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A Novel Speed-Breaker for Electrical Energy Generation Suitable for Elimination of Remote Parts of Power Systems where is Near to Roads

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ABSTRACT

To harness the wasted kinetic energy of vehicle flow in speed-breakers of streets, a novel Speed-Breaker Generator (SBG) proposed. The SBG uses an efficient linear topology with two independent translators can be pushed down by vehicle wheel to absorb kinetic energy of the vehicles. The proposed topology is modeled using an analytical approach. An efficient design is achieved using a multistage design procedure. To verify efficiency of the obtained design simulation are carried out using finite element analysis software package. The simulations confirm the effectiveness of the obtained design and the proposed SBG.
KEYWORDS:SBG, Linear electrical generator, Speed-breaker.

INTRODUCTION

For reduction of carbon dioxide emission, renewable energies are considered as proper alternative energy [1]. Renewable energies mainly refer to the wind, solar, biomass and marine currents which are less harmful to environment, attracting a wide attention of researchers in design and development of renewable energy conversion systems. Although improvement of renewable energy converters is in a fast rate, the systems to extract the wasted energy in conventional energy conversion systems are not developed as much as its technologies.

In many systems and processes, dissipation of energy is inevitable whatever renewable or conventional energy was used. For instance, as a car passes over a speed-breaker, most of car kinetic energy will be wasted as heat in it. On other hand, to ensure the security of the populated areas of streets, the speed-breakers are required, whatever we used electrical cars or the cars consuming gasoil. There are numerous similar cases which such vast energies are wasting. Like an elevator during going down, a car during going down on a sloppy street, where regardless the used type of energy or efficiency of systems energy is systematically wasting. It is mainly due to condition that the systems are operation in it.

In this paper, we focus on the fixed speed-breaker at the streets since a high amount of vehicles kinetic energy is wasting there. There are thousands of crowed cities with enormous flow of vehicles offers high amount of energy can be considered as near to urban resource of energy. Also, extraction of such energy allows eliminating of transmission system between the remote areas and urban area for lightings purposes. There is a little literature about extraction of kinetic energy from flow of vehicle in the streets. There is so little and invalid literatures in generation of electricity by speed breakers that but the most common approaches can be seen in [2- 3] In these proposed systems, mostly small radial flux generators with ineffective topologies have been employed.

Therefore it is necessary to design a suitable and efficient topology for design of an energy conversion system for extraction of kinetic energy of vehicles. This paper presents a novel speed-breaker generator (SBG) for extraction of kinetic energy of vehicle flow in the street. The SBG composed of two translators and three stators. By passing the vehicle over the SBG, the both translators are pressed down and generating electrical power in stators.

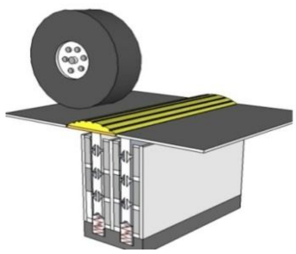

Figure 1. The proposed SBG

The main contribution this paper can be summed up as follows:
1. A novel energy conversion system for extraction of vehicle flow with efficient topology is proposed and modeled.
2. An optimized design of proposed topology is obtained using a iterative approach.

The rest of this paper organized as follow: In section 2, a brief description of proposed topology and its operation principle is presented. In section 3, the generator dimensions for a rated power are carried out using predicted magnetic field and an iterative method.

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In section 4, simulation of flux lines and flux densities in the generator cores is presented. Finally in section 5, the conclusion and perspective are presented.

SBG TOPOLOGY

The SBG consists of two translator and three stators described in following.

A. Translators

Each translator is a double slotted planar plate shown in Fig. 2(a). The translator is wounded as three-phase connection winding. The generated power in the translators is delivered to output terminals of generator using flexible wires.

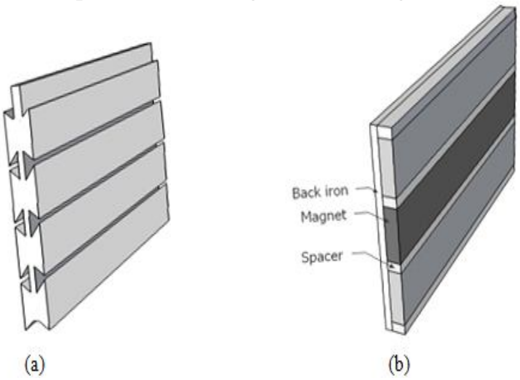

Figure 2. (a) Translator of the SBG. (b) stator of the SBG

B. Stator

The stator is a planar back iron with mounted magnets on it. The arrangement of magnets is $N-S-N$ as shown in Fig. 2 (b). There is a spacer with high permeability between each two adjacent magnets.

