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Review Article

On-Grid Solar Traction System

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Abstract

World Railways is making significant progress in introducing high-speed trains to fulfil the increasing demands of the traveling public. Massive energy is needed for electric railroads. Many railroads operate their specialized power plants. An energy-storage grid-tied photovoltaic solar plant has been proposed as a strategy to boost the capacity of the rail network grid connection and enable the railway to become self-sufficient. To use the ballast-less rails as energy transporters, The current plan calls for installing solar panels along an HS train network. Ballast-free tracks require very little upkeep, and the space between them provides plenty of surface area for the installation of PV module arrays to harvest solar energy. This generated energy will feed into the main power line by using the concept of an on-grid solar system this energy is not more in numbers to drive the entire traction system, but it helps a lot. From this project we have developed hybrid parallel power sharing for the railway network, under this project the current will be shared in the main power line by matching the grid frequency and voltages. The primary power is solar when it can generate enough electricity. Still, in an abnormal condition, like in the absence of sunlight, the main power continuously feeds electricity without disturbing the traction system.

Keywords: World Railways, high-speed trains, electric railroads, electricity, solar plant.

INTRODUCTION

The "ON-GRID SOLAR TRACTION SYSTEM" Combines Solar Energy and Electric Energy. The project aims to power a locomotive using solar energy while having a backup overhead line supply. During the availability of Sunlight (Solar) Energy, we can drive the locomotive with the help of a standby overhead line supply in the daytime we can also use the standby overhead supply. Another purpose of this project is to save energy using the "ON-GRID SOLAR TRECTION SYSTEM" It is also used for another purpose by the Ministry of Railway. Because of this project ministry of Railways can reduce their loss of money for generating energy to run the system. The term for a train engine, "locomotive", comes from the Latin terms "loco-," which is an ablative of "locus," which means "place," and "motives," which is a Mediaeval Latin word that means "causing motion." To distinguish between mobile and stationary steam engines, the phrase was initially employed in the early 19th century. Regenerative braking is a feature of electric locomotives that absorbs a large portion of the train's energy by using the traction motors as generators. Large rooftop resistor banks and cooling fans are used to simply dissipate the generated electricity as heat into the atmosphere as there is currently no method to store it. Non-fully electric trains can use regenerative braking rather than just dynamic braking and can even turn off their main power source when they are parked or idle when they have a storage system installed. Saving money and improving the environment are two benefits of this decrease in energy use. A more compact rendition of this notion can be observed in hybrid vehicles, such as the Volt. In a hybrid train, the batteries serve as energy storage devices for the electric motor. Unlike gasoline, which can only power the gasoline engine in a fuel tank, the electric motor in a hybrid train can both draw energy from the batteries and put energy back into them. Battery electric vehicles (BEVs) drive the wheels through an electric motor that is powered by electricity that is stored in a battery pack. When the batteries run low, grid electricity—which can come from a wall outlet or a special charging device—can be used to replenish them. The pollution produced by hybrid trains depends on how the electricity is generated. A train, railcar or locomotive

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that has a rechargeable energy storage system (RESS) between the traction gearbox system attached to the wheels and the power source on board is called a hybrid train.

Overall Concepts

There has been an increasing need to lower energy costs by integrating a renewable energy source, like solar power, into the power grid because significant-speed (HS) trains have significant operating expenses. This project aims to show that a PV solar cum battery storage power plant is feasible and capable of providing steady electricity to an HS rail link. This plant might greatly improve the financial viability of Railways by supplementing energy use during periods of high travel demand. The energy supply from the traction substation has already been decreased by roughly 5-8% thanks to a battery system that East Japan Railway has previously installed. Another example is the battery-powered train that Hitachi and Kyushu created to support through service on electrified sections. AC overhead lines charge the train. The existing dependency on fossil fuels and the requirement to cut carbon emissions have raised interest in creating novel and cutting-edge technology. Installing solar panels along HS rail networks to exploit the ballast-less tracks as energy carriers is one such possibility. Battery storage and enough capacity to run power trains and recharge the batteries are combined in this PV system. Grid-tie inverters that rely on batteries could draw and synchronize power from the grid and battery banks. Because of its extended life cycle, reduced maintenance requirements, and structural integrity, slab track systems are more effective for high-speed routes.

Mode of Operation

The grid, to which the solar PV system is attached, serves as a storage mechanism for sporadic power sources. There are plans to install a battery energy storage system (BESS) as well. The way the system works will be as follows: When the solar PV system is producing enough electricity during the day, it will feed the grid and consumer loads simultaneously, giving the solar PV system priority. But if PV power declines, the grid will connect to the consumer's AC load and the solar connection will immediately be cut off. The BESS will release the stored electricity in the evening to fulfil the energy requirements. The solar PV system will generate enough power to charge the BESS during sunlight hours. If the energy demands of the trains exceed the design limits due to increased frequency, then power will be drawn directly from the grid.

Advantages

- "Electric trains are environmentally friendly as they run on electrically powered engines, emitting no toxic gases or smoke into the environment, unlike trains that use unclean energy sources. By choosing electric trains, you'll be contributing to a healthier and greener climate."
- Electric vehicles (EVs) are becoming more popular, resulting in a wider selection of unique trains on the market.
- Electric trains are low maintenance as they run on electrically powered engines which require no lubrication. This eliminates the need for expensive engine work, reducing maintenance costs. Compared to gasoline-powered ones, electric trains require less frequent servicing, so you won't have to take them to a service station as often.
- Electric trains are much quieter, reducing noise pollution. They provide a smooth ride, with higher acceleration over longer distances.

Disadvantages

- Due to the battery size and construction, electric vehicles have a limited range. The charging time of a high-voltage battery varies based on the battery charge and power source.
- Although the benefits of electric mobility are clear, there are also drawbacks to consider before making the investment.
- Recharging your electric vehicle can be challenging, as electric fuelling stations are still developing. It is not yet common to find them in your daily destinations, It implies that you can be stranded somewhere until you find a charging station if you are traveling a long distance and run out of battery.
- It's important to remember that electricity isn't free, even when it comes to electric trains. If you're not careful about considering your options, an electric train can end up costing you more on your energy bill than you expected. Before purchasing an electric mobility, it's important to do your research to avoid making an unwise investment. Keep in mind that some electric trains require a significant amount of power to function properly, which can lead to a higher electricity bill each month.

