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Alternative Manufacturing Processes (AMP) for Wind Turbine Blade Material, in Isolated Regime Based on AHP

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Abstract – The newest cutting-edge technologies in Renewable Energy Sources (RES) projects provides economic benefits for project developers, especially when installing a wind power in isolated regime. The research was focused on finding technological alternatives, using an optimal composite material for wind blades structure. In this sense, the research team made a decision based on critical analysis of today existing technologies that can provide feasible solutions. The Analytic Hierarchy Process (AHP) method provides results for choosing alternative manufacturing processes, suitable for blades structure, in isolated regime.

Keywords: collaboration, wind turbine, blade, energy, AHP, environmental.

I. INTRODUCTION

All aspects of a *Renewable Energy Sources (RES)* project life cycles include higher complexity, involves greater demand on the capabilities of project teams that need to possess appropriate experience to understand the implementation process for every activity in the project and must have special attention and knowledge to supply important components when installing a wind power in extremely weather conditions and difficult land form.

The complexity of Renewable Energy Sources projects implementation requires finding collaborative alliances between suppliers and project developers..

A collaboratively logistics system requires to be permanently dimensioned properly selected and monitored. Supply chain activities in RES project, in isolated regime implies complex activities for transportation of heavy components, finding quality raw materials, storage and materials handling [1].

Previous studies conducted by the research team in RES projects showed bottlenecks in wind power supply chain and communication difficulties between specialized teams for choosing the optimal blade material structure for a Renewable Energy Sources project, in isolated regime [2].

A challenge for wind power project developers are the obstacles that they encounter when need to strictly respect component technical specifications according to inclement weather and wind fluctuation. They also must analyze all the situations that could jeopardize the project like land form, transportation, rural roads, special equipment.

For a RES project in isolated region most common situations encountered by developers in the wind power project are [3]:

- Elaborating the project plan and how the tasks and goals will be achieved.
- What resources are needed, budget planning and scheduling deadlines for project completion?
- Obtaining necessary permits and approvals for construction work. Check and verify the installing location for power and water.
- Analysis and research of opportunities for reducing costs, by diversifying and simplifying equipment, multi-purpose of the components.
- The Financial plan funds is required, various reorganizations and restructurings are needed to complete the project in time and to achieve the desired goals.
- Tough searching suppliers that have the ability to achieve RES components with high precision.

From the point of view of supply chain, research team also identifies most common problems encountered by project developers in choosing special components for RES project in isolated regime. Related issues are presented below for blades, gearboxes, bearings, generators, cast iron and forged components, towers:

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Wind blades

A crucial component made from special composite materials that require sophisticated production techniques, global supply is dominated by independent blade maker.

Making wind turbine blade requires the execution of a sequential chain operations and time duration (this involves matrix realization, metal inserts, walls palette, pasting, filling with foam, static load testing). Some operations can be meticulous and improper organization of tasks and supply malfunction can cause delays in delivery components for implementing the project.

Gearboxes

The role of gearboxes in traditional wind turbines is to make the generator to spin much faster than the wind turbine rotor, thus creating the possibility of designing a small generator. According to the literature, in the manufacturing process of wind turbine gearboxes, achieving these gearboxes were faced with the most difficult supply due to the limited number of manufacturers adapted to market for wind power [5].

The most common problems are caused by deficiency of large bearings and frequent defects registered by gearboxes of wind turbines.

Bearings

Gearbox and main shaft of the traditional wind turbine utilizes large bearings, which are used on larger scale in heavy industry. Given that installing projects for wind turbines represent just an isolated activity segment for bearings large suppliers, specific deficits were recorded in the procurement process for manufacturing turbines.

Generators

The generator converts the mechanical energy into electricity. The generators used in wind turbines are slightly different from the usual, because the generator has the wind turbine rotor for power supply, which ensures very fluctuating mechanical power (torque). In the wind industry are already quite many specialized providers for such dedicated generators, so the supply does not suffer difficulties for this component [6].

