Study and Evaluation of Offshore Wind Energy Potential in Indian Sub continent through TRIZ using CFD

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Abstract:

Offshore wind turbine is now being seriously considered as a crucial energy source to achieve not only CO_2 reduction, but also to meet the enormous power shortages that occur in India and around the world. Nevertheless offshore wind energy is not competitive as on today with other sources of energy. There are combination of some select technologies which could bring about improvement in offshore wind turbine and wind farm design to increase the overall power output to increase the robustness, efficiency, capacity factor etc. To achieve these, combination of several technologies like drive train, blade count, blade material, blade shape, foundation etc are needed. But, this paper brings about a new dimension to identify feasible regions for wind turbine placement through a new technique called TRIZ (Theory of Inventive Problem Solving). TRIZ uses scientific principles to identify and choose geographically the optimal location having high velocities. This new technique helped in applying the fluid flow principle of venturi to offshore applications. To evaluate the optimality of venturi region computational fluid dynamics (CFD) tool was used. This paper demonstrates the venturi effect created in a region between dhanushkodi (southern tip of India) and northern tip of Srilanka and its geographical advantage in generating higher wind speeds and thus achieving enhanced output. This paper introduced three new concepts, first TRIZ helps in relating its principles to scientific phenomenon in new areas to achieve optimality and improvement. Second it uses the venturi concept for wind energy applications and third it validates the working of the identified principle using CFD and demonstrates that a concept identified through TRIZ is practically implementable in solving real life problems.

KeyWords: Offshore wind turbine, Venturi Effect, TRIZ, CFD, Increased power Output, CO_2.

Nomenclature:

TRIZ – Theory of Inventive Problem Solving

CRZ – Coastal Regulation Zone

SODAR – Sound Navigation and Ranging

LIDAR – Light Detection and Ranging

I. INTRODUCTION

Wind energy has become a mainstream source of energy in most places in the world. This allows for rapid installation and expansion of the industry. India is one of the countries having largest wind turbine installations. As the price of the fossil fuel keeps rising every year, the growth prospects of wind industry is growing every year. Onshore wind farms are often subject to several restrictions and objections like obstructions with buildings, limited availability of lands, land use disputes, negative visual impact, noise etc. But the offshore wind farm does not have all these issues. It has higher and more consistent wind speeds, and consequently, higher efficiency. In offshore, there is a clear potential benefit at higher tip speeds, and less acoustic emission levels and its impact on society. Offshore wind turbines are costly than onshore wind turbines. Only 1.5% of the total installed capacity in the world is offshore wind turbines. Offshore energy has great potential in India. Scarcity of land, rising land prices and hurdles of acquiring vast starches of land due to peoples agitation are some of major hurdles in the growth of onshore wind farms in India. Center for Wind Energy Technology (CWET) has conducted a survey to find the feasibility of setting up offshore wind turbines in Bay of Bengal and Indian ocean region. Tata Power is the first private sector player to submit a formal request to the government of Gujarat and Gujarat Maritime Board for approval of an off-shore project in India.

