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Experimental Assessment of a Self- Electrical Recharging System in Vehicles Using Wind Energy

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ABSTRACT

Current paper is concerned with the concept of converting mechanical energy based on air - vehicle interaction into electrical one in term of charging the batteries in a vehicle. Mechanical energy had been obtained due to wind - vehicle interaction which is caused by the relative motion between them. A wind turbine was mounted on the head structure of the vehicle to generate energy with reducing the drag force (rather than the existing drag force due to front profile area and interaction friction) induced in the vehicle. Experimental results and elaborate aerodynamic analysis of the vehicle structure with the flow pattern and wind turbine is also presented in this paper. Some techniques and methods were proposed to minimize the drag imposed by the air entrance to the turbine vanes as much as possible. Optimum values of different design parameters and rated velocity of the vehicle are of prime concern. A mathematical model was derived based on the approach of **[13]** S.M. Ferdous, Walid Bin Khaled, Benozir Ahmed, Sayedus Salehin, Enaiyat Ghani Ovy, 2011 to estimate the theoretical harvesting energy and effect of drag wasted power. Then a system was suggested using wind turbine of 15" and two types of generators used to convert mechanical power into electrical one. An experimental approach was created such that the system tested under wind tunnel with speed up to 110 Km/hr. With this concept it was obtained harvesting about (100 – 300) watt power. Also it was indicated that the DC generator of direct current is best than alternative generator with indirect current. The comparison of the current results with other papers shows a good agreement from point view of the amount of harvesting power.

Keywords: Electric Vehicle, Air – vehicle interaction, Wind Energy, Wind Turbine, Air Drag.

الخلاصة

ان عدم القدرة على تخزين ما يكفي من الطاقة لتشغيل السيارة لفترة طويلة يعتبر من العيوب الرئيسية في المركبات التي تعتمد على الطاقة الكهربائية. اذ ان سعة تخزين الطاقة في البطارية المستخدمة في المركبات الكهربائية منخفضة جدا مقارنة بأنواع الوقود التقليدية المستخدمة في السيارات الحديثة. كما ان التشغيل و الأداء والكفاءة في المركبات التي تستخدم المحركات الكهربائية هي أفضل بكثير من التي تستخدم محرك احتراق داخلي ، وفي نفس الوقت السيارات الكهربائية هي صديقة للبيئة. لا يزال الاعتماد على السيارات الكهربائية متدني في صناعة السيارات بسبب مشكلة تخزين الطاقة. يستند هذا البحث على مفهوم شحن بطاريات السيارة الكهربائية اثناء حركتها. ويمكن القيام بذلك عن طريق استخدام طاقة الرياح الناجم عن الحركة النسبية بين المركبة والرياح. ان توربينات الرياح يمكن الاستعانة بها وتركيبها على هيكل المركبة لتوليد الكهرباء بحيث لا تؤدي الى توليد قوى احتكاك سلبية على السيارة. تم الحصول على النتائج التجريبية المتعلقة بالحركة النسبية بين التوربين والهواء والطاقة التي تم الحصول عليها. وقد تمت الاستعانة ببعض التقنيات والأساليب للحد من الاحتكاك في مقدمة المركبة إلى أقصى حد ممكن من خلال اختيار المكان المناسب والحركة. وقد تم حساب القيم لسرعة التوربين التي تعتبر العامل الاكثر تاثيرا في الطاقة المبتغاة. وقد تبين من خلال النتائج النظرية والعملية امكانية حصد واستغلال ما بين 20٪ -25٪ من الطاقة المهدرة عن طريق السحب الهواء.

كلمات دلالة: مركبة كهربائية ، تصادم مركبة – هواء ، طاقة رياح ، توربين هوائي ، احتكاك الهواء.

