on power mismatch vector and the fault-on speed vector as in the following equation (Fu and Bose, 1999):

$$dot1 = f \bullet \omega = \sum_{i=1}^{NG} f_i \omega_i \quad (3)$$

$$f_i = P_{mi} - P_{ei} - \frac{M_i}{M_t} \sum_{j=1}^{NG} (P_{mj} - P_{ej}) \quad (4)$$

where:

- $M_i$  = the inertia constant of each generator
- $M_t$  = the total inertia constant of all generator
- $P_{mi}$  = the mechanical power input for each generator
- $P_{ei}$  = the electrical power output for each generator
- $\omega_i$  = the rotor speed with respect to CI.

The dot product can give the measure of total accelerating power and the power system response to this accelerating power; therefore it could be an index for ranking dynamic contingencies.

Because the vector of rotor angle is also a significant measure besides the vector of rotor speed and accelerating power, there are two other dot products:

$$dot2 = f \bullet \theta = \sum_{i=1}^{NG} f_i \theta_i \quad (5)$$

$$dot3 = \omega \bullet \theta = \sum_{i=1}^{NG} \omega_i (\theta_i - \theta_i^{cl}) \quad (6)$$

where:

- $\theta_i$  = the rotor angles with respect to CI
- $\theta_i^{cl}$  = is the angle at fault clearing time for generator  $i$ .

So, there are three indices defined from the concept of these three dot products respectively, and they are formed as following:

$$I3 = \max dot1(t) - \min dot1(t) \quad (7)$$

$$I4 = \max dot2(t) - \min dot2(t) \quad (8)$$

$$I5 = \max dot3(t) - \min dot3(t) \quad t_{cl} \leq t \leq t_{cl} + T \quad (9)$$

where:

- $t_{cl}$  = the fault clearance time
- $T$  = the length of short period after fault clearing.

Traditional contingency screening and ranking methods need to do a load flow study and create a list according to the severity. However, while traditional screening includes technical factors, it ignores economic and social factors.

### 3 A new contingency screening and ranking index based on social and economic factors

For the systems under study, we have selected key cities for which we create an index of the level of dissatisfaction based both on the population and the social and economic conditions in the city.

#### 3.1 The index and its components

We need to rank contingencies in order to determine the severity of outages, which lead to cascading outages, voltage collapse, system instability, uncontrolled separation, *etc.* The state of economic and social conditions in a city will have a decided impact upon the public level of acceptance. Therefore, the level of public acceptance should be included in any system of ranking for contingencies. Clearly, local economic and social conditions assist in gauging the intensity of the effect of an outage on the public.

The design of our index for screening contingency is aimed at improving currently used automatic contingency screening techniques, which do not include social and economic factors. The overarching goal is to have a contingency indicator that captures social and economic factors as discussed in our paper.

In this paper we use two key variables to measure these conditions.

First, the state of the economy in a city measured by the average wage relative to the average wage of cities in the area is used as a proxy for productivity and economic loss during the outage. A higher average wage relative to the average wage in the system is used to reflect higher demand for power

Second, in order to introduce public perception to our model, we have created an index of economic and social factors. We will use this index to capture the socio-economic effect of an outage. The components of our index include the unemployment (*Unem*) rate in the city, the inverse of the city's bond rating ( $1/Bondrating$ ), a measure of social strife in the city (*SocialStrife*), and the crime rate in the city (*Crime*). We postulate that the higher the unemployment rates in the city, the greater the level of social dissatisfaction. Bond rating is used as a measure of the financial strength of the city. The lower the bond rating, the less is the ability of the city to provide local public goods and services. This, therefore, will have an impact on the level of social dissatisfaction and further worsen the impact of the outage. Social strife measures the degree of racial segregation of the city. If the minority population with less energy usage or income were evenly distributed across the city, the social strife measure would be zero. Therefore the higher the social strife index, the higher the level of dissatisfaction. Our final component in our index is the crime rate in the city. The higher the crime rate, the higher the dissatisfaction and the worse the social impact of the outage.

