Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 02, February-2020

# Analysis of Hybrid Solar Thermal and Wind Energies Combined in Compressed Air for Power Generation

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***Abstract*: This work analysis the configuration and operation principles of hybrid wind-solar with compressed air storage. This system integrates wind driven pump or compressor which imparts energy to air and solar parabolic trough collector(PTC) combined through compressed air passes in it for power generation in turbine by air expansion. PTC most commercially available (95%) and practically useful solution to our problem. Mathematical model and numerical analysis of concept is proposed. Numerical analysis gives efficiency of design about 55.6% .Heat transfer enhanced from 10-100KW/m$^2$K to 826.964 100KW/m$^2$K because of compressed air flowing inside PTC absorber hence lead to forced convection and better heat exchange. Inbuild pressure of air saves power of pump for circulating working fluid as in case of water. Also air is available every time at free of cost and can also be sink to environment without harm to it.**

***Keywords: Integration of energy sources, Solar energy, Wind energy, compressed energy of air, energy storage, turbo machinery turbine and compressor***

## 1. INTRODUCTION

This system integrates wind driven pump or compressor which imparts energy to fluid usually air and solar parabolic trough collectors with integral thermal storage for air heating and a turbine coupled with generator Large area solar air heating Parabolic trough collector integrated with high heat capacity thermal storage reservoir. Solar parabolic trough collector concentration focus over a large area to a line or spot where heat is collected in an absorber and being compressed air temperature more than 500$^0$ C can be attained. Number of wind turbine can be altered depending upon site potential and supply requirement and solar collector can be used on site as well as on point of consume. Variation due to seasonal availability of solar and wind energies for supply of energy compensate by each other when two energies will be used in integrated system as Solar radiation availability is highest in summer season and availability of wind speed is highest in rainy and winter season.

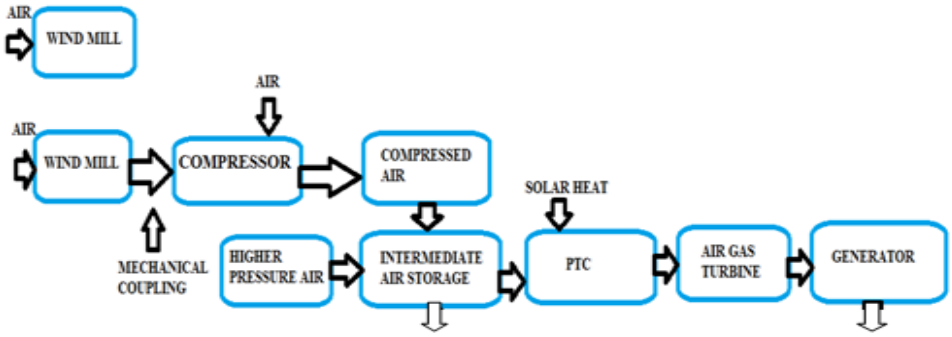


Fig:1 Flow Diagram Of Hybrid Wind And Solar Thermal Energy Concept

Integrated energy system is energy system designed and fabricated to obtain power using solar and wind energy sources. For supply power to load integrated energy combine solar and wind energy. More than 75 % of Indian houses suffer from power cut problem mostly in summer season hence integration of energies has huge prospect in india

## 2. METHODOLOGY

Cumulative work is imparted in a common working media(air) to drive a single turbo expander coupled with generator. Our system is analogous with Brayton cycle. Working fluid passes through closed loop in an ideal cycle for gas-turbine engines known as Brayton cycle. Combustion takes place at constant pressure heat addition and exhaust process takes place at constant pressure heat rejection.

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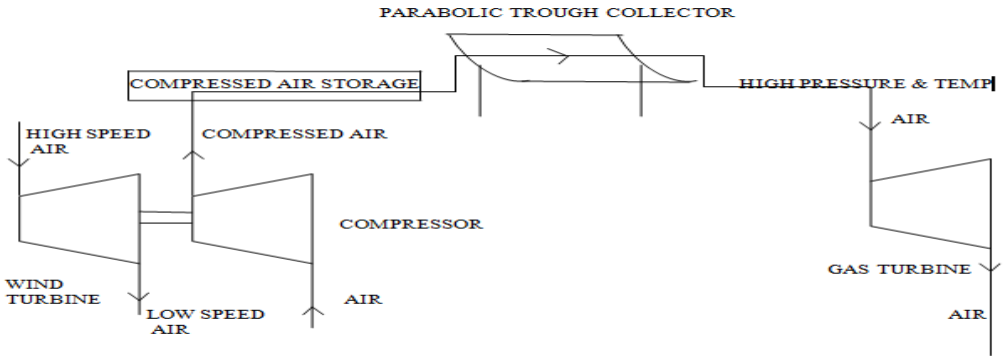


