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The Revolution in the UPS Technology

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Abstract: Most of the us who own a computer use uninterruptible power supply as a backup source to charge our computer. It is an important device present in offices, libraries, universities, industries, data centers etc. UPS is designed so well to offer temporary power during outages and maintain steady power supply during fluctuation from the utility lines. The UPS system has an inverter which recreates the AC power from the DC power stored in the battery bank. The UPS is first introduced in 1934 and it has a quite interesting story. This paper describes the development of UPS from 19th century till now and explains about the future trends of the UPS technology and how it benefits the customer.

Keywords: Uninterruptable power supply, electricity, safety, trends

I. INTRODUCTION

Getting electricity at economic cost and achieving customer satisfaction is very challenging these days. Moreover, it is tough to safeguard the electrical connections in a network against random system failures. Not all failures in electrical systems are due to internal connectivity in the systems, there are few disturbances in the circuit caused by external factors beyond the control of operating staff. The 19th century from 1st January 1801 to 31st Dec 1900 was an era of rapidly accelerating scientific discovery and invention. There were significant developments in the field of mathematics, chemistry, biology, physics, electronics, and metallurgy that led to the technological advancements of the 20th century. The first major advancement in land transportation in 19th century was the introduction of rail roads. This changed the livelihood of people.

The story of electricity started with the invention of the first commercial 'electric bulb' by Thomas Alva Edison in the year 1879. Those days there was no electricity when power goes, and it was the common resource of people in homes. Also, rails systems are run only on electricity unlike modern trains use electricity, diesel, or other fuel sources. John J Hanley who is the father of UPS was interested in rail passenger trains. Hanley's concern for railway safety and passengers led to the invention of first UPS in 1934. J.Hanley filed his first patent on 2nd November 1932 on "maintaining unfailing and uninterruptible power supplies of electrical energy" and was granted patent on 3rd April 1934.

John J Hanley's application mainly describes an apparatus which has automatic switches enabling a battery to cut in when an external power supplies. Hanley further envisioned his invention by utilizing certain electrical energy required to supply alarms and signal systems to maintain uninterrupted power supply to systems. Those were the days when no computers are available.

Another interesting fact about Uninterruptible power supply is, it is also known as Uninterruptible Power source or UPS or battery or flywheel backup. The first UPS systems used flywheel rotary design. The limitation of this design is that it only provided backup power of only about 20seconds to 90 seconds. The working principle of this design is when the high-speed flywheel spins, kinetic energy is built and stored. During power failure in the main supply, this kinetic energy provides DC current to the application. Another interesting fact is, the rotary flywheel UPS are still used these days in industries for small backup functions. However, these UPS proved inefficient as they didn't offer much surge protection and could not support modern servers and databanks.

It is interesting to know about UPS and it is used in wide number of applications. An uninterruptible power supply (UPS) is system or device which provides an alternate source of energy that can provide backup power to the connected load during failure of electrical power or during unacceptable voltage level. The characteristics of UPS mainly are:

1. It provides protection from power surges
2. It provides power quality supply for critical equipment
3. Isolates from transient, surge and spike suppression
4. Has battery backup
5. Regulate and support power instantly
6. Helps in auto file saving and user diagnostics.

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II. DESIGN APPROACH OF UPS

The basic parts of the UPS are AC to DC converter, a storage device, DC to AC converter and a static switch. A variety of design approaches are used to implement uninterruptable power supply systems, each of them are with distinct performance characteristics. The most common design approached are:

1. Passive standby (also called "Off-Line")
2. Line interactive
3. Double conversion (also called "On-Line")
4. Delta conversion on-line

A. Passive standby (also called "Off-Line")

Fig. 1 shows the Passive standby UPS. In this approach during normal mode, the load is supplied directly from utility (AC input) through a static switch. While in stored energy mode of operation, the load is supplied from the storage device through inverter.

