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Comparative Analysis of Degradation of Monocrystalline Solar Panel in three Different Districts of KPK Pakistan

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***Abstract*—** In this proposition understanding the phenomenon of degradation and the process of degradation during the outdoor operation is presented to evaluate the PV array's reliability. The value of studying degradation increases as it helps to establish acceptable standards and requirements for PV components with adequate guarantee times. With time, the major defects found in PV modules are decoloration, delimitation, glass breakage front grid finger oxidation and anti-reflective coating and back sheet bubbles. With the huge number of new solar energy, developers and site investors needed to make sure whether the panels matched the guarantee terms so that no degradation happened during the early phases of the photovoltaic plants' operation, otherwise the panels would be repossessed. It led to a growing demand for laboratories that are capable of analyzing initial degradation as well as secret problem in solar PV panel and caregivers ' industries. The aim of this research is that we can easily predict the expected life of the solar panel and also the expected output power of the solar panel over a defined period to find the delamination ratio and quality of solar panel in the different area of Khyber Pakhtunkhwa. On the basis of which we can easily carry out the system's payback evaluation in that particular area and also assess the warranty period for that area.

While two methods are followed to determine the rate of deterioration for the above mentioned reason, one is by finding the performance ratio while the other is by visual inspection.

***Keywords*—** Solar photovoltaic (SPV), Photovoltic (PV), Performance Ratio (PR), Ultravioltt (UV).

I. INTRODUCTION

Photo-voltaic impact is among the most efficient way to generate electricity from the radiation of the sun. Using the solar cell, radiation of the sun is transformed straightly into DC electrical energy. One PV cell can produce tiny quantities of electricity. In order to produce suitable power of electricity a big amount of PV cells is connected in series and parallels. The electrical energy generated depend on temperature, angle and solar radiation. Throughout the year and for every location this solar radiation is not same. It is excellent in the summer, mild in the winter, and agreeable in the monsoon. It is therefore not hypothetical to justify the plant's performance on the basis of quantity of electrical energy generated. Therefore, few metrics are necessary to evaluate the efficiency of the PV plant. Performance Ratio (PR) is the most significant measure taken by professionals in the solar sector to evaluate the plant's efficiency.

Climate circumstances such as elevated temperature and elevated humidity have adverse impacts on the photovoltaic plant's productivity and effectiveness. In addition to temperature many variables that affect the efficiency of solar photo-voltaic module are isolation, shading impact, climate impact, wind, load power matching, pollution, and MPPT function precision and multiply system losses such as array catch losses soil losses and invertor's losses. Although solar photovoltaic (SPV) modules are a very consistent and ecological welcoming cause of renewable energy but fields consequences [1], [2] show that solar photo voltaic modules can completely flop or destroy in many ways. A deep study is required for understanding the behavior and origin of these degradation for complete elimination or even to reduce these degradation. In this study, we will completely analyze different degradation mode by measure different performance parameter of solar photo voltaic module.

Understanding the origin and behavior of degradation mode is very essential for the improvement of reliability and performance parameter of solar photo voltaic module. It is sure for the low cost cheap thin-film modules, which degraded quickly for first exposure to sun due to some weak bond of bus bar. When the effect of these degradation is known on all the performance parameter then the researcher can find way to eliminate or reduce the degradation. In below Section the detail of some degradation modes observed in the solar photo voltaic SPV cells or modules along with their origin and effect on solar photo voltaic SPV module performance parameters are given.

A. Degradation Mode

i. Front Surface soiling

The vast buildup of dust on the module's top surface can cause this type of degradation. These losses for glass-surfaced modules are kept under 10% due to wind and rain self-cleaning. Moreover, the accumulated dirt can incompletely shade a cell in the array, due to which less current is produce than the other in string cells. If electrical protection is inadequate, partial shading of the cell may result in irreversible damage to the hot spot and even failure of the unit [2]. Upper side dirtying can be perceived by visual examination of a panel and on-field inspection.