Fig:2 Schematic Diagram Of Hybrid Wind Solar Plant

In this proposed integrated energy system power generation will be obtained from wind and solar energies. Integrated energy system has Less emission and better efficiency and reliability can be achieved at lower cost with this integrated system.Solar and wind energy sources have higher availability in india over all areas. This integrated system does not required to look for special location to install. Wind turbine is coupled to positive displacement compressor e.g screw compressor or vane compressor with suitable gear arrangement. The fluid air undergoes compression in compressor and result in rise in pressure. Intermediate storage for compressed air is provisioned so that by regulating flow rate load requirement fluctuation can be compensate. The Integrated energys system will compensates you for the excess grid supply with credits that are added to your electric bill When solar parabolic trough collector produces excess power, they feed energy back to the grid.This public grid supply to system will check about you will still have supply of power regardless of daily or seasonal fluctuation in solar radiation and power production potential. Integrated system's excess production can earn income from this new system.Net metering here signify that home maintains a connection to the grid even after you install the Integrated system. Solar parabolic trough collector may generate more electricity than requirement during the day or in summer season. But they will not produce at night when sunlight isn't available hence you can use from public grid as crediss earned by you from supplying excess electricity back to grid. Ideally, the credits from your collectors surplus production will cover you during the times when you need to draw electricity from the grid. In this case, the grid is serving as form of energy storage.

Atmospheric Air enters the compressor at ambient temperature where its pressure will rise. The air at high pressure passé through the combustion chamber where the fuel is burned at constant pressure. In our study we substitute solar parabolic trough collector (heat source) in place of combustion chamber. The Increased temperature (and high pressure) air passes into the turbine and expands to ambient state of pressure and work will be produced. The new scheme will ensure more capacity and uninterrupted supply. It can be installed near remote areas. Air compressors is made directly coupled to wind turpine or conventional wind turbines used to power and drive a central air compressor.High pressure bearing pipes can be make provisioned to collect air in compressed form coming from several turbines. High pressure, large diameter pipeline to transport the compressed air from the wind turbines to the solar site which will also contain the expander-generator .A storage for compressed air or a cavern make located either near the wind turbines, along the line of transmission or at the solar collector site. Solar thermal collectors with integral thermal storage for heating the compressed air to as high as $300^0$C-1000°C, and a uniquely designed turbo-expander driven generator.

