

A Digital Platform for Microgrids (DPM): Addressing Design Gaps for Historically Underserved Communities

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ABSTRACT

There's increasing opportunity for microgrids to improve quality of life in urban, tribal and rural communities. Microgrid management solutions are typically engineer oriented and not cognizant of local community members; nor do they incorporate customer interaction capabilities, which is essential in these target communities. It is critical to manage microgrid operations both physically and digitally to make the promise of sustainable, flexible, economically viable, and broadly accessible microgrids achievable. We are developing a cyber-physical-social platform to meet this promise. This paper addresses novel applications of data science, modeling, visualization, network communication, and optimization algorithms fostering effective integration of energy efficiency, demand flexibility, distributed energy resources (DER) in a microgrid setting. Tools are being designed to specifically target accessibility, viability and effective solutions for historically underserved communities. Research described comes directly out of practice and award-winning projects in remote rural villages abroad. We incorporate lessons learned and evolve the framework for deployment within Tribal nations, Low-and-Moderate Income (LMI) communities in urban areas and poor rural/exurban communities. Future microgrids will be interactive where inclusion of social and behavioral elements of consumers is crucial for operational success. Missing from existing SCADA and EMS systems is an ecosystem enabling dynamic interaction between operators and consumers. Software, sensors, and controls dynamically monitor technical management parameters, coupled with interactive consumer engagement.

Introduction

In Native American Nations, 14% of households have no access to electricity (Guevara-Stone 2014 and Peter M. and Trevor E. 2020). The average cost to connect a home to an existing electric distribution line in the Navajo Nation is \$40,000 (Brookings Report 2021) to \$70,000 (Lapastora 2019). There are many repercussions caused by this lack of electricity for Navajo families: little to no access to running water, unreliable lighting, the absence of modern forms of home heating and cooling and appliances such as refrigerators and microwaves (APPA News 2021). Moreover, the COVID-19 pandemic has "exacerbated already severe energy and economic inequalities in Indian country. For decades, many tribes have suffered from inefficient energy infrastructure, high costs and a lack of funding for new projects. Low electricity rates are compounded by limited cell and broadband service on many reservations. These needs have "only gotten worse during the pandemic", according to a recent report by The Guardian (The Guardian News 2020). The larger problems and same challenges exist in urban communities for low-to-moderate income families as well. Approximately half of all US households that face energy insecurity – that is, the inability of a household to adequately meet energy consumption needs – are African American. Table 1.

shows the concerning trend that this disproportionate burden has on underserved communities.

Table 1. Percentage of income spent on utilities (Carley and Konisky 2020)

Urban				Rural		
Average (all)	Low-income	African American	Higher - income	Average (all)	Low-income	Low-income, elderly, non-white, renting population
3.3%	7.2%	5.4%	2.3%	4.4%	9%	much higher than average

Renewable energy powered microgrids are a viable alternative to bring access to electricity for these communities. A microgrid is a local energy grid with control capability, which means it can disconnect from the traditional grid and operate autonomously (Department of Energy). A microgrid must have one or more sources of power generation and multiple loads. Such systems are extremely beneficial in locations where grid extension is difficult and expensive, for example, Native American Nations, and in locations wherein the quality of grid supply is unstable due to multiple factors such as extreme weather, sub-urban communities.

However, for the target disadvantaged communities, microgrids come with its own set of challenges. In more than likely cases, local capacities are needed to operate and maintain the systems. For the microgrid to be sustainable, reliable and scalable, it must incorporate multiple aspects such as transparency and efficiency of operations, customer interaction and satisfaction, real-time monitoring, control and maintenance of the connected assets. This can be achieved through a Digital Platform for Microgrids (DPM). It is a tool to better enable state and federal initiatives for ensuring that benefits of the energy transition flow to LMI households. For example, New York State Climate Act places front and center a concern for environmental justice, equity, and delivering results to historically underserved populations. *“The Climate Act requires the state to invest or direct resources in a manner designed to ensure that disadvantaged communities to receive at least 35 percent, with the goal of 40 percent, of overall benefits of spending”* (Climate Justice Working Group). A tool like DPM eases this transition.