BLOCK DIAGRAM

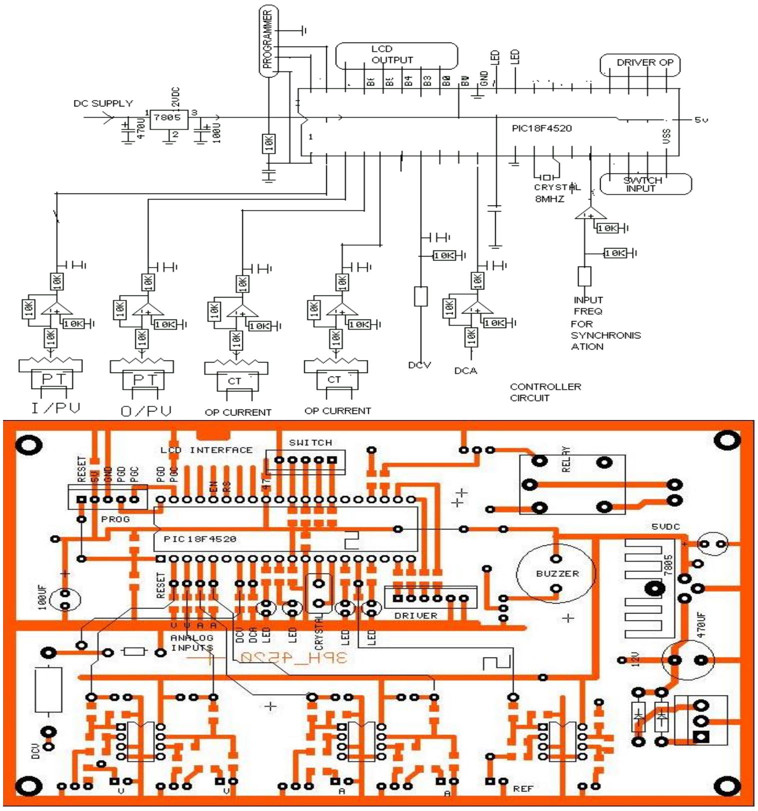


Figure 1: BLOCK DIAGRAM OF ON-GRID SOLAR TRACTION SYSTEM

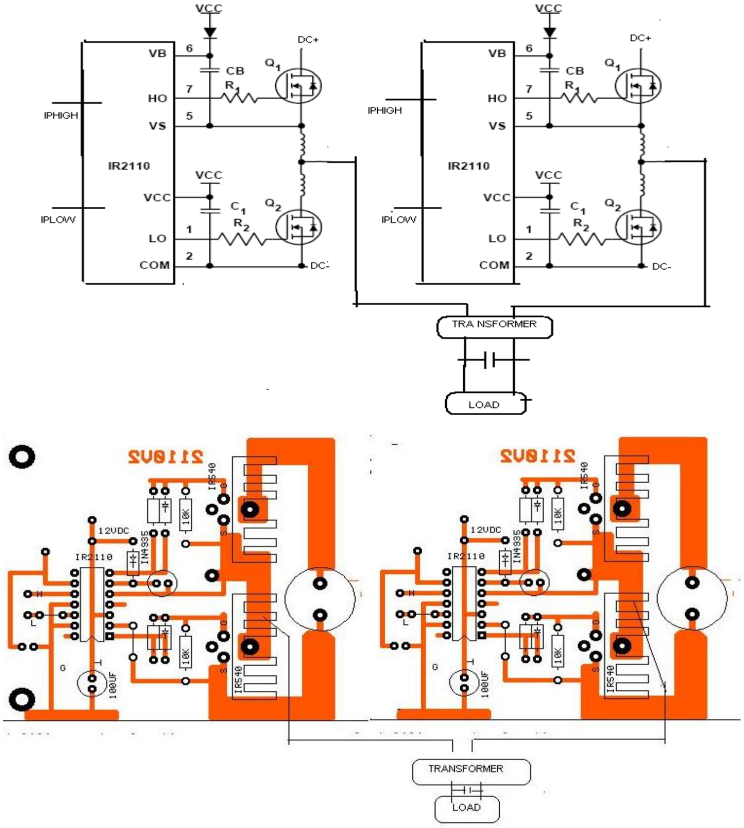


Figure 2: CIRCUIT DIAGRAM AND PCB DESIGN OF GRID TIE CONTROLLER CIRCUIT

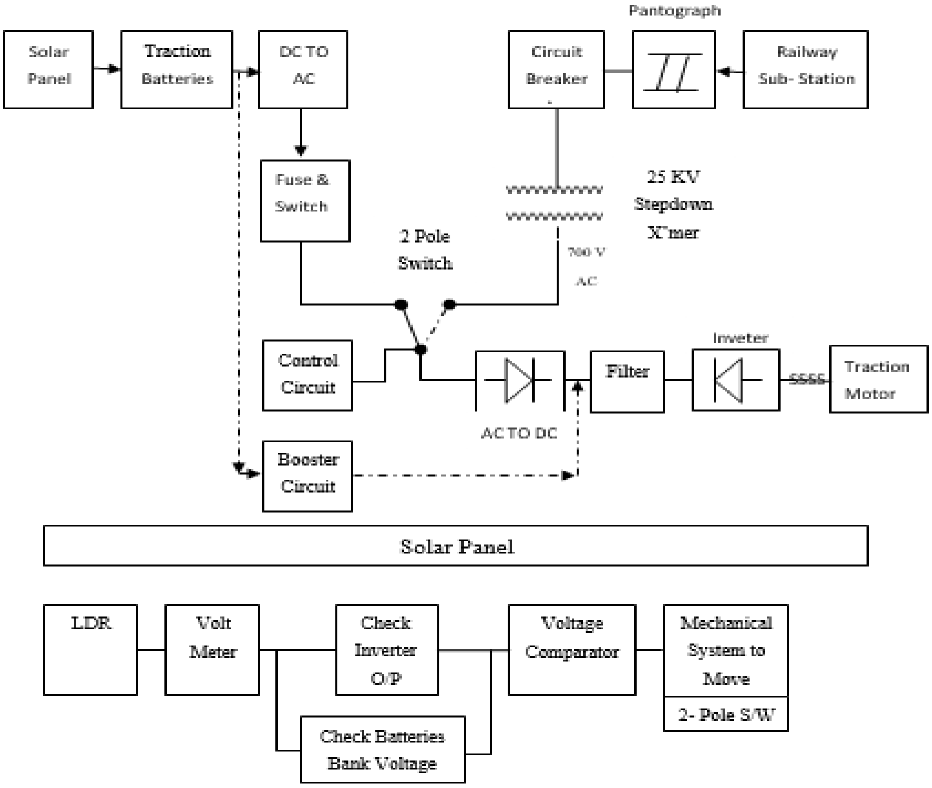


Figure 3: CIRCUIT DIAGRAM AND PCB DESIGNING OF GRID INVERTER

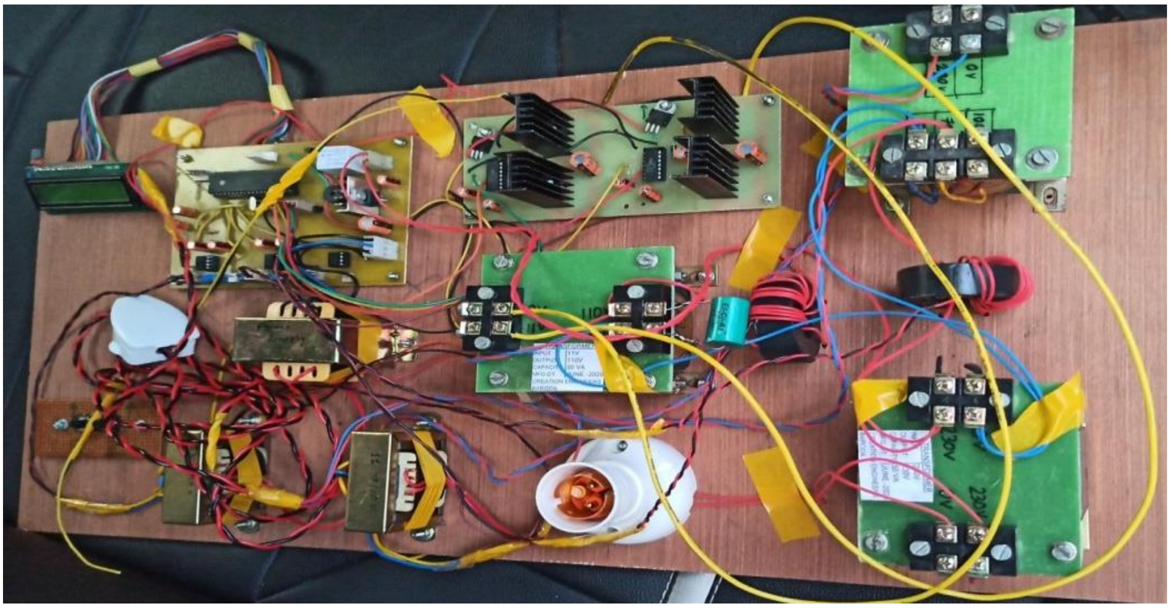


Figure 4: ACTUAL WORKING MODEL

Solar Panel

A renewable energy source is solar electricity uses radiant light and heat from the sun to generate clean electricity. It can be utilized to power machines, buildings, and commercial spaces. Nowadays, solar panels are becoming more common on rooftops, parking structures, schools, highway signs, and stores. They are employed to capture solar energy for a variety of uses, including water heaters, air conditioners, lights, and appliances. The popularity of solar energy is increasing because it is cost-efficient and environmentally friendly.

Solar energy is a dependable and effective source of electricity, particularly during times of peak demand, like hot afternoons when air conditioners are going full blast. There are three main types of solar power systems: solar thermal energy, solar thermal energy, and solar passive energy. The goal of passive solar energy design is to maximize a building's exposure to the sun. This is done by building walls, windows, and skylights that capture and disperse the sun's heat within the structure, without relying on external mechanisms. Features like glass windows and building overhangs are typical examples of passive solar design. Passive solar energy demands meticulous planning from the blueprint phase. Conversely, active solar energy systems rely on external components, like solar panels, to harness sunlight and produce electricity. Compared to passive solar energy, active solar energy is far more prevalent. To harness solar energy and turn it into electrical power, solar power systems require the installation of panels, wiring, and other components. Another method of heating water using solar radiation is solar thermal energy, which can help keep your pool warm and lower your water heating costs. Active solar power, on the other hand, is the most common type of solar power system that is used to reduce energy costs and consumption. Five primary elements go into effectively utilizing solar energy: Photovoltaic cells, which collect photons from sunlight, are the building blocks of solar panels. PV cells use semiconducting materials like silicon to convert sunlight into direct current electricity. The solar panels are wired to an inverter, which changes the direct current electricity into alternating current electricity on a much larger scale than the AC/DC plug on your small appliance.

Design of Solar Photovoltaic Power Plant

For the Mumbai–Ahmadabad high-speed rail link, a conceptual design and cost estimate have been developed for a grid-connected photovoltaic solar plant with a battery energy storage system (BESS). The design used for the Shinkansen in Japan served as the basis for this rail link. Takatsu (2015) states that the rail link features twin tracks with a canter-to-canter spacing of 4.3 meters, a track gauge of 1435 millimetres, and two x 25 kV AC at 50Hz electrification. A total of 508 kilometres of tracks are underground. The trains have ten carriages that can hold 750 passengers each and can travel at a top speed of 320 kmph. It is anticipated that the trains will operate on a ballast-less track system and run for twelve hours every day. The following is the installation design for the power supply: double lines from the transmission network power the incoming line. The feeding system uses two times 25 kV of single-phase AC at 50 Hz. The system's minimum permitted voltage is 22.5 kV, its maximum allowable voltage is 30 kV, and its standard voltage is 25 kV. Furthermore, there is a minimum voltage of 20 kV for certain periods. The substation system is a 50–60 km distance Traction Substation (TSS). The 191 MW PV station that would be part of the projected solar cum battery complex will have solar modules positioned along the train track. This will turn the railway line into a solar field per kilometer. In addition to the PV station, a BESS with a 134 MW battery bank that can store 268 MWh will be included. Power will be supplied to the load for 12 hours during peak times.

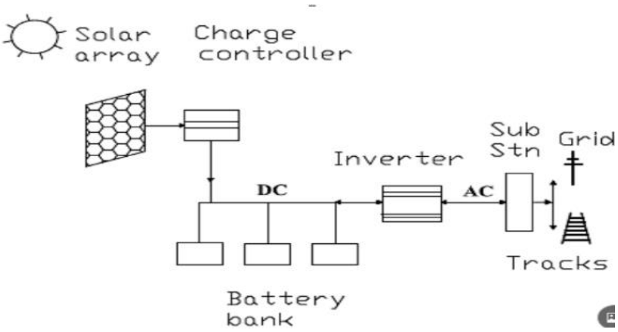


Figure 5: BLOCK DIAGRAM OF A PV SYSTEM WITH BATTERY BACKUP FOR HS TRACTION

Panel Generation Factor

When calculating the quantity of panels required for a solar power system, the Panel Generation Factor (PGF) is an important consideration. PGF is calculated based on the solar intensity and the number of hours of sunshine in a day. It is derived by dividing the solar irradiance by the standard test condition irradiance. For instance, if we assume an average solar irradiance of 5.56 kWh/m²/day (near Vadodara city) and an average of 8 hours of daily sunlight, then the PGF would be 5.56 x 10^3 / 1000 = 5.56.

Energy Demand of HS Rail Network

The traction system used by the Shinkansen high-speed EMUs is made up of 56 asynchronous motors with a combined power of 305 kW. This results in 17,080 kW of total rated power per train. Two trains will arrive and depart each hour, according to the schedule for service. Consequently, 2×2×17080 = 68,320 kWh would be the energy consumption for one hour. The trains run for twelve hours per day, which results in a daily energy usage of twelve x 68320 = 819,840 kWh. About 30% of the system's energy is lost. PV modules will therefore need to provide 1.3 x 819,840 = 1,065,792 kWh of electricity each day. It is anticipated that the following distribution of the PV plant's total energy over 8 hours will occur: The energy needed to drive the trains for the first eight hours of the day will be 8×1065792/12 = 710528 kWh/day, and it will come directly from the photovoltaic facility. BESS will be charged using the 355,264 kWh of residual energy. The BESS is made to release the energy produced by photovoltaic cells that is stored in batteries under the designated 4-hour load period.

Total Watt Peak Rating for PV Modules

To determine the total watt rating of a PV module, we must compute the ratio between the energy that must be generated by the solar panels and the factor that determines the panel generation. The PV module's total watt rating can be computed using the following formula: PV module total watt rating is calculated as follows: the energy needed from PV modules/panel generation factor. The PV module's total watt rating in this instance is 191,689 kW, or 1065792 divided by 5.56.

Table 1: Parameters of PV module

Model solar land SLP1905-24 Silver-mono solar panel	
Open circuit voltage	24v
Output current	5.16 A DC
Maximum power	190 wp
Dimensions	1580*808*35 mm

Number of PV Modules Required

The Solar Land SLP1905-24 Monocrystalline model of conventional solar panels is used in this investigation. The total watt peak rating / peak rated output of the PV module is the formula used to calculate the number of panels needed in the power plant. Using this calculation, the number of PV modules required is $191689\times10^3 / 190 = 1008.8\times10^3 \cong 1{,}009{,}000$.

Table 2: Area required for mounting panels.

Description	Data for length Cal
No modules required	1009000
Dimension of one PV module	0.808*1.58m
Modules in an array connected in series	4
Total width of each PV array	332m
No. of the array in the PV field	10090/4-252250
No. of field	252250/4-63062
Pitch distance	3.5m
Length of the solar field	63062*(3.5)-1.58-220719 = 221000m
Less for a) underground tunnel b) for 12 stations	21km 12*0.5-6km
Actual length of track available	508m
Net available	-508-(21+6)-481km

Inverter Sizing

The maximum power necessary determines the size of the inverter that is needed. Given that 191,689 kW of total wattage is needed, the inverter size should be 25–30% more than that, or 1.3 times the total wattage needed. This results in an inverter size of 249,196 kW. We have chosen an SAT Con Power gate Plus 500,480/3 inverter, which has a built-in system for tracking power points. We will require several inverters; we can determine the necessary number of inverters by dividing the inverter size by its rating. By doing this, we have 498.4, or about 500. At the edge of the track, these inverters will be spaced roughly 1000 meters apart. A total of 500 × 500 = 250,000 kW.

Battery Sizing

A Crown 860Ah deep cycle battery with a 41.28 kWh (16) battery bank from Wholesale Solar is the suggested battery type. The battery hours utilized in a day with a 4-hour usage are 4×68320 = 273,280 kWh. The battery capacity (Ah) is determined by taking the total watt-hours per day × days of autonomy / 0.85 × 0.6 × nominal battery voltage. The battery voltage is 48 V. The capacity is equal to 535,824 kWh ≅ 536 MWh $(11163 \times 10^3 \times 48) / 10^3$. 12,980 batteries will be needed to power the system, and each battery container will be positioned next to one of the 12 stations. If the battery is started with a full charge, it can produce 134 MW for 4 hours until the state of charge drops below 50%. However, the expected daily production of the PV plant's battery-charging section is 355 MWh. The battery can store 321 MWh of electricity, or 90% of the power generated by the PV plant on a daily cycle, with an initial state of charge (SOC) of 60%.

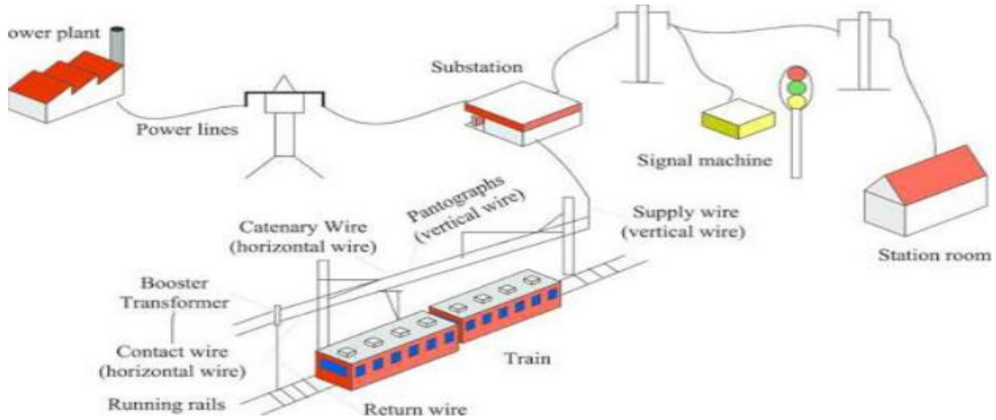


Figure 6: ELECTRIC POWER SUPPLY CONNECTION AND DISTRIBUTION

The overhead line equipment (OLE) is made up of many standardized components. OLE designers want to minimize system wear and guarantee continuous power delivery to the train by keeping the contact wire as steady as possible. To prevent deflection due to strong winds and excessive temperatures, the contact wire is tensioned between support structures. This guarantees that the current, even at high speeds, reaches the train in all weather conditions. The contact wire is suspended from droppers, or vertical cables, which are held up by catenaries, or longitudinal cables. Railway catenaries, or overhead wires, are suspended between support structures like masts or frames, which are normally placed roughly 50 meters apart. These cables are tensioned at both ends and are typically 1500 meters in length. Adjacent pieces of the wire overlap for approximately 180 meters to guarantee that the pantograph does not lose power. Strong winds must be taken into account by the engineering team while building the supporting structures, both across and along the rails. The structures are designed to be as rigid as possible to avoid any bending that would interfere with the collection process. To prevent making a groove in the pantograph, the contact wire also travels in a zigzag pattern above the track—a technique known as the "stagger." Usually, "pull-off" arms that are fastened to the support structures are used to generate the stagger.

Portal frames

In cases where there are more than two railway tracks, it may not be feasible to use cantilever masts. Instead, a steel frame known as a portal frame can be used, which spans across the tracks. As seen in the image below, the structure is composed of masts joined by a horizontal boom that can be either a H section or a lattice steel. On these frames, vertical components known as drop tubes fasten the cantilevers—which hold up the wires—to the boom.

