2022-08-02

Reviewing the External Factors that Influence PV Output Performance in the Irish Climate

Chibuisi Chinasaokwu Okorieimoh
Technological University Dublin, chibuisi.okorieimoh@tudublin.ie

Brian Norton Prof
Technological University Dublin, brian.norton@tudublin.ie

Michael Conlon Prof
Technological University Dublin, michael.conlon@tudublin.ie

Recommended Citation

Okorieimoh, C. C., Norton, B., & Conlon, M. (2021). Reviewing the External Factors that Influence PV Output Performance in the Irish Climate. Technological University Dublin. DOI: 10.21427/NVR6-3H14

Funder: Fiosraigh

REVIEWING THE EXTERNAL FACTORS THAT INFLUENCE PV OUTPUT PERFORMANCE IN THE IRISH CLIMATE

Chibuisi C. Okorieimoh, Brian Norton, Michael Conlon
Dublin Energy Lab, Technological University Dublin, School of Electrical and Electronic Engineering, Grangegorman, Dublin 7, Ireland.

ABSTRACT

The literature review presented in this paper centres on the external factors that influence PV output performance in the Irish climate.

Solar photovoltaic (PV) panels show long-term performance degradation, resulting in lower like-per-like efficiencies and performance ratios. Manufacturers of solar photovoltaic modules typically guarantee a life span of more than 20 years. But to meet such guarantees, it is necessary to track and mitigate PV module degradation during this period, and identify maintenance and repair requirements beyond this period. Solar PV modules degrade over time, becoming less efficient, less reliable, and, eventually, inoperable.

External factors such as solar irradiance, dust deposition, shading, ambient temperature, operating cell temperature, humidity and wind velocity affect the PV output performance in the Irish climate. This is because the performance of a PV system is heavily influenced by the meteorological conditions of the site locations.

Therefore, this paper reviews the external factors that influence PV output performance in the Irish climate.

KEYWORDS:
Long-term performance degradation, performance ratios, solar PV modules, external factors and PV output.

Introduction

Solar photovoltaic (PV) panels show long-term performance degradation compared to their initial performance, resulting in lower like-per-like efficiencies and performance ratios. Manufacturers of solar photovoltaic modules typically guarantee a life span of more than 20 years. But to meet such guarantees, it is necessary to track and mitigate PV module degradation during this period, and identify maintenance and repair requirements beyond this period. Solar PV modules degrade over time, becoming less efficient, less reliable, and, eventually, inoperable.

The problem of energy scarcity has reached a global scale due to the majority of energy production relying on non-renewable sources of energy (Okorieimoh, 2019a). Solar photovoltaic cells use the photovoltaic effect to convert solar energy into electrical energy (Okorieimoh et al., 2020). Solar energy can reduce emissions of carbon dioxide (CO_2) associated with the generation from fossil fuels as the only CO_2 emissions are those embodied in their manufacture (Norton, 1999). The performance of a PV system is heavily influenced by the meteorological conditions of the site locations, such as solar irradiation and ambient temperature (Shukla et al., 2016c). Transient variation in ambient temperature, wind velocity, shade, and dust reduce the output of PV panels (Okorieimoh et al., 2019b).

A PV system must be properly dimensioned to generate continuous energy throughout the year (Chandrakant et al., 2018). This necessitates a thorough investigation to make the best, most efficient, and least expensive decision (Missoum et. al., 2016). The PV system is distinguished by several performance parameters, including energy yield, ambient temperature, and performance ratio (Shukla et al., 2016b).

Several research studies on the review of literature on PV system performance investigation have been conducted. For example, Khatib et al. (2013) researched techniques for optimising the size of solar PV systems. As a result, it is critical to conduct a thorough analysis of various site locations to obtain accurate results. Various studies have also been conducted on the performance parameters of installed PV power plants in various geographical site locations and climatic conditions: Messinaa et al. (2014) investigated two 2.4 kWp grid-connected PV systems installed at two distinct sites locations: Tepic and Temixco-Morelos. Their findings revealed that the Temixco-Morelos solar PV system supplied nearly 90% of the electrical energy needed for the house, and they identified grid-connected PV systems as useful in urban and suburban areas. In an evaluation study of the performance of a 10 MW grid-connected solar PV power plant in India, Shiva and Sudhakar (2015) discovered an annual performance ratio of 86.12%. Sharma and Goel (2017) evaluated the performance of an 11.2 kW rooftop grid-connected PV system in Eastern India, resulting in a performance ratio of 78%.

