UNIVERSITI PUTRA MALAYSIA

GRAVITATIONAL ENERGY HARVESTING SYSTEM BASED ON MULTISTAGE BRAKING TECHNIQUE FOR MULTILEVEL ELEVATED CAR PARKING BUILDING

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By

YASIR MAHMOOD AL KUBAISI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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July 2020

Chairman : Associate Professor Wan Zuha Wan Hasan, PhD
Faculty : Engineering

Recently, the exploitation of renewable energy resources has been underlined in high-rise buildings and the contribution of buildings in energy conservation has witnessed increased advances in recent years in both residential and commercial sectors. Buildings account for 40% of the world's energy consumption and the multilevel car park is a part of many of these buildings. Therefore, developing an efficient, reliable, and cost-effective systems are crucial in such high-consumption buildings. Gravitational energy has a wide historical knowledge. One of that promising improvement of electrical energy is to use the potential energy of moving-down objects in high buildings. In this work addresses exploiting the gravitational energy of moving down mass for vehicles by designing a mechanical structure named as Gravitation Energy Harvester (GEH). Applying a methodology based on three basic aspects; Firstly, designing a (GEH) structure of a scaled-down prototype for the actual system describing the mechanism of the energy harvesting, which is inspired by the elevator structures. The rotational source was offset mass was anchored on the rotor pulls and rub to create torque. This produces a relative angular speed between the rotor and stator of the DC generator, which causes the power to be generated. Secondly, developing energy optimization criteria by adopting a multistage braking system inspired by regenerative brake systems,

this mechanism provides braking for the climbed down vehicles while aggregating more energy by adding electrical loads in each stage through the moving down period. Thirdly, modeling of electrical and mechanical parameters for the presented system such that the system performance matching the model, this process is performed by using a parameter optimization algorithm. For this purpose, the experimental measurements of the (GEH) structure conducted under different weights and different scenarios of operations, with and without braking mechanism. The measurements of the harvested power and energy show different profiles depending mainly on the weight values and the availability of the braking mechanism. Therefore, the presented (GEH) is able to generate 57.996 J when applying a Multi-Stage Braking System (MSBS) and 38.226 J without MSBS. The results showed that, 34.09% energy and 6.58% delay time have been improved using the proposed system and proposed optimised mass at 3.5 kg. Based on the MSBS experiment, the parameters used are being applied in developing an optimization model; both results are compared and obtained an 8.2% error. Thus, using the optimization model for estimating the real application of a high building (20 m) and vehicle mass (1500 kg) of 100 car spaces have generated 11.09 KWH harvesting energy that able to cover the electrical consumption of the parking building.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

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Oleh

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Pengerusi : Profesor Madya Wan Zuha Wan Hasan, PhD
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Baru-baru ini, eksploitasi sumber tenaga boleh diperbaharui telah digarisbawahi di bangunan tinggi dan sumbangan bangunan dalam penjimatan tenaga telah menyaksikan peningkatan yang meningkat dalam beberapa tahun kebelakangan ini di kedua-dua sektor kediaman dan komersial. Bangunan merangkumi 40% penggunaan tenaga dunia dan tempat letak kereta bertingkat merupakan sebahagian daripada banyak bangunan ini. Oleh itu, membangun sistem yang cekap, boleh dipercayai, dan menjimatkan kos sangat penting di bangunan dengan penggunaan tinggi. Tenaga graviti mempunyai pengetahuan sejarah yang luas. Salah satu peningkatan tenaga elektrik yang menjanjikan adalah dengan menggunakan tenaga berpotensi objek turun di bangunan tinggi. Dalam karya ini alamat mengeksploitasi tenaga graviti bergerak turun jisim untuk kenderaan dengan merancang struktur mekanikal yang dinamakan sebagai Gravitation Energy Harvester (GEH). Mengaplikasikan metodologi berdasarkan tiga aspek asas; Pertama, merancang struktur (GEH) prototaip yang diperkecilkan untuk sistem sebenar yang menggambarkan mekanisme penuaian tenaga, yang diilhamkan oleh struktur lif. Sumber putaran adalah jisim offset berlabuh pada tarikan rotor dan gosok untuk menghasilkan tork. Ini menghasilkan kelajuan sudut relatif antara pemutar dan stator penjana DC, yang

