ENVIRONMENTAL SAFETY AND OCCUPATIONAL HEALTH CONCERN IN BATTERY WIRELESS CHARGING BY MICROWAVE

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Abstract— Environmental safety and occupational health management have an objective to analyze hazards prior to conduct "A battery wireless charging by microwave research". This management refers to military standard: System Safety (MIL-STD-882E) and Occupational Health and Safety Management (OHSAS 18001), which compose of Identify hazard, Assess risks, Reduce risks, Accept Risks and Manage Life Cycle Risks. Total hazard lists are 11 items which are in serious level 18% and medium level 82% and after reduced risk by setting of safety standard operational procedure, personal protective equipment and checklist etc. the medium level are 27% and low level 73%

Index Terms— Wireless energy transfer, Battery wireless charging by microwave, Risk assessment, Environmental safety and occupational health management.

I. INTRODUCTION

Electrical equipments are vital for every military field missions but in some circumstances, battery cannot be charged with conventional method when it runs out. Therefore, battery wireless charging method will play a major role to accomplish the important military missions.

Defence Energy and Fuel Department under Defence Technology Institute (Public Organisation) Thailand will research the feasibility to transmit power wireless via microwave which can be sent at long distance. At initial phase, we will use microwave generator from microwave oven (Magnetron gun) which is cheap and easy to buy to do a test. If test result is satisfied with our assumption, we will implement higher power of microwave generator for further development.

In this research, there are some potential hazards which might be affected to environment and users. So environmental safety and occupational health effectively management is mandatory to be conducted.

A. Wireless energy transfer

Wireless energy transfer or wireless power is the transmission of electrical energy from a power source to an electrical load without artificial interconnecting conductors. The most common form of wireless power transmission is carried out using direct induction followed by resonant magnetic induction. [1]

Microwave transmission refers to the technology of transmitting information or energy by the use of radio waves whose wavelengths are conveniently measured in small numbers of centimeters; these are called microwaves. [2]

Microwave Energy is an electromagnetic energy in high frequency radio wave range which has wave length range of 0.01 – 1 m. and frequency is 0.3 – 300 GHz.

Microwave Power Transmission (MPT) consists of Microwave generator (Magnetron gun), Transmitting antenna and Receiving antenna (Rectenna). Microwave is generated in electrical equipment called "Magnetron" which produce microwave range in frequency S band at 2,450 MHz and electrical power at 500 – 1,100 W. Mechanism of microwave generator start with supplying of low voltage and transform to high voltage (about 30 times) by electrical transformer and sent to capacitor and other devices for changing alternating current to direct current. Then, direct current is supplied to Magnetron for producing microwave power [3] as shown in Figure 1.

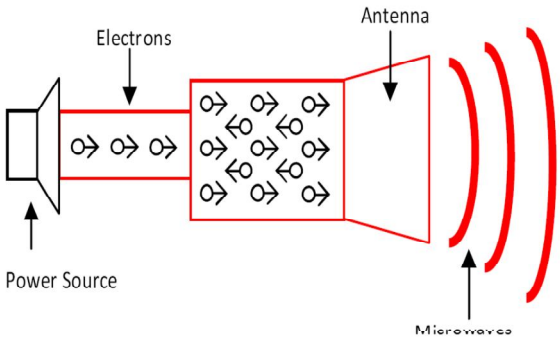


Figure 1. Microwave generator (Magnetron gun)

The electricity generation using microwaves is more friendly environments moreover it does not involve any emission of carbon gases. [3]

B. Battery

Battery is an energy storage device which consists of electrochemical cells to transform chemical energy into electricity by galvanic cell and electrolyte solution [4] .Battery in this research is Lithium Polymer Battery or well-known in Lithium – Ion Polymer Battery or LiPo, LiP, Li – Poly which is secondary battery or rechargeable battery. This battery is an inflammable gel that means reduce

explosion while charging, durable for overload charging, light weight if compare with capacity (mAh) and more supply current than capacity. [5]
Battery wireless charging by microwave refers the principle of wireless charging by radio wave type which uses an electromagnetic field to transfer energy between two objects. Energy is sent through an inductive coupling to an electrical device, which use energy to charge batteries or run the device.