I. INTRODUCTION

Electrical Energy Storage is one of the key technologies in the areas covered by the renewable energy. But one of the most drawbacks of hybrid Vehicle is the lack of capability of large sufficient energy sufficient to run the vehicle for a long time. Power capacity of the battery that used in electric cars is very low compared with traditional power of internal combustion engines used in modern vehicles. The economy, performance and efficiency of electrical motor driven vehicles are much better than internal combustion engine vehicles, furthermore electric vehicles are very much environment friendly. Due to the problem of nonsufficient energy, electric vehicles are still inapplicable in the automobile industries. When a vehicle moves it experience wind resistance which are classified in two different forms- frictional drag and form drag. Frictional drag arises due to viscosity of air and form drag arises due to variation of air pressure in the front and rear side of the vehicle **[15]** Thomas D. Gillespie. As the vehicle moves forward, it lefts the air stream behind. A turbulence or disturbance is created on the wind when a vehicle moves through it. If stationary wind propeller is placed in front of the moving vehicle then energy can be extracted from the wind stream generated due to the movement of the vehicle. If it is possible to capture those wind streams within the vehicle itself then it can be used to recover some of energy that has been used to overcome the form drag (aerodynamic drag) of the vehicle. If air streams are allowed to flow into the front propeller by any means then the form drag will be reduced by some amount and at the same time, it may be possible to generate electricity using the kinetic energy of wind and this gained energy can be used to recharge the battery of the electric vehicle itself.

Experimental simulation of the design is carried out in this paper, to analyze the behavior of the model and estimate the amount of the real gained power. Some theoretical formulas have been used for the purpose of the theoretical calculations.

II. THEORY

In order to derive a mathematical model of the system that suggested, it is assumed that the vehicle is moving with steady wind stream. If the vehicle is moving at a constant speed, then it can possible to consider a wind stream is flowing in opposite and around the vehicle. A drag force which is opposite to the direction of the vehicle propulsion is normally caused. At uniform speed with zero acceleration, the energy must be sufficient to pull the vehicle forward in addition to overcome the frictional force due to rolling resistance of road and to overcome drag resistance, **[2]** K.Sudhakar & Priyanka Saxena, 2013, and **[15]** Thomas D. Gillespie. The interaction of air – vehicle permitted wind stream through vehicle structure and it deflects it's orientation by stagnation at the front profile. This energy had been wasted from the vehicle to overcome the drag and aerodynamic effects. But if the air stream is allowed to enter propeller wind tunnel of a proper design; then it can be possible to use air streams energy to generate useful power. A considerable amount of some friction (drag) energy can be recovered and fed back to the battery by means of simple energy conversion tools. Mounting a wind turbine can successes the purpose, at the same time it will help to decrease the pressure distribution at the vehicle front profile (according to Bernoulii's equation pressure will be decreased if the stream velocity is increased and velocity will be reduced at the front side of the propeller system after energy extraction) which will reduce the drag force that existed by the suitable design of the vehicle. So, vortex shedding will be reduced at the vehicle front side. For these results, it is become necessary to study the new propose design of an electrical vehicles which gives provision of air flow through the vehicle, as shown in figure (1).

III. THEORETICAL MODELING

Modeling of wind power harvester system is dividing into three main parts, as shown in figure (2):