Background

Development Approach & Principles for Smart Solutions

SunMoksha’s development is anchored in interventions that are made to improve the quality of life of people at the bottom of the economic pyramid (BOP) through the mandate of the 8th Sustainable Development Goal (SDG-8): *Decent Work and Economic Growth*. It empowers the rural community towards economic progress so that they can take care of their basic needs (SDG:1-4). Economic interventions are made for the community at large that helps reduce inequalities in the community (SDG:10). Its energy, water and microenterprise solutions are anchored in SGD:6,7,9, and catalyze economic growth of the community. It is not only targeted to increase food production with reduced input costs, but also add value to the produce to increase the income of the farmers (SDG:12). It partners with the local community and stakeholders (SDG:17) to ensure long-term sustainable development.

SunMoksha's value propositions have been developed within the constraint of the P³ – people, planet and progress (SGD:13-16) and women-centric opportunities (SGD:5) that leads to sustainable socio-economic development. The cycle repeats as the community moves up the value chain in a systematic and organized manner, eventually leading to development of sustainable communities (SDG:11) and brings peace and justice in the society (SDG:16), as depicted in the illustration below.



Figure 1: Theory of change to achieve the 17 sustainable development goals.

SunMoksha's development principles are anchored in the empowerment of individuals and communities. It provides smart, sustainable solutions (or intelligent assets) to the community to create opportunities for employment and entrepreneurship, and ensures skills training and market linkage required to exploit these opportunities. It creates an ecosystem of interventions that empower the communities to move forward on the path of development.

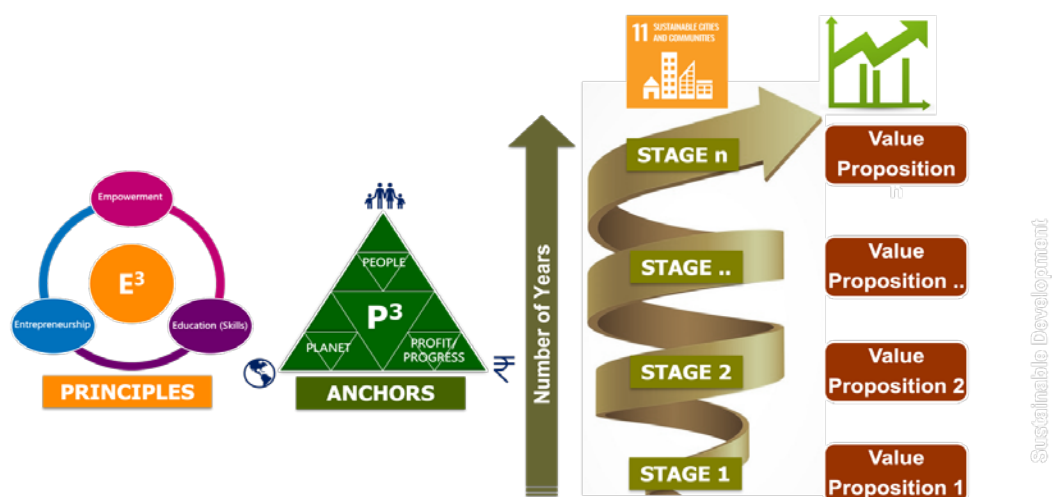


Figure 2: Development principles for empowerment of the communities to achieve the Sustainable Communities SGD-11.

Our development process begins with interventions through smart technologies and assets that provide access to essential services and create livelihood opportunities. It trains the

local personnel during and after the deployment of the solutions and assets. The creation of livelihood and enterprise activities through sustainable resources, in turn, reduces the pressure on agriculture and creates an ecosystem for development for improved quality of life. The interventions and smart solutions change as the community moves up the value chain, in a spiral of development, and eventually evolves into a sustainable community. The development is achieved over several years, or even over a few generations.

