Web Based Online Real-time Information System for Reliability of Electrical Energy Supply including WTG

Jaeseok Choi †, Jeongje Park *, Taegon Oh *, Kyeonghee Cho *, Joydeep Mitra ** and Mohammad Shahidehpour ***

Abstract – Web based online real-time reliability integrated information system is asked rapidly for more efficiency and demand response in recent. As the utilization of renewable resources has been receiving considerable attention in recent years, the information system requirement is increased. Specially, the reliability information system is more important for implementing the smart grid. This paper describes architecture of the WORRIS( Web Based Online Real-time Reliability Integrated Information System) Version 1.0 system developed preliminarily in this study. It is originally a reliability information system based one day go ahead system.

Keywords: Web Based Online Real-time Integrated Information System, Smart grid, Renewable energy, Reliability, CO2

1. Introduction

Web Based Online Real-time Reliability Integrated Information System is asked rapidly for more efficiency and demand response in recent. In last years, free-market capitalism is a global reality. Countries and various industries are restructuring. Liberalization has resulted in new utility structures with attendant problems of operating the power system. This function is called as system operation by its traditional name. But, it is recognized that it has to be carried out in a modified way to fit the exigencies of the liberalized market. This need has created the concept of a System Operator (SO), an entity not owning any generation, charged with the responsibility of maintaining quality and reliability of electric power service[1-3]. In order to supply information about the quality, reliability and security of electric service, some trial to adapt or modify traditional operation planning and real-time control functions and a redesign of control system hardware and software architectures has been tried[1-3]. Specially, the utilization of renewable resources has been receiving considerable attention in recent years. Furthermore, this system is more important for implementing the smart grid.

Fig. 1 shows a general architecture of Web-based support systems (WSS) [5]. A (thin) client/server structure, as shown in Figure 1, is one of possible structures for WSS [4].

Users, including decision makers and information seekers, are clients on the top layer. They access the system with browsers via the Web. The interface that is designed on the server side will be presented on the clients' side by browsers 24 hours a day, 7 days a week. The lower layers and components encapsulated by the oval dotted line are very similar to conventional computerized support systems. In other words, a Web-based support system is a support system with the Web as the interface. Various kinds of networks such as the Internet, intranet and extranet will play an important role in the WSS infrastructure. Web browsers are intermediates to access a WSS. WSS are fully accessible, open, and dynamic systems. We have to make sure the information is fully and friendly delivered to different types of users. There is intensive interactive human involvement. Interface design is another key issue of

This paper describes a Web Based Online Real-time Reliability Integrated Information System, which is called as WORRIS Version 1.0 system developed in this study. This is prototype and reliability evaluation of power system including WTG. It is possible not only to supply the information about reliability indices of power system but also estimation of CO2 emission at one day go ahead.

WSS design [5][6].

Fig. 2 shows an eventual purpose concept diagram in relationship with the WORRIS and demand response. The purpose of WORRIS yields the chance for customer to choose the electrical energy resource under environment of variety kind of resources in future.

3. Reliability Evaluation of Power Systems Including WTG

The paper is to supply the web based online real time reliability information of power systems including WTG as shown in Fig. 3. Thus, the probabilistic production energy can be calculated through reliability indices and reduction of production cost and CO2 emission can be obtained by inserting renewable energy(WTG) to the power systems. To evaluate the reliability of power systems, the power output of WTG should be modeled. Fig. 4 presents the relationship between the power output of a WTG and wind speed.

The outage capacity pdf of the WTG can be obtained by combining the WTG’s power output model and the wind speed pdf model as shown in Fig. 5. This yields a multi-state model because the wind speed is distributed widely. The probabilities of identical power are cumulated. Therefore, the state number is different from the wind speed band number. In this paper, the reliability indices for systems including WTG are evaluated using the multi-state model for the WTG and the two-state model for the conventional generators.

