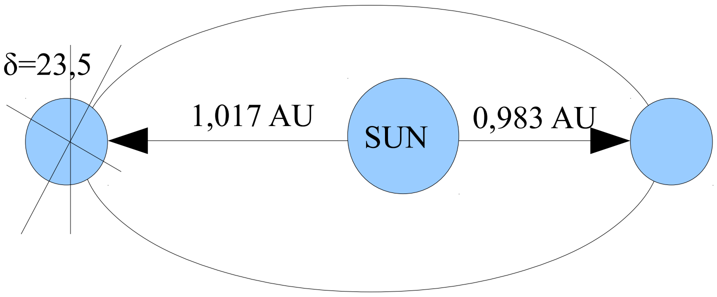
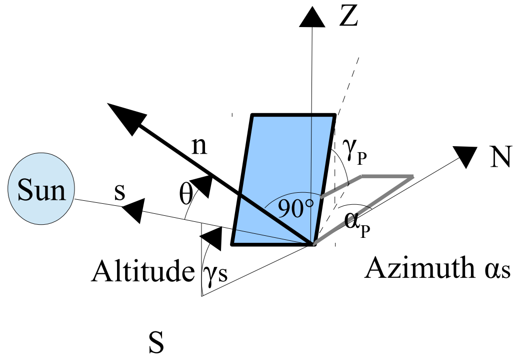
POSITION OF THE SUN





$$J' = 360° \cdot \frac{J}{365}$$

$$\delta = (0{,}3948 - 23{,}2559 \cdot \cos(J' + 9{,}1°) - 0{,}3915 \cdot \cos(2 \cdot J' + 5{,}4°) - 0{,}1764 \cdot \cos(3 \cdot J' + 105{,}2°))$$

$$TEQ = (0{,}0066 + 7{,}3525 \cdot \cos(J' + 85{,}9°) + 9{,}9359 \cdot \cos(2 \cdot J' + 108{,}9°) + 0{,}3387 \cdot \cos(3, J' + 105{,}2°))/60 \cdot h.$$

$$\text{Mean Local Time } MLT = (HourOFDay - TZ + 1\text{h} - 4 \cdot (15° - \alpha)/60°)\, h$$

$$\text{Ture Local Time } TLT = MLT + TEQ$$

$$\text{Angle } \omega = (12.00\text{h} - TLT) \cdot 15°$$

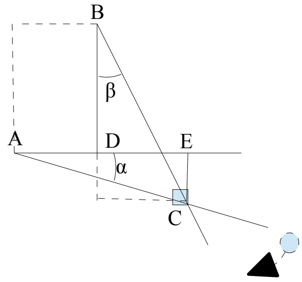
$$\gamma_s = \arcsin(\cos(\omega) \cdot \cos(\varphi) \cdot \cos(\delta) + \sin(\varphi) \cdot \sin(\delta))$$

$$\alpha_s = \begin{cases} -\arccos\left(\dfrac{\sin(\gamma_s) \cdot \sin(\varphi) - sind(\delta)}{\cos(\gamma_s) \cdot \cos(\varphi)}\right) & \text{für } TLT \leqslant 12 \\ +\arccos\left(\dfrac{\sin(\gamma_s) \cdot \sin(\varphi) - sind(\delta)}{\cos(\gamma_s) \cdot \cos(\varphi)}\right) & \text{für } TLT > 12 \end{cases}$$

$$\alpha = \arctan\left(\frac{EC}{EA}\right)$$

$$\rightarrow \alpha_S = \alpha + 90°$$

$$\beta = \arctan\left(\frac{DE}{BD + EC}\right)$$



Power and Energy from the Sun

$$\text{Irradiation Power Density } \dot{G} = \sigma \cdot \varepsilon \cdot A \cdot T_s^4$$

$$\text{Irradtiation Power Density Sun}: \dot{G}_s = \frac{\dot{G}}{A} = \sigma \cdot \varepsilon \cdot T_s^4 = 5{,}67 \cdot 10^{-8} \frac{W}{m^2 \cdot K^4} \cdot 1 \cdot (5777\,K)^4 = 63{,}15 \frac{MW}{m^2}$$

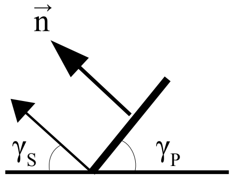
$$\text{Solar Constant}: \dot{G}_0 = \dot{G}_s \cdot \frac{4\pi \cdot R_s^2}{4\pi \cdot (AU)^2} = 63{,}15 \frac{MW}{m^2} \cdot \frac{(0{,}6963 \cdot 10^6\,km)^2}{(149{,}6 \cdot 10^6\,km)^2} = 1368 \frac{W}{m^2}$$