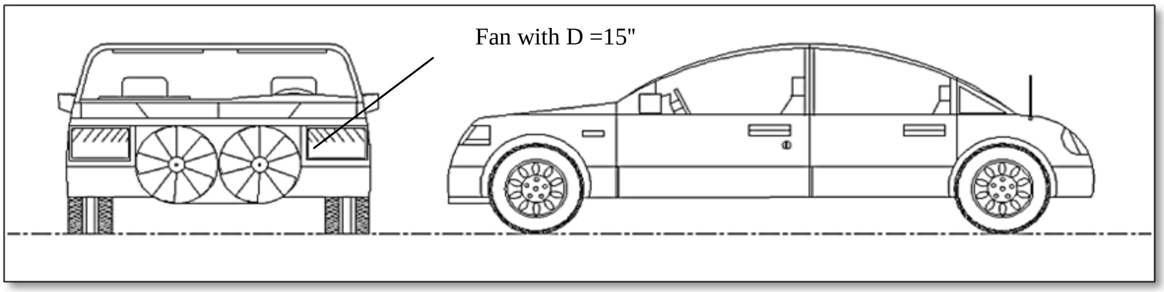


Fig (1): Suggested Configuration of electrical vehicle with small wind turbine

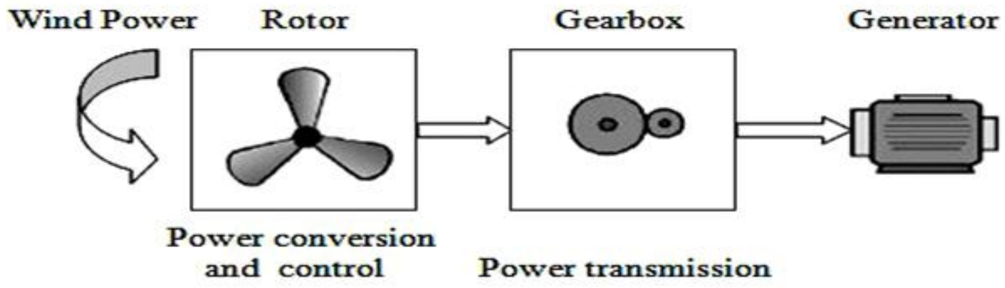


Fig (2): Mechanical Components of Wind Turbine.

3.1. WIND TURBINE CHARACTERISTICS

Output power of wind turbine is depending directly on the air flow kinetic energy, then, the theoretical output power from a wind turbine is given by **[13]** S.M. Ferdous, Walid Bin Khaled, Benozir Ahmed, Sayedus Salehin, Enaiyat Ghani Ovy, 2011, and **[15]** Thomas D. Gillespie.

$$P_T = \frac{1}{2} \cdot C_p \cdot \rho \cdot Q_v \cdot u^2 \quad \dots (1)$$

And the air flow rate through the turbine (Q_v) is given by **[7]** Godfrey Boyle,

$$Q_v = C_v A u \quad \dots (2)$$

Where:

P_T = Turbine output Power in (watts).

C_p = Power co-efficient

(C_p = 0.4 for the design), **[11]** Priya, S. & Inman, D. Godfrey Boyle, 2009.

ρ = air density; (1.225 kg/$m^{3)}$.

Q_v= air flow rate into the turbine ;(m^3/s)

$C_{v=}$turbine opening effectiveness

A = Fan Swept Area ;(m^2).

u = air stream velocity in (m/s)

[Value of (C_v) is 0.5 - 0.6 for perpendicular flow and 0.25 – 0.35 for skewed flow] **[14]** Terry S. Boutet,

Some features of the wind turbine is stated bellow: **[4]** Dr.Amalesh Chandra Mandal, Dr. Md. Quamrul Islam.

- Two blades (for low solidity).
- Horizontal axis.
- Lift type.
- High lift to drag ratio with efficiency ranging from 0.4 to 0.45.

They need to define a relatively high tip speed ratio as:

$$\lambda = \frac{\Omega . R}{u} \quad \dots (3)$$

Where:

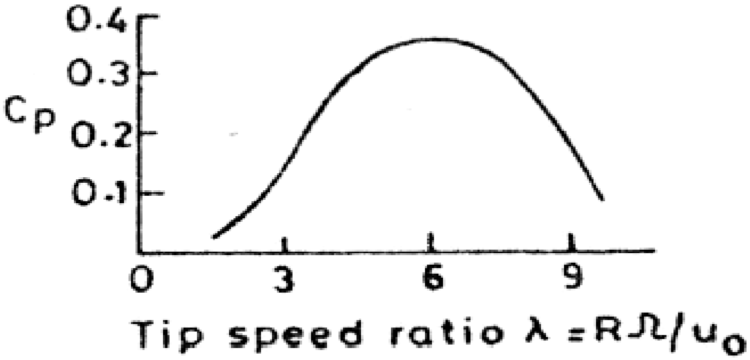
λ= speed ratio

Ω= propeller angular speed (rad/s)

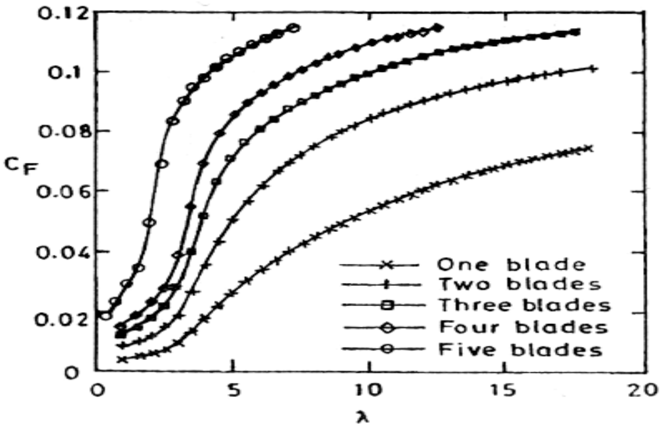
R=Propeller reduce (m)

u = Air stream linear velocity in (m/s)

