UNIVERSITI PUTRA MALAYSIA

DC-BASED PV-POWERED HOME ENERGY SYSTEM

AHMAD H. SABRY

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By

AHMAD H. SABRY

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

November 2017

DEDICATION

To my Parents,

To my Family,

To my Brothers and Sisters,

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

DC-BASED PV-POWERED HOME ENERGY SYSTEM

By

AHMAD H. SABRY

November 2017

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

In residential applications, energy engineers are always looking for optimal utilization of solar power to manage the energy use and reduce its impact on our economy and environment. The power source in such systems is direct current (DC) in nature, but the electricity infrastructure is still based on alternating current (AC), although most of the modern available household appliances consume DC power. Therefore, there are dissipated powers due to conversion stages to handle the solar power to the household appliances. A DC based home energy system, based on the source-load voltage matching concept, is proposed to improve system performance.

In a solar charge controller, the present MPPT based systems still have losses due to the switching of their semiconductor devices producing a rise in temperature that negatively affects the overall system. A controller based on an algorithm of one time maximum power point (MPP) is proposed to mitigate those losses.

The efficiency of the current traditional PV-powered system is inversely affected due to the multiple conversion stages that such a system has. Therefore, this work proposes the design and development of a wireless low power consumption prototype energy monitoring system using a novel solar-battery charge controller based on the DC voltage matching concept.

For more accurate mathematical representation for the empirical outcome power data, a mathematical model based on Bode Equations and Vector Fitting algorithm has been proposed to govern the load power profile of the proposed system.

The work initially investigates the feasibility of using the DC distribution system to power the locally available AC appliances, that are analyzed and evaluated individually to match the DC supply either by direct coupling or some modification. The appliances are classified according to their compatibility with the DC environment to determine the efficient operating voltage range. The algorithm of the proposed charge controller uses that voltage to be assigned as the value of the full charge voltage for the battery bank. The controller algorithm requires also the variation range of the geographical weather parameters (irradiance and temperature) to specify the MPP which is equivalent to that operating voltage at minimum weather parameters. The PV array output power is directly connected through high current parallel diodes or resistance to charge the battery bank when the battery voltage becomes lower than the calculated or full charge voltage level. By contrast, the charge controller exchanges to an auxiliary load path when the battery bank reaches its full charge value. This surplus power transfers to feed another load that might be used for ventilation to reduce the solar module temperature and add some improvements to system performance. The low power consumption wireless energy monitoring allows remote monitoring for the energy consumption of appliances and power rate quality. The system can be managed via a central computer which attains the energy data via only one remote XBee RF wireless node which is processing the sensors measurement of the system components. The proposed monitoring circuit is characterized by its low power consumption due to the lack of components and its ability to access six precise analogue channels with no additional microcontroller. The energy measurements are modelled by the new proposed mathematical equations. Simulink MATLAB is used as a simulation program to imitate the processes of the practical stages of this research.

The results show great utilization of the system losses, where in some appliances, the proposed topology can achieve about 99% power efficiency as compared with the traditional one. The savings of the proposed topology can be reached to about 2696.7 Wh as compared with the traditional AC-environment one, and to about 531.6 Wh as compared with the new current partly DC-environment system.

The monitoring outcome of the designed GUI proves the voltage matching concept between the PV array (as a source) and the battery/appliances (as a load), which represents a significant evidence for the considered matching concept. The disposal of the DC-AC inverter opens the horizon toward high efficiency Solar-Battery-Load system not only in the residential applications but also in general.

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

SISTEM TENAGA RUMAH KEDIAMAN BERKUASA-PV BERDASARKAN DC

Oleh

AHMAD H. SABRY

November 2017

Pengerusi : Profesor Madya Wan Zuha b. Wan Hasan, PhD
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Untuk aplikasi kediaman, jurutera tenaga sentiasa mencari penggunaan optimum kuasa suria untuk menguruskan penggunaan tenaga dan mengurangkan kesan terhadap ekonomi dan alam sekitar kita. Sumber kuasa di dalam sistem tersebut adalah bersifat arus terus (DC), tetapi infrastruktur elektrik masih berdasarkan arus ulang- alik (AC), walaupun sebahagian besar perkakas rumah moden yang ada menggunakan kuasa DC. Justeru itu, terdapat kelesapan kuasa kerana peringkat-peringkat penukaran untuk mengendalikan kuasa suria bagi perkakas rumah. Sesuatu sistem tenaga rumah berasaskan DC, berdasarkan konsep pemadanan voltan sumber-beban, dicadangkan untuk meningkatkan prestasi sistem .

Di dalam sesuatu pengawal cas suria, sistem-sistem MPPT yang sedia ada masih menghadapi kehilangan disebabkan pensuisan peranti-peranti semikonduktor mereka, menghasilkan kenaikan suhu yang berpengaruh negagif terhadap sistem keseluruhannya. Suatu pengawal berdasarkan algoritma titik kuasa maksimum satu kali (MPP) dicadangkan untuk mengurangkan kehilangan tersebut.

Kecekapan di dalam sistem berkuasa-PV tradisional semasa terjejas songsang akibat peringkat penukaran berbilang yang dimiliki sistem seperti itu. Oleh itu, kajian ini mencadangkan reka bentuk dan pembangunan suatu prototaip sistem pemantauan penggunaan tenaga wayarles kuasa rendah menggunakan pengawal caj bateri-suria baru berdasarkan konsep pemadanan voltan DC.

Untuk perwakilan matematik yang lebih tepat bagi data kuasa hasil empirik, suatu model matematik berdasarkan persamaan Bode dan algoritma penyesuaian vektor telah dicadangkan untuk mengawal profil kuasa beban sistem yang dicadangkan ini.