$$\text{Irradiance } G = \int_T \dot{G} \cdot dt$$

Transformation of irradiation

$$\vec{n} = \begin{pmatrix} r \cdot \sin(90° - (90° - \gamma_P)) \cdot \cos(\alpha_P) \\ r \cdot \sin(90° - (90° - \gamma_P)) \cdot \sin(\alpha_P) \\ r \cdot \cos(90° - (90° - \gamma_P)) \end{pmatrix} = \begin{pmatrix} \sin(30°)\cos(30°) \\ \sin(30°)\sin(0°) \\ \cos(30°) \end{pmatrix} = \begin{pmatrix} (1/2) \\ 0 \\ (1/2) \cdot \sqrt{(3)} \end{pmatrix} \wedge |\vec{n}| = 1$$

$$\vec{s} = \begin{pmatrix} r \cdot \sin(90° - \gamma_s) \cdot \cos(\alpha_s) \\ r \cdot \sin(90° - \gamma_s) \cdot \sin(\alpha_s) \\ r \cdot \cos(90° - \gamma_s) \end{pmatrix} \qquad \cos(\theta) = \frac{\vec{s} \circ \vec{n}}{|\vec{s}| \cdot |\vec{n}|} \qquad \dot{G}_{Tot} = \dot{G}_{dir} + \dot{G}_{dif} + \dot{G}_{ref}$$



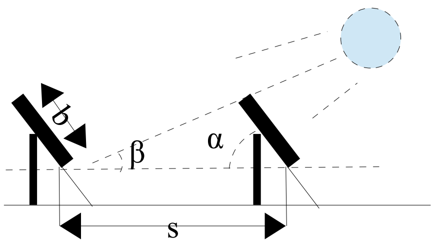
$$\text{Direct Radiation}: \dot{G}_{dir,tilt} = \dot{G}_{dir,hor} \cdot \frac{\cos(\Theta)}{\sin(\gamma_s)} \qquad \dot{G}_{Tot} = \dot{G}_{dir,tilt} + \dot{G}_{dif,tilt} + \dot{G}_{ref,tilt}$$

$$\text{Diffuse Radiation}: G_{diff,tilt} = \frac{1}{2} \cdot G_{diff,tilt} \cdot (1 + \cos(\gamma_P)) \cdot (1 + F \cdot \sin^3(\frac{\gamma_P}{2})) \cdot (1 + F \cdot \cos^2(\theta) \cdot \cos^3(\gamma_s))$$

$$\text{Cloudness Function}: F = 1 - \left(\frac{G_{diff,hor}}{G_{total,hor}}\right)$$

$$\text{Ground Reflection}: G_{ref,tilt} = \frac{G_{tot,hor} \cdot A_{Albedo} \cdot 1}{2} \cdot (1 - \cos(\gamma_P))$$

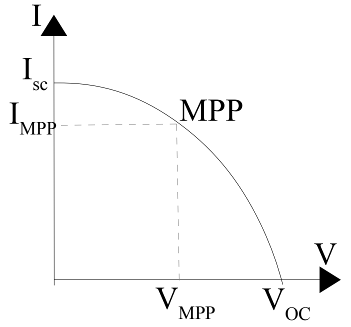
Shading



$$s = \frac{b \cdot \sin(180° - (\alpha + \gamma_S))}{\sin(\gamma_S)}$$

Photovoltaics Basics Modules and Generators

Photovoltaic Effect



$$Plank's\,quantum: h=6{,}62\,codt\,10^{-34}\,Ws^2 \qquad c=3\cdot10^5\frac{km}{s} \qquad e=1{,}6\cdot10^{-19\mathrm{As}}$$

$$Spectral\,sensitivity: S(\lambda)=\frac{e\cdot\lambda}{h\cdot c}\cdot\eta_{ext} \qquad E_{Ph}=h\cdot f=\frac{h\cdot c}{\lambda}>E_G$$

Operation of Photovoltaic Solar Cells and Modules

$$Standard\,Test\,Conditions: STC \rightarrow T_{PV}=25°;\ AM=1.5;\ G=\frac{1000\mathrm{W}}{m^2}$$

$$Fill\,Factor: FF=\frac{(V_{MPP}\cdot I_{MPP})}{(V_{oc}\cdot I_{SC})}$$

$$Open\,Circuit\,voltage: V_{OC}(T)=V_{OC}(25°)+\Delta V_{OC} = V_{OC}(25°)+\alpha\cdot V_{OC}(25°C)\cdot(T-25°C)$$

$$Short\,Circuit\,Current: V_{SC}(T)=I_{SC}(25°)+\Delta I_{SC} = I_{SC}(25°)+\beta\cdot I_{SC}(25°C)\cdot(T-25°C)$$

$$Maximum\,Power\,Point: P_{MPP}(T)=V_{OC}(25°)+\Delta P_r = P_{MPP}(25°)+\gamma\cdot P_r(25°C)\cdot(T-25°C)$$

$$Photo\,Current: I_{PH}(G)=I_{PH}(STC)\cdot\frac{\dot G}{\dot G_{STC}}=I_{PH}\left(1000\frac{W}{m^2}\right)\cdot\frac{\dot G}{1000\,Wm^2} \qquad Efficiency: \eta=\frac{P_{MPP}}{\dot G\cdot A_{Module}}$$

