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RANKING OF RISKS IN THE OPERATION OF SMALL ENERGY PLANTS

Milena Kirova[1], Igor Sheludko[2], Preslava Velikova[3]

*[1]University of Ruse "Angel Kanchev", Faculty of Business & Management,
8 Studentska Street BG-7017 Ruse, Bulgaria
Email: mkirova@uni-ruse.bg*

*[2,3]University of Ruse "Angel Kanchev",
8 Studentska Street BG-7017 Ruse, Bulgaria
Emails: [2]isheludko@uni-ruse.bg, [3]pvelikova@uni-ruse.bg*

Abstract. This research study aims to justify the approach that helps to select major risks to the operation of small energy farms. The approach modifies the method of Failure Mode and Effects Analysis (FMEA). The weights of relative importance are taken into consideration according to the risk factors that may be different at every stage of the small energy plants life cycle.

Keywords: innovation management, risk assessment, failure mode and effect analysis, small energy plants.

Jel classification: C67, D81, O32.

1. Introduction

The present study is based on the Failure Mode Effect Analysis (FMEA). This is an approach, used for identifying every possible failure in design, production process or creating a product or a service. FMEA is widely used in engineering area, but not only there. The method uses an assessment of known or potential failures in the systems, gaps in projects, processes etc. It is used for definition and identifying of failure and it's elimination before it would reach the costumer (Stamatis 1995). The method's aim is the elimination of possible damages. FMEA can be used in later phases for controlling processes, before and within the production operations, i.e. within the whole product's or service's life circle (Nancy 2004). This fact makes the present approach extremely suitable for this research.

Potential applications of FMEA:

- Creating, changing the product/service/process;
- New application of the existing process;
- Before developing of the control plans for new and modified processes;
- When an improvement of existing product/service/process is planned;
- Occasionally throughout the life of the product/service/process (Nancy 2004).

FMEA aims to avoid the disservice for customers, so the producer's or distributor's prestige and financial results could stay unaffected. The analysis is implemented by a multidisciplinary team which includes the experts from every branch and specialization that could be qualified for the exact case. There could be specialists on marketing, design, production, quality, support, consumption, distribution, sales, etc. In this way all components, systems, subsystems, processes, every participant in developing and operating the system are covered. The experts look for and estimate the existing discrepancy to the current project. Thus we can detect the errors that may lead to a failure (i.e. the error affects the functions of the project which form the consumer value).

In this research the attributes and concepts of risk analysis is used. Similarly to other cases a certain selection of risk factors is estimated, because of restricted resources for analyzing the wide range of risk factors.

The fact of common criticism and proposals of addition and improving the method confirms the capacity and the advantages of FMEA. Considering the nature of the method and its abilities, the aim of this study is to modify FMEA in the way it could be applied as a method for risk assessment in small energy plants (and particularly the photovoltaic (PV) based installations).

In this study the exploitation risk of small energy plants and particularly the photovoltaic based installations is observed. On the one hand, investors in this technology take in mind those risks (Szabóa 2010). On the other, having in mind the increasing application of this technology it is necessary to come up with methods for analysis of the possible risks with the purpose of the latter being minimized. Amongst the probable risks of photovoltaic systems there are several categories that could be mentioned. They are shown in table 1 which is not meant to be exhaustive:

The risk can be observed in different aspects. For instance utility company risks may affect the customer as well. Limited production of electricity or shortages in the supply may affect the daily schedules, and even be dangerous for the property. Nevertheless the risks in the Table 1 are observed basically from the perspective of the utility company.

Table 1. Possible risks categories (Source: Fthenakis *et al.* 2006; Chaves, Bahill 2010)

Risk	Description
Production of the system	Risks of impact on health and environment caused by the production materials usage
Utility company or grid	Operational risks: unavailability to meet the needs, limits of electricity produced etc.
Project development	Risks appeared throughout the process of the installation developing: changes of prices, design, permissions etc.
Technical problems	Hardware component risks: reliability, fire/explosion risks, relocation

End of Table 1

Risk	Description
Environmental	Local and environmental risks: effects on local population, climate, potential protests against environmental damages.
Policy	Government change risks: risks of the government politics change, geopolitical insecurity, war conflicts, changes of the national politics.
Financial	Risks of assets insufficiency, caused by theft, decreasing of the compensation price of energy, decrease of grants etc.