We believe that the four components of our index capture the major social and economic factors because they are either determined or correlated by a number of other variables. For example, bond ratings are determined by numerous financial and political conditions of a city, including, tax revenues, fiscal solvency of the city government, tax base, and political factors, *etc.* Thus, bond rating represents an excellent measure of the local government's ability to deal with a crisis. Unemployment rate is a measure of economic conditions and is highly correlated with poverty, levels of education, and general economic outlook of the area. The Social Strife factor attempts to capture the

level of trust between the local government and different population segments. It is highly correlated with the geographical isolation of lower income and minority populations in the city.

Crime rate is a strong measure of increasing fear and anxiety in the local area due to the expectation and possible realisation of looting, robberies and murders. In sum, our index provides a summary measure of the level of social dissatisfaction. Our four components capture and summarise the major social and economic factors.

In order to make a single summary index of the four variables for the 21 major cities in the area, we standardised each of them by dividing their mean values by their standard deviations. The composite index is then constructed as the geometric mean of all four variables.

The new index is used to rank contingencies for further security assessment. In this manner, the most critical contingencies can be identified. For comparison of contingencies, the factors of thermal limits, economic condition of the area, and the public perception are taken into account and normalised.

Our factors are developed as follows. Temperature affects power consumption; therefore the contingencies under the condition of different temperatures are ranked individually. The factor of temperature is constructed as follows:

$$f_{ti} = \frac{1 - e^{-kHC}}{1 - e^{-kHC}} \quad (10)$$

where:

- $k$  = the normalisation coefficient
- $f_{ti}$  = the factor of thermal limit for contingency  $i$
- HC = the heating and cooling degree days.

The factor of Average Wage Level of the city in the area is related to demand. If Average Wage Level is higher in a particular city than usual, as measured by Average Wage Level of the city divided by Average Wage Level of the cities in the area, the contingency should be more serious than otherwise, assuming the capacity of flow can match the demand requirements. This factor can be stated as follows:

$$R_i = \frac{AW_i}{AW} \quad (11)$$

$$f_{Ri} = \frac{1 - e^{-kR_i}}{1 + e^{-kR_i}} \quad (12)$$

where:

- $R_i$  = measure of the deviation from normal economic activity in city  $i$
- $AW_i$  = the Average Wage Level in the city  $i$
- $AW$  = the Average Wage Level of the cities in the area
- $f_{Ri}$  = the factor of demand or level of economic activity.

The factor  $I_i$ , the index of economic and social factors in city  $i$ , is used to create  $U_i$ , our measure of the level of dissatisfaction as follows:

$$U_i = Pop_i * e^{I_i} \quad (13)$$

$$I_i = \sqrt[4]{\frac{Unem_i}{\sigma_{unem}} \times \frac{1}{\frac{Bondrating_i}{\sigma_{Bondrating}}} \times \frac{SocialStrife_i}{\sigma_{socialstrife}} \times \frac{Crime_i}{\sigma_{crime}}} \quad (14)$$

$$f_{Ui} = \frac{1 - e^{-kU_i}}{1 + e^{-kU_i}} \quad (15)$$

where:

$U_i$  = or our public perception concept measures the level of dissatisfaction at the time of the outage occurrence in the city  $i$

$Pop_i$  = the population in the city  $i$

$I_i$  = the index of economic and social factors in the city  $i$

$Unem_i$  = the level of unemployment in the city  $i$  affected

$Bondrating_i$  = measure of the economic condition of the city  $i$  government

$SocialStrife_i$  = measure racial isolation in the city  $i$

$Crime_i$  = measure of crime rate in the city  $i$

$\sigma_{unem}$ ,

$\sigma_{bondrating}$ , = the standard deviations of unemployment, bond rating, social strife, and

$\sigma_{socialstrife}$ , crime for 21 cities in the area, respectively.

and  $\sigma_{crime}$

### 3.2 Limitations of our analysis

Due to the lack of micro data at the contingency level, the economic data could not be systematically matched to each contingency. In our analysis, each contingency was therefore matched with data from randomly selected cities. In future research, micro data will be developed at the contingency level.

## 4 Indices of contingency analysis impacts

After contingency selection and ranking, we use power loss on transmission lines, Available Transmission Capability (ATC), and Expected Socially Unserved Energy (ESUE) to evaluate the contingencies.

