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# A Proposal Approach for Human System Interface in NPP based on Lessons from Fukushima Accident

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**ABSTRACT**

The use of nuclear power plants to produce electric energy is a safety-critical process where ultimate operational decisions still depend on the control room's operator. Thus it is important to provide the best possible decision support. This paper presents a human system interface based on software code to increase operation safety by mitigating the potential effect of an earthquake according to regional, national and international regulations. Such mitigation could be achieved by using a software procedure to give the operator the facility for safe power reduction or automatic shutdown when detecting an event through the seismic monitoring system during plant operation phase.

***Keywords:*** *Fukushima Accident, Human System Interface, Nuclear Power Plant Safety, Seismic Monitoring System, Computer Application.*

## 1. INTRODUCTION

In nuclear power plant's [NPP] control theory [1], systems can be modeled as interrelated components that maintain the system's stability by feedback loops of information and control. The nuclear power plant's overall performance has to be controlled in order to maintain safety, quality and low cost. In such an arrangement both controllers (manual and automatic) play fundamental roles such as to establish system goals to know the system status, and its behavior in the near future. This is done through continuous monitoring the behavior in order to compare with system status to be able to act on the system to produce the desired outcomes. In this control mode, the human operator has a supervisory role related to the automatic controllers. The operator has access to system state information using the control room indicators, display units, strip charts, alarms and the automation controller status, and may have direct ways to manipulate the controlled process, and automatic systems interact with some sections of the plant rapidly and reliably.

Recently, the control rooms HSIs have changed by adapting modern computer techniques. The computerized HSI shown in figure (1) composed of three stages which are collecting raw data, processing data, monitoring system. The first stage is the data acquisition systems, which gather the different data in order to transfer it to the upper stage. The second stage process the data, interpret the NPP state, provide advices particularly during an event or any failures of complex dynamic process which need to be managed as quick as possible with minimal consequences [2], prioritize information and problems through the monitoring system. The processing stage increases the operator performance and decreases his errors. It could be hardware by means of logic gates or a software program [3]. After Fukushima the seismic researches have gained a great attention. A digital automatic seismic trip system is developed (3). It continuously monitors the peak ground motion from the seismic wave and automatically generates a trip signal according to a predefined set point by means of using logic gates. Also an earthquake early warning system [4,5,6,7] is introduced. It proposes alarm notification algorithm that prioritize the human users and Internet of things [lot] devices. A hardware design sensor systems is presented (2), it depends on wireless sensors network in collecting seismic data.

Those sensors are battery power and low power consumption based on using 12-bit analog to digital converter and a careful hardware design of preamplifiers and filters. This paper presents a human system interface as a part of the NPP supervision system. It based on a software program that reduces the NPP power according to the seismic event level and send a trip signal if the level reches the pre-defined upper bound.

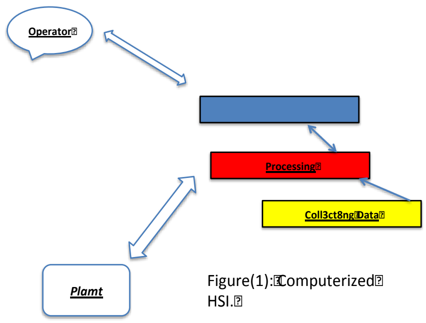



*Fig.1 . Compaterized HSI*

## 2. FUKUSHIMA ACCIDENT [8]

Three disasters earth, water and nuclear, had been struck Japan on March 11, 2011, when the biggest Tohoku earthquake in its history happened.

The magnitude 9.0 Tohoku earthquake and tsunami shattered lives. It was the Great East Japan Earthquake triggered an extremely severe nuclear accident at the Fukushima Daiichi Nuclear Power Plant [3], owned and operated by the Tokyo Electric Power Company (TEPCO). That accident was ultimately declared a Level 7 ("Severe Accident") by the International Nuclear Event Scale (INES).

When the earthquake occurred, Unit 1 of the Fukushima Daiichi plant was in normal operation at the rated electricity output according to its specifications; Units 2 and 3 were in operation within the rated heat parameters of their specifications; and Units 4 to 6 were undergoing periodical inspections. The emergency shutdown feature, or SCRAM, went into operation at Units 1, 2 and 3 immediately after the beginning of the seismic activity.