menyebabkan daya dihasilkan. Kedua, mengembangkan kriteria pengoptimuman tenaga dengan mengadopsi sistem pengereman multistage yang diilhami oleh sistem brek regeneratif, mekanisme ini menyediakan pengereman untuk kenderaan turun sambil mengumpulkan lebih banyak tenaga dengan menambahkan beban elektrik pada setiap tahap selama periode turun. Ketiga, pemodelan parameter elektrik dan mekanik untuk sistem yang disajikan sehingga kinerja sistem yang sesuai dengan model, proses ini dilakukan dengan menggunakan algoritma pengoptimuman parameter. Untuk tujuan ini, pengukuran eksperimen struktur (GEH) dilakukan di bawah bobot yang berbeza dan senario operasi yang berbeza, dengan dan tanpa mekanisme pengereman. Pengukuran daya dan tenaga yang dipungut menunjukkan profil yang berbeza bergantung terutamanya pada nilai berat dan ketersediaan mekanisme brek. Oleh itu, yang dipersembahkan (GEH) mampu menghasilkan 57.996 J ketika menggunakan Sistem Brek Berbilang Tahap (MSBS) dan 38.226 J tanpa MSBS. Hasil kajian menunjukkan bahawa, 34.09% tenaga dan 6.58% waktu tunda telah diperbaiki menggunakan sistem yang dicadangkan dan jisim dioptimumkan yang dicadangkan pada 3.5 kg. Berdasarkan eksperimen MSBS, parameter yang digunakan diterapkan dalam mengembangkan model pengoptimuman; kedua-dua keputusan dibandingkan dan memperoleh ralat 8.2%. Oleh itu, menggunakan model pengoptimuman untuk menganggarkan aplikasi sebenar bangunan tinggi (20 m) dan jisim kenderaan (1500 kg) dari 100 ruang kereta telah menghasilkan tenaga penuaian 11.09 KWH yang dapat menampung penggunaan elektrik bangunan tempat letak kereta.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AC	Alternating Current
AT	An automatic Transmission
B	Rotor viscous Friction Constant
BLDC	Brushless DC
BS	Braking System
CBR	Constant Braking rate
CO2	Carbon Dioxide
DC	Direct Current
DM	Dropper Mechanism
EMF	Electromagnetic Force
EMPOP	Electrical and Mechanical Parameter Optimization
ESS	Energy Storage System
EV	Electric Vehicles
g	Gravitational Field Strength
GE	Gravitational Energy
GEH	Gravitational Energy Harvester
GPE	Gravitational Potential Energy
h	Height
HEV	Hybrid Electric Vehicle
I	Current
IRLS	Iteratively Reweighted Least Square
J	Shaft Inertia (kg*m^2): = Jd

Jd	Moment of Inertia of the Rotor
KE	Kinetic Energy
Ke	Electromotive Force Constant
Km	Rotor torque Constant
L	Electrical Inductance
m	Mass
MRL	Machine-Room-Less
MSBS	Multi-Stage Braking System
ηrb	Energy Efficiency of Regenerative Braking
OLS	Ordinary Least Squares
PCB	Printed Circuit Board
PE	Potential Energy
PID	Proportional – Integral – Derivative
PMDC	Permanent Magnet Direct Current
R	Electric Resist are
RBS	Regenerative Braking System
TF	Transfer Function
v	Speed
V	Voltage
VM	Virtual Manufacturing
W	Weight
WLS	Weighted Least Square

CHAPTER 1

INTRODUCTION

1.1 Background

Recently, the exploitation of renewable energy resources in high-rise buildings has received much attention. There have also been increased advances in the contribution of buildings towards energy conservation in recent years in both residential and commercial sectors. The increasing demand for building services and comfort levels, population growth, and the fact that people are spending more time inside commercial buildings and homes, has led to an upward trend in energy demand. This demand is projected to rise in the future continually. Therefore, the conservation of energy in buildings is a significant objective in the overall energy policy [1].