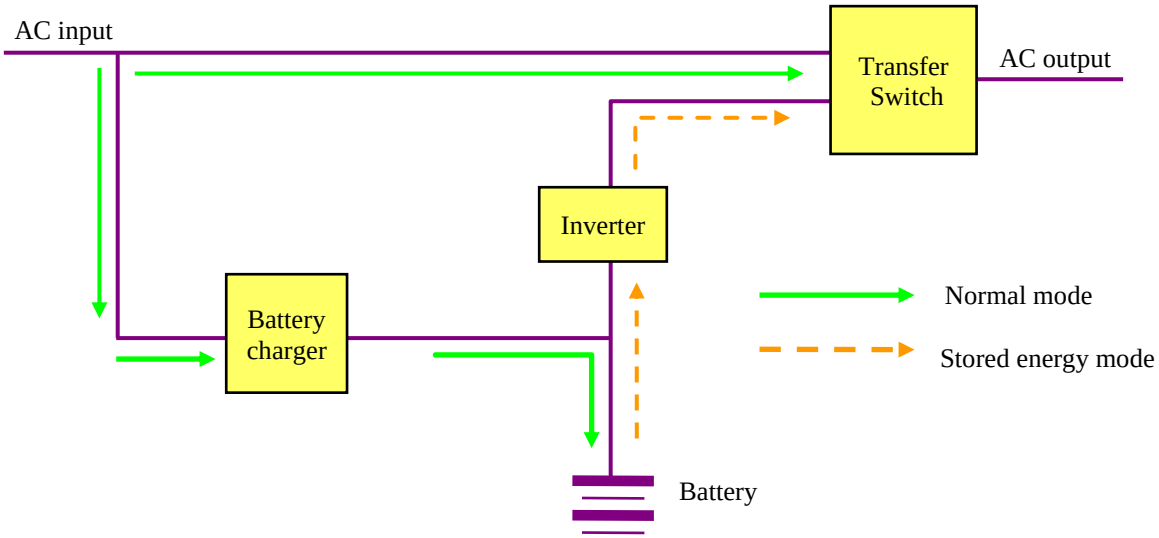

Fig. 1 Passive standby UPS design

B. Line interactive

Fig. 2 shows the Line interactive UPS. This design has power interface and the reversible converter. The power interface includes both output voltage conditioning and input switch disconnecting ac input during stored energy mode. During normal mode of operation, the utility (AC source) feeds the load directly. The reversible converter is connected in parallel, and it is the back-up of the utility power. The converter also provides output voltage conditioning. In the stored-energy mode of operation, the power interface having switch breaks the connection and the converter acts as the inverter and supply the power to the load. In this approach, the output frequency simply follows the input frequency.

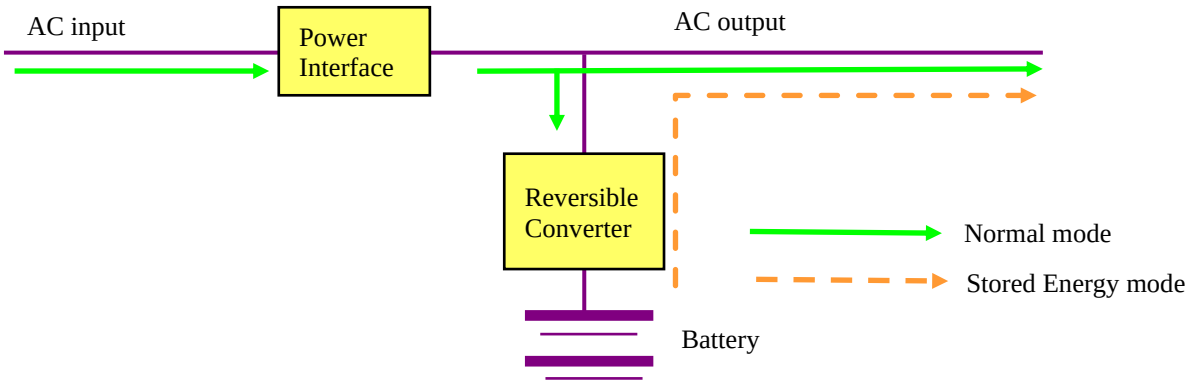

Fig. 2 Line interactive UPS design

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C. Double conversion (also called "On-Line")

In Double conversion design approach, uses the capacitor to stabilize the DC power. This approach has three modes of operation as in Fig. 3. During normal operation the load is fed from utility to load through both rectifier and inverter. As there are double conversion phenomena taking place, this approach allows good line conditioning and provides required voltage and frequency. In stored energy mode operation, the battery is charged by the converter and the required power is provided by the battery and the inverter. While in the By-pass mode of operation the load is directly transferred from utility through switch. Unlike Double conversion, in Eco mode of UPS operation the power flows from the utility through by-pass switch.

