CHARPTER II

LITERATURE REVIEW

Photovoltaic System

The photovoltaic (PV) system is simple in principle but complex in technology. In principle the energy from sunlight is converted into electricity directly by using semiconductor devices called solar cells [7]. The solar cell preparation process gives rise to different technologies depending upon material, its combinations, and cell manufacturing techniques. At present many types are available for commercial use and many more are under research and development. Following are the main types of solar cell technologies and their efficiencies [8].

Table 2 Types of solar cell technologies and their efficiencies [8]

Classification	Cell Efficiency (%)	Classification	Cell Efficiency (%)
Silicon		**Amorphous/nanocrystalline Si**	
Si (crystalline)	25.0 ± 0.5	Si (amorphous)	10.1 ± 0.3
Si (multicrystalline)	20.4 ± 0.5	Si (nanocrystalline)	10.1 ± 0.2
Si (thin film transfer)	19.1 ± 0.4	**Photochemical**	
Si (thin film submodule)	10.5 ± 0.3	Dye sensitised	11.0 ± 0.3
III-V cells		Dyesensitised submodule	9.9 ± 0.4
GaAs (thin film)	28.3 ± 0.8	**Organic**	
GaAs (multicrystalline)	18.4 ± 0.5	Organic thin film	10.0 ± 0.3
InP (crystalline)	22.1 ± 0.7	Organic (submodule)	4.2 ± 0.2

Table 2 (Cont.)

Classification	Cell Efficiency (%)	Classification	Cell Efficiency (%)
Thin film chalcogenide		**Multijunction devices**	
CIGS (cell)	19.6 ± 0.6	GaInP/GaInAs/Ge	34.1 ± 1.2
CIGS (submodule)	17.4 ± 0.5	a-Si/nc-Si/nc-Si (thin film)	12.4 ± 0.7
CdTe (cell)	16.7 ± 0.5	a-Si/nc-Si (thin film cell)	12.3 ± 0.3
		a-Si/nc-Si (thin film submodule)	11.7 ± 0.4

As described in chapter 1 the major part of solar modules installed in the world comprises of Silicon materials. The manufacturing process of crystalline silicon (both mono & poly) is more sophisticated than amorphous silicon (a-Si). However crystalline modules have higher efficiencies than a-Si as shown in table 2 above. As the solar cells are made through a complex manufacturing process and then combined in series and parallel combinations to form a module of desired output parameters, moreover they are packaged using sophisticated technologies and materials, thus it is obvious to occur degradation in the performance during field operation. Keeping in view all the factors responsible for degradation manufacturers provide a guaranteed pattern for degradation. These guarantees base upon a series of qualification tests which have to be carried out before marketing. These qualification tests can never be an alternative for actual field conditions, so researchers have studied the output parameters after short and long term operation in the field. The following section will present an overview of different studies carried out for PV module's performance evaluation.

PV Modules Degradation

Va´zquez, M., et al. [6] studied degradation of PV modules after field exposure and developed a model to ensure their reliability on the bases of degradation data. According to the study presently modules returned to the manufacturers are limited and thus apparently supports the guarantees offered. In depth study revealed that difficulty of testing the modules in accordance with guarantee conditions is a major reason for limited number of returns. As the installations of large scale power plants are increasing rapidly all over the world so the issues of module reliability and amount of output power after long term use is becoming more critical. The model developed will be helpful to estimate the useful life and power output of modules. It will enable the manufacturers to offer a defensible and realistic warranty.

The paper also present an overview of the degradation studies carried out in diverse climatic conditions for different module used over extended periods in the field. The analysis of these studies shows that:

1. The power degradation in modules occurs linearly over time.
2. The guarantee above 25 years requires degradation rate less than 0.5 %/ annum.
3. Crystalline silicon modules shows 0.3 - 3% degradation per annum, and in some studies degradation rate is higher in 1st year of operation.

Muñoz-García, M.A., et al. [9] explained characterization of thin film PV modules under standard test conditions. In the study a-Si, CIS and CdTe modules are considered. The basic objective of this study was to establish an easiest method of measuring I-V parameters under STC for thin film based modules. For Thin Film modules there are some important factors which need to be considered during testing process which includes the effect of light soaking, memory effects after sunlight exposure, light spectrum and sunlight activation. The spectral response is different and mostly nonlinear for different technologies (see Figure 1).

