

Investigating the electric shock's risk in the regeneration unit of Iran aluminum Production Company using FTA technique

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Abstract:In this study, the electrical shocks risks in the regeneration unit of aluminum Production Company was investigated using Fault tree analysis (FTA) method. By observing the production operation in regeneration unit, using of classified tasks existing in the establishment unit, the introduction with the staffs' major responsibilities and considering imperfect machineries as an effective factor of environment insecurity in electric shocks were evaluated. Given that in order to bringing about electric shock as the result of direct contact in compliance with the transformer isolated system the ground connection is one of the faults of electricity current and seems to be the necessary condition for electric shock, and placing of the staffs between pot and ground is considered as the enough condition causing undesirable event. So top event was determined by “and” and “or” gates, electric shock undesirable event analyzed, the occurrence reasons were defined, and modeling the fault tree was done in accordance with fundamental orders. Minimal cut set were prioritized ordered by importance, and electrical system of electrolysis line as well as the protection systems used in order to prevent the electric shock risks were identified, and based on the results obtained from the application of the above technique, a set of solutions and corrective suggestions were presented regarding the reduction of electrical shocks risks in the regeneration unit of Aluminum Production company.

[Ahmad Reza Mokhtari, Ramazan Mirzaei, Abbas Mokhtari. **Investigating the electric shock's risk in the regeneration unit of Iran aluminum Production Company using FTA technique.** *Life Sci J* 2013;10(1s):94-103] (ISSN:1097-8135). <http://www.lifesciencesite.com>. 15

Keywords: Fault tree analysis, aluminum resurrection, risk, electric shock

Introduction

Fault tree analysis (FTA) technique is one of the efficient methods in order to evaluate the possibility of undesirable event reasons in complex systems (Mohamadfam, E 2007). Electric shock risks is one of the most important incident factors among the industries which is caused by faults due to electrical stream such as body contact, ground contact, and short contact (Mojiri,a. 2007) and these incidents may result maim, death, etc (Shabanzadeh, F, 2007). electrical shock risks is one of the most important considered incident factors in the workshops which is used of electrical energy and the results can cause major health damages, death, and financial problems. Although the electrical shock risks is low but it can caused death because of the incident high intensity and the industry managers can't tolerate the aforementioned factor risk. The studies about the work incidents in Yazd province from 2004 to 2007 show that 43 electric shock occurred during the mentioned time that 27.9% caused death of staff, 34.88% injuries and fraction, 6.98% mutilation, and 30.23% other injuries such as

burning due to the electric shock (Hajihoseini, A. Marvdastizadeh, M. 2007).

Therefore, we should note that electrical uses for aluminum production in the regeneration unit of aluminum Production Company and in accordance with the Company antiquity, a lot of incidents occurred as a result of electrical factors until today (current statistics of incidents in the Iran aluminum Production Company). On the other side, the occurred faults caused workshop environment insecure and the mental effects is effective in production reduction due to this issue and beside the body injuries.

So, studies done by using the fault tree analysis technique in order to evaluate the electrical hazards factor risks in the aluminum regeneration Company and presenting suitable solution for preventing hazards and consumable energy reduction. Whereas the complete and exact knowledge of system is the first step of fault tree analysis (Vesely W.E. et al , 1981). so certain and detail information about the whole system sectors, physical and functional interaction between the sectors, and

normal and abnormal conditions gathered from current maps in technical archives and interviewing with staffs, experts, and others.

Task program (method)

In this study, we use FTA technique in the aluminum regeneration workshop in order to define electrical hazards factor risks. First, we recognized the current electrolysis line of electrical system in the aluminum Company and in order to evaluate this issue, we should check the power supply, consumer placing method (electrolysis pots) in electrical orbit, transformer isolation protection system, and protection system by insulating in accordance with the following expressions.

Power supply

230 KV alternate lines enter the power center distribution from country power plant and the voltage became 700-800 V and the 67-68 kilo amperage by using installation such as decreasing transformer and rectifiers (Shahrokhshahi,T, 2008).

Consumer placing method (electrolysis pots) in electrical orbit

Consumer placing method (electrolysis pots) in electrical orbit is series in each production line as we see in figure 1 orbit. So, the passing amperage is stable in all of the pots and equals 68-70 kilo amperage and the electrolysis pots consumable voltage is 4.8-5.3 V in normal condition.