Techniques to evaluate the wind resources potential at a specific onshore site are well established. But direct measurements at sea are more difficult and much more expensive. Offshore wind energy assessment is mainly based on long term measurements at nearby land sites. The paper [1] attempts to formulate a model to help the international community to understand how wind industry in China helps in meeting the increasing electricity demands and also to mitigate the global warming impacts from coal fired approach. Multiple wind turbine design characteristics and the potential synergistic effects of one design feature with another is discussed by Tugrul[2], and this paper provides an optimized design using mathematical and computer modelling relative to the cost, environment, robustness, and overall efficiency of an off-shore wind turbine. Souma [3], highlights ways to optimize the selection and placement of wind turbines in wind farms that are subject to varying wind conditions. Measure–Correlate–Predict method was used by J.F. Manwell [4] for coastal wind resource assessment and it data was validated using MesoMap software. Blaise [5], talks about improved techniques to calculate the wind power resource of an offshore area. It also evaluates the method to identify areas less suitable for development due to physical or technical constraints, safety or other hazards, environmental concerns, or competing uses. Efficient methodology for optimizing the arrangement of wind turbines in wind farm and selection of suitable size wind turbines based on varying wind conditions was discussed by Souma[6]. Tugrul [7], explains how the wind farm makes a remarkable improvement of 6.4%, when the farm layout and the turbine selection are simultaneously optimized. Markus [8] talks about the similarities and differences of TRIZ and classical methods using a case study from automotive industry by combining application of TRIZ and classical design methods. TRIZ was incorporated in eco-design to bring about QFD by Hideki[9]. TRIZ was used as a tool by K.K.Padmanabhan[10] to increase the power output of a roof top wind turbine. T. Van [11], explains how a venturi-shaped roof is used for wind- induced natural ventilation of buildings. The method has been validated using CFD for different design configurations. Statistical models were developed by C. Gallego[12] to forescast the offshore wind power. In order to improve the reliability of power losses calculation in many different kinds of environment; analytical models are going to be replaced by new Computational Fluid Dynamics (CFD) which seem to be more useful as said by Francesco[13], especially for large offshore wind farms.

II. NEED AND POTENTIAL TO BE EXPLORED

The map shown in [Figure 1(a)], shows the geography of night consumption of the world. The map shows that eastern United States is brighter in the U.S region. In the Asian map shown in [Figure 1(b)], the picture shows that India and China is very bright. There are still many regions in Asia which still appear dark. The brighter region represents the region of high industrial growth and development. Hence, there is a need to supply these areas with uninterrupted power supply. The darker region indicates underdeveloped region that lacks electricity. This depicts a wide gap between demand and supply.

Figure 1(a): Image Map showing the Night Electricity Consumption of the World

Figure 1(b): Image Map showing the Night Electricity Consumption of the Asia (Source:NASA)

In the world nearly 1.4 billion still have no access to electricity (87% of whom live in the rural areas) of these India accounts for over 300 million and another 1 billion have has access only to unreliable electricity networks. (*Rebeca Grynspan, UNDP Associate Administrator and Under Secretary General, Bloomberg New Energy Summit, April 7, 2011).* The electricity sector in India currently has an installed capacity of 210.951 GW as of December 2012. The International Energy Agency estimates India will add between 600 GW to 1200 GW of additional new power generation capacity before 2050. Strategies and methodologies should not have harmful effect on climate and environment. But instead should lead to new employment generation, optimal resource usage and eliminate environmental degradation and global warming.

India's electricity sector is amongst the world's most active players in renewable energy utilization, especially wind energy. As on December 2012, India had an installed capacity of about 17,000 MW of wind energy. India currently suffers from a major shortage of electricity generation capacity, though it is the world's fourth largest energy consumer after United States, China and Russia. The International Energy agency estimates that India needs an investment of at least $135 billion to provide universal access of electricity to its population.

III. GLOBAL OFFSHORE WIND SCENARIO

Offshore wind power is one of the promising energy sources to meet the energy needs of the world. The current global offshore wind power capacity totals just more than 4.1 GW [Table: 1]. The development is concentrated mostly in Europe, especially the United Kingdom.

Table 1: Summary of Installed global offshore capacity 2011. (*Source: BTM 2012)*

Region	**Country**	**Number of Operational Projects**	**Total Capacity(MW)**	**Total Number of Turbines Installed**
ASIA	China	4	211.4	75
	Japan	3	25.32	14
	Belgium	2	195	61
	Denmark	16	874.65	406
	Finland	3	32.3	11
	Germany	6	205.8	53
	Ireland	1	25.2	7
EUROPE	Italy	1	0.1	1
	Netherlands	4	246.8	128
	Norway	1	2.3	1
	Portugal	1	2.0	1
	Sweden	5	163.65	75
	United Kingdom	20	2117.6	640
	Total	**68**	**4102**	**1472**