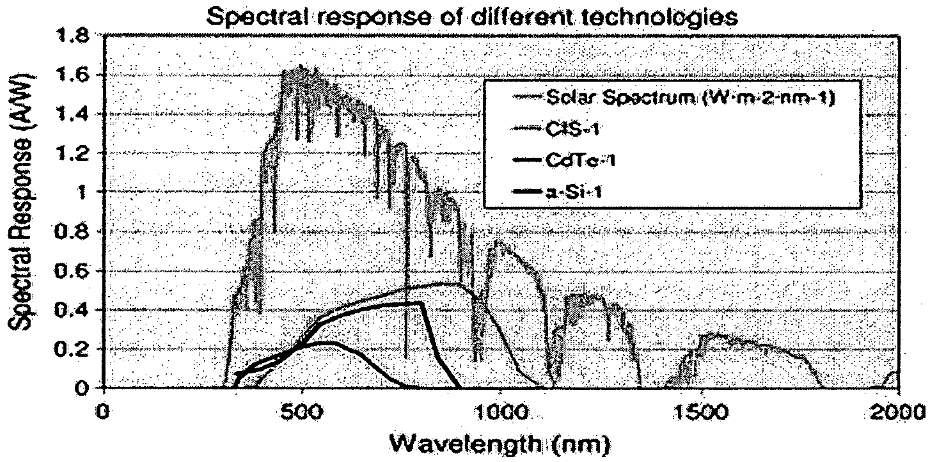

Figure 1 Typical spectral response of different thin film technologies and AM 1.5 spectral distribution [9]

The a-Si modules exhibit a significant loss in power during initial period of operation which is known as Staebler−Wronski Effect (SWE), while taking the measurements at STC this effect should be taken into account. In CIS and CIGS modules dark aging (drop in V_{oc} and FF) is to be considered which is recoverable after light soaking at 1000W/m² for an hour. Another important aspect is stabilization of output, which should be considered too before testing. The module can be stored in dark for 10 hours and then light exposure will restore its degradation. For CdTe PV module similar to CIS light activation is necessary for at least 4 hours before testing indoor under STC. The proposed method involves indoor measurements using solar simulator and taking into consideration the preconditions for each thin film technology as mentioned above.

Kaplanis, S. and Kaplani, E. [10] investigated 20 years old c-Si modules degradation and energy performance by comparing the present parameters with initial manufacturer's data. The annual degradation rate and its effect on energy yields and PBP have been discussed. A series of field experiments have been carried out to measure I-V parameters and transformed to STC. These values then compared with initial values to estimate degradation. Various causes have been determined for degradation like discoloring, junction's damage, humidity ingress, delamination and hot spot. The climatic conditions of the area are moderate with temperatures variations from 0°C (winter) to 40°C (summer) and humidity 71% in December -55% in July. Moreover reasonable winds were also faced by modules during their operational life. For the calculation of shunt and series resistances various approaches have been used and the average result has been considered. A significant reduction has been seen in the shunt resistance due to mechanical and/or thermal shocks. A progressive degradation of 11% has been measured for 20 years of operation. The energy yield has been calculated in accordance with the degradation rate, which seems to be satisfactory while taking into account the Feed in Tariff. The overall quality of these modules found good and are expected to operate successfully for more 5-10 years. Module positioning needs special attention as to avoid rusting and humidity ingress.

Machida, K., et al. [11] estimated yearly degradation in power output of mono and poly crystalline PV modules for 5 years. A total of 8 samples were collected from the population of 5 KW Power Plant near Tokyo, among these 5 were single and 3 poly crystalline modules. For measurement Japanese Industrial Standard C8914 "Measuring Method of Output Power for Crystalline Solar Cell Modules" was followed, and measurements were taken by using the same solar simulator as for initial ex-work testing. Also selected modules were tested at site for comparison.

The total average degradation over the period of 5 years in P_{max} of single crystalline modules was more (4.8%) than in polycrystalline modules (2%). Following chart depicts the changes in different parameters of both types.

Table 3 Degradation in c-Si Modules [11]

Module Type	P_{max}	I_{sc}	V_{oc}	**FF**
Single Crystalline	Decrease 4.8%	Decrease 5.3%	Decrease 0.7%	Increase 2.1%
Poly Crystalline	Decrease 2%	Decrease 2.5%	Increase 1.4%	No change

Moreover the measurement of P_{max} before and after the cleaning of modules shows a difference of 1.3%.The possible reasons of degradation can be clouding of glass, degradation of EVA and surface stains.