Thermal Behavior of the Modules

$$\sigma:=5{,}67\cdot10^{-8}\,W/(m^2\cdot K^4) \qquad \varepsilon:=emis.\,coef.(Glass: 0{,}88) \qquad \alpha:=Absorp.\,coef.(Glass: 0{,}7-0{,}9)$$

$$h_c=(h_{cW}^3+h_{cfree}^3)^{1/3} \qquad h_{cW}:=4{,}214+3575\,V_W \qquad h_{cfree}:=1{,}78(T_{PV}-T_0)^{1/3}$$

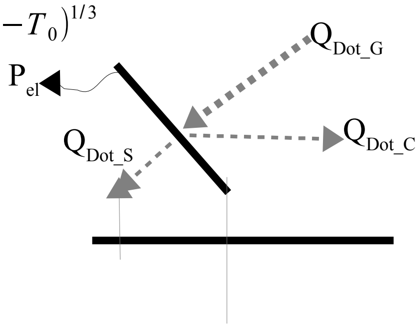
$$h_r=\varepsilon_{Mod}\cdot\sigma\cdot(T_{PV}^2+T_0^2)\cdot(T_{PV}+T_0)$$

$$Power\ fro\ the\,Sun: \dot Q:=\alpha_{Mod}\cdot\dot G\cdot A_{Mod}$$

$$Long\,wave\,irradiation\,exchange: \dot Q_s:=2\cdot A_{Mod}\cdot h_r\cdot(T_{PV}-T_0)$$

$$Convection\,losses: \dot Q_C:=2\cdot\left[h_{cW}^3\cdot h_{cfree}^3\right]^{1/3}\cdot A_{Mod}\cdot(T_{PV}-T_0)$$

$$P_{el}=\dot Q_G-(\dot Q_s+\dot Q_c) \qquad \eta=P_{el}/(\dot G\cdot A_{Mod})$$

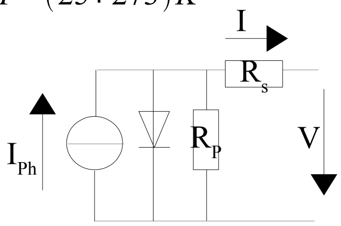


Modelling: Equivalent Circuits:

$$I_s(Saturation\,Curr.)=1{,}852\cdot10^{-9}\,A \qquad k(SBC):=1{,}38046\cdot10^{-23}\,J/K \qquad m(Fit\,Fact.):=1{,}0..1{,}2$$

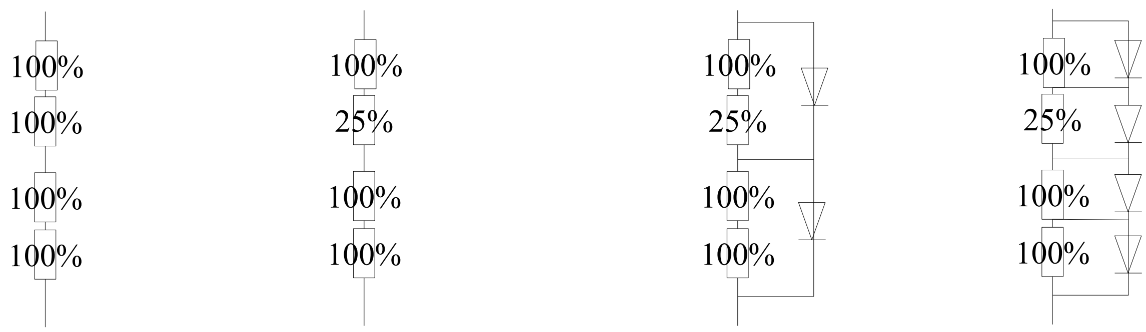
$$I_{ph}-I_s\cdot\left(e^{\frac{V+I\cdot R_s}{m\cdot V_T}}-1\right)-\frac{V+I\cdot R_s}{R_p}-I=0 \qquad V_T=\frac{k\cdot T}{e}\rightarrow V_T=0{,}026\,V\ for\ T=(25+273)K$$

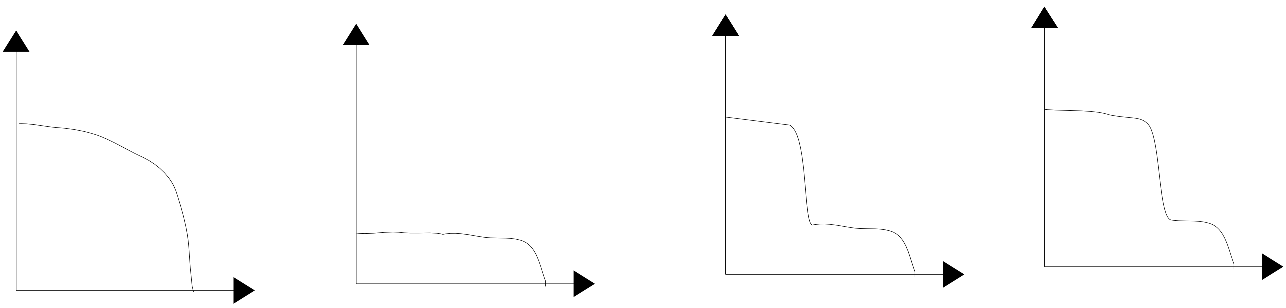
$$For\ n_s\,solar\,cell: I_{ph}-I_s\cdot\left(e^{\frac{V+I\cdot R_s}{n_s\cdot m\cdot V_T}}-1\right)-\frac{V+I\cdot R_s}{n_s\cdot R_p}-I=0=f(I)=0$$