The side view assembled representation of the SBG is shown in Fig. 3. As seen, the translators are between the stators. The translators can move freely along the stators in up and down directions. As the translators reach down side, the spring pushes them up to return them back to initial position.

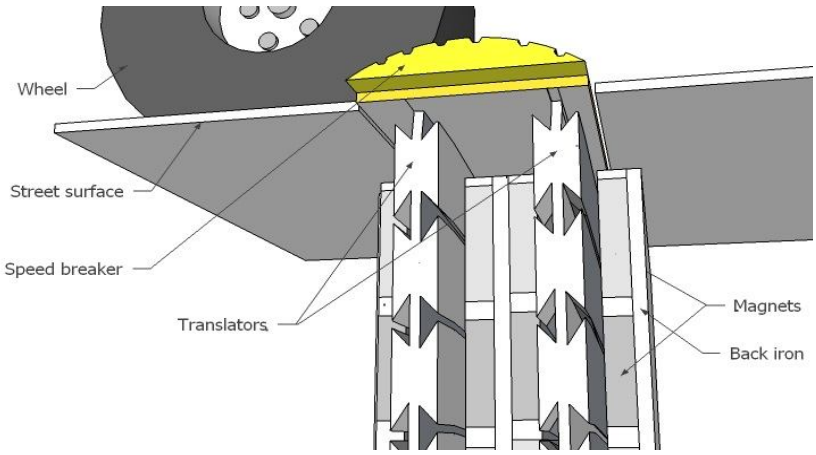

Figure 3. Side view representation of SBG

OPERATION PRINCIPLE

The operation principle of the SBG can be described as follow. As the vehicle wheels pass the SBG, the translators will be pushed down. Since the magnets have provided a high density magnetic field in the air-gaps, motion of translators cause to induction of voltage in translators' windings. The produced power will be transferred via the flexible wires to output terminal of generators. It should be noted that, the flexible wires can be interpreted as brush and slips ring in electrical rotating machines.

DESIGN PROCEDURE

A simple side view representation of SBG structure with its dimensions is shown in Fig. 4.

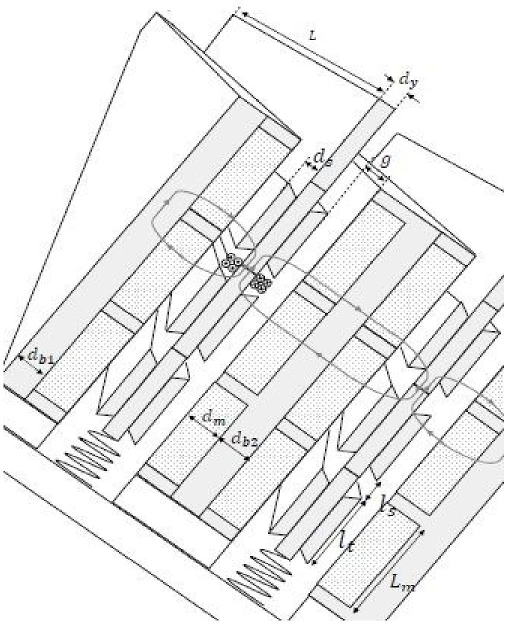

Figure 4. Side view represention of the design with its dimensions

The optimum design of the SBG is obtained through the following step by step procedure.

C. *Selection of material and user defined data*

The design set up with material data selection. The used magnet is $NdFeB/32/MGOe$. The used iron is $M-19$ steel which will be saturated in flux density of 1.7 T. The number of pole pairs,p, and the number of slot per pole per phase, q, will be selected in this phase. It should be noted that, the air gaps will be selected regard to mechanical constraints.

D. *Winding configuration and factor*

The configuration of translators winding is shown in Fig. 5. A, B, and C are the phases and direction of current are shown as sign of the "+" and "−", respectively.