Kajian ini pada awalnya menyiasat kebolehlaksanaan menggunakan sistem pengagihan DC untuk menggerakkan peralatan AC tempatan yang sedia ada, yang dianalisis dan dinilai secara individu agar sepadan dengan bekalan DC sama ada dengan gandingan terus atau beberapa pengubahsuaian. Peralatan dikelaskan mengikut keserasiannya dengan persekitaran DC untuk menentukan julat voltan operasi yang cekap. Algoritma pengawal cas yang dicadangkan menggunakan voltan itu sebagai voltan nilai cas penuh untuk tindanan bateri. Algoritma pengawal cas yang dicadangkan memerlukan juga pelbagai variasi parameter cuaca geografi (sinaran dan suhu) untuk menentukan MPP yang bersamaan dengan voltan operasi tersebut pada parameter cuaca minimum. Kuasa keluaran tatasusunan PV disambungkan secara langsung melalui diod selari arus tinggi atau rintangan untuk mengecas tindanan bateri apabila voltan bateri menjadi lebih rendah daripada tahap voltan cas dikira atau penuh. Sebaliknya, pengawal cas bertukar ke jalan beban bantuan apabila tindanan bateri mencapai nilai penuh casnya. Kuasa lebihan ini berpindah untuk membekalkan beban lain yang mungkin digunakan untuk pengalihudaraan bagi mengurangkan suhu modul suria dan menambah beberapa penambahbaikan pada prestasi sistem. Pemantauan tenaga wayarles dengan penggunaan kuasa yang rendah ini membolehkan pemantauan jarak jauh bagi penggunaan tenaga peralatan dan kualiti kadar kuasa. Sistem ini boleh diuruskan melalui komputer pusat yang mencapai data tenaga melalui hanya satu nod wayarles RF XBee yang sedang memproses pengukuran penderia komponen-komponen sistem itu. Litar pemantauan yang dicadangkan dicirikan dengan penggunaan kuasa yang rendah kerana sedikitnya komponen dan keupayaannya untuk mengakses enam saluran analog yang tepat tanpa mikropengawal tambahan. Pengukuran tenaga dimodelkan oleh persamaan matematik baru yang dicadangkan. Simulink MATLAB digunakan sebagai program simulasi untuk meniru proses-proses peringkat praktikal penyelidikan ini.

Hasilnya menunjukkan penggunaan kehilangan-kehilangan sistem dengan hebat, di mana bagi beberapa peralatan, topologi yang dicadangkan dapat mencapai kecekapan kuasa 99% dibandingkan dengan yang tradisional. Penjimatan topologi yang dicadangkan boleh sampai kepada kira-kira 2696.7 Wh berbanding persekitaran-AC tradisional, dan kepada kira-kira 531.6 Wh berbanding dengan sistem baru semasa sebahagian persekitaran-DC.

Hasil pemantauan GUI yang direka membuktikan konsep menyepadankan voltan antara tatasusunan PV (sebagai suatu sumber) dan bateri/peralatan (sebagai suatu beban), yang mewakili bukti penting bagi konsep menyepadankan yang dipertimbangkan. Pelupusan penyongsang DC-AC membuka jalan ke arah kecekapan tinggi sistem Beban Bateri-Suria bukan sahaja untuk aplikasi kediaman tetapi juga secara umum.

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I would also like to acknowledge the Electrical Engineering Department of Universiti Putra Malaysia for providing the numerous facilities and support for this research work.

I certify that a Thesis Examination Committee has met on 13th Nov 2017 to conduct the final examination of AHMAD H. SABRY on his thesis entitled "DC based PV-Powered Home Energy System" in accordance with Universities and University Colleges Oct 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the candidate be awarded the Doctor of Philosophy.

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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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ADC	Analogue to Digital converter
AC	Alternative current
API	Application Programming Interface
BLDC	Brushless DC
D	Duty cycle
DC	Direct current
E	The total energy
If	Forward current
δ_t^j	channel read j of the analog-to-digital converter at time interval, t
GUI	Graphical Interface Unit
Kv	Voltage scale down constant
Ki	The current scale down constant
I	Current
I_{rms}	Root mean square current
Irr	Sun Irradiance
$Irrmin.$	Minimum Sun Irradiance
$Irrmax.$	Maximum Sun Irradiance
$\mathrm{im}(\mathrm{r_n})$	Imaginary part of
RMS	Root mean square
RF	Radio frequency
$\mathrm{re}(\mathrm{r_n})$	Real part of
P_{DC}	DC power
P_θ	Phase power
$P_{attained}$	Total attained power
PL	Power losses
P_{bat}	Battery power
$P_{bat+inv}$	Inverter + battery power
PMAC	Permanent magnet
PCB	Printed circuit board
$Paux$	Auxiliary load power

$Pc.o$	Cut off power (one of the system design value)
p_j	New poles
q_j	Initial poles set
RAF	Rational Approximation Function
R_{AC}	AC resistance
$\check{r}_j$	The residues
ϴ	Phase
T	Temperature
Tmax.	Maximum temperature
T_d	Day time over which the integration applied
VF	Vector Fitting
V_{rms}	Root mean square voltage
Vt	The actual measured voltage value
VL	Load voltage
Vout	Scale down output voltage
VFch	Fully charge battery voltage
Vbat.max.	Fully charge battery voltage
Voc	Solar Open Circuit Voltage
Vmp	Solar array voltage at maximum power
MPP	Maximum power point
MPPT	Maximum power point tracking

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The energy amount delivered to earth in one day from the sun is adequate to cover the total energy requirements of the earth over one year. Energy conservation and security is one of the main concerns for the future all over the world. Fossil fuel resources are decreasing in quantity, while their prices are increasing more rapidly than predicted. Another transformation that is occurring very rapidly is climate change. Solar energy is one of the most important solution. It is clean and abundantly available. Solar technologies use the sun to provide heat, light, electricity, etc. For domestic and industrial applications. It has become an urgent necessity to invest in renewable energy resources that would power the future sufficiently without degrading the environment through greenhouse gas emission. The energy potential of the sun is immense, but despite this unlimited solar energy resource, harvesting it is a challenge mainly because of the limited efficiency of the array cells and that technology used to manage this energy source efficiently.