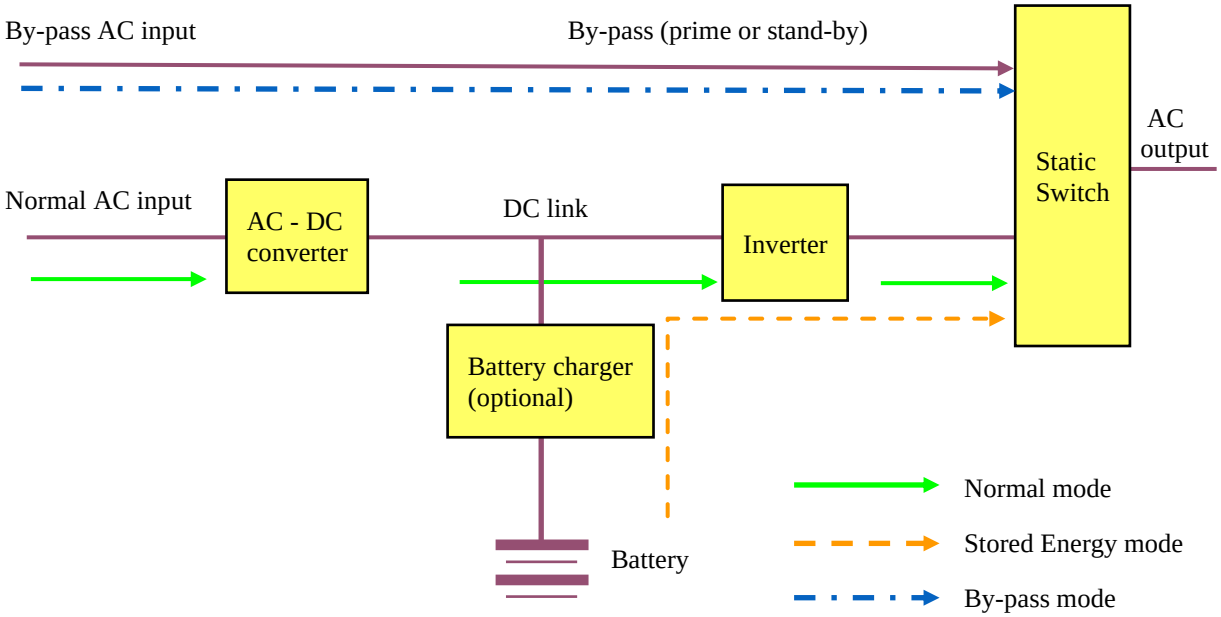

Fig. 3 Double conversion UPS design

D. Double conversion (also called "On-Line")

Fig. 4 shows delta conversion UPS. Like the double conversion on-line design, the delta conversion on-line UPS always has the inverter supplying the load voltage. However, the additional delta converter also contributes power to the inverter output. Under conditions of AC failure or disturbances, this design exhibits behaviour identical to the double conversion on-line.

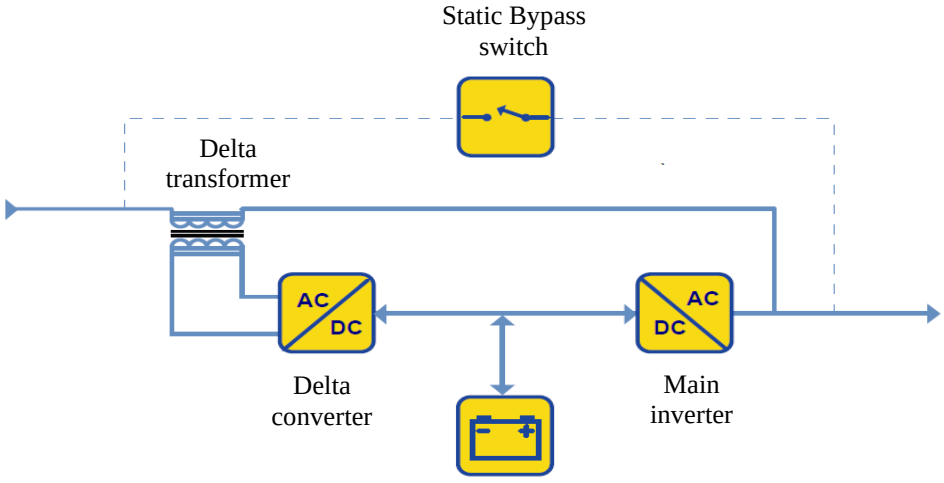

Fig. 4 Delta conversion UPS design

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The UPS system design is based on how powers move through the unit. Based on the performance and the applications the UPS design approach can be selected. Table 1 provides the comparison of the design.