The seismic damaged electricity transmission facilities between the TEPCO Shin Fukushima Transformer Substations and the Fukushima Daiichi Nuclear Power Plant, resulting in a total loss of off-site electricity. There was a back-up 66kV transmission line from the transmission network of Tohoku Electric Power Company, but the back-up line failed to feed Unit 1 via a metal-clad type circuit (M/C) of Unit 1 due to sockets differences.

The tsunami caused by the earthquake flooded and completely destroyed the emergency diesel generators, the seawater cooling pumps, the electric wiring system and the DC power supply for Units 1, 2 and 4, resulting in loss of all power—except for an external supply to Unit 6 from an air-cooled emergency diesel generator. In short, Units 1, 2 and 4 lost all power; Unit 3 lost all AC power, and later lost DC before dawn of March 13, 2012. Unit 5 lost all AC power.

Recovery tasks were further interrupted as workers reacted to the intermittent and significant after-shocks and tsunami. The loss of electricity resulted in the sudden LOSS OF MONITORING EQUIPMENT such as scales, meters and the control functions in the central control room. Lighting and communications were also affected. The decisions and responses to the accident had to be made on the spot by operational staff at the site, absent valid tools and manuals.

The loss of electricity made it very difficult to effectively cool down the reactors in a timely manner. Cooling the reactors and observing the results were heavily dependent on electricity for high-pressure water injection, depressurizing the reactor, low pressure water injection, the cooling and depressurizing of the reactor containers and removal of decay heat at the final heat-sink. The lack of access prevented the delivery of necessities such as alternative water injection using fire trucks, the recovery of electricity supply, the line configuration of the vent and its intermittent operation.

Those events mentioned above are overview of the severe accident that resulted an enormous amount of radioactive material into the environment.

About 300,000 people are still homeless, according to the Japanese government.

Think! It could happen elsewhere. No zone is safe from a mega-quake.

## 3. SEISMIC MONITORING SYSTEM

The seismic monitoring systems (9,10) in NPP's represent part of the safety instrumentation, they have two main functions: (1) to provide recorded accurate data on seismic input and dynamic behavior of structures and the vital hardline and processing control and protection systems, and (2) to enable the automatic alarm, and, in some cases, automatic stoppage of the processes that go on in NPP's in case of earthquakes with amounts higher than the previously defined values (it addresses the paper framework). These functions were done through exact records of seismic input and dynamic responses. The records are important to (1) enable fast inspection of NPP's after earthquakes by alarming or turning off individual systems and (2) enable checking of the previous design, verification, evaluation, possible correction of the results obtained from previously performed field and analytical and experimental investigations.

The seismic monitoring is worked continuously, within a long time period, in several phases of the NPP's. in site and design of the NPP-s investigation phase, monitoring of the site and its surrounding is performed by use of seismographs to obtain recorded data on the seismic activity of the immediate surrounding of the site where the NPP will be built. These investigations are part of the experimental-analytical investigations for definition of the seismic parameters of the site. In NPP construction phase, monitoring is continued, and recording of strong ground motion in order to verify the design seismic parameters. In NPP operation phase, integral seismic monitoring systems are installed in order to:

1. Recording of:
   - Input earthquake motion,
   - Dynamic response of the engineering structures and the equipment.
2. Protection of:
   - Structures, equipment and personnel in case of exceeding the predefined Setting of acceleration levels.

## 4. SYSTEM ARCHITECTURE

The proposed approach has two challenges, decreases the loss of power generation and satisfies the NPP safety requirements. It provides a human system interface (HIS) that facilitates the operator (in NPP operation phase) to reduce the NPP power gradually and manually based on seismic levels and categories.
According to International Atomic Energy Agency (IAEA) (11), two levels of ground motion hazard should be evaluated for each plant sited in a seismic area:
SL2 is the Safety Shutdown Earthquake (SSE) for which the NPP has to be safely shutdown.
SL1 is the Operating Basis Earthquake (OBE) for which the NPP has to be able to continue the operation.

A framework for human system interface (shown in figure (2)) was developed for acquiring, storing, classifying, processing and displaying seismic events data. The framework consists of the acquisition system, the processing program and monitoring panel.