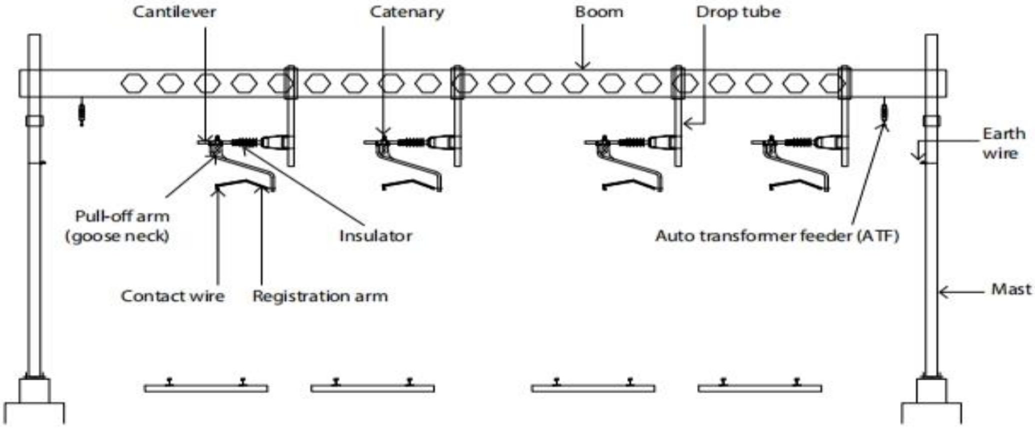


Figure 7: PORTAL FRAME OLE SUPPORT STRUCTURE

The catenaries and contact wires of OLE equipment are installed in sections that are tensioned at both ends to ensure that the contact wire remains still and maintains consistent contact with the pantograph, regardless of the weather conditions. The tensioned wires usually range from 1000m to 1500m long, having a maximum 195-meter overlap to give the trains a constant supply of energy. As seen in the diagram below, a typical tensioning system consists of an iron weight and a braced mast. Service disruptions could result from vandalism or mechanical failures in the existing transit system. To overcome this, new systems are now utilizing a spring tensioning mechanism, which requires two springs at each end of every wire. These springs are attached on top of the track to frames that span the line. The supporting frames are larger than normal OLE structures because of the higher forces at play.

Neutral sections

Gaps in the electrical wiring are known as neutral sections in Overhead Line Equipment (OLE). They serve the dual purposes of dividing power-supplied line lengths from several feeder stations and isolating wiring segments for maintenance. To prevent power from accidentally moving over the OLE from one feeder to another and avoid the National Grid's switching systems, this is required. The process of creating neutral sections involves fitting the catenary wire with insulators and sandwiching small electrically isolated or non-conducting parts between the lengths of the active contact wire. There are two basic types of neutral sections, which are illustrated on the following page. A full, "switched" neutral section is the first kind. It is made up of individual insulated contact wire lengths that overlap two conventional sections. The insulated neutral sections are connected to the regular contact wires via automated switches. When a train passes by, these switches activate automatically to provide a steady supply of electricity. A brief segment of non-conductive material spliced into the contact wire is another kind of neutral section. Local wire lengths can be disconnected in certain portions for maintenance reasons. Because trains that stop while their pantographs are on an insulated or isolated section may lose power and not be able to resume, it is necessary to put neutral portions away from junctions, signals, or stations. A piece of railway track with an expanded set of overlaps that is near a switchgear cabinet is known as a completely switched neutral section. Conversely, a short and less apparent neutral portion is fixed to a regular single-track cantilever mast. Neutral parts in places of considerable natural or historical importance should be screened or placed unobtrusively to reduce their visual impact.

Track Earthling

A closed electrical circuit is necessary for the current to go through in order for a train to move. Connecting the train wheels to the rails and the rails back to the feeder substation completes this circuit. On the other hand, some issues are brought on by long-distance power outages and safety-critical interference with communication and signalling networks.

Figure 8: TRACK EARTHLING

In electric traction, the overhead wire serves as the phase wire (or positive wire in DC traction) while the track acts as the neutral or returning path. The return current from the traction motor flows through the couch body-wheels-track and back to the track. It's important to check that the track is earthed at uniform intervals. If it's not earthed frequently, a person touching the track may receive an electric shock. This is because the track resistance might be higher than that of a human, and the current will take the path of least resistance. Some people think that since the track is on the earth, it doesn't require earthing. However, this is incorrect because the tracks are placed on concrete sleepers that don't provide sufficient earthing.

Neutral sections and low bridges

To accommodate trains that need to pass under low bridges, longer versions of short neutral sections are utilized. In place of a copper contact wire beneath the bridge, an insulated rod or cable is employed. The train's pantograph can be isolated using this technique in conjunction with automatic switches, allowing it to coast under the bridge. This allows for a future reduction of up to 200mm in the distance between the insulated wire and the bridge deck or arch. It's important to note that the system designed for trains to pass under bridges only works for trains that are moving slowly and when there is little chance that they will halt close to or beneath the bridge. Furthermore, to maintain the electrical connection between the OLE on either side, portal-type support for Overhead Line Equipment is required immediately on either side of the bridge to anchor contact wires and transport power cables. However, it's important to keep in mind that all this equipment can potentially damage or negatively impact the setting of historic bridges.

Shoes and Shoe gear

Systems for collecting current from third rails have many designs. The "top contact" system, in which the pick-up shoe glides on top of the rail, is the most basic design. Like the top contact system but with less exposure is another version known as the "side contact" system. The most effective design is the "bottom contact" system, which covers most of the rail and protects it from harsh weather. In a DC 3-Rail Traction System, the current rail is located between the running rails. A "shoe" is used to collect current on the train, which is so named because pioneers of the industry first called it a "slipper." However, the name "shoe" has stuck to this day, perhaps because it is a better description. Modern train shoe systems are equipped with remote lifting facilities. In the event of an emergency, all shoes must be removed from the existing rail, and these facilities are utilized. This is typically required when a shoe breaks off and the connecting line to the train's electrical equipment is securely fastened. While doing this, the other shoes on the same circuit must be isolated. Unless the entire section's current is cut off, it would disable multiple other trains. In the past, isolation was accomplished by tying the shoe with a strap or rope after putting a wooden "paddle" between it and the railing. Modern technology has made it possible to remotely raise shoes from the driving cabin of a train using mechanical or pneumatic systems. In trains, top contact shoes are usually hung from a beam that is positioned between the bogie's axle boxes. Using a few slotted links to adjust for movement, the suspension mechanism in earlier systems relied on gravity to apply the required pressure. On the other hand, radially mounted shoes are used in more recent systems to give lever action and a more stable contact. Radially mounted shoes are necessary to fit under protective covers for top contact systems in some situations, like the New York Subway.

Figure 9: SHOES AND SHOE GEAR

Microcontroller PIC 18F4520

Power Management Features:

The CPU and peripherals are both turned on while the device is in the "Run" mode. The CPU is shut off, but peripherals are left on in "Idle" mode. Both the CPU and peripherals are off when the system is in "Sleep" mode. The ultra-low 50nA input leakage of this device is present. The average current in "Run" mode drops to 11 µA, while in "Idle" mode it drops to 2.5 µA on average. The average current consumption in sleep mode is only 100 nA. The oscillator for Timer1 operates at 32 kHz and draws 900 nA at 2V. The average consumption of Watchdog Timer at 2V is 1.4 µA. Oscillator with two-speed startups.

Flexible Oscillator Structure:

This microcontroller offers a variety of clock modes to choose from, including four crystal modes with a maximum frequency of 40 MHz. It also features four-phase lock loops (PLLs) it works with internal oscillators as well as crystal ones. Two external clock modes and two external RC modes with a maximum frequency of 40 MHz and 4 MHz, respectively, are also present. When utilized with PLL, the internal oscillator block offers a full range of clock speeds from 31 kHz to 32 MHz, along with eight user-selectable frequencies from 31 kHz to 8MHz. Additionally, it can offset frequency drift. A fail-safe clock monitor that permits a safe shutdown if the peripheral clock stops is also available, along with a backup oscillator that uses Timer1 @ 32 kHz.

Peripheral Highlights:

With three external interrupts and four input change interrupts that may be programmed, this device has a High-Current Sink/Source of 25 mA/25 mA. Additionally, it has two Capture/Compare/PWM (CCP) modules that can be used: one for 28-pin devices that has Auto-Shutdown, and another for 40/44-pin devices that has an Enhanced Capture/Compare/PWM (ECCP) module. One, two, or four PWM outputs, adjustable polarity, programmed dead time, auto-shutdown, and auto-restart are among the features of the ECCP module.

Peripheral Highlights (Continued):

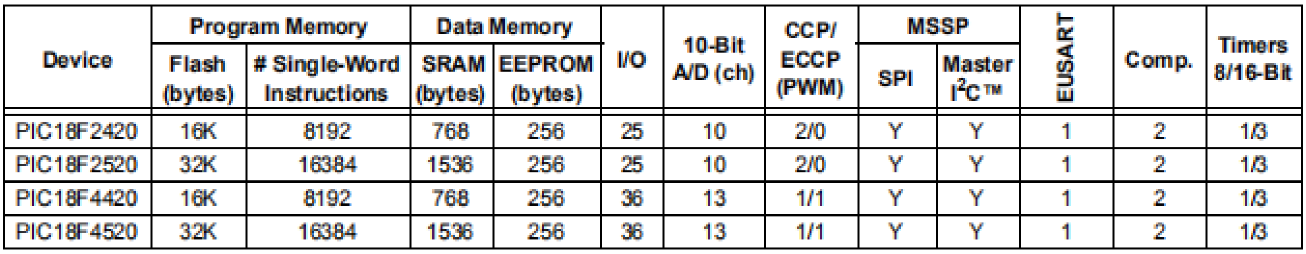
Among its many sophisticated features is a Master Synchronous Serial Port Module that allows for I2C Master and Slave modes as well as 3-Wire SPI. Additionally, it features an Enhanced Addressable USART module that can operate on RS-232, LIN/J2602, and RS-485 by utilizing the internal oscillator block.

Auto-wake-up on the Start bit and Auto-Baud Detect are also features. In addition, a 10-bit, up to 13-channel Analog-to-Digital Converter module with Auto-acquisition and conversion usable during Sleep is included with the device. Dual analog comparators with input multiplexing are another characteristic of it. In addition, it features a 16-level Programmable High/Low-Voltage Detection (HLVD) module that allows for interruptions based on high/low voltage detection.

Special Microcontroller Features:

An optional expanded instruction set that optimizes re-entrant programming is included in the C compiler architecture. The program memory has an enhanced flash capacity of up to 100,000 erase/write cycles, while the data EEPROM memory has a capacity of up to 1,000,000 erase/write cycles. The average lifespan of an EEPROM's flash and data is 100 years. The gadget features software-controlled self-programming and interrupt priority levels. An extended watchdog timer (WDT) with a programmable period ranging from 4 ms to 131s is also included, as is an 8x8 single-cycle hardware multiplier. There are two pins available for single-supply 5V in-circuit serial programming (ICSP) and in-circuit debugging (ICD). Also, the wide operating voltage range of 2.0V to 5.5V is possessed by this device.

Table 3: OPTION TABLE ENABLED BROWN-OUT RESET PROGRAMMABLE USING SOFTWARE



Device	Program Memory		Data Memory		I/O	10-Bit A/D (ch)	CCP/ ECCP (PWM)	MSSP		EUSART	Comp.	Timers 8/16-Bit
	Flash (bytes)	# Single-Word Instructions	SRAM (bytes)	EEPROM (bytes)				SPI	Master I^2C™			
PIC18F2420	16K	8192	768	256	25	10	2/0	Y	Y	1	2	1/3
PIC18F2520	32K	16384	1536	256	25	10	2/0	Y	Y	1	2	1/3
PIC18F4420	16K	8192	768	256	36	13	1/1	Y	Y	1	2	1/3
PIC18F4520	32K	16384	1536	256	36	13	1/1	Y	Y	1	2	1/3