TABLE I COMPARISON OF COMMON DESIGN APPROACHES OF UPS

UPS design	Power rating	Where used	Advantage	Disadvantage
Passive standby UPS	<2kVA	Personal computers	Simple, low cost	Long switching time, no regulation of output frequency & voltage
Line interactive	<5kVA	Small business, departmental services	Simple, low cost	Poor efficiency, no isolation of the load from distribution system, no regulation of regulated frequency
Double conversion	>10kVA	Servers, data centres, medical equipment's	Continuous protection of load, improved performance, good line conditioning	Expensive
Delta conversion	5kVA to 2MVA	Heavy duty works	Saves energy between starting and ending points, high efficiency, excellent voltage conditioning	Impractical under 5kVA

III. DEVELOPMENT IN UPS

There were many advancements made in the UPS topology from the past. The standard UPS systems shown in Fig. 5 consists of a rectifier, a battery charged by a rectifier and an inverter. This inverter is powered by a rectifier and the static switch helps in uninterruptable switching of the load between the grid (utility) and the inverter.

The advantages of standard UPS system are they are simple and cheap and fewer components are used; however, they have a limitation of periodically changing the batteries. Indirectly this is time consuming and not cost effective.

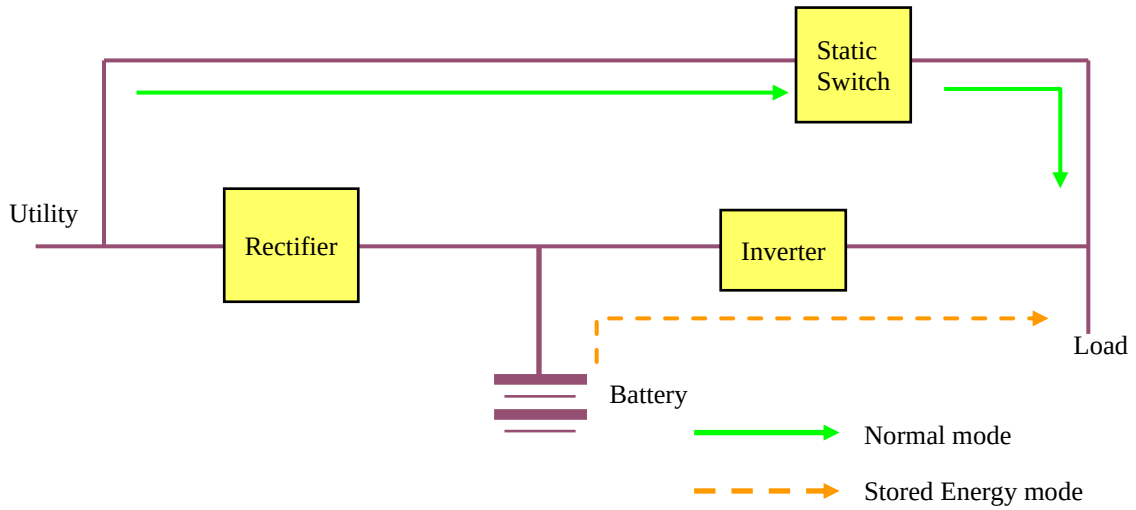

Fig. 5 Standard UPS design

In general, most of the UPS system uses Double conversion design approach as this approach provides uninterrupted power supply to critical loads.

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The AC voltage is first converted to DC voltage using a Silicon Controlled Rectifier (SCR) or an Insulated -Gate Bipolar Transistor (IGBT). Later the DC is converted to AC using Inverter. Batteries are placed in-between rectifier and inverter so that in case of failure of power from AC source or mains the batter help supplying power to the rectifier for successful transition of supply to load. Both these options SCR and IGBT can be configured in number of ways.

SCR based UPS systems are more than 50 years old technology. Over the years, SCR based UPS have advanced with 6 Pulse to 12 Pulse rectifier with filter design. The rectifier in this UPS is a thyristor which itself is known as high switching rectifier.