ii. Yellowing and Browning

The decoloration of the encapsulating material can result in optical degradation. Because of ultraviolet (UV) exposure, temperature, or moisture, the compressing material can yellow over long periods of exposure. It can also happen because of the injection of dust from the soiling of the front layer and from the moisture from edge of seals of the module. Using UV stabilizers and antioxidants, its lifetime could be increased if Ethylene Vinyl Acetate (EVA) is being used as a sealant. However, at extreme temps and when exposure to Ultraviolet irradiation, the stabilizer concentration gradually decreases [3]. When this concentration of the stabilizer falls below some critical value, the encapsulant rapidly degrades. This degradation is linked with EVA yellowing, followed by acetic acid formation. The latter creates the brownness of the EVA. The brown EVA accumulates a large fraction of solar radiation in the Ultraviolet region and thus reduces the number of photons sufficient for current generation. This encapsulant browning could reduce the performance of the Solar panel up to 50% [4]. The EVA can be visually perceived by concentrating a 375-nm ultraviolet lamp on the module. Under these circumstances, EVA areas that have begun to worsen will yield an almost white tint [5] as shown.

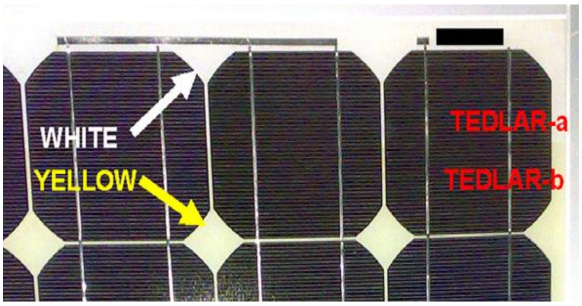

Figure 1. Browning effect

iii. Delamination Effect

Delamination is the absence of adherence between the PV module's different layers. It can happen between both the cells and the polymers encapsulant, as well as between the front glass and the cells. Delamination is an important issue because it may have two effects: light decoupling, as a result, light reflection and the possibility of water and dust penetration into the module body are both raised. Delamination become more dangerous when it happens at the module edges because, apart from losses in power, it also creates electrical hazard for the system as well as installation. Failure mechanism is more likely in hot humid environments. Different chemical reactions occur as moisture enters and some cause the module's separate components to degrade. The module is degraded because various components are transferred through the encapsulant. The effects are often metal corrosion in the frame of the modules. There is a rise in resistance or electrical failure in such a scenario. Delamination is also associated with a lack of transmittance because the material is not optically well balanced and part of the light escape. The result of delamination is shown below.

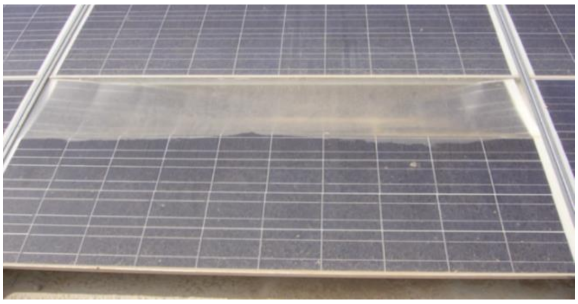

Figure 2. Sever delamination

iv. Bubble Effect

This type of deficit is similar to delamination, but the poor adherence to a EVA only damages a limited section and is linked to the blowing of parts where adherence has just been lost. Typically, bubble is caused by chemical reaction which releases other gaseous air. In the PV unit, a bulk tends to form a bubble in the polymer enclosure or the back cover. The heat transfer of the module is challenging due to bubbles the module is overheated and cell life subsequently decreases regardless of the fact that PV module's efficiency could not be compromised at the beginning when the defect occurred [6]. The show back surface of the bubble while front surface of the bubble effect in the SPV module.