PIN DIAGRAM

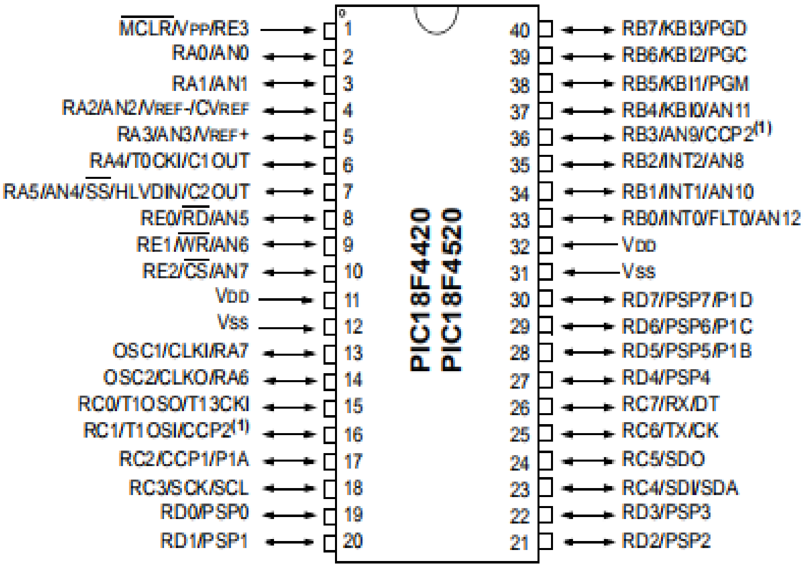
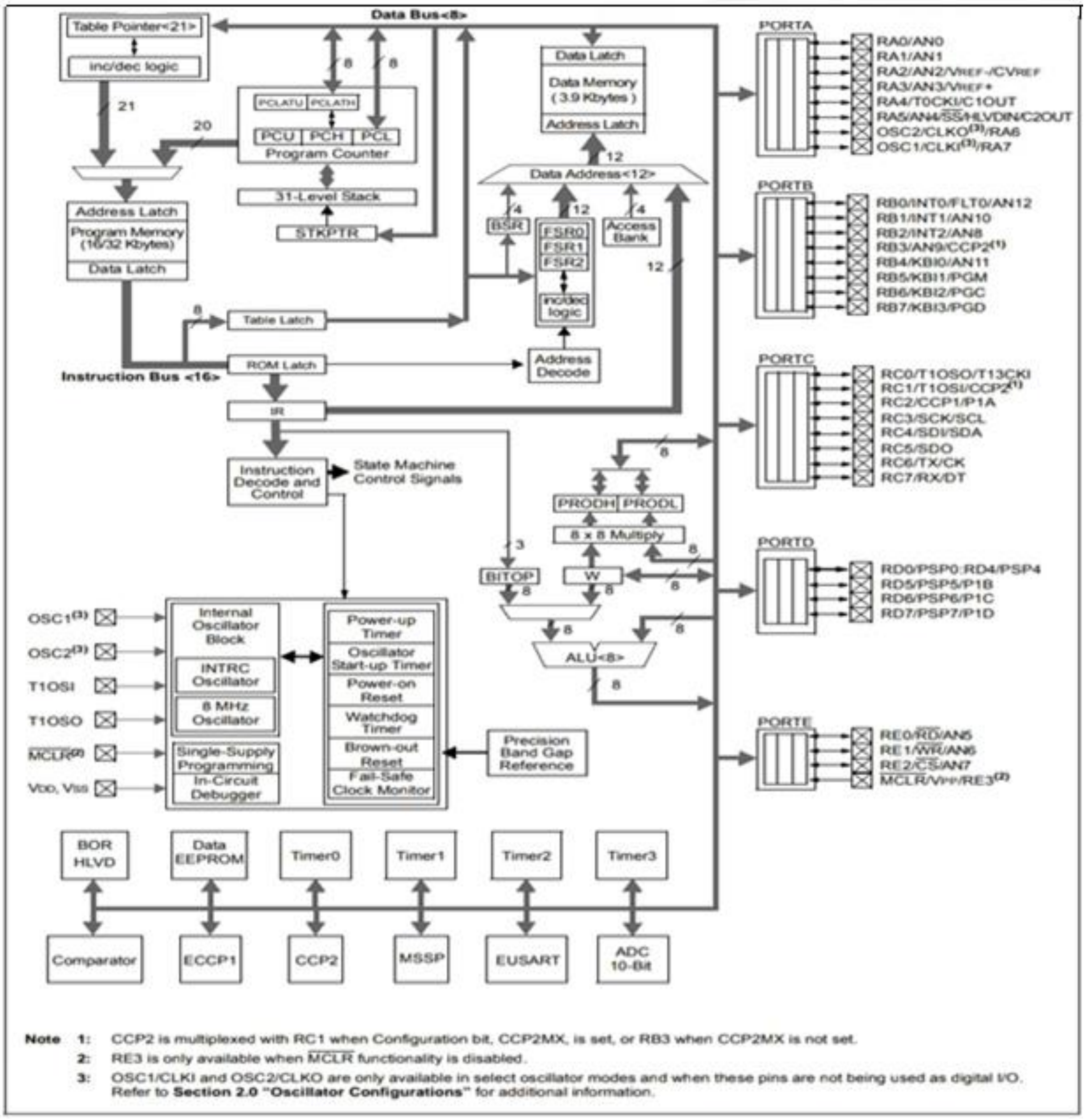


Figure 10: Pin Diagram of PIC18F4420

DEVICE OVERVIEW

The PIC18 microcontrollers are known for their high computational performance and cost-effectiveness. The PIC18F2420/2520/4420/4520 family, in addition to these features, furthermore provides improved flash program memory and great endurance. These microcontrollers are designed to cater to power-sensitive applications and include design enhancements that make them an optimal choice for such requirements.



Note 1: CCP2 is multiplexed with RC1 when Configuration bit, CCP2MX, is set, or RB3 when CCP2MX is not set.

2: RE3 is only available when MCLR functionality is disabled.

3: OSC1/CLKI and OSC2/CLKO are only available in select oscillator modes and when these pins are not being used as digital I/O. Refer to **Section 2.0 "Oscillator Configurations"** for additional information.

Figure 11: PIC18F2420 BLOCK DIAGRAM

MULTIPLE OSCILLATOR OPTIONS AND FEATURES

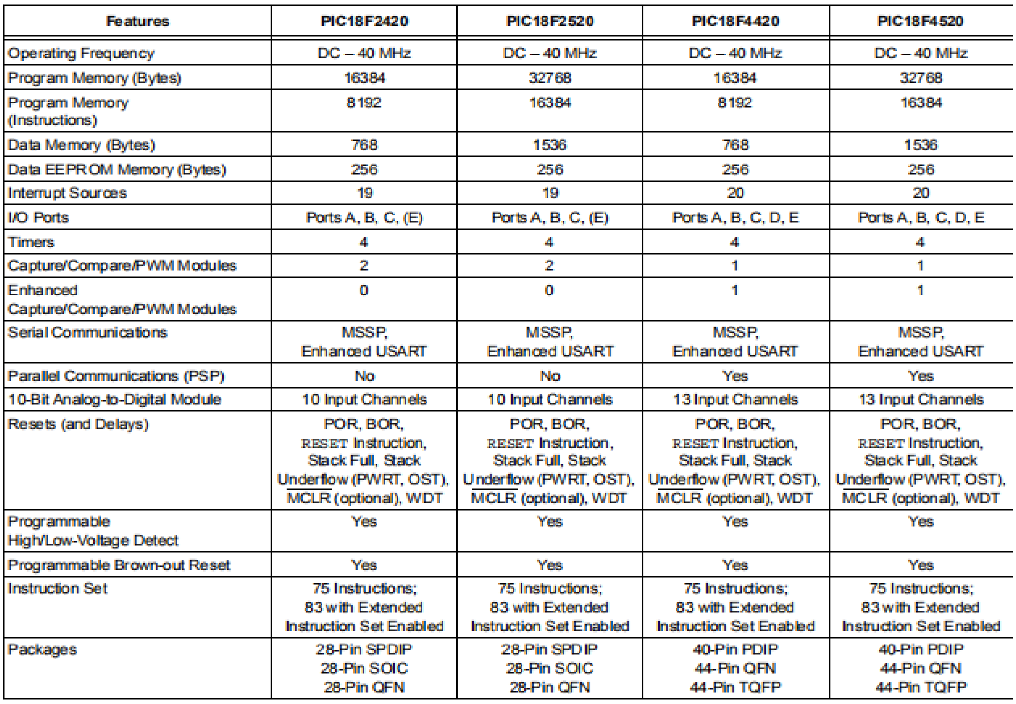
Ten distinct oscillator configurations are available to users of the PIC18F2420/2520/4420/4520 family of chips for the development of application circuitry. These choices include two external clock modes with the choice of using two pins (oscillator input and a divide-by-4 clock output) or one pin (oscillator input, with the second pin reassigned as general I/O), four crystal modes that make use of crystals or ceramic resonators, and two external RC oscillator modes with the same pin options as the external clock modes. Together with an INTRC source (about 31 kHz) and an 8 MHz clock, the internal oscillator block offers 6 user-selectable clock frequencies (ranging from 125 kHz to 4 MHz), for a total of 8 clock frequencies. By choosing this option, you can use the two oscillator pins as additional general-purpose I/O. In addition, an internal oscillator, and High-Speed Crystal mode each have access to a Phase Lock Loop (PLL) frequency multiplier that raises the maximum clock speed to 40 MHz. With the internal oscillator engaged, the PLL offers customers a wide range of clock rates, from 31 kHz to 32 MHz. This function does away with the requirement for an external clock circuit or crystal. The internal oscillator block gives the family further capabilities for reliable operation in addition to serving as a stable reference source and clock source.

- **Fail-Safe Clock Monitor:** This function periodically compares the primary clock source to an internal oscillator-supplied reference signal. The controller instantly switches to the internal oscillator module in the case of a clock malfunction. This guarantees that the application can be securely closed down or that low-speed processes can continue.
- **Two-Speed Start-up:** When this option is selected, the internal oscillator can either wake up from sleep mode or operate as the clock

source from Power-on Reset until the primary clock source becomes available.

- **Memory Endurance:** The program memory and data EEPROM of Enhanced Flash cells have a high endurance rating, which means they can be erased and written many thousands of times. The program memory can last for up to 100,000 erase/write cycles, while the EEPROM can last for up to 1,000,000 cycles. Additionally, With an estimated 40+ years of data retention without refresh, it's a dependable and long-lasting solution.
- **Self-programmability:** Under internal software control, these devices can write to their program memory areas. An application that can update itself in the field can be developed by using a boot loader routine that is found in the protected Boot Block at the top of the program memory.
- **Extended Instruction Set:** An optional expansion of the PIC18 instruction set is available with the PIC18F2420/2520/4420/4520 family. In addition to an Indexed Addressing mode, this extension includes 8 new instructions. Its purpose is to optimize re-entrant application code, which was written in high-level languages such as C originally. As a device setup option, you can activate this extension. An optional expansion of the PIC18 instruction set is available with the PIC18F2420/2520/4420/4520 family. In addition to an Indexed Addressing mode, this extension includes 8 new instructions. Its purpose is to optimize re-entrant application code, which was written in high-level languages such as C originally. As a device setup option, you can activate this extension.
- **Enhanced CCP Module:** This module can control half-bridge and full-bridge drivers with its 1, 2, or 4 modulated outputs while operating in PWM mode. Additionally, it has an auto-shutdown function that, in the event of an interruption or other predetermined situations, disables the PWM outputs. It also features an auto-restart feature that, after the issue has been resolved, reactivates the outputs.
- **Enhanced Addressable USART:** This module supports the LIN bus protocol and allows serial communication via the common RS-232 interface. It provides a number of improvements, including a 16-bit Baud Rate Generator for increased accuracy and automatic baud rate detection. For applications that need to communicate with external devices without the use of an external crystal, the EUSART guarantees reliable performance when the microcontroller makes use of its internal oscillator block.
- **10-Bit A/D Converter:** This module reduces code overhead by enabling channel selection and conversion without the need to wait for a sampling period.
- **Extended Watchdog Timer (WDT):** For an extended and consistent time-out range spanning voltage and temperature, this version has a 16-bit pre-scaler.

Table 4: DEVICE FEATURES



Features	PIC18F2420	PIC18F2520	PIC18F4420	PIC18F4520
Operating Frequency	DC – 40 MHz	DC – 40 MHz	DC – 40 MHz	DC – 40 MHz
Program Memory (Bytes)	16384	32768	16384	32768
Program Memory (Instructions)	8192	16384	8192	16384
Data Memory (Bytes)	768	1536	768	1536
Data EEPROM Memory (Bytes)	256	256	256	256
Interrupt Sources	19	19	20	20
I/O Ports	Ports A, B, C, (E)	Ports A, B, C, (E)	Ports A, B, C, D, E	Ports A, B, C, D, E
Timers	4	4	4	4
Capture/Compare/PWM Modules	2	2	1	1
Enhanced Capture/Compare/PWM Modules	0	0	1	1
Serial Communications	MSSP, Enhanced USART	MSSP, Enhanced USART	MSSP, Enhanced USART	MSSP, Enhanced USART
Parallel Communications (PSP)	No	No	Yes	Yes
10-Bit Analog-to-Digital Module	10 Input Channels	10 Input Channels	13 Input Channels	13 Input Channels
Resets (and Delays)	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), MCLR (optional), WDT	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), MCLR (optional), WDT	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), MCLR (optional), WDT	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), MCLR (optional), WDT
Programmable High/Low-Voltage Detect	Yes	Yes	Yes	Yes
Programmable Brown-out Reset	Yes	Yes	Yes	Yes
Instruction Set	75 Instructions; 83 with Extended Instruction Set Enabled	75 Instructions; 83 with Extended Instruction Set Enabled	75 Instructions; 83 with Extended Instruction Set Enabled	75 Instructions; 83 with Extended Instruction Set Enabled
Packages	28-Pin SPDIP 28-Pin SOIC 28-Pin QFN	28-Pin SPDIP 28-Pin SOIC 28-Pin QFN	40-Pin PDIP 44-Pin QFN 44-Pin TQFP	40-Pin PDIP 44-Pin QFN 44-Pin TQFP

Grid-tie inverter

As renewable energy becomes more prevalent, countries such as the USA, Canada, France, Spain, Germany, and Denmark require greater participation in power quality. Wind turbines need to have a low voltage ride-through capability due to their larger proportion, which presents challenges. On the other hand, photovoltaic (PV) systems, need rigorous disconnection during any grid faults, maximum power point tracking (MPP), and maximising active current. They are primarily utilized in single-phase applications connected to the low-voltage grid. National rules and interconnection standards like IEEE 1547, UL 1741, G83/1, or VDE 0126-1-1 must be adhered to by these systems. Distributed power generating systems (DPGS) are becoming increasingly popular in the renewable energy industry. Small photovoltaic systems are also in great demand, in addition to massive wind systems., as well as larger systems with multi-megawatt sizes, which can be built from central or string inverters. They require maximal power point tracking (MPP), strict disconnection during any grid failures, and active current maximisation. In single-phase applications linked to the low voltage grid, they are typically used. These systems have to follow national regulations and interconnection standards such as IEEE 1547, UL 1741, G83/1, or VDE 0126-1-1. In the field of renewable energy, distributed power generating systems, or DPGS, are gaining popularity. Not only are large wind systems in high demand, but small photovoltaic systems are too.