Shading

$$I_{Ph}=\frac{I_{SC}\cdot\dot G}{1000\,W/m^2}=I_{SC}\cdot a\,(a:=of\ Irr.\ Received)$$





A.Neupane WS-2012/13

Grid Connection Photovoltaic Systems

Efficiency

$$European\ Efficiency: \eta = 0{,}03\cdot\eta_5 + 0{,}06\cdot\eta_{10} + 0{,}13\cdot\eta_{20} + 0{,}1\cdot\eta_{30} + 0{,}48\cdot\eta_{50} + 0{,}2\cdot\eta_{100}$$

Master Slave Operation or Team Operation

P/kW	0	12,5	25	50	75	100	125	150	200	250
$P/P_{rOneUnit}$	0%	5%	10%	20%	30%	40%	50%	60%	80%	100%
$\eta_{OneUnit}$	0,0%	58,0%	78,0%	90,5%	93,6%	94,1%	94,4%	94,8%	95,5%	94,6%

From the load factor 50% on both inverters take over the same load

P/kW	0	25	50	100	150	200	250	300	400	500
$P/P_{rOneUnit}$	0%	5%	10%	20%	30%	40%	50%	60%	80%	100%
$\eta_{OneUnit}$	0,0%	78,0%	90,5%	94,1%	94,8%	95,5%	94,4%	94,8%	95,5%	94,6%

$$Effici.\ Of\ PV-Gen: \delta_{PV-Gen} := \frac{W_{DC}}{G_{Irr.}\cdot A_{Area}} \qquad \eta_{INV} := \frac{W_{AC}}{W_{DC}} \qquad G_{Modul} = G_{Hor}\cdot Tiltfaktor$$

$$Rated\ Power\ P_r = \dot{G}_{STC}\cdot A\cdot\eta_{STC} \qquad \eta_{Mod,STC} = \frac{P_r}{\dot{G}_{STC}\cdot A_{Mod}}$$

$$Final\ Yield: Y_F := \frac{W_{AC}(Grid)}{P_r} = \frac{G_{Modul=G_{Hor}\cdot Tiltfactor}\cdot A\cdot\eta_{WR=MeanEffInv}\cdot\eta_{PV-notSTC}}{P_r}$$

$$Performance\ Ratio: PR := \frac{Y_F\cdot\dot{G}_{STC}}{G} = \frac{W_{AC}}{G\cdot A\cdot\eta_{STC}} = \frac{Y_F\cdot P_r}{G\cdot A\cdot\eta_{STC}}$$

W_{AC} of a Loacation X in a Year with n in Serial and m Parallel PV Modules:

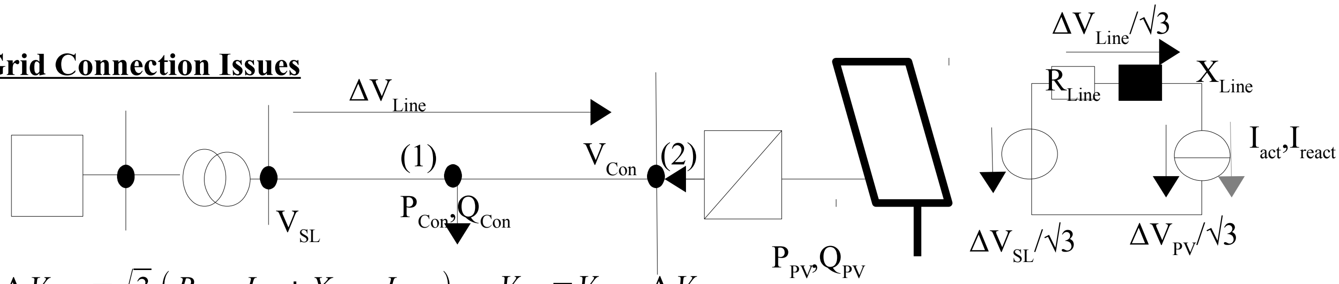
$$W_{LocationX} = G_{LocationX}\cdot n_{ser}\cdot m_{par}\cdot A_{Mod}\cdot\eta_{Mod-Not-STC}\cdot\eta_{Inv}\cdot\eta_{Cab}$$