Chamberlin, C. E., et al. [12] reported a comprehensive study results which was conducted on a 9.2MW power plant having 192 single crystalline (EVA) modules situated in Canada. The plant is located 150 meters away from ocean in a cool, corrosive coastal environment. All the modules were tested prior to their commissioning in 1990, again in 2000-2001 and now in 2010 for P_{max}, I_{sc}, V_{oc}, I_{mp} and V_{mp}. Results were adjusted to Nominal Operating Cell Temperature(NOCT) (1000W/m², 47°C), and it was established that P_{max} average was 39.86W. However nameplate ratings for the module's maximum power (P_{max}) were 46.4W (at NOCT) and 48 W at Standard Test Conditions (STC).

The calculations of degradation rate rely on the mean measured values of P_{max}, V_{oc} and I_{sc} (adjusted to NOCT) of the 192 modules. The yearly degradation rates for P_{max} were found 0.395% for the period 1990-2001 and 1.369% for 2001 to 2010. The total average degradation rate for 20 years comes out to be 0.807% per year which is in line with Machida, K., et al. [11] findings. The major change in power is due to decreased short circuit current I_{sc}, as there is no significant change in V_{oc} during the period. The changes in the parameters have occurred steadily over the time. Decay in I_{sc} can be attributed to browning, and delamination of EVA in modules.

Dechthummarong, C., et al. [13] report that 39 single crystalline silicon modules were collected from the field after a period of more than 10 years. These modules were installed at different Water pumping stations and battery charging stations in the north-eastern region of Thailand. The weather conditions of this area are tropical with monsoon rains. Along with the modes of physical deteriorations electrical parameters were studied for analysis about degradation after field use. Also the analysis of correlation between modes of degradations and decrease in electrical parameters has been done.

The name plate data for these modules was recorded and compared with the latest measurements taken under STC. A pulse flash simulator PASAN (class A) was used for I-V curve measurements in accordance with the IEC 61215 standard. A high degradation was observed in most of the PV module's short circuit current (I_{sc}) and hence P_{max} and I_{max}. However majority of the modules have no significant change in V_{oc}. The series and shunt resistances of modules have also been measured and found an increase in R_s and decrease in R_{sh}.

The observed reasons for degradation were partial cracking in cells, browning, moisture ingress, delamination of EVA from cell, corrosion in bus bars. The interesting observation was about the delaminating of EVA at center, of the most of modules rather than at edges.

Sakamoto, S., et al. [14] investigated visually over 2000 (poly & single) crystalline modules manufactured by different companies from Japan and tested 150 modules for I-V curve characteristics using indoor simulator facilities under STC. These modules totaling 100KW capacity were installed during 1990-1992 at 6 different sites including Hamamatsu Power System Test Site in Japan.

No significant drop in output power of the modules was noticed, neither module replacement was needed, except 14 cases of tempered glass breakage, which may happened due to some in built manufacturing discrepancy. The modules showed an initial rapid loss in I_{sc} for a fraction of the 1st year and then became stable. The authors based on the previous studies about LID estimates initial loss as 2%. As P_{max} is directly affected by I_{max} which in turn depend on I_{sc}, so performance loss has been considered 2% for Initial period of exposure.

The reduction in P_{max}.during the 10 years of operation was found to be 6.4% including initial loss of 2%. The power degradation per year comes out to be less than 0.5% per year if initial degradation of 2% excluded. The modules with a power loss of above 10% are only 3% of the total. The % degradation per year is less than reported in previous studies for generation of 1980's.

The three modes of degradation were determined during the study.

1. Delaminating of EVA from cell surface, which results in reduction of I_{sc}
2. Decrease in FF, which is a possible result of increased R_s due to cracks in the solder layers.
3. Current and voltage.

Francesco, D. L., et al. [15] reported in his work on degradation rates of c-Si PV modules after 22 years of field operation. Writers report the results for yearly degradation rate for modules under study. The bases chosen for calculating the degradation rate in this work is module efficiency at 28°C. For comparison the efficiency measured and extrapolated at the time of acceptance of modules has been used, rather than the name plate efficiency which is higher than the measured one.

The method used for efficiency measurement is known as swept method in which all the 58 modules were tested individually by charging a capacitor from their output currents in the outdoor environment. The dependents of efficiency were extrapolated to get efficiency. The overall annual efficiency degradation rate for 22 years was found to be 0.363%, and it was almost constant over the entire period.