POWER QUALITY AND GRID INTERCONNECTION

Power quality is a complex field influenced by various phenomena. Voltage quality is a key aspect that can be related directly to voltage and current quality, as per Ohm's law. In Central Europe, the EN 50160 standard defines the reference for voltage quality. The quality of voltage is determined by various factors, comprising the Voltage Unbalance Factor (VUF) and Total Harmonic Distortion (THD). The most recent edition of the guideline states that VUF should be between 2% and 3% and THD should be less than 8%. Grid imbalance has no direct effect on THD, which is determined by dividing the sum of the harmonics by the fundamental X1: $THD = \frac{\sqrt{\sum_{h=2}^{n=40} X_h^2}}{X_1}$ The Voltage Unbalance Factor (VUF) is a measure of the imbalance in the voltage of a system. It is computed by dividing the phase-to-phase voltages by the ratio of Negative Sequence (NS) to Positive Sequence (PS). No restrictions are set for the Zero Sequence (ZS) since it is not seen to be important for determining the potential interference of appliances that are connected to the grid.

$$VUF = \frac{|U^-|}{|U^+|} = \sqrt{\frac{6 \cdot (U_{ab}^2 + U_{bc}^2 + U_{ca}^2)}{(U_{ab} + U_{bc} + U_{ca})^2} - 2}$$

It should be mentioned that up to 1000 instances of brief grid outages may occur annually. It is crucial to make clear that this pertains to the expected values of the grid and does not include restrictions to produce harmonics or imbalance. The grid's present quality is not specified for malfunctioning circumstances, and it won't be considered going forward. The national grid codes have changed dramatically; instead of maximizing active power delivery and disconnecting in the event of a grid failure, they now share reactive power for voltage support, i.e., by maintaining a constant cos(ϕ) that is different from 1, and even provide grid support in the event of temporary failures. Voltage support needs are not well defined in most grid codes; hence this is still an undefined area. The requirements for integrating distributed power generating systems (DPGS) into high-, medium-, and low-voltage networks are outlined in the German grid codes. These protocols are regarded as the industry standard for advanced grid integration and contain some of the tightest rules for DPGS integration. Guidelines for voltage support during grid faults are included in the grid codes. DPGS shouldn't trip if a grid failure leaves the voltage above borderline 1. Temporary disconnection with specified resynchronization cycles is permitted if the voltage is between borderline 1 and borderline 2. Longer resynchronization cycles may result in DPGS disconnecting if the voltage is lower than borderline 2 and stays below 1500 ms. DPGS needs to disconnect after 1500 ms. There can be variations in the characteristic's dead band and slope. In addition, DPGS must act differently under the grid codes when there are malfunctions in the grid. Furthermore, the low voltage ride-through (LVRT) described in the regulations is more severe than high voltage ride-through (HVRT), which is referenced in the illustration as well. Germany's required reactive current I*R for voltage support can be defined as $i_R^* = k \cdot \frac{U}{U_N} \cdot I_N$ Please review the updated wording that follows. Usually, k has a value of 2. It is necessary to supply reactive current within 20 milliseconds of a power outage. If the reactive current's step response has a peak time of 60 ms and a settling time of 80 ms (defined as remaining within the tolerance band of 90% to 120% of the set point), wind systems can meet this deadline. Furthermore, the reactive current needs to be directed towards the voltage's positive sequence (PS).

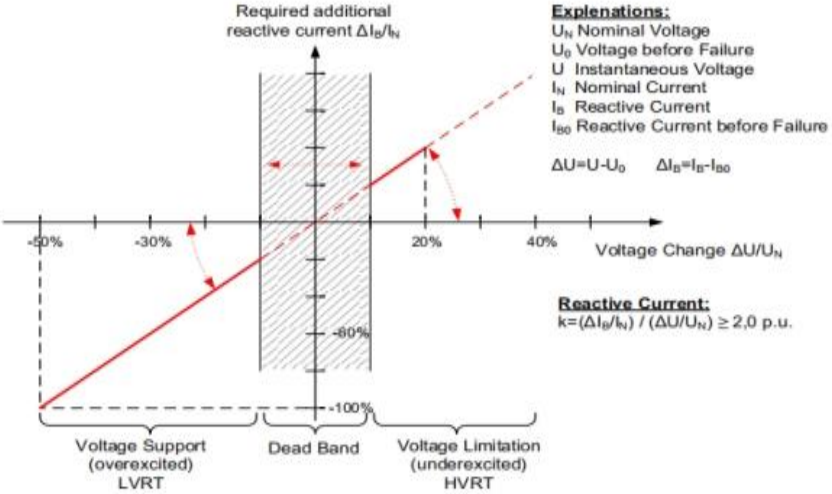


Figure 12: REQUIRED REACTIVE CURRENT FOR VOLTAGE SUPPORT

SIMULATION RESULTS

The following simulations show different voltage dips that happen at 1ms voltage fall and rise times, considering the length of the cable and the transformation from higher grid voltage levels. For all simulations, the booster was turned off to simulate a simple solar inverter. The symmetrical dip (a=b=c=50%) starts at 100ms and lasts for 75ms. Because of the changed voltage slope, currents increase throughout this time. In addition, because of different power transfers before the DC link controller has adjusted, there is a dip in the DC link voltage at the beginning and conclusion of the failure. Reactive power Q and active power P are displayed. If the grid currents are restricted, the inverters can manage symmetrical grid faults using a conventional control. Additionally, the simulation results from an unsymmetrical breakdown throughout the same period are shown. Conclusion: Symmetric grid disturbances can be handled by solar inverters with line current limits. With a normal control loop, however, they might not be able to tolerate asymmetric grid failures. The kind of PLL that is utilized mostly determines this. Furthermore, in both common cases, the inverter might not be able to supply the reactive current needed to support the voltage. To solve this, a sophisticated control loop was created, and it works effectively in unsymmetrical transient grid situations (a=b=100%, c=0%). The control tactics used can affect how well the active and reactive power function and every optimization has a unique set of side effects. The grid codes do not currently contain any explicit specifications for balanced or unbalanced currents. Thus, it is not required to apply such techniques, and they will not be taken into consideration. The reactive power signal Q in d indicates that a reactive current is being injected into the grid. The DC link capacitors' lifespan may be impacted by the fluctuations in both active and reactive powers brought on by this regulation. Nonetheless, this method maintains a lower total harmonic distortion (THD). According to the study, the grid currents get increasingly distorted the steadier the powers get.

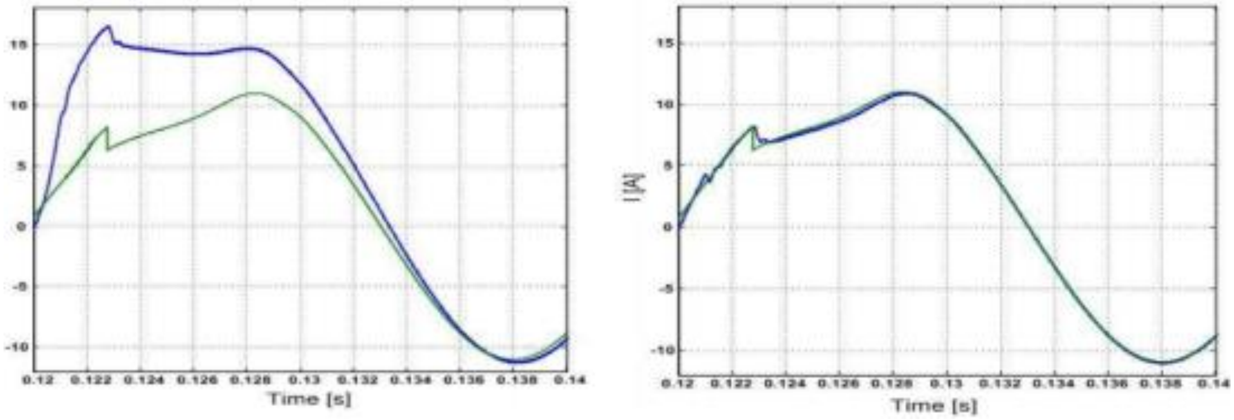


Figure 13: Control without grid voltage and Control with grid voltage feed-forward

MEASUREMENTS

- **Phase Locked Loop**: Tests of the PLL's performance with and without a pre-filter revealed that, as predicted by the models, unsymmetrical voltages can have a significant impact on the PLL. The PLL with PS pre-filter was found to work satisfactorily in unsymmetrical grid situations when a and b are 100% and c is 0%. To use reactive current under reference criteria, high-quality voltage support, and clear PS characterization of the grid voltage are necessary. The 100 steps that come after these measurements correspond to a 20ms grid cycle.

- **Sequence Separation and Detection:** The performance of three distinct techniques for sequence separation and detection over time was demonstrated by the simulation study. Regarding characteristic behaviour, detection time, and noise-induced behaviour, it was discovered that the measurement findings and the simulation results agreed well. The accuracy of dip/swell detection using the RMS approach was verified in the event of an asymmetrical grid failure (a=b=100%, c=0%). There may be a small deviation from the anticipated outcome of 57.4% remaining voltage; this could be related to the precision of the voltage measurement.
- **Low Voltage Ride:** We will employ a control loop without grid voltage feed-forward, LCL filter correction, or line current limiting to compare the simulation findings with the data. We will look at the symmetrical and unsymmetrical grid faults in Figure 12. The PLL will be pre-filtered using the T/4 technique. To minimize confusion, the grid voltage will be lowered to about one-fourth of the nominal voltage, and the necessary ramp-out of the reactive current will be disregarded. We shall select k = 1 as the reactive current's slope. The inverter will experience an uneven dip (a=b=c=12.5%) with a voltage remnant of roughly 13V. The symmetrical LVRT of the simulation figure, a=b=c=50%, is chosen. According to the models, the supplied currents would rise in proportion to the voltage slope. It was noted that although the failing phase's current grew as predicted while the current of another phase fell, the entire reactive current was not provided in a single period. Furthermore, harmonic distortion was superimposed on all currents, which was thought to be the 100 Hz produced by the NS's presence. As a corollary, assuming the line current limits are present, the system can tolerate symmetrical grid faults. A negative sequence (NS) that cannot be controlled by the conventional dq0 control might be caused by unbalanced faults in the power system. The reason for this is that the reference frame rotates in an upward direction. A negative direction dq0 reference frame rotation is required for extra NS compensation to resolve this problem. However, the resonant controller doesn't need this because it can handle both positive and negative reference frame sequences. After all, it has an ω2 in the integrator's return path. Furthermore, the previously mentioned basic requirements for transient voltage support can be satisfied by the dq0 control.

BOOST CONVERTER

An inductor resists variations in current, which is how the boost converter works. Every time, the output voltage exceeds the input voltage. The inductor stores energy and conducts current when the switch is turned on. The inductor's polarity shifts, and its stored energy tends to collapse when the switch is switched off, increasing the input voltage. Because of this, the input voltage and the voltage across the inductor are connected in series, which charges the output capacitor to a voltage greater than the input voltage. Two different states of operation exist for the Boost converter. Switch S is closed in the On-state, increasing the inductor current. When the switch is in the Off position, the flyback diode D, the capacitor C, and the load R are all crossed by the inductor current. In doing so, the energy built up during the On-state is transferred into the capacitor. Unlike with a buck converter, the input current is not discontinuous; rather, it stays constant with the inductor current. Consequently, compared to a buck converter, the input filter requirements are loosened.

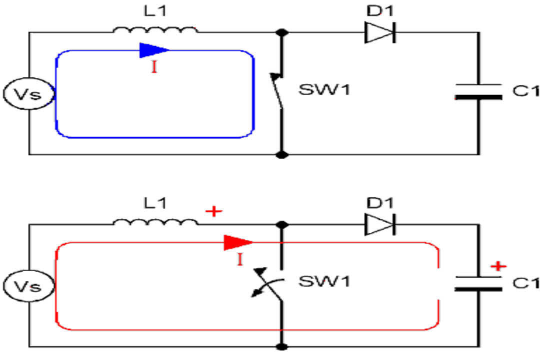


Figure 14: BOOST CONVERTER OPERATION CIRCUIT

CONTINUOUS MODE:

In continuous mode, a boost converter ensures that the current passing through its inductor never reaches zero. The diagram demonstrates the standard patterns of currents and voltages in a converter functioning in this mode. Assuming an ideal converter in stable conditions, the output voltage can be calculated as follows:

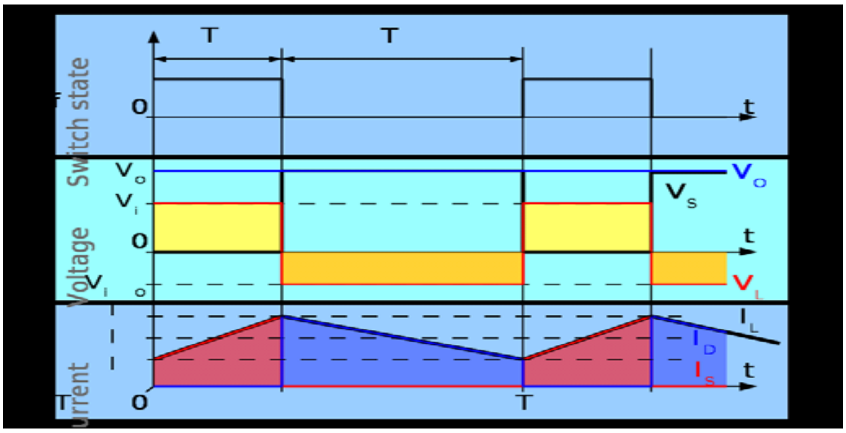


Figure 15: OPERATION IN CONTINUOUS WAVEFORMS

During the On-state, switch S is closed, and input voltage (Vi) appears across the inductor, causing a change in current (IL) flowing through the inductor during a time (t) according to the formula: $\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L}$ At the end of the on-state, the current IL increases, as a result: $\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i$ The percentage of the commutation period (T) that the switch is on is represented by the duty cycle (D). D can therefore fluctuate between 0 and 1. Switch S is open while the load is in the off state, permitting the inductor current to pass through it. The evolution of IL is as follows, assuming a diode with zero voltage loss and a large enough capacitor to maintain its voltage.: $V_i - V_o = L\frac{dI_L}{dt}$ Therefore, the variation of IL during the Off-period is: $\Delta I_{L_{Off}} = \int_{DT}^{T} \frac{(V_i - V_o)\,dt}{L} = \frac{(V_i - V_o)(1-D)T}{L}$ As we study that the converter works in steady-state situations, the quantity of energy stored in all of its components has to be equal at the start and the completion of a commutation cycle. In particular, the energy stored in the inductor is given by: $E = \frac{1}{2} L I_L^2$ At the start and end of the commutation cycle, the inductor current must remain constant, resulting in a net change of zero overall. $\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0$ Substituting $\Delta I_{L_{On}}$ and by their expression's yields: $\Delta I_{L_{On}} + \Delta I_{L_{Off}} = \frac{V_i DT}{L} + \frac{(V_i - V_o)(1-D)T}{L} = 0$ As the duty cycle increases from 0 to 1, the expression above shows that the output voltage is continuously higher than the input voltage. Additionally, when D approaches 1, the output voltage rises with D and, in theory, reaches infinity. For this reason, the converter is sometimes referred to as a step-up converter.