Wiring and Cable Losses of a Grid connected PV System

$$n_{String} = \frac{Modules_{Total}}{Modules_{perString}} \qquad \Delta U_{Lost1Phase} = 2\cdot I\cdot R = 2\cdot I\cdot\frac{l_{cable}}{\kappa_{cable}\cdot A_{cable}} \qquad \kappa_{Cu} = 56\frac{S\cdot m}{mm^2}; \kappa_{Al} = 35\frac{S\cdot m}{mm^2}$$

$$P_{Looses-1Ph-ACorDC} = 2\cdot I^2\cdot R = 2\cdot I\cdot\frac{l_{cable}}{\kappa_{cable}\cdot A_{cable}} \qquad P_{Looses-3Ph-ACorDC} = 3\cdot I^2\cdot R = 2\cdot I\cdot\frac{l_{cable}}{\kappa_{cable}\cdot A_{cable}}$$

Grid Connection Issues



$$\Delta V_{Line} = \sqrt{3}\cdot(R_{Line}\cdot I_{act} + X_{Line}\cdot I_{react}) \qquad V_{PV} = V_{SL} - \Delta V_{Line}$$

$$I_{actCon} = \frac{P_{Con}}{\sqrt{3}\cdot V_N} \qquad I_{actPV} = \frac{-P_{PV}}{\sqrt{3}\cdot V_N} \qquad R_{SL-2} = l_{SL-2}\cdot\Omega/km$$

$$R_{1-2} = l_{1-2}\cdot\Omega/km \qquad I_{react} = I_{act}\cdot\tan(\arccos(\cos(\varphi))) = \frac{Q}{\sqrt{3}\cdot V_N} \qquad \varphi = \frac{P}{\sqrt{P^2+Q^2}}$$

$$\Delta V_{SL-1} = \sqrt{3}(R_{SL-1}\cdot(I_{actCon} + I_{1actPV}) + X_{SL-1}\cdot(I_{reactCon} + I_{reactPV}))$$

$$\Delta V_{1-2} = \sqrt{3}(R_{1-2}\cdot(I_{PVactiv}) + X_{1-2}\cdot(I_{PVreactiv})) \qquad V_1 = V_{SL} - \Delta V_{SL-1} \qquad V_2 = V_1 - \Delta V_{1-2}$$

Characteristics of Batteries

$$Q_{in} = Charge\ in\ Ah\ into\ the\ battery \qquad Q_{Batt} = Charge\ in\ Ah\ in\ the\ battery$$

$$Q_{Out} = Charge\ in\ Ah\ in\ the\ battery$$

$$DOD = \frac{Q_{out}}{Q_{in}} \qquad SOC = \frac{Q_{Batt}}{Q_{in}} = 1 - DOD \qquad W_{BattTotal} = \frac{W_{AC}}{\eta_{DC-AC}\cdot\eta_{BatOut}\cdot\eta_{BatDOD}}$$

Battery SOC from t1 to t2

$$Capacity_{Batt} = \frac{W_{BattTotal}}{Volt_{Batty}} \qquad W_{PV\,t1-t2} = G_{t1-t2}\cdot A_{totalPVArea}\cdot\Delta t\cdot\eta_{PV}\cdot\eta_{DC-DC} \qquad W_{Load\,t1-t2} = \frac{\sum Load_h\cdot 1\text{h}}{\eta_{DCtoAC}}$$

$$W_\Delta = W_{PV\,t1-t2} - W_{Load\,t1-t2} \qquad For\ W_\Delta < 0 : W_{Batt\,t2} = W_{Batt\,t1} - \frac{W_\Delta}{\eta_{BattOut}}$$

$$For\ W_\Delta > 0 : W_{Batt\,t2} = W_{Batt\,t1} + W_\Delta\cdot\eta_{BattIn} \qquad SOC_{t2} = \frac{W_{Batt\,t2}}{W_{BattTotal}}$$

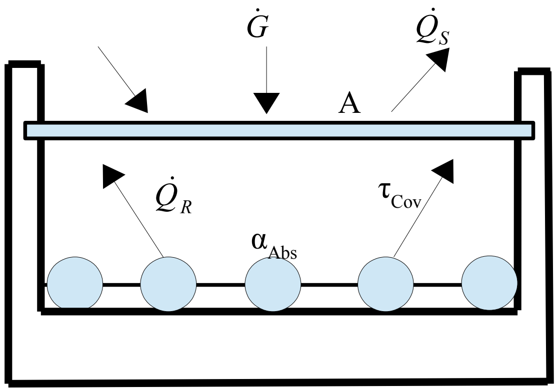
SOLAR THERMAL SYSTEM

Absorbtion coeff. =α; Reflection factor=ρ; Transmission coef. = τ

$$\alpha(\lambda)=\frac{Absorbed\ radiation}{Total\ radiation}\leqslant 1 \qquad \alpha(\lambda)+\rho(\lambda)+\tau(\lambda)=1 \qquad Because\ of\ isolation\ \tau=0\rightarrow\alpha=1-\rho$$

