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Renewable Energy Sources Integration and Control in Railway Microgird

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Abstract- The traffic rail increase implies an increase in the electric energy consumption. Hybridizing the railway sub-stations with hybrid energy sources based on renewable energy sources and storage units connected to a DC bus may be a solution to contribute to the partial independence of energy producers in the sector of traffic rail. A smart control is highly recommended in order to avoid disturbing the traffic or the energy quality of railway lines. This project proposes a reversible, self-adaptive, autonomous and intelligent distributed generator connected to the catenary thanks to the DC bus distributed control by the multi-agent system. The results analysis has shown that the proposed control architecture can be a solution to face the issues related to the traffic railway issues.
Key Words- Renewable energy, railway microgird, solar energy, wind energy, DC to DC converter.

I. INTRODUCTION

The subscribed power exceeding cost weighing the energy bill of the railway networks actors, its reduction will undoubtedly alleviate this increase. The placement of a new DC substation and/or the existing DC substation upgrades are the solutions actually implemented. From an economic point of view, these solutions do not solve the problems related to the losses generated by the power routing from the substation to the trains running on the line. It also introduces other investment costs related to the transmission and distribution network. Moreover, in the case of the renewal or extension, if the substation is powered by fossil energy sources, the energy produced will have a direct impact on the environment and its cost will be high following the refraction of this type of energy source. Reducing the subscribed power, eliminating the voltage drop in the line due to the acceleration and leading to the subscribed power exceeding and avoiding the voltage rise due to the deceleration by consuming the total of the regenerative energy not recovered by the other trains in the line, are the main issues related to the traffic railway. Indeed, it can occur that the regenerative power exceeds the consumed power, or the regenerated power is far from the consumed power. The techniques of the energy recovery are listed in [1]. Authors in [2] have proposed an intelligent control to plan the regenerative energy recovery. In fact, the line voltage increase, occurring due to the regenerative braking energy causes the traction materials damage, also the regenerative energy generates a bidirectional energy flow on the line. If it is not consumed, it can be exported to the main network.

A configuration of the substation that respects the reversibility without modifying the actual infrastructure, the proximity to the trains' consumption and facilitating the regenerative energy consumption that it is not recovered by the circulating trains is proposed in this paper. It consists of hybridizing the substation by Hybrid Power Generation System (HPGS) tied to a DC bus that it is directly connected to the catenary as depicted in Fig.1. It offers all services brought by the hybrid systems [3] and does not require any changes in the existing architecture of the substation. Linking renewable energy sources (RES) and storage units to the DC bus, connected to the catenary is the Hybrid Substation (HSS) studied in this paper. The proposed HSS characteristics are presented in Table I. It consists of a PV and wind turbine generators (PVG and WTG) and battery storage units.

Two RES from different nature are combined, to minimize their discontinuity and also to avoid their oversizing that can occur if only one source is available. Following their main characteristic the RES supply the railway line in complementarity. A storage unit such as the battery is tied to the RES. It provides the energy necessary to meet the peak power demand and consumes the excess of regenerative energy in the line thanks to the associated converter. Indeed the interconnection of the RES and the battery to a DC bus in the catenary can be viewed as distributed generator DG that reduces the subscribed power thanks to the RES generation, provides the energy necessary during acceleration phases to suppress the subscribed power exceeding and eliminates the drop voltage in the line thanks to the battery discharge and the RES generation simultaneously, and avoids the voltage increase due to the deceleration process by consuming the energy excess, thanks to the battery charge. The overall power of the proposed HSS is given in (1). According to (1) the trains will no more consume the energy needed for circulation only from the substation but from a judicious use of RES generated power PRES, battery power PBattery, and substation power PSubstation thanks to the Distributed Energy Management (DEM).

$$P_{trains} = P_{Substation} + P_{RES} + P_{Battery} \qquad (1)$$

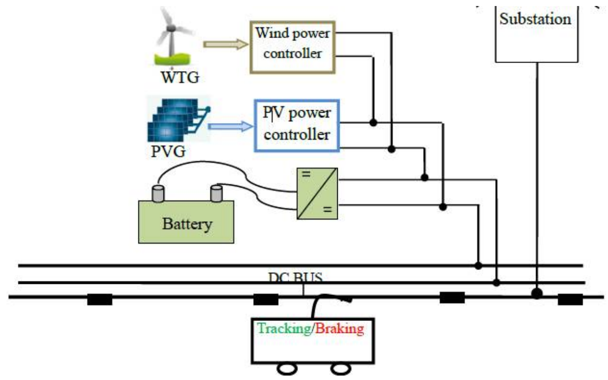

Fig 1: Block diagram of Railway Microgrid

A. Railway microgrid components' specifications

Subscribed power	PS=2.5MW
RES maximum power	PRES=0.5MW
Battery	PBat=3MW
Line resistance	RL=0.025Ω/Km
Line voltage	VL=1500 Volts (DC)

The integration of the distributed generation such as RES in the railway network should meet several technical constraints [4] [6]. The potential interest and the possibility of integrating RES in the railway substation have been studied in [7] [8], where it was pointed out that in order to improve the efficiency and reliability of the system, hybridizing a stationary system based on RES in the traffic railway can only be achieved by thinking of an intelligent approach, because the maximum railway traffic consumption is rarely correlated with maximum RES production.

The HPGS consists of a multi-source system with decentralized energy sources with different capacities and different generation. To derive all the benefits of the braking energy and to reduce the tracking energy cost and also in order to avoid disturbing traffic or the energy quality of the railway lines. The energy flow and information coming from each source should be controlled simultaneously while integrating the HPGS to the substation. That allows the judicious and effective use of each source. Therefore, a need for a DEM is raised.

The objective of the proposed DEM is to design a reversible, active, intelligent, self-adaptive, and autonomous DG connected to the catenary. Thereby, a DC bus distributed control where the HPGD is tied is required. Furthermore, the railway electrical network can be observed as a microgrid, because it is depicted as a chain of distributed loads when the trains are in acceleration mode and also as distributed generators when the trains are in deceleration mode. Having regard to this, a very sophisticated distributed DC bus voltagecontrol is highly recommended. This paper proposes DEM by Multi Agent System (MAS) to enable the implementation of railway microgrid with HSS based on HPGS.

MAS is extensively suggested as a suitable approach to manage complex distributed system [9] [10] such as the railway microgrid and it can give solution to a distributed control scenario. A large number of studies regarding the distributed control applications have been developed by MAS technology [11] [13].

The subscribed power exceeding cost weighing the energy bill of the railway networks actors, its reduction will undoubtedly alleviate this increase. The penalty costs related to the railway reflects the system's adaptation to energy consumption. If the energy production covers consumption, there is no penalty, and then the penalty cost is zero. On the other hand, if there is a certain lack or excess of energy, the penalty cost Cpenality depends on the square of the missing or surplus energy EExcess/lack according to (2).

$$C_{penalty} = C_u \times E^2_{Excess/Lack} \quad (2)$$
$$C_u : \text{Unit Cost of elements}$$

In the proposed railway microgrid, penalty costs are related to the integration of intermittent energy sources as RES and to the balance between supply and demand and the subscribed power exceeding.

The penalty costs associated to the RES correspond to the risk of unavailability during peak periods, this cost is covered by the battery in association with the available RES. Concerning the penalty costs related to the balance between supply and demand, it correspond to the acceleration and deceleration phases and to the surplus of the unused consumed energy as in the case where the RES are available while the trains running on the line are running with a constant traction speed or at the trains start or stop, where the trains speed running on the line is zero. The penalty cost associated with this excess energy is totally covered by the battery for reuse inthe event of peak or acceleration phases. Finally, the penalty cost related to the subscribed power exceeding is covered simultaneously by the RES and the battery.

II. SOLAR ENERGY

In today's climate of growing energy needs and increasing environmental concern, alternatives to the use of non-renewable and polluting fossil fuels have to be investigated. One such alternative is solar energy. Solar energy is quite simply the energy produced directly by the sun and collected elsewhere, normally the Earth. The sun creates its energy through a thermonuclear process that converts about 650,000,000[1] tons of hydrogen to helium every second. The process creates heat and electromagnetic radiation. The heat remains in the sun and is instrumental in maintaining the thermonuclear reaction. The electromagnetic radiation (including visible light, infra-red light, and ultra-violet radiation) streams out into space in all directions.

Only a very small fraction of the total radiation produced reaches the Earth. The radiation that does reach the Earth is the indirect source of nearly every type of energy used today. The exceptions are geothermal energy, and nuclear fission and fusion. Even fossil fuels owe their origins to the sun; they were once living plants and animals whose life was dependent upon the sun.

Much of the world's required energy can be supplied directly by solar power. More still can be provided indirectly. The practicality of doing so will be examined, as well as the benefits and drawbacks. In addition, the uses solar energy is currently applied to will be noted.

Due to the nature of solar energy, two components are required to have a functional solar energy generator. These two components are a collector and a storage unit. The collector simply collects the radiation that falls on it and converts a fraction of it to other forms of energy (either electricity and heat or heat alone). The storage unit is required because of the non-constant nature of solar energy; at certain times only a very small amount of radiation will be received. At night or during heavy cloud cover, for example, the amount of energy produced by the collector will be quite small. The storage unit can hold the excess energy produced during the periods of maximum productivity, and release it when the productivity drops. In practice, a backup power supply is usually added, too, for the situations when the amount of energy required is greater than both what is being produced and what is stored in the container.