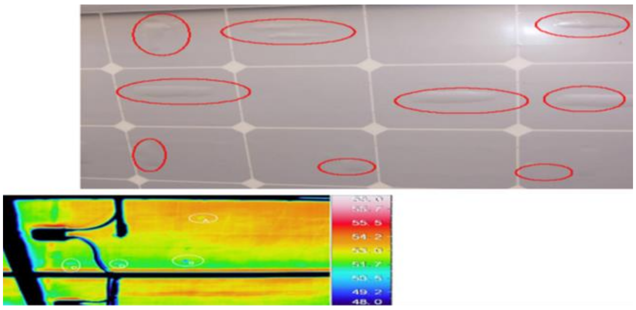

Figure 3. Back side Bubble Effect

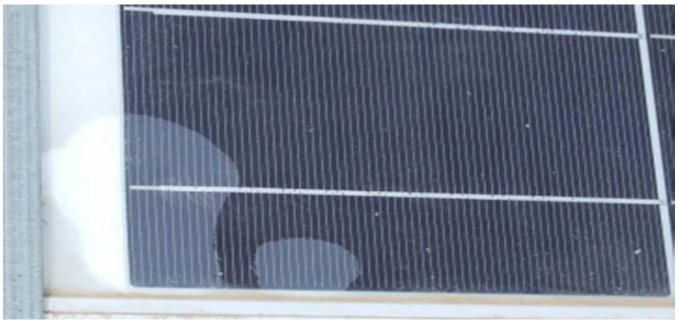

Figure 4. Front surface Bubble

v. Cell Degradation

Solar cell dilapidation can be induced by three reasons that result in the quality of the module gradually degrading. Such causes an upsurge in the series opposition of the cell, a decline in the shunt resistance of the cell and a degradation of the anti-reflection coating. Figure 5 shows the solar cell's two-diode equivalent-circuit model illustrating the series and shunt resistance. Such modes of cell degradation are important factors in evaluating degradation and failures of PV cells and modules. Such modes, which will be addressed further down, will gradually degrade module quality over long periods of operation.

A) Series Resistance: The serial impedance of a Photovoltaic panel is affected by resistance in cell solder bonding, emitters and base region cell passivation, cell-interconnect bus bars, and connection box termination opposition [7]. The resistance of the series decreases the voltage generated by the cell, thereby reducing the output of the PV cell and thus the module. Notwithstanding the fact that cell and component inventers diminish series resistance damages, many thermal cycling of modules deployed outdoors is caused by a steady increase in series resistance. Dark current tests can be used to test series resistance increases quantitatively. Changes in the module's shunt resistance, as well as other cell parameters, affect these steps [8].

B) Shunt Resistance: Some analogous high-conductivity alleyways (shunts) through the solar cell or on the cell's boundaries are referred to as shunt resistance [9]. Crystal impairment and contaminations at and around the junction will affect these, resulting in the shunt current shown in Fig. 5. Currents are diverted away from the particular load by such shunt routes, which has a detrimental effect on the device's efficiency at low amplitude levels. The quantity of shunts in solar cells can upsurge after protracted acquaintance to light [8]. The active shunt current in the cell increases as the number of shunts increases, increasing Rsh.

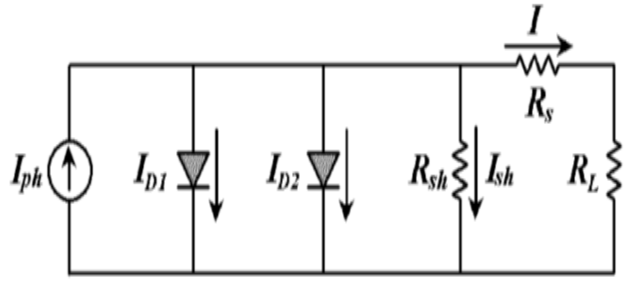

Figure 5. Eqvilent Circuits of PV cell

vi. Anti-Reflecting Coating

At the peak of the sun spectrum, which appears at the wavelengths of 600 nm, bare silicon reflectivity is roughly 35% [10]. By texturing the surface, this percentage can be reduced to about 20 percent and with the addition of (AR) an anti-reflective coating to about 3 percent [11]. Low reflection raises both open-circuit and short-circuit voltages, boosting a PV cell's power density [12]. AR materials must be opaque for understandable reasons; hence they are generally oxide. Due to inter diffusion of ions from the emitters area of the cell, the deterioration of these coatings over time can be linked to the AR coated and vice versa. When a cell's AR coating is weakened in a string of connected cells, the cell receives small amount of incoming photon and thus produces small amount of current than the other strings cells. The effect is a cell that is not balanced and addressed in the next chapter. The tone of the cell gives the appearance of AR coating degradation. The I_{sc} (short-circuit current) and V_{oc} (open-circuit voltage) modules can also be monitored over time [13].

vii. Mismatched Cell

Mismatching of cells are formed by soiling of the front layer, corrosion of the encapsulant, weakening of the AR coating, fabrication defects, splitting of cells and partial shading of the PV cell. Mismatched cells degrade the output of the module and are dangerous, particularly when all cells are connected in a module in series strings. When a module produces less current than that of the other module cells, it sometimes reverse the forward bias of the faulty cell. It allows the cell having fault to operate in the reverse voltage field, where it acts as a power consumer [14]. Figure 6(a) demonstrates that, due to the illustrated break, interconnecting bus can prevent a cell from generating less amount of current. Thermal stress and damage due to hail can cause cell cracking. During manufacturing and assembly, cracks can also be formed. Fig. 6(b) crack removes some part of the circuit part from the cell. Figure 1.7 shows the crack during outdoor operation formed in a cell. This will have the effect of the cell's decreased current. When a cell is partly shaded, the same phenomenon is observed. For solar cells, poor conditions allow the cells to heat up. When the temperature of the inconsistent cell exceeds a critical value (~50), cell encapsulant delamination can occur [15].