Microgrids are a one such key asset to achieve the development goals and catalyze the process for the disadvantaged communities. Microgrids are proving to be a more reliable, robust and resilient source of power supply for the communities, and even more so especially for underserved developing and remote communities. Off-grid microgrids have already made access to energy possible in Southeast and Pacific Asia, sub-Saharan Africa, Alaska, and remote regions in North America. Physical operations and maintenance (O&M) of the system requires skilled personnel, which are often not found locally. Poor performance from microgrids can cause a non-inclusion of the solution especially for the underprivileged communities, depriving them of access to a reliable and clean source of energy. Including their inputs into the design, operations and maintenance will not only make the microgrid inclusive but also sustainable. As mentioned earlier, in more than likely cases, local capacities are needed to operate and maintain the microgrids, it to be sustainable, reliable and scalable. Moreover, it requires transparency and efficiency of operations, customer interaction, and real-time management of the microgrid assets. A Digital Platform for Microgrids (DPM) is needed to achieve this.

Digital Platform for Microgrid (DPM)

The Digital Platform for Microgrids (DPM) addresses both the technical management of the microgrid together with the social management of the customers' energy needs. As shown in Figure 1, the information seamlessly flows horizontally across the operator/technical modules (System Model, System Diagnosis, System Prediction, Smart Actions) and the customer/social modules (customer Monitoring and customer Interaction). Both the operator and customer modules have a sub-module each to monitor various key performance indicators (KPIs). The platform is connected to an IoT layer that is used to transfer data and recommended actions (Human and Smart) from platform to physical assets and vice versa, through a controller.

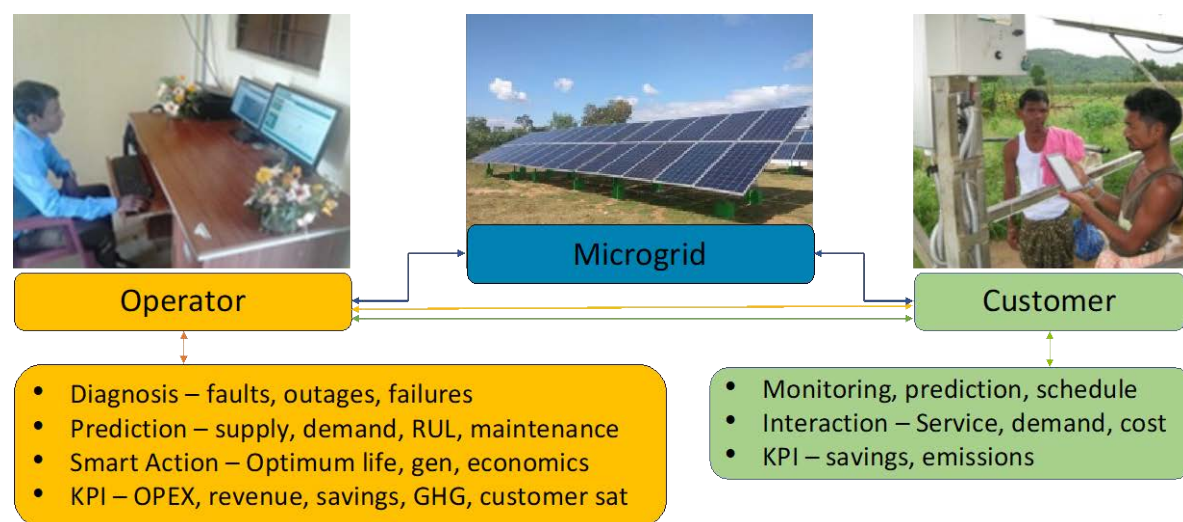


Figure 3: Concept of Digital Platform for Microgrids

Providing a platform that supports social (customer) interactions and the ability for customers to interact with the microgrid, i.e., the customers will have access to define their own energy usage on a day-to-day basis or via scheduling based on the tariff or anticipated usage. The parameters and variables for the consumers are kept simple and of immediate interest to the consumers. This dynamic interaction of customer with the microgrid is the key differentiator of our innovation that has been missing in the existing solutions.