Methods of collecting and storing solar energy vary depending on the uses planned for the solar generator. In general, there are three types of collectors and many forms of storage units.

The three types of collectors are flat-plate collectors, focusing collectors, and passive collectors.

Flat-plate collectors are the more commonly used type of collector today. They are arrays of solar panels arranged in a simple plane. They can be of nearly any size, and have an output that is directly related to a few variables including size, facing, and cleanliness. These variables all affect the amount of radiation that falls on the collector. Often these collector panels have automated machinery that keeps them facing the sun. The additional energy they take in due to the correction of facing more than compensates for the energy needed to drive the extra machinery.

Focusing collectors are essentially flat-plane collectors with optical devices arranged to maximize the radiation falling on the focus of the collector. These are currently used only in a few scattered areas. Solar furnaces are examples of this type of collector. Although they can produce far greater amounts of energy at a single point than the flat-plane collectors can, they lose some of the radiation that the flat-plane panels do not. Radiation reflected off the ground will be used by flat-plane panels but usually will be ignored by focusing collectors (in snow covered regions, this reflected radiation can be significant). One other problem with focusing collectors in general is due to temperature. The fragile silicon components that absorb the incoming radiation lose efficiency at high temperatures, and if they get too hot they can even be permanently damaged. The focusing collectors by their very nature can create much higher temperatures and need more safeguards to protect their silicon components. Passive collectors are completely different from the other two types of collectors. The passive collectors absorb radiation and convert it to heat naturally, without being designed and built to do so. All objects have this property to some extent, but only some objects (like walls) will be able to produce enough heat to make it worthwhile. Often their natural ability to convert radiation to heat is enhanced in some way or another (by being painted black, for example) and a system for transferring the heat to a different location is generally added. People use energy for many things, but a few general tasks consume most of the energy. These tasks include transportation, heating, cooling, and the generation of electricity. Solar energy can be applied to all four of these tasks with different levels of success.

Heating is the business for which solar energy is best suited. Solar heating requires almost no energy transformation, so it has a very high efficiency. Heat energy can be stored in a liquid, such as water, or in a packed bed. A packed bed is a container filled with small objects that can hold heat (such as stones) with air space between them. Heat energy is also often stored in phase-changer or heat-of-fusion units. These devices will utilize a chemical that changes phase from solid to liquid at a temperature that can be produced by the solar collector. The energy of the collector is used to change the chemical to its liquid phase, and is as a result stored in the chemical itself. It can be tapped later by allowing the chemical to revert to its solid form. Solar energy is frequently used in residential homes to heat water. This is an easy application, as the desired end result (hot water) is the storage facility. A hot water tank is filled with hot water during the day, and drained as needed. This application is a very simple adjustment from the normal fossil fuel water heaters.

Swimming pools are often heated by solar power. Sometimes the pool itself functions as the storage unit, and sometimes a packed bed is added to store the heat. Whether or not a packed bed is used, some method of keeping the pool's heat for longer than normal periods (like a cover) is generally employed to help keep the water at a warm temperature when it is not in use.

Solar energy is often used to directly heat a house or building. Heating a building requires much more energy than heating a building's water, so much larger panels are necessary. Generally a building that is heated by solar power will have its water heated by solar power as well. The type of storage facility most often used for such large solar heaters is the heat-of-fusion storage unit, but other kinds (such as the packed bed or hot water tank) can be used as well. This application of solar power is less common than the two mentioned above, because of the cost of the large panels and storage system required to make it work. Often if an entire building is heated by solar power, passive collectors are used in addition to one of the other two types. Passive collectors will generally be an integral part of the building itself, so buildings taking advantage of passive collectors must be created with solar heating in mind.

These passive collectors can take a few different forms. The most basic type is the incidental heat trap. The idea behind the heat trap is fairly simple. Allow the maximum amount of light possible inside through a window (The window should be facing towards the equator for this to be achieved) and allow it to fall on a floor made of stone or another heat holding material. During the day, the area will stay cool as the floor absorbs most of the heat, and at night, the area will stay warm as the stone re-emits the heat it absorbed during the day.

Another major form of passive collector is thermos phoning walls and/or roof. With this passive collector, the heat normally absorbed and wasted in the walls and roof is re-routed into the area that needs to be heated.

The last major form of passive collector is the solar pond. This is very similar to the solar heated pool described above, but the emphasis is different. With swimming pools, the desired result is a warm pool. With the solar pond, the whole purpose of the pond is to serve as an energy regulator for a building. The pond is placed either adjacent to or on the building, and it will absorb solar energy and convert it to heat during the day. This heat can be taken into the building, or if the building has more than enough heat already, heat can be dumped from the building into the pond.

Solar energy can be used for other things besides heating. It may seem strange, but one of the most common uses of solar energy today is cooling. Solar cooling is far more expensive than solar heating, so it is almost never seen in private homes. Solar energy is used to cool things by phase changing a liquid to gas through heat, and then forcing the gas into a lower pressure chamber. The temperature of a gas is related to the pressure containing it, and all other things being held equal, the same gas under a lower pressure will have a lower temperature. This cool gas will be used to absorb heat from the area of interest and then be forced into a region of higher pressure where the excess heat will be lost to the outside world. The net effect is that of a pump moving heat from one area into another, and the first is accordingly cooled.

Besides being used for heating and cooling, solar energy can be directly converted to electricity. Most of our tools are designed to be driven by electricity, so if you can create electricity through solar power, you can run almost anything with solar power. The solar collectors that convert radiation into electricity can be either flat-plane collectors or focusing collectors, and the silicon components of these collectors are photovoltaic cells.

Photovoltaic cells, by their very nature, convert radiation to electricity. This phenomenon has been known for well over half a century, but until recently the amounts of electricity generated were good for little more than measuring radiation intensity. Most of the photovoltaic cells on the market today operate at an efficiency of less than 15%[2]; that is, of all the radiation that falls upon them, less than 15% of it is converted to electricity. The maximum theoretical efficiency for a photovoltaic cell is only 32.3%[3], but at this efficiency, solar electricity is very economical. Most of our other forms of electricity generation are at a lower efficiency than this. Unfortunately, reality still lags behind theory and a 15% efficiency is not usually considered economical by most power companies, even if it is fine for toys and pocket calculators. Hope for bulk solar electricity should not be abandoned, however, for recent scientific advances have created a solar cell with an efficiency of 28.2%[4] efficiency in the laboratory. This type of cell has yet to be field tested. If it maintains its efficiency in the uncontrolled environment of the outside world, and if it does not have a tendency to break down, it will be economical for power companies to build solar power facilities after all.

Of the main types of energy usage, the least suited to solar power is transportation. While large, relatively slow vehicles like ships could power themselves with large onboard solar panels, small constantly turning vehicles like cars could not. The only possible way a car could be completely solar powered would be through the use of battery that was charged by solar power at some stationary point and then later loaded into the car. Electric cars that are partially powered by solar energy are available now, but it is unlikely that solar power will provide the world's transportation costs in the near future.

Solar power has two big advantages over fossil fuels. The first is in the fact that it is renewable; it is never going to run out. The second is its effect on the environment.

While the burning of fossil fuels introduces many harmful pollutants into the atmosphere and contributes to environmental problems like global warming and acid rain, solar energy is completely non-polluting. While many acres of land must be destroyed to feed a fossil fuel energy plant its required fuel, the only land that must be destroyed for a solar energy plant is the land that it stands on. Indeed, if a solar energy system were incorporated into every business and dwelling, no land would have to be destroyed in the name of energy. This ability to decentralize solar energy is something that fossil fuel burning cannot match.

As the primary element of construction of solar panels, silicon, is the second most common element on the planet, there is very little environmental disturbance caused by the creation of solar panels. In fact, solar energy only causes environmental disruption if it is centralized and produced on a gigantic scale. Solar power certainly can be produced on a gigantic scale, too.

Among the renewable resources, only in solar power do we find the potential for an energy source capable of supplying more energy than is used.[5]

Suppose that of the 4.5×10^{17} kWh per annum that is used by the earth to evaporate water from the oceans we were to acquire just 0.1% or 4.5×10^{14} kWh per annum. Dividing by the hours in the year gives a continuous yield of 2.90×10^{10} kW. This would supply 2.4 kW to 12.1 billion people.[6] This translates to roughly the amount of energy used today by the average American available to over twelve billion people. Since this is greater than the estimated carrying capacity of the Earth, this would be enough energy to supply the entire planet regardless of the population.

Unfortunately, at this scale, the production of solar energy would have some unpredictable negative environmental effects. If all the solar collectors were placed in one or just a few areas, they would probably have large effects on the local environment, and possibly have large effects on the world environment. Everything from changes in local rain conditions to another Ice Age has been predicted as a result of producing solar energy on this scale. The problem lies in the change of temperature and humidity near a solar panel; if the energy producing panels are kept non-centralized, they should not create the same local, mass temperature change that could have such bad effects on the environment.

Of all the energy sources available, solar has perhaps the most promise. Numerically, it is capable of producing the raw power required to satisfy the entire planet's energy needs. Environmentally, it is one of the least destructive of all the sources of energy. Practically, it can be adjusted to power nearly everything except transportation with very little adjustment, and even transportation with some modest modifications to the current general system of travel. Clearly, solar energy is a resource of the future.

