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Moment of inertia is infinite in a Infinite bus bar system.

Stand Alone Energy System ⇒

It is located at the load center & dedicated to meet all the electrical loads of a village/community or a specific set of loads.

Energy storage is generally essential. It is most relevant & successful in remote & rural areas having no access to grid supply.

Indicative.

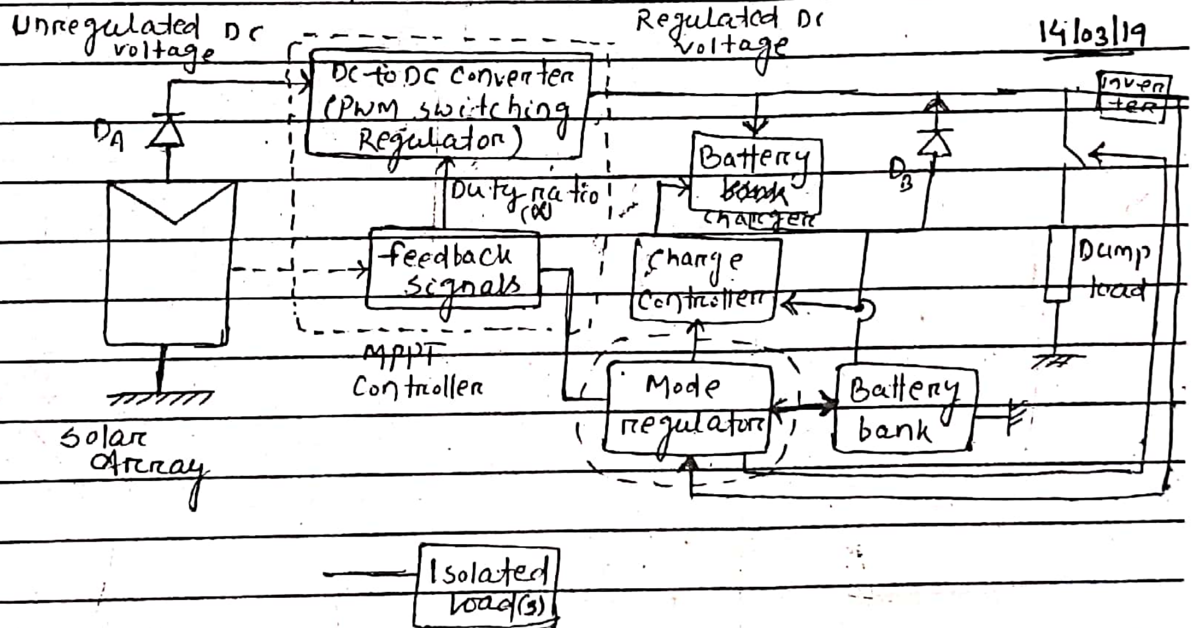
Stand alone solar PV system ⇒

(i) Solar thermal

(ii) Solar Photo voltaic

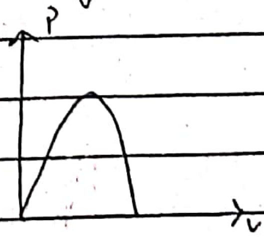
14/03/19

18%



Typical diagram of stand alone solar PV system.

MPPT ⇒ Maximum Power Point Trackter

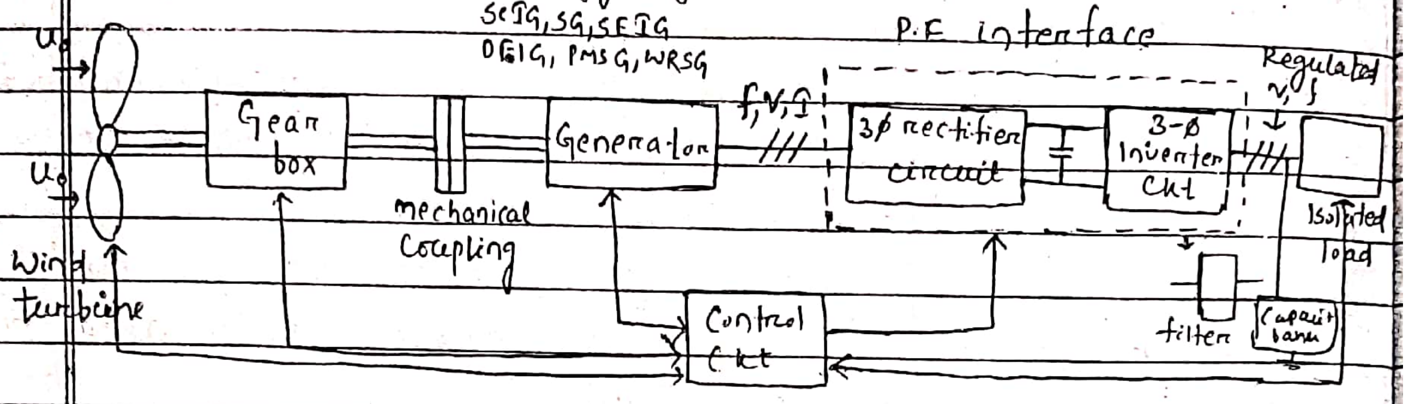


D_A ⇒ Diode of solar Array

D_B ⇒ " " Battery bank

⟷ ⇒ hall effect sensor

Stand Alone Wind Energy system →



→ (Cut in speed & Cut out speed) → Blade angle & control
⇓ must be maintained below limit