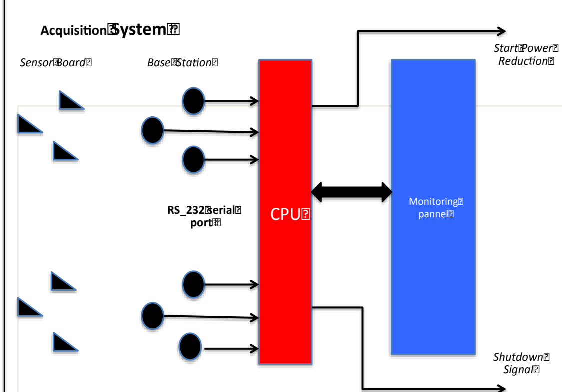
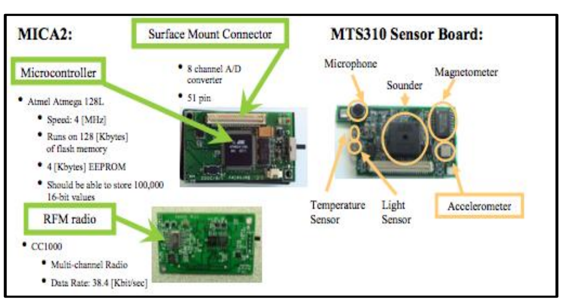



Figure (2): System Architecture.

### 4.1 Acquisition System

The data acquisition system consists of two separate channel, each channel is implemented by using wireless sensor network (WSN).
The WSN uses three MICA2 platform sensors manufactured by Crossbow Technology, Inc.(12) due to its low cost and low power consumption components. The sensor main components are MICA2 for data transmission, sensor board MTS310 which has ADXL2P2JE accelerometer (13) for detecting seismic events level and MICA2 base station for receiving data.




Figure(3): MICA2 components and MTS310 sensor board[11].

Figure(4): MICA2 base statin [11].

The MICA2 components are microcontroller, RFM radio and surface mounted controller with a specification illustrated in figure (3). The accelerometer has a range from -2g to +2g, sensitivity of 167 mV/h and resolution of 0.002g. The data collected by the accelerometer is transmitted to the MICA2 base station through MICA2. Each base station is connected to a main computer (central processing unit (CPU)) through RS_232 serial port to control, save, and process the accelerometer data. The main computer is connected to a monitoring panel that display seismic alarm system , process sequence, enable or disable operator reset button and historical button, and a shutdown LED.

## 4.2 Processing Program

The HSI second stage, manages the acquired data by means of a software algorithm stored in the main computer. The introduced algorithm has two types of input data, predefined data and variable data collected from acquisition system as follows:
-

SL1, SL2 #predefined values of OBE and SSE #

Operator reset button #logic button#

History button #logic button#

$CS_{11}$,$CS_{12}$,$CS_{13}$ #seismic event level from channel 1 sensors #

$CS_{21}$,$CS_{22}$,$CS_{23}$ #seismic event level from channel 2 sensors #

$CT_{11}$,$CT_{12}$,$CT_{13}$ #seismic event time for channel 1 sensors#

$CT_{21}$,$CT_{22}$,$CT_{23}$ #seismic event time for channel 2 sensors #

The proposed algorithm shown in figure (5) starts by evaluating the input signals and calculating the greatest seismic event level (gSEL) for each channel separately to ensure redundancy according to the following equations:-

$$C_1=CS_{11}.CS_{12}+CS_{11}.CS_{13}+CS_{12}.CS_{13}$$

$$C_2=CS_{21}.CS_{22}+CS_{21}.CS_{23}+CS_{12}.CS_{13}$$

Where C1,C2 are the corresponding channels flags which trigger the decision procedure.

*Fig. 5. Processing stage software program.*

```
1.  For i=1 to 2 do
    for j=1 to 3  do
      if event leve(i,j) > OBE then
          SEL(i,j)  = event level ij;
        CS(i,j) = enable;
          If SEL(i,j)>SEL(i,j-1) then
            gSEL(i) =SEL(i,j) else
             gSEL(i)=SEL(i,j-1);
          End if;
       End if;
  End for;
  End for;

2. /*calculate the greatest event level*/
If gSEL(1)>gSEL(2) then GSEL = gSEL(1)
    else GSEL = gSEL(2);
   End if;

3. /* evaluate the channels flag*/
   C1=CS11.CS12+CS11.CS13+CS12.CS13;
   C2=CS21.CS22+CS21.CS23+CS22.CS23;

4. /* decision procedure*/

  If C1+C2 = True then
4.1 /*compute set point & upper bound*/
     SP=SLav* Cf* Af* (1-Es);
     Upper bound= SL2* Cf* Af* (1-Es);
4.2 IF GSEL > SP then
    Set warning alarm;
    If (GSEL > SLav) . (Operator reset
      button =      false) . (GSEL < Upper
      bound) . (History button = true) then
       reduction rate=( GSEL- SP)/ GSEL ;
       set  reduction alarm;
        if  (operator reset button = true)+
          (history button =false ) then
             set reduction start alarm;
            start npp power reduction by reduction
            rate;
      end if;
     end if;
4.3  if  GSEL=> upper bound  then
        send a signal for reactor shutdown;
         set shutdown led;
end if;

end if;
```