Related work

PV Durability and Reliability Issues

The “bathtub” reliability curve shown in Figures 1 and 2 (Allen, 2009) represents the failure rate of a group of PV modules over time. The curve assists PV manufacturers in identifying the root causes of the failure and potential preventative measures (Allen and David, 2015). The curve is divided into three parts: failure mode A (infant mortality), failure mode C (normal life), and failure mode B (end of life failure). These are elaborated in Table 1.

Figure 1. “Bathtub” curve for PV Durability and Reliability (Allen and David, 2015).

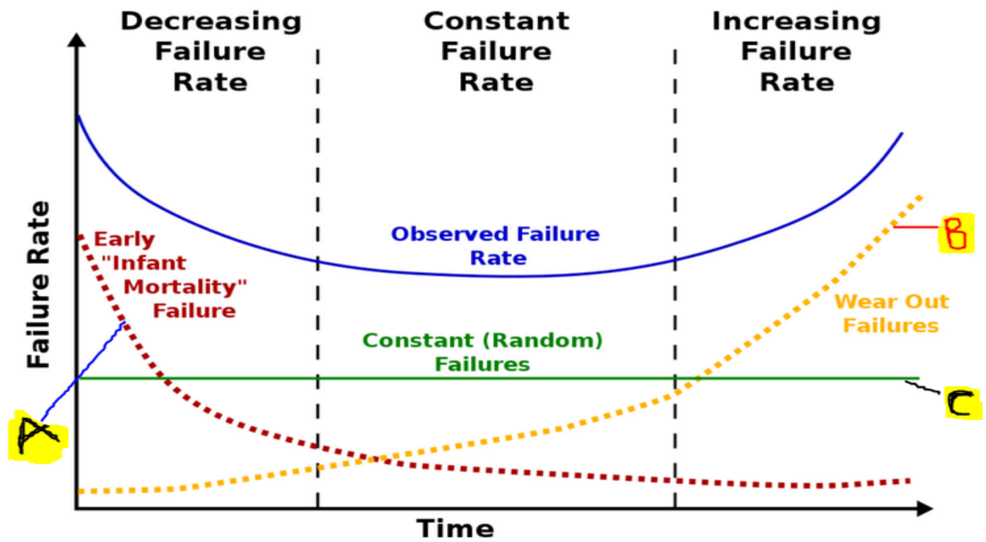

Figure 2. Multiple failure modes overlap of solar PV modules (Allen and David, 2015)

Table 1. Modes of failure occur in the PV cell life cycle

Failure modes	A	The early life failure (also known as infant mortality) typically occurs in the first 1-2 years of a PV module's life. Failure mode A manifests itself at the beginning of the module's life cycle. Failure mode A could be caused by fundamental design flaws, processing issues, manufacturing errors, or improper installation (Allen and David, 2015). Passing the IEC 61215 or 61646 qualification tests is not proof that a PV module has been tested and proven to be durable and reliable; rather, the IEC environmental stress test protocols are designed to test the period of early life failures (infant mortality) (see Figure 2) Allen (2009).
	C	Constant (random) failures are a type of failure mode (also, known as normal life) that occur over the PV module's lifespan. The types of failures associated with this mode are usually predictable.
	B	Failure mode B is the last part of the curve representing the PV module's end of life (also, known as the end-of-life wear-out). The curve steepens in this failure mode because many PV modules reach the point where they fail due to simple age or wear and tear, and this type of failure is fairly predictable.

Reliability issues across all the solar PV technologies include (Kurtz, 2011):

- Corrosion resulting in a loss of grounding;
- Fast connector reliability;
- Irregular insulation resulting in loss of grounding;
- Delamination;
- Fracture of glass;
- Failure of the bypass diode;
- Inverter reliability; and
- Moisture ingress.

Kurtz (2011) further shows specific individual PV technologies problems as seen in Table 2.