Although, the most well-known green technologies that include photovoltaic, wind turbines, fuel cells, and other forms of energy that are deemed more environmentally friendly are DC, unfortunately, the prevailing power system infrastructures are based on AC.

An increasing number of energy-efficient appliances operate on DC internally, offering the potential to use DC power from renewable energy systems directly and avoiding the losses inherent in converting power to AC and back.

The convergence of some factors is driving latest interest in utilizing the DC of the solar electric power system in its DC form to supply electricity to various appliances in buildings, instead of converting it to AC. The new millennium has witnessed continued and fast growth in the implementation of roof-install solar array systems and better interested in advanced PVtechnology, as concerns over climate change have increased. The metered PV power system, which have dominated over the renewable energy in residential sector, is a DC power source, as are batteries, which are the prevailing energy storage technology utilized by such system. The increasing of the recent efficient electrical household appliances that operate internally on DC drove that the savings of energy could be attained by direct coupling of DC source with DC appliances (Electric Power Research Institute (EPRI) 2006). Therefore, avoiding the conversions DC-AC and from AC-DC. Recent expressions with residential load have shown that considerable savings from energy can be attained when the DC power distribution delivered directly to DC electronics appliances, rather than using the AC. This research considers the relative energy savings of the direct coupling DC in residential applications.

Few publications addressed the DC distribution system as an environment for the household appliances to improve energy conversion and consumption efficiency. Several studies addressed only the DC environment for their system loads, but with two low level of voltages (24, 48)V, and only with TV and LED light as an electronic appliances (Ayai et al. 2012; Loomba et al. 2016). DC and AC distribution system as a power supply for household appliances is a widely known rather than only DC, but the DC in those systems are with more than two voltage levels (Ayai et al. 2012; Cheung et al. 2004; Ishigaki et al. 2014; Justo et al. 2013; Kakigano et al. 2006; Lee et al. 1999; Lucía et al. 2013; Oliver 2012; Rauf et al. 2016; Salomonsson et al. 2008; Shenai et al. 2011). The concept of direct coupling (source-load) for DC distribution system is investigated and implemented, but it was restricted by multi low levels of voltage (12-200)V to dirct link their appliances by DC supply (Ayai et al. 2012; Loomba et al. 2016; Lucía et al. 2013; Rauf et al. 2016). The previous efforts that proposed DC and AC environment, were forced to involve the AC inverter within their systems (Ayai et al. 2012; Ishigaki et al. 2014).

In spite of the above limitations for the previous DC based systems, only few researches addressed the moniroing or managing the energy of the DC system, but in contrast, their monitoring were limited by either with the consumptions of the electronic devices and lights (Ayai et al. 2012; Ishigaki et al. 2014) or induction heating appliance (Lucía et al. 2013).

Non of the above publications proposed mathematical model for such environment to describe the pattern of the power consumption.

The concept of the voltage matching of the source-load on DC environment and PV based energy supply need to be integrated by a solar charge controller. Therefore, this work proposes a controller uses the same concept in its operation to overcome the problem of the low performance due to partial shading in PV-powered systems. Although recent breakthrough in the technology of solar charge controller shows significant improvement, but the present MPPT systems still have losses due to the switching of their semiconductor devices as well as the normal rise in the temperature of the main system components during operation.

The goal of this thesis is to identify these areas and methods for improving the overall system efficiency and reliability as well as strengthen the economical competition for utilizing such energy. One of the methods is to dispense the power conversion equipments from the system in residential and office application, which is based on the voltage matching between the source and load.

The AC-based or AC-Bus PVmicrogrid configuration in the range (220-380)Vac has been usually considered, as seen in Figure 1.1(a). In AC-Bus PV system, the maximum power point tracker (MPPT) manages a higher power from PV arrays to supply into an AC-bus or AC-grid through an inverter. For a typical household appliances application, such as personal computer, electronic devices, or variable speed motor-based appliance, they generally have a rectifier, an AC 50 Hz filter, a power factor corrector (PFC), and a DC/DC or DC/AC converter to deliver the loads with electric power. But, this AC-based system guides to a conversion loss with high amount. Therefore, the concept of "DC-based or DC-Bus" on PV-powered home systems have been offered recently (T. F. Wu, Kuo, et al. 2013; Wu et al. 2010), such configuration is demonstrated in Figure 1.1(b). The power conversion efficiency can be calculated in the AC-bus system, which is obviously less than that for the DC-bus system about 12%. Besides, the DC-based PV system can also save a rectifier and a PFC circuits, there is also saving with the system components cost to about 25% (T. F. Wu, Chang, et al. 2013). Therefore, the DC-based configuration is more efficient in renewable energy power-distribution applications.

