한국사물인터넷학회논문지 Vol. 6, No. 1, pp. 73-81, 2020 https://doi.org/10.20465/KIOTS.2020.6.1.073

Cloud Computing Based Analysis Incorporated with the Internet of Things (IoT) in Nuclear Safety Assessment for Fukushima Dai-ichi Disaster

Tae-Ho Woo[1], Kyung-Bae Jang[2*]
[1,2]Professor, Dept. of Mechanical and Control Engineering, The Cyber University of Korea

후쿠시마 다이-이치 재해에 대한 원자력 안전 평가에서 사물 인터넷 (IoT)과 통합된 클라우드 컴퓨팅 기반 분석

우태호[1], 장경배[2*]
[1,2]고려사이버대학교 기계제어공학과 교수

Abstract The internet of things (IoT) using cloud computing is applied to nuclear industry in which the nuclear power plant (NPP) accident is analyzed for the safety assessment. The Fukushima NPP accident is modeled for the accident simulations where the earthquake induced plant failure accident is used for analyzing the cloud computing technology. The fast and reasonable treatment in the natural disaster was needed in the case of the Fukushima. The real time safety assessment (RTSA) and the Monte-Carlo real time assessment (MCRTA) are constructed. This cloud computing could give the practicable method to prepare for the future similar accident.

Key Words : Nuclear power plant (NPPs), Cloud computing; Internet of Things (IoT), Reliability, Monte-Carlo simulations

요 약 클라우드 컴퓨팅을 사용하는 사물 인터넷 (IoT)은 원자력 발전소 사고가 안전성 평가를 위해 분석되는 원자력 산업에 적용된다. 후쿠시마 원자력 발전소 사고는 지진으로 인한 플랜트 고장 사고가 클라우드 컴퓨팅 기술 분석에 사용되는 사고 시뮬레이션을 위해 모델링되었습니다. 후쿠시마의 경우 자연 재해에 대한 빠르고 합리적인 치료가 필요했다. 실시간 안전 평가 (RTSA)와 몬테카를로 실시간 평가 (MCRTA)가 구성된다. 이 클라우드 컴퓨팅은 미래의 유사한 사고에 대비할 수있는 실용적인 방법을 제공 할 수 있습니다.

주제어 : 원자력 발전소, 클라우드 컴퓨팅; 사물 인터넷 (IoT), 신뢰성, 몬테카를로 시뮬레이션

1. Introduction

It is proposed that the cloud computing based safety assessment is performed for the modeling of the Fukushima accident where the failure frequency of the event depends on the possibility of the event or Monte-Carlo simulations. The Japanese disaster in 2011 was extremely tremendous damages to the society. Especially, the Fukushima Dai-ichi nuclear power plant (NPP) accident was very serious affects to the nation in the historical aspect. The Richter scale

*교신저자 : 장경배(kbjang60@cuk.edu)
접수일 2019년 12월 7일 수정일 2020년 1월 28일 심사완료일 2020년 1월 31일

of the earthquake was 9.0 which is quite over than the design based scale of 6.5. Although the plant site was not a seismic center, the effects were very high and horrible. As seen in 〈Table 1〉, the frequency with the magnitude of the Fukushima case is very rare [1]. Considering the event scenarios, there were about 50 minutes from the earthquake to the station blackout by tsunami. This period was comparatively long considering the neutron behaviors which could be changed very much just within few seconds. The neutron kinetic energy is a major source of the nuclear power generation. Hence, it is necessary to make the wise transportations of the information in the natural disaster and the guide for treatment in the plant operations. The core had melted after the loss of power supply and the 392 fuel assemblies stored in spent fuel pool at that time [2]. Subsequently, the reactor building was damaged by hydrogen explosion on Mar. 12 and later, it had been reported the building cover was completed on Oct. 28 and the plant achieved a state of cold shutdown on Dec. 16 [2]. Hence, about 9 months were needed to be stabilized, because the quick treatment for the blackout was not done, when the electricity failure stopped the coolant pump operations.