### 4.1 Estimate using ATC

According to the North American Electric Reliability Council (NERC) definition, ATC is a measure of the transfer capability remaining in the physical transmission network for future commercial activity over and above already committed uses. The ATC is the viable increase in real power transfer from one point to another in a power system. It is a useful index of power transfer margin. The ATC is limited by thermal limits of transmission lines and transformers, voltage stability analysis for voltage limits, and transient stability analysis for stability limits. ATC can be expressed as  $ATC = TTC - TRM - CBM - ETC$ , where TTC is the total transfer capability, TRM is the transmission reliability margin, CBM is the capacity benefit margin, and ETC is the existing transmission commitments.

The steps for determining the ATC are as follows:

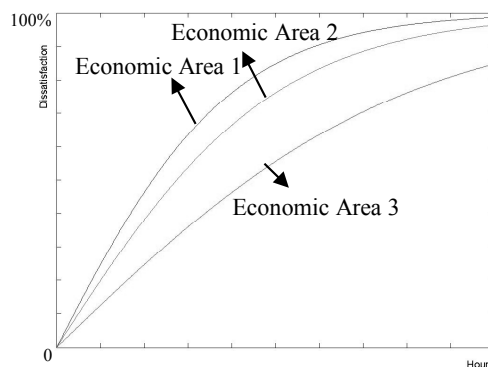
- 1 Establish and solve the base case power flow for the time period.
- 2 Select a transfer case.
- 3 Use Continuous Power Flow (CPF) to make a step increase in transfer power.
- 4 Establish a power flow problem consisting of the base case modified by the cumulative increases in transfer power from Step 3. Solve the power flow problem and check the solution for violations of operational physical limits.
- 5 If there are violations, decrease the transfer power to the minimum amount necessary to eliminate them.
- 6 Compute the ATC from the interface flows in the adjusted solution.
- 7 Return to Step 2 for the next transfer case.

#### 4.2 Estimate using ESUE and real power loss

In order to evaluate the economic and social effects of an outage, we create an index,  $Y_i$ , our normalised dissatisfaction function, Equation (16). We use this index to create the measure of ESUE of an area. In addition, the real power loss on the transmission line can be derived from the power flow calculation. ESUE is obtained based on the notion of its utilitarian effect on the consumer. Social and economic factors explained above are used to simulate ESUE. It measures consumers' forbearance of the impact of Expected Unserved Energy (EUE). Hence, contingencies selected based on these economic and social factors would be used to calibrate ESUE rather than vice versa.

The dynamic nature of  $Y_i$  is depicted in Figure 1. As observed in Figure 1, dissatisfaction curves differ from one city to another. For example, Area 3 consumers in Figure 1 have a lower negative sensitivity to power outage than Area 1 and Area 2.

**Figure 1** The dissatisfaction function



Equation (16) shows the dissatisfaction of the selected city, and Equation (17) is the ESUE of the selected city.

$$Y_i = \frac{1 - e^{-kt \cdot e^i}}{1 + e^{-kt \cdot e^i}} \quad (16)$$

$$ESUE_i = S_i \times \left(1 + \int_0^t Y_i dt\right) \quad (17)$$

where:

$Y_i$  = the measure of normalised dissatisfaction as measured in Equation (16) and consequently integrated over time. Given that areas differ in terms of their economic and social factors, the impact of outages across service areas would differ over time.

$t$  = the outage duration time

$S_i$  = the load level of area  $i$  which is determined by exogenous (weather) and endogenous (social and economic) factors

$ESUE_i$  = the expected socially unserved energy of area  $i$ .

Figure 1 depicts the dynamic nature of the normalised dissatisfaction function; it indicates that with an outage, dissatisfaction in Area 1 grows more rapidly with duration than that of other Areas.

Real power loss is a basic computation in power systems, and it can be presented as following:

$$P_{loss} = P_0 - P_G + P_D \quad (18)$$

where:

$P_{loss}$  = the total real power loss of the system

$P_0$  = the injected power at the slack buss

$P_G$  = the generated power of the system

$P_D$  = the power demand of the system.

The impacts of contingencies can be evaluated by the combination of the indices defined above.