While Europe (particularly the U.K. and Denmark) leads the global offshore market, China is making efforts to position itself as one of the leaders in offshore wind energy by announcing plans to Install 5 GW by 2015 and 30 GW by 2020. (GWEC 2012). Based on each country's announced targets various forecasts have predicted the global offshore wind market to reach between 55 and 75 GW of cumulative capacity by 2020 (IHS Emerging Energy Research 2010; BTM Consult 2010; BVG Associates 2011a). Among the various U.S offshore projects Baryonyx Rio Grande wind farm(1000 MW), Baryonyx Mustang Island wind farm(1000 MW) and cape wind farms (468 MW) are some of the largest offshore projects among several others.

IV. OFFSHORE WIND ENERGY SCENARIO IN INDIA

Prospects of offshore wind energy in India is very bright because it is covered on three sides by water and on one side by land having a coastline of 7516 kms (Mainland, 5046 kms, Islands 2470 kms). Coastal Regulation Zone (CRZ) Laws of India permit installation of Wind Turbines within 12 nautical miles from the Indian shores. Currently India does not have any offshore wind turbines. But the potential for offshore wind turbine is enormous. [Table 2] gives the list of first 10 countries having the high wind index. Wind Index are scales that indicate the energy yields with reference to a pre-defined long term mean value. Wind Indices are measured from actual data figures measured from metrological station over long time periods. Wind indices are also used for evaluating the energy yields from existing turbines and wind farms. Thus, the index helps in comparing the yield before and after commissioning.

Table 2: Wind Indices
(Source: Ernst & Young analysis, August 2012)

S.No	Rank	Countries	Wind Index	Onshore Wind	Offshore Wind
1	1	China	77	78	70
2	2	Germany	69	66	80
3	3	U.S	64	66	55
4	3	India	64	70	41
5	5	U.K	64	60	79
6	6	Canada	63	66	46
7	7	France	57	58	53
8	7	Italy	56	58	47
9	9	Sweden	55	55	53
10	10	Poland	54	57	44

The Indices show India at the third rank, indicating the vast potential of Indian wind turbine industry. The paper presents a review of suitable location to develop offshore wind turbines in Indian shores to harness maximum power, currently there are no offshore wind turbines in India today.

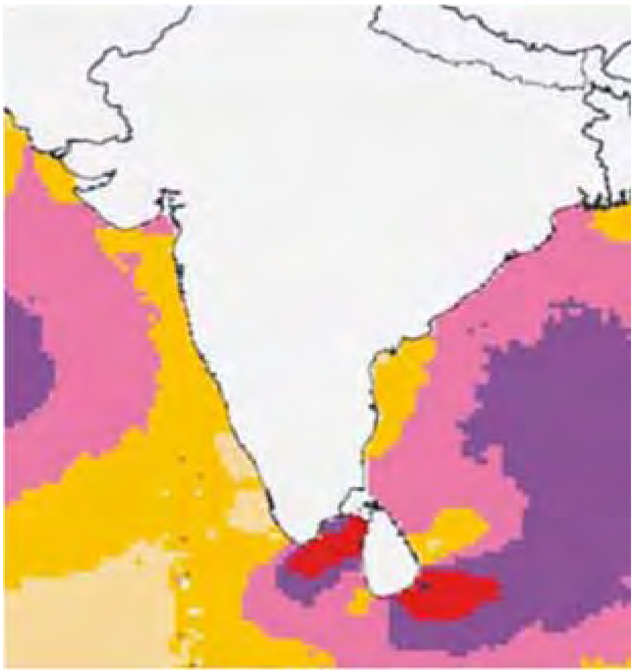

Figure 2(a): India Wind power density Map

Class	Resource Potential	Wind Power Density at 50m (W/m^2)
	Poor	0 – 200
	Marginal	200-300
	Fair	300-400
	Good	400-500
	Excellent	500-600
	Outstanding	600-800
	Superb	>800

Figure 2(b): India Wind power density values

A feasibility study was conducted by CWET to study the wind characteristics like wind speed, wind direction, sea temperature, sea current characteristics, wave data etc. The results of the study showed that Rameshwaram region in the southern tip of India in the Indian ocean and bay of bengal region has a wind power density of 600-800 W/m^2 as shown in [Figure 2(a) and 2(b)].