So, the electrical stream transferred to the anode of next pot exiting from one pot by the base bar after. Then, the electrical stream passed from anode,

entering melt hexafluoroaluminate($\text{Na}_3 \text{AlF}_6$) and alumina powder, reaching to cathode, exit by the collector bar, and finally transformed to next anode (Nikjalal,A, 2004).

Consumer (electrolysis pots) placing on pins in the above circle which is insulated from the materials between pins and pot (Kjar A, et al).

As it's obvious in figure 2, the circle balanced on the way that we have potential disagreement +375 V in the first pot of the hall and -375 V in the last pot of the hall in compared to ground because of electrical resistance equality of the pots and also equality in electrical resistance between pot and ground. So, the potential disagreement equals 750 V between the two end points of circle. On the other side, it defined that each pot has a 5 volt potential disagreement in compared to next pot and previous spot in normal condition in accordance with the pot voltage checking in compared to ground by voltmeter.

So, the potential disagreement equals -370 V and +370 V for both second pot of each hall in compared to ground and as we close to 75th pot, the potential disagreement will decrease by passing each pot until the potential disagreement of the 75th of both halls equals zero in compared to ground as we observe in figure 1.

We should consider that the pot will have the same potential with ground by lower resistance and the zero point will transfer to that pot in the circle if the insulation was not equal between the pot pins and pots.

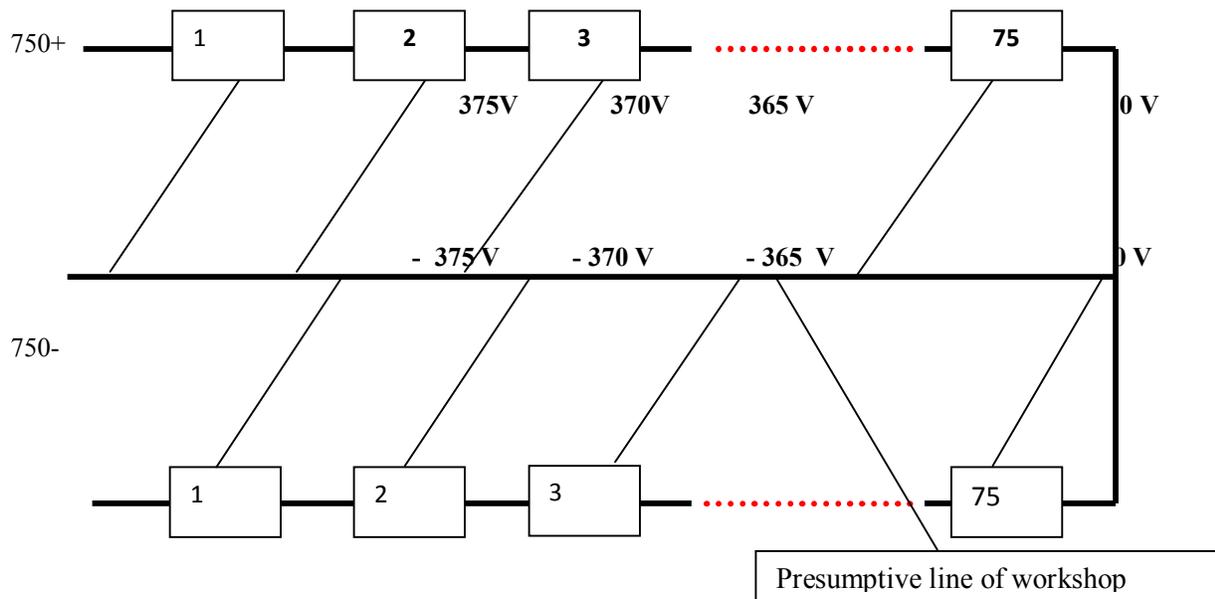


Figure 1. Electrical circle of the regeneration electrolysis pots with considering the pot potential disagreement in compared to ground

Anyhow in accordance with the faults due to the electrical stream includes:

- a) Body contact
- b) Short contact
- c) Ground contact

Aforementioned faults occurrence inevitable in most of the situation and working with the electrical devices can cause electric shock in people. So, it is necessary that the staffs protect from the electrical shocking. The transformer isolation protection system and protection system is done in workshop current condition by insulating. One of the necessary points of the people electric shock is that we need 3 important and necessary conditions for electric shock occurrence which are mentioned in the following:

1. Human placed in a close electrical circle.
2. Human placed in an electrical circle which has dangerous potential disagreement.
3. Human placed in an electrical circle which has dangerous amperage.