A. Photovoltaic System

PV modules generate DC current and voltage. However, to feed the electricity to the grid, AC current and voltage are needed. Inverters are the equipment used to convert DC to AC. In addition, they can be in charge of keeping the operating point of the PV array at the MPP. This is usually done with computational MPP tracking algorithms. There are different inverter configurations depending on how the PV modules are connected to the inverter. The decision on what configuration should be used has to be made for each case depending on the environmental and financial requirements. If the modules are not identical or do not work under the same conditions, the MPP is different in each panel and the resulting voltage-power characteristic has multiple maxima, which constitutes a problem, because most MPPT algorithms converge to a local maximum depending on the starting point. If the operating point is not the MPP, not all the possible power is being fed to the grid. For these reasons each case has to be carefully studied to optimize the plant and obtain the maximum performance.

B. Some Important Advantages of Photovoltaic -PV- Systems:

1) Photovoltaic (PV) systems provide green, renewable power by exploiting solar energy. We can use photovoltaic (PV) panels as an alternative energy source in place of electricity generated from conventional fossil fuels. Consequently, the more we use PV panels (or other renewable energy technologies) to cover for our energy needs, the more we help reduce our impact to the environment by reducing CO2 emissions into the atmosphere.
2) Photovoltaic (PV) panels constitute a reliable, industrially matured, green technology for the exploitation of solar energy. Photovoltaic (PV) companies give valuable warranties for PV panels in terms of both PV panel life span (years of PV life) and PV panels' efficiency levels across time. PV panels can last up to 25 years or more, some with a maximum efficiency loss of 18% only, even after 20 years of operation.
3) Unlike wind turbines, Photovoltaic (PV) panels operate autonomous without any noise generation as they do not incorporate any moving mechanical parts. In some cases photovoltaic (PV) panels may be mounted on adjustable rotating basis which is mounted on a fixed pole and allows some movement for better and longer solar tuning – turning the solar panel to follow the sun. Even in this adjustable PV systems, the movements are very moderate, almost negligible, and do not generate any disturbances.
4) With respect to operating costs and maintenance costs, Photovoltaic (PV) panels, unlike other renewable energy technologies, require minimum operating or maintenance costs; just performing some regular cleaning of the panel surface is adequate to keep them operating at highest efficiency levels as stated by manufacturers' specs.
5) Photovoltaic (PV) panels can be ideal for distributed power generation as they are highly suitable for remote applications, such as in a remote farmhouse. By maintaining relatively small power generation stations in a distributed power network, we can minimize energy losses in the network that are caused by the long distance between power generation and power consumption points. By utilizing small photovoltaic PV power stations, we can achieve cost reductions on the power network from increased network efficiency and lower power losses; similarly, distributed small scale Photovoltaic (PV) stations will also lead to lower capital expenditure for the construction of power network lines.
6) One of the most important advantages of Photovoltaic (PV) systems is actually inherited by all solar energy systems in general; solar energy peak power generation usually coincides with peak energy demand (e.g. in hot summer days). Consequently, solar energy systems is one renewable energy technology that can assist in balancing and smoothing-out the energy load curve and facilitate increased penetration of renewable energy technologies within the power mix – It should be noted that successful penetration of renewable energy technologies into the energy production chain is largely dependent on our technological ability to resolve reliability issues of renewable sources such as unpredictability of environmental conditions and intermittent supply of power generation. Energy storage is the key to resolving these issues but technological progress in this field is still not able to provide effective and viable solutions.
7) Photovoltaic (PV) panels have become very popular in the past years particularly in both home energy applications (domestic level) and small-scale power generation applications. Their high popularity has been driven on one hand by the ease of installation and use and, on the other hand, by reduction in PV costs (PV investment and installation) driven by industrial maturity of PV technologies. In the recent past, prices of Photovoltaic (PV) systems have witnessed a drastic decrease bringing the total cost around $1 to $1.3 per PV watt installed (cost for complete PV deployment). This reduction in PV prices together with tremendous proliferation of PV panels applications in a range of different applications, such as solar energy for home at roof tops, PV panels at building facades or through incorporated systems for PV on window glass, small or large power generation plants, or the use of photovoltaic cells for powering specific equipment or for co-generation of power systems, etc., have placed photovoltaic PV panels high up on the list of solar energy solutions for now and for the future. Although PV prices have seen a drastic reduction, the cost of installing photovoltaic PV systems is still a considerable investment that may not be viable without financial incentives; that is why installations of PV systems are amongst green investments that are being subsidized by governments (e.g. FITs or Tax incentives) in order to make their investment economically viable.
8) Following their popularity and being a proven technology, photovoltaic (PV) panels are amongst the first solar energy solutions promoted by financial institutions (banks) through green-power financial incentives and green-projects. Financial institutions are now offering green-loans mortgaging leveraged debt on the cash flows that Photovoltaic PV systems will generate. One important example is PV applications under government subsidy schemes through feed-in-tariffs (FITS) where utility providers buy electricity produced from Photovoltaic PV panels at a fixed price (e.g. $0.25 cents per kwh) – FITs vary depending on location, and efficiency of the technology used.

C. Disadvantages of Photovoltaic (PV) Panels:

1) Perhaps the biggest disadvantage of Photovoltaic (PV) panels is their limited efficiency levels; compared to other renewable energy sources – such as solar thermal – PV systems have a relatively low efficiency level ranging between 12-

20%. Although there is continuous technological development in PV materials for improving existing systems' performances or creating new products, PV systems are still limited by the capabilities of the materials used in PV cells (thin-films PV, mono or polycrystalline cells etc.).

2) Another disadvantage of Photovoltaic PV panels is that they produce direct electric current which must be converted to alternating current (AC) before it can be used for consumption (either to be transferred to the power grid, or directly for own consumption). To convert DC to AC, PV panel systems use inverters, expensive electronic equipment and with certain technological limitations, adding to the overall system's cost especially at larger power sizes.
3) Although supply of solar energy is, usually, concurrent with peak energy demand (e.g. for cooling in hot summer days), one of Solar Photovoltaic (PV) panels' main disadvantage is that it delivers only in direct sunlight and it cannot store excess amounts of produced energy for later use. This is particularly important when energy is needed for the night when there is no sunlight or when weather conditions are fluctuating (e.g. sensitive to cloud shading) conditions under which PV efficiency is further decreased. Consequently, reduction in PV panel efficiency will result in a lower output (kwh) which greatly influences financial performance of your PV investment.
4) Last but not least, it should be noted that low voltage output or fluctuation in PV electric current may lead to increased waste of electricity since it cannot be transmitted onto the network (intermittent output).

III. WIND ENERGY

A somewhat hilarious misconception that some people may have is that the only place that wind power is utilized is in Holland, where windmills have existed for centuries. It is almost as silly that most books about wind power do not recognize that wind power has been arguably the most important energy form man has ever used. When discussing wind power, it is necessary to specify what kind of wind power is meant. As the fuel for transportation, fishers or other people using boats have used the power of the wind. The United States could truthfully say that without the power of the wind, Columbus and other European explorers might not have found the Western world. A more exact presentation of the history of wind power is discussed at another page devoted to showing the changes in utilization of wind power over time. The power of the wind is everywhere, and is found in most abundance in some areas of the world that are not extremely accessible to humans. As a general rule, as the elevation is increased, the wind speed will also increase. Suppose a person decided to climb to the of a two story building. Standing on top of the building, he can feel the great increase of wind speed compared to being on the ground. Wind power stations are often found in the same place as large radio station antennae. Just as the high elevation helps the radio signals to travel farther, the increase heigh above sea level increases the wind speed and helps the station to produce more power. These tidbits of wind power geography are expanded at the wind power geography page.

Wind Power as an electricity provider is popular in many places across the world. One of the reasons that wind power is implemented across the world is the simplicity of the physical science processes that make the conversion from mechanical energy to electricity. The work of the wind moves the blades of the turbine, and the kinetic energy of the wind is converted to kinetic energy in the blades. By manipulating some basic physics equations, the energy transfered can be found. Wind power physics tackles the science of wind machines.

One characteristic of most alternative energy forms (excluding nuclear power), is the application for use in a home setting. Wind Power is often used on farms and housing in rural areas where there are fewer visual housing restrictions, and uses for wind powered devices. Many ancient civilizations used wind power for grain processing or irrigation, and these routines are still in high demand today. It is interesting to compare an industrial size wind power station and a home implementation of wind power because of the number of similarities. Often the new technologies of industrial strength wind power machines are passed directly onto smaller systems. A page complete with diagrams of wind power systems, both on the industrial level, and the home level are given. After learning about where the best places are for a wind power station, you can go to some of the different sites for wind power all over the world. This site offers a limited collection of links to english web sites in different countries that utilize wind power.

A. Wind Turbines

Clearly, wind energy is high on the governmental and institutional agenda. However, there are some stumbling blocks in the way of its widespread. Wind turbines come with different topologies, architectures and design features. Some options wind turbine topologies are as follows,

- Rotor axis orientation: horizontal or vertical;
- Rotor position: upwind or downwind of tower;
- Rotor speed: fixed or variable;
- Hub: rigid, teetering, gimbaled or hinged blades;
- Rigidity: still or flexible;

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- Number of blades: one, two, three or even more;
- Power control: stall, pitch, yaw or aerodynamic surfaces;
- Yaw control: active or free.