Power Output and Efficiency

τ	=Transmission coeff. Of cover
α	=Absor. coeff. of absorber
$\dot{G}$	=Power of Irradiation
$\dot{Q}_N=\dot{Q}_{use}$	=Useful power transferred to heat fluid
$\dot{Q}_S$	=Reflection losses of the glass cover
$\dot{Q}_R$	=Reflection losses of the absorber
$\dot{Q}_{Loss}$	=Power emitted in the long wave area + losses due to convection
$T_{Abs.}$	=Temerature of absorber
T_{Amb}	=Ambient temperature
$a_{0,}a_{1,}a_2$	=Given parameters of collector
$\alpha_{Abs.}\cdot\tau_{Cov}=a_0$	=Optic losses



Construction of a collector

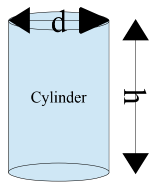
$$\dot{Q}_{Use}=(\dot{G}\cdot A\cdot\tau_{Abs.})-a_1\cdot A\cdot(T_{Abs.}-T_{Amb})-a_2\cdot A\cdot(T_{Abs.}-T_{Amb})^2$$

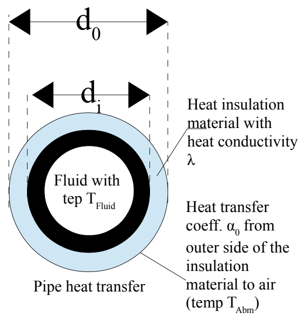
$$\eta_{Coll}=\frac{Q_N}{(\dot{G}\cdot A\cdot\tau_{Abs.})}=\alpha_{Abs.}\cdot\tau_{cov}-\frac{a_1}{\dot{G}}\cdot(T_{Abs.}-T_{Amb})-\frac{a_2}{\dot{G}}\cdot(T_{Abs.}-T_{Amb})^2$$

$$\eta_{Coll}=\frac{Q_N}{(\dot{G}\cdot A\cdot\tau_{Abs.})}=a_0-\frac{a_1}{\dot{G}}\cdot(T_{Abs.}-T_{Amb})-\frac{a_2}{\dot{G}}\cdot(T_{Abs.}-T_{Amb})^2$$

Thermal Stores:

m	Mass of water in store	T_{St}	Temperature of water in store
c	4,1868 kJ / (kg*K) = specific heat of water	T_{Amb}	Ambient temperature
h	Height of Cylinder	d	Diameter of Cylinder
U_{St}	Heat transfer coefficient	A_{St}	Surface area
l	Length of the Pipe		

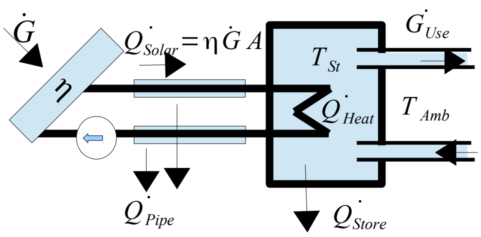




Pipe heat transfer

$$Q=c\cdot m\cdot(T_{St}-T_{Amb.}) \qquad A_{St}=2\,(\frac{\dot{d}}{2})\cdot\pi\cdot h+1\cdot(\frac{d^2\cdot\pi}{4}) \qquad Q_{Loss}=U_{St}\cdot A_{St}\cdot(T_{St}-T_{Amb.})$$

$$U_{Pipe}=\frac{\pi}{\frac{1}{2\cdot\lambda}\cdot\ln(\frac{d_0}{d_i})+\frac{1}{\alpha_0\cdot d_0}} \qquad \dot{Q}=l_{Pipe}\cdot U_{Pipe}\cdot(T_{Fluid}-T_{Amb})$$



Operational behaviour

$$\underbrace{\dot{G}\cdot A\cdot\eta}_{G_{Solar}}-\dot{Q}_{pipe}-\dot{Q}_{Use}-\dot{Q}_{Loss}=\frac{dQ_{Heat}}{dt}=\frac{c_p\cdot m\cdot dT_{St}}{dt}=c_p\cdot m\cdot\frac{\Delta T_{St}}{\Delta t}$$

$$\Delta T_{St}=\Delta\frac{t}{c_p\cdot m}\cdot(\dot{G}\cdot A\cdot\eta-\dot{Q}_{Pipe}-\dot{Q}_{Store}-\dot{Q}_{Use})$$

$$Solar\ Fraction: SF=\frac{Q_{offer}(Solar)}{Q_{demand}}$$

Rough design of solar thermal systems

Q	Required heat energy	c	4,19kJ/(kg·K)
m	Mass of warm water of temperature T_2 (m=V·ρ)	ΔT	Temperature of warm water T_2 minus temperature of cold water T_1 surface of absorber
A	Surface of absorber	δ	Mean efficiency
G	Mean irradiation per day	V	Volumen of required Water
ρ	Density of Water 1kg/*l*		

$$Q_{requiredHeat}=m\cdot c\cdot \Delta T=V\cdot \rho\cdot c\cdot(T_{Hot}-T_{Cold}) \qquad A_{requiredArea}=\frac{Q}{G\cdot\delta}$$