〈Table 1〉 Global frequency of earthquake

Magnitude	Average Annually
7-7.9	15
6-6.9	134
5-5.9	1319
4-4.9	13,000
3-3.9	130,000
2.2.9	1,300,000
8 and higher	1
Total	About 20,000

The cloud computing is applied to prevent the nuclear disaster which was happened in the Fukushima. The information transferring system is done by the cloud computing where the delivery of computing as a service rather than a product, whereby shared resources, software, and information are provided to computers and other devices as a metered service over a network [3]. That is, the information of earthquake is supplied by the cloud computing network instead of the conventional telephone or analog type communications. The speed and user connectivity are very improved and it is accomplished nearly in the base of the real-time. The information is communicated with the operator via the cloud platforms as internet of things (IoT). IoT was coined by Ashton in 1999, which means the networking and things connecting with lots of information [4].

There are some literature reviews in the cloud computing technology. Goscinski and Brock said that the cloud computing was an emerging paradigm where computing resources were offered over the internet as scalable, on-demand (Web) services [5]. While cloud vendors had concentrated their efforts on the improvement of performance, resource consumption and scalability, other cloud characteristics had been neglected. Sultan studied that the educational establishments continued to seek opportunities to rationalize the way they manage their resources [6]. The economic crisis that befell the world following the near collapse of the global financial system and the subsequent bailouts of local banks with billions of tax payers' money would continue to affect educational establishments that were likely to discover that governments would have less money than before to invest in them [6]. In addition, Wang et al. worked that the fault-tolerance is an important research topic in the study of distributed systems where, to counter the influence of faulty components, it was essential to reach a common agreement in the presence of faults before performing certain tasks [7].

The reasonable treatment for the real time action by the information technology (IT) can enhance the reliability of the system. So to speak, the real time safety assessment (RTSA) could be accomplished. Conventional analyses for the safety like the probabilistic safety assessment (PSA) have been performed by the basis of the experience, experiment, and judgment. This new study, however, can give the possibility of the RTSA by the extremely quick data analysis using the relevant IT system. The safety analysis result could be changeable by new data. In this Fukushima case, the tsunami could be expectable by the analysis in the small size computer which is equipped in the tablet PC. This is like the event that we can see the daily zodiac or fortune telling which is usually seen in the general newspaper or computer blog.

Regarding the past papers for RTSA, there are some conceptual approaches. Perryman et al. worked that their paper presented some of the insights obtained in using PRA in such a dynamic role and demonstrates that, by developing and using the plant-specific "living" probabilistic risk assessment (PRA), considerable safety and financial gains can be obtained [8]. Also, Salzano et al. studied the industrial equipment and systems could suffer structural damage when hit by earthquakes, so that accidental scenarios as fire, explosion and dispersion of toxic substances can take place. As a result, overall damage to people, environment and properties increases. The paper dealt with seismic risk analysis of industrial facilities where atmospheric storage tanks (anchored or unanchored to ground), horizontal pressurized tanks, reactors and pumps were installed [9]. In addition, Zhou showed that a set-pair analysis (SPA) based fuzzy assessment method (SPA-fuzzy) is proposed for the real-time risk assessment in this paper [10]. Based on principle of SPA and fuzzy logic theory, the likelihood of accident occurrence and the consequence of the accident can be assessed, and the risk value or risk degree can be evaluated [10].

2. Methods

Nuclear facilities are designed so that earthquakes and other external events will not jeopardize the safety of the plant [11]. The NPPs are designed to withstand an earthquake twice as strong as the 1000-year event calculated for each site in France. It is said that 20% of nuclear reactors in world are operating in areas of significant seismic activity. Therefore, the International Atomic Energy Agency (IAEA) has a Safety Guide on Seismic Risks for Nuclear Power Plants. There are many systems are used in planning, including Probabilistic Seismic Hazard Assessment (PSHA). There is the seismic assessment issue in the NPP [12]. First of all, the licensing bases for existing NPPs should be considered historical data at each site of NPPs. It is made for making the design basis loads from the interested region maximized possible earthquake where an additional margin should be included. Also, the United States Nuclear Regulatory Commission (USNRC) required existing plants to assess their potential vulnerability to earthquake events, including those that might exceed the design basis, as part of the Individual Plant Examination (IPE) of External Events Program [12]. The purpose of the work is to find the available safety margins of existing plants beyond the design basis (Safe Shutdown Earthquake) and to report on certain modifications of identified seismic vulnerabilities. Presently, the NRC performs a risk-informed regulatory approach, including insights from probabilistic assessments and traditional deterministic engineering methods to make regulatory decisions about existing plants where the licensing amendment decisions are included. The NRC licenses will use a probabilistic, performance-based approach to make the plant's seismic hazard and the seismic loads for the plant's design basis. There are requirements of safety-significant structures, systems, and components designed to explain as follows [12];