→ tip control

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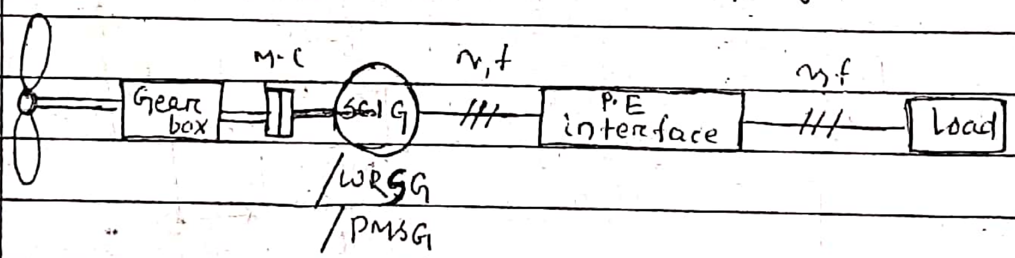
(i) SCIG based standalone wind energy system →

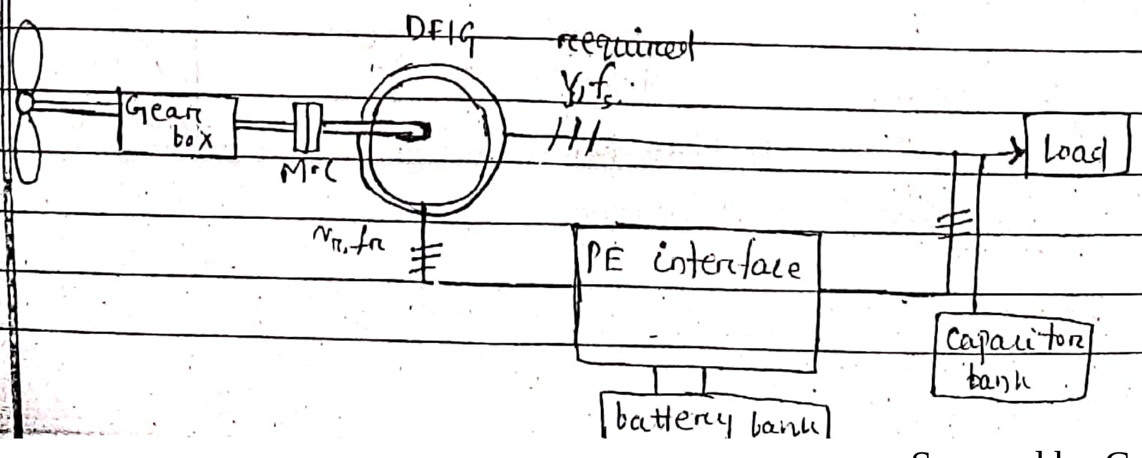


synch speed ≥ ~~Acts as~~ Generator
sych speed ≤ motor

(ii) PMSG based standalone wind energy system →
same as above

(12-15 m/s) cut out
(3m/s) cut in
(speeds)

(iv) DFIG → Wound Rotor induction Generator



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≥ 30kHz, MOSFET is used $V_R = SV_i$

≤ 30kHz, Power IGBT $f_R = Sf_s$

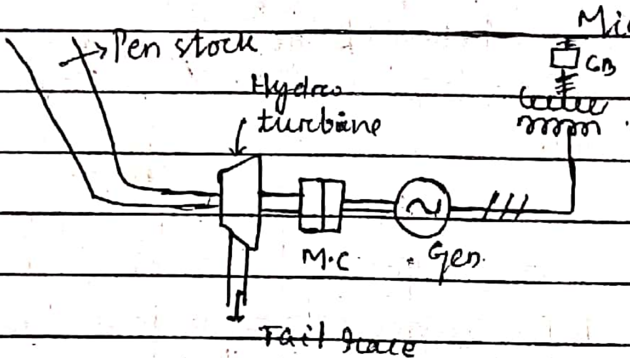
Advantages & Disadvantages 26/03/19

stand alone micro hydal system →

small hydro < 1MW - 10MW

Mini Hydal < 100kW - 1000kW

Micro " < 100 kW



Diesel generator system →

Solar } DC-AC 27/03/19

wind } AC-DC-AC.