Table 2. Problems specific to the individual technologies (Kurtz, 2011)

		Degradation mechanism
PV cell type	Silicon wafer	Light-induced degradation (LID), front surface soiling effect, glass effect on encapsulation performance, reduced adhesion resulting in corrosion and delamination, bus-bar adhesion degradation, and failure of a junction box.
	Silicon thin-film	Electrochemical corrosion of tin dioxide (SnO_2), initial light degradation (ILD).
	Cadmium telluride (CdTe)	Interlayer adhesion and delamination, electrochemical corrosion of tin dioxide fluoride (SnO_2:F), shunt hot spots at scribe lines before and after stress.
	Copper indium selenide (CIS)	Interlayer adhesion, bus-bar mechanical adhesion and electrical, notable sensitivity of transparent conductive oxide (TCO) to moisture, failure of moisture ingress of the package.
	Organic photovoltaic (OPV)	Photolytic instability, moisture-induced degradation, moisture ingress failure of package.

Distinguishing Transient Performance changes from longer-term degradation

PV module output varies with solar irradiance and module temperature and it is also affected by shading, rain, and dust (Dunlop and Halton, 2006; Tiwari et al, 2011). All these variations are transient on a variety of timescales and/or reversible. Degradation refers to the loss of output due to physical degradation or damage to the PV cell; the effects are not reversible (Okorieimoh et al., 2020). It refers to effects that will ultimately require the replacement of a PV cell for the system to return to its initial performance. The transient effect caused by an increase in PV cell ambient temperature can lead to reductions in output and efficiencies (Okorieimoh et al., 2019). Degradation is measured by changes in mean efficiency and/or performance ratio over the long term, as illustrated indicatively in Figure 3 (Okorieimoh et al., 2020). It can also be observed in perturbation caused by cell failure in the current-voltage (I-V) curves for an array (Okorieimoh et al., 2020).

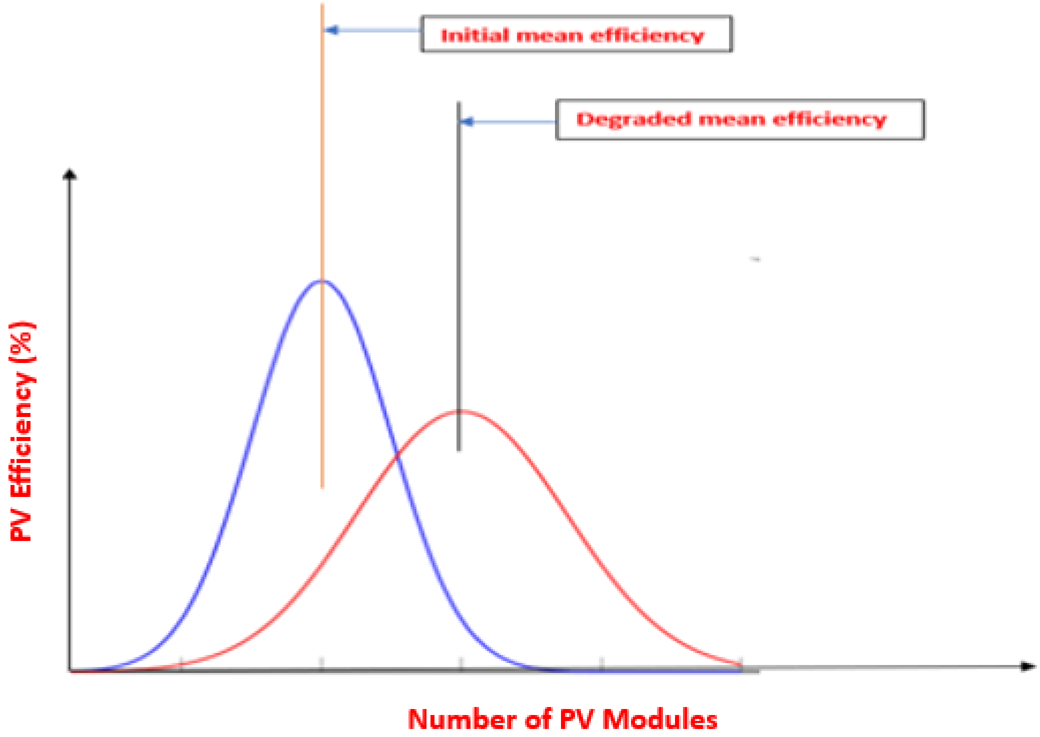

Figure 3 Degradation of Solar PV system (Okorieimoh et al., 2020).