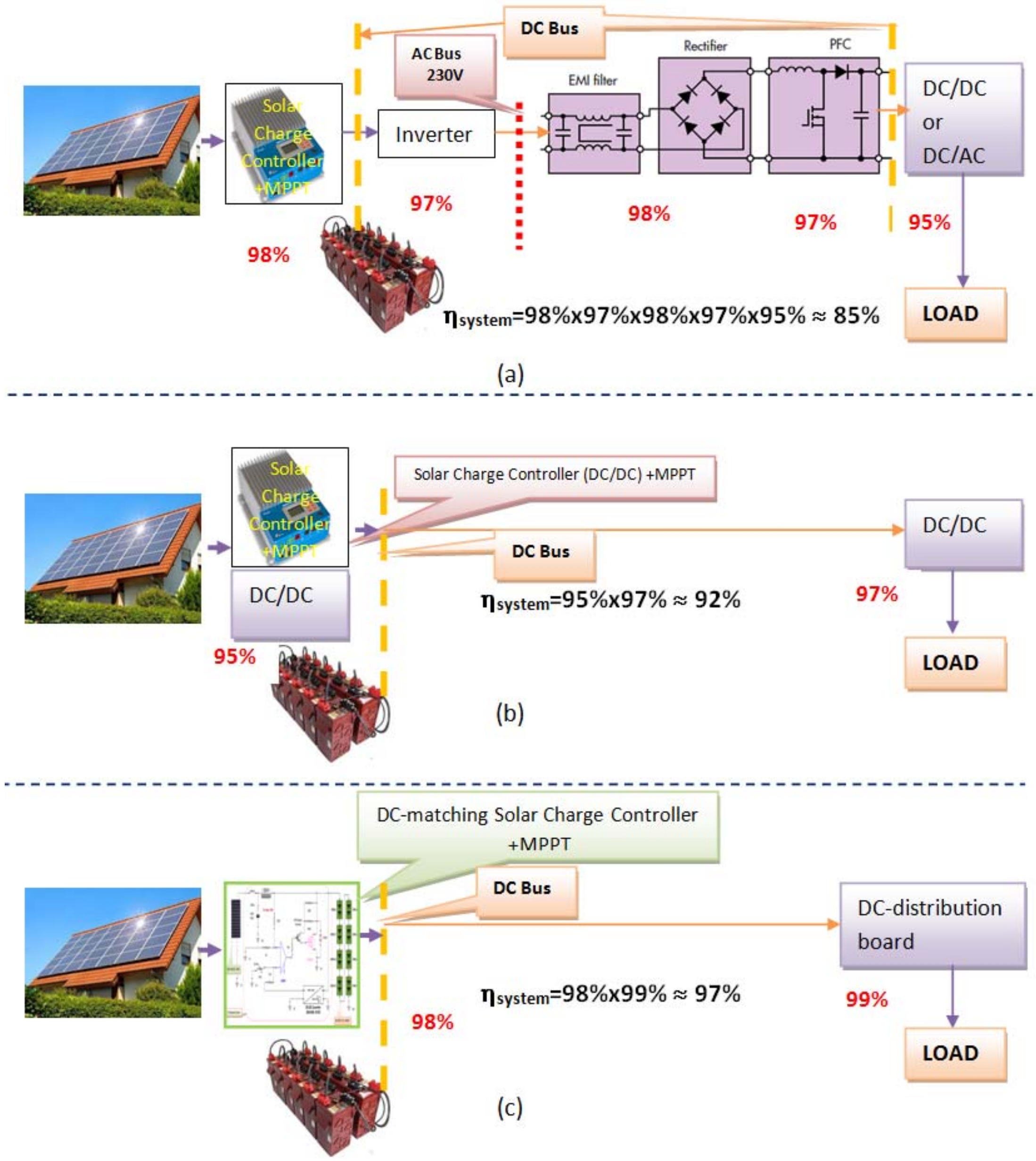

Figure 1.1 : Solar-powered Home system: Conceptual configuration (a) Traditional AC-based, (b) DC-based, and (c) Proposed DC-based systems

In smart house technology context, the proposed DC-based wireless home monitoring system provides savings in energy through intelligent energy monitoring and management capabilities. This configuration promises monitoring and control of the household appliances for energy savings that include temperature control, lighting and extra energy efficient functions and then, transfer a traditional solar-powered house into an intelligent one as shown in Figure 1.2.

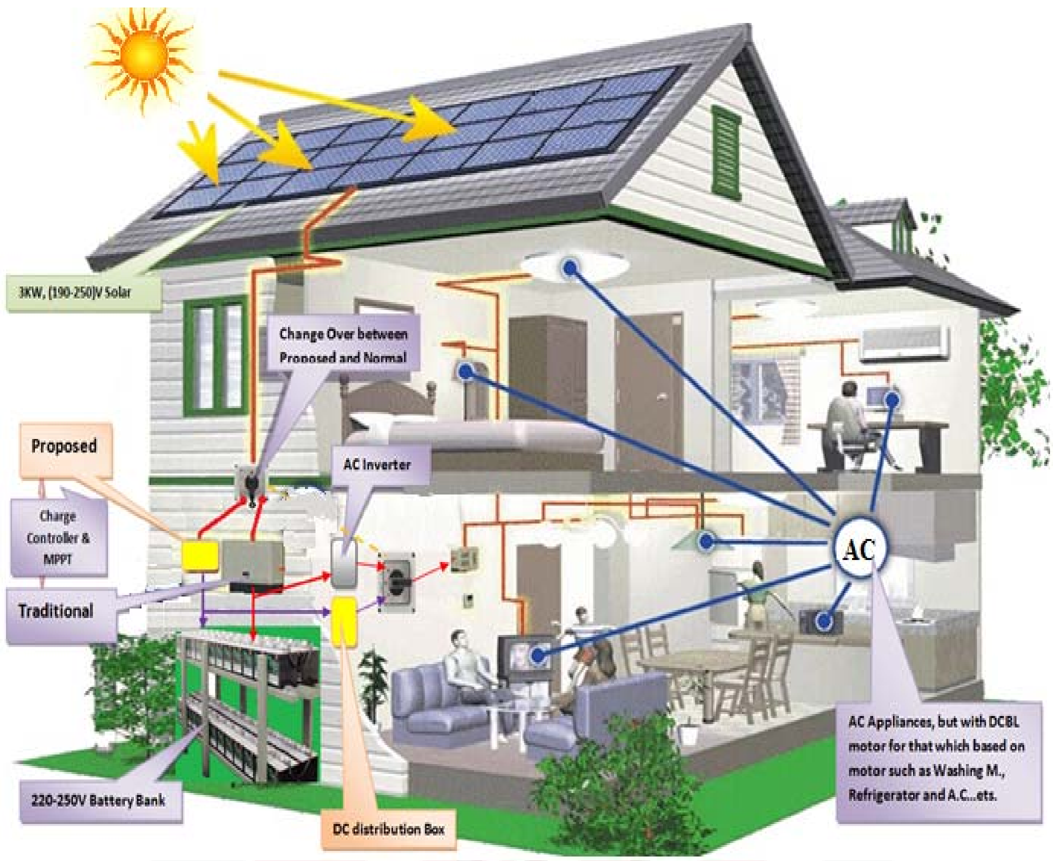

Figure 1.2 : Traditional to intelligent house by employing monitoring and driving the system for more power consumption savings