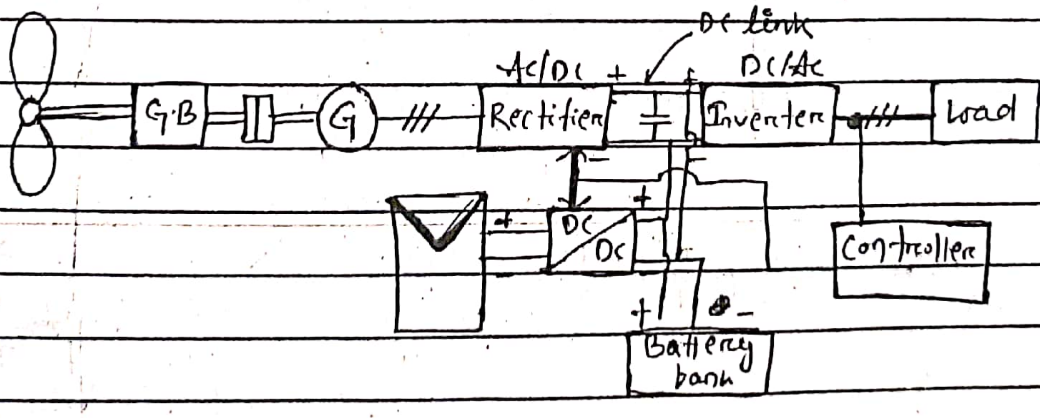
AHEC → Alternate Hydro

Micro hydal } Ac

Diesel } Ac

Hybrid systems →

1→ Solar & Wind hybrid system →



Duty ratio (S) = $\frac{T_{ON}}{T}$

Wind energy system → Book →

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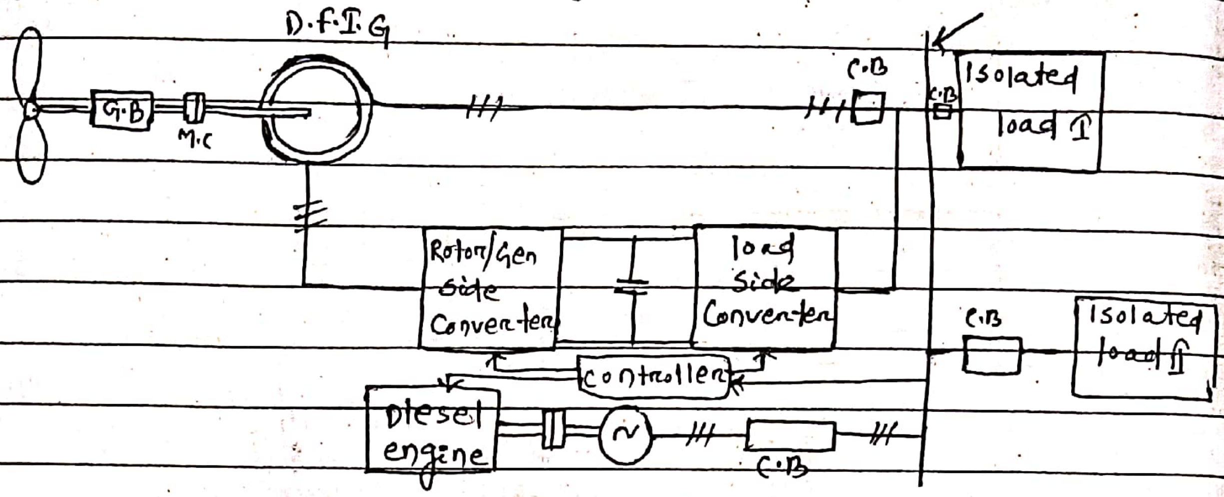
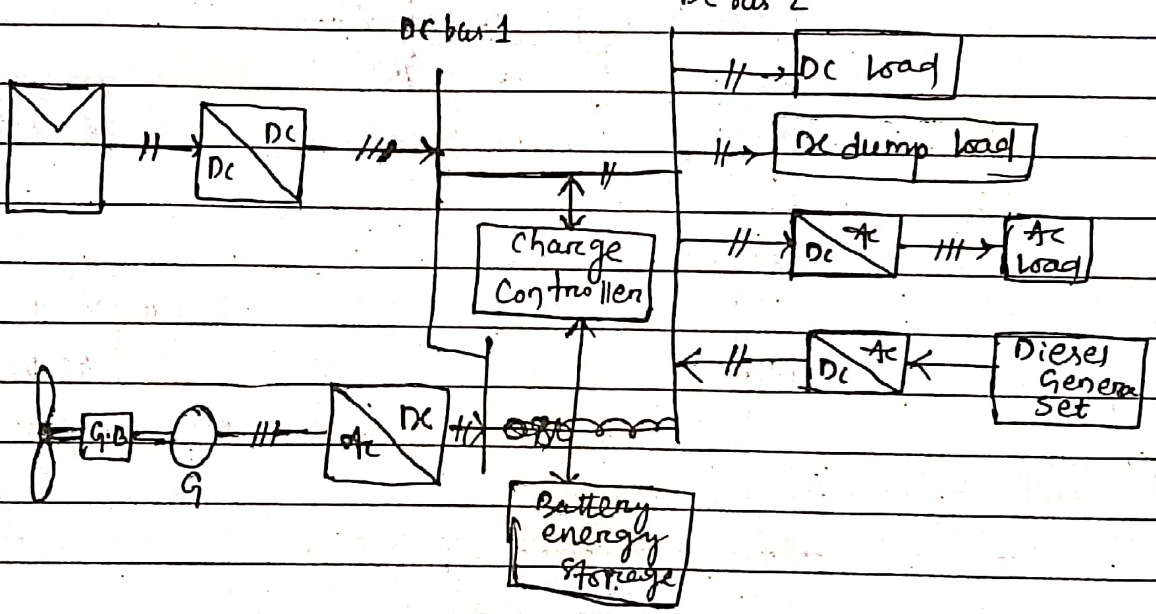
Hybrid wind & diesel Gen system →





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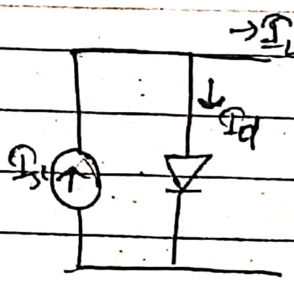
$$I = I_0 e^{\left(\frac{V}{V_T} - 1\right)}$$

$$I = -I_{sc} + I_0 e^{\left(\frac{V}{V_T} - 1\right)}$$

$$V_{oc} = V_T \ln\left[\frac{I_{sc}}{I} + 1\right]$$



$$I = -I_{sc} + I_d$$

$$P = \frac{1}{2} \rho u^3 A$$

$$V_T = kT/q$$

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Energy storage system →

Energy can be stored in various form. ~~the~~ some of the important energy

(1) Mechanical energy storage → (i) pumped
(ii) compressed air storage
(iii) fly wheel

(2) Chemical energy storage → (i) battery
(ii) hydrogen
(iii) Reversible chemical reaction

(3) Electromagnetic energy

(4) Electrostatic

(5) Thermal / heat energy

(6) Biological storage.