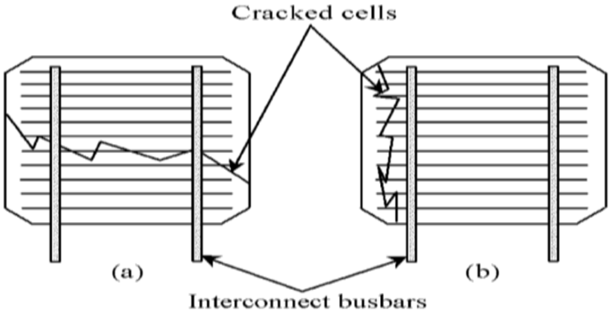

Figure 6. Crack cell structure

If the large reverse - biased current reaches the break down voltages, the cell will have scratched by thermal breakdowns. Hot spot appears on the PV cell in Figure 8 as a result of the above. The formation of hotspots in solar cells and modules affects not just module's effectiveness, but also open circuit voltage (V_{oc}), short circuit current (I_{sc}), maximum power output (P_{max}), and the fill factor ($FF=P_{max}/V_{oc}.I_{sc}$).

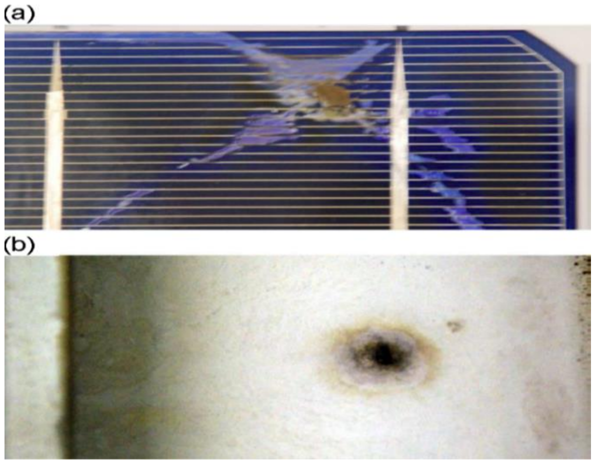

Figure 7. Front. Back hot spots

A mismatch situation can result in irreversible hot spot damage if modules with a mismatch cells has no embedded bypass diode with its connectivity circuits. When the device is biased forward, visual examination, I-V measurement, hot-spot endurance checking, and/or distinct cell temperature observing will usually detect inconsistent cells.

viii. Cell Induced degradation

a The dominant mode of degradation in a-Si and a-Si alloys is light-induced dilapidation, also classified as the Staebler-Wronski effect [16]. PV cells, when exposed to light, electron-hole (e-h) pairs are generated and recombined. Some of the weak Si-Si bonds in the cell's depletion region are thought to be capable of breaking the energy released during recombination. Broken bonds produce meta-stable defects, which act as recombination hubs. Such centers encourage e-h pair recombination, resulting in more meta-stable defects. classified as the Staebler-Wronski effect [16]. PV cells, when exposed to light, electron-hole (e-h) pairs are generated and recombined. Some of the weak Si-Si bonds in the cell's depletion region are thought to be capable of breaking the energy released during recombination. Broken bonds produce meta-stable defects, which act as recombination hubs. Such centers encourage e-h pair recombination, resulting in more meta-stable defects.

ix. Temprature Induced Degradation

PV module energy is measured under normal test conditions (STC: 1000 irradiance, 25 cell temperature and 1.5 global air mass spectrum). When a system is running outside, however, only about 15% of the incident energy is transformed to electricity. A substantial portion of the remaining 85% is converted to heat, while the remainder on the glass surface can be reflected or mirrored externally. Therefore, it is clear that an outdoor device will almost always have a temperature above 25 C. The band gap of the cells typically decreases at these elevated temperatures, meaning that photons of longer wavelengths can now be absorbed. Additionally, the lifetime of the minority carrier generally increases as the temperature rises. Both of these factors will increase the current produced by light and therefore Isc slightly. Nevertheless, with temperature increase, the saturation current decreases exponentially [18]. If the temperature increases, this tends to lower the cell's Voc.