Individual module degradation can be attributed to intrinsic property changes in the PV materials caused by external effects such as:

- Potential induced degradation (PID) (Pingel et al., 2010); and
- Light-induced degradation (LID) (Sopori et al., 2012).

The outdoor operation of cells as part of a module in an array means mechanisms external to the solar cell such as corrosion in interconnections and solder bonds play a significant role in performance degradation (Li, 2016). This makes it important to determine the degradation rates under outdoor operational conditions rather than indoor testing of isolated modules. Li (2016) classified the major difficulties in evaluating the degradation rates of PV modules from real operational data. System degradation and measurement degradation are shown in Table 3.

Table 3. System degradation and measurement degradation

Degradation	System	Large fluctuations of the operational data due to uncontrollable external parameters such as weather conditions like solar radiation, rain, cloud movement, wind velocity, and ambient temperature together with unexpected changes of factors external to PV systems such as unexpected shading, inverter problems, and control failures.
	Measurement	Systematic 'degradation' in the measurement of PV module operational performance caused by control sensor drifting with time as a result of electronic ageing of components such as the drifting of irradiance sensors.

Evaluation of Solar PV Failure Modes through Materials Degradation Approach

Failure modes and degradation mechanisms can analyse the reliability and durability of solar PV modules during outdoor operation (Pramod et al., 2019). Solar PV modules failure modes are associated with partial shading, inverter failure, EVA discolouration, series and shunt resistance, hot spot, corrosion, delamination, bubble, crack in solar PV cell, bypass diode, and potential induced degradation (PID) which occur in PV modules after long term outdoor exposure (Pramod et al., 2019). Each of these failure modes and their effects is summarised in Table 4.

Table 4. Solar PV failure modes and their defects (Pramod et al., 2019)

S/N	Failure mode	Effects	References
1.	Partial shading	Causes a significant amount of leakage current.	(Chaibi et al., 2019)
2.	Inverter failure	Causes a drastic drop in power	(Hacke et al., 2018)
3.	EVA discolouration	Laboratory exposure has shown that the power output of brown ensemble PV modules has probably degraded at an average rate of about 1%/year due to a decrease in I_{SC} caused by low transmissivity of solar radiation into the solar PV cell, thus reducing the FF.	(Weber et al., 2012),(Kempe et al., 2009), (Sinha et al., 2016).
4.	Series and shunt resistance	Causes a reduction in solar PV cell (example, a-Si PV) efficiency to about 1%.	(Fortes et al., 2014).
5.	Hot spot	A decrease in R_{Sh}, resulting in I_{SC} may be decreased. I_{SC} of 3 hot solar cells PV modules is marginally higher than 7 hot solar cells PV modules.	(Tamizhmani and Kuitche, 2014), (Rajput et al., 2018).
6.	Corrosion	The R_S of solar cell/module increases, which results in a performance decrease.	(Carlson et al., 2003)

7.	Delamination	It results in to increase in temperature, which destroys the layers of the PV module.	(Mau et al., 2004).
8.	Bubble	It is expected that bubble formation is one of the causes of delamination, which is one of the major problems linked to PV module reliability and durability.	(Köntges et al., 2011).
9.	Crack in solar PV cell	This affects 10% of solar cell area, growth hot spot, and significantly decreases the power and lifespan of PV modules.	(Wendet et al., 2009), (Reil et al., 2010), (Claudia et al., 2018).
10.	Bypass diode	A significant amount of leakage current may reduce.	(Delgado-Sanchez et al., 2017).
11.	Potential induced degradation (PID)	The negative side PV module degraded about 42% due to 9 years of outdoor exposure with negative voltage stress.	(Islam et al., 2018).

Effects of external factors on the performance of PV systems

The performance of solar PV systems is affected by external factors such as solar irradiance, dust deposition, shading, temperature, humidity and wind velocity (Topić, 2017).

