Evaluation of Human Error Probabilities of Power Grid Dispatchers Based on Hybrid Risk Analysis Method

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Abstract. In the power system, the dispatcher's inappropriate execution commands often have great impact on the safe operation and might lead to accidents. In order to further study the risk mechanism of human factors and calculate the human error probability (HEP), this paper proposes a hybrid risk analysis method called SD-SPAR (a System Dynamic Model for the Standardized Plant Analysis Risk (SPAR) Method), which combines the SPAR Human Reliability Analysis method with the System Dynamic (SD) approach to initialize a framework to model dynamic relationships between the Performance Shaping Factors (PSFs) and HEP. First of all, to reduce the uncertainty of grade division for the PSF stress and make the result of HEP more accurate, a physiological factor measurement method was adopted to calculate the dispatcher workload and help to divide the stress quantitatively. Second, based on the SD-SPAR method, the path dependence between the PSFs were summarized to reveal their influence on HEP and successful performance. Third, by analyzing the causality and feedback mechanism of the internal factors, the reasons accounting for incidents can be found to help analysts have a deeper understanding about the incidents, and to move forward improvement strategies to decrease the human error risk so as to achieve better task performance. This study can also be used to form the basis for the simulation of various control scenarios. It can help to explore better solutions to prevent and correct human error behaviors, and guarantee the safe operation of the power system.

1. Introduction
To a large extent, safety operation conditions benefit from increasingly reliable automation technologies, however, the complexity and the lack of transparency of the system put forward higher requirements for the control personnel of the complex system represented by the grid dispatcher. According to statistics, about 75% of accidents in power dispatching operations were caused by human factors [1]. In addition to the power dispatching, human error has been considered as a critical factor in the incidents and accidents in other complex systems, such as nuclear power and civil aviation[2]. Human error risk identification methods were widely studied in complex systems and the analysis of human error accidents provided useful information for system diagnosis. The system's human error reduction and prediction method (SHERPA) was developed for the nuclear reprocessing industry and was defined as a classification method to identify potential errors related to human activities [2]. A human error template method (HET) was raised for the civil flight deck to detect human error incidents [3]. The hazard and operation ability study (HAZOP) method was originally...
developed by ICI for the safety of power plant or operation [4, 5]. The cognitive reliability and error analysis method (CREAM) was identified as a human reliability analysis method, which can be used to predict potential human errors and analyze errors [6]. Based on the "Swiss Cheese" accident cause model of accident causation, the human factor analysis and classification system (HFACS) was developed to investigate and analyze human error in the aviation industry [7,8]. In this paper, a hybrid risk analysis method (SD-SPAR) was proposed to evaluate the human error probability and causation for the dispatcher’s poor execution behaviors, thus, to provide recovery strategies for the power grid system.

1.1 SPAR-H HRA Method
The Standardized Plant Analysis Risk (SPAR) human reliability analysis (HRA) method is a simplified HRA approach intended to be used in conjunction with the development of SPAR probabilistic risk assessment (PRA) models, and it is also a sufficient HRA tool for SPAR model used in risk analysis of operating events and conditions [9]. It had been used by analysts of the Nuclear Regulatory Commission to carry out their risk notification supervision activities. SPAR-H model combines stimulus-response and information processing methods, and names tasks in different stages of information processing as "diagnosis" and "action". HRA analysts need to be able to consider all aspects of diagnosis and action, as well as the potential for dispatchers to successfully perform operations that are usually identified by the program.

1.2 System Dynamics Model
The System Dynamics model is a methodology to recognize and solve the system problems by analyzing the information feedback, dealing with the dynamic structure and feedback mechanism between the qualitative and quantitative factors of the complex system, to obtain the overall cognition and problem solving of the system [10]. In order to help analysts to understand the dependency and dynamic relationship in the power grid system, the SD-SPAR system dynamics model was constructed to analyze the direct and indirect effects on the causality between HEP and PSFs.

1.3 Objective of the paper
In this paper, The SPAR-H HRA method was applied to analyze the human factors in the power grid dispatching system, which mainly includes two parts: identifying the nominal human error probability and modifying the human error probability on the basis of summarizing PSFs and dependence. The process of HRA implementation was divided into identification, modeling (representation) and quantification of HEP, while, uncertainty problem remained existing in the representation of PSFs divide level. To solve this problem, this paper adopted the physiological factors measurement method to work out the work load value to identify the stress quantitative level. Besides, the internal mechanism and dynamic relationships between PSFs and HEP were studied by the system dynamics model (SD-SPAR) to understand the causation of poor human performance and incidents. In summary, this paper provided a systemic and creative view for power dispatch human error risk analysts to put forward human performance recovery strategies and promoted the development and research of human factors in the field of power grid system.

