Adaptive Critical Load Management for optimal Green Energy Utilization

By

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CERTIFICATE OF CORRECTNESS AND APPROVAL

It is certified that work contained in this thesis“Adaptive Critical Load Management for optimal Green Energy Utilization”, was carried out by Hamza Ul Huda under the supervision of Asst Prof Dr. Ayesha Maqbool, for partial fulfilment of the degree of Masters of Information Security, is correct and approved. This thesis has been checked for Plagiarism. Turn it in a report endorsed by Supervisor is attached.

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ABSTRACT

Growing population and household comfort demands, huge pressure on grid supplies. We can't depend only on conventional generation sources renewable energy resources need to be embedded. The effective utilization of alternative energy sources, if properly designed and built can play a vital role in overcoming this problem, is one way to reduce these electrical crises and grid strain.

Traditional solar inverters are not equipped to fully utilize solar energy. The proposed solution Solar Infinity SI-1 device is composed of two parallel-connected bridges (magnetic conductors) operated through grid and manual/timer relay switch for critical electric load management. The device is placed between the solar and Grid system **(**figure 2.1**).** In the case of daylight and load shedding the maximum utilization of solar energy is achieved by switching the critical load to solar power is aimed at the optimal utilization of solar energy during the daytime, specifically addressing the gap in the current commercially available solutions in Pakistan. At present, the solar solutions provide the support of alternate sources (battery backup + solar energy) only during the blackouts (absence of grid electricity) in the daytime. Furthermore, the installers do not route the heavy load through the solar inverters during blackouts to save batteries.

This undermines the effective utilization of solar energy produced during the daytime. Our proposed solution i.e. Solar Infinity SI-1 augments the currently installed solutions and provides the consumer with better control of the solar resources.

DEDICATION

"The example of those who take allies other than Allah is like that of the spider who takes a home. And indeed, the weakest of homes is the home of the spider; if they only knew. Indeed, Allah knows whatever thing they call upon; other than Him. And He is the Exalted in Might; the Wise. And these examples, We present to the people, but none will understand them except those of knowledge."

(Chapter 20: Surah Al-'Ankabut: Ayat 41-43)

I would like to dedicate my thesis with complete sincerity and
commitment to my Parents, Teachers, and Mentors.
for their trust, love and support.

ACKNOWLEDGEMENT

I am grateful to Allah Almighty for giving me strength to keep going on with this thesis, irrespective of many challenges and troubles. All praises for HIM and HIM alone.

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I am very grateful to my Project Supervisor Asst Prof Dr. Ayesha Maqbool who supervised the thesis / research in a very encouraging and helpful manner. I am grateful to my supervisor who took me under his wing and her supervisions have always been a valuable resource for me.

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ACRONYMS

Indicative Generation Capacity Expansion Plan	IGCEP
National Institute of Standards and Technology	NIST
Photo Voltaic	PV
Direct Current	DC
Alternative Current	AC
Voltronic Manufacturer	VM
Feed-in-Tariff	FiT
Heavy load	HL
Essential load	EL
Magnetic contactors	MC
Smart Load Center	SLC
Programmable Logical Circuit	PLC
Extra Solar Power	ESP

Chapter 1

1 INTRODUCTION

In this chapter ,we will discuss about electrical energy, storage of energy, available renewable sources, the motivation for adopting green resources, problem statements and objectives concerning with the topic of project.

1.1 Introduction:

Energy' sources, for instance, wind, water, and sunlight. Keeping in view the disastrous threats of the current energy crisis the world faces, it is becoming essential day by day, to switch over to these greener, cheaper, alternatives. The skyrocketing prices of these fossil fuels and critical environmental pollution around the world motivate governments and organizations to shift their focus onto renewable energy sources.

Pakistan has tremendous potential to generate solar and wind power. According to the World Bank, utilizing just 0.071 percent of the country's area for solar photovoltaic (solar PV) power generation would meet Pakistan's current electricity demand. Wind is also an abundant resource. Pakistan has several well-known wind corridors and average wind speeds of 7.87m/s in 10 percent of its windiest areas.

Emphasis has been on the conversion to electricity using photovoltaic cells. Traditional solar inverter systems available in market are not too much intelligent to fully utilize solar power from panels. In third world countries like Pakistan solar systems lose most of the power. Solar Energy at day time (Peak hours) has not been used optimally.

1.2 Motivation:

The grid is being strained by growing population and household comfort demands. The utilization of alternative green sources like wind and solar can plays a key part in overcoming this problem, to reduce these electrical crises and grid strain. Increasing demand for green energy has prompted renewable sources assumed to play very important role in future power network's power sharing, result in reducing cost of per unit energy and also generates eco friendly energy.

Pakistan installed generation capacity reached 34,501 Megawatts by the end of May 2021. According to the Indicative Generation Capacity Expansion Plan (IGCEP) for 2021, 34 percent of this is renewable, consisting of hydro-electric, solar, wind, and biogases-based technologies, and 66 percent is thermal, consisting of natural gas, local coal, imported coal, RFO, and RLNG-based technologies. Pakistan has a solar power installed capacity of 400 megawatts as of May 2021.

To meet its energy needs, the country aims to migrate to renewable sources. According to reports, the government plans to generate 60% of its energy from solar, wind, and biogas by 2030, with 10% coming from gas, 10% from nuclear, 10% from coal, and the other 10% coming through local sources.

1.3 Problem Statement:

Under develop countries like Pakistan facing lots of difficulties in the energy sector. Unfortunately Pakistan belongs to the countries suffering with electricity shortage which leads to prolonged period of load shedding for 5-7 h per day and sometimes doubles specially in rural areas, having brownouts and frequently increases in the tariff.

Traditional solar inverters are not equipped to fully utilize solar energy [1]. In third world countries like Pakistan, solar systems lose most of the power. Normally the inverters are not capable to optimal use of solar power they just charged the power bank up to 100 % and dump excessive power from solar means lost most of potential. During the blackouts when load is on battery backup, not good for battery life to avoid this factor the most of the heavy load through solar inverters were not attached so that only limited load is attached.

During the blackout the load is on battery backup, it affects the battery life at daytime (peak solar hours). The solar excessive power is not fully utilized and heavy loads are usually bypassed from the inverter.

At present, the solar solutions provide the support of alternate sources (battery backup + solar energy) only during the blackouts (absence of grid electricity) in the daytime. Furthermore, the installers do not route the heavy load through the solar inverters during blackouts to save batteries.

In three phase connections the most common issues are" Phase failure". Either one or two phases are lost from three phases, this event leads the solar system to backup mode means load on power bank. And during day time solar with backup mode (disconnect itself from grid).

1.4 Research Objective:

The main objective of the thesis is to provide a solution that can achieve optimal consumption of alternative resources like (wind, solar etc.).Although alternative resources are already play vital role to covers the storage in conventional demand and supplies, due to irregularity in green energy and short duration most of power were lost.

Critical/heavy load management and essential load management are main and foremost objectives of this thesis. Normally, in the case of daylight and (blackouts/brownouts) we lost effective utilization of solar energy, addressing the gap in the current commercially available solutions in Pakistan.

Battery/Cell are used to store energy as backup for sudden electrical breakdown and if no other source available to feed load such grid /generator. Batteries have calculated number of cycles to charge and discharge. Protect battery backup from critical /heavy load for long battery life is another important objective.

1.5 Scope:

The scope of the research is the different kind of dump inverters already deployed and available on shelf to be installed in home and offices. The available alternative solar energy solutions are not capable to utilize solar energy. In solar peak hours and different scenarios like brownout/blackouts solar inverters dump most of power without any use. Our main focus is to routing power with the help of device for maximum/optimal utilization of solar energy.

1.6 Contribution:

This thesis will contribute in the following ways:

- Research areas for the effective use of solar system in under-develop for future is highlighted.
- Highlights weak area of currently available techniques/methods and devices for optima utilization of solar inverters and system as a whole.
- Provides solution for maximize the utilization of solar power through dump inverter. At day time (peak solar hours) the solar excessive powerfully utilized through this solar infinity device, by attaching some extra load other then essential load avoids overloading risk.
- Calculating loss of green potential in terms of units and cost of unit per year by assuming different scenarios.
- Provides solution for more efficient utilization of solar energy with the help of solar infinity SI-2 device with PLC based to clip heavy load.

1.7 Thesis Outline:

The basic outline of the thesis is:

Chapter 1: Introduction is given, including the problem statement, research objectives, scope ,and contributions.

Chapter 2: Literature review and analysis of available solar systems. What techniques and devices available to improve overall systems efficiency.

Chapter 3: Proposed Solution Device and its detailed explanation.

Chapter 4: Deployment of device with solar systems to check in different scenarios (like: Blackouts, Brownouts) to estimate how much revenue we can save per year.

Chapter 5: Device up gradation with the help of PLC and its results.

Chapter 6: Conclusion and the open areas for research are highlighted.

Chapter 2

2 PRELIMINARIES

2.1 Background:

With time, countries from all over the world have been continuously trying to deter their reliance on traditional energy generation methods such as fossil fuel coal ,oil and gas, while trying their utmost to switch to renewable energy sources.

Pakistan belongs to the countries suffering with electricity shortage which leads to prolonged period of load shedding for 5-7 h per day and sometimes doubles specially in rural areas, having brownouts and frequently increases in the tariff.

Overgrowing population and personal comfort requirements are putting more stress on electric grid. The usage of renewable energy sources, which, if properly designed and built, can play a key contribution in handling this issue, is one way to minimize these electricity crises and load on the grid. Increase in demand for green energy sources has led renewable sources of energy to play a major role in the power-sharing of future power networks, reducing not only the cost of per unit energy but also allowing for the production of environmentally friendly energy. [3].

Green energy recourses such as wind and solar power have been employed to create electricity since the early twenty-first century, but as these are very variable sources, more constant energy sources are required. Electric grids are being made smarter and more internet-like so that control systems can route power where it is much needed, as much as possible from solar, wind, and other green sources.

Electric grids are being made smarter and more internet-like so that control systems can route power to where it is needed, as much as possible from solar, wind, and other green sources. Smartness main focus is to eliminate of black and brownouts and also making the grid more efficient, greener and less costly.

For under –developed countries this idea to make grid smarter for optimal use of green energy is not practical. Although they utilize these green resources, but due to limited resource they lost most of potential.

2.2 Literature Review:

Global environment interests and the escalating demand, linked with constant development in renewable energy technologies, are give birth new opportunities for the utilization of alternative resources. While talking about solar energy it is the most abundant, clean, green and inexhaustible renewable energy till now.

How to use green alternatives like (solar, wind turbines) lots of research and development in this area had already done. Utilization of alternative green recourses with conventional grid system issues has been resolved. Now it's time to move forward to utilize green energy more efficiently and smartly. Our main objective of research is optimal use of renewable energy.

In this section we literally review green resources consider solar power mainly. We detail reviewed, how to use solar energy through different types of inverter available in market, technologies and devices were use to improve its efficiency, and what techniques/methods are in use?

Traditional solar inverter systems available in the market are not equipped to fully utilize solar power from panels [4].In third-world countries like Pakistan, solar systems lose most of their power as they are not utilized to the best of their capabilities. Solar Energy at day time (peak hours) is not been used optimally.

In under-developing, here are three types of solar system available in the market are [5]**:**

1. Off-grid solar system also known as standalone system.
2. On-grid solar system also known as grid-tie solar system.
3. Hybrid solar system- combination of On-grid and off-grid.

2.2.1 OFF-Grid Solar System:

Off-Grid solar systems are mostly used in home and offices to maintain backup [6], and minimize grid consumption which helps to reduce in bills .In case of sudden breakdowns backup will helps to drive essential load. Systems are capable to share load with grid and maintain backup at same time.