Figure (3) shows the relationships between power coefficient (C_p) and Axial Thrust Coefficient (C_F) with speed ratio (λ), **[3]** Daniel S. A. and Gaunden ,N.A and **[13]** S.M. Ferdous, Walid Bin Khaled, Benozir Ahmed, Sayedus Salehin, Enaiyat Ghani Ovy, 2011.



(a)



(b)

Fig (3): Power coefficient and axial thrust coefficient **[4]** Dr.Amalesh Chandra Mandal, Dr. Md. Quamrul Islam.

This implies that as at perfect dynamic matching generated power will be greater than the power spend due to thrust. In other words the generated power by a turbine will be greater than the thrust acting on the blade as an aero foil section has high lift to drag ratio, **[3]** Daniel S. A. and Gaunden ,N.A. 2001, and **[10]** N. Singh ,Sumit Kumar Jha, Sudhir Kumar Sinha, 2011.

3.2. GENERATOR CHARACTERISTICS

In general, electromagnetic generator (EMG) consists of wound copper coils, and magnetic field source, voltage develops in the coil's circuit proportionally with developing of the magnetic field source relative velocity. Current flow in the close load circuit produce inside magnetic field opposite in direction with original magnetic field, thus, EMG will resist rotating, depends on the amount of the current flow in the load circuit. Figure (4) shows the essential internal and external resistant in the DC generator circuit, **[3]** Daniel S. A. and Gaunden ,N.A. 2001.

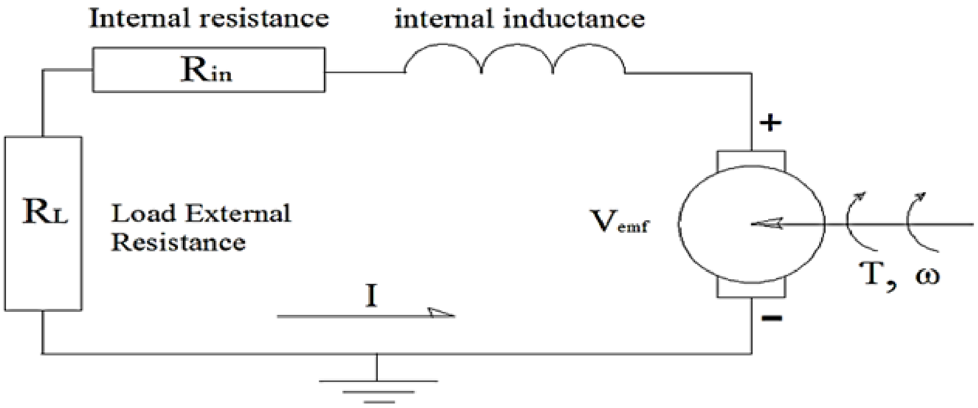


Fig (4): DC generator essential circuit resistant **[12]** Rizk, J. and Nagriak, M.H.

The electromotive force (e.m.f.), induced in a circuit is proportional to the time rate of change of the magnetic flux linkage of that circuit

$$V = -\frac{d\Phi}{dt}$$

Where (V) is the generated voltage or induced (e.m.f) and (Φ) is the flux linkage

In most of the applications the circuit consist of a coil of wire with multiples turns (N) and the magnet field is created with permanent magnets, so the voltage induced is given by

$$V = -N\frac{d\Phi}{dt}$$

Flux linkage for a multiple turn coil should be evaluated as the sum of the linkages for the individual turns, **[7]** Godfrey Boyle.