The rectifier in general is like a large container of capacitor. After converting AC voltage to DC voltage, the same voltage will not be provided to load through inverter. So, transformers in general are used to either step up or step down the voltage. It's noted that UPS having 12 pulse rectifiers can reduce harmonics and improve power factor compared to 6 pulse rectifiers. However, the 12-pulse rectifier is quite expensive and comparatively a 6-pulse rectifier uses one winding transformer whereas 12 pulse rectifier uses 3 winding transformers. Table 2 depicts the comparison of IGBT, and SCR based technologies in UPS design.

TABLE II COMPARISON OF IGBT TRANSFORMER LESS TECHNOLOGY WITH SCR-TRANSFORMER BASED TECHNOLOGY UPS DESIGN

Percentage of Loading	**IGBT based Rectifier Design**	**SCR based 6/12Pulse Rectifier + Filter Design**
Technology	IGBT is the Latest Topology being used in UPS system	More than 50 Years Old Technology
100 % Loading		
Input Power Factor	>0.99 without Filters	>0.9 with Filters
Overall Efficiency	≥96%	≥93.5%
Input THDi (Total hormonic distortion current)	< 3%	< 7%
Diesel generator Requirement	1.1 Times	1.5 Times
50 % Loading		
Input Power Factor	>0.99 without Filters	>0.95 with Filters
Overall Efficiency	≥96%	<90%
Input THDi (Total hormonic distortion current)	< 5%	< 10%
Diesel generator Requirement	1.1 Times	1.5 Times
25% Loading		
Input Power Factor	>0.99 without Filters	>0.95 with Filters
Overall Efficiency	>0.99 without Filters	< 87%
Input THDi (Total hormonic distortion current)	<8%	<17%
Diesel Generator Requirement	1.1 Times	1.5 Times
Mean time between failure, MTBF (Availability)	High	Low
Total Cost of Ownership (TCO)	Low	High

(*From primary and secondary sources, findings till 2023)

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IV. GROWTH OF UPS SYSTEMS

UPS design have changed predominately from last 15 to 20 years. Depending on the switching mode converters, the inverters used in UPS system are classified as 2-level, 3-level, and 4-level inverters. Two-level inverters control the voltage waveform of the converter output with 2 electric potentials. Three-level inverters control the voltage waveform of the converter output with 3 electric potentials. Similarly, the four-level inverters; controls the voltage waveform of converter output with 4 electric potentials. The efficiency of 4-level is high compared to 3-level and 2-level inverters. The 4-level inverter system design is complex compared to 3-level inverter system design. However, the reliability of 4-level inverter UPS is quite good and the total harmonic distortion present in the output waveform is reduced. In few UPS industries, soft switching technology has been used. In a scale of 0% to 100% load, efficiency of different types of inverters are not the same throughout. Studies from primary and secondary are made till 2023 and captured efficiency levels for different inverter system designed at 50% load as shown in Fig. 6.