2. PSFs in SPAR-H Method

2.1 PSF definitions
SPAR-H method uses PSF information in the calculation of HEP. Generally speaking, PSF analysis improves the authenticity of HRA analysis, and the scope of PSF analysis should be specific enough to determine the potential impact on relevant execution behaviors. To ensure the coverage of SPAR-H method is as considerable as possible, eight PSFs are included: available time, stress/stressors, complexity, experience /training, procedure, ergonomics/HMI, fitness for duty and work process, the descriptions and principles for grading them are shown in Table 1.
• Available time: the time required by the dispatcher or crew to diagnose and handle abnormal events.
• Stress/Stressors: undesirable conditions and conditions that prevent the dispatcher from completing the task easily. Stress can include mental stress, excessive work load, or physical stress.
• Complexity: the difficulty of task execution in a given context. Complexity takes into account the tasks to be performed and the environment.
• Experience /training: the experience and training of dispatchers participating in tasks.
• Procedures: the formal operation program currently existed and used by the task.
• Ergonomics/HMI: equipment, display and control, layout, quality and quantity information provided by the instrument, as well as the interaction between dispatchers/crew members and equipment to perform tasks.
• Fitness for Duty: whether the person performing the task is physically and mentally fit to perform the task at that time.
• Work process: all aspects of work, including inter-organization, safety culture, work plan, communication, management support and policy.

Table 1. Evaluate each PSF for diagnosis/action.

| PSFs             | PSF Levels                      | Multiplier |
|------------------|---------------------------------|------------|
| Available Time   | Inadequate time                 | \( P(\text{failure})=1.0 \) |
|                  | Time available                  | 10         |
|                  | Nominal time                    | 1          |
|                  | Time available \( \geq 5 \times \) | 0.1        |
|                  | \( \text{time required} \)     | 0.01       |
| Stress/ Stressors| Extreme                         | 5          |
|                  | High                            | 2          |
|                  | Nominal                         | 1          |
| Complexity       | Highly complex                  | 5          |
|                  | Moderately complex              | 2          |
|                  | Nominal                         | 1          |
|                  | Obvious diagnosis               | 0.1        |
| Experience/ Training | Low                   | 10(D),3(A) |
|                  | Nominal                         | 1          |
|                  | High                            | 0.5        |
| Procedures       | Not available                   | 50         |
|                  | Incomplete                      | 20         |
|                  | Available, but poor             | 5          |
|                  | Nominal                         | 1          |
|                  | Diagnostic/symptom-oriented     | 0.5(D)     |
| Ergonomics/ HMI  | Missing/Misleading              | 50         |
|                  | Poor                            | 10         |
|                  | Nominal                         | 1          |
|                  | Good                            | 0.5        |
| Fitness for Duty | Unfit                           | \( P(\text{failure})=1.0 \) |
|                  | Degraded Fitness                | 5          |
|                  | Nominal                         | 1          |
| Work Processes   | Poor                            | 2(D),5(A)  |
|                  | Nominal                         | 1          |
|                  | Good                            | 0.8(D),0.5(A) |

D means diagnosis task
A means action task
2.2 Applications of multiple PSFs

When calculating the human error rate of a task, if the number of negative PSFs involved (≥ 3) is directly multiplied, the calculation result of HEP may be more than 1. Therefore, the adjustment factor is introduced into the calculation process, and the formula is shown as follows:

\[
HEP = \frac{NHEP \cdot PSF_{\text{composite}}}{NHEP \cdot (PSF_{\text{composite}} - 1) + 1}
\]  

(1)

Where the \(NHEP\) is the nominal \(HEP\) and it equals 0.01 for diagnosis and equals 0.001 for action. The \(PSF_{\text{composite}}\) equals the result of involved PSFs multiplication.

Considering the authenticity and reliability of the research, this study took the actual grid dispatching task as an example: in the grid dispatching task, the main transformer fault trip was a complex and difficult task, which was mainly manifested in the diagnosis and action of two task types. It was necessary to analyze the PSF and its level division in the two types of work respectively for calculation, and then added up to get the final HEP.