![Fig. 3. Wind included generation system model.](image)

![Fig. 4. The relationship between the wind speed model and the WTG power output model.](image)
3.1 Reliability Evaluation

Probabilistic reliability indices have been used extensively for generation expansion planning. The indices can be calculated by using the Effective Load Duration Curve (ELDC referred to in the following as \( \Phi \)), (1) as given in [7].

\[
\Phi_i = \Phi_{i,0} \otimes f_{x,i} \\
= \left(1 - \sum_{j=1}^{\Phi_{i,0}} q_{ij} \Phi_{x,ij}(x) + \sum_{j=1}^{\Phi_{i,0}} q_{ij} \Phi_{x,ij}(x-C_j) \right)
\]

(1)

where,

- \( \otimes \): The convolution integral operator
- \( \Phi_{i,0} \): Original inverted load duration curve (ILDC)
- \( x \): Random variable of \( \Phi \)
- \( N_S \): The total number of states
- \( f_{x,i} \): The outage capacity pdf of generator \( i \)
- \( q_{ij} \): Forced outage rate (FOR) of generator \( i \) at state \( j \)
- \( C_j \): Outage capacity of generator \( i \) at state \( j \)

LOLE (hours/year) (2)

\[
LOLE = \Phi_{NG}(x)|_{x=L_P}
\]

EENS (MWh/year) (3)

\[
EENS = \int L_P^{IC} \Phi_{NG}(x)dx
\]

EIR (pu) (4)

\[
EIR = 1 - \frac{EENS}{ED}
\]

\[
\Delta E_i = EENS_{i+1} - EENS_i
\]

\[
\Delta PC_i = \lambda_a \times \Delta E_i + \lambda_b \times (1 - \sum_i^{FOR}) \times LOLE_{i+1}
\]

\[
CF_i = \Delta E_i \times \frac{CAP_i}{T} \times 100
\]

\[
TCE_i = \Delta E_i \times CE_i
\]

where,

- \( L_P \): Peak load [MW]
- \( IC_i \): Installed capacity of generator \( i \) [MW]
- \( ED \): Total demand energy [MWh]
- \( NG \): The total generator number
- \( \Phi_{NG} \): The final effective load duration curve
- \( \lambda_a \): Incremental cost coefficient
- \( \lambda_b \): Cost constant
- \( CE_i \): Total CO2 Emission of \( i \)th generator

The basic reliability evaluation indices, namely the Loss of Load Expectation (LOLE), the Expected Energy Not Supplied (EENS), the Energy Index of Reliability (EIR) can be calculated using the effective load duration curve, \( \Phi(x) \) by (2)-(4). Form reliability indices, probabilistic production energy \( E_i \), production cost \( PC_i \), capacity factor \( CF_i \) and CO2 Emission \( CE_i \) can be obtained.

4. WORRIS V1.0 Architecture

Fig. 5 shows the overall configuration for the WORRIS V1.0 system developed in this study.

![Fig. 5. A flow chart describing the proposed method.](image)

The configuration is a just research network that is the integration of academic processing with web based online and real-time reliability. It is not unfortunately to connect with EMS in now because this system is only prototype. Therefore, the assumed load data is installed at load data D/B. And also, the generation system is installed at generation system D/B.

5. Case Studies

The developed WORRIS V1.0 is established successfully on website: http://worris.gsnu.ac.kr/PraWin/. It is an opened system and prototype for everybody to contact until 2010. It is applied to Jeju Island power system in South Korea. The
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Jeju Island power system in 2010 year as shown in Fig. 6 is used to demonstrate the usefulness of the proposed method. Three wind farms were assumed at the locations where are Hanlim (HLM), Hangwon (HWN) and Sungsan (SSN) for case study. The data of Jeju island power system are shown in Table I. The actual CO₂ Emission data in 2008 year in Jeju Island and the pattern of load duration curve in 2008 year of Jeju Island were used as shown in Table I and Fig. 7 respectively. The total installed capacity is 890WM and wind turbine generation capacity 100MW added. Peak load in 2010 has been forecasted as 682MW[9]

![Fig. 6. Jeju power system in Korea.](image)