2. Modification of FMEA analysis – essence

FMEA uses the so called "Risk Priority Number" (RPN) for risk ranking. The value of this indicator is the criteria of the risk importance. The bigger the value of RPN – the more important the risk is – more attention should be given for its assessment in the next steps. Conventional FMEA determinates RPN as a multiplication of three characteristics of every risk factor.

$$RPN = O * S * D \tag{1}$$

where:
O is probability of the failure to occur,
S is severity of the failure,
D is ability to detect the failure, before it reaches the customer.

The three indicators have to be rated on a scale from 1 to 10. Thus RPN can range from 1 to 1000 and setting to zero the value of the overall rating is avoided. It is important for the next data processing. RPN is an important indicator of the risk factor's rank, it consists of the three most significant characteristics of the risk. Still it has certain disadvantages that have been criticized by many authors (Ben-Daya, Raouf 1996; Bowles 2004; Braglia *et al.* 2003; Chang *et al.* 2001; Gilchrist 1993; Pillay, Wang 2003; Sankar, Prabhu 2001), some of them are:

a) Different combinations of O, S, and D can produce the same value of RPN, but the consequences of their hidden risk differ greatly. For instance, two different events with values 2,3,2 and 4,1,3 respectively to O, S and D, have the same value of RPN (12), but the consequences caused by the hidden risks do not need to necessarily coincide. Thereby resources and time may be spent, and in some cases an event with high level of risk may stay unnoticed or at least be improperly ranked.

b) The relative importance between O, S and D is not considered. The weights of the three risk factors are treated as equal. It can be an obstacle for a comprehensive risk assessment using the FMEA approach.
c) Mathematical expression of RPN has been often criticized. There is no rational explanation why the multiplication of O, S and D produces RPN.
d) The three factors are difficult for evaluation and assessment.
e) The values of RPN are not continuous. There are lot of gaps between the values and they are mostly concentrated in the lower area of the scale from 1 to 1000. This is the reason for the problems in interpretation of the meaning of the differences between two RPNs. For example, is a difference between 1 and 2 is equal or is less to another difference between 900 and 1000?

There are many suggestions for overcoming these disadvantages in the literature, but in most cases they make the calculation process more difficult and may lead to new inaccuracies.

If we apply two changes to the characteristics we use, that would refer to all risk factors (not only those causing a failure), we could eliminate some of the most criticized aspects of FMEA:

- S – implementation of the weight of the damage instead of severity of the failure. The reason is that we evaluate the risks and their effects.
- D – implementation of a value for the possibility to overcome the negative influence of the risk factor at focus rather than just a possibility to uncover it.

Here is an example to support this modification:

The implemented value of preventing the negative effects possibility – D is rated on a scale from 1 to 10. As the higher mark means higher possibility to prevent the negative effect i.e. decreasing of the risk rank, this characteristic needs to be implemented as reciprocal. The modification of formula (1) will be:

$$RPN = O * S * \frac{1}{D}, \tag{2}$$

This change leads to:

- The overall rating of RPN will be limited to an interval from 1 to 100;
- Use of smaller numbers;
- Gap intervals decreases, so the intervals between the ratings can be observed easier;
- The values of the factors are more comparable;
- Eliminating of the problem of the wide location of RPN on the scale, as well as decreasing the large distances between close RPNs.

The most significant advantage of the modification is better unmasking possibility for hidden risks, as it was mentioned in subparagraph a).

For example, traditional FMEA formula:

RPN_1=2*3*2=12,
RPN_2=4*1*3=12,
RPN_2 which has higher detection ability and respectively lower risk compared to RPN_1 gets the same value of the importance.