V TRIZ Methodology

In Russia, TRIZ theory means Theory of Inventive problem solving. In English it is called TIPS, and was introduced by Genrich S.Altshuler (1926-1998) and a series of researchers in 1946, based on analyzing and researching more than 250,000 patents all over the world. TRIZ methodology was adopted as shown in [Figure 3(a)].

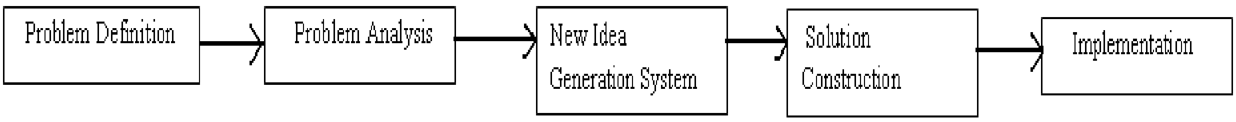

Figure 3(a) : TRIZ methodology adopted

A) *Problem Definition:*

(i) *Undesirable effect:* Choosing right location in seas is difficult due to plenty of governmental clearances and low yearly average wind speed.

(ii) *Task statement:* Adopt strategies and ideas to place turbines in the windiest region to keep the rotor rotating for maximum time period.

(iii) *Plausible root causes:* Certain locations in seas receive more wind due to geographical shape and the monsoonal wind directions of a country.

(iv) *Minimum set of Technical Systems required:*

To make practical measurements in sea, technically advanced measurements like SODAR and LIDAR is used. To make measurements over vast stretches of sea involves lot of cost, manpower and time. CFD is another technique by means of which wind speeds are assessed over a large region in a short span of time, at a lesser cost and difficulty.

B) Theory of Venturi Effect:

The Venturi effect is the reduction in fluid pressure that results when a fluid flows through a constricted section of pipe. The fluid velocity increases through the constriction to satisfy the equation of continuity, while its pressure decreases due to conservation of energy. The gain in kinetic energy is balanced by a drop in pressure or a pressure gradient force

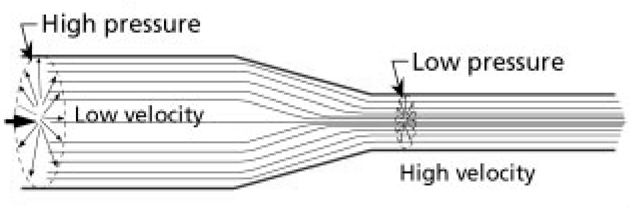

Figure 3(b) Venturi Effect

Referring to the [figure 3(b)], Bernoulli's equation is a special case of incompressible flows (such as the flow of water or other liquid, or low speed flow of gas), the theoretical pressure drop ($P_1 - P_2$) at the constriction is given by [Eq 2]

$$P1 - P2 = \frac{\rho}{2}\left(v_2^2 - v_1^2\right) \qquad [\text{ Eq 2 }]$$

Where

ρ is the density of the fluid(Assumed to be constant)

V_1 is the Initial (Slower) velocity of fluid.

V_2 is the Final (Faster) velocity of fluid.

P_1 and P_2 is the Initial and Final pressure of fluid

VI MONSOONAL EFFECT ON OFFSHORE WIND ENERGY POTENTIAL

In India winds occur mainly during the monsoon periods. This monsoon has two phases namely (a) Southwest [SW] monsoon and (b) Northeast [NE] monsoon as shown in Figure 4(a) and 4(b). (a) In SW monsoon, the surface winds blow along the western coast of Indian peninsula during the months from June to November and there are some occasional occurrences of cyclones in the Arabian Sea. Another phase is the (b) NE monsoon in which wind blows from northeast direction along eastern coast of Indian peninsula during the months from December to May and also associated with the occurrences of cyclones in Bay of Bengal during this period.