And if one of the aforementioned conditions doesn't exist, the electric shock won't happen (Mojiri a, 2007).

The electrical resistance of the human body is almost 1300-3000 ohm and it proved through the experiments that passing more than 50 milli amperage through the human body caused death. As a result, we can calculate the voltage range which is dangerous for human body by the following formula (Mojiri a, 2007):

$$V = I R$$

$$V = 1300 \times 0.05 = 65 \text{ V}$$

Protection system of transformer isolation

As it mentioned before, placing human body in a close electrical circle can be considered as a necessary condition for causing electric shock, so transformer isolated protection system is one of the protection systems which can prevent close electrical circle. We should note that the zero point is omitting in transformer isolated anyway and we should use Δ connections in secondary transforms. In the transformer isolated protection system, consumer power supply voltage will be separated from network voltage in case of electrical field. So, we have not the contact voltage between the contact spot and ground in the consumer (potter P.D, 2011).

Now in accordance with the aforementioned information, both primary and secondary connections will be Δ for both Dd6 and Dd0 transforms and only the secondary connection will be Δ for both yd5 and yd11 transforms (Soltani M, 2008). In case of financing on Dd6 and Dd0, we have no economical justification in accordance with the economical situation. So, all of the investors use yd5 and yd11 transforms for producing this protection system but we have a problem in protection systems which are

protected by transformer isolated. The problem is passing the dangerous electrical stream through the human body and caused electric shock if the electrical consumer parts connect to the ground (electrical stream faults) and staffs contact with the consumer electrical parts (potter P.D, 2011).

Protection system by insulating

Insulating protection system is that we use insulation subjects between the consumer electrical parts and the points which should be prevented from straight contact to it. This protection system used for the portable or movable tools such as the tools which worked with electrical engine and couldn't have the ground wire (such as electrical drill, electrical vacuum cleaner, electrical shaver, and radio), and the tools which have plastic covers. The defined sign of this protection system is \square on such devices.

Moreover, we use this system for insulating the environment. Thus we can protect anything from the contact voltage in compared to ground by insulating around the device such as ground floor, walls, and also staffs such as ground floor, walls, and also staffs. These kinds of protection can be operated for the devices which are stable in a certain point (Mojiri a, 2007).

Two aforementioned systems protect people from electric shock in the regeneration sector of Iran aluminum production Company as we see in the following way. Both yd5 and yd11 are the isolated transformers which have secondary Δ connections as the consumer power supply voltage separated from network voltage in the electrical field (Shahrokshahi,T, 2008). Thus contact voltage doesn't exist among the electrical parts and ground. When the electrolysis pots placed on ground, the electrolysis pots' connector and ground can cause the contact voltage between pot and ground. So, this system can't protect the people alone and the electrical contact generated between pot and ground with high resistance by using insulated protection system which is the supplement of the isolated transformer system. Now, if the person contact with the pot, the electrical voltage with high resistance will be series with the human body, the electrical stream won't pass through the human body and the electric shock won't happen in spite of existing of dangerous potential disagreement which is exist between aforementioned insulated pot and ground in all of the electrolysis pot pins with high resistance.

Creating fault tree

One of the most important issues in this research is the human effects as a small part of system on the whole system and also the system interaction on the human. On the other side, human fault is one of the most important incident factors which have an important role. So in accordance with the observation

of production operation in regeneration sector and also using the task expression collection in the organizations and methods of Iran aluminum production Company, we have been introduced to the staffs' tasks in this production unit and we should consider that incomplete tools have an effective role on environment insecure and it can cause unpleasant incidents. On the other side, using tools in this unit are almost metal, they have electrical transduction ability, contact with the different parts of electrolysis pots can cause faults due to the electrical stream which affects on the electric shock increscent. We introduced completely to all of the tools and their usage and also the users' tasks for using these tools in the regeneration unit of the Iran aluminum production Company. So in accordance with the aforementioned goal, it's obvious that the electric shock incident is considered as the top incident in the regeneration unit of the Iran aluminum production Company. The undesirable electric shock incident has been analyzed and the reasons defined and the modeling tree done in accordance with the fault tree primary roles (Rausand, M 2005). In accordance with the mentioned issues and also statistics of the Company's incidents, it has been defined that the undesirable electric shock happened in regeneration unit of the Iran aluminum production Company which are include the electric shock in case of straight contact and electric shock as a result of electrical arc.