C. Hazardous of microwave

Refer to Electromagnetic Environmental Effects Requirements for Systems: MIL – STD – 464A assigning that "The system design shall protect personnel, fuels, and ordnance from hazardous effects of electromagnetic radiation"

1) Health effect
   The proven adverse biological effects of non – ionizing (electromagnetic) radiation are thermal, resulting from overheating of human body tissue. The body response is dependent on the energy level, time of exposure and ambient temperature. Unlike ionizing radiation, no cumulative effects from repeated exposure or molecular changes that can lead to significant genetic damage to biological tissues have been proven.
   Radio frequency energy can induce currents into any object to arc or spark. Many part of system can act as receiving antennas. To avoid this hazard, transceivers should be not operated any closer than 10 feet.
   Electrically initiated devices in ordnance shall not be inadvertently actuated during or experience degraded performance characteristics after exposure to external electromagnetic. [6, 7]
2) Environmental impact
   The point of environmental impact of microwave beam passing through the atmosphere is the heating increases the temperature of the electron gas and turns a number of consequences for the plasma density and chemical content of the atmosphere at ionosphere heights, due to the dependence of the rates of chemical reactions on the electron temperature. [8]

D. Microwave safety standard

According to related electromagnetic field (EMF) limits standard as per ICNIRP Guidelines for limiting exposure to time – varying electric, magnetic and electromagnetic fields (up to 300 GHz) Table 6: Reference levels for occupational exposure to time – varying electric and magnetic fields (Unperturbed rms. values), state that "In the frequency range 2 – 300 GHz, equivalent plane wave power density value should not be exceed 50 W/m^2."[9]

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field strength (μT)	Equivalent plane wave power density (Wm^{-2})
Up to 1 Hz	-	1.63×10^5	2×10^5	-
1 – 8 Hz	20,000	$1.63 \times 10^5 / f^2$	$2 \times 10^5 / f^2$	-
8 - 25 Hz	20,000	$2 \times 10^4 / f$	$2.5 \times 10^4 / f^2$	-
0.025 – 0.82 kHz	$500/f$	$20/f$	$25/f$	-
0.82 - 65 kHz	610	24.4	30.7	-
0.065 - 1 MHz	610	$1.6/f$	$2.0/f$	-
1 – 10 M Hz	$610/f$	$1.6/f$	$2.0/f$	-
10 – 400 MHz	61	0.16	0.2	10
400 – 2,000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	$f/40$
2 - 300 GHz	137	0.36	0.45	50

Figure2. ICNIRP Guidelines Table 6: Reference levels for occupational exposure to time – varying electric and magnetic fields

II. EQUIPMENTS AND PROCEDURES OF BATTERY WIRELESS CHARGING BY MICROWAVE

A. Equipment

Equipments of this research are included as below. [10]

1) Microwave gun and beam cover: microwave power source more than 900 W.
2) Rectenna consist of antenna and rectifier

2.1 Antenna: is an electrical device which intercepts some of the power of an electromagnetic wave (frequency 2.45 GHz) in order to produce a tiny voltage at its terminals.

2.2 RF – DC Converter or Rectifier: is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction.

3) DC – DC Converter: is an electronic circuit which converts a source of direct current (DC) from one voltage level to another.
4) Lithium Polymer Battery: capacity more than 2000 mAh
5) Battery Charger Kit: is a device used to put energy into a secondary cell or rechargeable battery by forcing an electric current through it.