1.2 Motivations

Several motivations have been specified that encourage getting started in this work. The motivations generate a merge among interested advanced household appliances as a load from one side, and the photovoltaic (PV) system as a power source from another side. This approach has an intensive investigation and harvested great outcomes, but there is still some effort towards system integration and efficiency optimization. This section discusses several of these motivations:

1.2.1 Renewed Interest in Direct-DC.

At present, the infrastructures of the solar power system need to be first converted from DC power which is generated from the PVarray into AC. Therefore, more complexity would be added and reduced the efficiency of the energy system as a result of the power conversion process. Additionally, the increasing in the number of DC load consuming devices such as; PCs, TVs, and other electronic household appliances are being included into our homes/offices, the supplied power to these devices need to be converted once more from AC to DC which is adding additional complexity and losses to the energy system.

Because the energy impacts of using DC versus AC appliances lie not only on the differences between the household appliances, but also in the difference between the AC versus DC power systems connecting the appliances, PV system, and grid appliance-level savings tell only a part of the story. More specifically, to distinguish the impact of DC- versus AC-distribution, the study defined two sets of appliances for the modelling work. These appliances were identical in every way other than their front-end power interface. The DC-appliance constitutes the basis set. The AC appliance is just the DC-appliance with an AC-DC converter on the power input.

1.2.2 AC Versus DC Distribution System

The power losses comparison is simply prepared to power household appliances that start from the DC power source represented by the PV and end with household appliances. Figure 1.3, Obviously, shows the losses in power between two comparative power distribution topologies, the traditional (PV-Battery-Inverter-Appliances) and the proposed (PV-Battery-Appliances). Difference in losses is due to energy conversions, in AC—distribution, DC/AC and AC/DC between source which is a DC, and the appliance which is DC-internally, while in DC-distribution, power source is directly linked to the load.

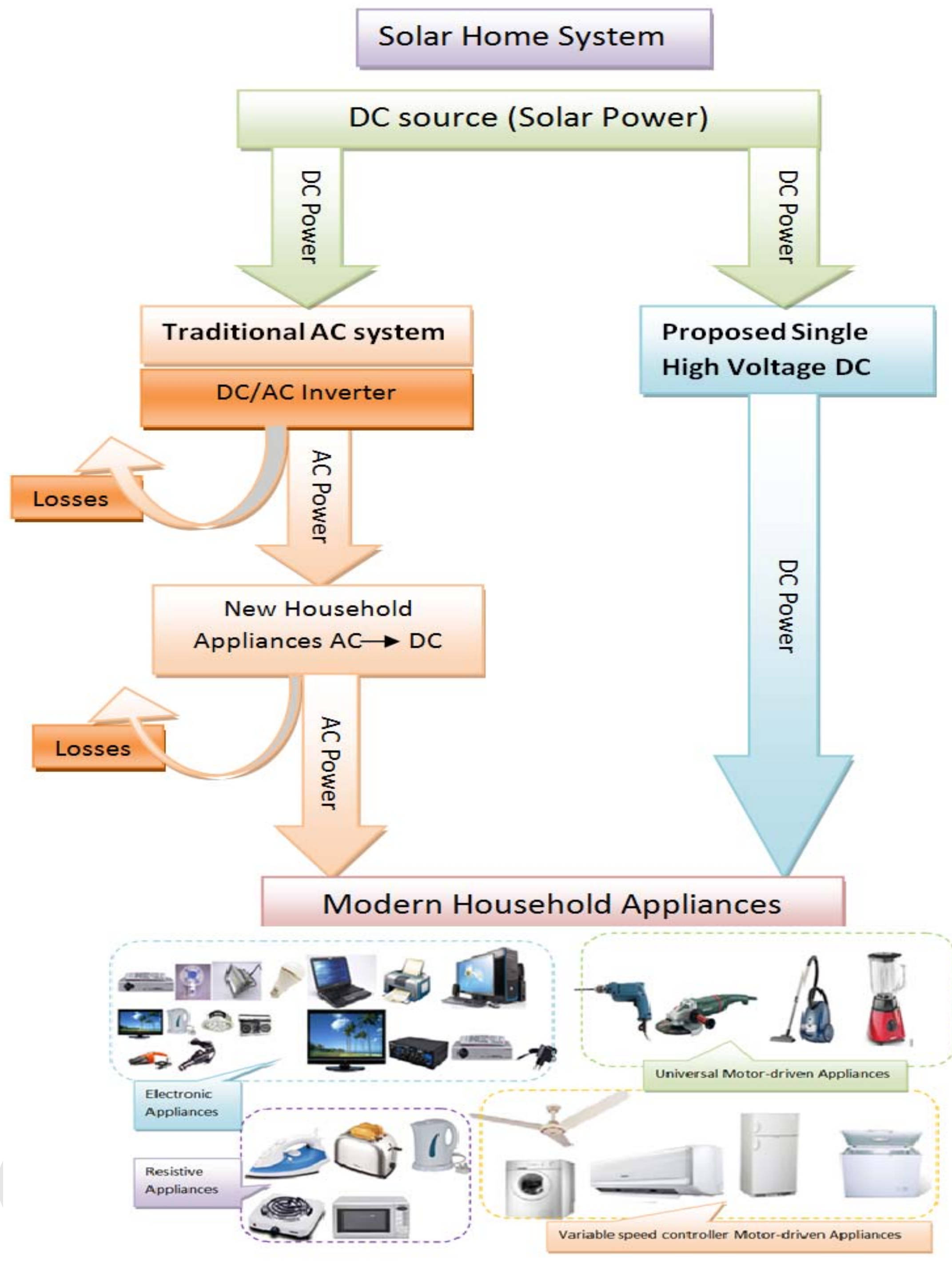

Figure 1.3 : AC-distribution vs. direct DC-distribution comparison in terms of power losses between the PV source and the DC-internal appliances

1.2.3 Rapid Increase in Residential PV and Decrease in its Price.

The PV dominates over other renewable electricity generation resources in the residential sector. Referring to Figure 1.4, the cost to purchase solar panels has dropped by more than 71% over the final 10 years, pushing the solar market to expand their products and deploy thousands of systems and development projects.