Modified formula:

$$RPN_1 = \frac{2*3}{2} = 3,\ RPN_2 = \frac{4*1}{3} = 1\frac{1}{3}$$

The factor with a higher value for the possibility of preventing its negative effect RPN_2, so more attention will be paid to RPN_1 where the risk is more difficult to uncover and with a more difficult to overcome influence.

The modification solves the problem of the right ranking of the risk factors, without applying additional criteria, such as weights of every factor, which is a prerequisite to achieving meaningful risk assessment in innovations.

The quality of the assessment depends on members of the FMEA team, the way they work in a team and separately. We should consider the circumstance that every expert will evaluate the risk factors of the area he/she is specialized in as well as the factors for the areas outside his/her competence. Thus the approach has a weakness, but in the same time it gives us a useful advantage. Experts are evaluating the risks in their profiles uncovered by components and systems from the others' profiles which could not be evaluated by the respective experts. For instance, the expert on mechanism reliability is not able to evaluate the risk of electronic systems, but can make the most accurate assessment of the mechanisms risks. It is a common case that a person without being specialized in the current area could mention a risk that has been out of sight of highly specialized experts. This case refers to events which from the customers point of view would be of crucial importance for accepting or rejecting a certain product.

The rules for using the scale are implemented for the needs of comparability and reliability of the marks. Since the marking is in the beginning of the risk analysis, it is necessary to develop a system, which requires minimum amount of the output values. The linguistic marking is a suitable method which transforms a mark into a certain digit. For example, very low level – 2-3; medium level – 4-6; high – 7-8; very high – 9-10. There could be a requirement for the marks: integers, integers with decimal fraction or intervals. There are different ways of processing of the produced data for every requirement. The three risk factor parameters O, S and D are rated on this scale. The evaluation data needs to be placed in a table:

Table 2. Values of the expert assessment (Source: compiled by author)

<table>
<tr><td rowspan="3" colspan="2">Risk factor № $i=1…m$</td><td colspan="7">Expert № $j=1…n$</td><td rowspan="3">$\overline{R_j}$</td><td rowspan="3">Ranking position</td></tr>
<tr><td colspan="2">1</td><td colspan="2">2</td><td rowspan="2">….</td><td colspan="2">n</td></tr>
<tr><td>r</td><td>RPN</td><td>r</td><td>RPN</td><td>r</td><td>RPN</td></tr>
<tr><td rowspan="3">1</td><td>O</td><td></td><td rowspan="3">RPN_{11}</td><td></td><td rowspan="3">RPN_{12}</td><td rowspan="3"></td><td></td><td rowspan="3">RPN_{1n}</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>S</td><td></td><td></td><td></td></tr>
<tr><td>D</td><td></td><td></td><td></td></tr>
<tr><td>⋮</td><td></td><td></td><td>⋮</td><td></td><td>⋮</td><td>…</td><td></td><td>⋮</td><td></td><td></td></tr>
<tr><td rowspan="3">m</td><td>O</td><td></td><td rowspan="3">RPN_{m1}</td><td></td><td rowspan="3">RPN_{m2}</td><td rowspan="3"></td><td></td><td rowspan="3">RPN_{mn}</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>S</td><td></td><td></td><td></td></tr>
<tr><td>D</td><td></td><td></td><td></td></tr>
</table>

If there is some table data for certain parameters (for example for the possibility), then this data can be used by all experts. In this case the table data is processed through proportional transformation or similarly to the transformation of the linguistic marks into values from one to 10.

In the other cases a subjective assessment will be given. Still the subjectivity decreases due to the fact that the final assessment is a result of all the evaluations of experts in n-number.

After the rating determination using formula (2) a certain number of factors have to be chosen and they will be analyzed in relation to photovoltaic installations. With the realization of this approach and in the course of time the importance of certain risks may change – some will be omitted and new once could be added. That is why an available data revaluation and reassessment need to be processed in every new phase, and, if necessary, a new risk factor ranking should be processed (Kirova 2011).