In rare circumstances where grid power is unavailable, an off-grid system must rely on batteries for storage because it is not connected to the power grid. System must be designed in proper way for enough power available throughout the year and also having adequate backup to satisfy the requirements even if there is low sunshine in winters.

OFF-Grid Solar invertors models available in the market is VM-1 with a battery solar inverter system capable to store energy for backup and can clip the Grid in the daytime if there is sufficient solar energy, these things help to reduce bills

OFF-Grid Solar invertors' models VM II&VM III(with or without a battery) solar inverters are available in the market capable to run load, maintain backup if batteries attached, and can share energy with the Grid at day time if there is insufficient solar production to run the load helps to reduce bills.

2.2.2 ON-GRID Solar System:

Solar systems that are connected to the grid, or on-grid, are the most popular and widely used by homes and businesses. Such systems do not require batteries since they are connected to the public power grid. You usually get paid a feed-in-tariff (FiT) or credits for any excess solar power you generate when you export it to the electricity grid. [7].

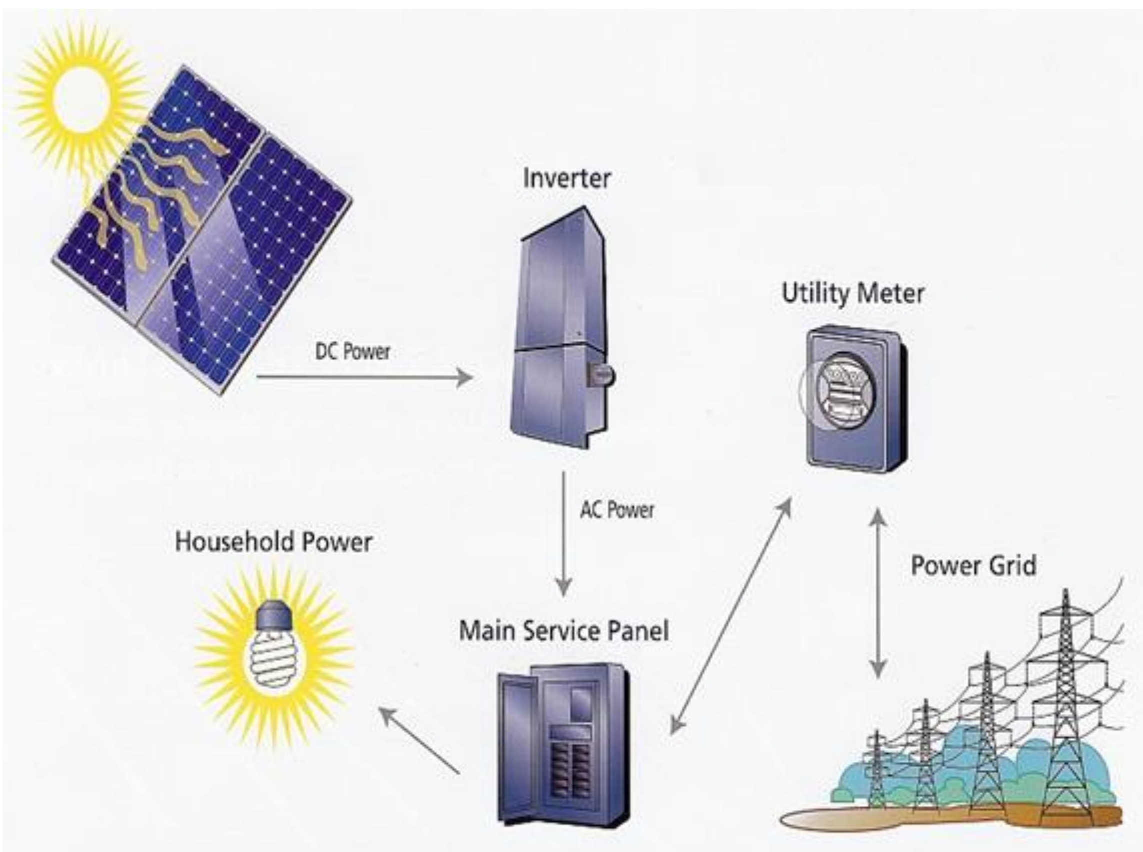

Figure 2-1 Basics Grid-tie Solar Electric System

The system consist of solar panels DC power source converted to AC through three phase grid-tie inverter which is attached parallel to gird. These Systems function without batteries helps to neutralize the bill by selling extra to the grid through (Net metering).

2.2.2.1 What is Net-Metering?

Electric consumers that produce their very own electricity from a solar photovoltaic (PV) or similar renewable energy systems often get involved in a billing arrangement which is referred to as Solar Net-metering. In a net metering system, the customer is billed by the utility only for the net consumption of electricity during a set period of time (e.g., a month). In simpler words, an individual making use of net-metering can basically harvest solar energy and further transmit it back to the electricity grid owned by electric companies, who in return pay back the customer. This process has thus brought in the role of a 'Smart Grid'.

2.2.2.2 How Net-Metering works?

Smart grids basically aim to provide the user with complete insights regarding electricity consumption, unit information, cost details and similar statistics. The working of this makes it reach a negative value, which means you get paid by your electricity provider. The whole system can be processed and accessed in real time with the assistance of GSM modules which give you insights of your system whenever required.

Now, moving onto the benefits, it's clear that such a system can reduce numbers on our monthly electric bills which means that it directly benefits the consumer. In 2014, a study commissioned by the Nevada Public Utility Commission [8] itself proved that net metering provided $36 million in gains to all energy consumers, assuring that solar power can provide money saving for both solar and non-solar consumers. In addition, solar panel installations will make less expensive grid up gradation necessary, resulting in extra savings. The study estimated a resultant gain of 166M USD over the lifetime of solar-panel systems installed through just 2016 alone. Furthermore, times when energy consumption is at peak, electric companies and grids won't have to deal with the immense burden since production is being carried out by individual businesses and people alongside them while preserving the fossil fuels.

Figure 2-2: Benefits of Net-Metering

The first net metering system was installed in California, USA, which today, is expected to reduce its power bills by more than 2.5bn USD over the next 30 years. If one plans to install such a system, it will take approximately 3 to 4 years to get his investment returned through profits.

A research conducted by the Maine Public Utility Commission back in 2015 placed an estimation of 0.33 USD per kWh on power produced by disseminated solar plants, contrasted with the normal retail cost of 0.13 USD per kWh — the rate at which power gets offered to private clients. The study presumes that solar power gives a generous open advantage since it diminishes power costs with the removal of increasingly costly energy sources, reduces air and atmosphere contamination, lessens prices for the electric lattice framework, diminishes the requirements to assemble more power generation plants to satisfy top need, settles costs, and advances vitality security.

2.2.2.3 Smart Grid:

Wind and solar power have been employed to create electricity since the early twenty-first century, but as these are very variable sources, more sophisticated energy sources are necessary. Electric grids are being made smarter and more internet-like so that control systems can route power to where it is needed, as much as possible from solar, wind, and other green sources.

The smart grid's primary function is to provide enough computer intelligence for better control the grid and make it more autonomous (self-aware) and self-healing [9].No need to built new power plants and substations, utilities will be able to use the existing power infrastructure more efficiently by able to move power around where it is much needed and this process will add “Megawatts” of energy from customers into the loop. Thus a smart grid will assure optimal use, effective power management, better reliability, less costly and more environment friendly energy generation.

2.2.2.4 Features of the Smart grid:

Our way of life has been transformed by technology, but our electric grid (which we depend on to keep power flowing to our homes, schools, workplaces, and hospitals) has not kept pace. With Smart Grids, it is now possible.

Smart grids keep our lights on, replace ageing equipment, equip the system to handle rising demand, minimize brownouts, blackouts, and surges, lower energy costs, enable power bill control, facilitate real-time troubleshooting, and save energy producers money.

The smart grid protects the United States' position as a global leader in the transition to a sustainable energy future. Three of the many advantages of smart energy meters include reliability, cost savings, and energy independence.

2.2.2.5 Need of Smart Grid:

A smart grid is a cost-effective system that makes use of a variety of information technology resources to reduce electricity waste and costs on new and existing gridlines. Smart grids enable the installation of smart metres in households to access variable and distributed sources of energy based on demand and availability. Smart meters empower the electricity clients to use energy according to the rates provided to them as rate fluctuates. Smart grids are efficient in case of both renewable and non-renewable sources when they are utilized to generate energy. When consumers are given the ability to track their electricity usage through smart meters, they can easily control their bills as well. Power theft can also be tracked by installing smart meters in smart homes which is only possible when smart grids are present. In a nutshell, need of smart grid is to reduce power theft, ensure reliability of power and use renewable power sources as well.

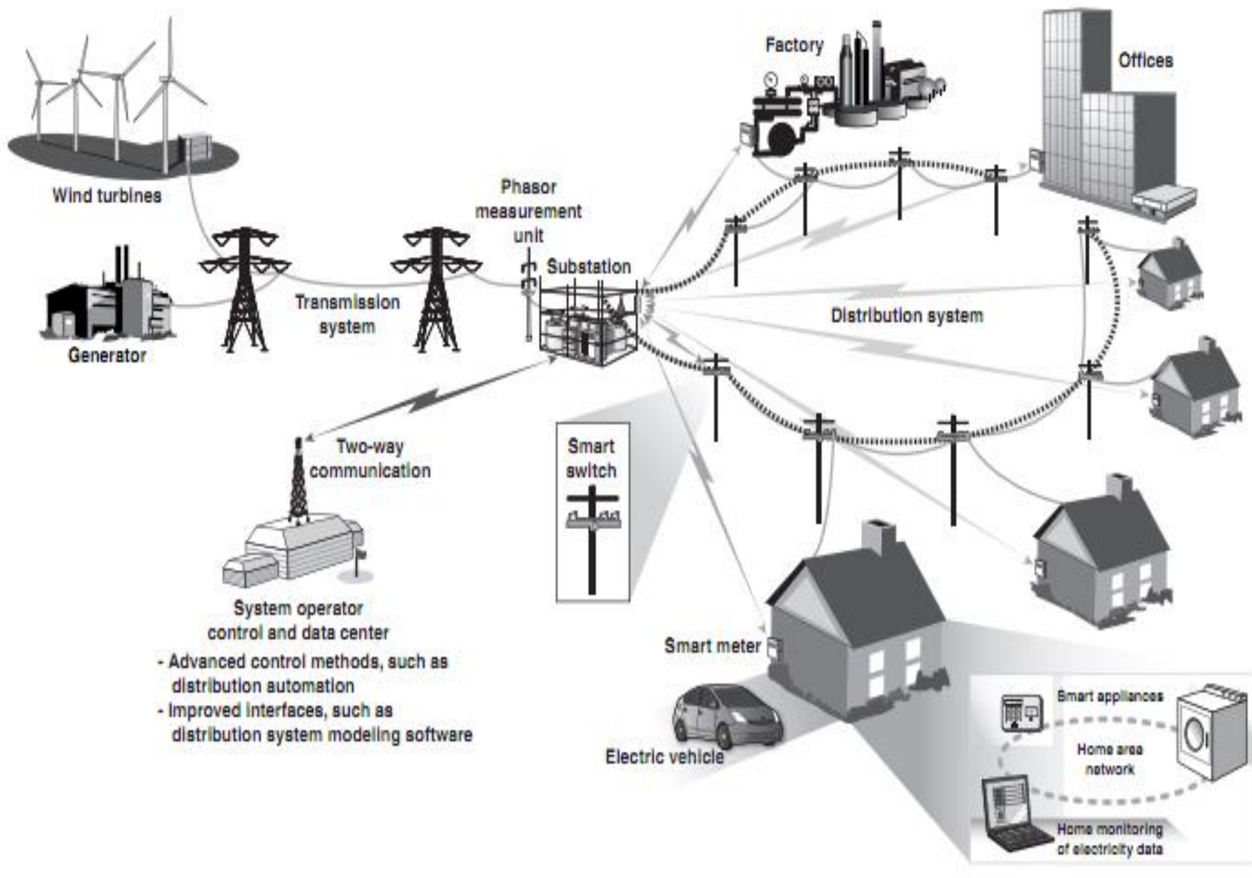

Figure 2-3: Architecture of Smart Grid

2.2.2.6 Architecture of Smart Grid:

Until date, numerous frameworks outlining the architecture of the smart grid have been presented by both business and academics, but the reference model has been proposed by the United States National Institute of Standards and Technology (NIST). The smart grid, according to this idea, is made up of seven interconnected areas. The first four domains are as follows:

1-Bulk Generation

2-Transmission

3-Distribution

4-Customers

And are responsible for the generation, transmission and distribution of energy and besides this, these domains also ensure the two way communication between the user (customer) and the AMI (Advanced Metering Infrastructure) utility head end.