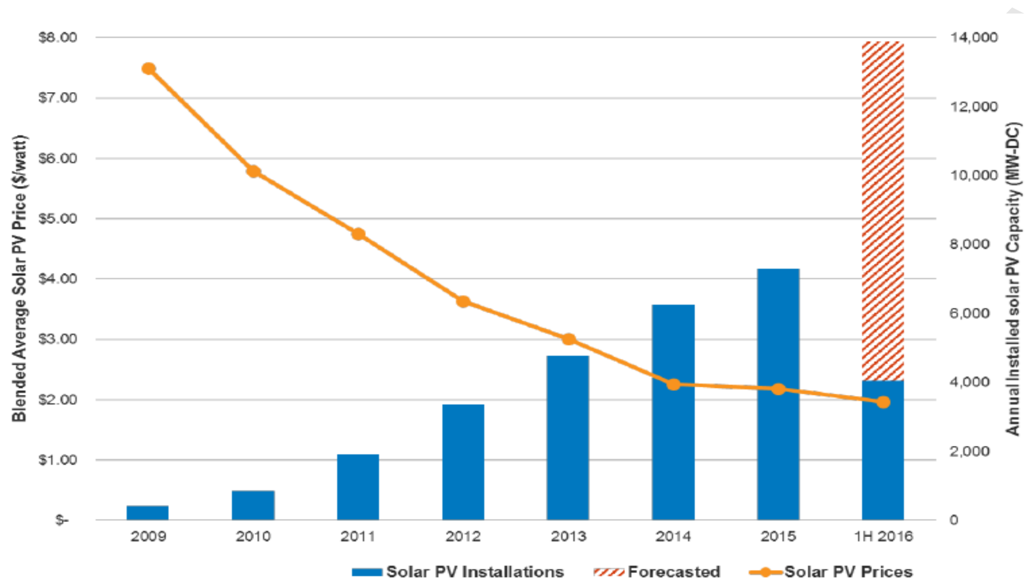

Figure 1.4 : According to the U.S. Department of Energy and SEIA, the increasing in solar installation, solar prices and the forecasted values for the remind months of 2016 in residential sector. Adapted from ((EPRI) 2016)

1.2.4 Increasing Use of DC-Based Loads.

The most important factor that favors the exploit of DC is the increasing number of electric household appliances that function internally on DC power. The fact that these recent household appliances technologies tend to be DC-internal load and more efficient than their equivalent AC (Seo et al. 2011; Whaite et al. 2015b). DC-internal-based household appliances include; communication technologies and all consumer electronics, such as computers, televisions, telephones, compact fluorescent lighting with electronic ballast, light emitting diodes (LED), as well as the universal-motor-based machines(Seo et al. 2011). Electronic drive fluorescent and the LED lighting consume one-fourth of the power or less than that for the traditional incandescent light. Permanent magnet DC motor (PMDC) can save 5-15% as compared with the traditional AC induction motors, and up to 30-50% of variable speed drive applications such; refrigeration, pumping, space cooling, ventilation, (Seo et al. 2011). Thus, the three reasons together propose that DC-internal appliances will continue to grow, and will probably grow rapidly:

- The increased focus on efficiency of sustainable energy because of climate change.
- The new DC-internal technologies have been approved recently as a more energy efficient than that AC equivalents in the conventional market.
- The fact that those technologies are capable of servicing virtually all household appliances.
- The fact that electricity consumption in the residential sector by DC-internal appliances grew from about 17% between 1990 and 2013 and is expected to increase by 250% by 2030 (Efficiency 2016).

1.2.5 Building Energy Consumption

Referring to Figure 1.5, the average electrical consumptions in Malaysia's residential buildings, space cooling or rather air-conditioning consume the largest percentage of electrical energy, which is exploited at home or office. Under Global Warming threat and the increasing of energy cost, the maintaining of home cool becomes a significant challenge in energy saving. Solutions to reduce these costs through the use of energy efficient household appliances certainly make sense.