A risk assessment cannot be comprehensive without being related to previously determined innovation’s economic criteria values. It is necessary to evaluate the factors that define the borders of the company abilities for overcoming the different risk factor negative effects. This kind of assessment is not the subject of the present study. This aspect has been mentioned only for the reason of defining of the way the risk factor assessment of an innovation process should be presented, especially the risk factor assessment using the present modification of the FMEA approach.

3. Use of FMEA for ranging risks of photovoltaic plants

3.1. Collecting data for analysis of the risks of photovoltaics[1]

Analyzing the risks of photovoltaics mentioned in the introduction will give the opportunity for applying the modified FMEA for their ranging. Risks are innate for every system and project including a photovoltaic plant. They represent a potential situation of loss or adverse course of circumstances. There are different definitions and classifications of risk that can be used. The approach of some researchers[2] is in the direction of identifying significant input received from experts and outsiders with the purpose of generating, quantifying and verifying risks. Therefore when creating a table or a matrix with the purpose of ranging the risks associated with photovoltaic plants it is necessary for them to be confirmed by professionals, academics, or other experts that can help verify, add or eliminate a certain risk (Kirova 2012). The risks appointed in this report are collected in its main part by Andrea Chaves and A. Terry Bahill from the University of Arizona, USA (Chaves, Bahill 2010) and are based on observations, statistical analyses, historical events or expert opinion. Also mentioned in the report are risks appointed in other sources. When analysing the potential risks associated with solar energy there are two categories that can be clearly distinguished. One of the groups of risks is related to factors that cannot be directly controlled like meteorological data and the second group is related to the software and hardware used, and human mistakes. Next follows an analysis of the risks associated with photovoltaics based on table 1 from the introduction.

3.2. Risks that can be associated with photovoltaic installations

The possible risks that may occur when applying PV innovations are described here with the purpose of defining their characteristics so as to demonstrate that they can be evaluated through the application of the modified FMEA analysis.

3.2.1. Climate risk

It is difficult to analyze risks that cannot be controlled and yet the climate conditions as a factor are also active and influence the work of the photovoltaic plants which means that they shouldn't be excluded from the analysis. Of all photovoltaic risks the main one is the risk associated with the weather conditions and more precisely the risk from less sunshine than expected. This is the sector that gives birth to the

[1] The risks for solar energy mentioned here are not specified whether they refer to the installation of the technology, its connection to the grid or its exploitation since this is not the purpose of the current report.

[2] There are a number of ways to classify risk but they are not the purpose of this research. The present report uses the classification of Haimes and Bahill (Chaves, Bahill 2010).

concept of climate risk management (Exsto Management 2012). Weather is a fundamental factor for these systems because they function based on it. While for the large systems built on renewable (photovoltaic) and conventional technology together there is a possible solution of increase of the unused production potential or connecting a technology for energy storage (Chaves, Bahill 2010), there are other options that are applicable for small plants:

- use of solar panels with two sides – they can produce up to 50% more energy from the conventional panels (Exsto Management 2012);
- use of climate derivatives (Plan for energy efficiency of Septemvri municipality 2011) and etc.

Today it is not possible to calculate with precision up to 1% what will the sunshine be in the next several years; its deviations could be predicted only with 10% to 12% accuracy (Plan for energy efficiency of Septemvri municipality 2011). Here data for the probable long term weather prognoses of the scientific centers of meteorology can be used.

3.2.2. Risks from the production of the systems

Part of the materials used for the production of photovoltaic panels are potential pollutants because of which the soil and air are exposed to contamination (Ghenchev 2010). At the same time there is risk for the people working on the production, installation and maintenance of the technology that they are exposed to (Vanelova 2012; Ungers *et al.* 1982; Moskowitz 1992). In order to minimize this risk the workers must be protected from falling from heights, unblocking systems, injuries at work when working with a crane and moving panels, electrical dangers, heat or cold stress, etc. These measures can be considered when evaluating the parameters of the different risks.