Remaining three domains out of seven are:

1-Markets

2-Operations

3-Service Provider

Another architecture was also adopted to study this. It was almost same as NIST's model but it was conceptualized as multi layered approach. It has divided the network into three layers

1-Lower Layer

2-Middle layer

3-Upper Layer

Lower layer that interconnect appliances with smart meters and energy management devices that report the premises consumption to the grid at any given time while also carry messages from the grid back to the premises.

Middle layer has networks that cover small geographic areas known as Neighbourhood Area Networks and are responsible for the interconnection of the smart meters of different kinds of premises with a distribution access point that gathers the data collected by them and forward them to the upper layer.

At the top layer of this conceptual model, we find the Wide Area Networks (WANs) interconnecting multiple NANs .All the data collected by NANS is processed through the following systems that also is in the upper layer.

2.2.3 HYBRID SYSTEM:

A hybrid (ON/OFF-Grid) system is capable to store energy, share energy, and feedback to the grid (Net metering). Once your batteries are fully charged, excess solar power not required by your appliances can be exported to the grid via your meters, depending on how your hybrid system is set up and whether your utility allows it. Hybrid systems available in the market are (Three-phase & Single-Phase) [10]**:**

- Goodwe
- Growatt
- SMA
- Tesla(VM)
- SAJ

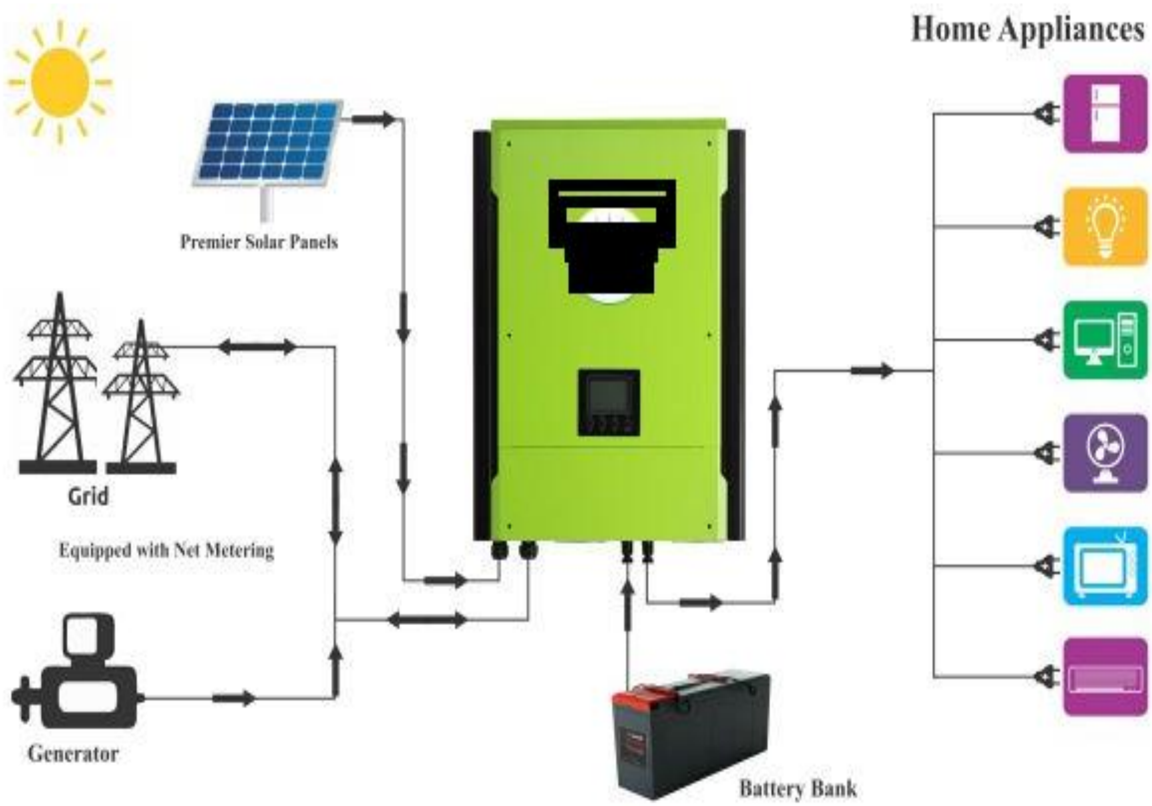

Figure 2-4Hybrid (On/Off-Grid) system interference

2.3 Techniques/Methods and devices commonly used for efficient utilization of Green energy (Solar energy):

As we all know that alternative resources are not sophisticated type of electrical energy. These types of resources have some peaks and off-peaks. Irregularity in behaviour of renewable energy and our bad habits in consuming green energies at its peak, are the main reasons due to which we lost most of potential and money.

When we talk about solar power, there are lots of research work has been done to consume its energy efficiently. In this section we reviewed different techniques/methods and devices were used in develop and under-develop countries.

2.3.1 Solar Tracking System:

Solar energy has the potential to drive the global economy in the near future. However, the current strategies for capturing this energy are barely 20% efficient. As a result, increasing efficiency is a significant problem. Single-axis and dual-axis tracking systems employ optical sensors and microcontrollers to maximise the efficiency of solar panels.

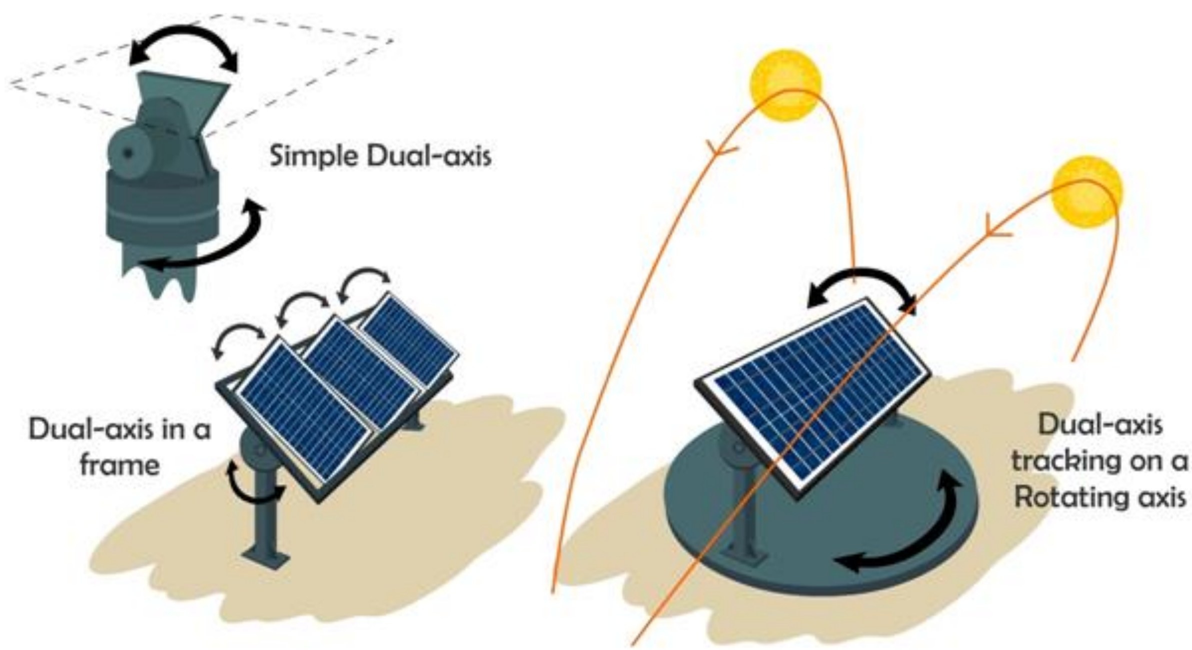

Figure 2-5: Single-axis and dual-axis tracking systems

Image processing is used in reference [11] to determine brightest location of the sun in the sky on a given day so that the tracking angle may be changed correspondingly.

A study on determining the position of sun using zenith and azimuth angles can be found in reference [12]. According to reference [13], the use of an Arduino-based solar tracking system increased efficiency. When the intensity of light drops as a result of sun’s position altering, the solar panels adjust their position to match the sun’s position so that they can collect the maximum amount of light.

Above all technology depending upon solar zenith and azimuth angles are popular in countries where solar maps are not very good, allows for the most efficient use of solar energy resulting in greater revenues from solar plants. But these technologies are not practical in the country like Pakistan according to the World Bank report Pakistan has very good solar maps no need to expend additional huge amount on such tracking technologies.

2.3.2 Optimal utilization of solar energy for irrigation and domestic applications:

For developing countries, solar energy is a blessing. In this respect, Pakistan is fortunate. A lot of effort has been put in this area. Until date, the main focus has been on utilizing solar cells to generate power. Solar cells are still prohibitively scarce and expensive. The conversion efficiency is also low.

Air conditioning is the most common use of electricity in house and commercial appliances in urban areas [14]. Obtaining subsurface water with electricity-powered tube wells is a common application in rural areas. For these purposes direct solar energy is more efficient. Solar absorption chillers are suggested for such uses in city environments. A better option is to use a DC supply. This would also allow for daytime water pumping without the use of storage batteries. Solar energy can be used for domestic cooling and irrigation in rural areas.

The idea of efficiently utilization of solar energy with separate solar setup for irrigation fields for just few hours and separate setup for cooling purposes in just three –four months of summers is not very suitable because of other than this we lost most of the potential without utilizing.

The developed countries are moving towards smart-grid systems. Loads and supplies like (grids, solar, generators and other renewable) resources are inter-connected and smart as well for effective utilization.

For Under-develop countries hybrid and on-grid solar systems are preferable systems than the proposed systems for optimal utilization and small ROI. However the solution is good for those remote areas where grid is not available.

2.3.3 Hybrid Solar Power system conditioning for Non-Critical and Critical loads:

Research aim is to design power conditioning unit to overcome separate offline inverter need, here MPPT charge controller and UPS for sensitive appliances .In this research critical load is necessary load. Another important feature of the proposed system is to isolate the critical load such as data servers, laptops, and other electronic devices from non-critical load for improve battery backup [15].

Design includes grid charger to charge battery through grid, MPPT charge controller used to utilize maximum power from sun source. DSPic controller is used to control the system.