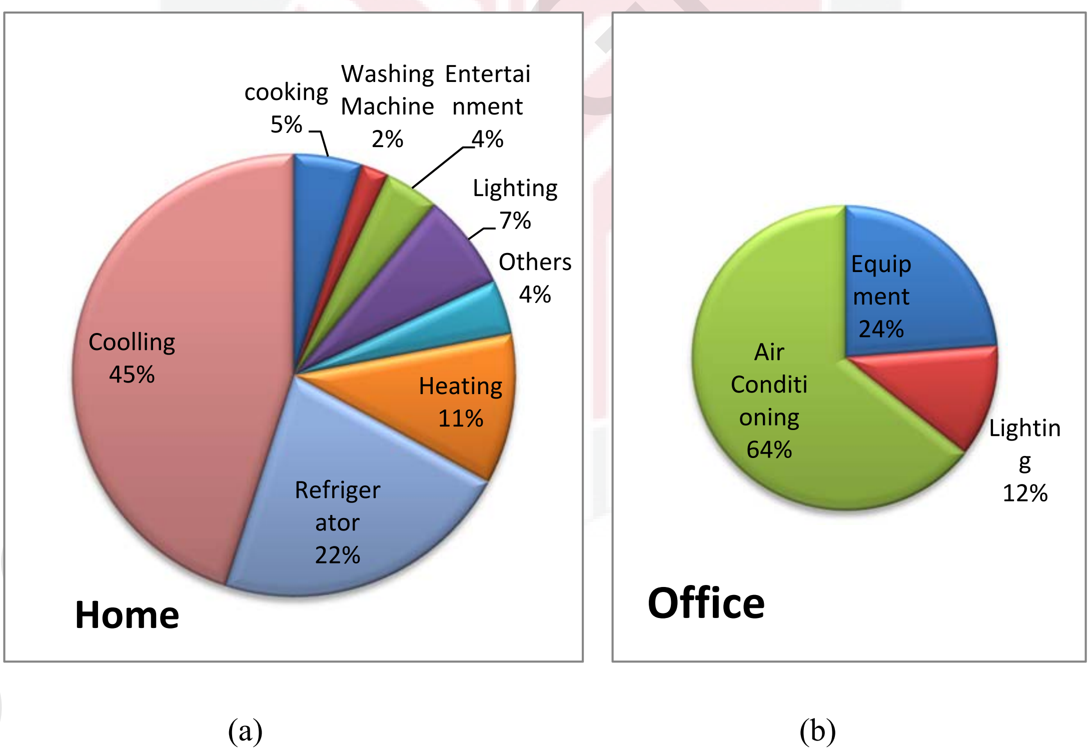

Figure 1.5 : Malaysian energy consumption for (a) homes and (b) office

1.3 Problem Statement

The aim of this research is to study the factors that limit the solar charge controller, energy efficiency, monitoring, and modelling the empirical data of a power profile of a PV powered home energy systems, to propose appropriate solutions to improve those factors.

- Solar Charge Controller: Different PV array configurations yield different levels of mismatch power loss, especially under partial shading conditions, and thus produce different total energy. Maximum power point tracking technique (MPPT) mainly solves this problem, but the present MPPT systems still have losses due to the switching of their semiconductor devices as well as the normal rise in the temperature of the main system components during operation.
- Efficiency: The efficiency of PV powered home systems is affected by that of its components, including the PV array, inverter, and the system configuration. Although the PV and most of recently household appliances are of DC nature, but most of the current work is still based on the alternative current (AC) environment. Therefore, there is a dissipated power due to the conversion stages when the household appliances handle solar power (i.e. DC to AC and back to DC again). Only a few investigations address the DC environment with PV but only to power individual or only a group of household appliances and they need to be developed to cover all the appliances with enhancement of energy monitoring system.
- Power Profile of DC-Based System: The power system always has several variations in its profile due to random load changes or environmental effects such as device switching effects when generating further transients. Thus, appropriate solutions need to be worked out to derive an accurate mathematical model because most system parameters vary with time. Curve modelling of power generation is a significant tool for evaluating system performance, monitoring and forecasting, especially for appliances that operate under a DC distribution system.

1.4 Objectives

This research aims to propose PV powered home system under DC environment (consisting of PV array, charge controller, battery bank, and appliances interface and monitoring circuit) which deliver better energy yield, higher efficiency, and monitoring system with mathematical modelling for the power consumptions. Therefore, more specific objectives of this thesis are:

- To propose a novel maximum power point controller based on one time MPP control algorithm.

- To design and develop a prototype wireless PV-powered energy monitoring system using a novel solar-battery charge controller based on DC voltage matching concept.
- To develop an empirical mathematical model that governs the load power profile for the proposed system.

1.5 Scope of Research

This work addresses the energy conservation and optimization in a residential application reduce its impact on our economy and environment. Therefore, this work is looking for a better realization of how solar powered homes consume energy and how to improve this consumption by proposing DC framework environment as a single supply voltage for all household appliances. The main points that define this scope can be listed as follows:

- Studying and classifying all the local household appliances from the viewpoint of the electrical energy consumption.
- Specifying the household appliance's voltage as an operating voltage to be starting step which adopted in the research algorithm.
- The study sets an algorithm based on the site geographical parameters such as; irradiance and temperature, to propose a new charge controller depends on once maximum power point (MPP) calculation to assign the system operating voltage.
- Designing a new Solar-Battery charge controller circuit in which the PV array output power is directly connected through a bypass MOSFET to charge the battery bank whenever the battery voltage becomes lower than the setting (proposed) level. The controller will switch to another path when the batteries reaches its full charge value through another MOSFET path to transfer to an Auxiliary load (fans or auxiliary battery). This surplus power is used for the system ventilation to reduce the temperature and adding more improvements of system performance.
- The proposed system and prototype covers all the new household appliances that locally available in the market, but it is not suitable for all the old appliances that are designated.
- The system has its own wireless energy management supported by GUI-based PC which comprising XBee-RF-based design and prototype for monitoring the power consumption rate of a DC powered appliances in a solar home and for controlling the solar charging process.
- Six analogue channels are processed directly by the remote XBee which acquires the data from various energy sensors to be sent in a real-time communication with (11.6 -123) Hz sampling frequency to record the possible surge power of the appliances.
- A new mathematical modelling equations have also been proposed in this work to extract the formulas that govern the supply and load profiles of the system for further analysis, forecasting and monitoring.

1.6 Research Contributions

- Solar-Battery Charge Controller with new control algorithm based on one-time maximum power point (MPP) and site weather parameters (irradiance and temperature) variation range.
- Single Voltage DC Distribution System framework for the interconnection of all the local market commercial appliances.
- Wireless Energy Monitoring Prototype for such DC-environment application with lower cost and less complexity.
- Measurements-based mathematical modelling by Bode Equations and Vector Fitting (BEVF) algorithm that can be used for steady-state and transient analysis, forecasting and monitoring of the power profile for both the supply and consumptions.