A	$-C$	B	$-A$	C	$-B$	A	$-C$

τ_{cp}

Figure 5. Phase arrangment in the translators winding

Following [3], the winding factor of a linear electrical machine is consisted of two components ofk_p, k_d:

$$k_w = k_p k_d \tag{1}$$

Where, k_p, $k_d$are the pith factor and distributions factors, respectively:

$$k_p = \sin\left(\frac{p\tau_p}{2}\right) \tag{2}$$

$$k_d = \frac{\sin\left(q\frac{\theta_d}{2}\right)}{q\sin\left(\frac{\theta_d}{2}\right)} \tag{3}$$

Where, θ_d is:

$$\theta_d = {abs(l_m - \tau_{cp})\pi}/{\tau_p}. \tag{4}$$

E. *Determining maximum flux density in the air- gaps*

Saturation of machines core is one major problem in operation of machine. Hence, there is a limitation in the air-gap flux density which should be considered in the design procedure.

In [4], an accurate solution for prediction of magnetic field in liner permanent machines is presented. But, for simplicity of design process, we used magnetic equivalent circuit for prediction of magnetic flux density. The magnetic circuit of the SBG is shown in Fig. 6. The reluctance of back irons and translators are denoted as $\Re_b$and $\Re_t$, respectively. These reluctances are neglected compared to the air-gaps and magnets reluctance denoted as $\Re_g$and$\Re_m$, respectively.

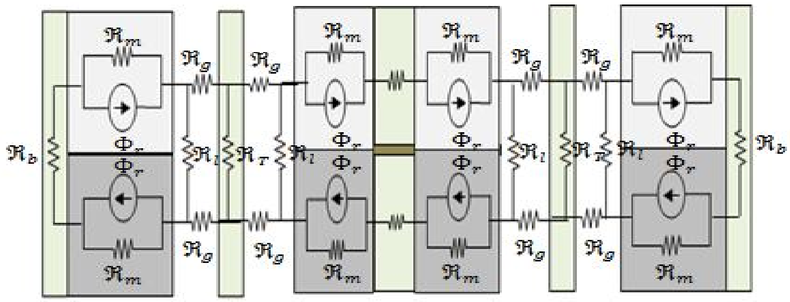

Figure 6. Equivalent magnetic circuit of the SBG

By calculation of magnetic circuited the air-gap, flux density will be:

$$B_g = \frac{B_r}{1+\frac{2g\mu_r}{d_m}} \tag{5}$$

Due to symmetry of the SBG topology, the magnetic flux densities in all air-gaps are equal.

F. Determination of teeth and slot width

The width of the slot and teeth are depending on the maximum air-gap flux density and the SBG ampere loading:
.

$$w = \frac{H}{2pq} \tag{6}$$

By increasing the air-gap flux density, the width of teeth should be increase for prevention of saturation. A wider tooth involves in a smaller slots and a lower allocated space for the conductor, which results in a lower ampere loading. Since the relationships among the rated power, air gap flux density, the teeth and slot width, and the slot depth are difficult to solve to achieve an optimum design with minimum volume, we use a simple relation between dimension of teeth and slot which is proposed in [5]:

$$l_t = (1 - l_s)l \tag{7}$$

Where, l_t is between value of $0.5l$ and $0.6l$:

$$0.5l < l_t < 0.6l \tag{8}$$

By using this relation a design with minimum volume is achievable. For simplicity in the design calculations, we considered the slot and teeth widths the same. Thus, to avoid saturation as well as having a generator with minimum volume, the teeth and slot width should be:

$$l_t = l_s = \frac{H}{k_{st}N_s} \cdot \frac{B_g}{B_{sat}}. \tag{9}$$

G. Determination of magnet dimensions

To keep away the magnets from high demagnetization during operation of the SBG, the magnets should be chosen enough thick. The thickness of the magnets can be found by multiplication of air-gap by premance, PC, of the magnets. In [4] the values between of 5-20 have been chosen for premnace which guarantees the magnets to be away from magnetization. We choose the value of 5 results in lower cost in here, thus the thickness of magnet will be:

$$l_m = g.PC. \tag{10}$$

H. Determination of conductor and series turns per phase

As the stator length converged to the desired length via iterative calculations, the conductor diameter can be computed using the obtainedN_{ph}:

$$d_c = 2\sqrt{\frac{k_{sf}A_{slot}}{\pi N_{cs}}} \tag{11}$$

Where, A_{slot} is the slots area:

$$A_{slot} = d_s l_s. \tag{12}$$

Therefore, the number of conductor per slot will be:

$$N_{cs} = \frac{N_{ph}}{pq}. \tag{13}$$

I. Determination the of the translator and its back irons dimension

The minimum thickness for back iron and translators to avoid saturation should be calculated using the predicted flux density.