Off-Grid hybrid solar inverters are widely used for commercial and domestic applications it is effective replacement. The traditional solar inverters are deigned to feed the load through single channel so it impossible to differentiate load priorities. Proposed system has two load channels is design to ensure the uninterrupted supply to specific load such as (data servers , laptops, computers and other electronic devices) even if grid and solar available or not. In this proposed design noncritical load are like AC's, motors, fans and other heavy appliances.

The main idea or concept behind this proposed system is to isolate sensitive loads from non-critical load. Thus sensitive load do not effected during power loss and improves backup time.

In third world countries like Pakistan thousands of Off-grid and hybrid inverters are already installed and operational with mega watts capacity of panels. These systems have single output channels for load means no power discrimination and no priorities for sensitive/critical and noncritical load. The scope of proposed system is to feed sensitive load only.

2.3.4 KOOLBRIDGE Solar:

The SMART LOAD CENTER (SLC) was designed by the company named "KOOLBRIDE Solar" in 2016 to make the most of renewable energy like sun , batteries, generators, and wind [16]. When the sun is shining, it maximizes the usage of solar energy and draws power from the grid when solar energy, direct or stored in the battery, is in short supply. It tracks, displays, and records a homeowner's energy usage down to the circuit breaker level, giving them insight into where and when energy is used in their home.

SMART LOAD CENTER features are:

- Minimize the dependency on grid.
- Maximize free solar energy.
- Consumption details of present and historical usage on LCD display.
- Day time operations can be programmed.
- Controls peak demand.
- Battery technology agnostic.
- Inverter agnostic.

In under developed counters like Pakistan, conventional systems already installed and available to deployed such as (off-grid, on-grid and Hybrid solar systems) are not very smart shown in table 2-1. Most of the potential lost without any use. Consumers don’t have smart appliances, smart breakers and smart solar inverters for optimal utilization of solar energy.

In Pakistan, the consumer market has yet to adopt smart appliances. Furthermore even with the availability of smart resources due to inherent complexity, most of the population might not adopt such systems. It can be perceived that shortly a huge share of the market will employ the conventional solution.

2.4 Analysis of Existing Solar Systems and device:

Our main objective of the thesis is to optimal utilization of green energy .Based on the literature review we have a detailed comparison analysis for existing solar systems and devices available in the market. .

Table 2-1: Analysis of Existing Solar System

Sr. no.	Systems (Hardware)	Type	Merits	De-merits
1	Solar Inverter	On-Grid	Zero your electricity bills, Low maintenance	No Backup option, Blackouts
2	Solar Inverter	Off-Grid	Monthly saving , No Blackouts	Avoid to attach critical , , Loss most off the power, overload problems ,Solar is pricier, Maintenance is high
3	Solar Inverter	Hybrid(On-Off Grid)	Big monthly saving, No Blackouts	Avoid to attach critical load, Loss most off the power, overload problems , Phase failure issue
4	KOOLBRIDGE Solar	Device	Optimal use of Green Energy from Solar Systems	Compatible with Smart Appliances and Smart Circuit Breakers

2.5 Analysis of Methods/Techniques and Devices adopted for optimal use of Solar Systems:

Based on the literature review we have a detailed comparison analysis for methods/techniques and the devices are use to for the most efficient use of solar energy greater revenues from solar plants.

Table 2-2: Analysis of Methods/Techniques for optimal use of solar system

Sr. no.	Techniques/ Methods/Device	Type	Merits	De-merits
1a	Solar tracking	Image processing for sun light	Maximize the efficiency of solar panels by collect the maximum amount of light.	Additional cost for country like Pakistan known for good solar potential ,High maintenance, Costly
1b	Solar tracking	Arduino-uno based control	Maximize the efficiency of solar panels by collect the maximum amount of light.	Avoid to attach critical, Loss most off the power, overload problems ,Solar is pricier, Maintenance is high
2	Solar power for irrigation and domestic application	DC Pumps, DC appliances	Solar energy can be used for domestic cooling and irrigation in rural areas where no grid power, conversion efficiency is also low	Loss most of Solar DC Power when appliances are not in use, Need to replace AC appliances
3	Hybrid Solar system for critical and non-critical load	Hybrid(On-Off Grid)/Off-grid (proposed design proto-type)	Uninterrupted power supply for critical/sensitive load, No Blackouts for critical/sensitive load, Save batteries life.	Avoid to attach critical/heavy load, overload problems
4	KOOLBRIDGE Solar	Device	Optimal use of Green Energy from Solar Systems	Compatible with Smart Appliances and Smart Circuit Breakers

Chapter 3

3 Solar Infinity (SI-1)-DEVICE

3.1 Introduction about Device:

Our proposed solution named "SOLAR INFINITY SI-1" device helps to manage the critical load (heavy load which normally bypass) of the domestic and commercially installed single/three-phase solar system optimally and saves batteries life. This section is about how SI-1 helps to manage heavy load through the inverters, what benefits we achieve, device detail description, components, and its working.

Figure 3-1: Depicts the proposed Solar Infinity SI-1hardware device

3.2 Benefits of Solar Infinity SI-1:

Adaptive optimal green energy solution with Solar Infinity, we believe in using quality solar solutions that will perform to, or above users/customer's expectations.SI-1 helps to manage the critical load of the domestic and commercially installed single/three-phase solar system optimally and saves batteries life. It ensures the provision of user energy consumption optimally and positively changes energy behavior, resulting in more savings than traditional systems available in the market.

The key benefits of the SI-1 are:

- Extreme optimal condition (Fully use of Solar Power)
- Control critical infrastructure (Critical load) management

- Essential load management
- Handle Load shading issues (Blackouts)
- Handle breakdown issues
- Protect battery life
- Limit load at night when PV and grid are not available
- Minimize Bill
- Handle Phase failure issues

3.3 Detailed Description:

Normally the inverters are not capable of optimal use of solar power; they just charge the batteries/power bank up to 100% and dump excessive power of generated solar energy. During the blackouts when the load is on battery backup, the heavy load is not passed through the solar inverters, to safeguard the batteries.

3.3.1 Device Compatibility and its functions:

The solar infinity SI-1 device is attached between the power grid and single/three-phase off-grid and Hybrid (On-Off Grid) inverter systems as shown in figure 4.1, a schematic top perspective view of Hybrid (On-Off Grid) system components and its compatibility with Grid and Solar Infinity SI-1.

At day time (peak solar hours) the solar system excessive energy is fully utilized through Solar InfinitySI-1, by augmenting some extra load other than the essential load, due to overloading risk installers usually avoids to attached heavy load through traditional solar systems.

In the case of daylight and load shedding the maximum utilization of solar energy is achieved by switching the critical load to solar power is aimed at the optimal utilization of solar energy during the daytime.

In the case of blackouts at night time (non-solar energy hours) heavy loads are clipped from the inverter automatically through the Solar Infinity SI-1 device and only essential load is given to batteries/power bank. The SI-I also proposes safety features such that in case of phase failure, the load is shifted to batteries and an alarm is generated to make the user aware of the phase failure.

3.3.2 Components and its connections details:

The proposed solution consists of following components and connections as mention in figure 3.2.

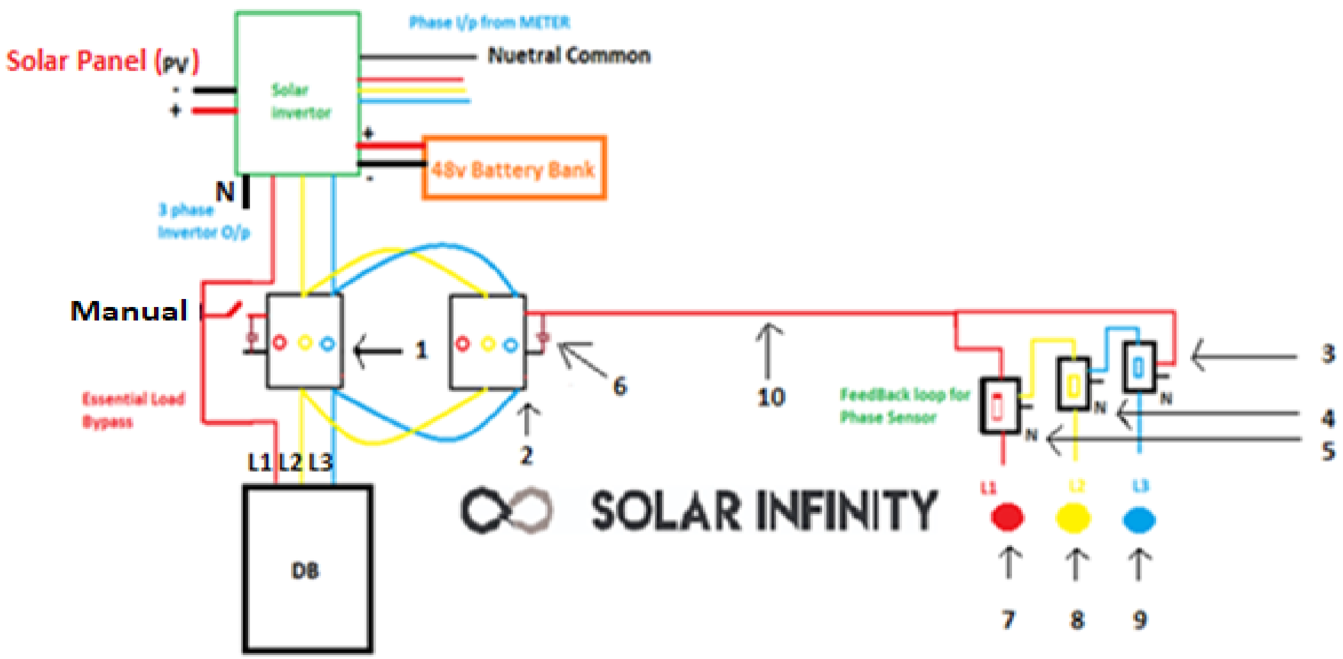

Figure 3-2Represents the logical/circuit diagram of solar infinity detailed technical overview.

Figure 3.2, is a of the Solar Infinity SI-1schematic top perspective view of electrical components. At phase one (L1) essential load is attached through inverters output which is bypass from the magnetic conductors (MC-1 and MC-2).

At phase two (L2) and phase three (L3) critical/heavy load were attached at inverter’s output through both magnetic conductors (MC-1 and MC-2) as common.

The labelling on the figure 3.2 depicts:

1 →Magnetic conductor (Manual control or Timer Relay Switching)

2 →Magnetic conductors (Grid control)

3 →Relay (L1 phase check)

4 → Relay (L2 phase check)

5 → Relay (L3 phase check)

6 → Capacitor

7 →Led (Red) light phase: L1

8 → Led(Yellow)light phase: L2

9 → Led(Green)light phase: L3

10 →AC (8mm) copper wires

3.3.3 Components and its functionality:

Solar infinity SI-1 components are defined briefly as:

3.3.3.1 Magnetic Conductor (MC):

Magnetic conductor is a type of an electrical relay. We have used two magnetic conductors of Fuji (Brand) with 3 pole standard specifications.

MC-2 is functioning to sense grid power. i.e. it has grid power control with phase failure detection if any of three phases unavailable conductor clipped the Critical load Or WAPDA electricity Grid input is available MC-2 allows critical loads to pass through it otherwise it clips heavy load.

MC-1 is especially for solar hours, MC-1operates through manual (Inverter output) switching smart relay switch (client's choice). i.e. During solar hours(daytime), either grid is available or not heavy load is allow through MC-1.

3.3.4 Relay:

A relay is a type of electrical switch that is operated by an electromagnetic. When electricity is applied to the coil, the relay switches on and off. We use 3 relays of Finder (brand) (10 A-250 v) with base sockets to detect phase drop.