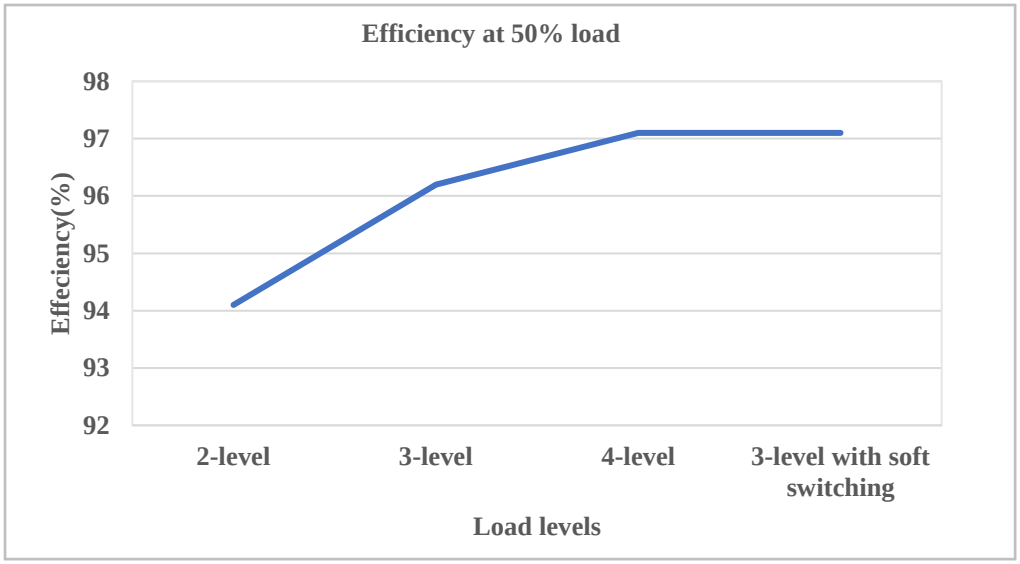

Fig. 6 Efficiency of 2, 3, 4 and 3-level with soft switching inverters

V. PRODUCT SAFETY STANDARDS

The UPS should not be operated at a high temperature and extreme humidity levels. And the materials inside the UPS battery can be harmful to the skin and the eyes. A few standards are mandatory to follow to maximize the protection of the machines and the operators. The safety standards applicable are begun as:

A. IEC 60529:1989: Amended in 1999 and 2013

This international standard defines the Ingress protection (IP) ratings used to define protection of sealing enclosure from any foreign matter like dust, water etc. It means the Internal standard IEC 60529 is applicable only to the external enclosures but not to the inside enclosure of the UPS system. For internal enclosure's other international standards are followed.

B. IEC 62040-1:2008

This international standard defines the protection of operators from restricted access areas and service access areas. IEC 62040-1:2008 refer to the reference document IEC 60950-1:2005, which defines operator's accessibility level. For protection, the operator's area is locked and cannot be accessed without the use of a tool. Both these standards also define to install Chloride industrial systems in restricted access location.

C. IEC 62040-1:2017: Amended in 2021 and 2022

IEC 62040-1 is amended in 2017 with additional and revised information. The latest revision of the standard mainly focuses on the ability of the people to identify risks. That means, only skilled and with proper authorized people will be granted access to restricted access location of UPS systems. The requirement 'Protection against electric shocks' is defined by standards IEC62040-1:2017 and IEC 62477-1:2012.

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VI. FUTURE TRENDS FOR UPS SYSTEMS

As per the market anticipation, the future of UPS is considered to raise rapidly between 2023 and 2030.The UPS technology have advanced over the past on battery backup systems. The technology is more accessible to homeowners and helped in boosting the growth of Industries.

Further advancements to UPS systems were made on remote monitoring, compact size to fit in small space, decentralized static bypass switches and controls, modular design, and mechanical fly wheel energy storage. The UPS is designed to provide temporary power during power outage when the grid energy quality is undesirable. Other expected trends on UPS system are:

A. Better Power Density

As we know the power requirements of data centers are increasing, and most of the data centers are built with limited space. Therefore, power density is considered as an essential feature for reducing the footprint. The power rating of UPS is defined by Kilowatt (kW), or Kilovolt-Ampere (kVA) and the UPS provides better efficiency if the power factor is close to unity. In other words, the higher the efficiency, the better the power density. The smaller the footprint with a higher kW real power rating, the more beneficial it would be for the users.

B. Fly energy storage

The government's commitment to reduce the common emission and stringent compliance criteria have helped in driving the market to design and produce higher efficiency UPS. The flywheel energy storage systems are another emerging technology used in data centre UPS systems. These systems are of highly efficient and can provide rapid backup power. The efficiency of the UPS with the past advancements have improved from 95% to 96%. The forecast is to move forward from 96% to 97% and above.

C. Artificial intelligence

Though UPS have remote monitoring technology, introducing AI-powered UPS helps to develop new UPS systems that anticipate any power outages and start up generators before the outage occurs.

D. Microgrids

Microgrids are small-scale power grids that act as a single controllable entity. As microgrids operate independently from the main electrical grid they can be used to provide reliable power to data centers, during power outages.

E. Hybrid UPS technology

The UPS system works with a backup generator. Most of the data centers have diesel generators separately in the center occupying some space. Hybrid UPS technology (diesel generator + UPS) saves huge money and electricity while charging.

F. Solar-based technology

Using the solar-based technology in UPS can reduce size and cost. The efficiency of the system can also increase, as its more user-friendly customers would show interest.

VII. CONCLUSION

The UPS technology has evolved since 19th century to present and offered the best protection systems. With the growing need of UPS in industries, educational institutions, hospitals etc, the UPS market is expected to reach close to $11 billion by 2030.

With the steady growth and demand for UPS systems the industries have been working on improving the capacity, efficiency, and footprint. With the future trends in UPS technology, the customers can save huge money as well they can reduce their CO2 emission helping the world to be a better place to live.

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