Solar irradiance

The influence of solar irradiance on PV systems is dependent on the type of silicon (Si) technologies. For instance, it has been investigated that the efficiency of wafer-based Si technologies is not as much affected by fast solar irradiance changes as Si-based thin-film technologies (Topić, 2017). For this reason, amorphous-silicon (a-Si) technologies show higher efficiencies at low solar irradiances, while monocrystalline-silicon (m-Si) show higher efficiencies at high solar irradiances (Topić, 2017). However, each PV technology owns a different spectral response. Spectral response is the probability that the absorbed photon will generate a carrier to the photocurrent of the PV cell. This is demonstrated in Figure 4.

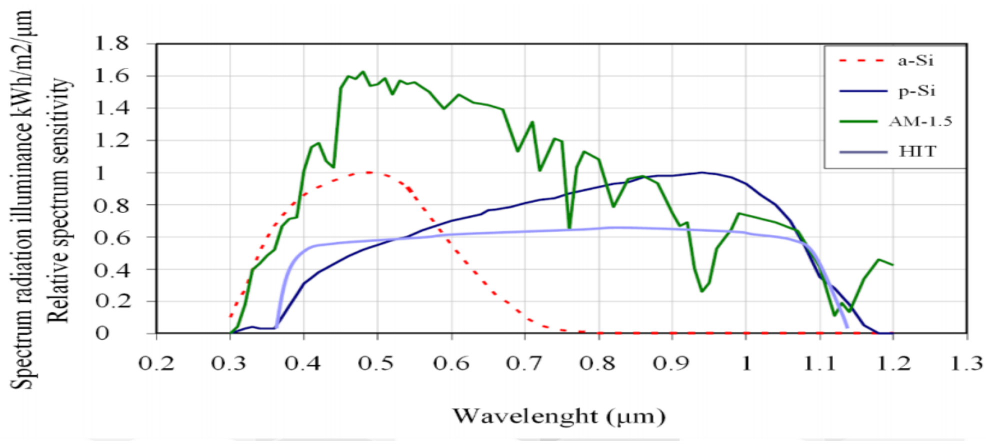

Figure 4. Spectrum response of different PV technologies (Sirisamphanwong, 2013).

Dust deposition

The influence of dust deposition depends on different factors such as geographical location, climate (desert, tropical), microclimate, site, dust type, and tilt angle of the module. Tanesab et al. (2015) investigated the contribution of dust deposition to the long-term degradation of the performance of different types of PV modules. Modules were in operation for eighteen years without any cleaning. Their results show that the degradation of power during eighteen years was around 19 to 33 %. (Perth, Australia) – temperate climate region. The main influences on the degradation of tested modules (seven different modules: two m-Si, two p-Si and three a-Si, north-oriented with a tilt angle of 32°) were not affected by dust. The influence of corrosion, delamination and discolouration on power output losses was around 71–84 %. Power output losses caused by dust were about 16– 29% which is still significant. This means that dust deposition was responsible for 3.04% - 9.57% of power degradation. Therefore, they concluded that dust has a fairly uniform influence on performance degradation for all three technologies (m-Si, p-Si and a-Si). Lopez- Garcia et al. (2016) investigated the long-term influence of soiling (dust deposition) on a PV module in moderate subtropical climates (Ispra, Italy). They investigate the influence of soiling on silicon PV modules performance that was exposed to outdoor conditions for more than 30 years. Their results showed that the overall power increase after cleaning was between 3.5 % and 19.4 %. The average value of power increase after the cleaning of modules was 9.8 %.

Shading

Shading has a significant influence on the power decrease of the PV module. Just like solar irradiance, the influence of shading varied with different technologies of PV modules. For some types of PV modules shading of even a small area of the module (e.g. 10%) can lead to a decrease of output power close to zero. During the designing process of PV systems, the shading should be considered to avoid shading influence as much as possible and this is illustrated in Figure 5.