As labelled in Figure 3.2

3→ Relay (L1 phase check)

4→Relay (L2 phase check)

5→Relay (L3 phase check)

Relays (a, b, c) are operated at feedback mechanism and its output results operate MC-2 to manage critical load (Y& B) as shown in figure 3.2.

Relays in Solar Infinity are used for phase failure indication. In case of phase (L1, L2, or L3) failure load is on (solar panels + battery bank) at day time or on battery bank at night, heavy load through batteries is clipped automatically and a signal/alarm is generated.

3.2.3 Capacitor:

There are two capacitors of 3.5μF that are used in parallel with Magnetic conductors MC-1and MC-2 operating points to overcome the effect of high voltage (figure 3.2).

3.2.4 Led light:

These three led lights (Green, Yellow and Red) are used to indicate phase (L1, L2 and L3) respectively, showing 3 phase availability as shown in **(**figure 3.1**).**Figure 3.1, represents the hardware view of Solar Infinity SI-1. The labelling of the figure shows:

- Led(Green)light for phase : L 1
- Led(yellow)light for phase: L 2
- Led (Red) light for phase: L 3
- Input/ Output slots

3.4 Deployment of Device in overall setup:

Consider PV solar system with battery power bank installed in house as mentioned in figure 3.3:

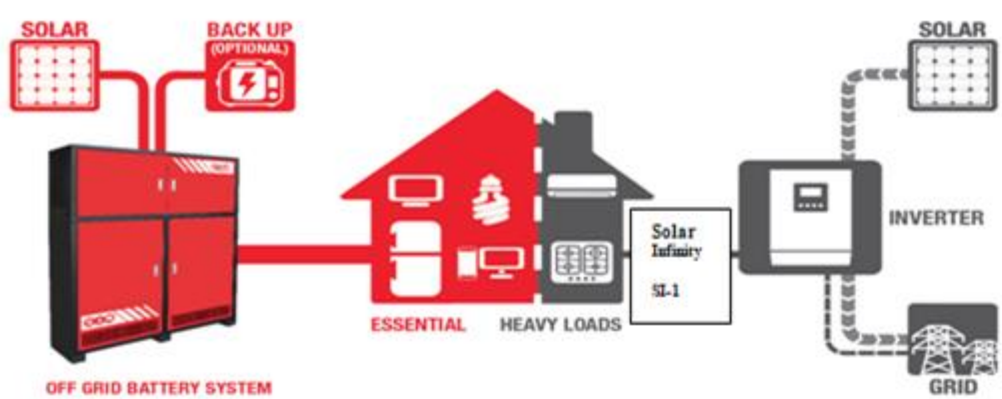

Figure 3-3: Deployment of SI-1 device in Hybrid systems

Solar panels (Solar panels also known as PV (Photo Voltic) module, an assembly of photo-voltic cells have capacity to convert sunlight into direct current DC) are attached with Hybrid (On-Off grid solar inverter).

Here Battery Back-Up (Battery bank for electric energy storage used for backup are attached with inverter for uninterrupted supply. Attached three phase grid supply is used for sharing load, reversing extra power through bidirectional meter, charging batteries and for driving load when solar is not available at night.

Solar Infinity (SI-1) device is placed between Hybrid inverter and the essential loads (examples: Led TV, BULB, Fridge) / heavy loads (examples: AC, Motor, Electric burner)

4 Deployment of device in different Scenarios and its Findings

In this chapter we deployed our proposed device Solar Infinity SI-1 with 10KW Three Phase Hybrid Inverter to study different scenarios. Finding how much green potential not in use and what we loss in terms of money. Suppose solar hours from 8am morning to5pm evening on average is equal to 9hours per day time. Most common scenarios are:

1. Heavy Load Bypass (Critical load not through Inverter)
2. Blackout (3-6 hours)
3. Brownout (1-5 hours approx)
4. Breakdown Period (Maintenance approx 4-6 hour's approx)

4.1 Three Phase Hybrid Inverter with solar infinity SI-1:

Consider PV solar system with battery power ban installed in house comprise of:

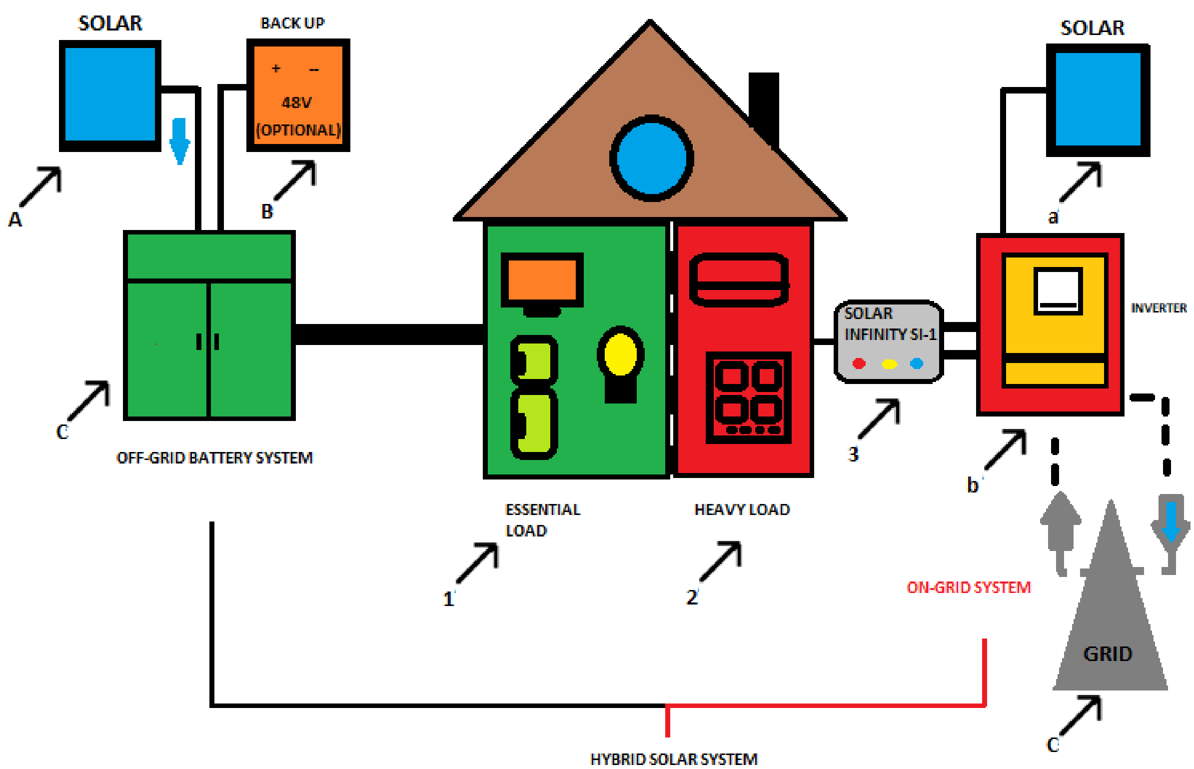

Figure 4-1: Hybrid systems with Grid and SI-1 device

The labelling on the figure 4.1 depicts:

A→ Solar panels (Solar panels also known as PV (Photo Voltic) module, Photo Voltic cells have capacity to convert sunlight into direct current DC)

B →Battery Back-Up (Battery bank for electric energy storage used for backup)

C →Distribution Board (Electrical distribution panel consist of breakers, fuses etc)

a →Solar panels

b → Hybrid (On-Off grid solar inverter)

c →Grid Supply

1 → Essential Loads (examples: Led TV, BULB, Fridge)

2 → Heavy Loads (examples: AC, Motor, Electric burner)

3 →Solar Infinity (SI-1) devices

If batteries are not attached at the time of power breakdown the load is on solar PV if available. Solar infinity (SI-1) device clip the heavy load through an inverter. Solar infinity (SI-1) device allows essential load 25% of the whole system only because there is no other backup source like WAPDA & Batteries.

4.2 House electric load:

Normally there are two types of Electric loads one is essential and other is heavy or critical load considering house electric load are:

- Essential Load (EL) of house (3,000 watts) approx consists of:

Fan	100Wattsapprox
LED Bulbs	20Wattsapprox
LED TV	100Wattsapprox
Fridge	600Wattsapprox

- Heavy load (HL) of house (12,000watts) approx including**:**

AC	(500~2000)Watts approx
Motor	1500Watts approx
Iron	1000Watts approx
Microwave Oven	1500Watts approx
Washing Machine	700Watts approx
Electric Heater	1500Watts approx

4.3 Extra Solar Power (ESP) for 10 KW hybrid systems:

Suppose solar hour's ($8am - 5pm = 9hours$) day time.

The average production rate (PR) from our designed solar power system (PV) is 50% (5000 watt=5 units per her) approx.

$$PR = 5000watts ------ (A)$$

Consider the average essential load (EL) connected from the inverter is 2000 watts all the time.

$$EL = 2000watts ------ (B)$$

Essential load is on solar power and batteries but the heaviest load is not attached through inverter although there is extra solar power available but not in use.

$$By\ using\ (A)\ \&\ (B)$$

$$ESP = PR - EL = 5000 - 2000 = 3000\ watts$$

$$The\ Extra\ solar\ power\ (ESP)\ not\ in\ use\ ESP = 3000\ watts\ approx ----- (C)$$

$$Consider\ Average\ per\ unit\ cost\ = Rs\ 12\ approx ---- (\alpha)$$

4.3.1 Scenario-1: Heavy Load Bypass (Critical load not through Inverter):

If heavy load (AC,MOTOR etc) is attached through the inverter the at time of load shading the heavy load is direct on batteries(Evening and night hours) which lowers the battery backup hours and also effects its life specially . Although at day time PV supports to run heavy load but at night when there is no PV it's impossible. That's why usually heavy load is bypassed.

The Extra solar power (ESP) not in use 3000watts=3units per day on average from equation (C)

Means, on average 3 units per hour not in use due to heavy is bypassed through inverter.

LOSS	DURATTION*UNITS	RESULTS
Per day	8hours *3units	24 units approx
Per month	30days*24units	720units approx
Per year	12months*720units	8,640units approx

Net Savings:

By using Solar Infinity (SI-1) we can attach Heavy load through inverter, this can help to consume Extra Solar Power (ESP) =3000watts approx per hour not in use and can save $Units\ per\ year * Cost\ per\ unit\ is\ equal\ to\ 8{,}640 * Rs12 = \ Rs103{,}680/- \qquad approx$ per year.

4.3.2 Scenario-2: Blackout (3-6 hours):

A blackout occurs when all power in a certain service region is lost. Blackouts are service interruptions that are carefully planned and executed. A brownout is a transient drop in the voltage or total capacity of a system. Blackouts occur without warning and last for an indefinite period of time. They are usually caused by catastrophic equipment failure or extreme weather. Who is affected depends on the kind and source of the blackout. Utility companies intentionally induce rolling blackouts, which usually occur with at least some advance notice and last for a set period of time.