Dunlop, E. D. [16] presented a comparison of original and weathered 18 crystalline silicon modules after 19 years of use. These modules were installed in March 1982 and tested for power output in October 1982. It was found that P_{max} decreased by 3.9% with respect to declared Power. Bishop, J., et al. [17] estimated that in crystalline modules initial degradation (LID) was approximately 2.6%± 1.3%. On this basis, the initial loss of 3.9% can be divided into two parts, one attributes to LID (2.6%) and other to the deviation from Declared P_{max} (1.3%).

Since October 1982 the average weighted degradation rate per year has been recorded as 0.27%. If the initial photon degradation loss will be included the degradation rate per annum will become 0.4%. This loss is somewhat less than reported in [18] but can be linked with excellent maintenance and replacement of components. Also the degradation rate measured is in agreement with the results (0.4% per annum) of reference [19] which shows a consistency and reliability of measurement. It should be noted that modules manufacturer in both cases was same.

The possible causes of degradation could be discoloring, delamination, cover glass cracking, detaching of back sheets, wiring degradation and junction box failure. The initial photon degradation has less effect on energy life of PV module than the continuous long term degradation rate.

Summary of literature review

Literature review revealed that researchers used diverse approaches for measuring the degradation rates in terms of electrical parameters. The most basic among all parameters is P_{max} and manufacturers also offer guarantees in relation to the P_{max}. Some researchers have used the efficiency as a base for comparison to signify the degradation [15, 20], some others use measured P_{max} at NOCT or STC (normalized) at site when modules were received for installation [11, 12, 16, 19], while some use nameplate data as base for calculation [13, 14]. In addition to these some researchers used energy yield to signify the degradation phenomena [4].

In view of the above it is not appropriate to compare all the power degradation rates directly as they have been calculated on different bases. The reason for using different base is the diversity among research objectives. The studies focusing on the degradation modes have given least priority to choose a firm base for comparison of electrical parameters measured [15, 20]. The researches with focus on the determination of annual degradation rates mostly used their own measured initial value, either on STC or transformed to STC using coefficients [11, 12, 16, 19]. Only fewer studies whose focus was on the reliability of the modules and trust of the user and /or investor and evaluation of guarantees used nameplate data as a base for measurement of degradation rates [10, 13, 14].

A summary of percentage degradation per annum calculated by different researchers is shown below.

Table 4 Summary of percentage degradation Rate per annum in PV modules

Type of Module	% Yearly Degr. Rate	Years in operation	References	Base for calculation
Single Crystal Silicon	0.36	22	[15]	Field measured Efficiency
Single Crystal Silicon	0.96	5	[11]	Own measured I-V values
Poly Crystal Silicon	0.40	5	[11]	Own measured I-V values
Single Crystal Silicon	0.81	20	[12]	Own measured I-V values
Single Crystal Silicon	0.39	11	[19]	Own measured I-V values
*Crystalline Silicon	0.40	19	[16]	Own measured I-V values

Table 4 (Cont.)

Type of Module	% Yearly Degr. Rate	Years in operation	References	Base for calculation
*Crystalline Silicon	0.55	20	[10]	Manufacturer data Sheets
	0.62	10	[14]	Manufacturer data Sheets
Crystalline Silicon	1.00	8	[21]	own measured values

*Type of crystal is not mentioned in paper.

Most of the investigations revealed that in Crystalline silicon (poly & mono) the initial Light Induced Degradation (LID) rate is 1-5%, however some studies showed that rate of initial degradation is higher in mono crystalline silicon modules as compared with multi crystalline silicon modules. The long term annual average degradation rate is found to be less than 1% per year in most of the studies. However in some cases it is remarkably high, which can be attributed to poor installation, careless transportation, very harsh weather conditions, poor quality control at manufacturer's end and use of low grade materials. The degradation rate found to be slower in early years of field operation while it increased in the later periods, proving that there is no linearity in the slow degradation process. Some studies showed very small percentage of power degradation even after 20 years of operation, which can be attributed to excellent quality control, proper installation & follow up, vigilant monitoring and suitable environments.

The most common modes of degradation in modules were, discoloring due to delaminating of EVA from cell surface, moisture ingress, rusting & cracking of bus bars, hot spot formation and initial light induced degradation.

As the objective of this study is to evaluate the guarantee conditions, so this study will use the nameplate data as a base for finding the degradation in power output of modules after long term field exposure under Thailand weather conditions.