Quadrical Ai

Digital Twins

for the Renewable Industry

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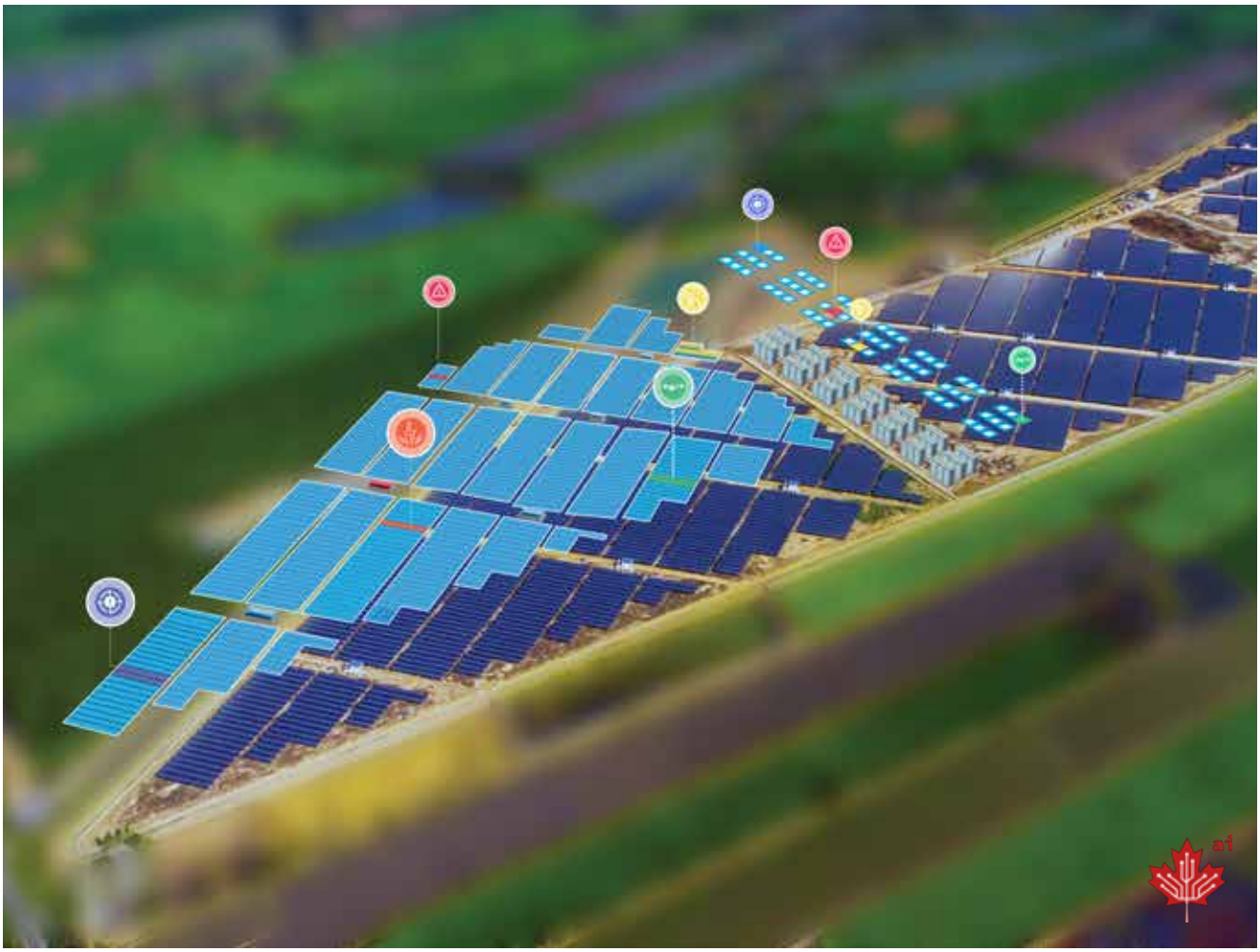


Digital Twins
For Renewable Industry

Renewable assets spend years in development, design, construction and commissioning. They move on next to operate for the next 25 – 30 years before decommissioning. Digital Twin Models are used by the renewable industry during all these phases in their life cycle from design to decommissioning.

The purpose of Digital Twins, which are a digital replica of the physical system is to use simulation to represent changes from integration, testing, monitoring, and providing predictive maintenance based on the stage of the process.