Consider the average load shedding occurs in this time period is (1-3 hours approx).
During solar hours if the load shedding (LS) is done for 2hours a day.
Power loss not in use for 2hours load shedding per day by using (A) & (B) we have:

LOSS	DURATTION*UNITS	RESULTS
Per day	2hours *3units	6 units approx
Per month	30days*6units	180 units approx
Per year	12months*180units	2,160 units approx

Net Savings:

By using Solar Infinity (SI-1) we can attach Heavy load through inverter, this can help to use Extra Solar Power (ESP) =3KHW not in use and can save $Units\ per\ year * Cost\ per\ unit\ is\ equal\ to\ 2,160units\ * Rs12 =\ Rs\ 25{,}920\ /-$ approx per year

4.3.3 Senario-3: Brownout (1-5 hours approx)

A brownout is a voltage drop in an electrical power supply system that is either intentional or inadvertent. In an emergency, intentional brownouts are utilized to reduce load. In contrast to short-term voltage sag, the decline lasts minutes or hours. The word "brownout" refers to the dimming of light due to the voltage fluctuations. A voltage reduction may occur as a result of an electrical grid disturbance, or it may be enforced on occasion in order to reduce demand and avoid a blackout.

Brownouts are typically caused by electricity supply companies as an preventive measure to avoid failing blacking out the whole system.

The Extra solar power (ESP) not in use $3000watts = 3units$ per day on average from equation (C)

Means, on average 3 units per hour not in use due to heavy is bypassed through inverter.

LOSS	DURATTION*UNITS	RESULTS
Per day	3hours *3units	9 units approx
Per month(suppose 3 days)	3days*6units	27 units approx
Per year (suppose 7 months)	7months*27units	189 units approx

Net Savings:

By using Solar Infinity (SI-1) we can attach Heavy load through inverter, this can help to use Extra Solar Power (ESP) =3KWH approx not in use and can save $Units\ per\ year * Cost\ per\ unit\ is\ equal\ to\ 189units * Rs12/- =\ Rs2,268/-$ approx per year.

4.3.4 Scenario-4: Breakdown Period (Maintenance approx 4-6 hour's approx)

Usually in winter power from grid has been cut-off for maintenance purposes (like cleaning Hydropower turbines, cutting trees heading towards transmission lines).

Consider maintenance hours are 4-6 hours approx at day time, Essential load is on solar power and batteries but mostly heavy load is not attached through inverter although there is extra solar power available but not in use.

The Extra solar power (ESP) not in $use\ 3000watts = 3units$ per day on average from equation (C)

Means, on average 3 units per hour not in use due to heavy is bypassed through inverter.

LOSS	DURATTION*UNITS	RESULTS
Per day	3 maintenance hours *3units	9 units approx
Per month(suppose 6days)	6days *9units	54 units approx
Per year (suppose 3months)	3 months*54units	162 units approx

Net Savings:

By using Solar Infinity (SI-1) we can attach Heavy load through inverter, this can help to use Extra Solar Power (ESP) =3000watts approx per hour not in use and can save $Units\ per\ year * Cost\ per\ unit\ is\ equal\ to\ 162units * Rs12/-= Rs1,944/-$ approx per year.

4.3.5 Overall Net Savings for different Scenarios:

Sr. No	Scenarios	Net Savings
1	Heavy Load Bypass (Critical load not through Inverter)	Rs103, 680/-
2	Blackout (3-6 hours)	Rs 25,920 /-
3	Brownout (1-5 hou0rs approx)	Rs2, 268/-
4	Breakdown Period (Maintenance approx 4-6 hour's approx)	Rs1, 944/-
	Net Savings Grand Total	**Rs 133,812/-**

4.4 5KW Single Phase Inverter with solar panels deployed with Solar Infinity SI-1:

Now we deployed our proposed device Solar Infinity SI-1 with 5KW Single Phase Off-Grid Inverter to study different scenarios as above. Finding how much green potential not in use and what we loss in terms of money. Suppose solar hours from 8am morning to5pm evening on average is equal to 9hours per day time.

PV solar system with or without battery power bank installed in house comprise of (figure 4.2):

- 5KW single phase Off grid Inverter(VM||Or VM|||)
- 5KW Solar panels attached
- 200 amp 48volts battery bank(2~3 hours backup)
- Application/Electric load

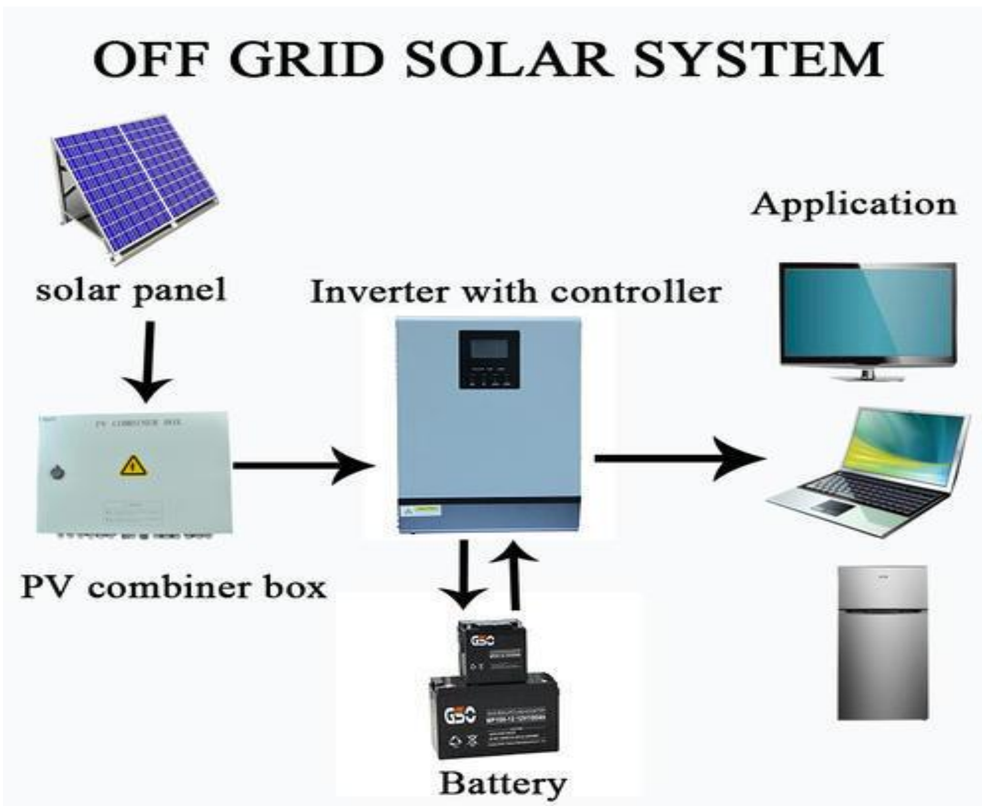

Figure 4-2: OFF-Grid Solar System interference

If batteries are not attached at time of power breakdown the load is on solar PV if available. Solar infinity (SI-1) device clip the heavy load through inverter. Solar infinity (SI-1) device allows essential load 25% of whole system only because there is no other backup source like WAPDA & Batteries.

4.4.1 House electric load for Single phase:

Normally there are two types of Electric loads one is essential and other is heavy or critical load considering house electric load are:

- Essential Load (EL) of house (3,000 watts) approx consists of:

Fan	100Watt approx
LED Bulbs	20Watt approx
LED TV	100Watt approx
Fridge	600Watt approx

- Heavy load (HL) of house (12,000watts) approx including**:**

AC	(500~2000)Watt approx
Motor	1500Watt approx
Iron	1000Watt approx
Microwave Oven	1500Watt approx
Washing Machine	700Watt approx
Electric Heater	1500Watt approx

4.4.2 Extra Solar Power (ESP) for 5 KW Off-Grid solar systems:

Suppose solar hours (8am-5pm=9hours) day time.

The average production rate (PR) from our designed solar power system (PV) is 50% (2500 watt=2.5 units per her) approx.

$$PR = 2500watts ------(X)$$

Consider the average essential load (EL) connected from the inverter is 1000 watts all the time.

$$EL = 1000watts ------(Y)$$

Essential load is on solar power and batteries but mostly heavy load is not attached through inverter although there is extra solar power available but not in use.

$$By\ using\ (X)\ \&\ (Y)$$

$$ESP = PR - EL = 2500 - 1000 = 1500\ watts$$

$$The\ Extra\ solar\ power\ (ESP)\ not\ in\ use: ESP = 1500\ watts\ approx\ -----\ (Z)$$

$$Consider\ Average\ per\ unit\ cost\ = Rs\ 12\ approx\ ----(\alpha)$$

4.4.3 Scenario-1: Heavy Load Bypass (Critical load not through Inverter):

If heavy load (AC,MOTOR etc) is attached through the inverter the at time of load shading the heavy load is direct on batteries**(**Evening and night hours) which lowers the battery backup hours and also effects its life specially . Although at day time PV supports to run heavy load but at night when there is no PV it's impossible. That's why usually heavy load is bypassed.

The Extra solar power (ESP) not in use 1500watts=1.5 units per day on average from equation (Z)

Means, on average 1.5 units per hour not in use due to heavy is bypassed through inverter.

LOSS	DURATTION*UNITS	RESULTS
Per day	8hours *1.5units	12 units approx
Per month	30days*24units	360 units approx
Per year	12months*360units	4,320 units approx

Net Savings:

By using Solar Infinity (SI-1) we can attach Heavy load through inverter. This can help to use Extra Solar Power (ESP) =1.5KWH approx not in use and can save $Units\ per\ year * Cost\ per\ unit\ is\ equal\ to\ 4{,}320 units * Rs12/- = Rs51,840/-$ approx per year.

4.4.4 Scenario-2: Blackout (3-6 hours):

A blackout occurs when all power in a certain service region is lost. Blackouts are service interruptions that are carefully planned and executed. A brownout is a transient drop in the voltage or total capacity of a system. Blackouts occur without warning and last for an indefinite period of time. They are usually caused by catastrophic equipment failure or extreme weather. Who is affected depends on the kind and source of the blackout. Utility companies intentionally induce rolling blackouts, which usually occur with at least some advance notice and last for a set period of time.

Consider the average load shedding occurs in this time period is (1-3 hours approx).During solar hours if the load shedding (LS) is done for 2hours a day.

Power loss not in use for 2hours load shedding per day:

By using (X) & (Y)

LOSS	DURATTION*UNITS	RESULTS
Per day	2hours *3units	6 units approx
Per month	30days*3units	90 units approx
Per year	12months*90units	1,080 units approx

Net Savings:

By using Solar Infinity (SI-1) we can attach Heavy load through inverter This can help to use Extra Solar Power (ESP) =1500watts approx per hour not in use and can save $Units\ per\ year * Cost\ per\ unit\ is\ equal\ to\ 1{,}080 units\ * Rs12 =\ Rs12{,}960/-$ approx per year.

4.4.5 Scenario-3: Brownout (1-5 hours approx):

A brownout is a voltage drop in an electrical power supply system that is either intentional or inadvertent. In an emergency, intentional brownouts are utilized to reduce load. In contrast to short-term voltage sag, the decline lasts minutes or hours. The word "brownout" refers to the dimming of light due to the voltage fluctuations. A voltage reduction may occur as a result of an electrical grid disturbance, or it may be enforced on occasion in order to reduce demand and avoid a blackout.

Brownouts are typically caused by electricity supply companies as a preventive measure to avoid failing blacking out the whole system.

The Extra solar power (ESP) not in use 1500watts=1.5units per day on average from equation (Z)

Means, on average 1.5 units per hour not in use due to heavy is bypassed through inverter.

LOSS	DURATTION*UNITS	RESULTS
Per day	3hours *1.5units	4.5 units approx
Per month(suppose 3 days)	3days*4.5units	13.5 units approx
Per year (suppose 7 months)	7months*13.5units	94.5 units approx

Net Savings:

By using Solar Infinity (SI-1) we can attach Heavy load through inverter, this can help to use Extra Solar Power (ESP) =1500watts approx per hour not in use and can save $Units\ per\ year * Cost\ per\ unit\ is\ equal\ to\ 94.5\ units * Rs12 =\ Rs1,134/-$ approx per year.