Buildings account for about 40% of the world's energy consumption. A multilevel car park is a building designed for parking cars and usually has some levels or floors dedicated to the purpose. Parking space can be specified in new building parking requirements as imposed by cities or states. Many car parks are standalone buildings dedicated exclusively to parking purposes. In recent times, car parks designed to serve commercial and residential properties have been built as part of a larger building [2]. This enables land to be utilized for other functions (as opposed to solely a car park building), is cheaper and more practical in most cases than a separate building, and the car park is also usually hidden from view. There are two types of kinetic energy in multilevel elevated car parking buildings when a vehicle uses such building energy consumed for moving up, and energy used for moving down. This work addresses the exploitation of the descending mass (the vehicle) by designing a mechanical structure similar to that used in elevators called a Gravitational Energy Harvester (GEH) [3]. The proposed system is used for descending the car from the top level to the ground level and exit without stope in between.

From the perspective of energy efficiency and safety, highlighting Gravitational Energy (GE) is a meaningful step to take. Still, it can also be considered as a big challenge. This research initially presents a comprehensive review of what has been done in the harvesting of gravitational energy, braking energy of moving vehicles, and controller techniques for aggregating

such energies. Towards this end, the research divides the potential energy and kinetic energy of the descending vehicles in such buildings into mainly related technologies for utilizing all possible energy, which can be converted to electricity. Thus, it investigates the feasibility, control, and energy management strategies of the Regenerative Braking System (RBS) in electric vehicles (EV), railways, and elevators by relying on the most current research works [4].

This research will review several aspects that have a practical impact on the project from the perspective of the gravitational harvesting energy applicability range. Gravitational energy has historically been well-researched, but the findings from previous research are frail in terms of its application. The regenerative brake system has been actively adopted when the hypothesis of this research is formulated because the harvested energy comes from the gravity source, which is the mechanical potential energy of moving objects that have kinetic energy. Therefore, the strategies that adopt this type of power generation are considered in this study, such as energy-efficient railway transport systems, brake regeneration in electric vehicles, and brake regeneration in elevators. Energy storage systems in such power generation will also be covered by this research [5].

A brief description of the actual system represented by the block diagram, as shown in Figure 1.1, which contains:

1. Multilevel car park building.
2. A vehicle which is located in a high-level building has potential energy.
3. Gravitational Energy Harvester (GEH) Structure: it is contained all the system equipment and converts the potential energy into kinetic energy.
4. DC generator: it is used to harvesting the electrical energy from the kinetic energy (vertical motion).
5. Multi-Stage Braking System: controls the descending weight according to stages of the connected electrical load depending on the shaft encoder signal and speed control to improve the harvested energy.
6. Multi electrical load: represents the electrical power consumption.