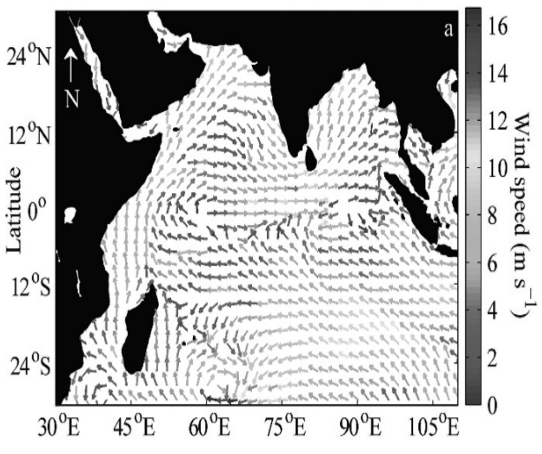

Figure 4(a): South West Monsoon

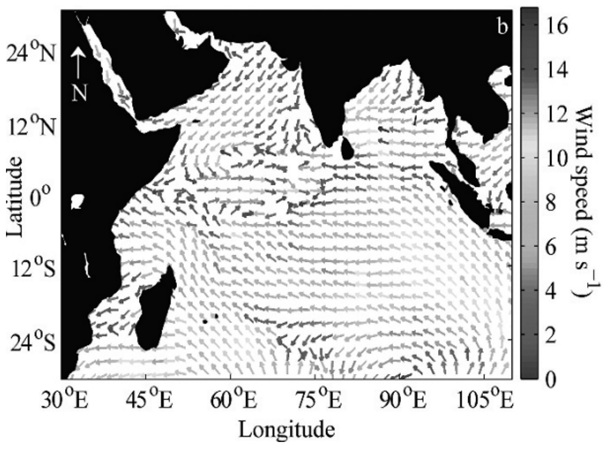

Figure 4(b): North East Monsoon

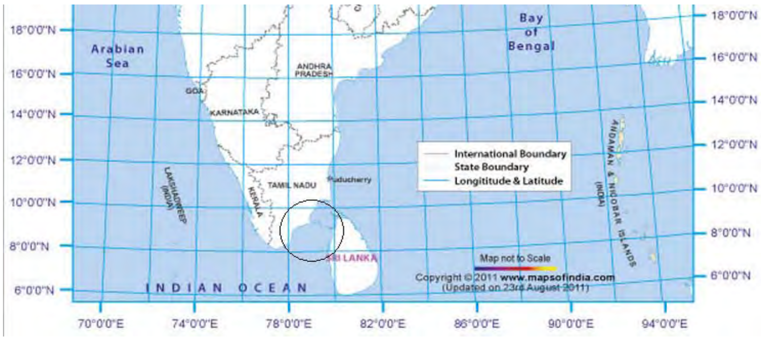

Figure 5(a) Southern part of India

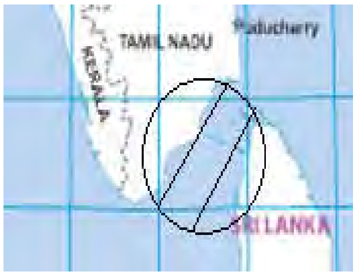

Figure 5(b) Enlarged View

It is observed that the region at the southern tip of the country near rameshwaram (Encircled) as shown in Figure 5(a) and 5(b), receives significant wind velocities during both these monsoonal seasons. It covers an area of almost 2^0 on latitude and 2^0 on longitude. Each degree is approximately 111 kilometers (69 miles).

Latitudinally, from 8^0 to 10^0 degree it coverage is 222 kms and longitudinally from 78 to 80 degree the strech covers 222 kms. Clearly the potential area that can be harnessed is 222 x 222 km = 49284 km.