Conclusions

The faults due to the electrical stream are the most important factor in electrical shocking. In accordance with the used protection system in the regeneration unit of the Iran aluminum production Company, ground connection defined as a fault due to the electrical shocking. So, the pot can have electrical contact with the ground without insulated subject.

In accordance with the ground connection existing in the transformer isolated protection system, the electrolysis pot has same potential with ground in which contact with the ground. So, the pot potential disagreement is zero in compared to the ground and the zero point transferred from 75 electrolyzes pots of both halls to the ground pot. Now, if staff contact with another pot which have more dangerous potential disagreement in compared to ground, the electrical stream will pass from the electrolysis pot through the human body and it will transferred from human body to the ground by mentioned potential disagreement and it went to the grounded electrolysis pot which have lower resistance in compared to other electrolysis pots (there is a high resistance between pot and pot leg by insulation). It will create a close circle and the electrical stream will pass through the human body. It can caused electric shock if this electrical stream has a high risk.

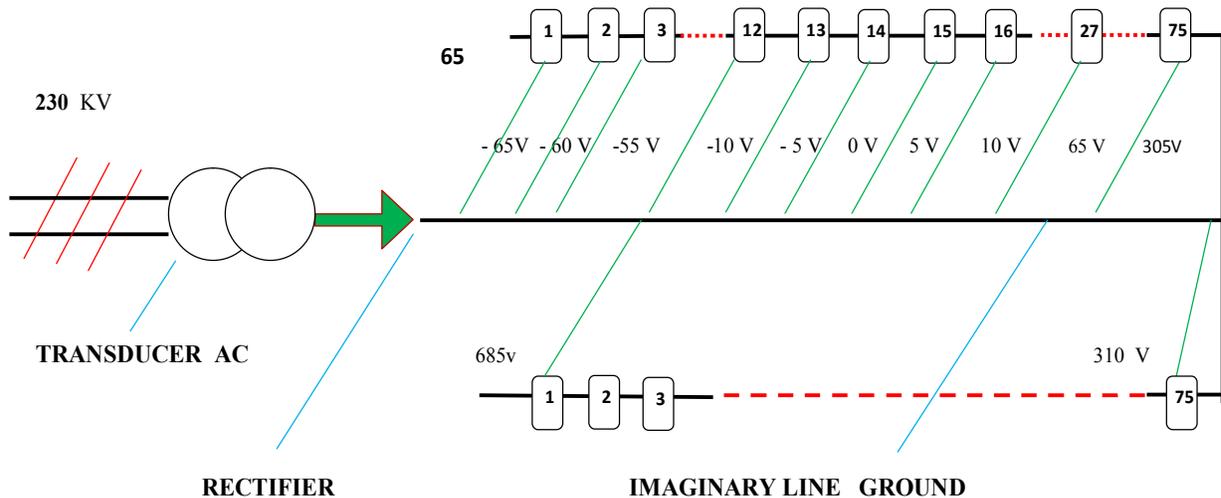


FIGURE2ELECTRIC CIRCUIT OF REGENERATION UNIT WHEN POT 14 IS AT THE PRODUCTION LINE OF GROUND CONNECTION

For example as we see in the circle of figure 2, the pot itself has no danger if the electrolysis pot number 14 grounded because it have potential agreement with the ground so, the potential disagreement of the grounded pot will be zero in compared to the ground. But the pots before and after the grounded pot will have 5 Volts potential disagreement per a pot in compared to the ground in normal condition (if the pots resistance were normal in the production line) and we have potential disagreement increscent if we far away from the grounded electrolysis pot and we have 65 Volts potential disagreement from pot number 1 and after the pot number 27 and it can be dangerous. If a person contacts with the electrolysis pot after the electrolysis pot number 27, the dangerous electrical stream will pass through the human body and it can caused electric shock because the insulation will be ineffective in this condition (by the metal such as aluminum instead of 140.000 ohm insulation). It was an insulated subject which placed between the electrolysis pot number 14 and ground and the resistances will series with the human body resistance and it prevents electrical shocking

So, the electric shock caused as a result of straight contact in accordance with the transformer isolation protection system due to the fault of electrical stream. It's a necessary condition for electric shock and when a person placed between pot and ground, it can cause an undesirable incident. So, they connect with each other in "and" gate.