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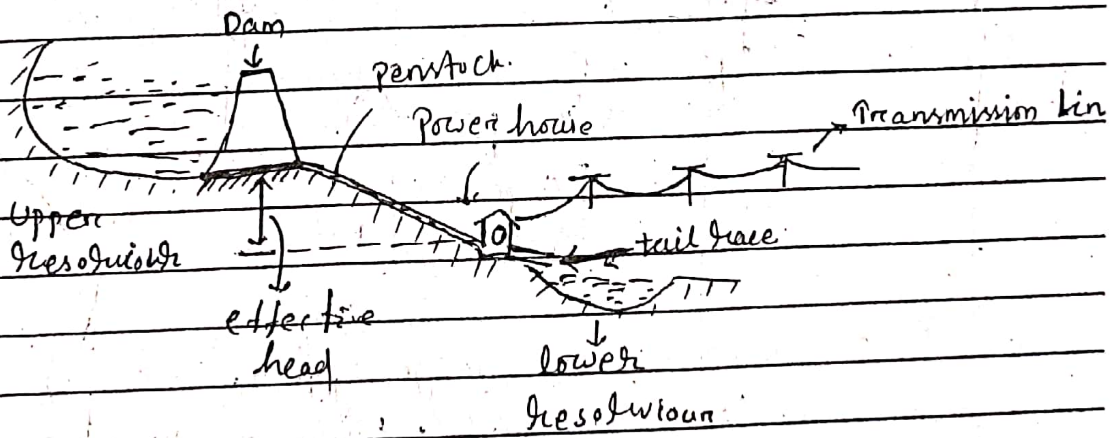
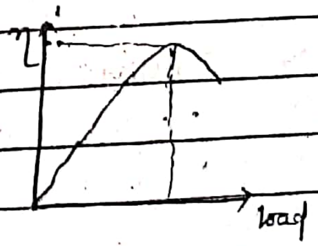
(i) **Pumped storage system →**



(i) Pumped storage is the most successful, economical & widely used energy storage technology.



(ii) Electrical power in excess of immediate demand is used to pump water from a supply (lake, river, lower reservoir).

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at a lower level to a reservoir at a higher level.

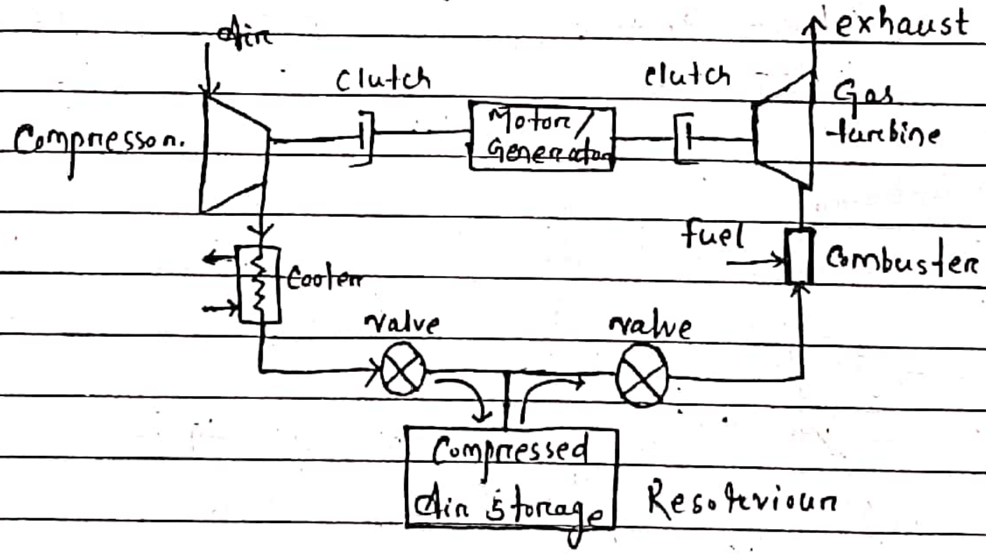
(iii) During peak demand period when the demand exceeds the water is allowed to flow backwards through a hydraulic turbine which drives an electrical generator & produces power to meet additional demand.

(iv) In most pump storage plants, the turbine generation system is reversible & can ~~pump~~ serve to pump water as well.

(v) The overall energy recovery efficiency of pumped storage plant i.e. the recovered electrical energy or gas a % of electrical energy used to pump water is about 70%.

11/04/19

Compressed air storage →



In a compressed air storage system, excess electrical energy is used to compress air, which is stored in a reservoir to be used later in the combuster of a gas turbine to generate electrical power.

In a gas turbine, roughly 60% of power of o/p is consumed in compressing air for combustion of the gas. Compressed air can also be used to produce mech o/p through an air turbine.