VII CFD ANALYSIS OF MONSOONAL WINDS

The diagram of India was drawn using solid works modelling software and analyzed using computational fluid flow analysis package of version 2014. The fluid flow parameter under which the fluid flow simulation analysis test was conducted is given in [Table 4].

Table 4: Parameters of CFD Analysis

S.No	Parameter	Values
1	Fluid	Air
2	Roughness	0.0001 m
3	Pressure	101325 Pa
4	Temperature	293.2 K
5	Flow Characteristics	Laminar and Turbulent
6	Flow Type	Steady Flow
7	Mesh Type	Volume Mesh
8	Mesh Count	122546
9	Reference Axis	X
10	Velocity in X-Direction	6 m/s
11	Flow Parameters	Uniform flow Normal to Face
12	Boundary Condition Type	Inlet Velocity
13	Turbulence Intensity	0.1%
14	Turbulence Parameter	k-ε

(A) South West Monsoon:

In case of southwest monsoon, the wind blows along the western coast of Indian peninsula. As the wind passes through the region between India and srilanka, there is an increase in velocity of wind. This increase in wind velocity occurs due to the naturally located venturi shaped location near Rameshwaram. The shape creates a venturi effect. The venturi effect refers to increase in fluid speed due to decrease in cross section. This paper investigates the extend to which the venturi effect contributes to the increased wind speed in the passages.

The fluid velocity increases through the constriction as shown in [Figure 6(a)]. The enlarged view of the location is given in [Figure 6(b)]. This increase in velocity from 6 m/s to 9.67 m/s and then upto 17.4 m/s occurs due to pressure drop(P_1-P_2) at the constriction.

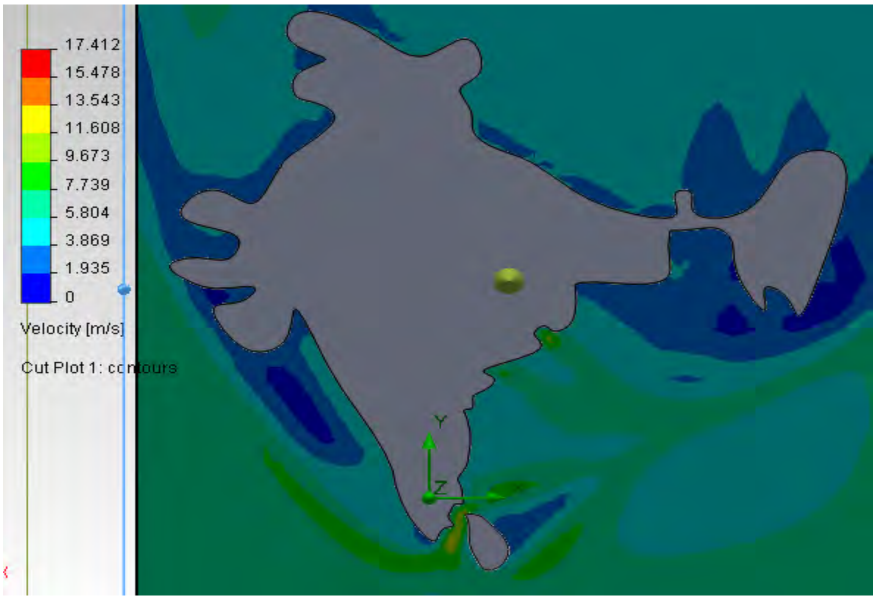

Figure 6(a): India map showing the wind velocity at southern tip during South West Monsoon.

The velocities taken for computation at sea level have a roughness length of 0.0001 m.

The hub height at which the turbine is to be placed is at 100m. The wind velocities at higher altitudes can be evaluated by extrapolation as given in [Appendix 1].