Every one of the following factors can cause grounded pots. So, all of the followings connect with each other in the "or" gate.

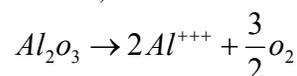
So they are correlated with gate "or".

Each one of the abovementioned factors will be alone led to the connection of pots' ground. So, all of the following issues are correlated with each other.

- Pot's perforation and placing of the aluminum between pot and ground results in the permanent ground and will cause ground connection error up to taking it out from under the pot.
- Connection of towing wire of crane with pot
Connection of towing wire of crane with pot is among the operational errors and brings about temporary ground.
- Decay of the crane hook's insulation
Temporary ground is caused by the exposure to the hook's insulation and their deterioration when contacting with pot.
- Placement of the individuals between pot and ground resulting from workshop procedure on electrolysis pots will be the factor of the appearance of the temporary ground connection.

- Procedure of switching the pot's light by production line pot attendant

In order to convert alumina into melted aluminum through electrolyte regeneration according to relation 1, alumina is ionized in chlorite. In cathode (negative electrode) aluminum is formed and in anode (positive pole) oxygen is produced. In the meantime, oxygen along with carbon forms CO and CO₂ gases (Sneyd A.D, 1992).



Produced CO and CO₂ gases prevent the establishment of electrical current between anode and cathode. So, pot have warning signs so that the lamp installed on the pot will be turns on and pot attendant should take the produced gases using appropriate tools and by making turbulence inside the available molten to establish the electric connection between anode and cathode. Considering the fact that making turbulence in the pot is done using a metal tool calling ROK, there is a possibility of its contact with pot.

- The procedure of refining the pot's inkiness
The procedure of refining the pot's inkiness is also done by pot attendant after the removal of light to taking the available impurities out in the pot. So, the used tools will have the possibility of contact with pot.

- The procedure of taking the cut anode out
The lack of proper anode quality or passage of excessive current through it will be the cause of cut of the anode-of-anode handler. Therefore, personnel are supposed to discharge these anodes from inside of the pot.

To discharge the anode from inside of the pot, workshop crane is used. So, at the time of conducting the procedure, there is the possibility of contact of the individual's hand with towing wire. Moreover, since towing wire is connected to the bridge and crane's bridge is connected to to the workshop's structure and structure is connected to the ground, there will be the risk of electric shock.

- Anode change procedure
With regard to the passage of anode life, carbon-putting personnel should replace it. Since this procedure is also done by crane, there is the possibility of individual's hand contact with crane towing wire.

- The procedure of melton discharge out of pot

The procedure of melton discharge out of pot is done using a tool calling Psiphon so that one

head of Psiphon is placed inside the pot and the other one inside the Crosibel (melting pot) and negative pressure is made using the pressured air and melton is discharged from pot inside Crosibel.

During the implementation of such procedure, there is also the probability of Psiphon contact with pot and on the other side with the pressured air pipes that are stretched as the stimulating power up to near the pot, and in the case of simultaneous placement of individuals between pot and ground resulting from the above quintuple workshop procedure at a distance more than 13 pots that causes the potential difference above 65v about ground, a single electrical closed circuit between 2 individuals is appeared and electric shock happens. Investigating the electric shock incidents in the in the regeneration unit of Iran aluminum Production Company reveals that some of the electric shock incidents have been caused due to electric arc. Given that just high pressure voltages are capable of ionizing the air

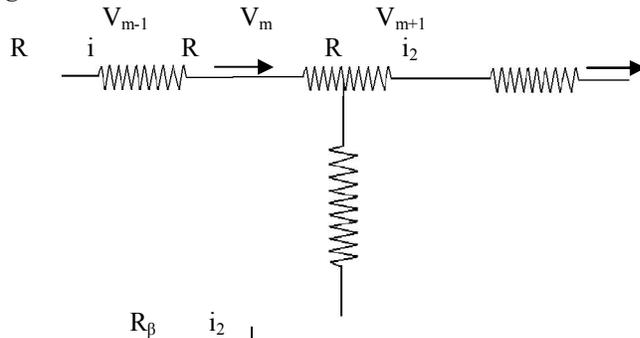
and causing the electric arc, so such events seemed implausible, since the measurements done in the electrolysis pots of Iran aluminum Production Company reveals that the difference in the potential of electrolysis pots about the ground is maximum 750v and about electrolysis pot before and after it approximately 5v.