DISCONTINUOUS MODE

An excessive ripple current amplitude could cause the inductor to fully discharge before a commutation cycle ends. For a short while, this can result in the inductor's current dropping to zero. The output voltage equation may be significantly impacted by even a small change. The effect can be calculated using the formula below:

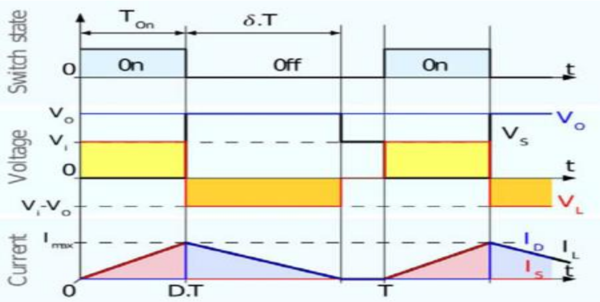


Figure 16: OPERATION IN DISCONTINUOUS MODE

Since there is no inductor current at the beginning of a cycle, its highest value $I_{L_{Max}}$ (at $t = DT$) is $I_{L_{Max}} = \frac{V_i DT}{L}$ Using the final two equations, IL decreases to zero during the off period., δ is $\delta = \frac{V_i D}{V_o - V_i}$ The average diode current (ID) equals the load current Io. In the off state, the diode current equals the inductor current. Consequently, the output current may be expressed as $I_o = \bar{I_D} = \frac{I_{L_{max}}}{2}\delta$ Substituting IL max and δ with the yields of their corresponding expressions: $I_o = \frac{V_i DT}{2L} \cdot \frac{V_i D}{V_o - V_i} = \frac{V_i^2 D^2 T}{2L\,(V_o - V_i)}$ By replacing IL max and δ with their respective expressions, the output voltage gain can be written as: ` $\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2 L I_o}$ Compared to continuous mode, the expression used to calculate the output voltage in discontinuous operation is more complicated. In this mode, in addition to the duty cycle, other variables that affect the output voltage gain include the inductor value, input voltage, switching frequency, and output current.

POWER FACTOR

The power factor of an AC electric power system is a dimensionless number between 0 and 1 that is computed by dividing the actual power delivered to the load by the circuit's perceived power. The ability of the circuit to operate at a given time is referred to as its actual power. The circuit's current and voltage are multiplied to get apparent power. There are two reasons why the apparent power will be higher than the true power: either the load stores energy that is then returned to the source or the load is non-linear and causes the current drawn from the source to have a different wave shape. In an electric power system, a load with a low power factor transfers the same amount of useful power with greater current than a load with a high power factor. Larger cables and other equipment are needed because the greater currents cause more energy to be lost in the distribution system. When there is a low power factor, electrical utilities typically charge higher rates to commercial or industrial clients due to the costs of larger equipment and lost energy. A load with a low power factor in an electric power system transfers the same amount of useable power with more current than a load having a high power factor. The increased currents in the distribution system result in more energy loss, necessitating the need for larger cables and additional equipment. Due to the higher expenditures of larger equipment and energy loss, commercial and industrial clients typically pay higher rates to electrical utilities when there is a low power factor.

LINEAR CIRCUITS

In a strictly resistive AC circuit, the voltage and current waveforms switch polarity at the same time, at the beginning of each cycle. Every watt of power that enters the load is used up. The energy storage in reactive loads, like capacitors and inductors, causes a temporal delay between the voltage and current waveforms when they are present. While a linear load may alter the relative timing (phase) between voltage and current, it does not alter the current's waveform shape.

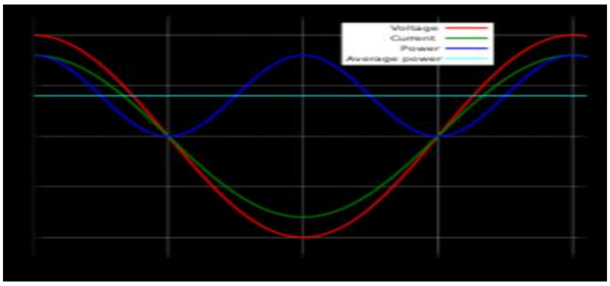


Figure 17: PURELY RESISTIVE A.C CIRCUIT

Reactive power is used by inductive loads like transformers and motors (or any kind of wound coil), where the current waveform lags the voltage. Reactive power is produced by capacitive loads, which include underground cables and capacitor banks, where the current phase leads the voltage. Both kinds of loads will take in energy from the device's magnetic or electric field for a portion of the AC cycle, store it there, and then use the remaining energy to return the energy to the source.

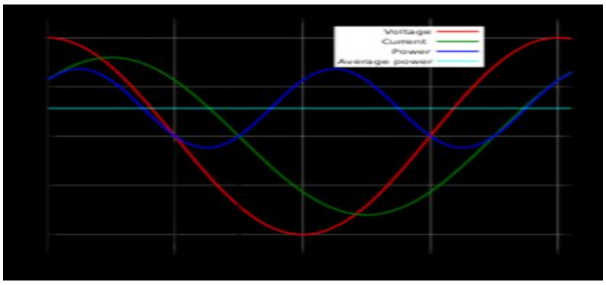


Figure 18: INDUCTIVE LOAD WAVEFORM

NON-LINEAR CIRCUITS:

Electric welding equipment, arc furnaces, and fluorescent lights are examples of non-linear loads on a power system, as are rectifiers like those found in power supplies and other arc discharge devices. The current in these systems has frequency components that are multiples of the power system frequency because switching activities interrupt the current. The average power transmitted to the load is reduced by the harmonic distortion of a load current, as indicated by the distortion power factor.

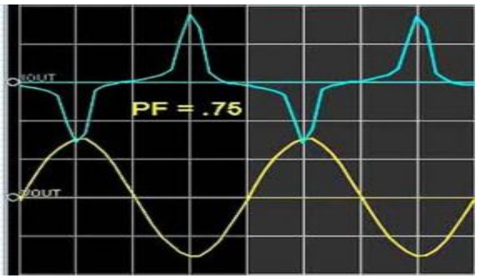


Figure 19: VOLTAGE AND CURRENT WAVEFORMS FOR NON-LINEAR LOADS

NON-SINUSOIDAL COMPONENETS:

Non-linear loads cause the current waveform to take on a different shape than a sine wave. Harmonic currents are produced by non-linear loads in addition to the initial AC current at the fundamental frequency. Harmonic currents can be kept out of the supply system by using filters made of inductors and linear capacitors. In linear circuits with sinusoidal currents and voltages at a single frequency, the phase difference between the current and voltage is the only source of power factor. This is called the "displacement power factor". The concept can be extended to an actual power factor, distortion power factor, or total power factor, where the apparent power includes all harmonic components. This holds significance in real-world power systems that comprise non-linear loads like rectifiers, switched-mode power supplies, electric arc furnaces, welding apparatus, and several other devices. When a non-sinusoidal load is drawn, a standard multimeter will read the average value of a rectified waveform, which will yield inaccurate readings. Next, the effective, RMS value is determined by calibrating the average response. The real RMS voltages and currents must be measured with an RMS-detecting multimeter. It is necessary to utilize a watt meter intended for use with non-sinusoidal currents to measure the reactive or real power.

DISTORTION POWER FACTOR

The distortion power factor shows that the harmonic distortion of a load current reduces the average power transferred to the load. $\text{distortion power factor} = \frac{1}{\sqrt{1+\mathrm{THD}_i^2}} = \frac{I_{1,\,\mathrm{rms}}}{I_{\mathrm{rms}}}$ is the entire load current's harmonic distortion. This definition assumes that there is no distortion in the voltage. In practical terms, this simplification is often a good estimate. both the overall current and its fundamental component are reported as root mean square values. The result is the displacement power factor (DPF) multiplied by the total, often known as the actual power factor or just the power factor. (PF): $\mathrm{PF} = \mathrm{DPF}\frac{I_{1,\,\mathrm{rms}}}{I_{\mathrm{rms}}}$

REGULATED POWER SUPPLY CIRCUIT

With a controlled power supply, circuits with linear integrated circuit parts can be used. Its purpose is to extract the 5 volts needed to supply DC to electrical appliances. Typically, the power source is the primary 220V AC energy supply. It is simple to design the variable-regulated power supply using an adjustable positive linear voltage regulator (LM 317 IC). Depending on the resistor values, the output voltage can be adjusted between 2- and 24-volts DC. The DC output voltage of this dual-regulated power supply is 6.8 V at maximum and 1.2 V at minimum. For proper operation, modern electronic equipment requires a wide range of DC voltage. A power supply's main function is to feed the source. The AC to DC converter, which comprises a transformer that converts the common 220V, 50Hz AC, is the fundamental component of this power supply.

SOLAR-BASED BATTERY CHARGING CIRCUIT: -

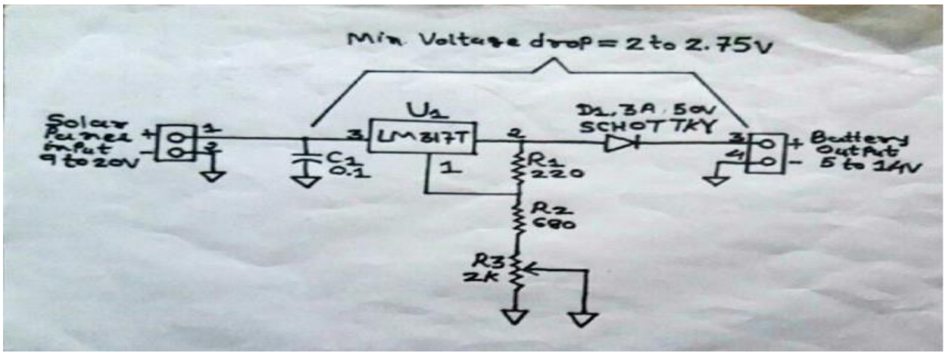


Figure 20: SOLAR-BASED BATTERY CHARGING CIRCUIT

Solar battery charger specifications

- Solar panel rating: 20W (12V) or 10W (6V)
- Output voltage range: 5 to 14V (adjustable) (may be reduced further by shorting R2)

- Max power dissipation: 10W (includes power dissipation of D1)
- Typical dropout voltage: 2 to 2.75V (depending upon load current)
- Maximum current: 1.5A (internally limits at about 2.2A)
- Voltage regulation: ±100mV (due to regulation of series rectifier)
- Battery discharge: 0mA (this control will not discharge the battery when the sun doesn’t shine)

6V Application

- Output Voltage: Set for 7V.
- Input voltage: Battery discharged (6V): 8.75V Min @ 1.5A (this is a little high for panels that are characterized for 6V applications)
- Battery charged (7V): 9V Min @ 10mA (e.g.)

12V Application

- Output Voltage: Set for 14V.
- Input voltage:
- Battery discharged (12V): 14.75V Min @ 1.5A (Available from solar panel characterized for 12V)
- Battery charged: (14V): 16V Min.

Minimum Head Voltage

It's also known as "drop-out voltage." The input voltage must be 2.75V higher than the output voltage at 1.5A. Thankfully, as the battery drains, the output voltage drops, resulting in a corresponding drop in the solar panel voltage. When the battery is fully charged, the voltage will be high, but the current will be very low. Currently, the voltage drop-out occurs to approximately 2V, and the voltage of the open circuit solar panel is also affected. The voltage drops of the Scotty rectifier, which is approximately half that of a standard silicon rectifier at 1.5A, were chosen to lower this head voltage need. More sophisticated controls will perform better in marginal circumstances and require a lot less head voltage.