Cast iron and forged components

This represents the highlights pieces, with which they configured the main frames used to support nacelle and rotor hub and main shaft, which connects the rotor gearbox. Similar situation encountered in large bearings, the market was again affected by high levels of activity in the heavy industry sector, with an increasing demand for both steel and wrought iron [7].

Towers

Although in the major wind farms, most turbine towers are made of rolled steel, currently tends to redirection producers to use concrete as a cheaper alternative. Manufacturing a wind turbine tower is an increasingly complex technical process and expertise from the design phase is more clear and available for alternative solutions than for other components.

Knowing these aspects in the RES supply chain can affect the collaborative behavior of suppliers and also can provide potential risks for quality and inventory. These risks affect the proper functioning of informational processes, materials and products between different parts of the supply chain in collaboration with other manufacturers and suppliers in RES.

The most difficult situation for project developers in implementation of the wind power project is the fact that when they purchase components through public procurement for a RES project in isolated regime. For public procurement project managers, must select those suppliers who fulfils all the technical requirements imposed by the isolated region. This process is very complex and time consuming and can made the project to surpass the installation time.

In order to identify wind blade specialized supplier in choosing optimal wind turbine blades for a RES project in isolated regime, the research team, propose a multi-criteria analysis method, that can provide feasible technical solutions for this type of project when are purchase components through public procurement.

Also, for type of project specialists' teams have been put in difficult situations to harmonize different equipment to install the components for wind turbine in the location and complete some additional activities like:

- Finding quality raw materials;
- Select an optimal construction and foundation;
- Strictly assembly process;
- Special storage handling.

In this scenario, a good collaboration between specialists' teams was a must because the isolated region characteristics had relative disadvantages for extremely weather conditions and landform, which made the wind turbine difficult to implement. The characteristics of isolated region has implied a smaller number of panels, and a power reduction of the wind generator. RES project in isolated region with extremely weather conditions and landform has required to use a wind turbine less than 1.0 MW.

The research was focused on finding technological alternatives, suitable for wind blades structure, in isolated region. Given the harsh weather conditions and wind speed, necessary wind blades were designed with great precision. Thus, it was required a multidisciplinary collaboration in decision making, to achieve an aerodynamic model and a structural model for wind blades.

The design process involved a structural model of the blade, to obtain a reduction in blade weight, which corresponds to the power of the wind turbine, less than 1 MW, using an optimal composite material structure. Based on the rare situation of the isolated regime, namely resulting solution of the designing process, the research presented in this paper offer a decision based on critical analysis of today existing technologies that can provide feasible solutions for wind blade structure adapting to isolated regime.

II. WIND BLADE STRUCTURE

Blades are placed in category of sensitive aerodynamic devices. Due to the fact that blades have a special design, these will not perform at full capacity if damaged, therefore, it is important to handle carefully when installing at the wind farm site. Back in the days in wind energy industry, large wind turbine blades have start to be manufactured from steel, aluminum and wood. Over the time, blades made from steel and aluminum has proven to be inefficient because of the overweight that has cause a poor functionality and energy waste. Meanwhile, manufacturers have turn their attention to composite materials, usually fiberglass and carbon fiber. Carbon fiber material provides the highest strength-to-weight ratio and stiffness, but has not been widely used because of his high costs. Typical reinforcement used in composite materials are stiff, strong and lightweight fibers such as e-glass fibers (good specific strength, low specific stiffness, relatively inexpensive) and carbon fibers (high specific strength and stiffness, expensive).

A good performance for wind blades implies a special manufacturing process, higher resin properties, quality fiber material, a higher level of automation, and a consistent process reduction in blade weight. The main objective of the manufacturing process is to reduce blade weight both on the blade and also on the rotor blade. Manufacturing methods have consequence on blade life. Blades manufacturing process and structure assembly represent a crucial process that required sophisticated production techniques for wind blades. In this case was obtained several alternative manufacturing processes (AMP): resin infusion, automated preform, thermoplastic resins, fully integrated structures and separately-cured spar structure (Figure 1). These AMP through Automated Preform Manufacturing represent a modern option to wind industry [4].