More accurate examination regarding the available electrical circuit and library studies and investigation of the similar electrical circuits showed that according to the following relations necessarily and in all case the potential difference of electrolysis pot about the ground and about the pot before and after itself is not in compliance with the measurements done. So that where the current I is done in the *m*th electrolysis pot and in *m*th electrolysis pot the ground connection has been made as well.

According to the figure 3 the current intensity is divided into two branches of i_1 and i_2 , namely:

$$i = i_1 + i_2$$

Figure 3



Now in the series circuit we have:

$$i = \frac{V_{m-1} - V_m}{R}$$

$$i_1 = \frac{V_m - V_{m+1}}{R}$$

$$i_2 = \frac{V_m - 0}{R_\beta}$$

$$\frac{V_{m-1} - V_m}{R} = \frac{V_m - V_{m+1}}{R} + \frac{V_m - 0}{R_\beta}$$

So the relation... will be equal to:

$$\beta = \frac{R_\beta}{R}$$

if and we simplify the above relation, the potential difference can be calculated using the following relation:

$$V_{m+1} = V_m (2 + \beta^{-1}) - V_{m-1} \quad (\text{Reitz, J R, et al, 1979).}$$

we may find out of the analysis of the above relation that:

- 1- If the grounded pot resistance about the ground (R_β) is too small, and tends to zero, β^{-1} in the above relation will tends to infinity, so pot's potential difference after (V_{m+1}) about the ground and about the pot before itself tends to infinity.

Namely:

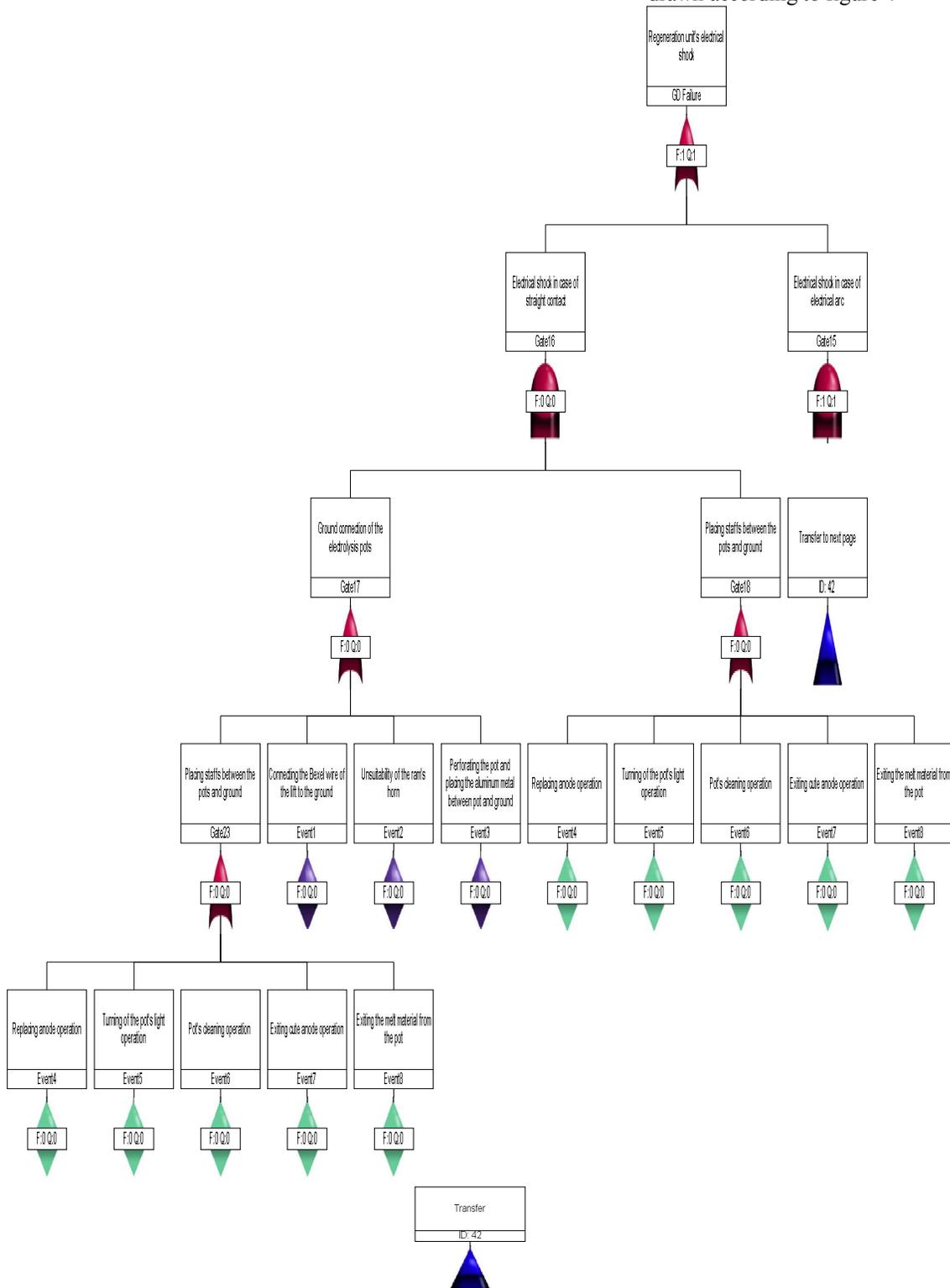
$$R_\beta \xrightarrow{0} \text{so } \beta^{-1} \xrightarrow{\infty} \text{and } V_{m+1} \xrightarrow{\infty}$$