Maximum Power Dissipation

The LM317T and heat sink's respective thermal resistances limit the power of this solar battery charger project. The power must be restricted to roughly 10W to maintain the junction temperature below the 125°C maximum. The maximum power dissipation needs to be de-rated if a smaller or less efficient heat sink is utilized. Thankfully, the LM317 features inbuilt temperature limitations that allow it to shut down and prevent harm if it becomes too hot. When charging a 12V battery at 1.5A, max power is applied, meaning that battery voltage equals 12V and solar panel voltage equals 18V. 18V − 12V * 1.5A = 9W is P. It is therefore closely matched to the present rating thermally. The maximum current must be lowered to roughly 0.7A if a 12V solar panel is used with a 6V battery; for example, battery voltage = 6V, solar panel voltage = 18V. 18V – 6V * 0.7A = 9.6W is P. The solar panel's power in this instance may not be more than 10W. The heat sink typically runs warm during charging. The heat sink gets hot when starting to "top off" or finishing the charge at maximum voltage. The heat sink operates cold when it is completely charged. This heat is surplus electricity that is not required when charging a battery, thus it is not technically wasted energy.

Feeder stations

Using the Autotransformer System significantly lowers the number of feeder stations needed due to the additional voltage. For example, just four feeder stations—at Cardiff, Didcot, Melksham, and Kensal Green in London will supply electricity to the Great Western Main Line. By reducing the number of feeder stations, less infrastructure, buildings, and wires are needed, which lessens the visual impact of electrification. Each feeder station typically serves two distinct electrical parts of the route, as the graphic illustrates. There are neutral sections available to keep various circuits apart. Final arrangements are now being made on the locations of feeder stations on the Trans Pennine route and the Midland Main Line.

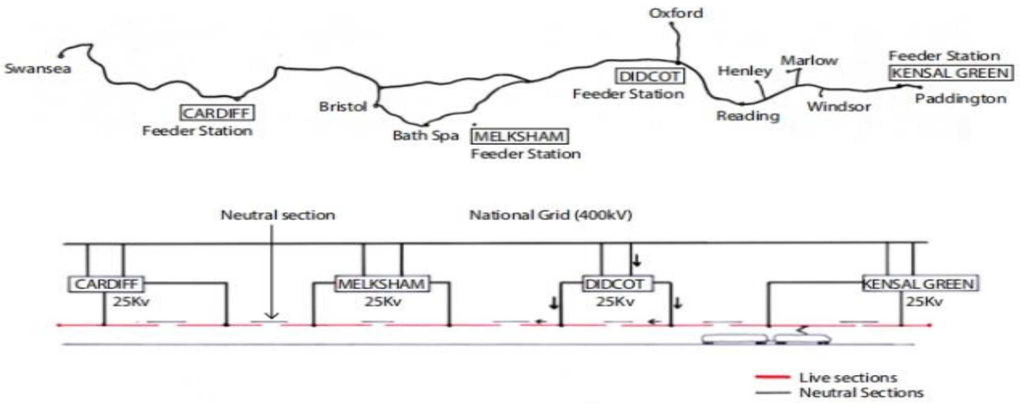


Figure 21: LOCATION OF FEEDER FOR WESTERN MAIN LINE ELECTRIFICATION PROJECT

Power Supply

A power supply that the trains can always access is the primary requirement for the electric railway. It should be inexpensive, secure, and simple to use. It can be used with either DC (direct current) or AC (alternating current); the former was easier to use for railway traction for a long time, while the latter is more cost-effective and effective over longer distances, but it was more challenging to control at the train level until recently. Power is always moved either by using an overhead wire to transfer power along the track or by using a third rail that is positioned close to the running rails to transfer power at ground level. AC systems always need overhead wires, but DC systems may use a third rail or an overhead wire. In any overhead system, the train needs to have at least one collector fastened to it for it to stay in contact with the power. Many overhead current collectors were referred to as "pantographs" until around 30 years ago when they started to be used. The return circuit is connected to the substation via running rails. The running rails are at earth potential and are connected to the substation.

Return

How is the electricity return doing? A complete circuit must exist between the energy source and the consuming item (such as a train, stove, or lightbulb) and back to the source for our railway to operate. Using the steel rails that the wheels run on is easy. If measures are made to keep the voltage from rising above the ground's zero, it functions admirably and has for the past century. Naturally, more care must be taken to shield the operating rails from interference because many trains also utilize them for signalling circuits. The return to brushes rubbing on the axle ends completes the power circuit on the train. Because they are steel, the wheels carry it to the moving rails. This is connected to the electricity substation, which is what accomplishes the task. For overhead line supplies that are DC or AC, the same method is applied.

Catenary Suspension Systems

Depending on the system, its age, location, and the speed at which trains use it, several types of catenary suspension are employed (see diagram below). The complexity of the "stitching" increases with speed, however on a high-speed path, if the support posts are sufficiently close to one another, a basic catenary will typically be adequate. A straightforward catenary that has been slightly tilted to achieve optimal contact is frequently used in modern installations. It has demonstrated good performance at up to 125 m/h. In contrast, just one wire supported by insulated supports may be present in a tram depot. It is possible to witness the wire rise and fall thanks to a pantograph that crosses it. That's all that is required. I haven't talked about trolley poles to collect current yet. Although they were once widely utilized on streetcars and trams, they are now out of use. They were employed for current collection on low-speed overhead lines. DC overhead cables are frequently thicker, and many wires are utilized in scenarios with exceptionally high loads, such as the 1500-volt DC supply system utilized by Hong Kong Mass Transit. DC mainline systems, which use up to 3000 volts overhead in some parts of France, Belgium, and Italy, may also use a third rail if the voltage is less than 1500 volts. Because there is a greater chance of the third rail being touched at ground level, it is challenging to operate. It also implies that until the current is switched off, passengers won't be allowed to walk the track if trains need to be stopped and evacuated. Third-rail routes require extra security to guarantee their safety. However, some individuals feel that the overhead centenary system is an environmental intrusion. For instance, it is prohibited to use it outside of tunnels in Singapore.

Booster Transformers

Special measures are implemented on lines that have AC overhead wires installed to minimize interference in communications cables. Uneven voltages may be induced in a communications cable if it is installed next to rails that carry the overhead line supply's return current. Uneven voltages might provide a safety risk over extended distances. Booster transformers were employed in various systems to solve this issue. These are spaced periodically throughout the route atop poles. They are connected to the feeder station by a return conductor wire that is strung from the masts and positioned approximately the same distance from the track as the overhead line. The return conductor is connected to the running rail regularly to parallel the return wire and rails. With this setup, safe voltage levels are maintained while the communications line's noise level is reduced. An illustration illustrating the configurations for 25 kV AC electrification systems using the autotransformer system (lower image) and booster transformers (upper drawing). The autotransformer system eliminates voltage drop, allowing substations to be located farther apart.

Pantograph

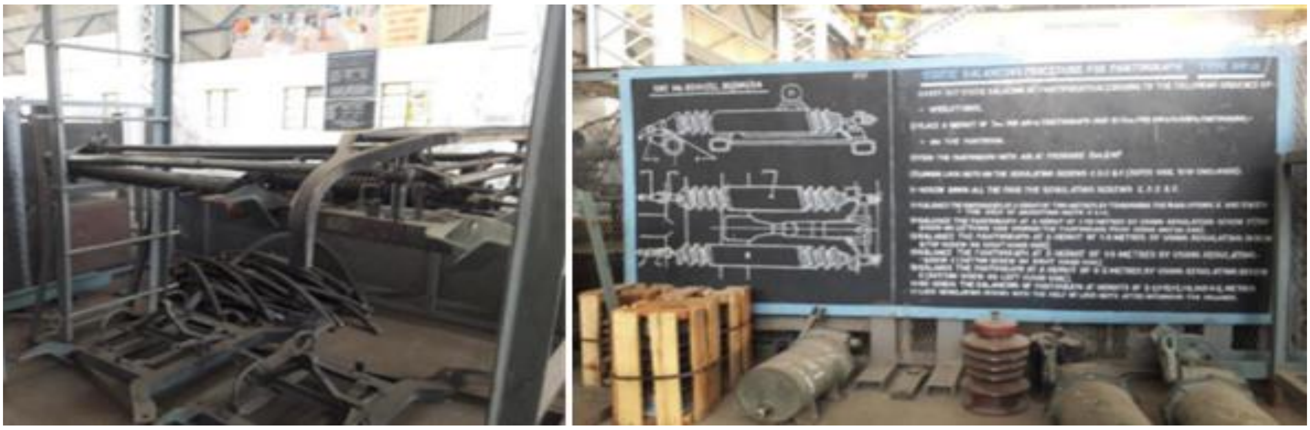


Figure 22: PANTOGRAPH & IT'S SPECIFICATION

An electric train's pantograph is a device that is installed on the roof and uses an overhead tension wire to gather power. The wire tension controls how much it lifts or drops. Usually, one wire is utilized, with the track serving as the return current. This kind of current collector is typical. Usually, only one wire is utilized, and the track carries the return current. The electric transmission system in modern electric rail systems consists of an upper, weight-bearing wire known as a catenary, from which a contact wire is strung. The spring-loaded pantograph presses a contact shoe up against the underside of the contact wire to draw the power required to run the train. The railroads' steel rails serve as the electrical return. Train movement causes the contact shoe to slide down the wire, potentially creating acoustical standing waves in the wires that weaken current collection and break the contact. This implies that contiguous pantographs are prohibited on some systems. Since they can use higher voltages than a third-rail system, even though they are more brittle, pantographs with overhead wires are still the most widely used technique of current collection for contemporary electric trains. Pantographs are often activated by compressed air from the vehicle's braking system, which lifts the unit and holds it against the conductor or lowers it when springs are employed to control the extension. In the second case, a catch maintains the arm lowered to avoid pressure loss. The same air supply is utilized in high-voltage systems to "blow out" the electric arc when using circuit breakers installed on the roof. A pantograph might have two arms or just one. Double-arm pantographs may be more fault-tolerant but also heavier and require more force to lift and descend.

MOTOR

Figure 23: TRACTION MOTOR

As seen on the left, the torque vs. speed and current relationship is linear; that is, when a motor's load increases, its speed will decrease. The features of an average motor are depicted in this graph. Long life and good performance are expected if the motor is operated at high efficiency (shown by the darkened area). If the motor is used outside of this range, high temperatures will increase, and the motor parts will deteriorate. When a motor in a locked rotor condition is continuously exposed to electricity, it will overheat and eventually fail. As a result, there needs to be some kind of defence against rising temperatures. The base rating point of a motor is somewhat less than its maximum efficiency point. Measuring the current drawn while the motor is connected to a machine whose real load value is known will yield the load torque. Once we have your details, we will choose the best motor for your application. As can be seen on the left, no load speed and starting torque fluctuate according to changes in the applied voltage. The speed properties of a voltage are parallel to those of other voltages. As a result, a DC motor can run at a voltage lower than its rated voltage. But below 1000 rpm, the motor will not run smoothly, and the speed becomes erratic. The motor we're utilizing is a 9-volt DC. This engine has a 3000-rpm speed.

Relay

Relays are electromagnetic switches that can turn on or off much greater electric currents. They are powered by relatively tiny electric currents. An electromagnet is a relay's central component. A relay can be compared to an electric lever. It's an electromagnetic relay with an iron core around a wire coil. A very low resistance magnetic flux path is supplied for the switch point contacts and the movable armature. The movable armature is coupled to the yoke, which is mechanically fastened to the switch point contacts. These pieces are firmly held in place by a spring. The spring leaves a gap in the circuit when the relay de-energizes. An iron core is encircled by a control coil. The electromagnet is powered by a control switch and connections to the load, as can be seen. When electricity flows through the control coil, the electromagnet energizes and intensifies the magnetic field. Consequently, the higher contact arm and the lower fixed arm start to draw near to one another, shutting the contacts and cutting off the load's power. Conversely, if the contacts were closed and the relay was already de-energized, the contact would move in the opposite direction and create an open circuit. A force will return the movable armature to its starting position as soon as the coil current is cut off. This force will be nearly half the magnetic force's strength. There are two primary sources of this force. They are gravity and the spring. Relays are mostly used for two functions. Applications come in two Flavors: low voltage and high voltage. Reducing the overall circuit noise will be prioritized for low-voltage applications. Their primary use in high voltage applications is to lessen an arcing issue.

The Full Wave Bridge Rectifier

An alternative type of circuit that produces the same output waveform as the full wave rectifier circuit described above is the full wave bridge rectifier. This type of closed loop "bridge" rectifier connects four independent rectifying diodes to produce the desired output. The main advantage of this bridge circuit is that it requires no special canter-tapped transformer, making it smaller and less expensive. The load is connected to one side of the diode bridge network and the single secondary winding to the other, as seen in the illustration below. The "series pairs" of four diodes, D1 through D4, are only conducting current in two diodes every half cycle. Diodes D1 and D2 conduct in series during the positive half cycle of the supply, while diodes D3 and D4 are reverse biassed, and the current flows through the load as shown below. Diodes D3 and D4 conduct in series during the supply's negative half cycle, but diodes D1 and D2 switch "OFF" since they are now reverse-biased. There is no change in the direction of the current passing through the load.