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Excess electrical power during immediate demand is supplied to the motor/generator unit which drives the compress. The compressed air (at about 70 Atm pressure) is stored in a suitable resorviour.

The air is heated during compression & may have to be cooled prior to storage in order to prevent damage of the resorviour walls. When additional power is needed to meet the demand, the compressed air is released & heated in a combuster using gas or oil fuel. The hot compressed air is then expanded in a gas turbine connected to the motor/generator unit which now acts as generator.

The overall recovery efficiency is 65%-70%.

Clutch is used for coupling & decoupling of motor/generating unit with the compressor/turbine unit respectively.

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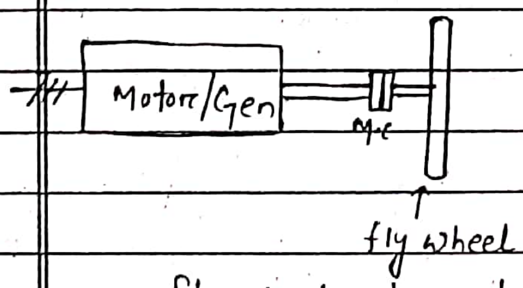
Flywheel Energy Storage →



Flywheels have been extensively used to smooth out power pulses from reciprocating engine. The same principle may be extented to store surplus electric energy.

A specially designed flywheel called as superfly-wheel is used for energy storage. The fly wheel driven by a electric motor during off peak hours stores mechanical energy (K.E) as its speed is increased.

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The stored energy may be retrieved when required to produce electrical energy by coupling a generator to it. The same machine serves both as a motor when electrical energy is supplied to it & as a generator when the flywheel serves as a prime mover & electrical energy is regenerated.

The energy recovery efficiency is estimated to be up to 90%.

ω = Angular velocity (rad/s)

$K.E = \frac{1}{2} m v^2$ (linear)

$= \frac{1}{2} I \omega^2$ (Angular).

$[I = \frac{1}{2} m a^2]$ (a = radius)

I = Moment of Inertia

The K.E of rotation of an object is ($K.E = \frac{1}{2} I \omega^2$).

$\therefore K.E = \frac{1}{4} m a^2 \omega^2$

Thus energy density of an object is $\boxed{\frac{K.E}{m} = \frac{1}{4} a^2 \omega^2}$

When energy is added to the flywheel its speed rises to a higher value. Similarly when energy is retrieved its speed falls. For a flywheel to serve as a useful store/source of energy (and not just a smoothing device) it must rotate as fast as possible.

However its angular velocity is limited by the strength of the material which has to resist the centrifugal forces fling it apart.

Advanced (or super) flywheels are those which operate at a very high speed have high mechanical strength & low friction losses. For eliminating bearing friction the rotor can be magnetically levitated by permanent magnets. Wind friction is eliminated by putting the flywheel in a shield vaccum chamber. These super flywheels are used for storing mechanical energy for long & short term basis.

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Chemical Energy storage →

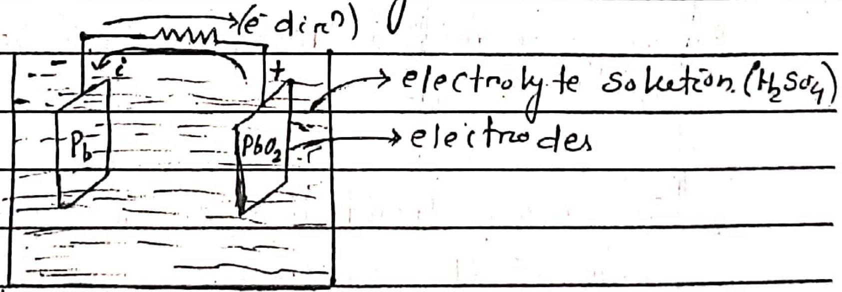
(a) **Battery storage** → A storage battery receives electrical energy as direct current & stores it in the form of chemical energy by a reversible electrochemical reaction.

On connecting to the electrical load, its supplies electrical energy by converting the stored chemical energy in to electrical energy as direct current.

Thus both i/p & o/p are electrical in form although storage is a chemical form.

The energy recovery efficiency depends upon the type of battery & rate of discharge. The typical value is around 75%.

The most widely used storage battery is Led-Acid based battery invented by Gaston Plante in 1859. The led-acid battery technology has attained maturity & having high performance over cost ratio, Even though it has the least energy density by weight & volume as compared to other rechargable batteries.



$H_2SO_4 \longrightarrow H^+ + HSO_4^-$

$Pb + HSO_4^- \longrightarrow PbSO_4 + H^+ + 2e^-$ (discharging eqⁿ)

$PbO_2 + HSO_4^- + 3H^+ + 2e^- \longrightarrow PbSO_4 + 2H_2O$ (charging eqⁿ)

The e.m.f of a lead acid battery depends upon the concentration of H_2SO_4. The voltage of a fully charged cell is close to 2.1V.

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And specific gravity of electrolyte is ~~2.18~~ 1.6–1.8 at 25°c.

On discharge the sulphuric acid is consumed by both electrode as both Pb & PbO_2 are converted into $PbSO_4$ (lead sulphate) water is produced which dilutes the acid. with reduced acid concentration, the emf of cell also decreases slowly.

The cell is generally regarded as fully discharged when the specific gravity is about 1.08 at 25°c & the emf is roughly 1.7v. both a.c concentration & emf are stored when the cell is charged

Lead acid batteries are commonly used as mobile source of energy for SLI (starting, lighting, ignition). systems of automobile.