- Both of normal and accident conditions effects with the natural phenomena are done.
- It has been reported that in the most severe natural phenomena for the site and surrounding area, NRC adds a margin for error to account for the limited historical data accuracy.
- The importance of the safety functions could be performed.

The earthquake information is supplied by the U.S. Geological Survey (USGS). One can use the data for the analysis.

Cloud computing is the delivery of computing as a service rather than a product, whereby shared resources, software, and information are provided to computers and other devices as a metered service over a network (typically the Internet) [3]. The communications are performed as the IoT platforms in which the several clouds are connected each other. Although the information is transferred mechanically, the control processing is done by the operators. There seems to be many definitions of cloud computing around the term [6]. A study by McKinsey found that there are 22 possible separate definitions of cloud computing. In fact, no common standard or definition for cloud computing seems to exist [13,14]. A more commonly used definition describes it as clusters of distributed computers which provide on-demand resources and services over a networked internet [6]. The meaning of the cloud was intuitive by IT concept which imagines the cloud shape to hide the complexity behind them.

〈Table 2〉 Accident sequence of Fukushima NPP Unit 1

Time (Mar. 11)	Time After Earthquake	Time and Event
14:47	0 min.	Earthquake, loss of offsite ac power, and plant trip
14:52	5 min.	Isolation condenser operated to cool reactor
15:03	16 min.	Isolation condenser stopped operating
15:37	50 min.	Tsunami and total loss of ac power–station blackout(SBO), Loss of ability to inject water to the reactor
15:37	50 min.	Water level below top of fuel
~17:00	~133 min.	Partial core damage (several hours after tsunami)
-----	-----	

It is needed to consider the accident scenarios of the Fukushima case for the modeling. There is the event sequence in Mar. 11 of the accident of Unit 1 in 〈Table 2〉 [15]. The NPP system means the boiling water reactor (BWR) which is one of commercial NPP types. The isolation condenser operated to cool the core in 5 minutes. However, this stopped in 16 minutes. This system used the steam exiting the turbine flows into condensers, located below the low pressure turbines, where the steam is cooled and returned to the liquid state by condensation. After that, this condensate should be pumped through feedwater heaters that raise its temperature using extraction steam from various turbine stages. The feedwater entered the reactor pressure vessel by nozzles high on the vessel which is above the top of the nuclear fuel assemblies. So, this could make the serious condition in the plant. As it is seen, the station blackout was done after 50 minutes. During this period, the safety situation was significantly changed. Using the event procedures, one can construct the simple data quantification for event assessment as follows which is called the Monte-Carlo real time assessment (MCRTA);

Step 1 : One can put an event A to data base.
Step 2 : Value of event A is decided by an operator.
Step 3 : Random number is generated.
Step 4 : Comparisons as Random number (generation between 0 and 1) 〈 Value of event A then 1, else 0.

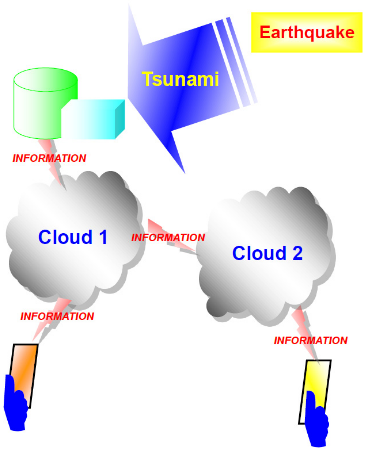
Step 5 : Following proposed event procedures, the data propagations are done.