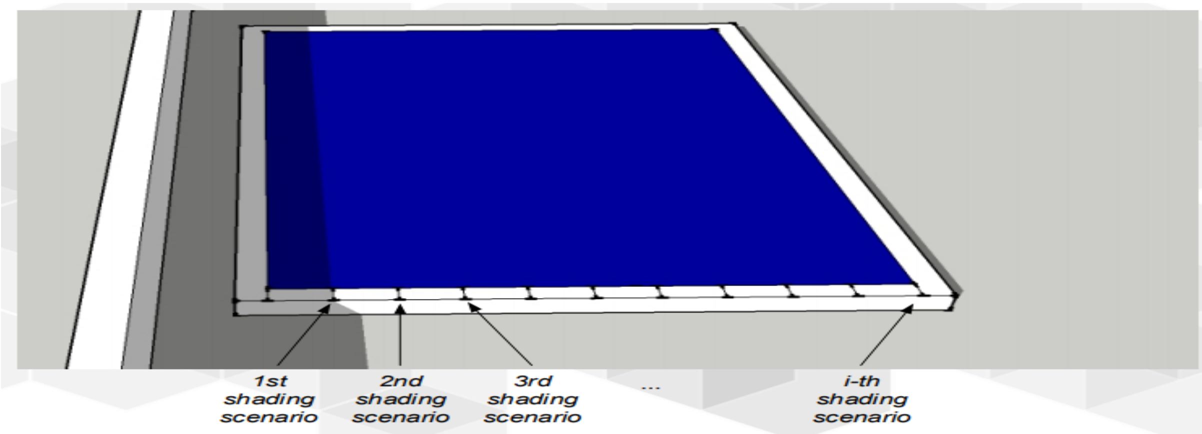

Figure 5. Influence of shading effect on PV modules (Topić, 2017)

Effect of temperature, humidity and wind velocity

Apart from the influence of dust deposition, solar irradiance and shading effect on electricity generation from PV systems, other parameters such as humidity, wind velocity, ambient temperature and most importantly, an operating temperature can affect PV power output and efficiency.

Conclusion

Since environmental factors such as humidity, dust accumulation, wind velocity, shading, ambient temperature and operating cell temperature reduce PV systems' output power and efficiency, it is necessary to minimise these effects through the inspection of the proposed geographical location before the installation of PV systems. Because of the variability of climates, it is important to increase the optimisation considerations to achieve a more significant result. Rather than using standard methods for installing a solar PV system, it is important to consider dominant factors such as wind directions and speeds, which have transient effects on solar PV system output performance.

However, the influence of shading has the strongest effect on the reduction of PV modules output power. Because of this, during the design phase of PV systems, it is important to consider avoiding shading as much as possible. The influence of shading is different for different technologies of PV modules, and shading influence is different for different PV module orientations (portrait/landscape).

References

Allen Z (2009) 'PV Durability and Reliability Issues', Atlas Material Testing, Journal of Renewable Energy World, 1, Issue 5.

Allen F.Z., David P.D (2015) 'Photovoltaic Module, Weather Durability and, Reliability "Will my module last outdoors?", Solar Energy Competence Centre, Atlas Material Testing Technology LLC, Available at www.atlas-mts.com.

Chandrakant D, Deepak P, Anshul A, Akash K.S., Sudhakar K, Murali MSR, Amit B (2018) 'Performance simulation of grid-connected rooftop solar PV system for small households', A case study of Ujiain, India, Energy Reports, 4, pp. 546-553. https://doi.org/10.1016/j.egyr.2018.08.002

Chaibi Y, Malvoni M, Chouder A, Boussetta M, Salhi M (2019) 'Simple and efficient approach to detect and diagnose electrical faults and partial shading in photovoltaic systems', Energy Convers. Manag., 196, pp. 330-343.

Carlson D.E., Romero R, Willing F, Meakin D, Gonzalez L, Murphy R, Moutinho H.R., Al-Jassim M (2003) 'Corrosion effects in thin-film photovoltaic modules', Prog. Photovolt. Res. Appl., 11, pp. 377-386.

Claudia B, Mariacristina G, Marco P (2018) 'Fatigue crack growth in Silicon solar cells and hysteretic behaviour of busbars', Sol. Energy Mater. Sol. Cells, 181, pp. 21-29.