III. MULTI-CRITERIA DECISION MAKING

To achieve optimal selection for a wind blade structure in a RES project in isolated regime a Multi-Criteria Decision Making (MCDM) methods provide a logical framework to investigate, analyze, and solve such problems: Vargas (2010) offers schematic approach for the AHP method [9]:

- Provide an effective structure in decision-making process;
- Shows objectives which decision maker has identified;
- Measurable evaluation criteria of objectives are established;
- Provides several ways of aggregating data concerning criteria for obtaining indicators (scores) of alternatives performance;
- Helps to maintain decision makers thinking models by deriving the relative weight of each component;
- It is assigned a numerical value to each alternative of the problem;
- Through mathematical calculation is chosen the optimal alternative.

*One of the MCDM methods it is represented by **Analytic Hierarchy Process Method**.*

The algorithm AHP is done in six stages:

1. Hierarchical scheme composition of the problem that need to be analyzed. (Figure 2) In this phase it is presented fundamental purpose of the problem to be analyzed. Decision criteria are identified. Depending on the preferences of the analyst alternatives are presented and ranked by the decision. Utilization of AHP method involves the decision tree decomposition into criteria and alternatives. (Figure 2)

2. Establish relative weights by comparing them in combinations of two. The relative weights are based on a numerical scale from 1 to 9 through Saaty scale followed by subjective evaluation of the decision-maker comparisons are made in pairs. By comparison is obtained the degrees of importance of a criterion to each other (Table 1) [8].

3. The relative prioritization of the criteria is obtained by comparing criteria two by two depending on the decision criterion, in order to rank them.

4. Pairwise comparison is made for criteria gives them a global priority. Global priority for each decision criteria is determined by the result of multiplying each priority vector for each criterion on the second level of the decisional tree.

Table 1. Relative importance through Saaty scale [8]

#	***Verbal menaing for risk factor evaluation***	***Verbal menaing for alternative evaluation***
1	Equally important	Equally prefered
2	Equally to moderately more important	Equally to moderately prefered
3	Moderately more important	Moderately prefered
4	Moderately to strongly more important	Moderately to strongly prefered
5	Strongly more important	Strongly prefered
6	Strongly to very strongly more important	Strongly to very strongly prefered
7	Very strongly more important	Very strongly prefered
8	Very strongly to extremly more important	Very strongly to extremly prefered
9	Extremly more important	Extremly prefered

5. Performance matrix is achieved by calculating the relative prioritization of the alternative for each criterion. In this step is necessary to assess alternatives relative weights from the third level of the hierarchy, the process is similar to that has been used in criteria group for the purpose decision-making. This process is executed as the previous step, but the difference does that this step is performed assessment of each alternative beside each criterion.

6. The final decision is obtained by choosing alternative priority with maximum points.

IV. ALTERNATIVE MANUFACTURING PROCESSES (AMP)

It is known that infusion processes have the potential for low-cost, high-quality production of wind turbine blades, with the added benefit of having low volatile emissions. Additional benefits may be possible if the infusion process is combined with automated preforming technologies [4].

Automated preform manufacturing have advantage to reduced hand labor, improve quality of fiber placement and orientation, and reduce production cycle times. The research team indicated the main criteria through Automated Preform Manufacturing: **Stitched Hybrid Fabrics, Cut-and-Sew Preforming, 3-D Woven Preforms, 3-D Braided Preforms and Oriented Sprayed-Fiber Preforms** (Table 2 and Figure 1).

Automated Preform Manufacturing processes for blade structure indicated that all preforms are assumed to be a combination of carbon / fiberglass material showing different benefits and limitation for each criterion.

After the information's were obtained in Tab.1 the research team must to take into account what material composite structure for wind blade has an automated preform manufacturing that is relevance for the RES project, in isolated regime. Analyze the options presented in Table 2 indicates that Cut-and-Sew Preforming can reduce production cycle times but is not very reliable and could not easily be adapted. This is the reason way Cut-and-Sew preforming would not be compered due to the lack of information for delivery time and difficulty rate.