Advantages→ 1/05/19

(i) These are modular in nature & are easily adaptable to any type of storage with varying capacity.

(ii) These are capable of rapid reversal of operation. betn charging & discharging. This makes the battery specially convinient for electrical applications.

(iii) They permit dispersed distribution by locating storage facilities near load.

Limitations→

(i) The main limitation of batteries are high cost & short life of the battery.

(ii) An ordinary battery can't be allowed to discharge more than 50% of its stored energy. such a discharge is known as deep discharge.

Sometimes it is not possible to recharge or revive the battery after a deep discharge because if the discharged reaction is allowed to go to completion, all the lead may be consumed & there would be no electrode left for reverse reaction.

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Similarly if the concn of H_2SO_4 is allowed to fall too low, the electrolyte ceases to be an adequate conductor.

(iii) Heavy weight of the battery is another problem. Non active materials (separators, battery case, water etc) contributes significantly to the total weight of the battery. Therefore the energy density of the battery is low.(typically 0.09 MJ/kg)

(iv) The cost of battery storage is high.

(v) The internal impedance of a battery is high which causes voltage fluctuation during transient load.

Other types of rechargable batteries used for mobile applications are (i) NiCd battery
(ii) Nickel metal hydride battery
(iii) lithium ion
(iv) " polymer
(v) Zinc Air battery

Lithium ion battery:

This is a recently developed technology & offers '3' times the energy density over that of a lead acid battery. This is due to low atomic weight of 6.9 vs 207 for lead.

(i) Higher cell voltage of 3.5v vs 2v for lead acid battery cell. Therefore this requires fewer cells in series for a given battery voltage. thus cost, size reduces.

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Hydrogen storage →

Energy can be stored & transported as hydrogen which serves as a secondary fuel. The i/p energy usually electrical serves to decompose water by electrochemical reaction (electrolysis) into hydrogen & oxygen. These substances can be combined to release the stored energy as required.

$$H_2O \longrightarrow 2H^+ + O^-$$

Instead of using the oxygen produced from water oxygen from air is commonly used. The pure oxygen from water can then be sold for industrial applications.

The chemical energy in hydrogen (oxygen) can be converted into thermal, mechanical or electrical energy. One possibility is to burn hydrogen in air in a similar manner (to natural gas) to produce thermal energy for use in home/industries.

Hydrogen can also serve as fuel in place of gasoline in automobiles to obtain mechanical energy. Hydrogen fired steam turbines can also be used to obtain mechanical energy. Electrical energy can be generated from mechanical energy thus obtained using a generator. Electrical energy may also be obtained efficiently at about 55-60% conversion efficiency directly from hydrogen by means of a fuel cell.

Hydrogen can be stored in 3 ways. (1) gas form →

Hydrogen in large quantity can be stored in underground caverns such as those from which natural gas has been extracted. But storage of hydrogen gas even if compressed is bulky. It occupies more volume than natural gas.

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(2) Liquid form → Hydrogen can be liquified for storage but since its boiling point is 20K, therefore its storage are difficult to maintain due to refrigiration requirme

(3) Metal hydride form → Hydrogen can be stored as reversible metal hydrides in large volumes. When required hydrogen is released by heating the hydride.

ex → $Mg_2Ni + 2H_2 \underset{Discharge}{\overset{Charge}{\rightleftharpoons}} (Mg_2Ni)H_4 + Heat.$

This reaction is reversible & the hydride stored can be replanished with hydrogen. A portable hydride store can be used for distribution of energy like a conventional mobile fuel tank.

The store can be replanish with hydrogen at a central filling station. The main difficulty is the weight & cost of the metals used.

7/05/19

Reversible chemical reaction storage →

Thermal energy can be stored in chemical bonds by means of by reversible thermo chemical ~~energy~~ reaction.

Electromagnetic energy storage → (Super conducting magnetic energy storage/SMES) →

In this system energy is stored in a magnetic field. As an example a coil with an inductance of 300 Henry carrying a current of 5000 Amp can store energy of $E = \frac{1}{2} L I^2 = 3.75 \times 10^9 J$ (which is nearly 1 MWh $= 3.6 \times 10^9 J$) in its magnetic field.

Under ordinary cond's, losses result from the resistance of the wire of inductor and energy must be supplied to maintain the required current. However if the resistance of the wire is made 0 the current

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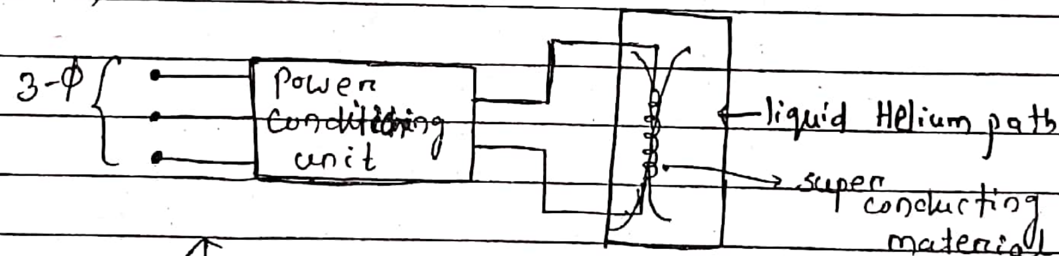
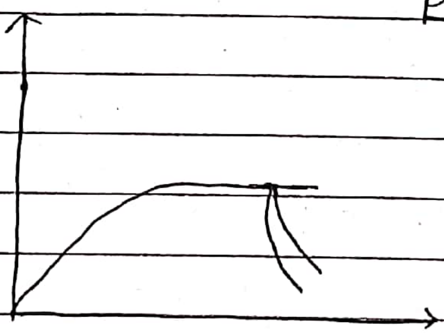
would remain almost constant. Therefore the stored energy in the magnetic field would be maintained indefinitely. By connecting the coil to a load, the stored energy can be recovered as electrical energy.