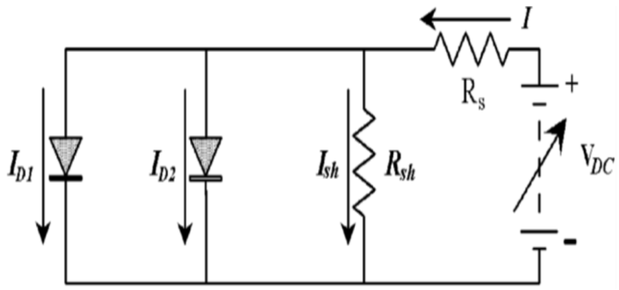

Figure 8. Equivlent circuit for cell in Dark

As the temperature rises, the decrease in Voc is slower than the rise in Isc, resulting in a decrease in the cell's fill factor and performance. High temperatures have an effect on the consistency of all materials, some more than others. That is why it is critical to understand the temperature reliance of individually module. Calculating the temperature dependence of the modules will reveal a alteration in the temperature coefficient. When operating outside, certain coefficients can be used to enlighten the performance of the modules.lamp on the module.

II. RESEARCH METHODOLOGY

The methodology used to calculate the output capacity, device performance, and degradation rates of photovoltaic power plants installed in Dir, Swabi and Peshawar are discussed in this chapter. Many criteria for performance analysis are specified in IEC standards to outline the overall performance in terms of solar resource, energy production, and the total impact of power loss. Reference yield, array production, final outcome, energy output, equipment competency, inverter proficiency, Photo - voltaic modules proficiency, energy loss (that also includes system and array capture losses), efficiency ratio, and capacity factor are among the most significant constraints for specifying overall performance of the system. Temperature models with the POA irradiance as an input are used to measure the rate of degradation.

A. Photovoltaic Array System Energy Production (Edc)

A Solar photovoltaic (PV) array is made up of a set of PV panels and their supporting structure. When approached to STC, solar cell arrays and modules are typically rated dependent on their maximum amount. The DC energy production is designed based on the DC power value that was reported.

$$E_{dc,daily} = T_\tau \times \sum_{t=1} V_{dc} I_{dc}$$

T_τ= Recording time interval

$$E_{dc,monthly} = \sum_{d=1}^{N} E_{dc,daily}$$

N = Number of working days per month for the system

B. Yield of energy or energy fed into the utility grid (Eac)

Every 5 minutes, the data recorder calculates the energy through the output terminals of the inverter and feeds it to the grid. Below is a list of the monthly AC energy generated and the total everyday detected quantity of AC power yield.

$$E_{ac,daily} = T_\tau \times \sum_{t=1} P_{ac}\ kWh$$

$$E_{ac,monthly} = T_\tau \times \sum_{d=1}^{N} E_{ac}\ kWh$$

The AC power recorded is Pac = Vac x Iac.
The daily averages of DC energy from the PV array, energy supplied to the grid, and usable energy from the device are described below.

$$E_{dc,daily} = T_\tau \times \sum_{day} P_A\ kWh$$

Since PA stands for Power from Array,

$$E_{USE} = E_{ac} + E_{L,daily} kWh$$

Monthly and annual average values can also be calculated in the same way as $EL._{Daily}$=Daily Energy to Load.

a. Reference Yield (Ry)

To get YR, divide the complete in-plane solar radiation or global in-plane horizontal irradiation by the usual radiance exposed to STC, which is 1 kW/m2.

$$Y_{R,daily} = \int_\tau \frac{G_i dt}{G_{STC}}$$

It is based on the in-plane solar irradiance on a regular basis. It is the sum of hypothetical energy that can be obtained at a specific location.

$$Y_{R,daily} = \frac{T_\tau \times (\sum_{day} Gi}{G_{STC}}$$

After the effects of ambient and PV module temperature, YR is referred to as corrected reference yield (YCR).