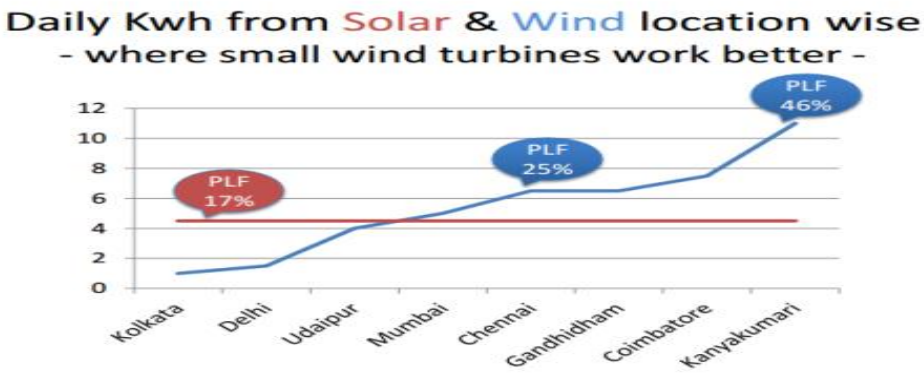


Fig:3 Site Potential Graph Of Two Energies

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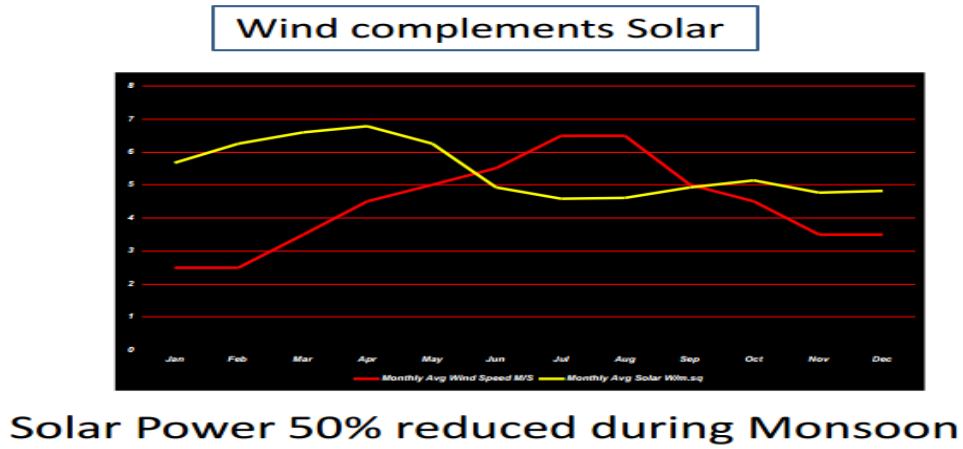


Fig:4 Compensation Graph of Two Energies

***Components***

1. solar parabolic trough collector 2. wind turbine 3. compressor for rising pressure of air 4. flow control mechanism, valves 5 single generator 7. thermal storage 8 compressed air storage (adiabatic).

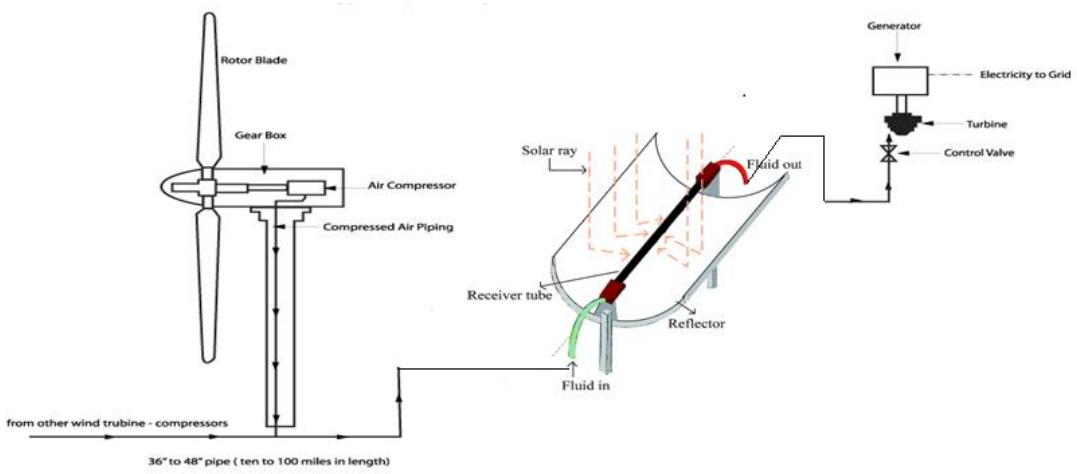


Fig:5 Schematic Diagram Of Concept

Power input to wind mill=2 to 2.5 MW and 50Hz, Rotor diameter -95.0 m

Tab: 1 Wind Mill Specifications

| Tower height (m) | Rotor height (m) | Hub height(m) |
|---|---|---|
| 77.5 | 79 | 80 |
| 87.6 | 89 | 90 |
| 96.2 | 90 | 100 |

Annual average wind speed 8.5 m/s

Rotor speed = 12.1 to 17.6 rpm

Gearbox – A typical gearbox design for 2 MW machine has one planetary stage and two parallel stage have in total three shaft where each shaft has axial load and guiding. The gearbox has in total 20 bearing and 9 Gear wheels

**$P = ½. \rho (AW) (V)^3$**

Mass flow rate required m=9.863 kg/s

***Stage 1-2- Compression, Stage 2-3-Pressure drop, Stage 3-4-Heat addition, Stage 4-5-Expansion***

$W= \upsilon_1 p_1 (^n/_{n-1})[\{p_2/p_1\}^{(n-1/n)} - 1]$ = change in enthalpy of air $=h_2-h_1$