Stitched Hybrid Fabrics is somewhat more expensive, have a higher rate to operate, and it is very reliable but not very adaptable. 3-D Woven Preforms is a little less reliable than Stitched Hybrid Fabrics due to delivery time but is claimed by the manufacturer to have a wide range of alternative uses. 3-D Braided Preforms and Oriented Sprayed-Fiber Preforms have the same difficulty rate but different benefits [4].

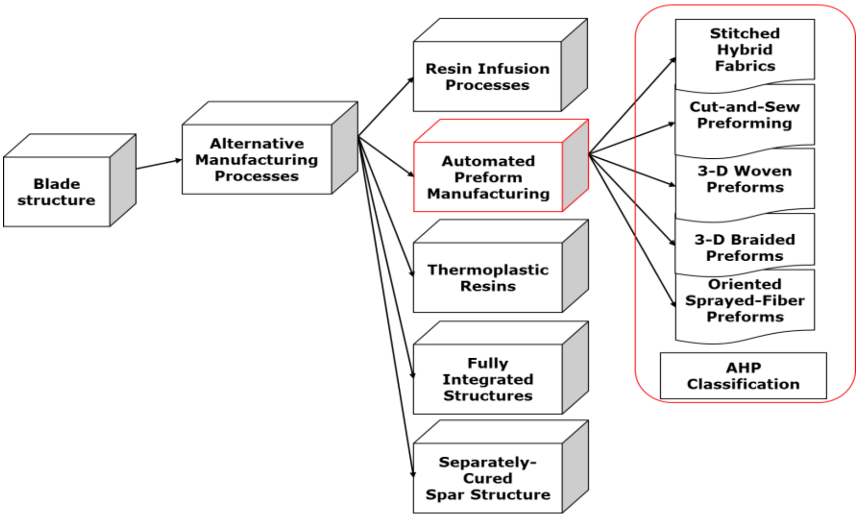

Fig. 1. Blades alternative manufacturing processes [1]

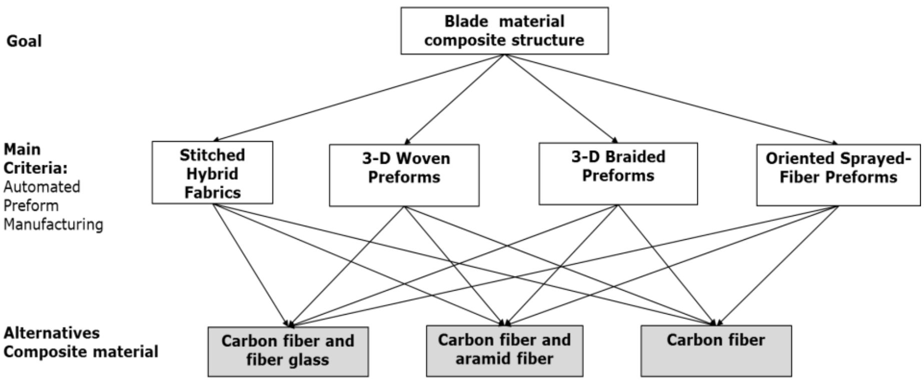

Fig. 2. Blades structure [8]

Table 2. Blade material composite [4]

APM for blade structure	*Benefits*	*Limitations*	*Material combination*	*Delivery time*	*Difficulty rate*
Stitched Hybrid Fabrics	carbon fiber contributes high tensile compressive strength and stiffness and reduces the density, while glass reduces the cost	increased cost and weight of the spar cap structure	unidirectional carbon fibers with e-glass tri-axial fabric	3 weeks	Higher
Cut-and-Sew Preforming	combination of unidirectional or multiaxial fabrics and as a result can be used to reduce production cycle times	not yet identified a manufacturer to evaluate the potential of cut-and sew preforming for application to wind turbine blades	N/A	N/A	N/A
3-D Woven Preforms	higher stability for fiber placement and laminates have higher resistance to crack propagation	considered unlikely to be cost-effective and more difficult to infuse with resin	carbon in the warp direction and e-glass in the fill and axis directions	4 weeks	Very higher
3-D Braided Preforms	manufacture of small (50 to 100 kW) wind turbine blades achieving the objectives for reduction of labor costs, less material costs and improved blade quality and reliability	braiding processes considered appear non-competitive for manufacturing large wind turbine blade spar cap structure	unidirectional carbon fibers	2 weeks	Moderate
Oriented Sprayed-Fiber Preforms	low hand labor costs, control of fiber placement, control of fiber orientation, high level of consistency, capability to produce complex geometrical shapes, low waste of raw materials, and decreased cycle times	large wind turbine blades	carbon and fibers	2 weeks	Moderate