This is fundamentally based on the conventional event/fault tree. However, the computer program, vensim [16], can be used in the portable PC with simple programming. The fast and simple characteristics of the algorithm are reflected.

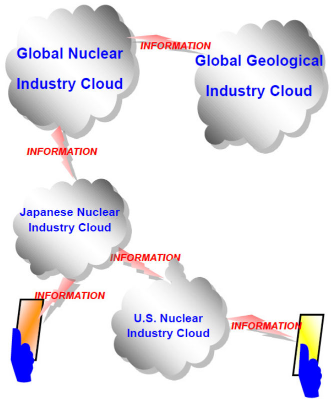
The simulation is performed by Vensim code system which is used for constructing models of business, scientific, environmental, and social systems [5]. This is based on the Monte-Carlo simulation tool with random sampling applications. [Fig. 1] shows the enhanced safety system which is modeled for the NPP. The earthquake and its induced tsunami produce the information which is transferred by the cloud computing platform which has the function of information connection as the IoT role [17]. This is connected to other cloud computing platform. In [Fig. 2], the national nuclear industry cloud computing platform is connected to the other nation's cloud computing platform of related industries. Globally, this platform is connected to the global nuclear industry and the global geological industry cloud computing platforms.

[Fig. 3] shows the diagram for the reliability for the accident in Fukushima NPP Unit 1. This is modeled by the event sequence of the accident on Mar. 11, 2011 [1]. This diagram is made by the Vensim code system where the non-linear event flows are shown. Comparing to the conventional event/fault tree method, the event direction is very freely changed. The feedback line is also shown in the diagram.

〈Table 3〉 shows the basic event likelihood of occurrence based on SECY-93-092 [18]. The values are produced by the expert judgment incorporated with the random numbers in Table 4. For example, in Earthquake of 〈Table 4〉, the generated random number between 0.0 and 1.0 is lower than 0.5, it is 1.0. Otherwise, it is 0.0. The earthquake initiates the accident of the core damage. There are event connections for the Isolation Condenser.



[Fig. 1] Algorithm of cloud computing reliability (CCR) for the nuclear accident



[Fig. 2] Global cloud computing construction

〈Table 3〉 Modified event likelihood of occurrence based on SECY-93-092

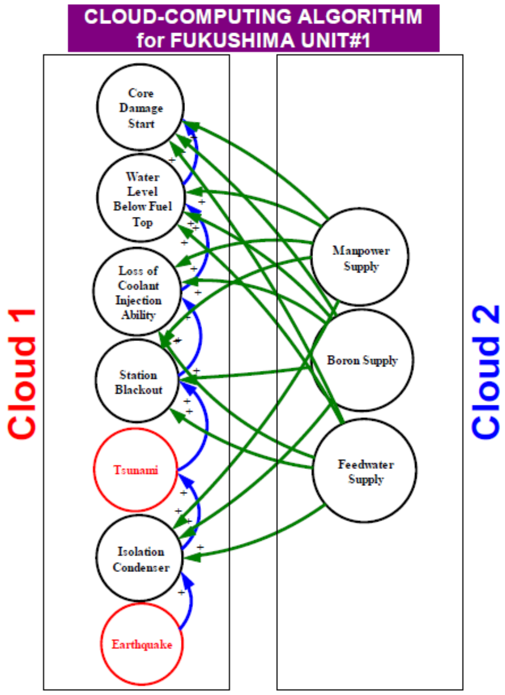
Event	Frequency of Occurrence
Likely events	> 10^{-2} / plant-year
Non-likely events	10^{-2} ~ 10^{-4} / plant-year
Extremely non-likely events	10^{-4} ~ 10^{-6} / plant-year
Very rare events	< 10^{-6} / plant-year