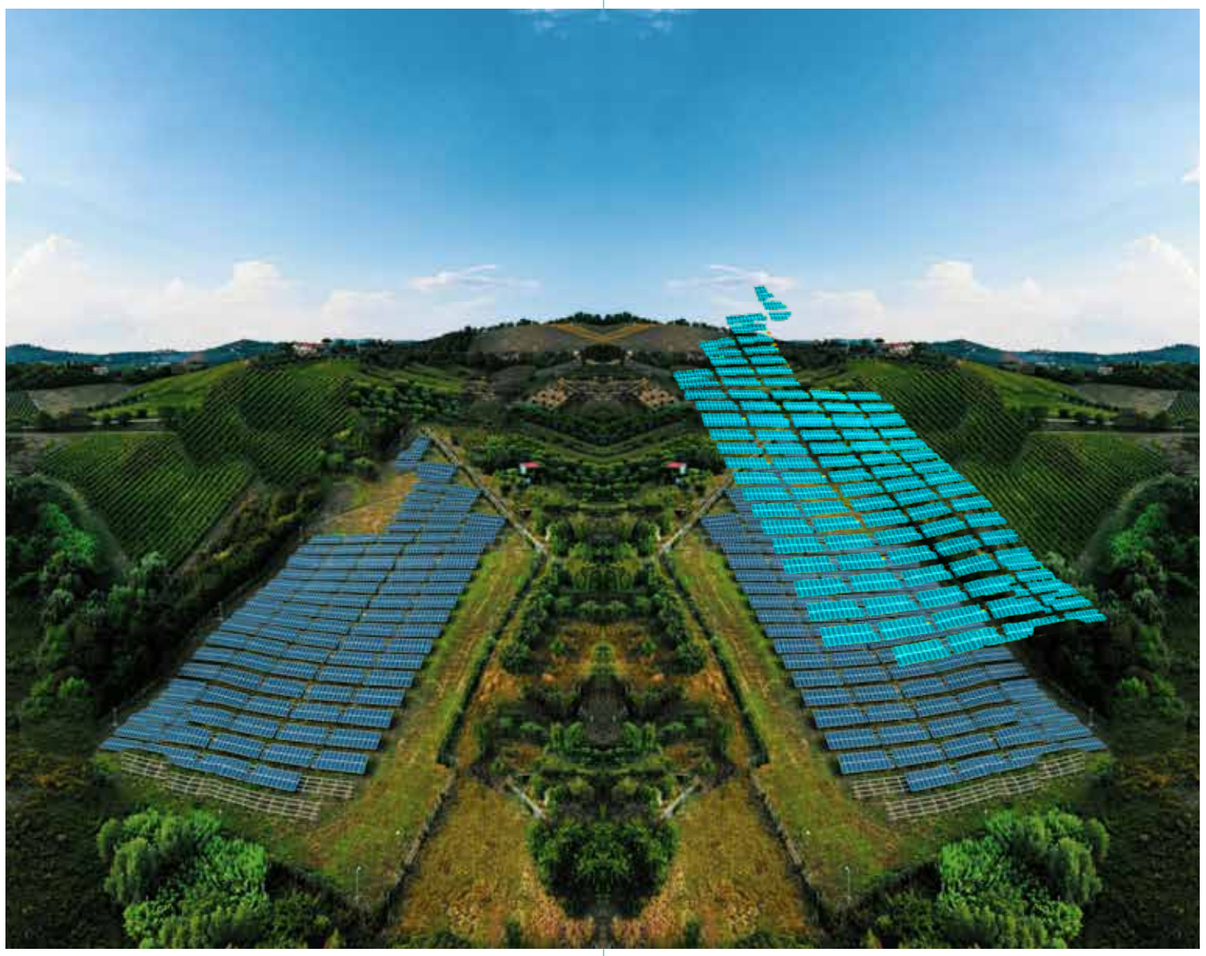
Examples of Digital Twins used include PV Syst, a statistics-based system for estimation during development, plant digitization during construction and information digital twins used by IT teams. It is this value provided across the entire life of solar and storage plants which makes them crucial to our industry.

Our paper will focus specifically on data-driven Digital Twins which are used to optimize operations, ensuring effective generation over the next two and a half decades of the plant's operation.

As the concept of 'Digital Twin' becomes increasingly familiar in the solar industry, this paper aims to simplify and clarify the concept plus explain how Digital Twins are utilized.

For faster understanding, this paper is divided into five sections, concluding with Quadrical's qualifications for providing these insights.

1. Basics of Digital Twin Technology for Operations
2. Benefits to Solar (Storage in next paper)
3. Implementation Issues
4. Best Practices for Success
5. Why Quadrical?