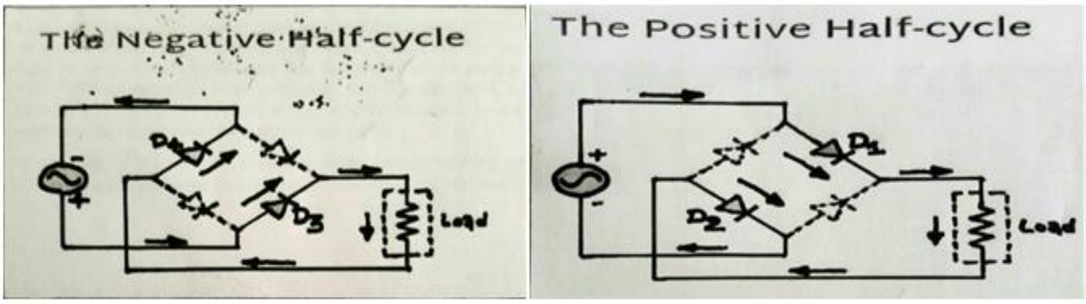


Figure 24: POSITIVE AND NEGATIVE HALF-CYCLE

Due to the unidirectional current passing through the load, just like in the previous two diode full-wave rectifiers, a unidirectional voltage is produced across it. Consequently, 0.637 Vmax is the average DC voltage across the load. The output voltage amplitude is two times smaller than the input Vmax amplitude due to two voltage dips (2 x 0.7 1.4V) caused by the current flowing through two diodes instead of just one during each half cycle. The ripple frequency with a 50Hz supply would be double the supply frequency, or 100Hz. Four independent power diodes can be used to produce full wave bridge rectifiers but pre-made bridge rectifier components are "off-the-shelf" and available in a range of voltage and current capacities. They can be soldered directly into a PCB circuit board or connected using spade connections. In the illustration on the right, a normal single-phase bridge rectifier has one corner removed. This cut-off corner indicates that the positive or +tv Output terminal or lead is the one next to the corner. The negative or -tv output off lead is on the other (diagonal) lead. The other two connecting leads of a transformer are connected to the input alternating voltage from the secondary winding.

The Smoothing Capacitor

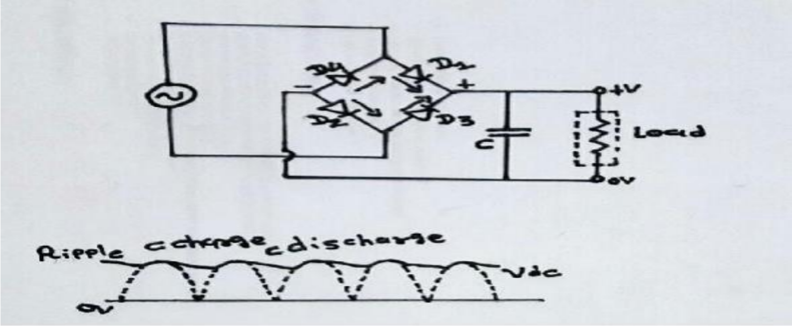


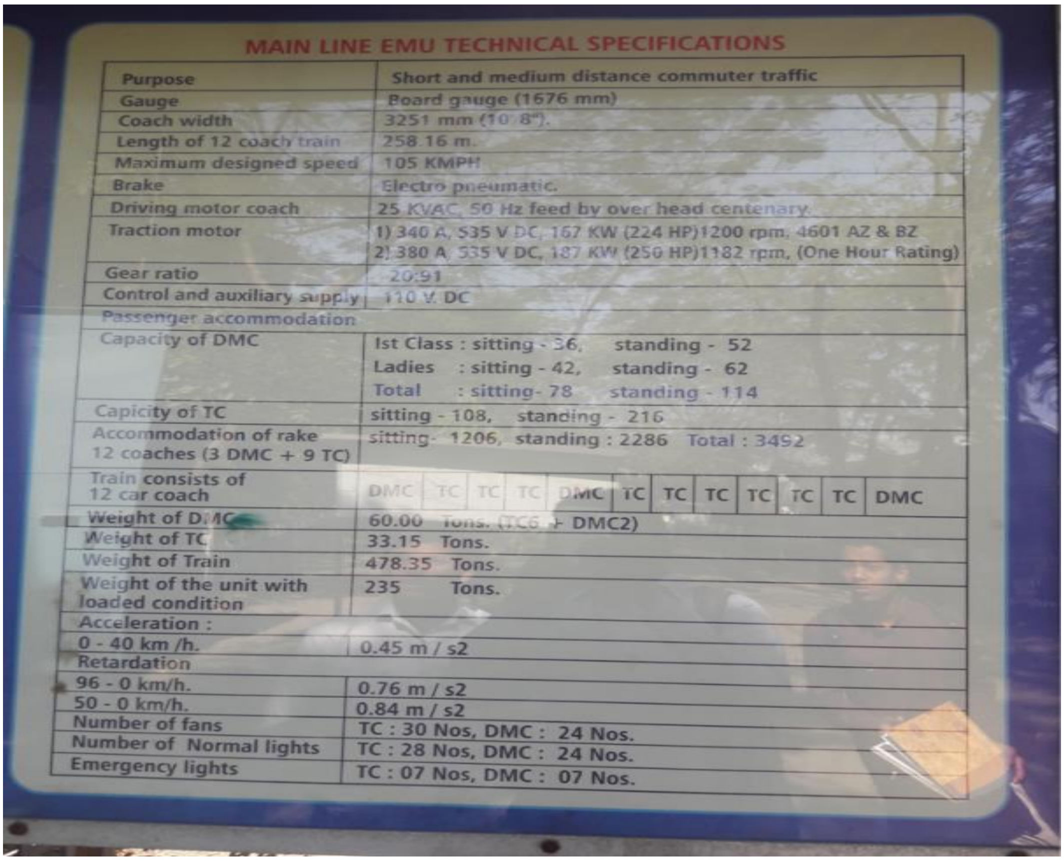
Figure 25: THE SMOOTHING CAPACITOR FILTER

As we saw in the last part, using this kind of circuit to generate a C value output wave every half cycle and that continuous DC supply was not realistic. Instead, we used a single-phase half-wave rectifier. The output waveform has less superimposed ripple but is twice as frequent as the input supply frequency. We may therefore increase the bridge's average DC out by connecting a suitable smoothing capacitor across its output, as seen below. The smoothing capacitor converts the rectifier's full wave rippling output into a steady DC output voltage. With a capacitance value of 100uF or greater, aluminium electrolytic smoothing capacitors are commonly used in DC power supply circuits. The capacitor receives a peak voltage charge from the rectifier's periodic DC voltage pulses. However, there are two important factors to consider when choosing a suitable smoothing capacitor: its capacitance value, which determines the amount of ripple that will be superimposed on top of the DC voltage, and its working voltage, which must be greater than the rectifier's no-load output value. The capacitor has very little effect on the output waveform if the capacitance value is too low. The output voltage will be almost as smooth as pure DC, though, if the load current is not too high and the smoothing capacitor is large enough (parallel capacitors can be used). We are looking for a ripple voltage peak that is smaller than 100 mV.

Overhead Line Isolator

In Britain, new OLE systems are being implemented in the railway sector. The new equipment, dubbed Series 1, Series 2, and Master Series, won't appear significantly different to the general public from the structures we are accustomed to, but it is meant to be incorporated into the network for upcoming electrification projects. These new systems include numerous technology advancements and are made to comply with European standards for train interoperability throughout the continent. To lessen the possibility of wires falling during severe weather, which seriously disrupts the East Coast Main Line, the wire tensioning system has been upgraded. For instance, the systems need less wires. However, the Autotransformer System is arguably the most important development in the context of this article. This is how power is fed into the line via feeder substations from the National Grid. The existing approach necessitates the installation of booster transformers on masts every 3 to 8 kilometres along the line, significantly disrupting the surrounding ecosystem. An autotransformer system drastically reduces the overall number of feeder substations required, negating the requirement for these booster transformers. A segment an insulator is a piece of equipment that is installed with a contact wire to insulate two basic parts where the locomotive's pantograph smoothly negotiates and keeps the current continuous. Crossovers, turnouts, repair pits, yard lines, and other applications employ it. The locomotive pantograph moves in a smooth, uninterrupted motion as it first crosses the runner and then moves to the contact wire on the opposite side. Section insulators are only used on slow-speed lines and should not be used on the main line due to their 70-mph speed restriction.

Table 5: MAIN LINE SPECIFICATIONS



MAIN LINE EMU TECHNICAL SPECIFICATIONS

Purpose	Short and medium distance commuter traffic
Gauge	Board gauge (1676 mm)
Coach width	3251 mm (10' 8").
Length of 12 coach train	258.16 m.
Maximum designed speed	105 KMPH
Brake	Electro pneumatic.
Driving motor coach	25 KVAC, 50 Hz feed by over head centenary.
Traction motor	1) 340 A, 535 V DC, 167 KW (224 HP)1200 rpm, 4601 AZ & BZ 2) 380 A, 535 V DC, 187 KW (250 HP)1182 rpm, (One Hour Rating)
Gear ratio	20:91
Control and auxiliary supply	110 V. DC
Passenger accommodation	
Capacity of DMC	Ist Class : sitting - 36, standing - 52 Ladies : sitting - 42, standing - 62 Total : sitting- 78 standing - 114
Capicity of TC	sitting - 108, standing - 216
Accommodation of rake 12 coaches (3 DMC + 9 TC)	sitting- 1206, standing : 2286 Total : 3492
Train consists of 12 car coach	DMC TC TC TC DMC TC TC TC TC TC TC DMC
Weight of DMC	60.00 Tons. (TC6 + DMC2)
Weight of TC	33.15 Tons.
Weight of Train	478.35 Tons.
Weight of the unit with loaded condition	235 Tons.
Acceleration :	
0 - 40 km /h.	0.45 m / s2
Retardation	
96 - 0 km/h.	0.76 m / s2
50 - 0 km/h.	0.84 m / s2
Number of fans	TC : 30 Nos, DMC : 24 Nos.
Number of Normal lights	TC : 28 Nos, DMC : 24 Nos.
Emergency lights	TC : 07 Nos, DMC : 07 Nos.

RESULT ANALYSIS

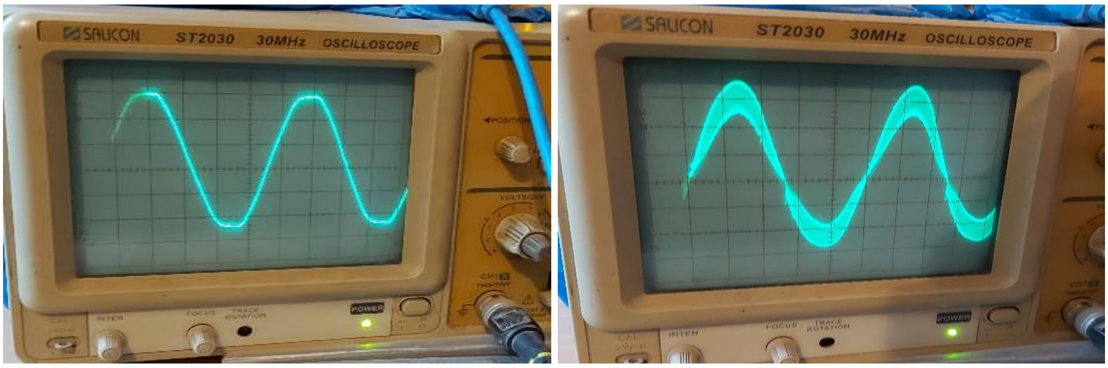


Figure 26: MAINLINE POWER SUPPLY AND SOLAR PANEL POWER SUPPLY WAVEFORM

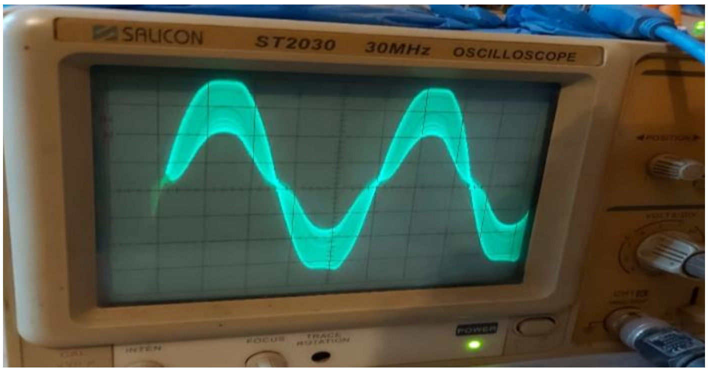


Figure 27: PARALLEL POWER SHARING POWER SUPPLY WAVEFORM

CONCLUSION

Hence initial study about the hybrid locomotive system has been done. The "ON-GRID SOLAR TRACTION SYSTEM" integrates solar and electric energy to reduce operational costs and environmental impact on locomotives. It utilizes solar power during the day, supplemented by a standby overhead line supply when needed. This provides a cost-effective energy solution for the Ministry of Railways. The system features innovative regenerative braking, enhancing operational efficiency and aligning with broader environmental goals by reducing pollution. Beyond rail transport, it promotes versatility and energy efficiency in electric transportation. In summary, the system serves as a sustainable transportation model, showcasing the synergy between solar and electric power. Its successful implementation could revolutionize energy use in transportation, establishing a cleaner and more economically viable future. The application has been put forward.

FUTURE SCOPE

Based on prevailing patterns, rail seems to have a promising future. Global concerns about climate change combined with growing demand for passenger and freight capacity are causing something of a rail revival worldwide. There are obstacles to be addressed, not the least of which is constructing the necessary capacity in a timely manner and at a price that the market can bear. The motor, a PMSM, is employed with the goal of increasing efficiency. In terms of structure, a modular design has been implemented to facilitate future installation of higher-performance storage batteries and to make maintenance easier and more feasible.

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