〈Table 4〉 Frequency of occurrence of earthquake

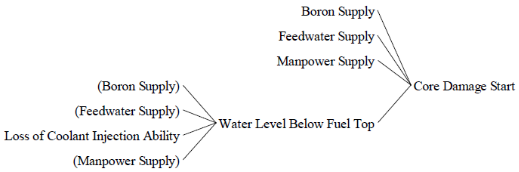
Event	Numeric Value
Earthquake (Richter scale 9.0)	Random number (0, 1) 〈 0.5 then 1, else 0
Isolation Condenser	Random number (0, 1) 〈 0.5 then 1, else 0
Tsunami	Random number (0, 1) 〈 0.2 then 1, else 0
Station Blackout	Random number (0, 1) 〈 0.3 then 1, else 0
Loss of Coolant Injection Ability	Random number (0, 1) 〈 0.3 then 1, else 0
Water Level Below Fuel Top	Random number (0, 1) 〈 0.3 then 1, else 0
Core Damage Start	Random number (0, 1) 〈 0.2 then 1, else 0
Feedwater Supply	Random number (0, 1) 〈 0.1 then 1, else 0
Boron Supply	Random number (0, 1) 〈 0.2 then 1, else 0
Manpower Supply	Random number (0, 1) 〈 0.1 then 1, else 0

3. Results

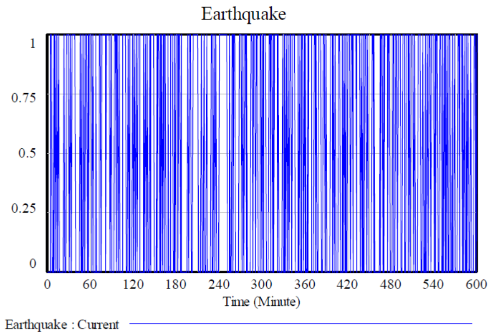
The loops of the connections show how the Isolation Condenser accident for core damage is connected in [Fig. 4]. [Fig. 5] shows the event value of Earthquake where the Boolean values are obtained as 0.0 and 1.0.



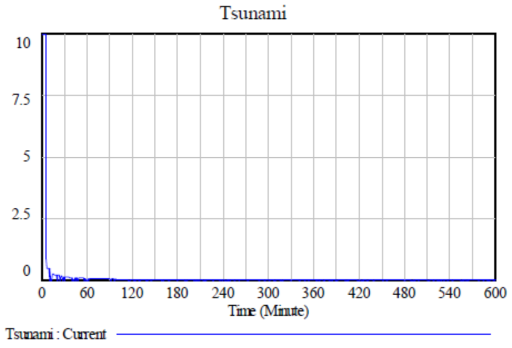
[Fig. 3] Diagram of reliability for Fukushima Unit1



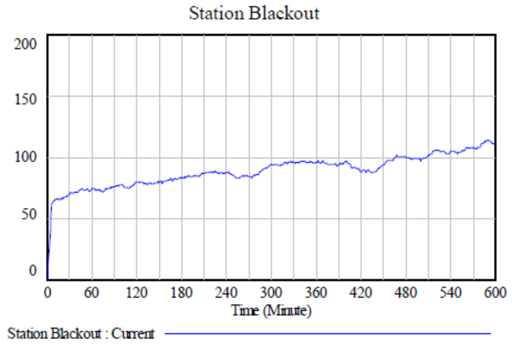
[Fig. 4] Connections of Isolation Condenser accident