Concentration Reflecting Trough Collectors

A_R	Reflector surface = apeture	F	Absorber surface = A_R/C
R_S	Distance Sun Earth = $0{,}695\cdot10^6$km	σ	Temperature of AbsorberStefan Bolzmann law. $5{,}67\cdot10^{-8}$ W·m-^{2}·K^{-4}
C	Concentration Factor Cmax=46211	T_S	Temperature of Sun = 5777K
$G_{dot,s}$	Direct radiation	T_{Abs}	Temperature of Absorber
$G_{dot,0}$	Radition with reaches earthsurface	ρ_{Abs}	Reflection coeff. Of reflecotr =(1/ρ_R)
ρ_R	Reflection coeff. Of reflector	ρ_{Abs}	Reflection coeff. Of obsorber=(1/ρ_R)
U_{Abs}	Heat transmission coeff. Of absorber in W/(m^2·K)	α_R	Emission coeff of reflector =(1-ρ_R)
T_{Amb}	Ambient temperature	$Q_{dot,N}$	Useful Power
m_{Dot}	Mass Flow	c_P	Heat capacity

$$Concentration\ Facor: C=\frac{A_{Abs.}}{F} \qquad \frac{1}{C_{max}}=\frac{R_s^2}{(AE)^2} \qquad \dot{G}_s=\sigma\cdot T_s^4 \qquad \dot{G}_0=\frac{\dot{G}_S\cdot 4\cdot\pi\cdot R_s^2}{4\cdot\pi\cdot(AE)^2}$$

$$\dot{G}_0\cdot A_R=\sigma\cdot T_s^4\cdot A_R\cdot\frac{R_s^2}{(AE)^2} \qquad \dot{G}_0\cdot A_R=F\cdot\sigma\cdot T_{Abs.}^4$$

$$T_{Abs.}^4=T_s^4\cdot\frac{R_s^2\cdot A_R}{(AE)^2\cdot F}=T_s^4\cdot\left(\frac{C}{C_{max}}\right)\rightarrow T_{Abs.}=T_S\cdot\sqrt[4]{\frac{C}{C_{max}}}$$

$$Engergy\ on\ aperture\ comming\ from\ the\ sun=\dot{G}\cdot A_R \qquad Energy\ absorption\ on\ reflector=\alpha_R\cdot G\cdot A_R$$

$$Engergy\ reflection\ on\ absorber\ as\ F=A_R/C:=\rho_R\cdot\rho_A\cdot\dot{G}\cdot F=\rho_R\cdot\rho_A\cdot\dot{G}\cdot\frac{A_R}{C}$$

$$Engergy\ convection\ losses\ on\ absorber:=U_A\cdot F\cdot(T_{Abs.}-T_{Amb})=U_A\cdot\frac{A_R}{C}\cdot(T_{Abs.}-T_{Amb})$$

$$Emitted\ engergy\ by\ absorber:=\varepsilon_{Abs.}\cdot F\cdot\sigma\cdot(T_{Abs.}^4-T_{Amb}^4)=\varepsilon_{Abs.}\cdot\frac{A_R}{C}\cdot\sigma\cdot(T_{Abs.}^4-T_{Amb}^4)$$

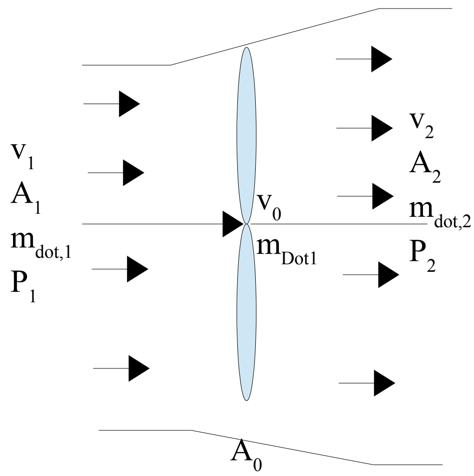
$$\dot{Q}_N=\dot{G}\cdot A_R\cdot\left[\rho_R(1-\rho_{Abs.})-\frac{U_A}{\dot{G}\cdot C}\cdot(T_{Abs.}-T_{Amb})-\varepsilon_{Abs.}\cdot\sigma\right]$$

$$\eta=\frac{\dot{Q}_n}{\dot{G}\cdot A_R}=\rho_R(1-\rho_{Abs.})-\frac{U_A}{\dot{G}\cdot C}\cdot(T_{Abs.}-T_{Amb})-\frac{\varepsilon_{Abs.}\cdot\sigma}{\dot{G}\cdot C}\cdot(T_{Abs.}^{4.}-T_{Amb}^4)$$

$$Mass\ flow: \dot{m}=\frac{\dot{Q}_{Abs.}}{c_{POil}\cdot\Delta T}$$

Wind Engergy Converters WEC

a	Hellman-exponent	V_H	Velocity of Wind in 10 height
A	Scaling factor	C	Sharpe parameter
v_1	Wind speed before Rotor	V_m	Medium wind speed
c_P	Power coeff.	λ	Speed coefficient
ρ	Density of Air	p	Power per m²
P_{Wind}	Power from Wind	A_0	Rotor Circle Area
P_{sh}	Shaft power	P_{el}	Power fed to the Grid