The decision procedure starts by calculating the set point and upper bound according to the following equations:-

$$Sl_{av}=(SL!+SL2)/2$$

$$SP= SL_{av}* C_f* A_f* (1-E_s)$$

$$UB= SL2* C_f* A_f* (1-E_s) \quad \ldots\ldots\ldots\ldots\ldots$$

where

SP set point.
UB upper bound.
$C_f$ Conversion factor.
$A_f$ Amplification factor.
$E_s$ Sensor error.

To ensure the functional complementarity of safety related systems, structures and components, the calculation of UB and SP depends on SSE and OBE levels. By this method the introduced HSI works in a range bellow SSE level, which verify the IAEA requirements. According to Regulatory Guide1.60 and [1, 4], In this case, the computed 5% damped response spectrum of the artificial ground motion time history shall not exceed the target response spectrum at any frequency by more than 30% in the frequency range of interest. Consequently, the conversion factor is 70%.

The amplification factor differs according to the NPP location because it depends on the ratio between the minimum floor response spectra at the sensor location to the design ground response spectra.

The execution of step 4.2 starts by giving a warning alarm to the opera to make him monitor the panel carefully, if the event level exceeds the set point. The execution of the following statement depends on many factors, first of all is the operator reset button, which is a logical button that could be changed manually by the operator to disable this step to avoid power reduction. Through this button the first challenge has been verified because it facilitates the operator to stop power reduction in case of the GSEL did not increase during data transferring time or processing time. The button default value is false.

The second factor is the History button which is a predefined value (true).It changed according to the history of the ground motion at the NPP location. It could work as a redundant for the operator reset button. The other factors are the average event level that depends on OBE and SSE, the detected event level and the upper bound based on SSE.

If the conditions verified the reduction rate of the NPP power will be calculated according to the following equation:-

Reduction rate = (GSEL- SP) /GSEL

Then set the reduction alarm to alert the operator, that if he did not change the operator reset button status or the history button status (according to the displayed successive event level at the sensor window) reduction start alarm will be set and reducing the NPP power by reduction rate.

But if the conditions are not verified the program will test the GSEL if it is greater than or equal to upper bound (UB) a trip signal will be sent and set a shutdown LED. By this step the NPP safety requirement is verified.

4.3 Monitoring Panel

The proposed HIS introduces an active monitoring panel by means of the operator reset button and the history button. It displays the seismic data for each channel separately as shown in fugure (6).

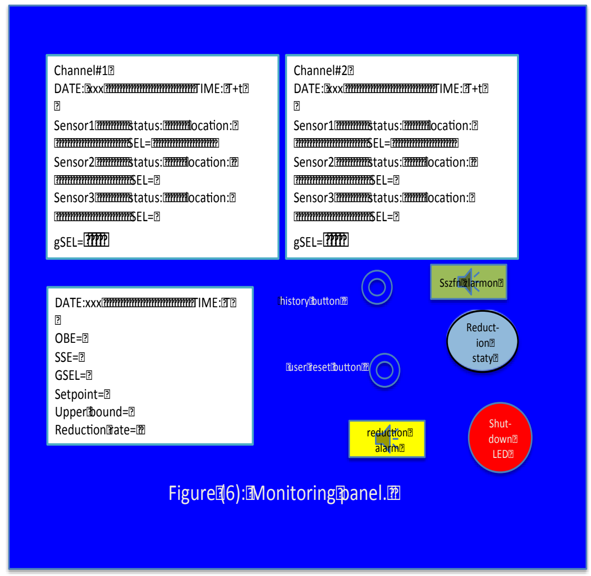



Figure (6): Monitoring panel.

It has a window for each channel that display the event level detected by each sensor at time T+t (where t is the time taken for data processing ). In addition to a third window for displaying the data calculated by the processing program based on the detected event level at time T. Also there are two active button for operator reset button and history button, a reduction alarm to alert the operator and an alarm for starting reduction and finally a shutdown LED.