### 4.3 Overall performance estimation

In order to capture technical and non-technical aspects of the impact of contingencies, we develop an overall performance index. This index is created by weighting the line loss ( $P_{loss}$ ), the ATC and ESUE associated with the expected contingency. The higher the level of overall performance index ( $F$ ), the greater the value of the contingency is. The overall performance index is:

$$F_i = w_1 P_{loss_i} - w_2 ATC_i + w_3 ESUE_i \quad (19)$$

where:

$F_i$  = the overall performance index of contingency  $i$

$P_{loss_i}$  = the line loss due to expected contingency  $i$

$ATC_i$  = the ATC value due to expected contingency  $i$

$ESUE_i$  = the expected socially unserved energy value due to expected contingency  $i$

$w_1, w_2,$   
and  $w_3$  = the weights for the indices respectively.

To choose the best weights, we calculate the weights of each area using linear programming, and choose the one that make the sum of  $F$  for the total system minimum.

$$\text{Min} \sum_{i \in C_j} F_i \tag{20}$$

$C_j$  = the contingency set of area  $j$

s.t.  $Ploss_i w_1 - ATC_i w_2 + ESUE_i w_3 = F_i$

$$w_1 + w_2 + w_3 = 1$$

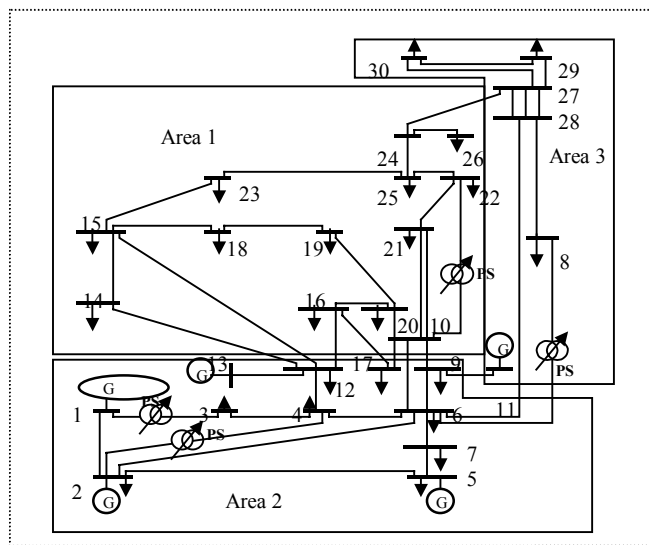
$$w_1, w_2, w_3 > 0$$

Here  $w_1, w_2$ , and  $w_3$  are variables.  $Ploss$ ,  $ATC$ , and  $ESUE$  are computed for each area by using Equations (16)–(18).

### 5 Simulation

In this section, we will select the most urgent contingencies using the index. Figure 2 is the modified IEEE 30-bus test system, and there are 41 branches, five generators, four phase shifters and 37 switches.

**Figure 2** Modified IEEE 30-bus test system



From different areas, expected contingencies are selected. In Area 1, lines 15–18, 10–21, and 12–14 are outages. In Area 2, lines 1–3, 6–7, and 2–6 are outages. In Area 3, lines 27–29, 8–28, and 6–8 are outages.

The modified IEEE 30-bus system is given with the following new assumptions:

	<i>Abnormal days</i>	<i>R<sub>i</sub></i>	<i>Population (Million)</i>	<i>Sensitivity</i>	<i>Load level (p.u.)</i>
Area 1	>200	>1.2 and <0.8	<0.5	<0.3	<1
Area 2	>100 and <200	>1.2	>3	>0.3 and <0.7	>1.8
Area 3	<100	<0.8	>0.5 and <3	>0.7	>1 and <1.8

In accordance with the above assumptions, the contingency factors for different areas are shown in Table 1. The last value in Table 1 is the weighted sum of the factors. Here we assume all the weights are the same. The values of temperature, average wage level, and the measure of dissatisfaction are presented by  $f_t$ ,  $f_R$ , and  $f_U$ , respectively.