Dunlop E.D., Halton D (2006) 'The performance of crystalline silicon photovoltaic solar modules after 22 years of continuous outdoor exposure', Prog Photovoltaics, 14(1), pp.53–64. DOI: 10.1002/pip.627.

Delgado-Sanchez J, Sanchez-Cortezon E, Lopez-Lopez C, Aninat R, Alba M.D (2017) 'Failure mode and effect analysis of a large-scale thin-film CIGS photovoltaic module', Eng. Fail. Anal., 76, pp. 55-60.

Fortes M, Comesana E, Rodriguez J.A., Otero P, Garcia-Loureiro A.J (2014) 'Impact of series and shunt resistances in amorphous silicon thin-film solar cells', Sol. Energy, 100, pp. 114-123.

Hacke P, Lokanath S,Williams P, Vasan A, Sochor P, Tamizhamni G, Shinohara H, Kurtz S (2018) 'A status review of photovoltaic power conversion equipment reliability, safety, and quality assurance protocols', Renew. Sustain. Energy Rev., 82, pp. 1097-1112.

Islam M.A., Hasanuzzaman M, Abd R.N (2018) 'Investigation of the potential induced degradation of on-site aged polycrystalline PV modules operating in Malaysia', Measurement, 119, pp. 283-294.

Khatib T, Mohamed A, Sopian K.A (2013) 'Review of photovoltaic systems size optimisation techniques', Renew. Sustain. Energy Rev., 22, pp. 454-465.

Kurtz S (2011) 'Photovoltaic Module Reliability Workshop', Technical ReportNREL/TP-5200-60170.

Kempe M.D., Moricone T.J., Kilkenny M, Zhang J.Z (2009) 'Accelerated stress testing of hydrocarbon-based encapsulants for medium concentration CPV applications' 34th IEEE Photovoltaic Specialists Conference, Photovoltaic Specialists Conference (PVSC), pp. 001826-001831.

Köntges M, Kajari-Schröder S, Kunze I, Jahn U (2011) 'Crack statistic of crystalline silicon photovoltaic modules', 26th European Photovoltaic Solar Energy Conference and Exhibition, pp. 3290-3294.

Li XY (2016) 'Degradation analysis of photovoltaic modules based on operational data: effects of seasonal pattern and sensor drift', IOP Conf. Series: Earth and Environmental Science 40, 012063. DOI:10.1088/1755-1315/40/1/012063.

Lopez-Garcia J, Pozza A, Sample T (2016) 'Long-term soiling of silicon PV modules in a moderate subtropical climate', Sol Energy, 130, pp. 174–83.

Missoum M, Hamidat A, Imessad K, Bensalem S, Khoudja A (2016) 'Impact of a grid-connected PV system application in a bioclimatic house toward the zero-energy status in the north of Algeria', Energy Build., 128, pp. 370-383.

Messinaa S, Paz Hernández R.I., Saldaña Durán C.E., Jesús Q.J., Nair P.K (2014) 'Comparative study of system performance of two 2.4 kW grid-connected PV installations in Tepic-Nayarit and Temixco-Morelos in México', Energy Procedia, 57, pp. 161-167.

Mau S, Krametz T, Jahna W, Fechner H (2004) 'Quality testing for PV-modules according to standard and performance control for supporting manufacturing', 19th EUPVSEC, 7-11 June, Pairs, France, NREL/CP-520-33531, pp. 1-3.

Norton B (1999) 'Renewable Electricity what is the true cost?', Power Engineering Journal. 13, pp. 6-12.

Okorieimoh C.C (2019a) 'Energy efficiency', Global scientific journals, GSJ, 7(4), pp. 763-775. Online: ISSN 2320-9186. Available at www.globalscientificjournal.com

Okorieimoh C.C., Norton B., Conlon M. (2020) ‘Long-Term Durability of Solar Photovoltaic Modules’, In: Scott L., Dastbaz M., Gorse C. (eds) Sustainable Ecological Engineering Design. Springer, Cham, pp. 317-325. Available at https://doi.org/10.1007/978-3-030-44381-8_24

Okorieimoh C.C., Norton B., Conlon M (2019b) ‘Effect of transient performance changes on photovoltaic modules output’, Poster presentation at 10th Annual Graduate Research School Symposium, Technological University Dublin, Ireland. DOI: 10.13140/RG.2.2.28516.94083.