The introduced HSI operates in NPP operation phase. All the detected events are displayed in channel#1 and channel#2 windows as soon as it received from the sensor (at time T). The decision procedure starts to compute SP & UB when plot SEL $_{SSE}$. According to the detected event value if it is equal or greater thane UB a shutdown signal will be send and a shutdown LED is set or the conditions in step 4.2 figure (4) is satisfied, a reduction alarm is set to alert the operator to watch if the second event level at T+t js greater than the event level at T so he can decides to reset the reduction operation or not. The start reduction alarm is set and NPP power reduction signal is sent if the operator did not disable the operation. In case that the event level is equal or greater than UB a trip will be sent and a shutdown LED is set. A data plot could be added to each channel to retrieve the sensor data graphically among time.

### 4.4 Experimental results

A software program has been built using MATLAB under OSX 10.6 . It assumes that the input event level [15] is random between -0.2g and +0.2g as shown in figure (7) , SL1= 0.09, SL2=0.18, $C_f$= 0.7 , $E_s$=0.1 and $A_f$ = 1.5 . According to the proposed program, UB=0.17, $SL_{av}$ =0.135, and SP=0.127 according to the previously assumed values. The algorithm gives an alarm (at t=3 ) when the SEL exceed 5.4% below $Sl_{av}$ to warn the operator that he should watch the panel carefully.

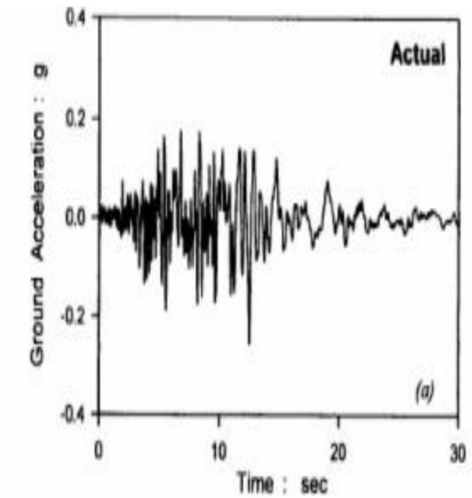



*Fig. 7. Input ground motion [15].*

While the algorithm executes step 4.2 depending on the event level which exceeds $Sl_{av}$ at t=5 and display the corresponding values in the lower window, the upper windows show that the event level continue its increasing. Consequently, the operator who was watching the upper windows did not push the reset button until he listen the reduction alarm. In this case, he has the facility to continue the reduction process or disable it through the reset button or the history button according to the data displayed in the upper windows at this moment. If he decided to continue, the reduction start alarm will be set and the NPP power reduction will starts by a reduction rate of 15.3%.

The algorithm sent a trip signal at 5.4% below SSE (t=7), which represent the UB percentage related to SSE. This provide the NPP safety and verify the SSC integrity.

In normal case, the NPP takes 3 seconds to shut down from 100% power. However, in our case, it takes 2.55 sec to shut down due to the usage of the introduced algorithm. Moreover, even if it is destroyed during the 2.55 sec the emitted heat and radiation are less than normal.

## 5. CONCLUSION

This paper introduces a software program for an active human system interface that facilitates the operator to response against the seismic events during operation phase in order to mitigate the earthquake consequences. The introduced approach consists of wireless sensor for event detection, central processing unit for data processing by means of a decision maker procedure's software, and an active monitoring panel which composes of two windows to display the detected data from each channel separately, a window for screening the procedure outputs, a group of buttons to enable the operator to stop the reduction procedure in case that the event level decrease, a group of alarms to warn the operator to watch the upper windows or to inform him that the reduction process will start, and two LED's, one for Automatic Shutdown and the other LED to indicate that the power reduction is in process. The approach has flexibility for instrumentation upgrade or elements re-use, which is a great advantage. The problem of false alarms is minimized by means of continuous updates, redundancy from several measurements at the same geographic location and diversity (the usage of different sensor technology). Also, the usage of wireless sensors reduces the cables' problems. Additionally the seismic network routinely record ground motions from numerous small earthquakes and tele-seismic events is important for basic research. Moreover, it ensures that the system operates properly when relatively rare large events occur. The approach decreases the loss of power generation and satisfies the NPP safety requirements. To be efficiently applied, this approach requires experienced operators. Consequently, human errors are hugely minimized by means of the automatic power reduction if the operator does not respond to manual reduction. The experimental results show a decrease in shutdown time by 15% in case that an earthquake struck the NPP. Safety margin calculation (reduction rate) and timing should be considered in future research.

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