Since the flux in the back irons is half of flux in the teeth, the required thickness for back iron can be written as:

$$d_{b1} = \frac{H\alpha_m}{4k_{st}p} \cdot \frac{B_g}{B_{sat}} \tag{14}$$

$$d_{b1} = {d_{b2}}/{2} \tag{15}$$

Where, $\alpha_m$is magnets pole coverage factor:

$$\alpha_m = \frac{l_m}{l_m + l_s}. \tag{16}$$

J. Determination of the SBG length

Length of the SBG and the number of the series turn per phase, N_{ph}, are directly relate together. There is a reverse relation between the machine length and number of turn per coils. By increasing the series turn turns per phase, the SBG length decreases. Thus to determine a specific length for the SBG with a constant height, the number of series turn per phase, N_{ph} , in the Eq. (17), Should be iterated while the machine length converges to the desired length.

$$P_{gap} = P_{out} + P_{Core} + P_{Copper} \tag{17}$$

Where, P_{out} is the output power of the SBG which simply can be found by multiplication linear speed of the translator at the acted force on it:

$$P_{out} = F_{ave} v_s \tag{18}$$

The losses in the SBG include hysteresis and eddy current losses in the translator and back irons, losses in the conductors as well as the losses in the magnets. According to [1], these losses can be written as:

$$P_{Copper} = \frac{2N_{ph}(L + d_y)}{\sigma_{cu} A_{cu} K_p} I^2 \tag{19}$$

$$P_{core} = P_{iron} + P_{mag} \tag{20}$$

$$P_{iron} = P_h + P_e \tag{21}$$

$$= c_h B^n f + c_e B^2 f^2 \tag{22}$$

$$P_{mag} = \frac{\sigma}{48}(d_m L)\tau^3 B^2 {w_e}^2 \tag{23}$$

Where, P_{cov} is the air-gap power in liner electrical machines can be written as:

$$P_{cov} = k_C k_w \big(A.B_g\big)(H^2 L) \tag{24}$$

Where, A and k_C are the ampere loading and correction factor, respectively:

$$A = \frac{6N\sqrt{2}IN_{ph}}{LH} \tag{25}$$

K. J. SBG efficiency

Since numerous designs for the SBG with desired length with same lengths can be obtained, we used efficiency constraint to achieve higher efficiency. The losses due to air frictions are neglected.

$$\eta = \frac{P_{out}}{P_{out}+P_{Core}+P_{Copper}} \qquad (26)$$

The drawn flowchart of the design process is shown in Fig. 7. The input data and the resulted design trough are given in Tables 1 and 2.

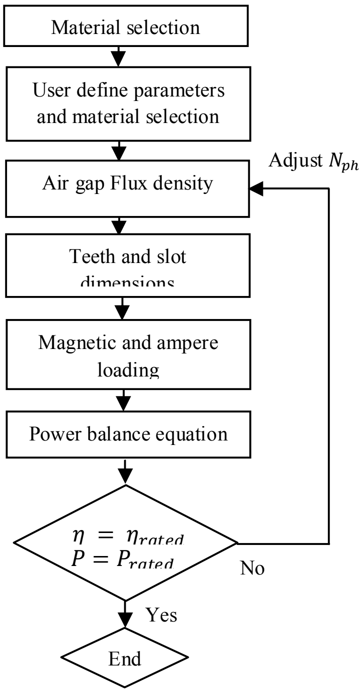

Figure 7. Flow chart of design process

SIMULATIONS

Simulation of the flux line and flux densities in the SBG including translator and the stators can help to see visibly the saturated and under saturation areas. The resulted design in the previous section can be assessed with such simulations. The flux line and flux amplitude density are simulated for no-load and full-load conditions using finite a element analysis software package Magosoft Flux2D. The two dimensional view of flux lines and flux amplitude density in no-load condition are shown in Fig. 8(a) and Fig.8(b), respectively.