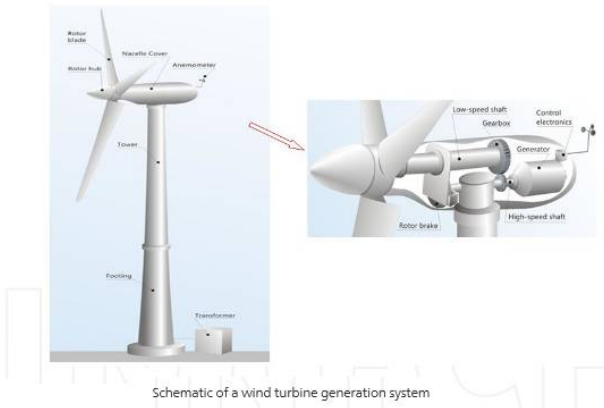


Fig 2: Schematic of a wind turbine system

Wind turbines include critical mechanical components such as turbine blades and rotors, drive train and generators. They cost more than 30% of total capital expenditure for offshore wind project. In general, wind turbines are intended for relatively inaccessible sites placing some constraints on the designs in a number of ways. For offshore environments, the site may be realistically accessed for maintenance once per year. As a result, fault tolerance of the wind turbine is of importance for wind farm development.

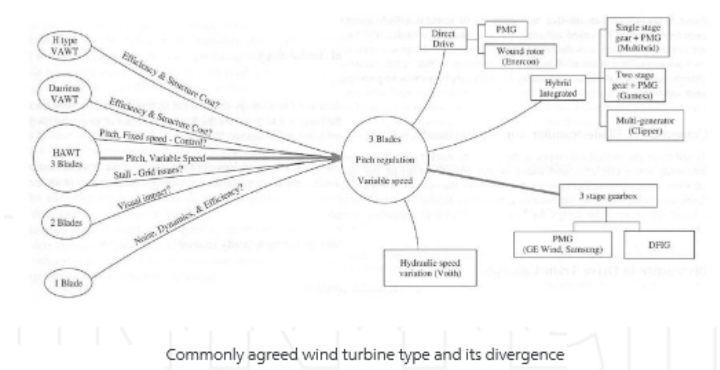


Fig 3: Commonly agreed wind turbine and its divergence

One of key components in the wind turbine is its drive train, which links aerodynamic rotor and electrical output terminals. Optimization of wind turbine generators can not be realized without considering mechanical, structural, hydraulic and magnetic performance of the drive train. An overview of the drive train technologies is illustrated for comparison. Generally, they can be broken down into four types according to their structures:

• **Conventional:** gearbox and high speed generator with few pole pairs.

• **Direct drive:** any drive train without a gearbox and low speed generator with many pole pairs.

• **Hybrid:** any drive train with a gearbox and the generator speed between the above two types.

• **Multiple generators:** any drive train with more than one generator.

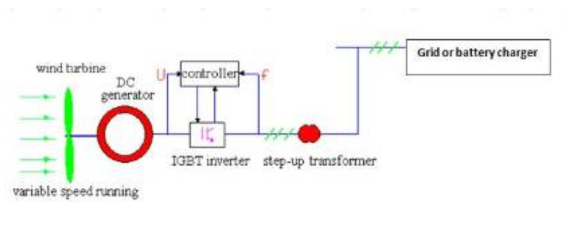
Drive train topologies may raise the issues such as the integration of the rotor and gearbox/ bearings, the isolation of gear and generator shafts from mechanical bending loads, the integrity and load paths. Although it may be easier to service separate wind turbine components such as gearboxes, bearings and generators, the industry is increasingly in favor of system design of the integrated drive train components.

B. Wind Turbine Generators

One of limiting factors in wind turbines lies in their generator technology. There is no consensus among academics and industry on the best wind turbine generator technology. Traditionally, there are three main types of wind turbine generators (WTGs) which can be considered for the various wind turbine systems, these being direct current (DC), alternating current (AC) synchronous and AC asynchronous generators. In principle, each can be run at fixed or variable speed. Due to the fluctuating nature of wind power, it is advantageous to operate the WTG at variable speed which reduces the physical stress on the turbine blades and drive train, and which improves system aerodynamic efficiency and torque transient behaviors.

C. DC Generator Technologies

In conventional DC machines, the field is on the stator and the armature is on the rotor. The stator comprises a number of poles which are excited either by permanent magnets or by DC field windings. If the machine is electrically excited, it tends to follow the shunt wound DC generator concept.



Schematic of a DC generator system

Fig 4: Schematic of a DC generator system

It consists of a wind turbine, a DC generator, an insulated gate bipolar transistor (IGBT) inverter, a controller, a transformer and a power grid. For shunt wound DC generators, the field current (and thus magnetic field) increases with operational speed whilst the actual speed of the wind turbine is determined by the balance between the WT drive torque and the load torque. The rotor includes conductors wound on an armature which are connected to a split-slip ring commentator. Electrical power is extracted through brushes connecting the commentator which is used to rectify the generated AC power into DC output. Clearly, they require regular maintenance and are relatively costly due to the use of commutators and brushes. In general, these DC WTGs are unusual in wind turbine applications except in low power demand situations where the load is physically close to the wind turbine, in heating applications or in battery charging.

D. AC Synchronous Generator Technologies

Since the early time of developing wind turbines, considerable efforts have been made to utilize three-phase synchronous machines. AC synchronous WTGs can take constant or DC excitations from either permanent magnets or electromagnets and are thus termed PM synchronous generators (PMSGs) and electrically excited synchronous generators (EESGs), respectively. When the rotor is driven by the wind turbine, a three-phase power is generated in the stator windings which are connected to the grid through transformers and power converters. For fixed speed synchronous generators, the rotor speed must be kept at exactly the synchronous speed. Otherwise synchronism will be lost. Synchronous generators are a proven machine technology since their performance for power generation has been studied and widely accepted for a long time.

In theory, the reactive power characteristics of synchronous WTGs can be easily controlled via the field circuit for electrical excitation. Nevertheless, when using fixed speed synchronous generators, random wind speed fluctuations and periodic disturbances caused by tower-shading effects and natural resonances of components would be passed onto the power grid. Furthermore, synchronous WTGs tend to have low damping effect so that they do not allow drive train transients to be absorbed electrically. As a consequence, they require an additional damping element (e.g. flexible coupling in the drive train), or the gearbox assembly mounted on springs and dampers. When they are integrated into the power grid, synchronizing their frequency to that of the grid calls for a delicate operation. In addition, they are generally more complex, costly and more prone to failure than induction generators. In the case of using electromagnets in synchronous machines, voltage control takes place in the synchronous machine while in permanent magnet excited machines, voltage control is achieved in the converter circuit.

E. AC Asynchronous Generators

Whilst conventional power generation utilizes synchronous machines, modern wind power systems use induction machines extensively in wind turbine applications. These induction generators fall into two types: fixed speed induction generators (FSIGs) with squirrel cage rotors (sometimes called squirrel cage induction generators-SQIGs) and doubly fed induction generators (DFIGs) with wound rotors. Cutaway diagrams of a squirrel-cage induction generator and a doubly-fed induction generator are presented and their system topologies are further illustrated.

When supplied with three-phase AC power to the stator, a rotating magnetic field is established across the air gap. If the rotor rotates at a speed different to synchronous speed, a slip is created and the rotor circuit is energized. Generally speaking, induction machines are simple, reliable, inexpensive and well developed. They have high degree of damping and are capable of absorbing rotor speed fluctuations and drive train transients (i.e. fault tolerant). However, induction machines draw reactive power from the grid and thus some form of reactive power compensation is needed such as the use of capacitors or power converters. For fixed-speed induction generators, the stator is connected to the grid via a transformer and the rotor is connected to the wind turbine through a gearbox. The rotor speed is considered to be fixed (in fact, varying within a narrow range).

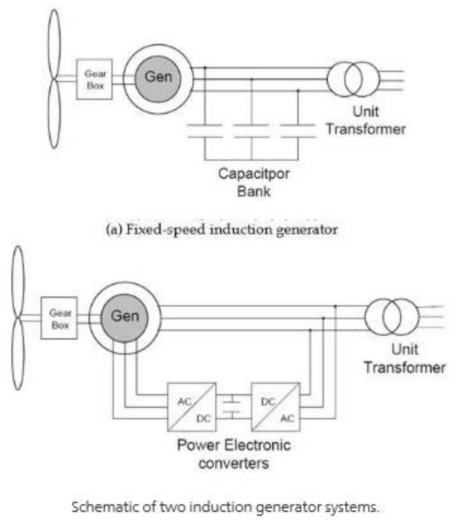


Fig 5: Schematic of two induction generator system

The rotor of the DFIG is mechanically connected to the wind turbine through a drive train system, which may contain high and low speed shafts, bearings and a gearbox. The rotor is fed by the bi-directional voltage-source converters. Thereby, the speed and torque of the DFIG can be regulated by controlling the rotor side converter (RSC). Another feature is that DFIGs can operate both sub-synchronous and super-synchronous conditions. The stator always transfers power to the grid while the rotor can handle power in both directions. The latter is due to the fact that the PWM converters are capable of supplying voltage and current at different phase angles. In sub-synchronous operation, the rotor side converter acts as an inverter and the grid-side converter (GSC) as a rectifier. In this case, active power is flowing from the grid to the rotor. Under super-synchronous condition, the RSC operates as a rectifier and the GSC as an inverter. Consequently, active power is flowing from the stator as well as the rotor to the power grid.