4.4.6 Scenario-4: Breakdown Period (Maintenance approx 4-6 hour’s approx)

Usually in winter power from grid has been cut-off for maintenance purposes (like cleaning Hydropower turbines, cutting trees heading towards transmission lines).

Consider maintenance hours are 4-6 hours approx at day time, Essential load is on solar power and batteries but mostly heavy load is not attached through inverter although there is extra solar power available but not in use.

The Extra solar power (ESP) not in use 1500watts=1.5units per day on average from equation (Z)

Means, on average 3 units per hour not in use due to heavy is bypassed through inverter.

LOSS	DURATTION*UNITS	RESULTS
Per day	3 maintenance hours *1.5units	4.5 units approx
Per month(suppose 6days)	6days *4.5 units	27 units approx
Per year (normally in winters consider 3months)	3 months*27units	81 units approx

Net Savings:

By using Solar Infinity (SI-1) we can attach Heavy load through inverter, this can help to use Extra Solar Power (ESP) =1500watts approx per hour not in use and can save $Units\ per\ year * Cost\ per\ unit\ is\ equal\ to\ 81 units * Rs12 = Rs972/-$ approx per year.

4.4.7 Overall Net Savings for different Scenarios:

Sr. No	Scenarios	Net Savings
1	Heavy Load Bypass (Critical load not through Inverter)	Rs51, 840/-
2	Blackout (3-6 hours)	Rs12,960/-
3	Brownout (1-5 hours approx)	Rs1, 134/-
4	Breakdown Period (Maintenance approx 4-6 hour's approx)	Rs972/-
	Grand Total	**Rs66,906/-**

5 Solar Infinity (SI-2) – PLC Based Control

5.1 About Device:

This device "SOLAR INFINITY SI-2" is an improvement of our proposed solution named "SOLAR INFINITY SI-1" device. This device is basically an improve PLC based control of heavy load attached phases which are previously operates manually in SI-1 as shown in (figure5.1). Both devices are helps to manage the critical load (heavy load which normally bypass) of the domestic and commercially installed single/three-phase solar system optimally. This section is about how SI-2 helps to manage more efficiently heavy load through the inverters for maximum utilization of green energy, additional feature, device components, and it's working.

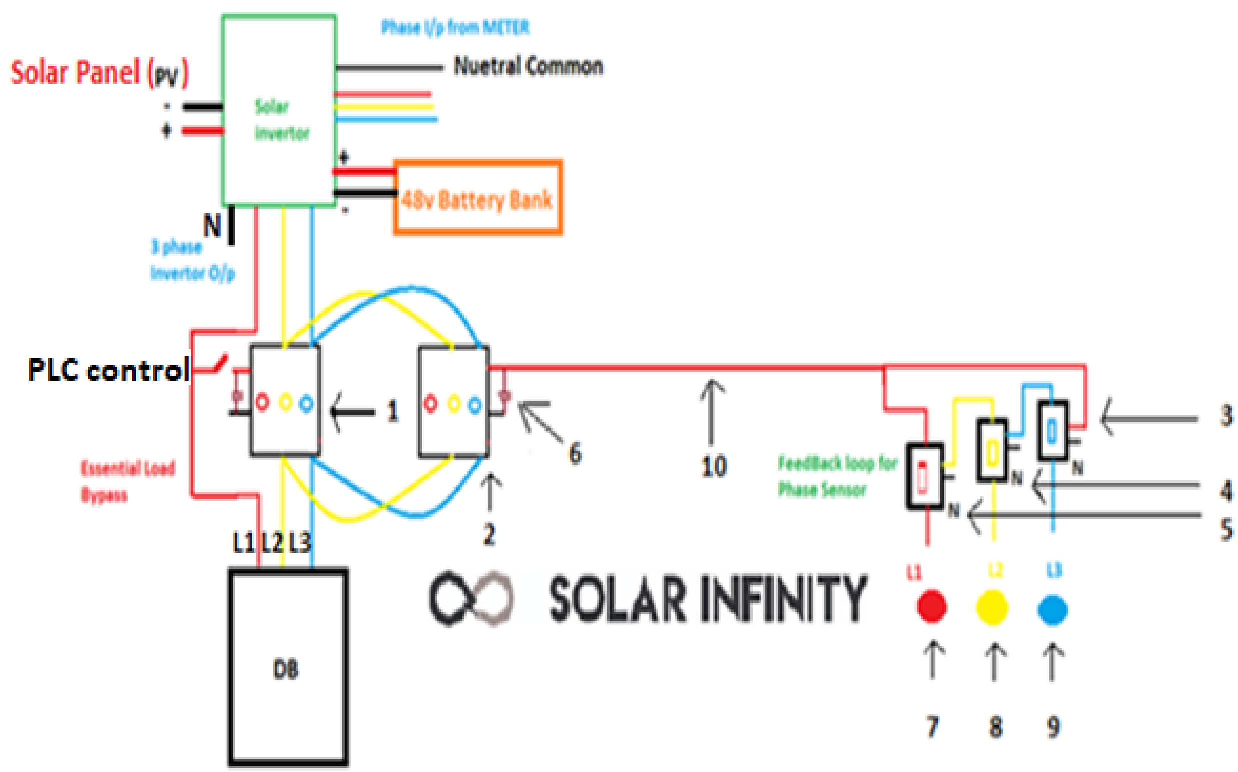

Figure 5-1: Solar Infinity SI-2 with PLC control for MC-1

5.2 Features of SOLAR INFINITY SI-2:

With Solar Infinity SI-2, we believe in using quality solar solutions that will perform to, or above users/customer's expectations. SI-2 helps to manage the critical load of the domestic and commercially installed single/three-phase solar system more optimally and saves batteries life. It ensures the provision of user energy consumption more optimally and positively changes energy behaviour, resulting in more savings than traditional systems available in the market.

- Minimize dependency on electrical grid
- Maximize use of free solar energy
- Saves batteries life
- Peak Demand Control

5.3 Basic Concept:

In basic we have solar panels from PV range 250~600v and batteries power bank from DC voltage range 56~44volts are sense/read with the help of PLC Ana log to digital (ADC) port comparing with the parameters which are pre-define in ladder logic which is programmed through PPI port to make decisions either relay is ON or OFF.

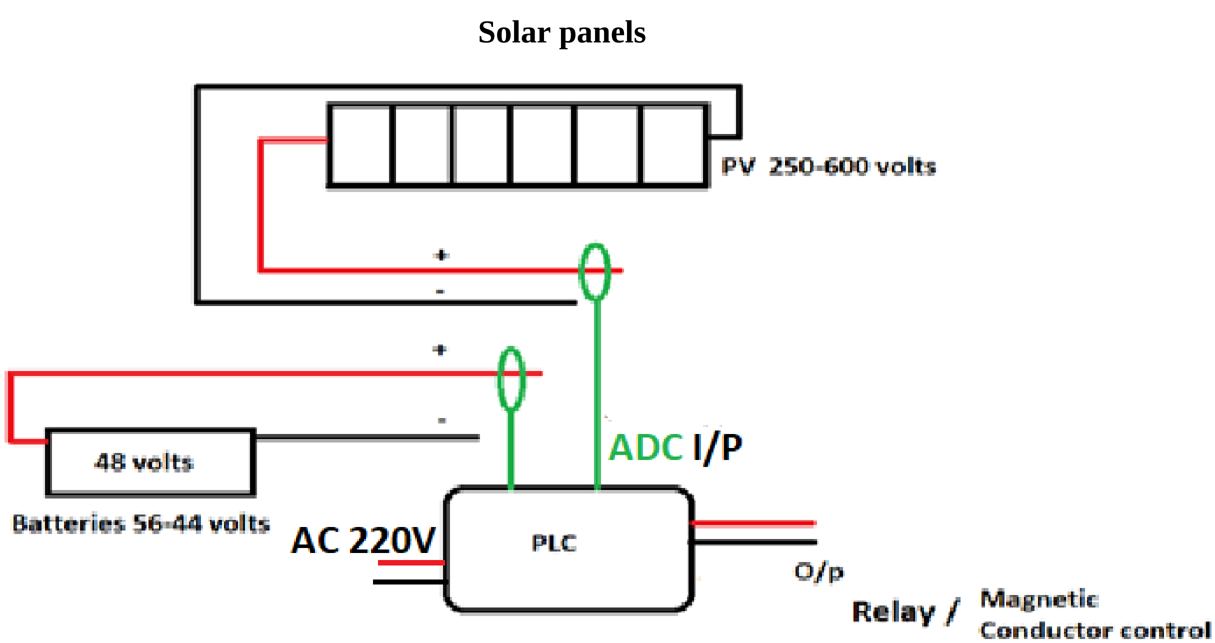

Figure 5-2: PLC Control Block Diagram for Magnetic Conductor-1

5.4 Programmable Logical Controller (PLC):

Programmable logic controller (PLC) or programmable controller is a modular and modified industrial computer which is used to control manufacturing processes like assembly lines, machineries, robotic devices, or any other activity that requires high dependability, ease of programming, and process fault diagnosis.

Small modular devices with a few tens of inputs and outputs (I/O) in a housing built into the processor to huge rack-mounted modular devices with thousands of I/O that are frequently networked with other PLC and SCADA systems are all examples of PLCs.

Figure 5-3: PLC (AMX 214-2BD23-0XB8)

5.5 Analog-Digital Converter (ADC):

An Analog to Digital Converter (ADC, A/D, or A-to-D) is an electronic device which converts analogue signals into digital signals, such as sound recorded by a microphone or light entering a digital camera. An ADC, which is an electrical device that converts an input analog voltage or current to a digital number that reflects the magnitude of the voltage or current, can also offer an isolated measurement. Although the digital output is often a two-s complement binary number equal to the input, there are other options [17].

Figure 5-4: ADC Converter

ADC architectures are available in a wide range of forms and sizes. Due to their complexity and the need for precisely matched components, all ADCs except the most specialized are manufactured as integrated circuits (ICs). Metal–oxide–semiconductor (MOS) mixed-signal integrated circuit chips frequently combine analogue and digital circuits.

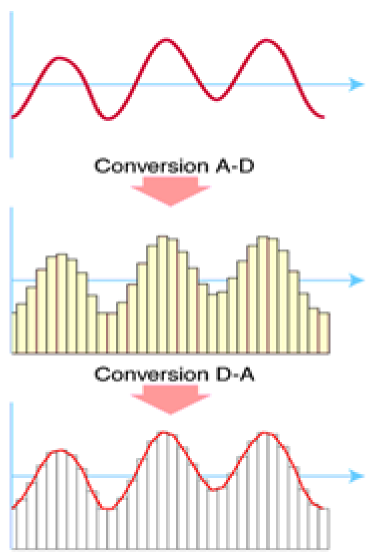

Figure 5-5: Conversions A-D and D-A

An ADC converts a continuous-time and continuous-amplitude analogue signal to a discrete-time and discrete-amplitude digital signal. There is bound to be some inaccuracy or noise in the conversion because it incorporates quantization of the input.

5.6 Operational Methodology:

PLC (AMX 214-2BD23-0XB8) operates on AC 220 volts basically uninterrupted power output of inverter.PLC has built-in ADC ports which convert raw voltages from PV source and battery bank into the required scaled values**.** These ADC values are used to make decision.