The research contributions also can be expressed by the diagram in Figure 1.6.

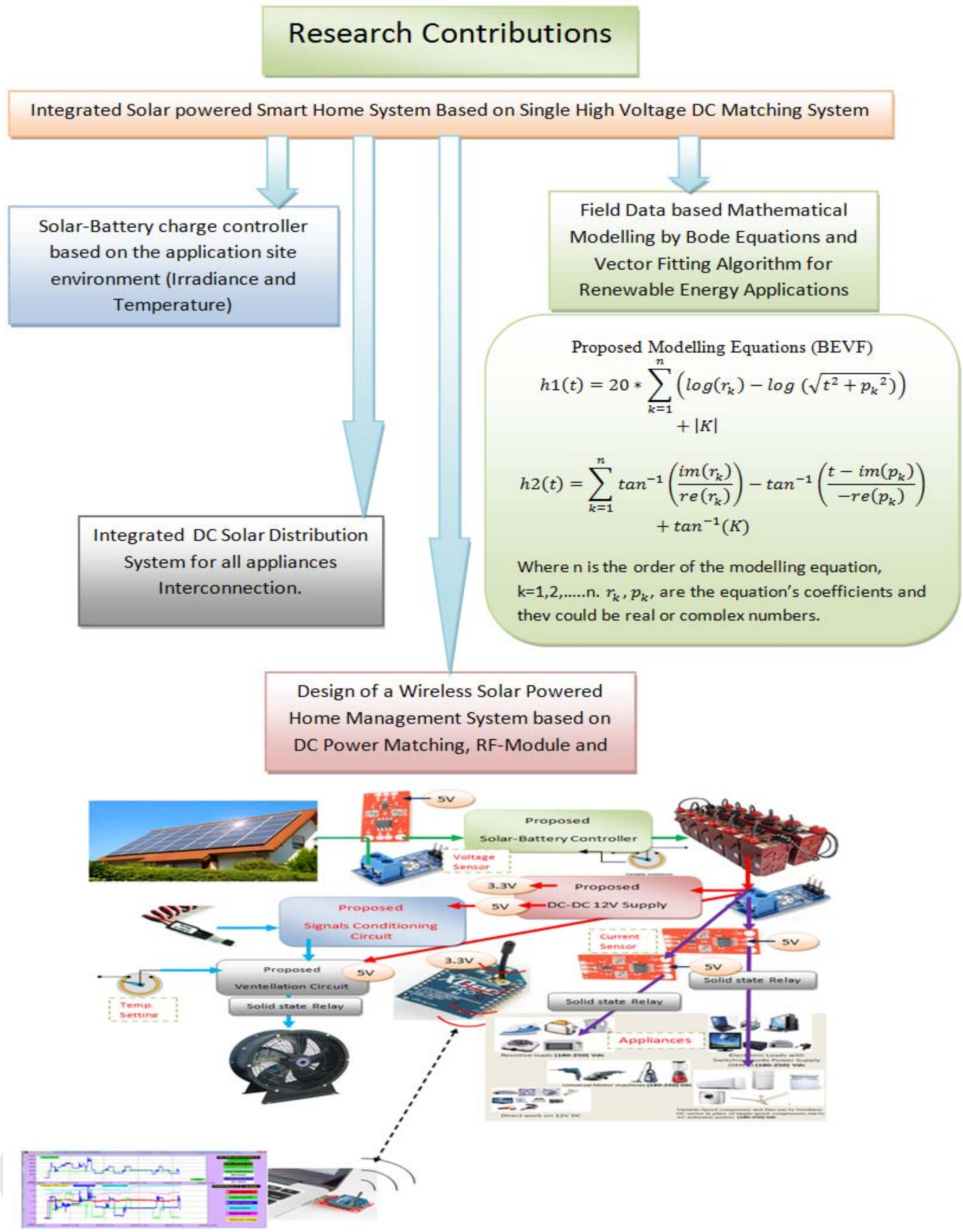

Figure 1.6 : The main novelties of the research in diagram form

1.7 Thesis Layout

After discussing the main research aspects and the main topology of the whole system, the remainder of the document is laid out as follows:

Chapter Two summarizes the literature review of the research trends like the current AC environment, household situation and the traditional solar powered home/office system as well as discusses the energy usage, modelling, managing, monitoring, and design. This chapter will consist of details on the AC household and DC household models, the loads for each household appliance, and what had been achieved in this area. Additionally, this chapter will summarize the strength points of the proposed system components and processes under the DC environment.

Chapter Three discusses the main research hypothesis, algorithm and the main topology of the whole system which is based on the DC-voltage matching concept. This chapter subdivided into three mainly topics; First, addresses the current and the local market household appliances classifications according to DC compatibility and ability for dispensing some AC-DC adaptors, a MATLAB editor code and Simulink have been adopted as a simulation program to initially verify the concept and to imitate the processes of the practical stages of this research. Second, addresses the proposed alternative solar-battery charge controller which is based on a new algorithm seems to be inversely calculated because its start from the appropriate DC value of the load voltage, then the full charge battery voltage and so on, a Simulink Matlab simulator is also attempted in the simulation phase of this research as well as an experimental data has been collected to verify the circuit function and energy saving goal. Third, discusses the DC-based Wireless Home Management System (DCWHEMS) and the new proposed wireless monitoring and management circuit which is designed for such application with low cost and consumption to increase the system efficiency and to reduce the total electricity generation cost to consumers, and meanwhile, to smoothen demand peaks.

Chapter Four describes the new proposed mathematical modelling equations for both system source and appliances power profiles.

Chapter Five discusses all the research outcome results of the simulation and experimental phases in some details that are required to design the proposed embodiment over different types of AC appliances. Analyzing the source and load performance under DC environment to compare with the operation under the AC conditions.

Chapter Six; Summarize the general conclusions of the thesis and the recommendations for future research

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