B. Research Procedures

1) Attach beam cover at the end of magnetron gun and fix it together on test bench.
2) Place antenna in the range of microwave beam.
3) Route wire from end of antenna and connect to RF-DC Converter (Rectifier).
4) Connect Rectifier with DC-DC Converter and then connect to battery charger kit
5) Put battery in explosion proof bag and connect it to battery charger kit.
6) Turn on magnetron gun after installing process and measure power, voltage and current while charging battery.

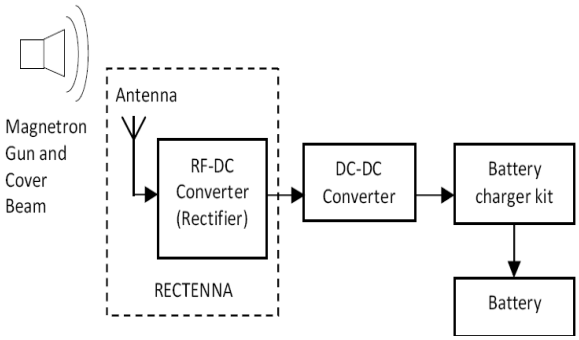


Figure3. Research procedure block diagram

III. ENVIRONMENTAL SAFETY AND OCCUPATIONAL HEALTH MANAGEMENT PROCESS

The system of environmental safety and occupational health management process will be followed as MIL–STD–882E [11] and OHSAS 18001 standards [12] consist of 7 elements as figure.

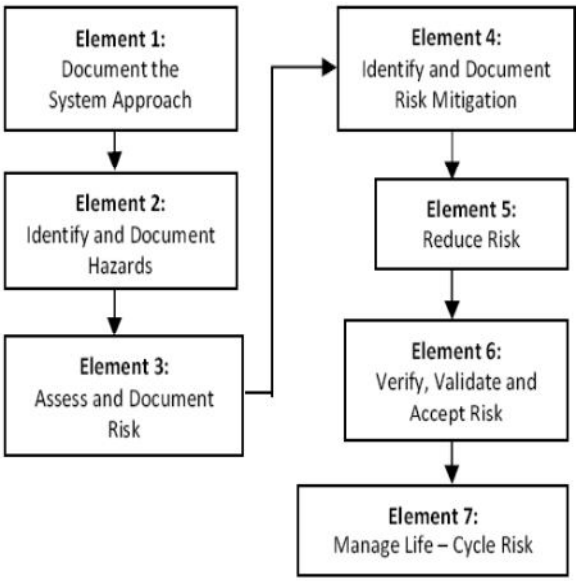


Figure 4. Environmental safety and occupational health management process

A. Document the system approach

Project Manager and teams should be classified activity from working procedure or job description and identified workplace or environment.

B. Identify and document hazard

Identify risk hazard (Preliminary Hazard List; PHL) by consideration of effect and cause from checklist or what if analysis method.

C. Assess and document risk

Risk analysis will be analyzed and defined severity and probability level from preliminary hazard list.

1) To determine the appropriate severity category at a given point in time, potential for death or injury, environmental impact or monetary loss.

Table 1. Severity categories

Severity Categories		
Description	**Severity**	**Mishap Result Criteria**
Catastrophic	1	Death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to or exceeding 6,000,000 Baht.
Critical	2	Permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, reversible significant environment impact, or monetary loss equal to or exceeding 600,000 Baht but less than 6,000,000 Baht
Marginal	3	Injury/ occupational illness resulting in one/ more lost work day, reversible moderate environmental impact, or monetary loss equal to or exceeding 60,000 Baht but less than 600,000 Baht
Negligible	4	Injury/ occupational illness not resulting in a lost work day, minimal environment impact or monetary loss less than 60,000 Baht

2) To determine the appropriate probability level at a given point in time, likelihood of occurrence of mishap.