**Table 1** The factors of contingencies

	<i>Contingency</i>	$f_t$	$f_R$	$f_U$	<i>Weighted sum</i>
Area 1	15–18	0.0649	0.0050	0.0719	0.1418
	10–21	0.0500	0.0100	0.1076	0.1676
	12–14	0.0549	0.0100	0.0790	0.1439
Area 2	1–3	0.0500	0.0300	0.1955	0.2755
	6–7	0.0350	0.0200	0.2041	0.2591
	2–6	0.0400	0.0200	0.2127	0.2727
Area 3	27–29	0.0400	0.0050	0.1253	0.1703
	8–28	0.0450	0.0060	0.1150	0.1660
	6–8	0.0500	0.0075	0.1357	0.1932

From Table 1, we can rank the contingencies in the same areas. In this analysis, the higher the sum of the factors is, the more valuable the contingency.

After calculating the factors and ranking the contingencies, load flow is done under the prioritised contingencies. The weights we use in Equation (19) are determined by using Equation (20). The weights and the overall performance index,  $F$ , are presented in Table 2.

**Table 2** The comparison of weights and  $F$

	$w_1$	$w_2$	$w_3$	$F$
Area 1	0.6533	0.2467	0.1000	75.6187
Area 2	0.1000	0.6490	0.2510	-104.5715
Area 3	0.6529	0.2471	0.1000	75.2168

From Table 2, the weights of Area 2 were chosen as the optimal weights since they minimise the sum of the  $F_i$ s. Therefore, these weights are chosen as the optimum weights to be used in Equation (19).

The real power losses, ATCs, and ESUEs of expected contingencies are shown in Table 3.

**Table 3** Results comparison

	<i>Contingency</i>	<i>Ploss(MW)</i>	<i>ATC(MW)</i>	<i>ESUE(MW)</i>	<i>F(MW)</i>
Area 1	15–18	17.7668	134.8845	216.7620	–31.3561
	10–21	18.0279	92.6068	219.7230	–0.1486
	12–14	17.8831	93.3864	243.3270	2.2556
Area 2	1–3	27.4012	70.0000	206.8950	9.2408
	6–7	19.3532	85.1320	212.3550	0.0142
	2–6	20.3738	81.9170	204.9840	0.3242
Area 3	27–29	18.0411	91.4413	124.7040	–6.2406
	8–28	17.6549	93.6677	116.1840	–9.8627
	6–8	18.6311	86.5466	113.6880	–5.7699

The  $F$  of expected contingency 1–3 is largest, which means this contingency has the most technical and non-technical impact on the system when real power loss, ATC, and ESUE are utilised as indices to evaluate the expected contingencies.

Western Systems Coordinating Council (WSCC) system has 179 buses and 263 branches. It is divided into four areas and shown in Figure 3. We select three critical contingencies from each area.

The factors are calculated and shown in Table 4.

**Table 4** The factors of contingencies

	<i>Contingency</i>	$f_i$	$f_R$	$f_U$	<i>Weighted sum</i>
Area 1	78–80	0.3104	0.0593	0.0378	0.4075
	74–78	0.2811	0.0534	0.034	0.3685
	75–78	0.4391	0.0563	0.0397	0.5351
Area 2	89–90	0.365	0.0455	0.0329	0.4434
	117–119	0.2367	0.0598	0.0387	0.3352
	100–101	0.3065	0.0527	0.036	0.3952
Area 3	50–57	0.1714	0.0491	0.0299	0.2504
	48–62	0.2456	0.0535	0.0472	0.3463
	150–154	0.2503	0.0519	0.0138	0.316
Area 4	163–164	0.3258	0.0542	0.0391	0.4191
	14–24	0.3516	0.0457	0.0193	0.4166
	158–166	0.2616	0.0377	0.0372	0.3365