3.2.3. Risks for the utility company/ connection to the grid

The risks related to the grid include frequency of the net beyond the permissible restrictions, feeder circuit disconnects and shorts to ground. The abovementioned risks increase with the enhanced production of energy from photovoltaics since they can generate variable voltage different from the one on the grid. There is also risk for the business itself, for example from the obsolescence of the technology (The Economist 2012), as well as a risk from inability of the technology to take an unexpected potential momentary increase in the energy demand.

3.2.4. Hardware risks

The risks related to the construction of the plant (Schieg 2006) are amongst the least probable and include malfunction of a certain element or external factors like a lightening or dust. The incidence of failure with PV systems like invertors, PV modules, technology for energy storage and so on are classified as low to medium risks according to the expected consequences which may vary from a restart of the system to complex maintenance. Faults with the fitting are possible as well – short circuit, excessive voltage as well as problems related to the issuing of the necessary permits.

3.2.5. Technical problems

Incidents and human mistakes are amongst the most serious risks because they endanger human life. Such accidents though take place rarely and their incidence is extremely low. Risks of damage on the property are possible as well (for example, vandalism) or intervention from third parties arising from faults with the construction or testing of the new plant. The possibility of unplanned breaking off of the installation due to the insufficient available resources and as a result failure in the system or any of its components exists. The literature also points out risk from fire/ explosion that is related to dangerous materials released in the atmosphere during such an accident (Moskowitz, Fthenakis 1990) and risk during the transfer of the energy produced.

3.2.6. Environmental risks

Environmental risks (Moskowitz 1992; Kaygusuza 2009) include the direct risks of harming the surroundings (for example with fire) as well as the risks that appear in the future (like the demolition of the system after the period of its functioning ends or after irreparable damage). Bureaucratic resistance when intending to install the technology and during its work is possible. Unlike the large PV systems small plants cannot harm the local fauna or divert the paths of migration of species which is one of their pluses.

Risks related to the garbage generated when throwing away the system are not high because the PV does not contain any dangerous materials. The risk could increase if a change of the policy regarding the application of requirements related to the recycling with the purpose of decrease of the negative influence on nature appears.

Here belongs the risk of emitting carbon dioxide in the atmosphere. The production of energy from PV installations does not generate CO_2 but exactly the opposite is the case with the production of the elements of the photovoltaic systems.

3.2.7. Policy risks

The government risks include change in the legislation related to the policies on carbon dioxide or change in the price of the energy produced by photovoltaics, geopolitical instability, military conflicts, change in the national policy, etc. An influential factor would also be the change in the politics related to subsidizing energy from PV (The Economist 2012) as well as potential abuse and corruption when financing (Center for the study of democracy 2010). Possible are regulatory, governmental or contract risks, related to suppliers of equipment, contractors and third parties working on the implementation of the plant, arising from national priorities or restrictions.

3.2.8. Financial risks

Uncertainty in the price of energy and price for subsidizing of the energy are probable. Credit or budget limitations may be expected, for example insufficient access to capital which assumes the possible requirement of short term payback of the investment. Risks related to the currency exchange when purchasing equipment from the international markets and influencing the price of the carbon credits and the benefits of the increased productivity for the goods produced. Discrepancy of the investment costs, costs for saving energy, budget and credit limitations and the potential expenses related to the depletion of the available credit for energy efficiency instead for increase of the sales may occur (Kleindorfer 2011). Present is a market risk from decrease of the price of the purchased energy (The Economist 2012), risk from theft or malicious actions that represent a direct expense for the investor (Ghenchev 2010).

It is evident that the appointed risks - although some of them are very specific, are similar to the common risks with technical and technological innovations. This means we can conclude that there are no obstacles to apply FMEA analysis for their ranking.

4. Ranking of the risks through the FMEA analysis

Due to the fact that the number of the evaluations of every risk parameter of every risk factor is equal to the number of experts, the RPN has an interval value. The final value can be interpreted as an interval or as number value. Each type of the interpreting the value can be used in different ways of data processing. It is easier to represent the risk assessment as a digit for smaller companies and innovations. For this reason the modified model of FMEA is applied. The weight of RPN in the modified FMEA is not included, because the ranking is solved through the change in the very beginning – at the stage of RPN determination. The modification includes RPN, created in the suggested in point 1 manner, instead of failures. For each and one risk factor the following could be used:

$$R_i = \sum_{j=1}^{n} RPN_{ij} \,, \tag{3}$$

where, RPN_{ij} are the *n* numbers of the rating of the risks from the *i* row of Table 2, that have been defined by every *j* expert.