Pingel S, Frank O, Winkler M, Daryan S, Geipel T, Hoehne H, Berghold J (2010) ‘Potential induced degradation of solar cells and panels’, Proc. 35th IEEE Photovolt. Spec. Conf. pp. 2817-22.

Pramod R, Maria M, Nallapaneni M.K., Sastry O.S., Tiwari G.N (2019) ‘Risk priority number for understanding the severity of photovoltaic failure modes and their impacts on performance degradation’, Case Studies in Thermal Engineering, 16. https://doi.org/10.1016/j.csite.2019.100563

Rajput P, Shyam, Tomar V, Tiwari GN, Sastry OS, Bhatti TS (2018) ‘A thermal model for N series-connected glass/cell/polymer sheet and glass/cell/glass crystalline silicon photovoltaic modules with hot solar cells connected in series and its thermal losses in real outdoor condition’, Renew. Energy, 126, pp. 370-386.

Reil F, Althus J, Vaaben W, Herrman W, Strohkendl K (2010) ‘The effect of transportation impacts and dynamic load tests on the mechanical and electrical behaviour of crystalline PV modules’, 25th European Photovoltaic Solar Energy Conference and Exhibition/5th World Conference on Photovoltaic Energy Conversion, pp. 3989-3992.

Shukla A.K., Sudhakar K, Baredar P (2016c) ‘Exergetic assessment of BIPV module using parametric and photonic energy methods’, A review Energy Build., 119, pp. 6273.

Shukla A.K., Sudhakar K, Baredar P (2016b) ‘Design, simulation, and economic analysis of standalone rooftop solar PV system in India’, Sol. Energy, 136, pp. 437-449.

Shiva K.B., Sudhakar K (2015) ‘Performance evaluation of 10 MW grid-connected solar photovoltaic power plant in India’, Energy Rep., 1, pp. 184-192.

Sharma R, Goel S (2017) ‘Performance analysis of 11.2kW rooftop grid-connected PV system in Eastern India’, Energy Rep., 3, pp. 76-84.

Sopori B, Basnyat P, Shet S, Mehta V, Binns J, Appel J (2012) ‘Understanding light-induced degradation of c-Si solar cells’, Proc. IEEE Photovolt. Spec. Conf. pp. 5200-54200.

Sinha A, Sastry O.S., Gupta R (2016) ‘Non-destructive characterization of encapsulant discoloration effects in crystalline-silicon PV modules’, Sol. Energy Mater. Sol. Cells, 155, pp. 234-242.

Sirisamphanwong C (2013) ‘The effect of photon flux density and module temperature on power output of photovoltaic array’, Energy Procedia, 34: pp. 430–8.

Tiwari G.N., Mishra R.K., Solanki S.C (2011) ‘Photovoltaic modules and their applications: A review on thermal modelling’, Applied Energy, 88, pp.2287-2304.

Tamizhmani G, Kuitche J (2014) ‘Accelerated lifetime testing of photovoltaic modules’, Photovoltaic Reliability Laboratory Arizona State University, USA, Available at www.solarabcs.org

Topić D (2017) ‘Influence of external factors on the performance of PV systems’, Faculty of Electrical Engineering, Computer Science and Information Technology Osijek, Zagreb Energy Congress.

Tanesab J, Parlevliet D, Whale J, Urmee T, Pryor T (2015) ‘The contribution of dust to performance degradation of PV modules in a temperate climate zone’, Sol Energy 120, pp. 147–57.

Weber U, Eiden R, Strubel C, Soegding T, Heiss M, Zachmann P, Nattermann K, Englemann H, Dethlefsen A, Lenck N (2012) ‘Acetic acid production, migration, and corrosion effect in ethylene-vinyl acetate EVA-based PV modules’, 27th European Photovoltaic Solar Energy Conference and Exhibition, pp. 2992-2995.

Wendet J, Träger M, Mette M, Pfennig A, Jäckel B (2009) ‘The link between mechanical stress induced by soldering and micro damages in Silicon solar cells’, 24th European Photovoltaic Solar Energy Conference, pp. 3420-3423.