How are Digital Twins used
for Renewable Energy Operations?

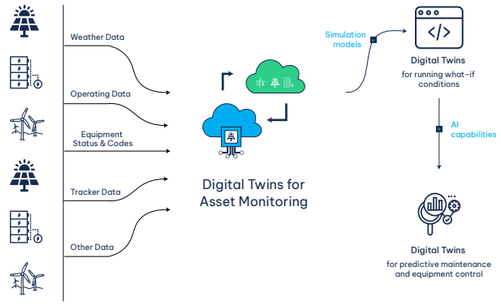
Data-based Digital Twins for operations are an interactive, digital representation of actual solar and storage plants. Well-designed Digital Twins include the integrations and relationships between all devices on the plant connected via IoT sensors. They are customized based on location, historical performance data, weather and climate conditions.

Next along with historical data, advanced analytics, modeling, statistics (Rules), physics-based models and perhaps ML/AI or integrative intelligence are added.

These combinations create a dynamic, virtual context of the operating environment or operational setting.

To keep current, these virtual data-based Digital Twins, keep capturing RealTime data within an intelligent, self-adaptive system. This means performance can be modeled across any timelines via Digital Twins, based on data from actual site physical conditions at that time in history.

Building effective Digital Twins requires data – both historical and in RealTime. IoT devices capture data and relay it to the cloud where AI algorithms match RealTime sensor readings against historical data which allows platform to "see" if the equipment is functioning properly. Managers access data-based insight using the web, desktop or mobile dashboards. They help determine where repairs are required to effectively manage assets scattered across large areas with actionable information for operators.



Digital Twins monitor, optimize operations & control plants.

Benefits of
Digital Twins for Solar

Operational Efficiency & Cost Reduction

The primary benefit of Digital Twins for operators of solar plants is that they provide a faster and sharper tool for monitoring and optimizing plants. This tool can reduce operational costs, optimize resource use and provide visibility into operational processes. It also helps make everyone more accountable

Digital Twins do this by simulating real situations & outcomes and predicting potential problems - making them an analytical powerhouse. They allow operators to pick up even the smallest fluctuations in patterns of energy generation, identifying underperformance faster.

Real-Time Monitoring & Decision Making

Continuous monitoring provides RealTime insights, so operators make faster diagnostic decisions and more importantly, take quicker corrective action. This boosts both efficiency and reduces downtime at the plant level. Time is scarce both for technicians in the field and for Performance Engineers. With visuals, on top of Digital Twins, they can quickly explore large streams of data, as, ML models underneath continually model both deviations and their possible causes. This systematized approach also increases plant safety.

Portfolio-Level Impact

Reporting via dashboards may also be generated/scheduled automatically so teams focus on O&M decisions, applying insights gained via data analytics. This adds up to significant cost savings and a higher Return on Investment (RoI) by reducing downtime and enhancing maintenance efficiency. Additionally, by extending the lifespan of the plant's components, Digital Twins increase both the value and longevity of assets over time. Finally, impact is multiplied by taking this across the portfolio level of assets which may be spread across the globe.

Challenges in Implementation
Digital Twins for Solar

A Digital Twin-based solution appears to be a clear winner in the way it both improves efficiency and reduces operational costs, but it is not without some challenges.

Data Quality

Digital Twins are dependent on quality and timely data. These are in turn dependent on access to sensors (device, weather), meters and controllers in RealTime. Luckily, in 2024, most plants have robust SCADA or DAS systems to ensure quality and timely data. Even then problems of incorrect readings, missing data or not calibrated equipment leads to unreliable values. Bad data thus would make it tricky for a platform, utterly dependent on quality data to perform well, if data quality is an issue. In that case, discrepancies would impact both the availability and value of insights.

Solar plants are an integrated mix of transformers, inverters, relays of strings and panels which produce electricity. Often each produces data in completely different formats and frequencies across locations, time zones etc. This mix may often include outliers, false positives or just plain junk values, alongside other issues related to data integration. Integration challenges are compounded as each plant provides differing frequency and granularity of data, ranging from 1-min to 30-min intervals, sometimes more. Plants in a portfolio are of varying ages, leading to more integration issues – which may easily become more complicated and expensive creating even more issues with computing KPIs.