For a microgrid enterprise to be sustainable, reliable and scalable, the entrepreneurs, operators and investors would need to incorporate multiple aspects such as transparency and efficiency of operations, customer interaction and their satisfaction, real-time monitoring, management and maintenance of the connected assets. DPM via SaaS enables microgrid entrepreneurs and investors to penetrate the market with smart features, either by upgrading the existing microgrids or through setting up new smart microgrids. Smart microgrids dynamically manage demand and supply to meet the user requirement within the limited power supply in a microgrid. It supports the interaction between users and microgrid operator, where users can adjust their own energy usage strategies according to the current energy supply situation, and the microgrid operator can formulate the energy supply mode according to all users' energy strategies to meet users' needs. The smart microgrid collects the energy use data of different users, calculate the corresponding rules for energy usage, formulates reasonable energy use strategies, and feeds it back to users as an optimal use strategy for users to choose (Microgrid Protection and Control, 2021). For example, in the context of underserved and unserved communities, during working hours, the power supply can be scheduled to supply only for the productive (livelihood generating) loads instead of the domestic (non-critical and curtailable). Furthermore, for appliances such as refrigerators, the load can be defined and only that quantity of power will be supplied to the homes. The rest of the power generation will be diverted to shops or SMEs. Similarly, when the community members return home, through scheduling, the power generation is diverted to the domestic loads instead of productive loads. Based on the requirement from the productive loads, the required power supply will be provided to them outside of working hours.

New York has adopted ambitious goals for integrating a high percentage of, or operating entirely on, renewable energy. This means that the grid of the future will be dominated by variable energy resources. There are certain functions, important to reliability needs, that cannot be performed by variable energy resources. As a consequence of the significant and rapid deployment of variable grid resources, the NYISO is looking at comprehensive changes as to how they pay for resource adequacy (Swider M. 2022). At a recent webinar Mike Swider, Senior Market Design Specialist at the New York Independent System Operator (NYISO) delivered an informative and illuminating presentation describing several NYISO market initiatives under consideration with potential implications for highly flexible microgrids.

New market initiatives will likely create revenue opportunities in the future for qualifying dispatchable electric resources. Swider points out that "to the extent that a qualifying resource can follow a NYISO dispatch signal it can participate by selling energy, reserves and capacity. (CHP TAPs) The DPM Platform has the capability to send such dispatch signals. Furthermore, these resources will be needed in significant capacity, which means that the opportunity created is extensive.

The DPM platform incorporating cyber-physical-social dimensions encompasses onsite power tightly integrated with advanced controls, sensors, communications, climate management, lighting and mechanical systems within a multi-factor constrained optimization ecosystem. In the following section we more fully describe the decision support systems for the DPM.

Why a Digital Platform for Microgrids (DPM)?

Renewable and hybrid low carbon high efficiency microgrids are becoming a more viable alternative to bring access to electricity into remote rural (off-grid) as well as urban and peri-urban communities. Microgrids help achieve “energy democracy and social justice”, where communities are better able to make and consume their own energy (Energiewende Team. 2017). In case of developing communities, energy optimization, i.e., efficient use of energy for the loads is critical from the point of view of sizing the microgrids and the capex associated with it. A specialized platform is needed to provide the flexibility services to the community and the utility, if available. The power sharing and most importantly, the capability to define the scheduling hours and quantities, lies in the hands of the community members and can be achieved in consultation with the operators. This leads to a more informed power consumption that leads to better energy prices and a greener energy consumption regime.

This platform addresses the ever-increasing challenges of the utility grid and upcoming technologies to be accommodated. Smart appliances are one such advancement that is changing the landscape of the microgrid. So is the increasing number of prosumers (power users that produce alternative energy on their own) and the technology adapted by the grid connected systems. The number of electric vehicles are on a rapid rise, leading to several V2X applications and must be accommodated within the platform for real-time consumption and backup power. To ensure resilience and energy security, operators must make informed decisions based on load forecast, generation forecast, and weather forecast.