Electromagnetic energy storage requires the use of superconducting materials. These materials suddenly lose the resistance to the flow of electric current when cooled blow a critical / transition temperature. All superconducting materials have transition temperature in the cyrogenic range (low temperature of the order of 0'K (-273°c) to -150'c or 0'k to 123'K).

In the SMES the coil is immersed in a cyrogic fluid like liquid Helium, is charged by pumping direct current.





The current then is keep on circulating & there results a high magnetic field standing the coil. ~~This gives rise to~~

Useful superconducting material available commercially are niobium-titanium (Nb-Ti) alloy at temperature below -263'c & a compound of niobium & tin (Nb_3Sn) below -255'c

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A number of problems associated with SMEs are

(i) operation & maintainance of cryogenic (refrigeration plant) for producing the liquid Helium required for low temperature.

(ii) special structures are to be needed to withstand strong magnetic field or forces.

One very interesting SMEs being used by the Bonnville power administration in USA has the following details (i) Maximum power capability (10MW)

(ii) Maximum storage capacity (30 MJ) = 8.33 kWh

(iii) Coil current at full charge is 4.9 kAmp, maximum Coil terminal voltage 2.18 kV.

(iv) Coil operating temperature 4.5 kelvin.

(v) Magnetic field strength 2.8 Tesla.

8/05/19

Electrostatic Energy storage →

A capacitor stores energy in an electrostatic field when charged. To store a significant amount of energy a very large capacity of capacitor known as super/ultra capacitor is required (in kFarad range).

The capacity of a capacitor can be increased by increasing the area of plates & minimizing the distance between them. This is achieved in ultra capacitors by coating a lair of activated porus carbon on metal foil eclectrodes. These foils are separated by a paper separator & dipped in an electrolyte. The paper separator prevents electrical connection betn the electrodes but allows free movement of ions across it.

There are at present about 10 manufractures of ultra capacitors. Ness cap is producing a unit of 5k farad at 2.7v in package.

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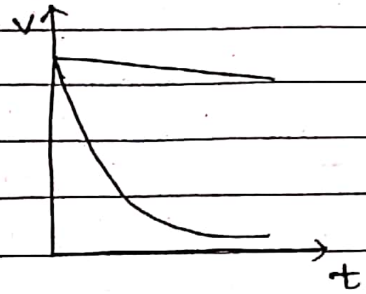
A super capacitor is having much better life cycle. (typically about 500000 cycles). These compared to batteries

These ultra capacitors can be charged in seconds rather than hours (as in case of battery). And can function at more extreme temperatures.



Commercially available ultra capacitors can store about 3-4 watt hour per kg compared to 60-70 watt hour/kg in Ni-metal hydride battery or 110-130 wh/kg in Lithium-ion battery.

An ultra capacitor with battery would be irresitable to a large number of user specially hybrid electric vehicle. With their light weight, fast charging & discharging capabilities, ultra capacitors could handle the power surges needed ~~the~~ for acceleration. ~~Similarly~~ In fuel cell powered cars ultracapacitor make a very important role because fuel cells deliver power to slowly to accelerate a full sized car which can be overcome by coupling the fuel cell with ultra capacitors.

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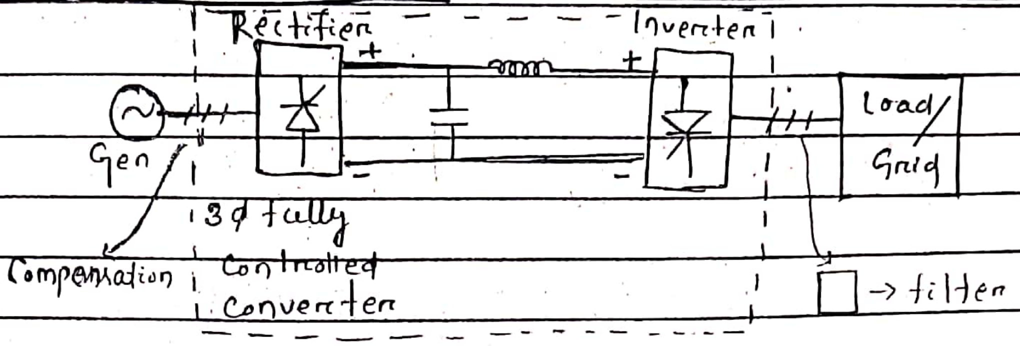
Power Electronics Interface →



Converter

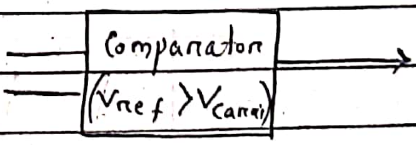
- Rectifier
  - 1φ
    - half wave
      - +ve half wave uncontrolled
        - +ve half wave
        - −ve half wave
      - controlled
        - +ve
        - −ve
    - full wave
      - uncontrolled
        - mid point
        - bridge type.
      - semi controlled
      - fully controlled
  - 3φ
- Inverter

14/05/19

	IGBT	MOSFET
switching losses	High	low
Conduction losses	low	high

PWM Technique →

Carrier wave (kHz)
Reference " (50 Hz − 60 Hz)



reducing pulse width decreases o/p voltage.