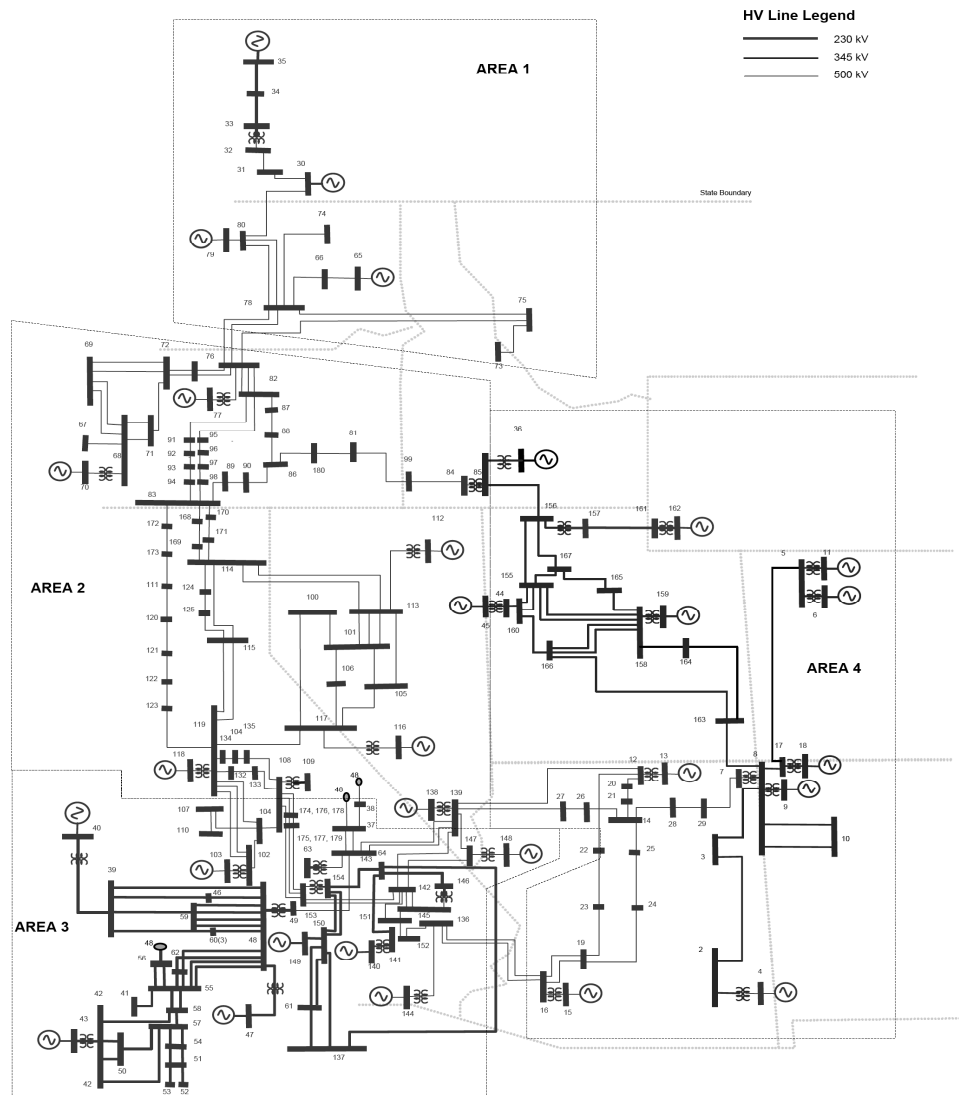
Equation (20) is used to decide the weights. The weights are shown by areas in Table 5.

**Table 5** The comparison of weights and  $F$

	$w_1$	$w_2$	$w_3$	$F$
Area 1	0.1000	0.8000	0.1000	2935.6
Area 2	0.1000	0.7372	0.1628	3311.3
Area 3	0.1103	0.7897	0.1000	2990.5
Area 4	0.1015	0.7985	0.1000	2943.6

From Table 5, the weights of Area 3 make the value of  $F$  in all areas minimum, so they are chosen to be the weights defined in Equation (19).

**Figure 3** WSCC 179-bus system



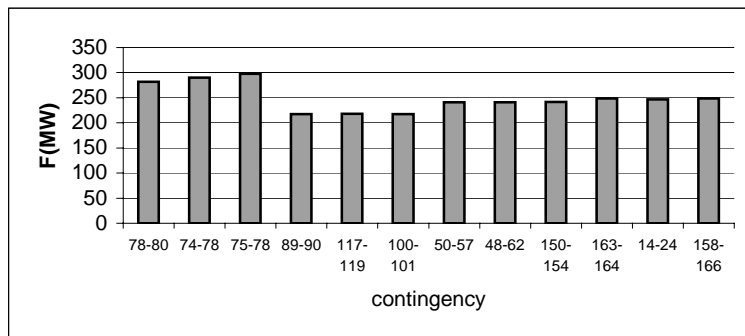
Then the load flow study is done for different contingencies. The results are shown in Table 6.