Furthermore, rapid and fundamental changes to the manner in which we produce, distribute and consume power, are underway across the globe. In this paper we integrate a scenario developed around New York State’s landmark Climate Law and Community Protection Act (CLCPA, or “Climate Act”). The Climate Act mandates a 100% renewable powered grid by 2040, with an interim step of 70% renewable powered by 2030. A critically important feature of the Climate Act and one that has in part motivated this paper and its accompanying research, is New York’s landmark commitment for agencies to invest 35 percent with a goal of 40 percent of clean energy program resources to benefit disadvantaged and environmental justice communities (NYSERDA Newsroom 2020).

The State’s grid planners, the New York ISO, have identified the need for as much as 32 Gigawatts (GWs) of Dispatchable Emissions Free Resources (DEFRs) (NYISO Factsheet). In addition to the need for DEFRs, the NYISO has recognized a sizeable requirement for Price Responsive Demand (PRD), on the order of 2% to 5% of total requirements in 2040 (Climate Change Resilience).

The rapid and foundational (transformative) evolution of the grid, taken together with the imperative to reach unserved and poorly served communities makes DPM universally applicable, makes this paper important, impactful and quite timely. It leverages onsite experiences in the villages where the communities are dependent on external resources for the microgrid systems and their management. This hampers the underserved communities from being completely self-reliant for energy, as they are not able to monitor, operate, and manage the power systems on their own. The current solutions are engineer oriented that cannot be managed by local community members; nor do these incorporate customer interaction capabilities with the microgrid, which is essential in these target communities.

The social benefits of the DPM leads us to broaden and deepen our research questions, to encompass disadvantaged and environment justice communities whose needs

must be thoughtfully addressed so that grid transformation does not further exacerbate the wide disparity in wealth, ownership, entrepreneurship, income and access to training.

Microgrids have traditionally been found in large, single owner campus settings but with cost and quality enhancing process, product innovations, and technological changes, microgrids are more so appearing in new settings in California, New York and Hawaii, as well as Australia and the EU. Proliferation of microgrids into low- and moderate- income communities holds the promise of providing significant benefits. Though the potential for disadvantaged communities is quite real, this will not occur organically. In this paper we will address how the DPM with cyber-physical-social models provides a pathway for designing, delivering and operating microgrids to consciously with planning forethought enhance the well-being of historically under-served communities.

Method: Decision Support Systems for the Digital Platform

Sustainable Development is a complex problem that requires identification of equitable, viable and feasible interventions. In order to make appropriate decisions, it is necessary to understand the dynamics, interaction and interdependencies between technology, stakeholders and the physical world. Likewise, designing a policy requires understanding the behavior of the individuals, communities, and their responses to each aspect of policy, which adds elements of uncertainty that needs to be taken into account. Furthermore, policies need to be evaluated based on their potential outcomes, and not just on their intentions.

SunMoksha has formed a group of researchers and practitioners to develop tools to support DPM and have a larger impact on the world. These have been developed in collaboration with universities in the USA, UK, and India, working on disruptive innovations in the sustainable development sector. Our tools for Decision Support are a step in helping our customers and us to make better decisions where uncertainty arises due to complex integration of Cyber-Physical-Social systems in the context of Sustainable Development. Our tools and methods help assess the impact of an intervention, as well as, anticipate the future state of affairs to build robust, holistic solutions for the future. The tools can be used for planning interventions and formulating policies.