Compressor $W=2.5766\times10^5$ J/kg

or $P= W\times m=2.5$ MW

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$Q=hAdt=mc_pdt$
$h = Nu\times D /K$ {$Nu = hD/K$}
$Pr = \mu c_p/K=0.6992552$
$Re = \rho VD/\mu=3283596.3$
$Nu= hD/k =0.023(Re)^{0.8}(Pr)^{0.333}$
$h=826.964\ W/m^2K$
$W= h_4-h_5 = \upsilon_4 p_4 (^{n}/_{n-1})[\ 1 - \{p_5/p_4\}^{(1-n/n)}]$ = change in enthalpy of air in expansion in gas turbine
And Turbine work, W=234.6 kJ/kg
P= W×m=2.3139 MW
Amount of compressed air storage require to compensate for wind energy fluctuate
$W=2.576598\times10^5$ J/kg
Energy required for day E=2.5931 MW×3600×24=$2.2404\times10^{11}$ J/day
**m=E/W** =$2.240404898\times10^{11}$ J/s /$2.576598\times10^5$ J/kg =86952.1 kg/day
**V=m/ ρ**=86952.055/0.1888246=460491.17 $m^3$/day
V=460491.136 $m^3$/day, At an average pressure of p=9.141674 bar
Length of PTC=30m, With assuming uniform temperature of absorber surface at $250^0$c
The pressure drop in compressed air , $dp =7.57\times q^{1.85}\times L\times10^4/ d^5\times p$
dp =1.8799 bar from 9.14167 bar
Air has heat transfer coefficient of 10 to 100 $W/m^2K$ in free convection. In our case forced convection get with advantage of heat transfer coefficient. of 826.964 $W/m^2K$. Overall thermal efficiency comes out to be 55.6%.

TAB 2: Proposed Material For System

| SN | Part | Material |
|---|---|---|
| 1 | Tower | Welded Steel Patel According To En 10025 |
| 2 | Nacelle | 42crmo4/42crmos4 |
| 3 | Hub | En-Gjs-350-22u-Lt |
| 4 | Blades | Glass-Fiber Reinforced Plastic (Grp)/Epoxy |
| 5 | Glass Mirror | Material Tempered And Toughed Solar Grade Glass Tested for scratches and durability. |
| 6 | Support Structure | Standard Structural steel as per IS' 2062 |
| 7 | Absorber | Stainless steel 304 grade |
| 8 | Heat Transfer Pipe | Galvanized Iron/ Mild Steel/ Stainless Steel |
| 9 | Absorber Coating | Black Chrome/Solar Grade Absorber Paint/ Selective Coating (As (C2-80)) |
| 10 | Glass Cover | Borosilicate glass |
| 11 | Reflective Coating | Solar Grade silver film of 0.10 -0.12 mmthickness |

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## 3 RESULT AND CONCLUSION

Mathematical modeling of concept design is prepared along with numerical analysis of 2MW autonomous power plant and theoretical efficiency comes out of 55.6% gives better agreement than other thermal power plants. Heat transfer enhanced from 10-100KW/$m^2$K to 826.964 100KW/$m^2$K by 726.964 W/$m^2$K because of compressed air flowing inside PTC absorber hence lead to forced convection and better heat exchange. Exergy of air while expanding in turbine will produce 2MW power at generator. Air used as working fluid as it is compressible, environment friendly and available at free of cost. Cost of compressed air storage can be compensating by dealing with uninterrupted load requirement. Parabolic trough collector technology is the most proven and lowest cost large scale solar power technology available today. It can be installed near target customer like in remote areas to fulfill power requirement of local community and reduce cost of long distance transmission of electricity. Indian prospects also support concept as more than 40% of Indian sub continental area have potential for wind mills and being near to equator more exposed to solar radiation.By developing infrastructure and increasing the production of the equipment, cost can be lower down as more systems will be produced lead to need for assembly line and supporting venture. In order to investigate further a combined solar/wind power plant is necessary to experiment with different case studies so we realize the complicate way of its operation. Some generalized rules can not be established that they can be apply everywher(any case study) due to the specific demands of each project thus it has some common characteristics. Integrated energy system will reduce the transmission cost and losses because of the power can be utilize at place where it is generated . It needs initial investment. Integrated system will have long life span . It could not be provided 100% autonomy and the cheapest solution as renewable as the main energy sources and Overall it is good, reliable and affordable solution for electricity generation.

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