Table 2. Probability levels

Probability Levels				
Description	**Level**	**Specific Individual Item**	**Fleet/ Inventory**	**Quantitative**
Frequent	A	Likely to occur often in the life of an item.	Continuously experience.	Probability of occurrence greater than or equal to 10^{-1}
Probable	B	Will occur several times in the life of an item.	Will occur frequently.	Probability of occurrence less than 10^{-1} but greater than or equal to 10^{-2}
Occasional	C	Likely to occur sometime in the life of an item.	Will occur several times.	Probability of occurrence less than 10^{-2} but greater than or equal to 10^{-3}
Remote	D	Unlikely, but possible to occur in the life of an item.	Unlikely, but can reasonably be expected to occur.	Probability of occurrence less than 10^{-3} but greater than or equal to 10^{-6}
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced in the life of an item.	Unlikely to occur, but possible.	Probability of occurrence less than 10^{-6}
Eliminated	F	Incapable of occurrence. This level is used when potential hazards are identified and later eliminated.		

3) Assessed risk by using the risk matrix table which combined severity and one probability.

Table 3. Risk assessment matrix

Risk Assessment Matrix				
Severity Probability	**Catastrophic (1)**	**Critical (2)**	**Marginal (3)**	**Negligible (4)**
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

4) Enlist the risk analysis by set priority of risk level from maximize to minimize.

D. Identify and document risk mitigation measures

Create action plans according to risk level control. The goal should be to eliminate the hazard if possible or reduce to the lowest acceptable level within the constraints of cost, schedule and performance.

Table 4. Risk level control

Risk Level	Description of Risk Criteria	Risk Control
High	Can lead directly to a catastrophic or critical mishap.	These risks are unacceptable. Substantial improvements in risk controls are necessary, so risk is reduced to a tolerable or acceptable level. Work activity should be halted until risk controls are implemented that reduces the risk so that it no longer very high. If it is not possible to reduce risk the works should remain prohibited.
Serious	Can lead directly to a marginal or negligible mishap.	Substantial efforts should be made to reduce the risk. Risk reduction, measures should be implemented urgently within a defined the period and it might be necessary to consider suspending or restricting the activity, or to apply interim risk control measures, until this has been completed. Arrangement ensures the controls are maintained, particularly if the risk levels are associated with harmful consequences.
Medium	Influences a marginal or negligible mishap, reducing the system to a single point of failure.	Consideration should be given as to whether the risks can be lower, where applicable, to tolerable level, and preferable to an acceptable level, but costs of risk reduction measures should be taken into account. Risk reduction measures should be implemented within a defined time period. Arrangements should be made to ensure the controls are maintained, if risk levels associated with harmful consequences.
Low	Influences a catastrophic or critical mishap, but independent function interlocks or human actions remain.	No additional controls are required unless they can be implemented at very low cost (in terms of time, money and effort). Actions to further reduce these risks are assigned low priority. Arrangements should be made to ensure made to ensure that the controls are maintained.
Eliminated	-	These risks are considered acceptable. No further action is necessary other than to ensure that the controls are maintained.

E. Reduce risk

To select and implement plan by adopting a methodology for test, introduce protective devices and warning device, prepare instructions, choose personnel and educate. If the risk level is found to be MEDIUM or SERIOUS or HIGH, Project Manager will be stated accept risk.

F. Verify, validate and accept risk

Check all of selected risk mitigation measures through appropriate analysis testing, demonstration and inspection. Before exposing people, equipment or environment to known system – related hazard, the risk will be accepted by appropriate authority.

G. Manage lift – cycle risk

After system is fielded, risk assessment should be reviewed any spotted problems, near miss and accident. Other relevant data; for instance, test material, environmental factor etc., is obliged to be updated constantly.

IV. RESULTS

There are 4 steps in battery wireless charging by microwave. Once risks have been done total 11 items of hazard lists can be detected. Some examples of hazards were shown in Table 5 and 6.