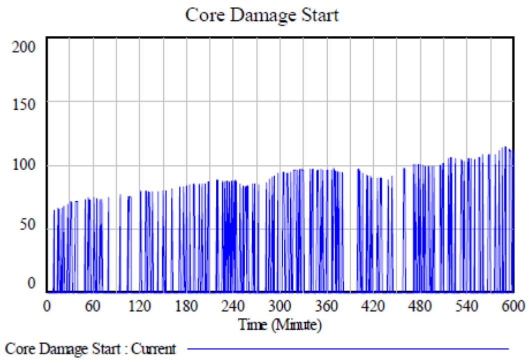
[Fig. 5] Event value of Earthquake



[Fig. 6] Event value of Tsunami



[Fig. 7] Event value of Station Blackout



[Fig. 8] Event value of Core Damage Start case

The event values for the Tsunami is obtained in [Fig. 6] where the highest one is shown in the early stage. Otherwise, the Station Blackout has the trend of the gradual increasing in [Fig. 7]. The event values of the Core Damage Start are shown in [Fig. 8] where the values are oscillated with increasing values during 10 hours. Values are quantified as the relative values. Hence, the quantities are compared each other. The highest value is 111.26 which is extremely highest comparing to the initial value of 0.0. So, the accident possibility is shown as increasing values as the relative values with no dimension. Although the safety system is supplied to the plant, the accident possibility is very high as one can see the truth. This means the tsunami damage is very high in this paper. This means the possibility of the core damage. The higher value is the much more possible in core damage. There are zero and non-zero values. That is the possibility is changed dynamically and non-linearly which is due to the random number generations. It is reasonable to make the oscillating values because the core damage accident is originally prepared in the design stage. However, if the accident happens, this design is proved to be wrong. So, the dynamical oscillating can express the possibility of unexpected cases.

4. Conclusions

The cloud computing incorporated with IoT is applied for the safety assessment using the modeling of the Fukushima accident. The failure frequency of the event depends on the possibility of the event like the probability or Monte-Carlo simulation results. The cloud computing is used with the portable tablet computer which has the very tractable and light weight. The global scale communications enhance the safety level of the NPPs significantly. The human errors would be reduced by the easy communications of the cloud computing, because the experts can connect easily to the cloud computing platform. The cost would be gone down, as the communication system is developed. So, the IT skill can improve the safety as well as the economy in the nuclear industry. In addition, the global communication can make the synergy in the technological convergence [19], because the nuclear engineers can contact to the global geologist. During first 50 minutes in Fukushima accident, the tsunami could be examined by many experts, if the cloud computing was equipped. The station blackout made the nuclear disaster which had affected the national and global disaster by the radioactive fallouts.

If this simple method incorporated with the portable tablet PC were developed before the Fukushima disaster, the precious time before the station blackout could save the plant without the level 7 nuclear accident. Hence, the IT based methodology can enhance the reliability of the NPP system without any expensive investment. Frequently, the civilian telecommunication system is used in the military operations. This is affected by the vast and high quality of the higher generation telecommunication system. The nuclear industry can easily use the civil telecommunication system for the better safety performances.

Following the natural disaster, the applications of the technology have been developed in the human history. It is very good time for us to apply to the nuclear industry using the cheap and simply logics like the cloud computing. There are some significant matters in this paper.

- The cloud computing with IoT is examined by the nuclear accident.
- The fast and reasonable treatment is possible in the natural disaster.
- Human error will be reduced significantly.
- The portable tablet pc is used in the NPPs.
- Advanced smart IT skill is applied to the NPPs.

In the further study, the other industry could use the applications. The assessment of the industry is very effectively changed by the fast communications in the cloud computing. This can make the RTSA which is made by the time step of unit of second or minute. If the accident would be happened, the assessment value in the future could be changed. This technology will be accomplished in the cloud computing system. For example, the traffic system has the characteristics of the very high speed information transfer where the safety is very important. Currently, a mobile phone style communication will be changed with the global platform where the fast and suitable information transferring would be accomplished. This IT will be converged with nanotechnology (NT) and biotechnology (BT) in plant. This is a general trend in the 21st century industry. The hardware technology in the semi-conductor would be improved much more by the NT with the speed of the memory quality in the application of the IT. Additionally, the medical system would be significantly improved by the cloud computing. The telecommunication based surgery is a very common skill in the hospital area, because the medical doctor with specified skill has the difficulty to move to far distant place. The vast communication skill of the cloud computing can change very much in the many fields of the industry including the energy sectors like the oil and coal power plants.

REFERENCES

[1] USGS, Earthquake Facts and Statistics, 2012.

[2] The Mainichi Daily News, Fukushima plant still needing great care a year after tsunami, the Mainichi Newspapers Co. Ltd., Japan, 2012.

[3] NIST, The NIST definition of cloud computing, special publication 800-145, National institute of standards and technology (NIST), U. S. Department of Commerce, 2012.