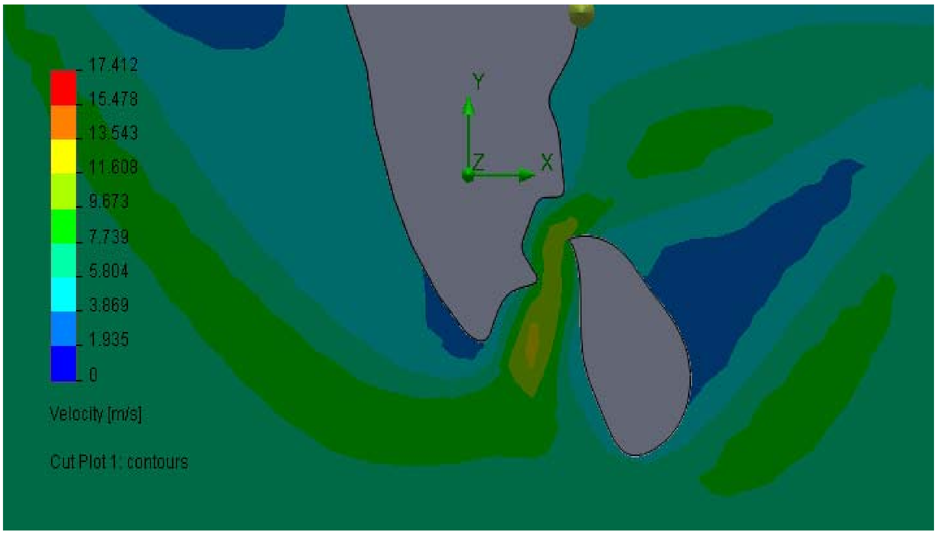

Figure: 6(b) Enlarged view of Southern part of India during South West Monsoon.

(B) North East Monsoon:

In case of North east monsoon, wind blows from north east direction along the eastern coast of Indian peninsula as shown in [Figure 7(a)], enlarged view of the specific location is given in [Figure 7(b)]. The initial wind speed given was 6 m/s. To make the offshore wind turbine economically viable, wind speed of more than 6.5 m/s is needed.

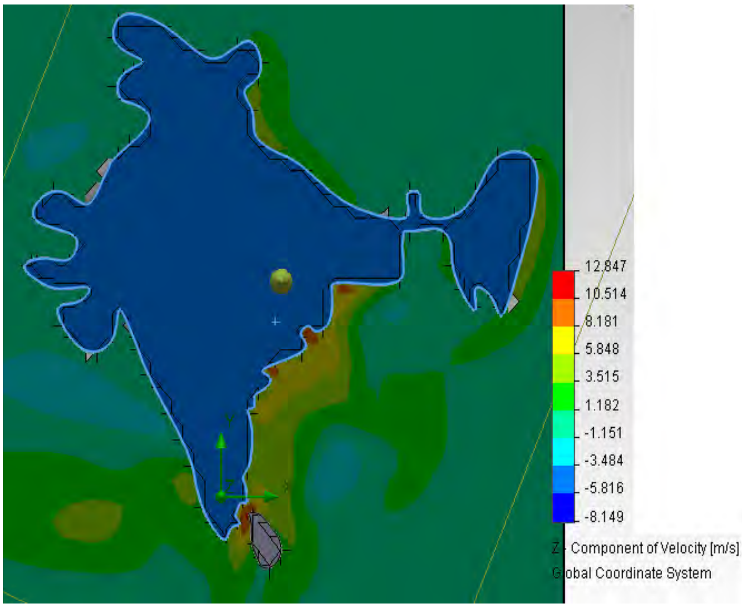

Figure 7(a): India map showing the wind velocity at southern tip during North East Monsoon.