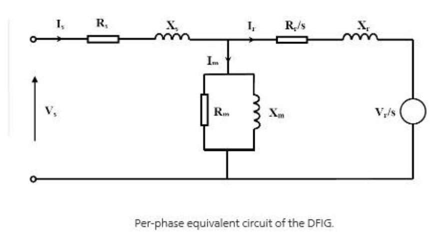


Fig 6: Per phase equivalent cicuit of DFIG

To analyze the DFIG’s performance, it always needs to adopt its per-phase equivalent circuit. From this figure, it can be seen that the DFIG differs from the conventional induction machine in the rotor circuit where a voltage source is added to inject voltage into the rotor circuit. The actual d-q control of the DFIG is similar to the magnitude and phase control of the injected voltage in the circuit. The matrix form of the equation for this circuit is,

$$\begin{bmatrix} V_s \\ V_r / s \end{bmatrix} = \begin{bmatrix} R_s + j(X_s + X_m) & -jX_m \\ -jX_m & R_r / s + j(X_r + X_m) \end{bmatrix} \begin{bmatrix} I_s \\ I_r \end{bmatrix}$$

The input power Pin can be summarized from the output power Pout and the total loss Ploss. The latter includes stator conductor loss Pcu1, rotor conductor loss Pcu2, core loss Pcore, wind-age and friction losses Pwf and stray load loss Pstray. Among these losses, Pcu1is assumed tovary with the square of the stator current Is while Pcu2 varies with the square of the rotor current Ir. The stray load loss could be split into two parts: the fundamental component Pfun occurring at the stator side and Phar at the rotor side. Thus Pfun is proportional to Is2 while Phar is proportional to Ir2. The total loss is then given by,

$$P_{loss} = 3I_s^{\ 2}(R_s + R_{fun}) + 3I_r^{\ 2}(R_r' + R_{har}) + P_{core} + P_{wf}$$

The efficiency of the DFIG is

$$\eta = \frac{P_{out}}{P_{in}} = \frac{3V_{out}\cos\varphi_r}{6I_s(R_s + R_{fun} + R_r' + R_{har}) + 3V_{out}\cos\varphi_r}$$

The efficiency can be expressed as a function of the load current Is and this function is continuous and monotonic. Consequently, the maximum efficiency can be found when,

$$\frac{\partial \eta}{\partial I_s} = 0$$

That is, the condition of maximum efficiency for DFIGs is,

$$P_{core} + P_{wf} = P_{cu1} + P_{cu2} + P_{stray}$$

In order to optimize the DFIG machine design, its losses and efficiency need to derive numerically or experimentally. An additional refinement parameter is the machine's operational point. The condition of the maximum efficiency occurrence indicates: when the load dependent losses equalise the load-invariant losses, the machine efficiency peaks. In the design and operation of DFIGs, it is beneficial to match the generator's characteristics with the site-specific wind speed by moving this maximum efficiency point close to the rated or operational load. For control purposes, the DFIG mathematical model is based on the synchronous reference frame as follows,

$$\begin{cases} v_{sd} = r_s i_{sd} + \dfrac{d\psi_{sd}}{dt} - \omega_s \psi_{sq} \\ v_{sq} = r_s i_{sq} + \dfrac{d\psi_{sq}}{dt} + \omega_s \psi_{sd} \end{cases}$$

$$\begin{cases} v_{rd} = r_r i_{rd} + \dfrac{d\psi_{rd}}{dt} - (\omega_s - \omega_r)\psi_{rq} \\ v_{rq} = r_r i_{rq} + \dfrac{d\psi_{rq}}{dt} + (\omega_s - \omega_r)\psi_{rd} \end{cases}$$

$$\begin{cases} \psi_{sd} = (L_{ls} + L_m) i_{sd} + L_m i_{rd} \\ \psi_{sq} = (L_{ls} + L_m) i_{sq} + L_m i_{rq} \end{cases}$$

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$$\begin{cases} \psi_{rd} = (L_{lr} + L_m) i_{rd} + L_m i_{sd} \\ \psi_{rq} = (L_{lr} + L_m) i_{rq} + L_m i_{sq} \end{cases}$$

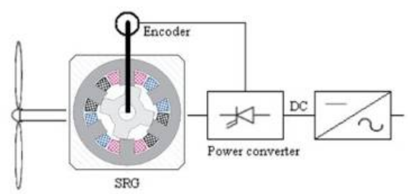
Where rs and rr are the stator and rotor resistances in Ω, Lls and Llr are the stator and rotor leakage inductances in H, Lm is the magnetizing inductance in H. ωs is the synchronous electrical speed in rad/sec. ωr is the rotor electrical speed of the DFIG and its relation with rotor mechanical speed ωg is ωr = Pωg, where P is pole pairs.The electromagnetic torque is given by,

$$T_e = \frac{3}{2} P L_m (i_{sq} i_{rd} - i_{sd} i_{rq})$$

In DFIGs, active power is used to evaluate the power output and reactive power is responsible for its electrical behavior in the power network. The DFIG requires some amounts of reactive power to establish its magnetic field. In case of grid-connected systems, the generator obtains the reactive power from the grid itself. In case of isolated system operation, the reactive power needs to be provided by external sources such as capacitors or batteries.

F. Switched Reluctance Generator Technologies

Switched reluctance WTGs are characterized with salient rotors and stator. As the rotor rotates, the reluctance of the magnetic circuit linking the stator and rotor changes, and in turn, induces currents in the winding on the armature (stator).



Schematic of a switched reluctance generator system

Fig 7: Schematic of switched reluctance generator system

The reluctance rotor is constructed from laminated steel sheets and has no electrical field windings or permanent magnets. As a result, the reluctance machine is simple, easy to manufacture and assembly. An obvious feature is their high reliability because they can work in harsh or high-temperature environments. Because the reluctance torque is only a fraction of electrical torque, the rotor of switched reluctance is generally large than other with electrical excitations for a given rated torque. If reluctance machines are combined with direct drive features, the machine would be extremely large and heavy, making them less favorable in wind power applications.

G. Design Considerations and Challenges

Generally speaking, wind turbine generators can be selected from commercially available electrical machines with or without minor modifications. If a wind turbine design is required to match a specific site, some key issues should be taken into account. These include:

- Choice of machines
- Type of drive train
- Brush topology
- Rated and operating speeds
- Rated and operating torques
- Tip speed ratio
- Power and current
- Voltage regulation (synchronous generators)
- Methods of starting
- Starting current (induction generators)
- Synchronizing (synchronous generators)

- Cooling arrangement
- Power factor and reactive power compensation (induction generators)
- Power converter topology
- Weight and size
- Protection (off shore environment)
- Capital cost and maintenance.

IV. DC TO DC CONVERTER

In electronics engineering, a DC to DC converter is a circuit which converts a source of direct current from one voltage to another. It is a class of power converter. DC to DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries. Such electronic devices often contain several sub-circuits with each sub-circuit requiring a unique voltage level different than that supplied by the battery (sometimes higher or lower than the battery voltage, and possibly even negative voltage). Additionally, the battery voltage declines as its stored power is drained. DC to DC converters offer a method of generating multiple controlled voltages from a single variable battery voltage, thereby saving space instead of using multiple batteries to supply different parts of the device.

A. Conversion Methods

Linear

A simple method of converting one voltage to another is a circuit known as a voltage divider. This technique uses resistors in series with the voltage supply to provide a lower voltage. However, this method suffers serious drawbacks:

- Provides no voltage regulation
- Requires knowledge of the resistance of the load
- Poor efficiency, which also leads to excess heat dissipation
- Impossible to generate voltages higher than the supply voltage
- Impossible to generate negative voltages, unless the system ground is defined by a node in the resistor network.

Any kind of voltage regulator solves the first two problems, however, linear regulators still have the last three problems.

B. Switched-Mode Conversion

Electronic switch-mode DC to DC converters are available to convert one DC voltage level to another. These circuits, very similar to a switched-mode power supply, generally perform the conversion by applying a DC voltage across an inductor or transformer for a period of time (usually in the 100 kHz to 5 MHz range) which causes current to flow through it and store energy magnetically, then switching this voltage off and causing the stored energy to be transferred to the voltage output in a controlled manner. By adjusting the ratio of on/off time, the output voltage can be regulated even as the current demand changes. This conversion method is more power efficient (often 80% to 95%) than linear voltage conversion which must dissipate unwanted power. This efficiency is beneficial to increasing the running time of battery operated devices. A drawback to switching converters is the electronic noise they generate at high frequencies, which must sometimes be filtered.

Isolated DC-DC converters convert a DC input power source to a DC output power while maintaining isolation between the input and the output, generally allowing differences in the input-output ground potentials in the range of hundreds or thousands of volts. They can be an exception to the definition of DC-DC converters in that their output voltage is often (but not always) the same as the input voltage.

A current-output DC-DC converter accepts a DC power input, and produces as its output a constant current, while the output voltage depends on the impedance of the load. The various topologies of the DC to DC converter can generate voltages higher, lower, higher and lower or negative of the input voltage; their names are:

- Buck
- Boost
- Buck-boost
- Ćuk

In general, the term "DC to DC converter" almost always refers to one of these switching converters. Switching DC to DC converters are available in a wide variety of input and fixed or adjustable output voltages. DC to DC converters are now available as integrated circuits needing minimal extra components to build a complete converter. DC to DC converters are also available as complete hybrid circuits, ready for use within an electronic device.

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C. DC-DC Converter Basics

A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc. This is a summary of some of the popular DC-to-DC converter topologies.