- 2- If the electrolysis pot resistance (R) tends to infinity, β^{-1} will tends to infinity and V_{m+1} will also tend to infinity that there is this possibility in the regeneration unit of Iran aluminum Production Company due to the loose plate's switch screw of electrolysis pots at the time of pot's discharge out of production circuit.

Namely:

$$R \text{ and } V_{m+1} \xrightarrow{0, \text{ so } \beta^{-1}} \xrightarrow{\infty} \infty$$

So these two incidents are correlated with gate "or" with each other. So, error tree was drawn according to figure 4



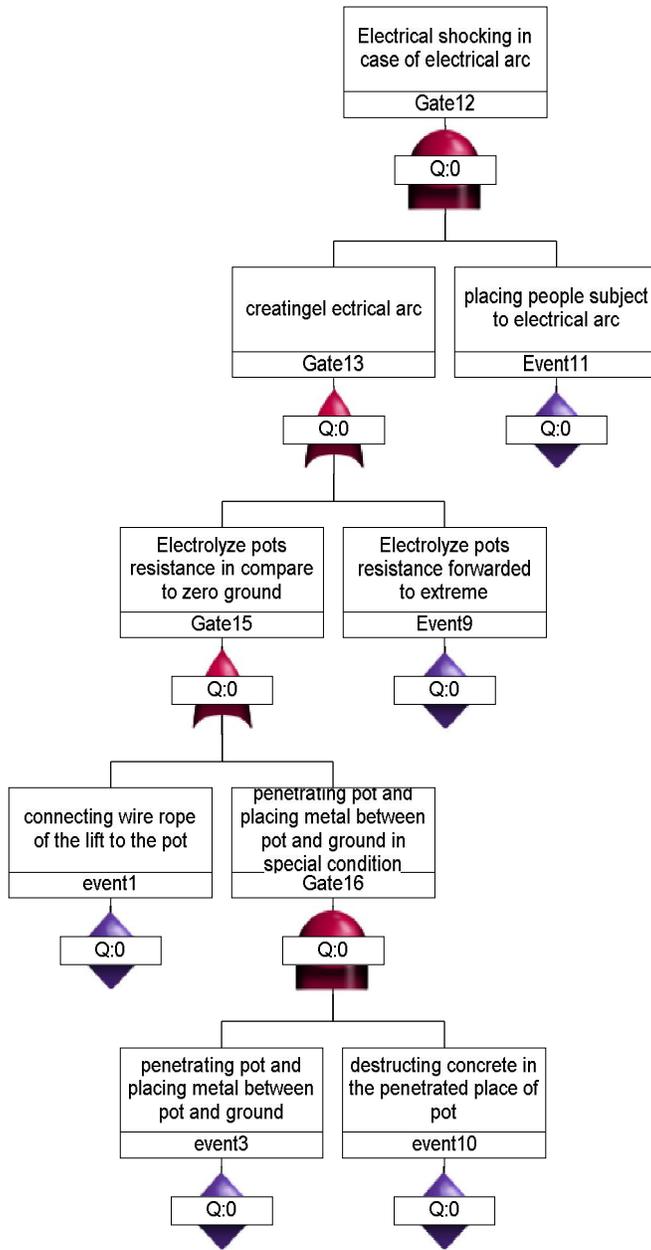
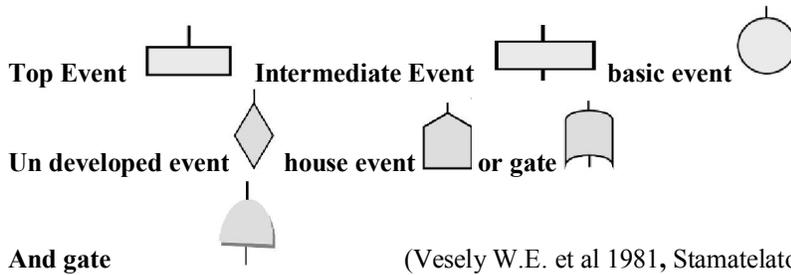