In most electromagnetic generators, the motion between the coil and the magnet field in a single direction is produced by the permanent magnet and has no time variations, so in this case the voltage equation simplifies

$$V = -\frac{d\Phi}{d\theta}\frac{d\theta}{dt} = -N_c\frac{d\Phi}{d\theta}\frac{d\theta}{dt} \qquad \cdots (4)$$

Where: (θ) is the armature angular displacement. To extract power from generator the coil terminals must be connected to a load resistance (R_l) allowing a current to flow in the coil. The interaction between the field caused by the induced current and the field from the magnets gives rise to a torque (T_d) which opposes the rotation and is proportional to the current and the velocity

$$T_{in} = T_d\frac{d\theta}{dt} \qquad \cdots (5)$$

$$\therefore P_{in} = T_{in}\frac{d\theta}{dt} \qquad (6)$$

Where (P_{in}) is required power to turn the generator, (T_{in}) is required of armature input torque, (T_d) is the generator resist torque or generator damping torque and $(\frac{d\theta}{dt})$ is armature angular velocity.

Maximizing the power in the form of electrical energy involves the maximization of the electromagnetic damping (T_d). As a result of this is important to know which parameters can be used to maximize electromagnetic damping.

The instantaneous power extracted is shown in the equation below

$$P_e = \frac{V^2}{R_T} = \frac{V^2}{R_L + R_c + jwL_c} \qquad (7)$$

and this power is dissipated in the coil impedance (Rc +jwL$_c$) and load resistance (R_L). [6]

Then,

$$P_{in} = P_e \qquad (8)$$

Taking equation (4), (5), (6) and (7), and substituting in (8) the result is an expression for the electromagnetic damping

$$T_d\left(\frac{d\theta}{dt}\right)^2 = \frac{\left(\frac{d\Phi}{d\theta}\right)^2\left(\frac{d\theta}{dt}\right)^2}{R_L + R_c + jwL_c} \qquad \cdots (9)$$

Simplifying the equation (9) to get:

$$T_d = \frac{1}{R_L + R_c + jwL_c}\left(\frac{d\Phi}{d\theta}\right)^2 \qquad \cdots (10)$$

The idea will be to maximize the flux linkage gradient and minimizing the coil Impedance, **[6]** G.N.Tewari, A.K. Bansal.

Then, we can define the output electrical power as **[1]** Dongbing Zhang, 2013, and **[9]** Muljadi, E., Piercek, K.and Migliore, P, 1998.:

$$P_e = i^2R_{eq} = \frac{V^2}{R_{eq}} = T_d\left(\frac{d\theta}{dt}\right)^2 \qquad \cdots (11)$$

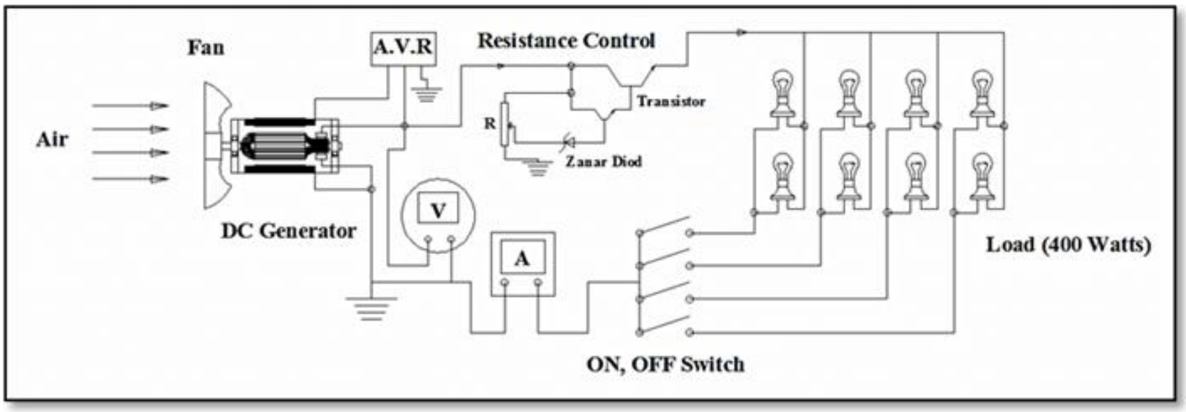


Fig (5): DC Generator and electrical load circuit

IV. EXPERIMENTAL WORK

Two types of dc generators are tested in this study; these generators are connected directly with the fan shaft (without gear box ratio). The first generator characteristics are 12V, 25A, 2000 r.p.m, direct DC current output from rotating armature with two coal brushes and the stator contains four stationary magnetic field coils (four poles). The second generator characteristics are 12V, 30A, 3000 r.p.m, indirect DC current (Alternator) with 3-Φ windings stator coils (as a main coils) and the rotor have magnetic field coils with eight poles.