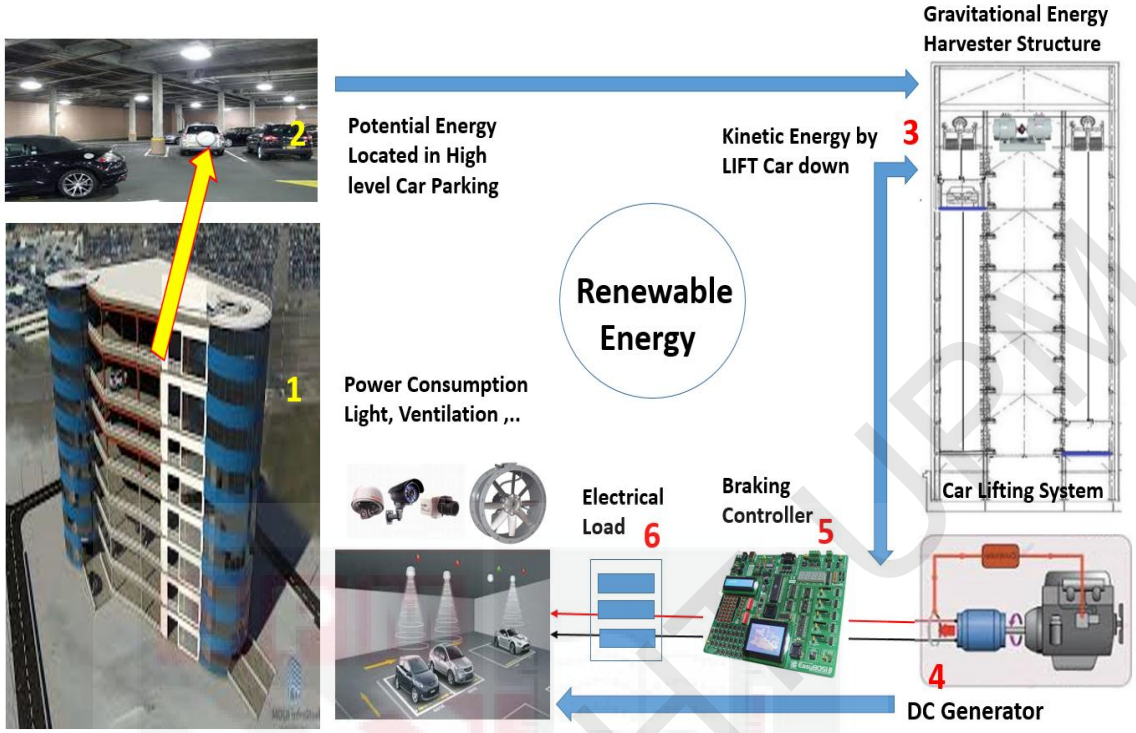

Figure 1.1 : Illustration of Renewable Energy for Gravitational Energy Harvester

1.2 Problem Statement

There are two types of kinetic energy for a vehicle using a multilevel car park building; energy consumed for moving up and energy for moving down in line with gravity. This work addresses the exploitation of gravitational energy in the mass of a descending vehicle by designing a mechanical structure called the Electrical Energy Harvester (GEH) mechanism for the harvesting of the gravitational energy. As a result, it is possible to list the problems as follows:

1. Various kinds of high residential constructions have increased in different countries since at least the 1940s [6]. The study of energy consumption and assessing the impact of policies are aimed at reducing carbon emissions in modern cities [7]. There are also several types of green energy that have been wasted and not used till now [8]. A vehicle's mass located at a high point of a building contains potential energy. The driver used the fuel energy to move the significant weight of the vehicle down; this exit motion costs money due to wasting energy, increases CO2 emission, and negatively affects the environment [9].
2. In recent years, many measures have significantly focused on the prevention of global environmental problems. Among these measures is the expansion of energy-saving systems for electrical elevators [10]. Several types of green elevators can regenerate energy for energy-saving purposes; the elevators can collect renewed energy and discharge the stored energy during operations [10][2]. However, this energy-saving method can only achieve up to 30% savings in elevator energy consumption [11][12][13].
3. There are different types of car park buildings, with a different number of levels, heights, and functions. The buildings are also used by vehicles of various weights. All these vehicles use one system to descend. Thus, implementing this system involves many parameters for estimating the design transfer function (TF) accordingly. The optimisation technique should be tuning the electrical and mechanical coefficients to resolve any drawbacks between its elements as well as problems. [2][13][14][15].

The suggested mechanism is called the Gravitational Energy Harvester (GEH). The methodology of the device is based on three fundamental aspects, first, by designing a scaled-down prototype describing the mechanism of energy harvesting. This process is performed by using a least-square algorithm for parameter optimization.