Figure 4. The fault Tree likelihood of electric shock resuscitation unit

A number of symbols used in the construction of error tree



The minimal cut set in the error tree of figure 4 are as follows that have been prioritized ordered by importance (Clemens P. L, 1993).

$$MCS_1 = E_3, E_{10}, E_{11}$$

$$MCS_2 = E_7$$

$$MCS_3 = E_5$$

$$MCS_4 = E_6$$

$$MCS_5 = E_4$$

$$MCS_6 = E_3, E_7$$

$$MCS_7 = E_3, E_5$$

$$MCS_8 = E_8$$

$$MCS_9 = E_3, E_7$$

$$MCS_{10} = E_2, E_7$$

$$MCS_{11} = E_2, E_5$$

$$MCS_{12} = E_3, E_4$$

$$MCS_{13} = E_2, E_6$$

$$MCS_{14} = E_2, E_4$$

$$MCS_{15} = E_3, E_8$$

$$MCS_{16} = E_2, E_8$$

$$MCS_{17} = E_1, E_{11}$$

$$MCS_{18} = E_9, E_{11}$$

$$MCS_{19} = E_7, E_5$$

$$MCS_{20} = E_7, E_6$$

$$MCS_{21} = E_5, E_6$$

$$MCS_{22} = E_7, E_4$$

$$MCS_{23} = E_5, E_4$$

$$MCS_{24} = E_1, E_7$$

$$MCS_{25} = E_6, E_4$$

$$MCS_{26} = E_1, E_5$$

$$MCS_{27} = E_7, E_8$$

$$MCS_{28} = E_1, E_6$$

$$MCS_{29} = E_5, E_8$$

$$MCS_{30} = E_6, E_8$$

$$MCS_{31} = E_1, E_4$$

$$MCS_{32} = E_4, E_8$$

$$MCS_{33} = E_1, E_8$$

Conclusion:

The minimal cut set in the fault tree of figure 4 lead us to provide necessary techniques to reduce the risk of electric shock as follows:

- 1- The increase in the distance between pot and ground. Given that now the distance between electrolysis pots in the regeneration unit about the ground is approximately 30cm, so if the building of pot's placement on the concrete pillars changes so that this distance increases about 1m or more, the metal which is filled due to the perforation of pot between pot and ground, in this state will not cause the pot and ground connection.
- 2- Authorities supervision and emphasis on the staffs use of individual protection proportionate to the work at the time of workshop procedure implementation
- 3- Insulation of the middle of crane winch and pertinent bridge. Instead of the insulation between hook and towing wire of crane, one should insulate between winch and bridge of the crane.
- 4- Insulation of the handle of the metal machinery used. Considering the fact that in order to implement the workshop procedure on the electrolysis pots, metal machineries are used, the use of electric insulation on the machineries reduces the risk of electric shock.
- 5- Permanent wrenching of the plate switches' screws of the electrolysis pots. Pots which are getting out of the production circuit, their plate switch screws should be permanently wrenched to prevent the resistance against the passage of the current.

- 6- Staffs' training. Educational classified planning for the occupational groups at the risk exposure in order for their awareness of the available electric system status and the way of probable errors appearance as well as the fashion of electric shock appearance in the regeneration unit will reduce human errors.

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11/22/2012