The circuit of the two generators are supplied with terminal voltage controller, eight DC lamps (50 watts for each lamp) used as a load circuit, and variable series resistance controller, as shown in figure (5).

Voltage control is used to give a constant 12V, by variation the magnetic field by variation of the feedback coils current with the variation of the speed of the stream air or the r.p.m of the turbine keeping the terminal voltage fixed. Series load resistance controller is used to limit the minimum allowable load resistance to get maximum output power depending on the definition of (T_d) in equation (10).

Generator is assembled directly with (15" in diameter) five blades fan and the system is connected in the standard air tunnel as shown in the figure (6).

CFM 6901device is used to measure the stream air speed inside the tunnel, TD-2236 device is used to measure the fan rotating speed (r.p.m), and digital Voltmeter and Ammeter are used for measuring voltage and current flow in the DC and Alternator circuit respectively, as shown in figures (7,8 and 9).

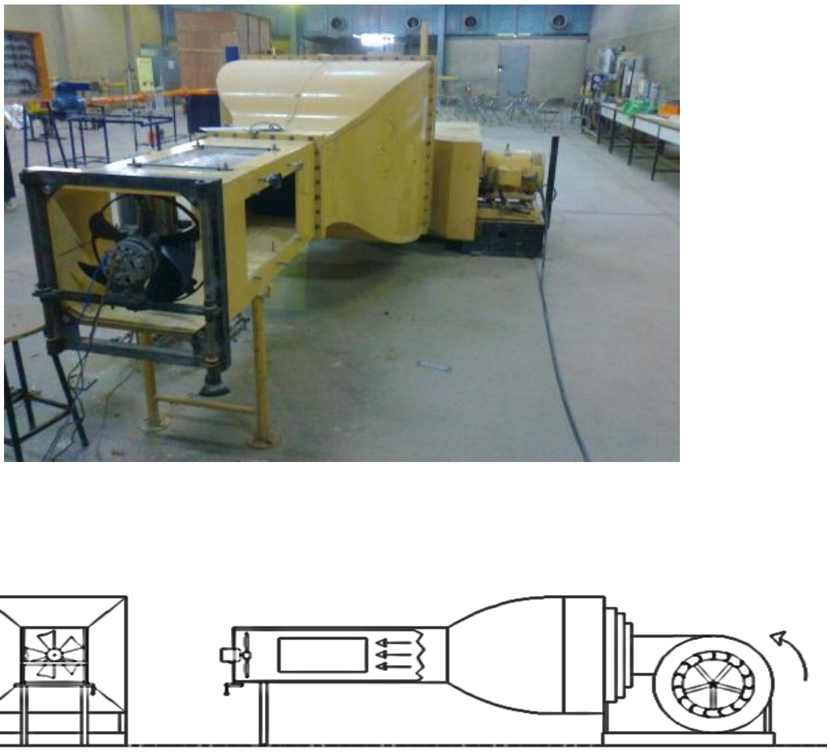


Fig (6): Standard (18" *18") air tunnel system.