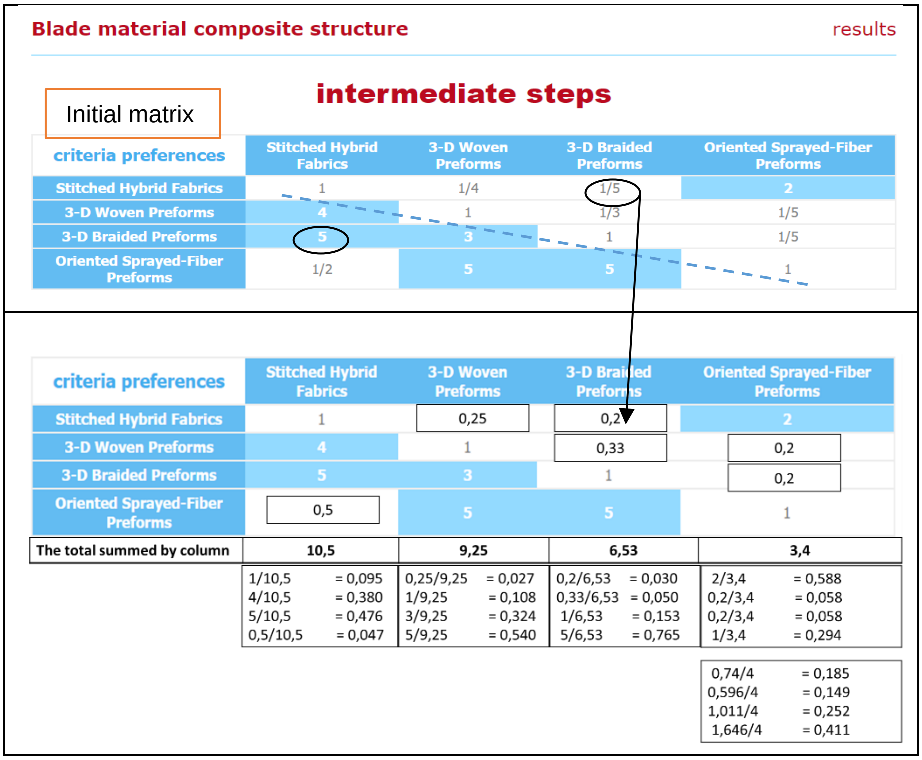

Fig. 3. Initial matrix for criteria

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V. AHP RESULTS

Automated preform oriented sprayed fiber ofers low hand labor costs, control of fiber placement, control of fiber orientation, high level of consistency, capability to produce complex geometrical shapes, low waste of raw materials, and decreased cycle times.

A decision hierarchy is configured through a graphical representation of the goal, the main **criteria,** (*Stitched Hybrid Fabrics, Cut-and-Sew Preforming, 3-D Woven Preforms, 3-D Braided Preforms and Oriented Sprayed-Fiber Preforms*) and **alternatives** (*Carbon fiber and fiber glass, Carbon fiber and Carbon fiber and aramid fiber*). This hierarchic frame and decomposition represent a succinct summary of the decision problem.

In order to have a clear evidence it was employed a numerical rating to 1-9 and reciprocal rating of the Saaty scale [7]. Using Saaty scale, a basic, but very reasonable, assumption is that if criteria 3-D Braided Preforms have a ***Strong importance*** than criteria Stitched Hybrid Fabrics and his value is 5, then Stitched Hybrid Fabrics is ***Less important*** and his value is 1/5.