D. Buck Converter Step-Down Converter

In this circuit the transistor turning ON will put voltage Vin on one end of the inductor. This voltage will tend to cause the inductor current to rise. When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode. We initially assume that the current through the inductor does not reach zero, thus the voltage at Vx will now be only the voltage across the conducting diode during the full OFF time. The average voltage at Vx will depend on the average ON time of the transistor provided the inductor current is continuous

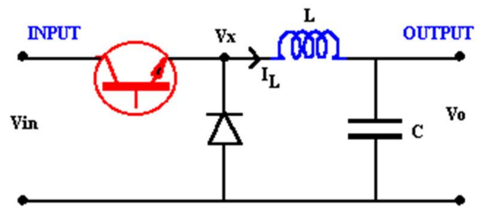


Fig 8:Buck Converter

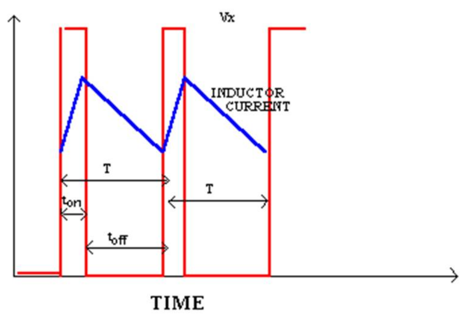


Fig 9: Voltage and Current Changes in Buck Converter

To analyse the voltages of this circuit let us consider the changes in the inductor current over one cycle. From the relation

$$V_x - V_o = L\frac{di}{dt}$$

the change of current satisfies

$$di = \int_{ON}(V_x - V_o)dt + \int_{OFF}(V_x - V_o)dt$$

For steady state operation the current at the start and end of a period T will not change. To get a simple relation between voltages we assume no voltage drop across transistor or diode while ON and a perfect switch change. Thus during the ON time $V_x = V_{in}$ and in the OFF $V_x = 0$. Thus

$$0 = di = \int_0^{t_{on}}(Vin - Vo)dt + \int_{t_{on}}^{t_{on}+t_{off}}(-Vo)dt$$

which simplifies to

$$(Vin - Vo)t_{on} - Vo\, t_{off} = 0$$

or

$$\frac{Vo}{Vin} = \frac{t_{on}}{T}$$

and defining "duty ratio" as $D = \frac{t_{on}}{T}$ the voltage relationship becomes Vo=D Vin Since the circuit is lossless and the input and output powers must match on the average $V_o * I_o = V_{in} * I_{in}$. Thus the average input and output current must satisfy $I_{in} = D\ I_o$ These relations are based on the assumption that the inductor current does not reach zero.

1) *Transition between Continuous and Discontinuous:* When the current in the inductor L remains always positive then either the transistor T1 or the diode D1 must be conducting. For continuous conduction the voltage V_x is either V_{in} or 0. If the inductor current ever goes to zero then the output voltage will not be forced to either of these conditions. At this transition point the current just reaches zero as seen in Figure 3. During the ON time V_{in}-V_{out} is across the inductor thus

$$I_L(peak) = (Vin - Vout) \cdot \frac{t_{on}}{L}$$

The average current which must match the output current satisfies

$$I_L(average\ at\ transition) = \frac{I_L(peak)}{2} = (Vin - Vout)\frac{dT}{2L} = Iout(transition)$$

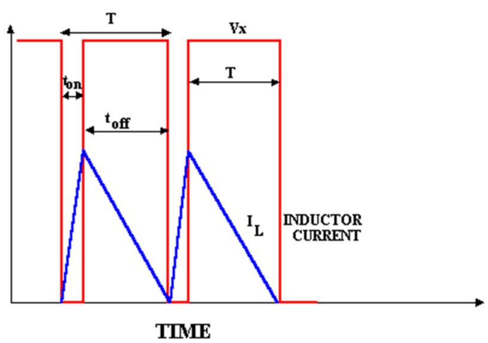


Fig 10: Waveforms of Buck Converter at Boundary

If the input voltage is constant the output current at the transition point satisfies

$$Iout(transition) = Vin\frac{(1-d)d}{2L}T$$

2) *Voltage Ratio of Buck Converter (Discontinuous Mode):*

As for the continuous conduction analysis we use the fact that the integral of voltage across the inductor is zero over a cycle of switching T. The transistor OFF time is now divided into segments of diode conduction d_dT and zero conduction d_oT. The inductor average voltage thus gives

$$(V_{in} - V_o)\ DT + (-V_o)\ \square_d T = 0$$

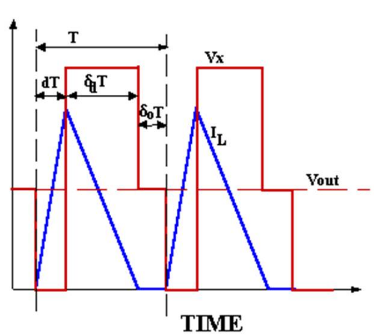


Fig 11: Buck Converter - Discontinuous Conduction

$$\therefore \frac{Vout}{Vin} = \frac{d}{d + \delta_d}$$

for the case $d + \delta_d < 1$. To resolve the value of δ_d consider the output current which is half the peak when averaged over the conduction times $d + \delta_d$

$$Iout = \frac{I_L(peak)}{2} d + \delta_d$$

Considering the change of current during the diode conduction time

$$I_L(peak) = \frac{V_0(\delta_d T)}{L}$$

Thus from (6) and (7) we can get

$$I_{out} = \frac{V_0 \delta_d T \cdot (d + \delta_d)}{2L}$$

using the relationship in (5)

$$Iout = \frac{Vin\, d\, \delta_d T}{2L}$$

and solving for the diode conduction

$$\delta_d = \frac{2L\, Iout}{Vin\, d\, T}$$

The output voltage is thus given as

$$\frac{Vout}{Vin} = \frac{d^2}{d^2 + (\frac{2L\, Iout}{Vin\, T})}$$

defining k* = 2L/(V_{in} T), we can see the effect of discontinuous current on the voltage ratio of the converter.

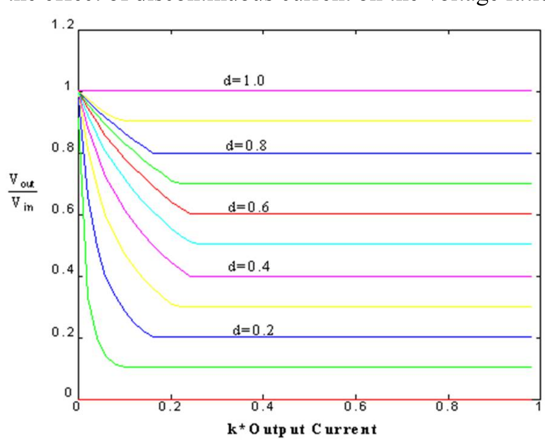


Fig 12: K^+ output current

3) Output Voltage vs Current:

As seen in the figure, once the output current is high enough, the voltage ratio depends only on the duty ratio "d". At low currents the discontinuous operation tends to increase the output voltage of the converter towards V_{in}.

E. Boost Converter Step-Up Converter

The schematic in Fig. 6 shows the basic boost converter. This circuit is used when a higher output voltage than input is required.

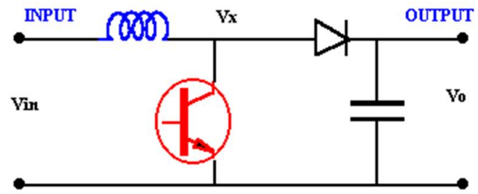


Fig 13: Boost Converter Circuit

While the transistor is ON $V_x = V_{in}$, and the OFF state the inductor current flows through the diode giving $V_x = V_o$. For this analysis it is assumed that the inductor current always remains flowing (continuous conduction). The voltage across the inductor and the average must be zero for the average current to remain in steady state

$$Vin\, t_{on} + (Vin - Vo)t_{off} = 0$$

This can be rearranged as

$$\frac{Vo}{Vin} = \frac{T}{t_{off}} = \frac{1}{(1-D)}$$

and for a lossless circuit the power balance ensures

$$\frac{Io}{Iin} = (1-D)$$

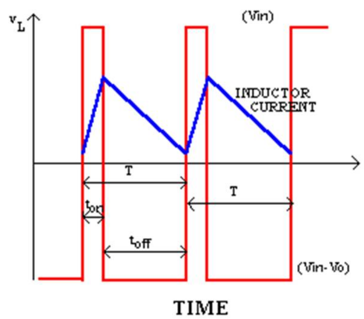
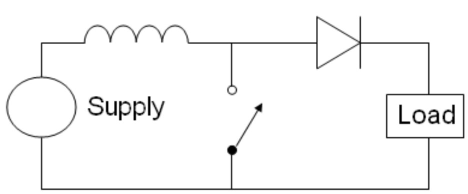


Fig 14: Voltage and current waveforms (Boost Converter)

Since the duty ratio "D" is between 0 and 1 the output voltage must always be higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.



F. Overview

Power can also come from DC sources such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Since power (P = VI) must be conserved, the output current is lower than the source current.

A boost converter may also be referred to as a 'Joule thief'. This term is usually used only with very low power battery applications, and is aimed at the ability of a boost converter to 'steal' the remaining energy in a battery. This energy would otherwise be wasted since a normal load wouldn't be able to handle the battery's low voltage.