Upfront Investments

There are often initial investments for set-up with ongoing expenses and staff training for any new technology. These investments may be both financial and cultural. More expensive staff may now be needed to work on higher-level performance issues, as basic issues are optimized automatically. However, if these initial investments are managed, reduction in downtime and the optimization of energy generation will justify investments of time and money, with staff now engaging in more interesting and valuable work.

Lastly for energy installations, *security is concern #1 when deploying any software.* No breaches can ever be allowed as they would impact both finances and reputation. If these challenges are faced carefully, implementations are more likely to be successful.

Best Practices
to Ensure Success

Cost-Benefit Analysis

Deploying a Digital Twin platform may be complex, but with the right strategy along with a positive but careful attitude, the results should justify effort spent. A cost-benefit analysis on all areas of the system along with acknowledging known issues which may cause later troubles would be the first of the best practices for an asset owner to pay attention to.

Ensuring Data Accuracy

Success will also require that the asset investor, owner, IPP or O&M operator understand and develop strategies to ensure data accuracy and availability are in place. The system will also need integrating the system with current alarms, alerts and notifications in place.

Integration with Current Systems

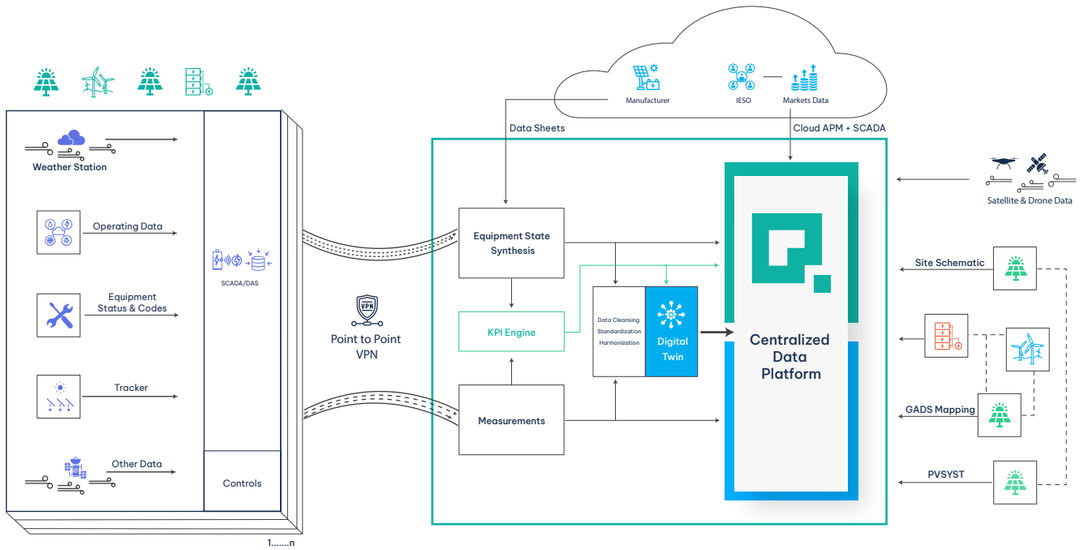
Next, new analytics must be fully leveraged with the provision of training and testing available for your teams. Conversations need to begin during development and deployment and continue even after the launch and safe functioning of the system. For long-term success, feedback should be provided continuously, listened to and new features understood and integrated.

Feedback and Improvement

Your thoughtfulness and participation in the process will vastly increase the probability of success, reduce surprise issues, and help avoid unplanned future expenses. Having read this far, you have hopefully decided that a Digital Twin-based platform IS right for you. In that case, we'd like to talk to you about why we think Quadrical may be the best option.

Why Quadrical?
Renewable's Oldest Digital Twins

Quadrical has quietly been working with Digital Twins, Machine Learning & Data focused on Solar since 2019 – making us the oldest in the industry. Located in Waterloo, Canada's answer to MIT, the University of Waterloo, Blackberry, it now boasts a unique startup ecosystem.



Quadrical's Digital Twin Platform.

Unique & Proprietary Technology

Quadrical's Digital Twins are unique "twins" created by looking at the historical performance of every equipment on plant and it's exact production capability. This 1-Time activity creates Quadrical's proprietary and patent-pending dynamic, accurate, personalized digital replicas for solar & storage.

Next we leverage advanced machine learning focuses on advanced solar plant data analytics. Integrating diverse data streams from weather stations, equipment status codes, trackers, and other operational inputs into a centralized data platform.

This platform synthesizes equipment states and measurements, feeding into our Digital Twins for data cleansing and standardization. By incorporating manufacturer data, market insights, drone data and detailed site schematics, we ensure comprehensive monitoring and optimization.