In the process of diagnosis, PSF such as available time (AT), stress/stressors (SS), complexity (C), experience/training (ET), ergonomics/HMI (HMI), procedures (P) were involved. Combined with the dispatcher’s situation and the real operation conditions, each PSF was rated, and the HEP value was calculated by the above formula. The assignment of the PSF levels and associated multipliers are shown in Table 2:

**Table 2. PSF level assignment for the diagnosis process**

| PSF  | Status    | Multipliers |
|------|-----------|-------------|
| AT   | Nominal time | 1           |
| SS   | Extreme    | 5           |
| C    | High       | 5           |
| ET   | Nominal    | 1           |
| EH   | Nominal    | 1           |
| P    | Incomplete | 20          |

PSF composite score = \[1\times5\times5\times1\times20 = 500.\]  

(2)

HEP for diagnosis = \[\frac{0.01\times500}{(0.01\times(500-1) + 1)} = 0.83.\]  

(3)

In the process of action, it was necessary to send the conversion process command of diagnosis results to the site staff, mainly involving work process (WP), Training (T), available time (AT). Each PSF should be classified and calculated according to the actual implementation, the assignment results are as shown in Table 3.

**Table 3. PSF level assignment for the action process**

| PSF  | Status    | Multipliers |
|------|-----------|-------------|
| WP   | Good      | 0.8         |
| T    | Nominal   | 1           |
| AT   | Time available | 0.1       |

Since the number of passive PSFs involved was less than 3, direct phase multiplication could be used to calculate HEP.

HEP for action = \[0.8\times1\times0.1 = 0.08.\]  

(4)

To sum up, the probability of human error that might occur when performing the fault trip task of the whole main transformer was:

HEP = 0.83 + 0.08 = 0.91.  

(5)

This result indicated that the probability of human error was very high, while the classification of PSF was just based on the expression of the rating table to determine the rating value that lead to existing uncertainty. In addition, the mutual uncertainty between PSFs could affect the result of HEP.
In this example, for some objective PSF, such as: available time (AT) can be determined by calculating the given time, experience/training (ET) level value could be judged according to the dispatcher's knowledge and working years of power grid dispatching, ergonomics / HMI (HMI) level value could be obtained from the interaction of the field operation interface, and complexity value could be obtained through the calculation and action of the difficulty of the task. However, the stress/stressors was identified as a personal subjective feeling, it was impossible to determine the PSF level value through the description, which existed great uncertainty. Therefore, it was necessary to introduce objective and measurable variables that were directly related to the stress to correct the stress level value, so as to make the result of HEP more accurate.

2.3 Work load improves stress rating

The manifestation of stress is mental pressure, excessive work load or physical pressure. The common methods of stress measurement include skin electrical response (GSR), heart rate (HR), blood volume pulse (BVP), etc[9]. This paper adopted the physiological factors measurement method to measure the factors of heart rate, voice and action volume to calculate the comprehensive work load of dispatchers from the two aspects: physiology and psychology[11], and mapped the work load value to the stress grade. The data source was divided into the following parts: the voice acquisition equipment obtained the audio information, the wearable heart rate meter measured the heart rate, and the video monitor obtained the exercise volume. Relevant data sources are shown in Figure 1.

![Figure 1. Physiological measurement data sources](image)

![Figure 2. Results of overall workload](image)

According to the data consistency processing and PCA method, the collected data was calculated, and the calculation formula of the work load was obtained as follows:

\[
W = 0.6902M + 0.1637H + 0.1379S
\]

Among them, \(W\) means the calculation of work load, \(M\) represents the amount of exercise, \(H\) represents the heart rate, and \(S\) represents the entropy of speech.

Data collection and calculation were carried out for the whole process of dispatcher operation task, and the work load results are as shown in Figure 2.

It can be seen from Figure 2 that the average work load value of the dispatcher was 6 in the diagnosis period, while it was 3 in the action period. In this method, the value range of work load was \([0,10]\), and the value range of stress was \([0,5]\), so the grade of stress in the diagnosis period could be obtained by the mapping equation as follows:

\[
\text{Stress} = \frac{\text{Workload}}{2}
\]
Therefore, the actual stress level calculated by workload was 3, and the calculation of HEP for diagnosis above should be adjusted:

\[
\text{PSF composite score} = 1 \times 3 \times 5 \times 1 \times 1 \times 20 = 300
\]

\[
\text{HEP for diagnosis} = \frac{0.01 \times 300}{(0.01 \times (300-1) + 1)} = 0.75
\]  

Compared with the previous calculation result, the HEP had adjusted from 0.83 to 0.75 and the accuracy had improved by 10%. The physiological measurement method was regarded as an efficient way to evaluate the grade of PSF stress and provided analysts a more accurate result to analyze the dispatcher’s execution behaviors.