**Table 6** Results comparison

	Contingency	Ploss(MW)	ATC(MW)	ESUE(MW)	F(WM)
Area 1	78–80	584.26	152.2794	971.1413	281.8131
	74–78	574.92	152.1777	1065.7	290.1584
	75–78	734.90	140.0000	1062.8	297.8975
Area 2	89–90	619.98	144.4758	351.9477	217.6711
	117–119	577.39	152.5410	336.0680	217.7545
	100–101	575.77	152.1341	338.4985	217.4976
Area 3	50–57	574.80	152.4247	569.9281	240.7630
	48–62	575.81	152.4102	573.4181	241.2120
	150–154	574.49	151.9307	580.9348	241.4394
Area 4	163–164	581.98	148.9807	668.8720	248.7297
	14–24	584.83	152.1486	621.5715	246.8156
	158–166	578.39	152.4102	646.0154	248.7563

Figure 4 illustrates the impacts of contingencies on overall performance index ( $F_i$ ). In this case, both technical and non-technical impacts are concerned by using the overall performance index ( $F_i$ ). The expected contingency 75–78 is much more critical than other expected contingency. Expected contingency 74–78 and 78–80 are also more critical but less critical than 74–78.

**Figure 4** Contingency selection versus overall system impacts ( $F_i$ )



## 6 Conclusion

A new index for ranking contingencies is developed in this paper. It incorporates social and economic factors and can be used to rank any set of expected contingencies. The uniqueness of our approach stems from the inclusion of specific social and economic measures such as unemployment rate, social strife and crime as well as the economic

conditions of the affected area. This method allows decision-makers to readily grasp the most important contingencies. Our test results on sample power systems demonstrate the implementation of our method. The factors used to construct the index are by no means exhaustive. Other factors could be employed in constructing a similar index for ranking and evaluating the contingencies.

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### **Note**

- 1 Framework for Stochastic Reliability of Bulk Power System with Stability Constraints, EPRI, Palo Alto, CA, and Bonneville Power Administration, Vancouver, WA: 2004. 1009506

## Appendix

The data for calculating the factors are shown in Table 1. The data come from Bureau of Census.

**Table 1** Economic and social data of selected cities

<i>Area</i>	<i>Unemployment rate (%)</i>	<i>Bond rating-codes</i>	<i>Social strife index</i>	<i>Crime index</i>	<i>City population</i>	<i>Heating + cooling days</i>	<i>Average wage (\$)</i>
Area 1	8.3	7	0.079435	7 137.50	247 057	4406	28 585
	2.3	8	0.011539	2 943.90	894 943	2284	76 252
	2.8	7.5	0.184851	5 725.10	776 733	2284	59 288
	4.2	9	0.096714	9 164.70	563 374	6419	45 344
	3	8	0.197834	5 256.00	554 636	7118	41 401
Area 2	6.1	7.5	0.269894	4 588.70	3,694 820	5014	39 671
	3.2	7.5	0.022562	8 992.40	486 699	6103	29 194
	4.1	7	0.118689	5 184.90	478 434	7927	31 647
	5	7	0.095004	4 152.20	461 522	2114	37 546
	3.1	7.5	0.014593	9 766.10	448 607	5571	30 409
Area 3	12.9	7	0.088182	7 137.50	427 652	2971	25 916
	5.2	7.5	0.099828	6 610.80	407 018	6032	36 595
	3	7	0.095004	4 003.60	1,223 400	3463	37 546
	2.2	7	0.014593	6 168.20	396 375	11298	34 925
	3.2	7.5	0.056715	5 189.80	360 890	2998	33 039
Area 4	4.6	7	0.003114	3 597.20	337 977	5014	39 671
	2.9	8	0.050979	7 720.20	1 321 045	11298	34 925
	2.9	7.5	0.95004	3 373.90	328 014	5014	39 671
	2.2	7.5	0.056715	5 646.70	276 393	7118	41 401
	5.4	7	0.065191	4 385.70	255 166	3463	29 552