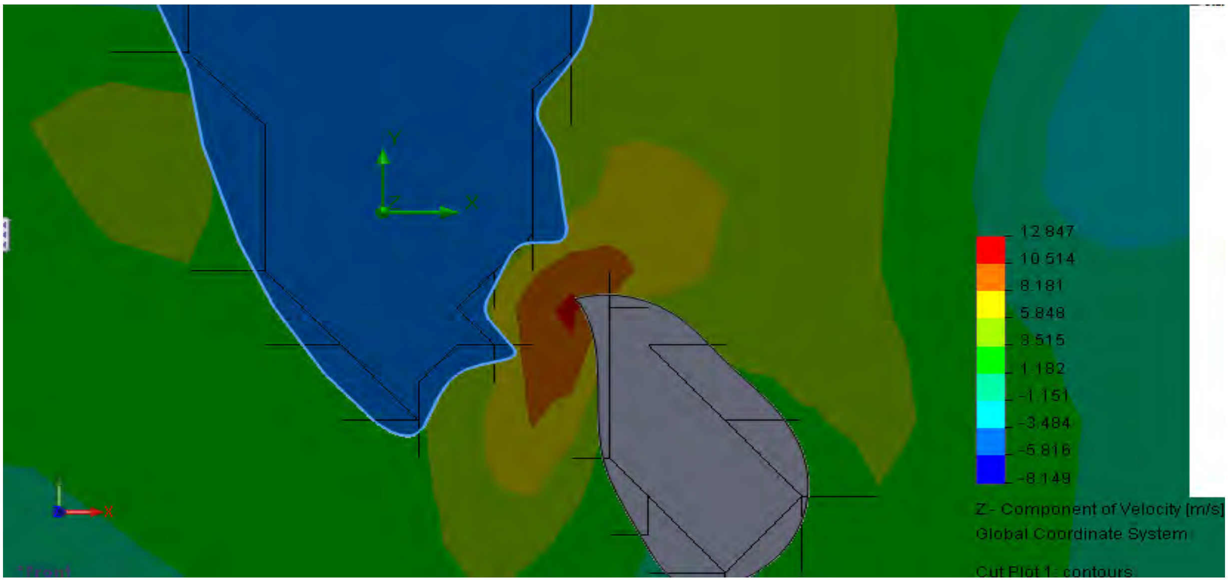

Figure 7(b): Enlarged view of Southern part of India during North East Monsoon

The observed velocity increase in the narrow passage near rameshwaram as indicated in [Figure 7(b)], shows a velocity of 12 m/s.[Figure 8(a),(b),(c)] shows the aerial view of the region under evaluation. The increase in velocity from 6 m/s to 12 m/s is double the initial value. Considering a turbine of hub height 100m, rotor diameter of 136 m, with a capacity factor of 0.3. The increase in power output due to veturi effect of wind velocity is from 0.58 MW to 4.63 MW. There is an eight fold increase in power output, due to venturi effect.

8. CONCLUSIONS AND DISCUSSION

The concept of venturi has many vital applications in the field of fluid mechanics. The shape of the container in which the wind flows has a significant effect on the pressure and velocity of the fluid.

Performance maximization, cost minimization and profit maximization are the general objectives of any project. This paper identified the possibility of applying the venturi effect in a geographical location using TRIZ methodology. This methodology was evaluated using CFD by drawing the geographical stretch spanning 222 Km length and 111 Km width. The Indian border lies only till 12 nautical miles(19.3 Km) from the shores, beyond which it is international waters. So, the total rectangular area of the Indian stretch is 222x19.3 = 4285 km^2 . By placing turbines of 136 m diameter at a hub height of 100m in 222 rows and 19 columns, with distance between each turbine as 1 km, 4218 turbines could be placed.

The rated power output from each turbine is 4.63 MW. The total possible power generation potential is 19529 MW at this offshore location. 1MW of wind energy can offset approximately 2,600 tons of carbon dioxide (CO_2) every year [source: NREL]. So, 19529 MW generation through offshore wind helps in reducing a massive quantity of CO_2 , which otherwise would be met through coal and other non renewable sources. The state of Tamilnadu now faces a power shortage more than 4000 MW and the shortage is likely to increase every year by an additional 1500 MW. To meet this huge power deficit, utilizing this offshore location would be best solution.

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