The obtained R_i includes the maximal and minimal values as well.

As we implement the 10 grade scale and consider 1 mark as a mark that shows no risk, we get a 9 grade scale, which means:

$$1 \le \frac{RPN_{j\max}}{RPN_{j\min}} \le 9. \quad (4)$$

The expert evaluation of each one of the experts for every risk under this condition will be in the 1 - 9 interval. The geometric average of the minimal and maximal value of the assessment is used for calculating the overall risk assessment, which includes the evaluations of all FMEA team experts, and it is situated in the interval:

$$\overline{R_i} = \sqrt{R_{ij\max} * R_{ij\min}}. \quad (5)$$

The application of the geometrical average has some advantages to other types of average values. Firstly, if we observe the geometric average values from the calculations of the FMEA team in the examples it becomes evident that the average geometrical value is closer to the prevaling values. Furthermore, it is the result of two values – optimistic and pessimistic, and it excludes underestimating or overestimating of the common value based on the end values without their mutual elimination. Geometrical average value is more meaningful and comprehensive for representing the interval in a digit value.

Here it is necessary to justify why we allowed the preparation of a ranking based on final marks which in the methods for use of confidence intervals is eliminated. When using geometrical values their influence on their common value is strongly decreased. Their influence can slightly shift the interval in the direction of their more strongly expressed extreme value. This is why these were not eliminated. The end values were not eliminated based on the fact that the different values of RPN belong to different profiled experts for one and the same risk factor. This does not exclude the opportunity for the experts who gave values different from the average ones to have correctly evaluated the corresponding factor if for example it is in their area. Having in mind that the risks are based on hypothetical or probable quantities the use of a probability and a suggestion in this detail will not worsen the end result – it will only show another probability. If the number of experts is bigger the possibility for a mistake is decreasing which is evident from formula (6).

$$R_{iav.} = \frac{\sum_{j=1}^{n} R_j + \overline{R_i} - \left(R_{ij\max} + R_{ij\min}\right)}{n-1}, \quad (6)$$

where, n is the number of experts.

Basically in this formula (6) the end values are replaced with their average geometrical value which gives the opportunity to compare with the average geometrical value of the marks. This is done for verification purposes. When applied at several calculations as an example it shows enough reliability of the suggested method for evaluation of the risk factors for their ranking. In this way the ranked risks can be used in any known methodology for risk assessment.

5. Conclusions

This study represents a modification of FMEA analysis. There are six conclusions made to summarize the main concepts of the current study:

1. FMEA is an analysis that can be adapted to other areas for wider application. That can be clearly seen on other succeed examples of FMEA modification. The proposed approach for the risk rank determination and its value or interval of values assessment expands the FMEA method application area outside the assessment of failures in the systems.
2. The RPN determination based on the proposed approach includes the values of the main characteristics of the risk factors. Thereby this number has the risk assessment role from the early beginning of the analysis, instead of a conditional value. It turns this modification into a direct instrument for risk assessment.
3. An expert team method using in FMEA brings an opportunity for a reliable and unbiased assessment of those factors, for which the statistical data is missing – the factors that usually do the preponderance of the cases in innovation process.
4. The adapted modification of FMEA for the risk factor assessment and ranking of innovations brings additional opportunities for the right risk evaluation using available and reliable methods and minimal output data amount.
5. Ranking of the risks when applying the modified Failure Mode Effect Analysis gives an opportunity for interpreting them as a value or as an interval. It could be used simultaneously according to the researchers needs.
6. The proposed modification for use of FMEA is based on a combination of pessimistic and optimistic values, which makes the intervals wider, but more truthful, and the risk geometrical average value is a representative way for interpreting the interval in one digit value.

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