Fig (7): Measuring of speed of air flow stream

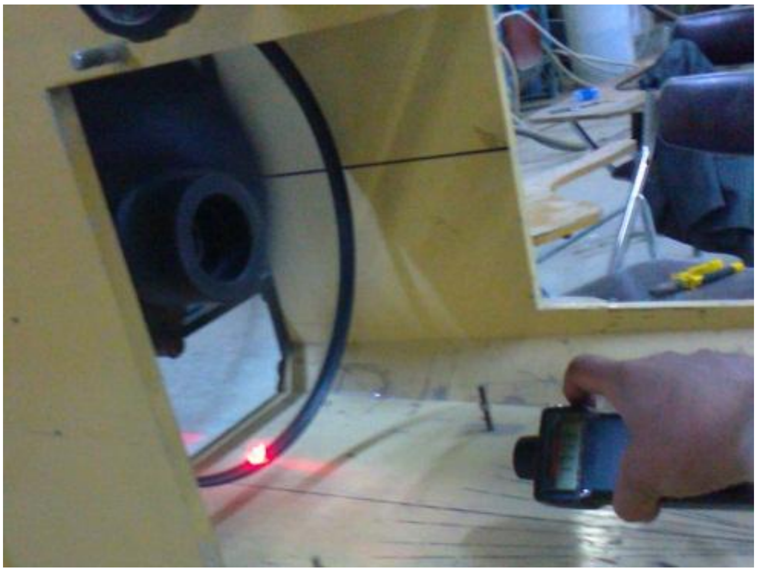


Fig (8): Measuring of fan angular speed

Fig (9): Testing of two generator types, direct DC generator and Alternator

V. RESULT AND DISCUSSIONS

Figures (10 and 11) show the experimental amount of harvested power with air flow speed in (m/s) or vehicle speed in (km/hr) respectively, where the upper curve represents the theoritical power of the air stream calculated by application of equations (1,2) , while the middle and lower curves represent the expermental harvested of electrical power from direct DC generator and Alternator, respectively.

Figure (12) shows the experimental relation between fan angular speed with harvested power from DC generator and Alternator verses vehicle speed.