Table 1 Design Input Data

Quantity	Value
Apparent power, S	80kVA
No-load phase voltage (rms)	230V
Phase current (rms)	40
Number of phase, m	3
Power factor, pf	0.72
Rated linear speed	12 m/s
Iron	Type of 1008
B_{sat}	1.7 Tesla
Pole pairs numbers, p	4
Number of slot/ pole/phase	3
Outer dimeter, D_o	140 mm
Air-gap axial length	1 mm

Table 2. Design Results

Quantity	Value
Machine length	1100 mm
Machine axial length	3000 mm
Slot depth, d_s	6 mm
Tooth width, w_t	12 mm
Slot width, w_s	11 mm
Axial length of second rotor yoke,Y_{r2}	2.5 mm
Number of series coil per phase, N_{ph}	17
Number of conductor per slote, N_{cs}	4
Conductors	AWG 17
Air gap peak flux density, B_g	0.825 T
Output power, P_{out}	4450 W
Ampere loading, A	20312 A/mm^2
Active power per generator mass	16 kWT $/kg$

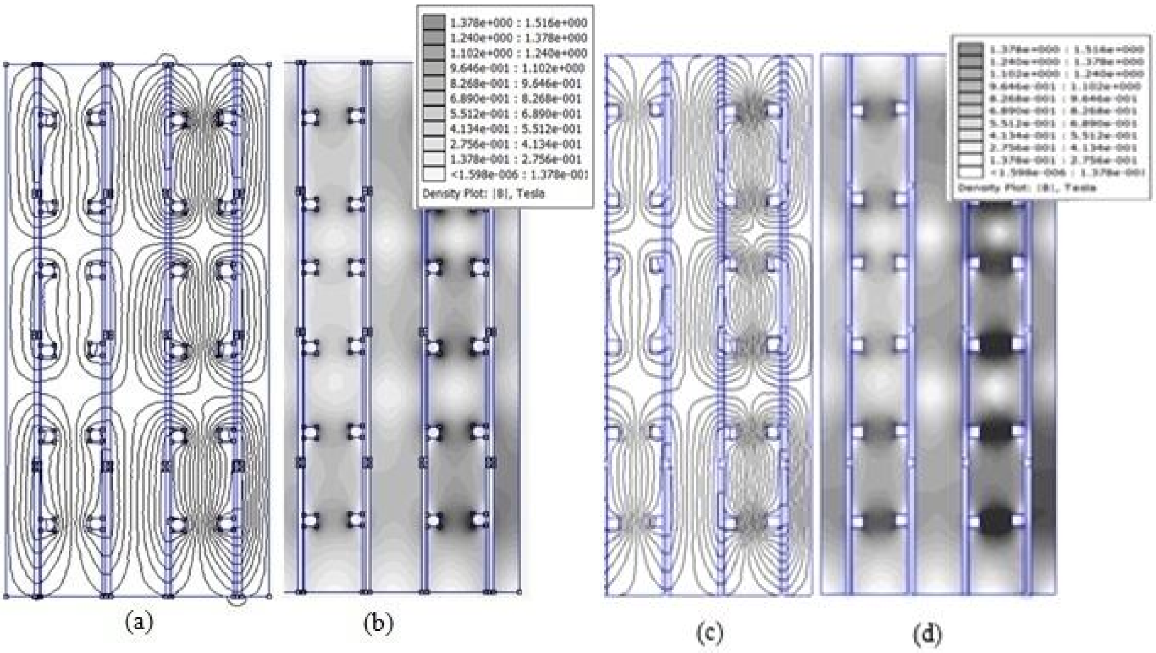

Figure 8. (a) Magnetic flux lines in no-load ondtion (b) The magnetic amplitude density distributioni in no-load condition (c) Magnetic flux lines in full-load condtion (d) The magnetic amplitude density distributioni in full-load condition

By, checking the magnetic flux density in various points of machine it can be seen that the maximum flux density is approximately 1.4 while the use iron will be saturated at flux density of 1.7 T. The maximum magnitudes of magnetic fluxes in all component of the SBG are given in Table III.

Table 3. The magnitude of flux in parts of the SBG

B (Tesla)	No-Load	Full-load
Transaltors	1.42	1.43
Stators	1.38	1.40
Back Irons	1.58	1.52

CONCLUSION

This paper proposed a new system to extract the kinetic energy of vehicle flow in the streets entitled as speed- breaker generator SBG. The SBG is introduced and a designed procedure to achieve and optimized designed is followed. Simulations of magnetic flux lines and magnetic flux density in no load condition the cores are carrying out. The simulation confirmed that the machine cores are under saturation. At the end it is worth to say that, this current work is a preliminary study open a view in design of system can extracted resource of energy which are note fully realized.Further work a focus on experiments to achieve a low cost and commercial SBG.

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