3-D Braided Preforms is focused on manufacture of small wind turbine blades (50 to 100 kW) achieving the objectives for reduction of labor costs, less material costs and improved blade quality and reliability. Criteria preferences are designed through a matrix noted with numerical value from Saaty scale.

Criteria Stitched Hybrid Fabrics is ***Less important*** compared with 3-D Braided Preforms and his reciprocal value is 1/5, namely 0.2 and the same calculation are done for all reciprocal criteria. It is provided an initial matrix for pairwise comparisons in which the principal diagonal contains entries of 1, as each criteria is as important as itself (Figure 3).

In order to interpret and give relative weights to each criterion, it is necessary to normalize the previous comparison matrix. Stitched Hybrid Fabrics has a total summed by column a value of 10.5 (1+4+5+0.5). The normalization is made by dividing each table value by the total summed in column value, namely 1/10.5, 4/10.5, 5/10.5 and 0.5/10.5.

Criteria preferences for Stitched Hybrid Fabrics has a value of 0.185 and has been calculated in line summing the values (0.095+0.027+0.030+0.588) and divided by 4 (represent the number of criteria) (as presented in Figure 3).

Final result provided by AHP algorithm are obtained and criteria importance has indicated **Oriented Sprayed Fiber Preforms**.

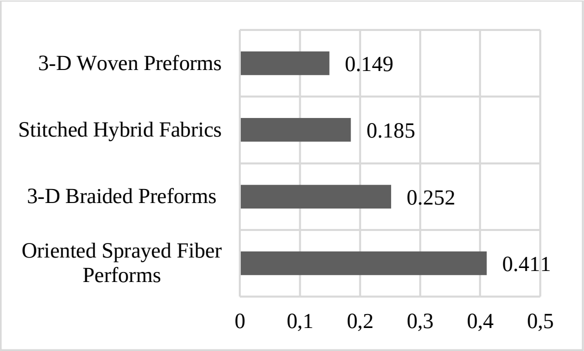

Fig. 4. Criteria importance

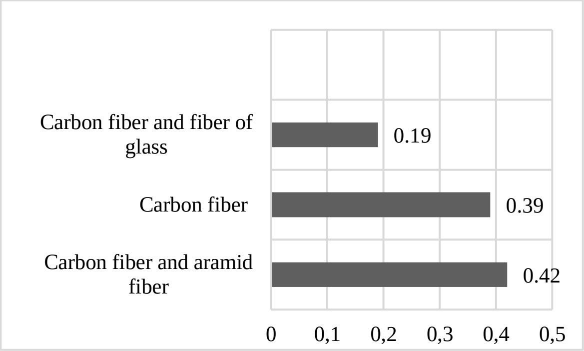

Fig. 5. Alternatives importance

An impediment using this preform made by the manufacturer was that this type is more suitable for large wind turbine and in this RES project in isolated regime the wind turbine used was less than 1.0 MW power.

Second option given by AHP method was the **3-D Braided Preforms** because it is specialize to manufacture small (50 to 100 kW) wind turbine blades, but also achieving the objectives for reduction of labor costs, less material costs and improved blade quality and reliability (Figure 4).

Using AHP algorithm identified the optimal combination of composite blade structure so as to meet the unique technical parameters specific for RES project. ***The alternative provided by AHP algorithm indicated using a hybrid composite material for wind blades, respectively carbon fiber and aramid fiber (0.420)(Figure 5)***

VI. CONCLUSION

This ***hybrid composite material*** offers economic and environmental advantages for assembling a wind turbine in isolated regime. Given the harsh weather conditions and wind speed, the 3-D Braided Preforms for wind blades can ensure a reliable alternative.

Based on AHP method, decision obtained for 3-D Braided Preforms provide feasible solutions. RES projects in isolated regime are a compromise solution, but implementation on such projects provides local energy needs in isolated locations. Even in this case these represent an important way for generating green energy which in a visible manner sustain the strategy to achieve Romania's mandatory targets within the EU strategy 20/20

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