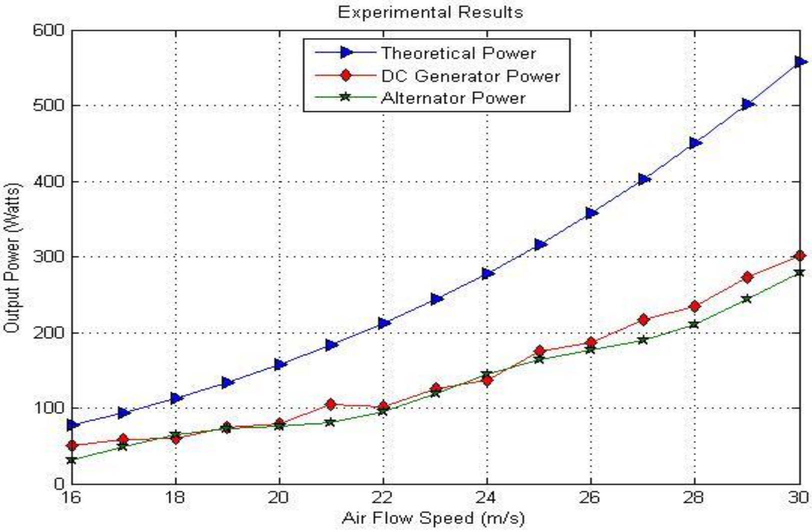


Fig (10): Experimental harvested power verses speed of the stream air flow

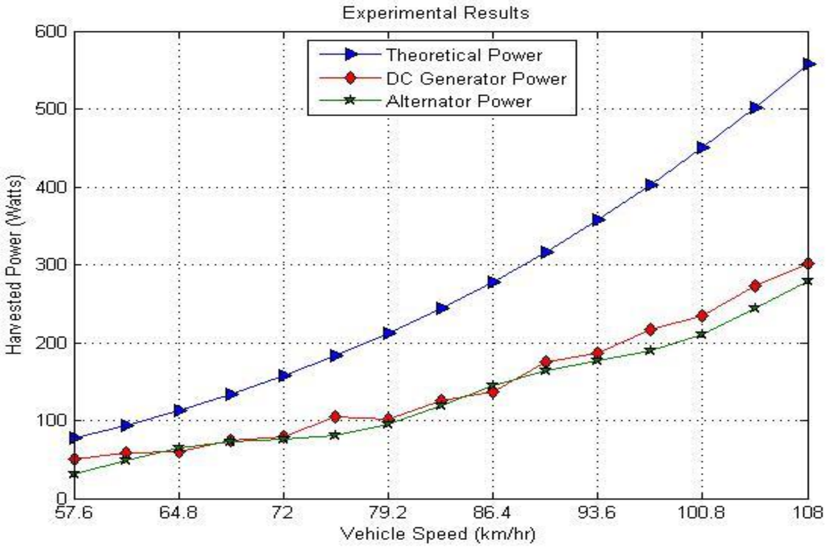


Fig (11): Experimental harvested power verses vehicle speed

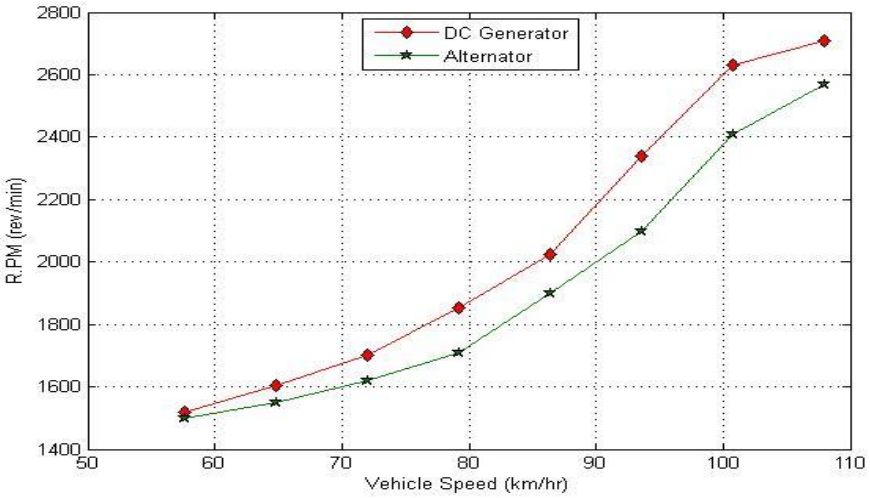


Fig (12): Angular speed of DC generator and Alternator verses vehicle speed.

The results indicated that the harvested power from DC generator is better than that is of Alternator generator, for many reasons; Alternator is wasting large amount of energy in the rectifier resistance system while the DC generator has no rectifier system. The Alternator is designed for higher angular speed while the DC generator is designed for medium and low speed witch is applicable in the current work.

It’s noted that a large amount of energy of the air stream wasted due to the system configuration. Thus a resistance controller was mounted to the electrical circuit to maintain the dropping in the voltage under higher load. To extract large power from generator the coil terminals must be connected to small load resistance, this is leading into dropping in the terminal voltage. Voltage controller allowed streaming of high current to the close load circuit to produce interior magnetic field opposite in direction with original armature magnetic field. Thus, the generator damping torque (T_d) increased, and EMG overcame the angular inertia.

When the rotation of generator decreases, the terminal voltage is dropping sharply and the voltage controller is losing its governance; therefore, resistance controller is suggested to avoid this problem by giving the system the minimum resistance automatically for harvesting the highest possible power from the system.

The suggested design configuration ensured a power of about (100-300 watts) as a mean value to be stored as a potential in the battery for a single small fan with five blades and diameter (15") with a vehicle speed range of (75 - 110) km/hr.

VI. COMPARISON

S.M. Ferdous, Walid Bin Khaled, Benozir Ahmed, Sayedus Salehin, Enaiyat Ghani Ovy **[13]** suggest a system for harvesting power of a vehicle based on estimation pressure distribution through vehicle structure. Their system was increased the mileage of an electric vehicle up to 20%-25% and it will also save the charging time of the battery to a great extent with 360 watt harvested power.

Lei Zuo * and Pei - Sheng Zhang**, 2012 [8].** proved that between (100-400 watts) as a mean value of power potential is available from the four shock absorbers of a typical middle-size passenger car travel at 60 mph (96km/hr) on the good (Class B) and average (Class C) roads, and on road test of a super compact vehicle, is a (60 watts) of mean power potential is estimated at vehicle speed 25mph (40km/hr) on campus road.

VII. CONCLUSIONS AND RECOMMENDATIONS

From the results and comparisons it can be concluded that the harvested power results from the suggested system in this paper, around the type of output power wave and ability to harvest wasted energy from vehicles traveling is better than the results that were harvested from Zuo design, **[8]** Lei Zuo * and Pei - Sheng Zhang, 2012. For factures work it is required to check the multistage fan to maximize the harvesting power. Also its required to study the effects of fan blade profile and shape for the possible harvesting power.

ACKNOWLEDGEMENTS

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