3. SD-SPAR Model

Dependence among these PSFs could make the SPAR-H method calculate HEPs either too conservative or too optimistic. For example, when reviewing the deleterious effects of PSFs upon performance, correlated factors will make the resulting HEP more conservative than is the case. Conversely, when reviewing HEPs where strongly positive PSFs are present, the final HEP may be overly reduced. To solve the correlation problem and help prevent the analysts from being affected by repeated calculation when allocating the PSF threshold in HEP quantification, the correlation dependence degree among eight PSFs were analyzed, as Figure 3 shows.

![Figure 3. Path diagram showing PSF relationships](image)

![Figure 4. SD-SPAR model](image)

In Figure 3, the red line indicates a strong correlation between two PSFs, the blue line indicates a medium correlation between two PSFs, double arrows mean that two PSFs interact with each other. From the figure, the medium-high relationship between PSFs and the direct and indirect impact on HEP can be obtained, and a few significant conclusions have been drawn.

First, the relationship between the two PSFs can be one-way. It means PSF$_i$ may influence PSF$_j$ strongly, whereas PSF$_j$ can have little or no influence on PSF$_i$. For example, complexity has a strong effect on available time to diagnosis, while, available time to diagnosis has no impact on complexity, which is often the result of the multiple calculations or movements. Second, some PSFs keep an inverse relationship. It means PSF$_i$ increase, while PSF$_j$ decrease. For example, stress decrease, whereas fitness for duty may have a better condition. Third, some relationships among PSFs can be bidirectional, they can influence each other. For example, complexity increase can upgrade the difficulty of the task and then stress increased. Conversely, when stress increased means many problems needed to be deal with, so the complexity of the task increased.

Figure 4 illustrates the causal relationship between PSFs and HEP in the SD-SPAR model. Reinforcement feedback identified as R is a strengthening process that can produce its movement. In this process, the consequences are caused by the movement and the action will be transmitted so that the original trend will be strengthened. Balance feedback identified as B, which tries to reduce the deviation of the system state from the target state (or balanced state), so the balance feedback loop can also be called negative loop or self-tuning loop.

- Loop R1 (Work Pressure (Work Load → Stress → Fitness for Duty → HEP → Task Result → Work) → Work Load)
Load), which reflects that higher work load leads to higher stress, thus negatively affects personal work status, increasing human error probability, and causing horrible task result. Therefore, reasonable work load can improve the performance of tasks.

- **Loop B1** Effect of incident learning (Complexity→Stress→Fitness for Duty→HEP→Incident→Incident Learning→Complexity). After analyzing and learning from the incident, it can help the dispatcher find a more effective way to deal with the task, so as to reduce the complexity of the task operation, thereby reducing HEP and affecting incidents [12]. It is the most important loop in this model and can help the analyst find improvement strategies and solutions to reduce the HEP.

- **Loop B2** Effect of Work Process (Work Process→Complexity→Stress→Work Process) shows that the more detailed the safety culture and work plan within the department and the closer the communication between dispatchers, the less complex the task will be, thus the stress of dispatchers can be decreased so as to obtain well work performance.

- **Loop B3** Time Control (Work Process→Procedures→Available Time to Diagnosis→Stress→Work Process), when dispatcher has adequate time to diagnosis, he will be in a good work condition and have more opportunities to analyze the problems and find a better way to execute the task. So the time control is very important for human performance, thus the department should arrange the appropriate work intensity and schedule reasonably to create a safer work condition.

All above mentioned loops reflect the internal relationship between PSFs in the system and their influence on HEP from reinforcement feedback and balance feedback respectively. Through detailed analysis of the causal relationship in the loop, it provides a systemic and clear theoretical support for the power grid dispatching analysts to construct a deeper understanding of human error risk.

### 4. Conclusion

In this study, the hybrid risk analysis method SD-SPAR was established to evaluate the dynamic relationship and feedback mechanism between PSFs and HEP. It adopted the system dynamics approach to analyze the shaping scenario of the power grid dispatcher’s HEP in the relevant operation tasks.

The main results of this study are as follows: (1) The physiological factors measurement method was used to map and express the degree of stress by calculating work load value, to effectively solve the uncertainty problems in stress quantitative process. (2) Base on the establishment of the SD-SPAR method, the internal dependencies and dynamic relationships between PSFs were analyzed to reveal the impact on HEP and successful human performance. (3) The causes account for incidents could be found by analyzing the causality and feedback mechanism of the internal factors in the reinforcement feedback and the balance feedback. In this means, more practical and reliable solutions could be proposed to reduce the probability of human error.

Importantly, the SD-SPAR model can be used as the basis for other actual scenario simulations. Further researches are needed to reduce and improve the situation of human error in the process of task execution, and a series of effective solutions can be proposed to ensure the safe operation of the power grid.

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