**Table 1. The Generators Data of Jeju Island Power System**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
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<tbody>
<tr>
<td>HWN</td>
<td>WTG</td>
<td>50</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SSN</td>
<td>WTG</td>
<td>30</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HLM</td>
<td>WTG</td>
<td>20</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HVDC</td>
<td>DC</td>
<td>75/150*</td>
<td>1</td>
<td>0.004</td>
<td>1.312</td>
<td>45.207</td>
<td>43.300</td>
<td>0.65</td>
</tr>
<tr>
<td>NMJ1</td>
<td>T/P</td>
<td>100</td>
<td>2</td>
<td>0.004</td>
<td>1.787</td>
<td>43.259</td>
<td>43.300</td>
<td>0.65</td>
</tr>
<tr>
<td>HJU1</td>
<td>T/P</td>
<td>75</td>
<td>2</td>
<td>0.004</td>
<td>1.832</td>
<td>43.223</td>
<td>43.300</td>
<td>0.65</td>
</tr>
<tr>
<td>HLM1</td>
<td>T/P</td>
<td>55</td>
<td>2</td>
<td>0.004</td>
<td>2.407</td>
<td>43.223</td>
<td>43.300</td>
<td>0.70</td>
</tr>
<tr>
<td>HLM2</td>
<td>S/E</td>
<td>30</td>
<td>2</td>
<td>0.004</td>
<td>2.407</td>
<td>43.223</td>
<td>43.300</td>
<td>0.95</td>
</tr>
<tr>
<td>NMJ1</td>
<td>T/P</td>
<td>10</td>
<td>4</td>
<td>0.006</td>
<td>1.999</td>
<td>1.360</td>
<td>43.300</td>
<td>0.62</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>945</td>
<td>21</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

![Fig. 7. Pattern of hourly peak load variation curve in Jeju power system.](image)

The data related to the two wind farms and one solar farm are given in Table II.

**Table 2. The data of each WF**

<table>
<thead>
<tr>
<th>WF Name</th>
<th>HLM-WF</th>
<th>SSN-WF</th>
<th>HWN-WF</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTG capacity</td>
<td>20MW</td>
<td>30MW</td>
<td>50MW</td>
</tr>
<tr>
<td>Cut-in speed(V_{ci})</td>
<td>5m/sec</td>
<td>5m/sec</td>
<td>5m/sec</td>
</tr>
<tr>
<td>Rated speed(V_{R})</td>
<td>14m/sec</td>
<td>15m/sec</td>
<td>16m/sec</td>
</tr>
<tr>
<td>Cut-out speed(V_{co})</td>
<td>25m/sec</td>
<td>25m/sec</td>
<td>25m/sec</td>
</tr>
<tr>
<td>Wind speed range</td>
<td>0–35</td>
<td>0–45</td>
<td>0–45</td>
</tr>
<tr>
<td>Mean wind speed</td>
<td>6.4</td>
<td>8.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>9</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

WORRIS Interface consists of the Project, Generator List, Load Information, Execute and Execute Result panes as shown in Fig. 8. In project pane (pane 1), there are several parameters that are information of model system. The characteristic data of each generator are in generator list pane (pane 2). The load information such as maximum, minimum and average load are in load information pane (pane 3). There are three buttons in execute pane (pane 4). The execute button is to run program. The DRI (Deterministic Reliability Indices) button is to see the results that are total installed capacity, peak load and CO₂ emission as shown in Fig. 9. The PRI (Probabilistic Reliability Indices) button is to see the results that are LOLE (Loss of Load Expectation), EENS (Expected Energy Not Served), EIR (Energy Index of Reliability) and SRR (Supply Reserve Rate) as shown in Fig. 10.

The overall results that are total installed capacity, peak load, LOLE, EENS EIR and SRR are in execute result pane (pane 5) as table.

Fig. 9 and Fig. 10 show the results of WORRIS for Jeju power system.

![Fig. 8. WORRIS’s whole control panel for Jeju power system.](image)
6. Conclusions

This paper describes a Web Based Online Real-time Reliability Integrated Information System, which is called WORRIS Version 1.0. This paper presents preliminary findings and basic architecture from the web based information system in power system. The results show how a web-based monitoring system can form the basis for customers to identify the reliability information of power system including wind turbine generator. But, it is still not perfect real time information system but a reliability information system based one day go ahead system. It is also expected that the proposed method can evaluate the various effects on power system by adding WTG. And it can be helpful that the installation of renewable energy is successful to power system and customer can choose their electrical energy recourse in future.

Acknowledgements

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References

[12] Le-Ren Chang-Chien, Yin-Juin Lin, Chin-Chung Wu,”


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