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G. History

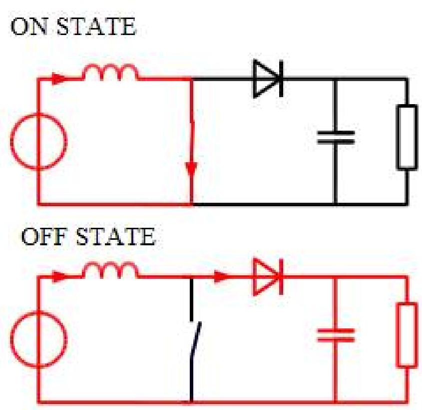
For high efficiency, the SMPS switch must turn on and off quickly and have low losses. The advent of a commercial semiconductor switch in the 1950's represented a major milestone that made SMPSs such as the boost converter possible. Semiconductor switches turned on and off more quickly and lasted longer than other switches such as vacuum tubes and electromechanical relays. The major DC to DC converters were developed in the early 1960s when semiconductor switches had become available. The aerospace industry's need for small, lightweight, and efficient power converters led to the converter's rapid development.

Switched systems such as SMPS are a challenge to design since its model depends on whether a switch is opened or closed. R.D. Middlebrook from Caltech in 1977 published the models for DC to DC converters used today. Middlebrook averaged the circuit configurations for each switch state in a technique called state-space averaging. This simplification reduced two systems into one. The new model led to insightful design equations which helped SMPS growth.

H. Applications

Battery powered systems often stack cells in series to achieve higher voltage. However, sufficient stacking of cells is not possible in many high voltage applications due to lack of space. Boost converters can increase the voltage and reduce the number of cells. Two battery-powered applications that use boost converters are hybrid electric vehicles (HEV) and lighting systems.

The Toyota Prius HEV uses a 500 V motor. Without a boost converter, the Prius would need nearly 417 cells to power the motor. However, a Prius actually uses only 168 cells and boosts the battery voltage from 202 V to 500 V. Boost converters also power devices at smaller scale applications, such as portable lighting systems. A white LED typically requires 3.3 V to emit light, and a boost converter can step up the voltage from a single 1.5 V alkaline cell to power the lamp. Boost converters can also produce higher voltages to operate cold cathode fluorescent tubes (CCFL) in devices such as LCDbacklights and some flashlights.



I. Operating principle

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged it acts as a load and absorbs energy (somewhat like a resistor), when being discharged, it acts as an energy source (somewhat like a battery). The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages.

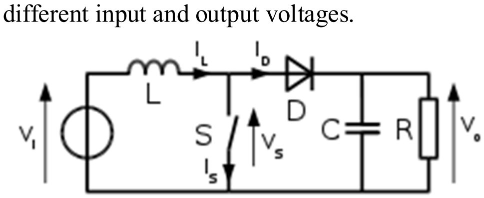


Fig 15: Boost converter schematic

The two configurations of a boost converter, depending on the state of the switch S.

The basic principle of a Boost converter consists of 2 distinct states (see figure 2):

- In the On-state, the switch S (see figure 1) is closed, resulting in an increase in the inductor current;

- In the Off-state, the switch is open and the only path offered to inductor current is through the flyback diode D, the capacitor C and the load R. This results in transferring the energy accumulated during the On-state into the capacitor.
- The input current is the same as the inductor current as can be seen in figure 2. So it is not discontinuous as in the buck converter and the requirements on the input filter are relaxed compared to a buck converter.

J. Continuous Mode

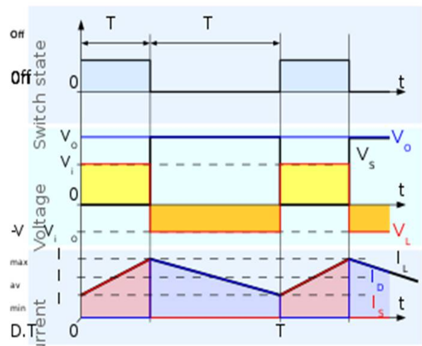


Fig 16:Waveforms of current and voltage in a boost converter operating in continuous mode.

When a boost converter operates in continuous mode, the current through the inductor (I_L) never falls to zero. Figure 3 shows the typical waveforms of currents and voltages in a converter operating in this mode. The output voltage can be calculated as follows, in the case of an ideal converter (i.e. using components with an ideal behaviour) operating in steady conditions:
During the On-state, the switch S is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current (I_L) flowing through the inductor during a time period (t) by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L}$$

At the end of the On-state, the increase of I_L is therefore:

$$\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is On. Therefore D ranges between 0 (S is never on) and 1 (S is always on).
During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of I_L is:

$$V_i - V_o = L\frac{dI_L}{dt}$$

$$\Delta I_{L_{Off}} = \int_0^{(1-D)T} \frac{(V_i - V_o)\, dt}{L} = \frac{(V_i - V_o)(1-D)T}{L}$$

Therefore, the variation of I_L during the Off-period is:
As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by:

$$E = \frac{1}{2} L I_L^2$$

So, the inductor current has to be the same at the start and end of the commutation cycle. This means the overall change in the current (the sum of the changes) is zero: This can be written as:

$$\frac{V_o}{V_i} = \frac{1}{1-D}$$

Which in turns reveals the duty cycle to be:

$$D = 1 - \frac{V_i}{V_o}$$

From the above expression it can be seen that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a step-up converter.

K. Discontinuous Mode

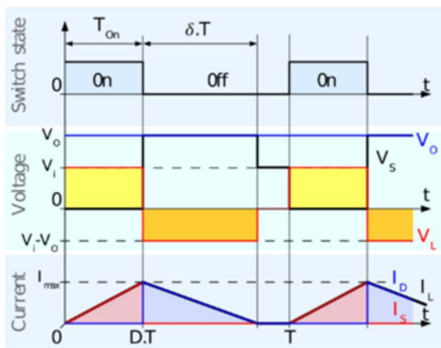


Fig 17: Output Waveforms of Boost converter

Waveforms of current and voltage in a boost converter operating in discontinuous mode.

In some cases, the amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle (see waveforms in figure 4). Although slight, the difference has a strong effect on the output voltage equation. It can be calculated as follows:

As the inductor current at the beginning of the cycle is zero, its maximum value (at t = DT) is

$$I_{L_{Max}} = \frac{V_i DT}{L}$$

During the off-period, I_L falls to zero after δT:

$$I_{L_{Max}} + \frac{(V_i - V_o)\,\delta T}{L} = 0$$

Using the two previous equations, δ is:

$$\delta = \frac{V_i D}{V_o - V_i}$$

The load current I_o is equal to the average diode current (I_D). As can be seen on figure 4, the diode current is equal to the inductor current during the off-state. Therefore the output current can be written as:

$$I_o = \bar{I_D} = \frac{I_{L_{max}}}{2}\delta$$

Replacing I_{Lmax} and δ by their respective expressions yields:

$$I_o = \frac{V_i DT}{2L} \cdot \frac{V_i D}{V_o - V_i} = \frac{V_i^2 D^2 T}{2L\left(V_o - V_i\right)}$$

Therefore, the output voltage gain can be written as flow:

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2LI_o}$$

Compared to the expression of the output voltage for the continuous mode, this expression is much more complicated. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current

V. SIMULATION RESULTS

A. Simulation Diagram

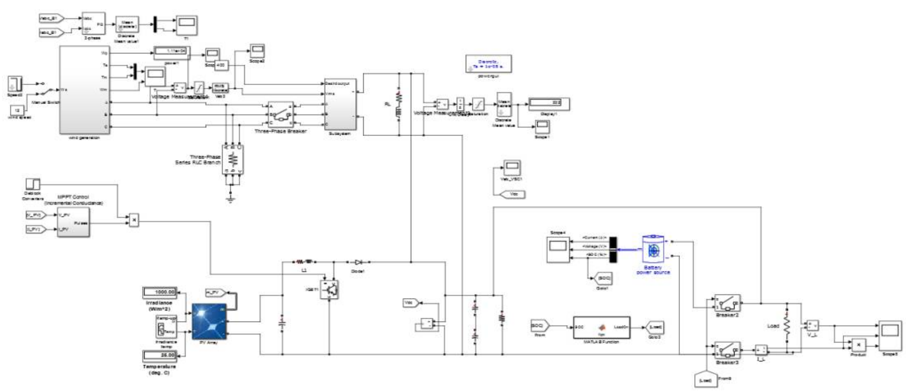


Fig 18: Simulation Diagram

B. Wind Energy

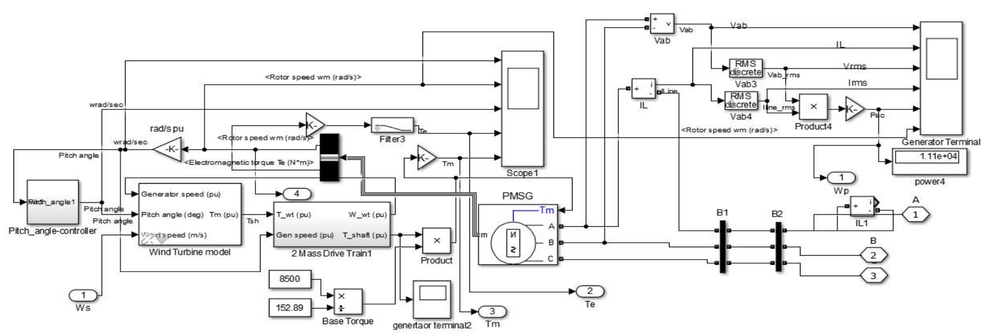


Fig 19: Wind energy simulation diagram

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C. Maximum Power Point Tracking