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There are

PWM inverters ⇒

The square wave inverter suffers from two major drawbacks.

(i) for fixed square voltage the o/p voltage of inverter can't be controlled. To achieve voltage control the inverter must be fed either from a controlled ac/dc converter. ~~then~~ or using a dc-dc ~~PWM~~ converter.

(ii) The o/p voltage contains appreciable amount of harmonics of low frequency range.

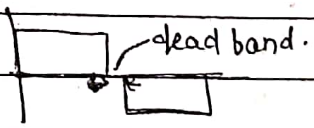
To achieve voltage control within the inverter & to reduce the lower order harmonic content in the output voltage PWM inverter's are used. In PWM inverters width of o/p pulses are modulated to achieve the voltage control.

There are number of modulation technique. 21/05/19
The simple modulation technique is (i) single PWM, (ii) second is multipulse / uniform PWM.

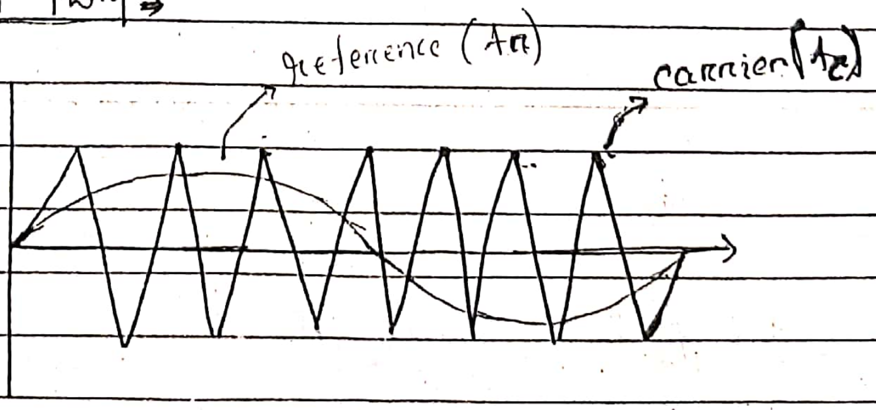
(iii) sinusuidal PWM

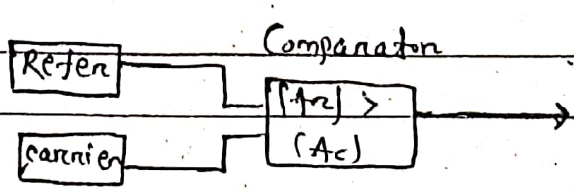
(iv) Modified sinusoidal PWM

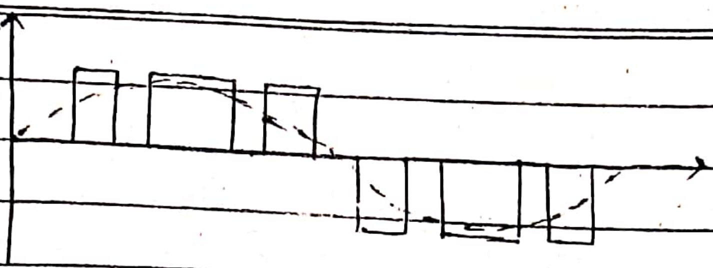
(v) Phase displacement control.



Sinusoidal PWM ⇒

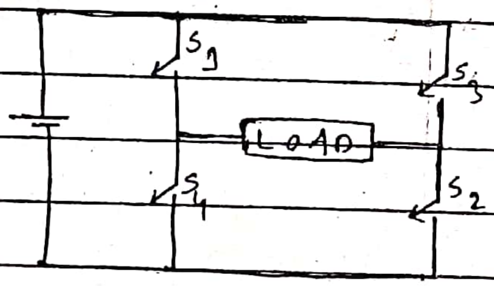


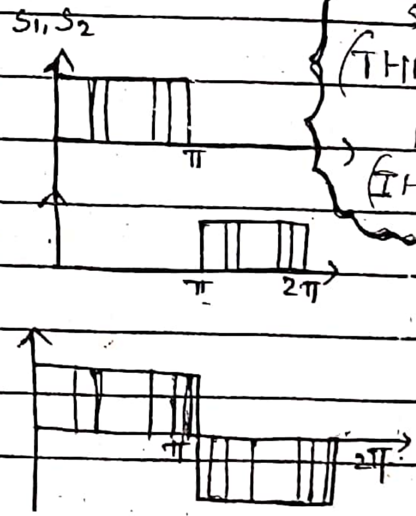




The width of each pulse is varied in proportion to the amplitude of a sine wave. The distortion factor or distribution factor & low order harmonics are reduced significantly.

The gating signals are generated by comparing a sinusoidal reference wave with a triangular carrier ~~the~~ wave of frequency (fc). The rms o/p voltage is given by





Should be (THD ≤ 5%)
Individual (THD ≤ 3%)

→ Voltage THD is more (> 48.3%) but current THD is less for PWM. (≤ 5%)