C. Array Yield (YA)

The photovoltaic plant's time to generate theoretical power, Edc, is represented by YA. So it's the ratio of the photovoltaic plant's monthly or daily mean direct current energy to its measured photovoltaic capacity. Equation 11 is used to calculate the daily YA [17].

$$Y_{A,daily} = \frac{E_{dc,daily}}{P_o}(\frac{h}{d})$$

D. Final Yield (YF)

In terms of theoretical power capacity, YF is the amount of time the photovoltaic plant requires to produce Eac on a regular basis. As a result, the ratio of final output power generated (Eac) to measured photovoltaic power recorded by the producer at STC becomes the ratio of final output power generated (Eac) to assessed photovoltaic power. YF can be calculated monthly and as a daily mean, just like YA. It is determined by the mounting structure as well as the position. The standard YF looks like this:

$$Y_{f,daily} = \frac{E_{dc,daily}}{P_o}$$

E. PV Module Efficiency (PV) or Energy Efficiency

It displays the module's usable energy in relation to the available irradiation. The photovoltaic array's instantaneous efficiency is expressed as

$$\eta_{pv} = \frac{P_{dc}}{G_I A_{module}}$$

Where

P_{dc} = the photovoltaic array system generates direct current electricity.

G_i = Irradiation from the sun on a global scale.

A_{modual} = Pv module Area

The average monthly output of photovoltaic modules is calculated as follows.

$$\eta_{pv,monthly} = \frac{E_{dc,daily}}{G_I A_{module}} \times 100\%$$

Where:

$E_{dc}.{}_{Daily}$ =Overall Daily Current Energy Yield

F. Invertor Efficiency

The maximum of device and module efficiency is considered to be inverter efficiency. Inverter efficiency, the ratio of AC power given by the inverter to DC power generated by the photovoltaic array system is known as conversion efficiency. The following formula is used to measure INV's instantaneous efficiency:

$$\eta_{INV} = \frac{P_{ac}}{P_{dc}}$$

The monthly Invertor Efficiency is given as under

$$\eta_{INV,monthly} = \frac{E_{U,daily}}{E_{dc,daily}} \times 100\%$$

G. System Efficiency

The performance of PV systems is linked to the efficiency of devices that have an inverter module and a PV generator. The instantaneous system efficiency is given as under.

$$\eta_{SYS} = \eta_{PV} \times \eta_{INV}$$

The capacity factor (CF) is a method of defining how much energy an electric power distribution system distributes. If a device distributes maximum measured power on a continuous basis, its capacity factor would be unity. It is the ratio of actual annual energy yield to the amount of energy a photovoltaic plant will distribute for 24 hours per day, 365 days per year at its measured capacity [19]..

$$CF = \frac{Y_{F(annual)}}{24 \times 365}$$

It varies in relation to the YF.

H. Energy Loss

The three chief losses in a PV system are module temperature loss, system loss, and array capture loss. The loss of cell temperature is negligible in contrast to the other two, so it was ignored in this review. For every 1°C increase in temperature above STC, the maximum power of a photovoltaic module decreases by 0.3–0.4%. In a real-world scenario, the estimated losses add up to the system's performance:

- Non-vertical radiance and low radiance magnitudes cause optical reflection losses.
- Discontinuous inverter operation, including tripping and breakdown.
- The effect on invertor efficiency is due to a decrease in radiance and a decrease in PR as temperature rises.

The things surrounding the installed photovoltaic device trigger shadowing effects (fractional shadow).

I. Array capture Loss

The dissimilarity between YR and YA is the array incarceration loss. The loss is caused by the actual radiance fluctuating from the hypothetical or orientation radiance.

$$L_C = Y_R - Y_A[\frac{kWh}{kW - day}]$$

J. Thermal Capture Loss

The dissimilarity between YR and YCR is the thermal capture loss. Such losses are due to solar thermal loss, which is noticeable as the temperatures of a module rises above 25 degrees Celsius. The thermal losses are stated as

$$L_{ct} = Y_R - Y_T[\frac{kWh}{kW - day}]$$

K. Miscellanous loss

Miscellaneous capture losses are caused by a number of factors including low radiance, shading effects, wiring losses, mismatch losses, diode loss, losses due to maximum power point monitoring, and dust accumulation on the module. Miscellaneous capture loss is defined as the difference between thermal capture losses and array, as expressed by the equation.

$$L_{cm} = L_C - L_{CT}\left[\frac{kWh}{kW - day}\right]$$

L. Degradation loss Analysis

The degradation rate is determined using either the Performance ratio or the Performance index process, based on the thermal modes of the PV modules. The degradation rate varies from technology, but it often decreases the power yield over time.