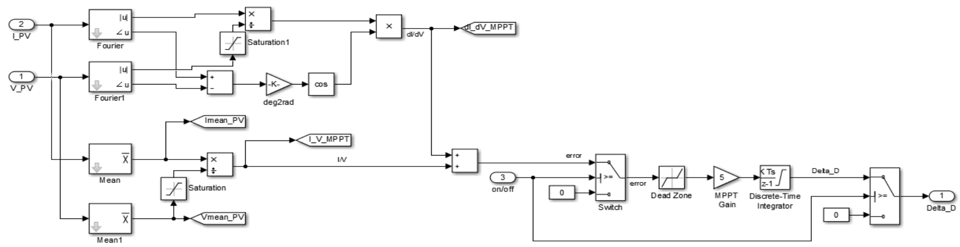

Fig 20: Maximum power point tracking simulation diagram

D. Wind Output Voltage

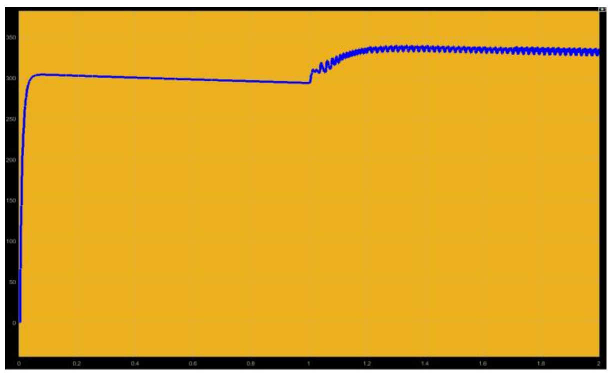

Fig 21: Wind output voltage

E. Solar Output Voltage

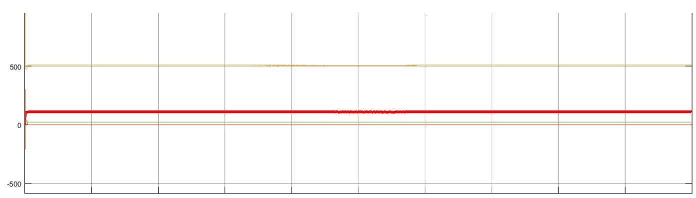

Fig 22: Solar output voltage

F. Solar Boost Converter Voltage

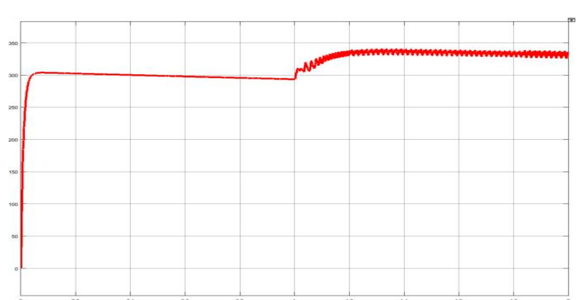

Fig 23: Solar boost converter voltage

G. Battery Voltage , Current and State of Charge

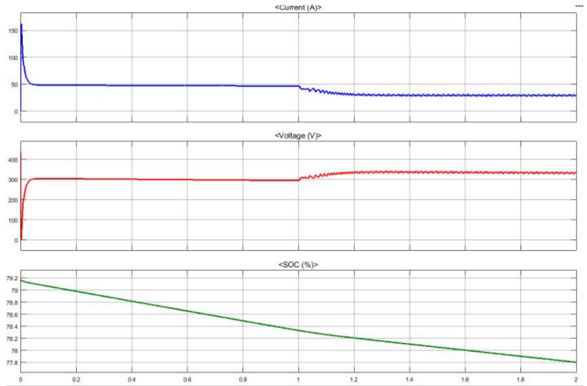

Fig 24: Battery volatage, current and state of charge

H. Output voltage

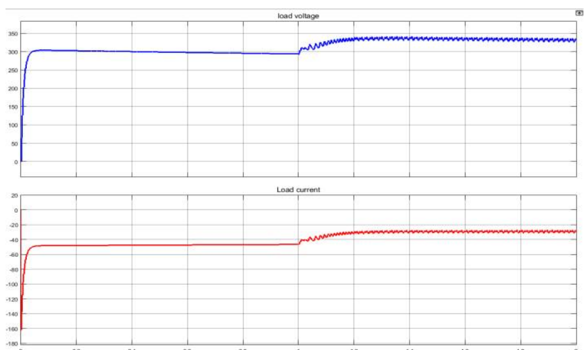

Fig 25: Output voltage

VI. CONCLUSION

This project deals the DEM by MAS in the railway microgrid with HSS based on HPGS to meet the limitations of rail transportation systems in terms of energy saving. The HPGS consists of a multi-source system with decentralized energy sources with different capacities and a different generation, therefore, judicious use and integration of each element were respected. Reducing the subscribed power, eliminating the voltage drop in the line due to the acceleration and leading to the subscribed power exceeding and avoiding the voltage rise due to the deceleration by consuming the total of the regenerative energy not recovered by the other trains in the line, remain the main issues that should be taking into account while hybridizing the substation without modifying the existing architecture It was shown the ability of the proposed control to reduce the subscribed power and to omit the subscribed power overrun by the RES generation and the storage system which is represented by the battery. penalty costs related to the subscribed power exceeding and the RES intermittence and also to the acceleration and deceleration were suppressed, thanks to the simultaneous control of the battery with the generation of the RES.

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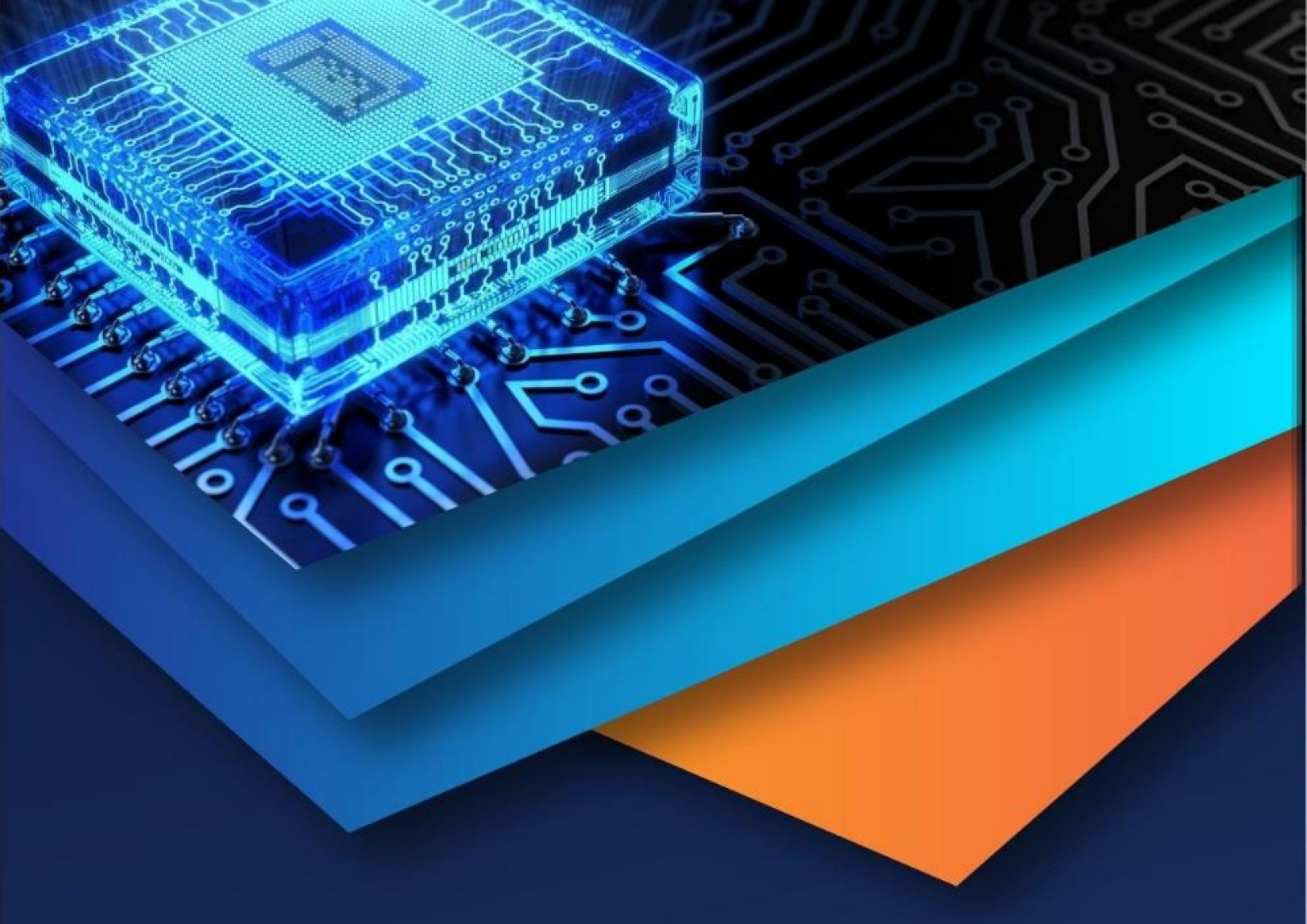

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