[4] A. Wood, The internet of things is revolutionising our lives, but standards are a must, The Guardin News and Media Limited, London, UK, 2015.

[5] A. Goscinski and M. Brock, “Toward dynamic and attribute based publication, discovery and selection for cloud computing,” Future Generation Computer Systems, Vol.26, pp. 947-970, 2010.

[6] N. Sultan, “Cloud computing for education: A new

dawn?" International Journal of Information Management, Vol.30, pp.109-116, 2010.

[7] S.S. Wang, K.Q. Yan and S.C. Wang, "Achieving efficient agreement within a dual-failure cloud-computing environment," Expert Systems with Applications, Vol.38, pp.906-915, 2011.

[8] L.J. Perryman, N.A.S. Foster, D.R. Nicholls and J.F. Grobbelaar, "Real-time risk assessment of operational events," Nuclear Engineerng and Design, Vol.160, pp.203-211, 1996.

[9] E. Salzano, A.G. Agreda, A.D. Carluccio and G. Fabbrocino, "Risk assessment and early warning systems for industrial facilities in seismic zones," Reliability Engineering & System Safety, Vol.94, pp.1577-1584, 2009.

[10] J. Zhou, "SPA-fuzzy method based real-time risk assessment for major hazard installations storing flammable gas," Safety Science. Vol.48, pp.819-822, 2010.

[11] World Nuclear Association (WNA), Design criteria, Nuclear Power Plants and Earthquakes, 2011.

[12] USNRC, Fact Sheet on Seismic Issues for Nuclear Power Plants, 2011.

[13] R. Grossman, "The case for cloud computing," IT Professional, Vol.11, No.2, pp.23-27, 2009.

[14] J. Voas and J. Zhang, "Cloud computing: New wine or just a new bottle, cloud computing: New wine or just a new bottle?" IT Professional, Vol.11, No.2, pp.15-17, 2009.

[15] USNRC, Recommendations for enhancing reactor safety in the 21st century, the near-term task force review of insights from the Fukushima Dai-Ichi accident, 2011.

[16] Ventana, Vensim Simulation Software. Ventana Systems, Inc., 2015.

[17] Kyung-Bae Jang and Tae-Ho Woo, "Nuclear Power Plant Safety Assessment Using the Cloud Computing Based IoT," 2019 Conferences of Korea Internet of Things Society, Vol.4, No.1, pp.19-20, 2019.

[18] USNRC, SECY-93-092, PRA attachment 4. USNRC Commission Papers, 1993.

[19] J. Lim, "A Study on the Characteristics of Human Resources Required in Electronics Company," Journal of The Korea Internet of Things Society, Vol.3 , No.2, pp. 33-39, 2017.

우 태 호(Tae-Ho Woo) [정회원]

- 1991년 2월 : 경희대학교 원자력공학과 (공학사)
- 1993년 2월 : 서울대학교 원자핵공학과 (공학석사)
- 1999년 8월 : 미시간대학교 원자핵 및 방사선공학과 (공학석사)
- 2013년 2월 : 서울대학교 에너지시스템공학부 (공학박사)
- 2007년 3월 ~ 2013년 2월 : 서울대학교 에너지시스템공학부 BK21연구원
- 2015년 9월 ~ 현재 : 고려사이버대학교 기계제어공학과 교수

〈관심분야〉
사물인터넷, 에너지, 원자력, 정책

장 경 배(Kyung-Bae Jang) [정회원]

- 1995년 2월 : 광주과학기술원 기전공학과(공학석사)
- 2006년 8월 : 고려대학교 일반대학원 전기공학과(공학박사)
- 1997년 2월 ~ 2000년 3월 : SK하이닉스반도체 주임연구원
- 2000년 4월 ~ 2008년 8월 : 현대모비스 선임연구원
- 2008년 12월 ~ 2013년 5월 보건복지부 국립재활원 공업연구관
- 2014년 3월 ~ 현재 : 고려사이버대학교 기계제어공학과 교수

〈관심분야〉
사물인터넷, 제어시스템, 로봇