Dependence of the wind speed on the height

$$v_H = v_{10} \cdot \left(\frac{H}{10 \cdot m}\right)^a \qquad a = \frac{\ln\left(\frac{v_H}{v_{10}}\right)}{\ln\left(\frac{H}{10 \cdot m}\right)}$$

Conversation of wind speed v_1 of height h_1 to v_2 of height h_2

$$v_2(h_2) = v_1(h2) \cdot \frac{\ln\left(\frac{h2}{Z_0}\right)}{\ln\left(\frac{h_1}{Z_0}\right)}$$

Idealised wid speed distribution

Weibull distribution

$$f(v) = \frac{C}{A} \cdot \left(\frac{v}{A}\right)^{(C-1)} \cdot e^{\left(\frac{v}{A}\right)^C} \qquad v_m = A \cdot \left(0{,}568 + \frac{0{,}434}{C}\right)^{\left(\frac{1}{C}\right)}$$

For C=2 and A=(v_m·2)/√(π) the Willbull-distribution goes over into the Rayleigh-distribution

$$f(v) = \frac{\pi}{2} \cdot \left(\frac{v}{v_m^2}\right) \cdot e^{-\left(\frac{\pi}{4}\right) \cdot \left(\frac{v}{v_m}\right)^2}$$

Example: v_m= 7,0 m/s ; t=8760h ;v=5,0m/s; class of wind 4,95-5,05 m/s ; t in a year for this class of wind ?

$$f\left(5 \cdot \frac{m}{s}\right) = \frac{\pi}{2} \cdot \frac{5 \cdot m \cdot s^2}{7^2 \cdot s \cdot m^2} \cdot e^{-\left(\frac{\pi}{4}\right) \cdot \left(\frac{5}{7}\right)^2} = 0{,}1074 \cdot \frac{s}{m}$$

$$T\left(4{,}95 - 5{,}05 \frac{m}{s}\right) = 0{,}1074 \cdot \frac{s}{m} \cdot 8760\, h \cdot \left(|4{,}95 - 5{,}05| \frac{m}{s}\right) = 94\, h$$

Offered wind power

$$1\, N \cdot m = 1\, W \cdot s = 1 \frac{kg \cdot m^2}{s} \cdot 1 \frac{W}{m^2} = 1 \frac{kg}{s^3} \qquad v_0 = \frac{1}{2} \cdot (v_1 + v_2) \qquad \dot{m}_0 = \dot{m}_1 = \dot{m}_2$$

$$P_{Wind} = \frac{1}{2} \cdot \rho \cdot A_0 \cdot v_0^3 \qquad p = \frac{P}{A} ; [p] = \frac{W}{m^2}$$

Power coefficient c_P und speed coefficient λ : r=Rotor radius; n = Revolutions per second [n]=Hz; v = wind speed at hub height in front of WEC

$$c_P = \frac{P_1 - P_2}{P_{Wind}} = \frac{1}{2} \cdot \left(1 + \frac{v_2}{v_1}\right) \cdot \left(1 - \left(\frac{v_{v2}}{v_1}\right)^2\right) = \frac{P_r}{\frac{1}{2} \cdot \rho \cdot A_{WEC} \cdot \eta_{mech} \cdot v_r^3} \qquad \lambda = \frac{2 \cdot \pi \cdot r \cdot n}{v} \qquad P_{sh} = P_{wind} \cdot c_P$$

Output electric power of a WEC:P_{el}

$$P_{el} = \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \cdot \eta = \frac{1}{2} \cdot \rho \cdot \frac{d^2 \cdot \pi}{4} \cdot c_P \cdot \eta \qquad v_{rated\ wind\ speed} = \sqrt[3]{\frac{P_{el}}{\frac{1}{2} \cdot \rho \cdot A \cdot c_P \cdot \eta}}$$

Output energy

Example: A class of Wind speed 9,5 – 10,5 m/s; Δv=1m/s; C=2,13 ; A=8,0 m/s (A=sklaling Faktor not Area)

$$f(v) = \frac{2{,}3 \cdot s}{8 \cdot m} \cdot \left(\frac{10 \cdot m/s}{8 \cdot m/s}\right)^{(C-1)} \cdot e^{\left(\frac{10}{8}\right)^{2{,}13}} = 0{,}06859 \cdot \frac{s}{m} \qquad T_{Class} = 0{,}06859 \frac{s}{m} \cdot 8760\, h \cdot 1 \frac{m}{s} = 600{,}8\, h$$

$$W_{Class} = P_{Class} \cdot T_{Class}$$