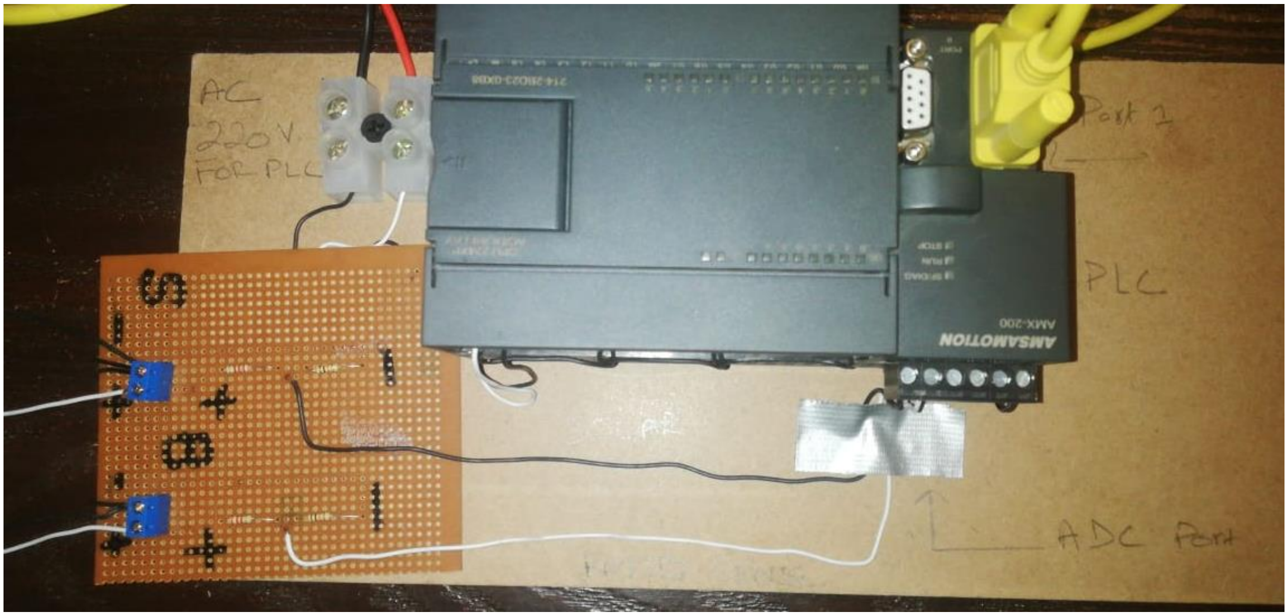

Figure 5-6: PLC based control for Solar Infinity SI-2 (Prototype)

PLC has two PPI ports for coding /ladder logic and user interference by using Step7 Micro-WIN 4.0(Software).The ADC values are measured on predefined parameters time, Solar and battery source voltages.

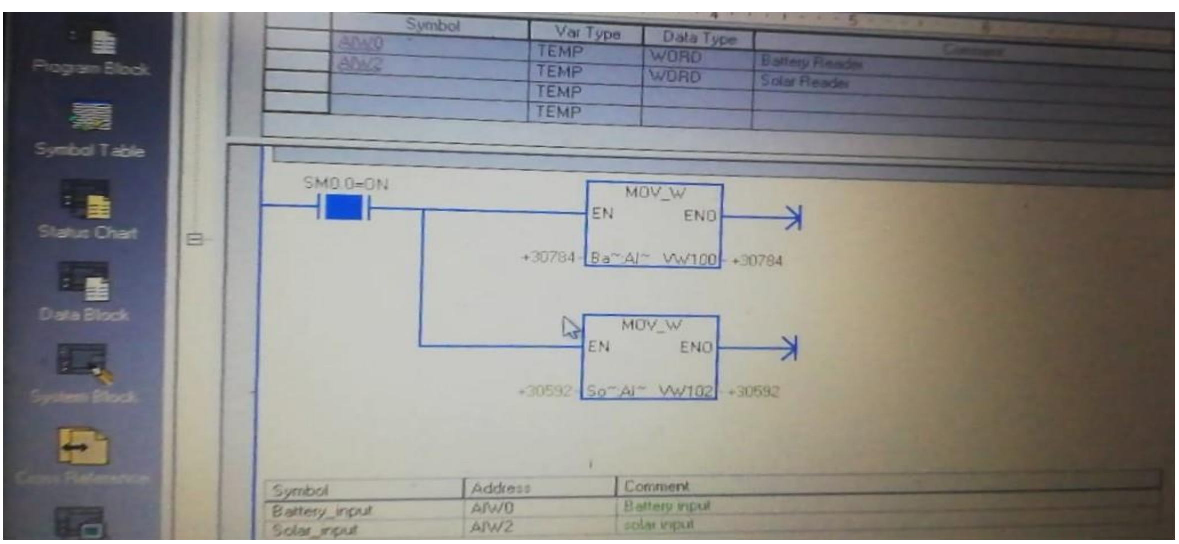

Figure 5-7: Ladder logic and user interference by using Step7 Micro-WIN 4.0(Software).

5.7 PLC Based Control under predefine parameters:

For testing PLC based control under defines parameters consider:

- Solar Panel voltage (VOC) range (9volts to 12 volts)
- Battery voltage range (8volts to 12 volts)
- PLC (AMX 214-2BD23-0XB8) operates on AC 220 volts
- Magnetic Conductor (MC-1) Control through PLC.

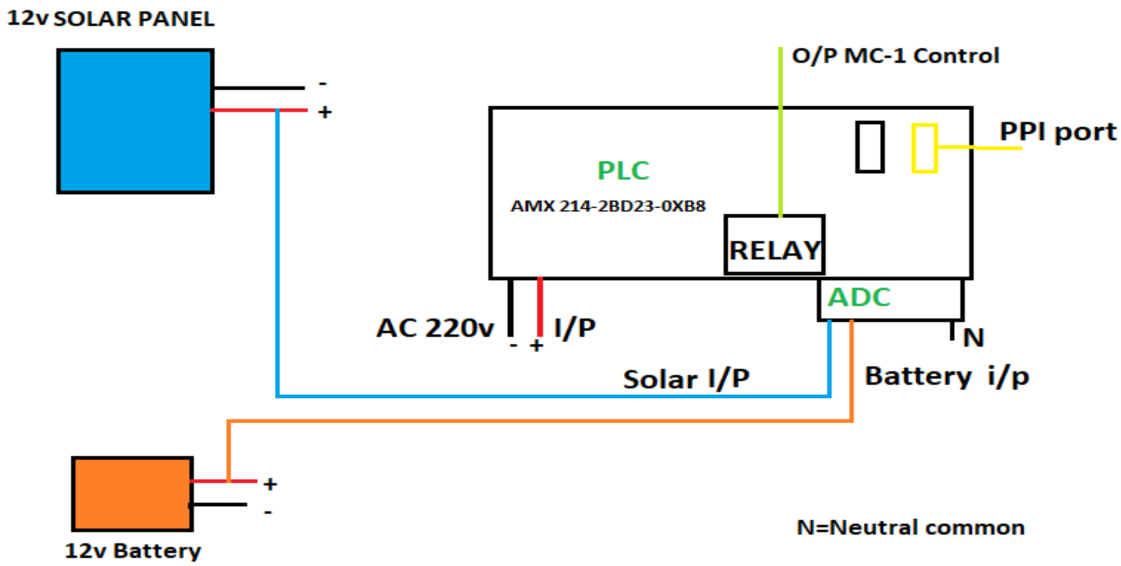

Figure 5-8: PLC Control for Critical Load Management OR PLC Control for Magnetic conductor-1

Voltage checks: Solar VOC (10volts~12volts) & Battery (9.5volts~12volts)=Relay is ON beyond these VOC ranges Relay is OFF.

OR

For Analog –Digital converter (ADC) Value Check: Solar ADC (25396~30272)&Battery ADC(24651~30272)=Relay is ON beyond these ADC ranges Relay is OFF.

Note: Magnetic Conductor (MC-2) Control through gird.

RELAY is OFF means critical loads (L-2 & L-3) are clipped through magnetic conductor (MC-1) with the help of PLC relay as shown in figure 5.1.

RELAY is ON means critical load (L-2 & L-3) are allowed through magnetic conductor (MC-1) with the help of PLC Relay as shown in figure 5.1.

5.4.3 Tabular Analysis:

This tabular analysis describes detailed response against Solar panel and Battery voltages/ADC. Also describes status of magnetic conductor MC-1 either allows the critical load (L-2&L-3) or clip.

Table 5-1: Comparison table results:

Time (Day /Night)	Solar panel PV (10~12V)	Analog-Digital Converter (ADC Values for PV)	Battery (8~12v)	Analog-Digital Converter (ADC Values for Battery)	PLC(O/p) RELAY	Magnetic Conductor (MC-1)
5am-8am(D)	9 v	23432	8v~12v	19872~30272	OFF	Clipped
5am-8am(D)	9.5v	24651	8.5v~12v	22001~30272	OFF	Clipped
5am-8am(D)	9.5v	24651	9v~12v	23432~30272	OFF	Clipped
8am-5pm(D)	10v~12v	25396~30272	9.5v~12v	24651~30272	ON	Allow Critical load
8am-5pm(D)	10v~12v	25396~30272	10v~12v	25396~30272	ON	Allow Critical load
8am-5pm(D)	10.5v~12v	26400~30272	10.5v~12v	26400~30272	ON	Allow Critical load
8am-5pm(D)	11v~12v	27616~30272	10.5v~12v	26400~30272	ON	Allow Critical load
8am-5pm(D)	11v~12v	27616~30272	11v~12v	27616~30272	ON	Allow Critical load
8am-5pm(D)	11.5v~12v	29008~30272	11v~12v	27616~30272	ON	Allow Critical load
8am-5pm(D)	11.5v~12v	29008~30272	11.5v~12v	29008~30272	ON	Allow Critical load
8am-5pm(D)	12v~12v	30272	11.5v~12v	29008~30272	ON	Allow Critical load
5pm-5am(N)	3v~9v	6872~23400	8v~12v	19872~30272	OFF	Clipped
5pm-5am(N)	2v~9v	4372~23400	8v~12v	19872~30272	OFF	Clipped

Chapter 6

6 CONCLUSTION AND FUTURE WORK

Pakistan belongs to the countries, where great potential for solar energy. Instead of using normal inverters to convert solar energy into electricity, store in batteries and dump the extra available power without utilizing in black/brownouts, use solar optimal devices it may be more economical to for domestic as well as commercial applications.

6.1 Conclusion:

The overall outcome of the proposed solar device is to attach with traditionally installed inverters by this we can achieve maximum benefits of solar power by managing critical/heavy loads, protecting batteries for fast drainage and allows most of solar power used resulting in greater revenues from solar plants.

Extreme optimal condition can be achieved by using proposed device with solar inverters it will helps to minimize our electricity bills. Peak load on the utilities can be reduced due to sharing factor.

Handles black/brownouts and cloudy weather issues more effectively by limiting critical load protecting battery at night when PV and grid not available. Phase failure issues will also addressed with the proposed system to avoid overload issues on batteries.

For rural irrigations DC solar pumps are effective options. VFD's need to improve i.e. if pumps are not in use then solar power should use for other multiple purposes.

6.2 Future work:

If government gives incentives and serious actions to promote renewable resources most of the energy related problems can be solved. We as a citizen need to change our habits, ensure that you are using most of electricity during day light or peak hours.

Open areas for

- The orthodox system needs to upgrade loss most of the green energy.
- To maximise the investments on green potential such as, solar power need to change our habits ensure that you are using most of electricity during day light or peak hours.

- Smart hardware implementation.
- The device or concept needs to be built inside future inverters.
- Smart breakers interface for more optimum utilization and control.
- Making the device smart for further connectivity with the smart grid system.

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