1.3 Motivation

Green energy sources provide a clear alternative to the fossil fuel-based engines of the internal combustion electricity generators that run on petrol and diesel. These fuel types are being consumed active, and alternative energy sources necessity be put into application. The depletion of fossil fuels increases

yearly as more generators are used due to population growth, and the corresponding increases in power demand. Fossil fuels are not replaceable and cannot keep up with demand. Green energy sources, especially the one addressed in this work, present many advantages as discussed above and are also environmentally-friendly. Due to the benefits of renewable gravitational energy, electrical energy must be saved through more sophisticated systems that have optimum performance and more significant energy conservation, as they are an essential part of any green building in the future. Electrical, gravitational energy harvester systems that are enhanced by the generative braking technique must use an electric energy source that is more reliable and simpler as well as makes the origins of green electrical energy more efficiently. If such systems are incorporated into green multilevel buildings and their benefits are seen by all, then the application of gravitational, electric power for similar structures will grow globally. This system is especially important in developed countries that have a high demand for electricity, where the results of pollution due to fossil fuel use in big cities have produced the population to suffer from health problems. An increase in the number of green buildings will benefit society and the environment. The widespread use of multilevel parking systems will also start to bring down the cost of other green alternative energy sources like solar and wind.

1.4 Objective

The goal of this research initiative is to design and improve an electrical energy harvesting system from an efficient gravitational mechanism for multilevel car park buildings. The work includes: 1) a Prototype Structure; 2) Generative Braking Scheme, and 3) System Modelling and Simulation using Nonlinear Least Square Algorithm for Parameter Optimisation. Several objectives have been identified to achieve this goal, as follows:

1. To introduce a Gravitational Energy System (GEH) mechanism of a multilevel car parking building model based on gravitational energy as stable renewable energy from a mass moving down without deducting the counterweight mass.
2. To propose a multi-stage braking system with a multi-stage speeding controller to increase the amount of harvested energy and control the dropped mass speed.
3. To propose an optimization technique based on experimental parameter data to describe the actual size of the system.

4. To validate the harvested energy based on the proposed GEH structure with the estimated energy using TF of the structure.

1.5 Scope of Research

This work addresses gravitational energy as one type of renewable energy and the concept that has been adopted to realize and design the mechanism of the proposed green energy source from descending vehicles in buildings that have multilevel parking. Energy conservation and optimization in both residential and commercial buildings will be investigated in this research. The application of this system will reduce the impact on our economy and environment. Therefore, this work seeks to gain a better understanding of how gravitational energy is generated and how to improve its effectiveness by proposing a control algorithm and a power system framework for the parking area electrical loads.

Regenerative braking is a technique used in EVs to capture the energy that the vehicle has due to its horizontal motion, or in other words, it's kinetic energy that would have been wasted when the vehicle decelerates or comes to a standstill while braking. By taking a measure of the initial and final vehicle velocity, the amount of kinetic energy that is lost to braking can be calculated [16] [17] [18].

The Gravitational Energy Harvester GEH as a scale down prototype for a four-level car parking system used to descending and exit the vehicles from heigh level to ground level to exit the building. The GEH system limitations can be listed as follows:

1. The GEH structure body height 2m, to represents a scaled-down prototype for four-floor car parking building in the laboratory.

2. Using a 40-watt PMDC with speed up gare to convert the kinetic energy to electricity and choosing this type of machine because of less cost, more efficiency, and easy to control it.

3. The suitable weight from 2 to 3.5 kg. In the laboratory, various mass (1 to 5) kg was used, but the optimum results were obtained between 2 and 3.5 kg.

4. Using only 3- stages of the multistage braking system, it represents three-floors braking (2^{nd},1^{st}, and G floor).

5. The speed limitation between 0.5 to 1 m/sec, because less than 0.5 m/sec it will not cross the threshold value of the friction, and more than 1 m/sec was difficult to control the stoping of the dropped mass.

This thesis also analyses the impact of different braking strategies on the total energy consumption of a test mechanism across various samples of scaled-down prototypes. The concept of (GEH) is shown in Figure 1.2.