Our KPI engine provides actionable insights and predictive maintenance capability to drive efficiency and reliability for long term solar energy production. Capacity issues are flagged by comparing production with Digital Twin expectations and also compared with the plant's expected generation for reporting. A system which puts up no 'false positives' would be much easier.

However, no false positives also mean, lots of generation loss-causing issues are not caught. We think a better way is to provide issues flagged automatically, prioritized by revenue impact. This helps decision makers who have actual knowledge of the plant – creating an "Integrated Intelligence."

Working together with specific Digital Twins for String Yield, Inverter Efficiency, Pyranometer calibration and soiling, our Rules engine can compare the benchmark with actuals to make required meaningful decisions about ticketing as well as loss estimation.

Finally, the model produces automated Audits on all equipment to manage further losses and degradations while constantly tuning for data drift and model accuracy.

Quadrical's AI-powered loss waterfall tool improves solar plant analytics by identifying even the slightest variations in generation patterns. These subtle discrepancies often slip past traditional Digital Twin systems, but Quadrical's cutting-edge technology catches them with precision - allowing plant operators to swiftly address and mitigate the impact of under-performing assets.

By meticulously identifying and quantifying these factors, Quadrical empowers operators to implement targeted maintenance strategies, optimize performance, and maximize energy output. This holistic approach ensures that every aspect of the solar plant's operation is fine-tuned for peak efficiency, ultimately driving higher profitability and sustainability in solar energy production.

Real-World Applications for Solar

1. **Y-Connector Issue Detection**

Fig 1 : A Y-connector issue (green) detected by physics based rules.

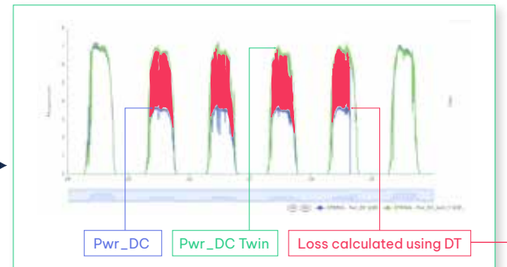


Fig 2 : For complete event duration, loss is calculated as difference between Digital Twin based expected power generation and actual power generation.

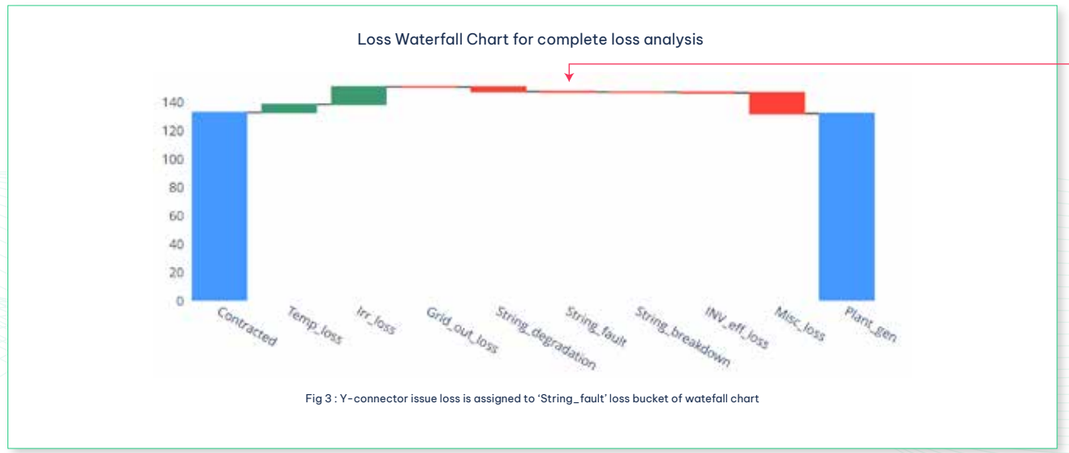


Fig 3 : Y-connector issue loss is assigned to 'String_fault' loss bucket of watefall chart

Real-World Applications for Solar

2. String Breakdown Detection

Fig 4: Represents a string breakdown event (green) detected by our rule engine.

Fig 5:For complete event duration, loss is calculated as the difference between Digital Twin based power generation and actual power generation .