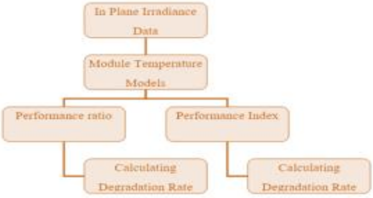

Figure 9. Step for finding degradtion

The two year degradation of the installed solar photo-voltaic system was analyzed using two techniques, one is performance ratio (PR) based on outdoor measurement information assessment and the other is visual inspection. In the first technique DC power is extracted from the individual module of installed system in different district of Khyber Pakhtunkhwa (KPK) and is compare with data collected from the new panel in that area with same set of module temperature, irradiance data set for the period of one day. This technique is the most significant factors for assessing a SPV system's efficiency. In particular, PR is the ratio between real yield and theoretically calculated yield. PR is percentage representation and remain a comparative variable for all SPV system installed around the world.PR shows the percentage of electricity available for export to grid after the deduction of power loss and operating energy consumption. The energy losses include heat losses and conductor losses. If the value of the PR is near to hundred it means that the system operates efficiently. Hundred percent PR cannot be attained as inevitable losses always occur when the PV system operates. The performance ratio can be calculated by the following. Whereas the nominal yield or energy yield is equal to GHI (in Kwh/m2) multiply by rated module efficiency, again multiply by module area in m2 while in numerator the Actual Energy Generated is the energy generated by the module in specific time interval. The performance ratio can be calculated on daily, monthly and annual basis. But in our research, we calculate the performance ratio of one panel installed already in the field and compare it with the performance ratio of the panel present in the stock of the said company and then find degradation from that comparison. For finding the performance ratio a DC

250watt constant power load was continuously connected to the PV module for 10 hours. The current, voltage value were continuously recorded for every 30 minute and from them the out power was calculated. The voltage and current is calculated by a multi meter UNI-T of series UT204 having the following DC voltage and current specification.

TABLE I. DC VOLTAGE LIMIT

Rang	**Resolution**	**Accuracy**	**Overload Protection**
400.0mV	0.1mV	±(0.8%+3)	600V DC/AC
4.000V	1mV	±(0.8%+1)	
40.00V	10mV		
400.0V	100mV		
600V	1V	±(1%+3)	

TABLE II. DC CURRENT LIMIT

Rang	**Resolution**	**Accuarcy**	**Overload Protection**
40.00A	0.01A	±(2%+5)	400A DC/AC
400.0A	0.1A	±(2%+3)	

During measuring both PV module were mounted on the rooftop with the fix stand at a tilt angle of 38 degree facing to the south and separate loads of 250 watt were connected to both PV module (New PV module and old PV module). The voltage and current reading were continuously recorded and an excel sheet is develop for calculation of watt, average watt and performance ratio. The relationship between watt and time is also plotted with help of excel sheet. The same procedure is repeated for each district as well as for each PV module for assessing performance ratio.

CONCLUSION

In the research the auther investigate the degradation in two different way.

1. Optical degradation
2. Performance ratio

In optical anaylises the following result were obtained in three different site of KPK.

TABLE III. OPTICAL DEGRADATION

S.No	**Degradation**	**Peshawar**	**Lower Dir**	**Swabi**
1	Front surface soiling	No	No	No
2	Hot spot	Yes	No	No
3	Yellowing & Browning	No	No	No
4	Delamination effect	No	No	No
5	Bubble effect	No	No	No

Only in Peshawar the hot spot problem was reported in only one solar panel during the research.

As the performance ratio is discuss in the above chapter.So in in this chapter we will only give information about degradation in each district based on the performance ratio discuss earlier.

The average power generated as well as the performance ratio in Lower Dir by both old and New solar panel is greater than that of Peshawar and Swabi. The average power generated in district Swabi is greater than that of Peshawar.

TABLE IV. AVERAGE POWER GENERATION

S.No	**District**	**Average Power**
1	Peshawar	170.093
2	Swabi	173.196
3	Lower Dir	174.590

But in degradation the scenery is quit opposite which are given below I tabular form.

TABLE V. DEGRADATION

S.No	**District**	**Degradation**
1	Peshawar	1.82 %
2	Swabi	2.5 %
3	Lower Dir	2.2 %

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