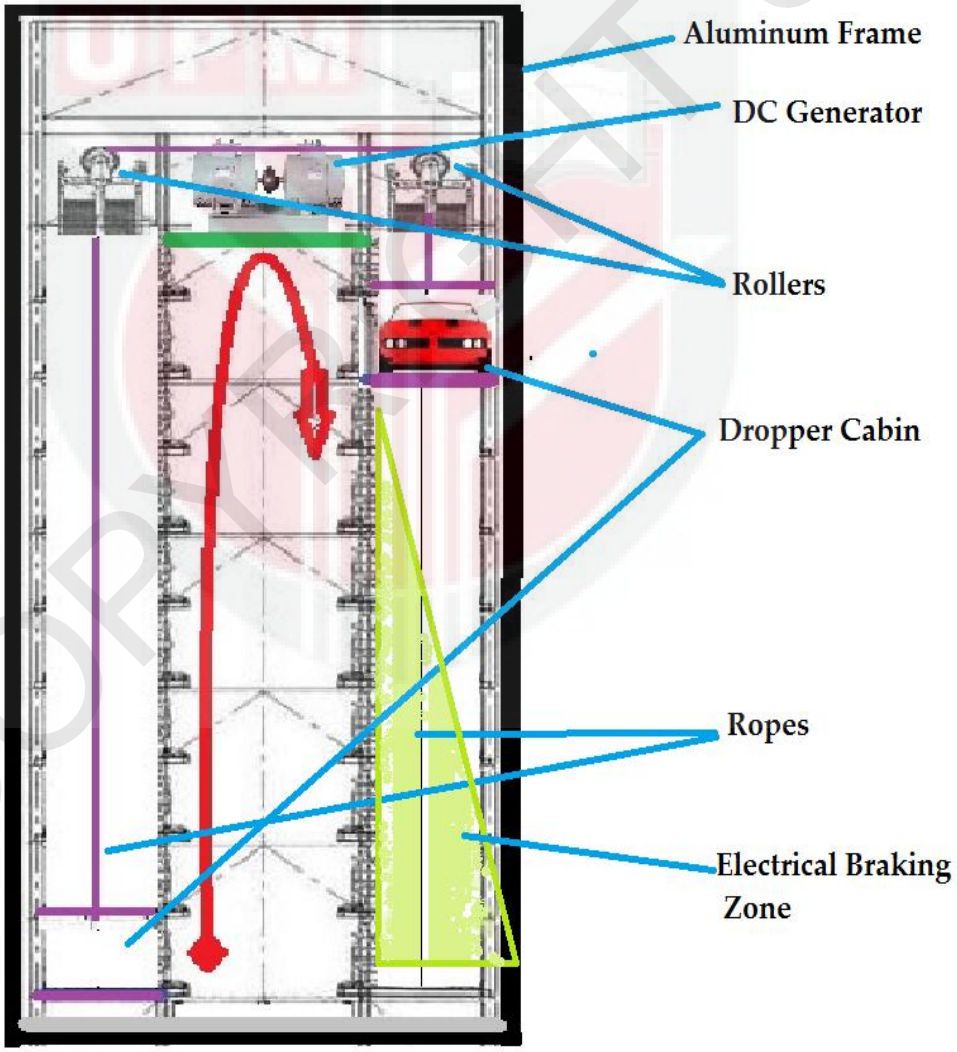

Figure 1.2 : The Model of Gravitational Electrical Energy Generator (GEH)

1.6 Thesis Organisation

This thesis consists of five chapters. The first chapter is the introductory chapter, which gives us an outline of gravitational and electric energy, generative braking, and their systems. It also includes the benefits of such a system and indicates the objectives behind the project.

The second chapter is a literature review. It provides a detailed description of several previous research works and their findings, which have been helpful during the carrying out of this research project. The history and principles of these are mentioned in the chapter.

The third chapter is the theory and methodology of the proposed system. This chapter includes the details of the practical steps of gravitational energy for the dropped objects and the proposed mechanism of the Gravitational Energy Harvester. It also consists of the control algorithm and the use of MATLAB simulation to optimize the model parameters.

The fourth chapter presents the findings along with discussions. Also, it describes the circuits which have been used in the project work. The simulation, hardware construction are described as well the results shown in one graph and explained.

Finally, the fifth chapter provides a summary and the conclusions based on the findings of this research. The motivation behind this work, together with suggestions, and recommendations for future research in this area, is also presented in the final chapter.

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