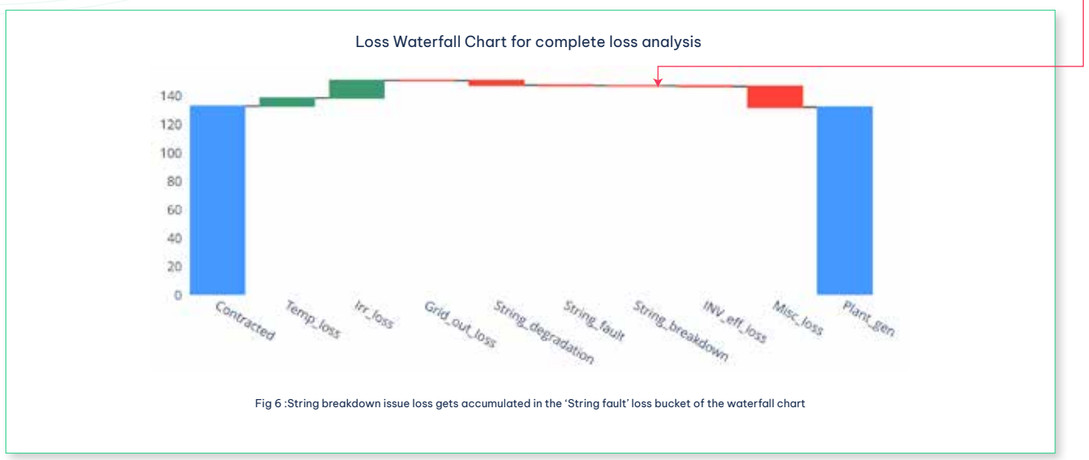


Fig 6 :String breakdown issue loss gets accumulated in the 'String fault' loss bucket of the waterfall chart

Handling Data Gaps and Quality

Data from solar plants, both the volume and complexity bring challenges. However, data is where lies the primary expertise of our two founders (both electrical engineers by training) who have been working with data plus Advanced Analytics, and AI/ML for multi-decades. We have built automated systems for analyzing incoming data for outliers, data quality or missing data. Our platform provides a comprehensive assessment of data availability and quality for every plant as it knows which inputs may be trusted and which data should be fed into the algorithm. This is because we have been working at the intersection of data, Digital Twins and solar for more than five years. In the case that SCADA or DAS systems are not able to provide quality data, Quadrical can install proprietary RTUs. We currently have RTUs working on 20 sites, along with 100's in buildings where renewable energy is being received.

Advanced Analytics

Quadrical's technology uses best average yields of peers, combined with their respective capabilities and pyranometer data to define irradiance at each granular part of the plant. These inputs multiplied by true capacity helps define availability losses. It uses these to estimate how each of the PV components should be producing in each specific condition. This allows us more granularity, more specifically to estimate the asset's total power output – which becomes the benchmark. There is not one Digital Twin but often hundreds of them on a 50MW site – as they represent each separate use-case.

Next, we go to work.

- Create a highly accurate model to predict the performance of the generation capacity of each inverter, SCB, and panel string.
- Add up generation capacity by device bottom up.
- The delta from actual provides accurate availability losses.
- Finally, this analysis happens within 24/7 RealTime monitoring within a full Asset Management platform, not a separate optimization widget.

Technology firms for solar used to either provide asset optimization or portfolio monitoring. The Remote Operations Center (ROC) with performance engineers monitoring SCADA 24/7 for alerts communicated with Maintenance teams about the correct course of action.

Quadrical's Digital Twins + Rules models are not just optimization – they are fully integrated into our Asset Operations Management Platform. *Our Data Acquisition | Monitoring | Advanced Analytics | Physics-Based Rules Simulation | Ticketing | Reporting help you run your renewable energy business on one platform.*

Only a decade ago, solar plants were small, built close to or in large towns. The industry was boutique making inspection and repair easy. Today's plants cover areas as large as 200 square miles making it hard to ensure smooth, trouble-free operations. At the same time, Power Purchase Agreement (PPA) rates have fallen heavily – making it imperative that Independent Power Producers (IPP's) of renewables fight for every kWh. That is what our Digital Twins help you do.

Here's to the long productive life and health of your renewable assets.

Deployed on 3000 MW Solar + 5000 MWh Storage + 200 MW Wind

Dr. Prateek Malhotra

Dr. Prateek Malhotra is a data scientist specializing in solar plant data analytics. With extensive experience in renewable energy sector, he has made significant contributions to optimizing solar plant performance through advanced machine learning & data-driven solutions.

Kitty Chachra

Based in Waterloo, Canada she has been working with global renewable clients sharing insights and knowledge for the last five years. Her switch to Renewables followed a long career in Brand Management for consumer products.