Table 5. Example of risk assessment of battery wireless charging by Microwave (before taking safety measures)

Work process	Hazard	Eff	Sev	Cause	Current Process Control	Prob	RAC
Turn on magnetron gun after installing process	Fire, Explosion from antenna	A, B, C, D	1	Over heat	Monitor antenna temp. by thermometer	D	S
	Heat from microwave beam	A, B,	2	Touch microwave beam range	Turn off magnetron switch when operator in area	D	M
	Inhale chemical fume	A, B	3	Doesn't wear half mask	Work in open air and suitable ventilation	D	M
	Short circuit	A, C	3	Damage wire	Pre – check wire condition	D	M
	Fire, Explosion from battery	A, B, C, D	1	Over heat	Put battery in explosion proof bag	D	S

Notice: A : Operator injury AA : Operator death
B : Colleague injury BB : Colleague death
C : Asset/ Machine damage D: Environment effect
E : Community effect

Table 6. Example of risk of battery wireless charging by Microwave (after taking safety measures)

Work process	Risk Min Plan / Control Plan / Surveillance Plan	Action Results Sev.	Prob.	Risk
Turn on magnetron gun after installing process	- Restrict area of experiment - Prepare fire extinguisher	2	E	M
	- Restrict area - Prepare fire extinguisher - Environment monitoring by microwave leakage meter	1	E	M
	- Prepare half mask	4	E	L
	- Checklist of post installation	4	E	L
	- Monitor battery charging voltage, current and temperature	3	E	M

Table 7. Summary of battery wireless charging risk level

Process	Hazard	Risk Level									
		High		Serious		Medium		Low		Eliminate	
		before	after	before	after	before	after	before	after	before	after
Attach beam cover at the end of magnetron gun and fix it on test bench	2					2			2		
Place antenna in microwave beam range and connect to Rectifier.	2					2			2		
Connect Rectifier with DC-DC Converter and battery charger kit after that put battery in explosion proof bag and connect to battery charger kit	2					2			2		
Turn on magnetron gun after installing process	5			2		3	3		2		
Sum	*11*			*2 (18 %)*		*9 (82 %)*	*3 (27 %)*		*8 (73 %)*		

From risk analysis in table 7, there are total 11 hazards in serious level 2 items or 18% and medium level 9 items or 82%. Once risk minimizing plans, process control plans and surveillance plans are taken into action, risk level can be reduced as following, the serious level are none, medium levels are 3 items or 27% and low levels are 8 items or 73%. Serious levels are fire, blast from unclear keep metal out and battery short circuit as table 8.

Table 8. Hazard characteristic

Risk Level	Hazard	
	Before	After
Serious	- Fire, Explosion from antenna - Fire, Explosion from battery	-
Medium	- Hand cut by sharp metal - Inhale chemical fume from soldering process - Heat from microwave beam - Short circuit	- Fire, Explosion from antenna - Fire, Explosion from battery - Heat from microwave beam
Low	-	- Hand cut by sharp metal - Inhale chemical fume from soldering process - Short circuit

V. ENVIRONMENTAL SAFETY AND OCCUPATIONAL HEALTH MANAGEMENT

Hazard lists will be identified by risk assessment, which show cause and effect of all potential accident. In order to, minimize or eliminate these accidents, following procedure are required such as

1) Preparation of Safety Standard Operational Procedure; SSOP
2) Preparation of Personal Protective Equipment; PPE e.g. glove, half mask.
3) Set restrict area from electromagnetic field (EMF) limits standard (equivalent plane wave power density value should not exceed 50 W/m^2.)
4) Environmental monitoring by microwave leakage meter
5) Monitoring electrical measurement (power, voltage and current)
6) Training : hazard risk, SSOP, PPE, fire prevention
7) Warning sign
8) No permit communication equipment, fuel, ordnance or sparking in this area at less 10 feet.

CONCLUSIONS

Risk analysis according to MIL–STD–882E and OHSAS 18001 standards are suitable to analyze the crisis job in battery wireless charging by microwave research because of the accuracy and coverage all of potential hazard lists, the realistic risk levels enable the protection and prevention effectively.
In case of changing of microwave power source or processes, risk assessments must be re-identified according to new activity and environment.

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