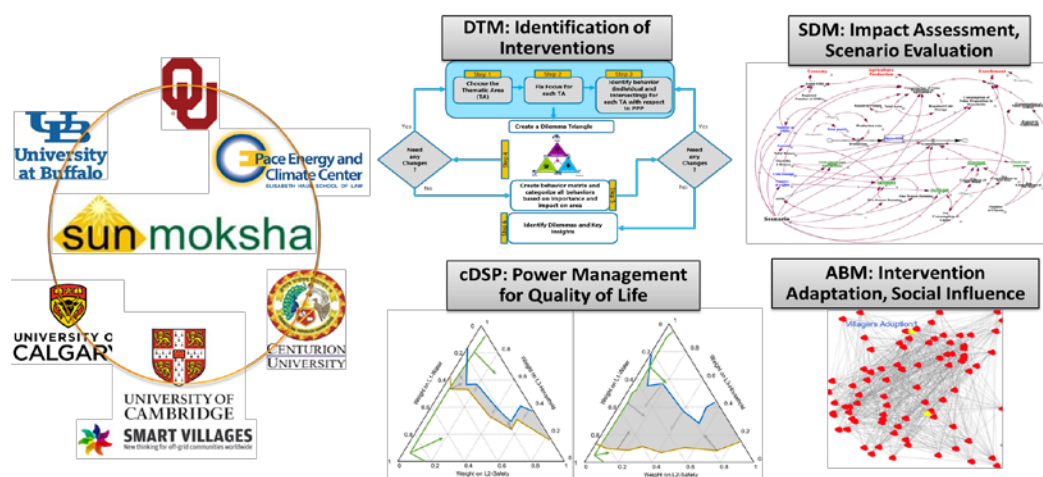


Figure 4: Examples of Cyber-Physical-Social Models and Tools

We use multiple analytical tools to convert raw data into useful information for better decision making. Following are the tools and a short description of their methods that we use. The Dilemma Triangle Methods (DTM) are used to get a holistic bottom-up view of the focus

areas and issues from the perspective of people, planet and progress. It helps in identification of the interventions for the subject community. Systems Dynamics Models (SDM) give a top-down approach necessary for visualizing impact of an intervention and/or a policy on an aggregated population. It can be used to develop scenarios of impact of various policies on overall systems. An Agent-based Model is a bottom-up approach used for understanding the behavior changes and human-influence in a community. It can be used to study how policy will be adopted by the individual and how will they respond to particular intervention. Digital Twins are tools to simulate the physical systems in cyberspace to understand the dynamics of interactions of multiple physical systems, as well as, predict the outcome under possible scenarios.

Learning from the Field Applications in India

We have successfully implemented Renewable Energy (RE) based smart microgrid systems in remote Indian villages. The electricity provided by the microgrid brings energy-sufficiency to the village and provides a complete smart infrastructure to manage the entire grid operations remotely. Moreover, the system integrates supply and distribution of hybrid renewable-powered electricity, with or without grid power, together with smart-grid functionality for transmission and distribution (T&D). Our solution also helped commercial customers to reduce their energy consumption through the monitoring and control.

We implemented India's first renewable-energy powered smart microgrid at Chhotkei village in a remote Tiger Reserve in Odisha, serving 140 households for lighting, streetlights, irrigation, and microenterprises in 2016. We also implemented a solar-powered smart microgrid using on the island village of Kudagaon, Odisha, making it the first off-grid smart-island in India. It has been operational since February 2019. The project recently won the highest recognition at the Microgrid Greater Good Award 2022, by Microgrid Knowledge (Greater Good Award 2022). Moreover, it is developing a Smart Village in Kantashola, Jharkhand using the community development approach and creation of Micro-Economic Zone (MEZ) powered by smart hybrid microgrids. Local decentralized power generation ensures uninterrupted critical operations such as irrigation, water services, Governance, and micro-enterprise activities. The impacts of these installations were profound.

Significant changes were observed in the community after the implementation. Many parents set evening studying hours for their children, and are hopeful to have a tuition center in the village so that their children get additional guidance. A village mother said that she wanted her daughter to become a teacher, and now is certain that her dream will come true! Home-lighting and streetlight provide safety from the snakes in and out of the house. Streetlights have enabled socializing and entertainment in the evening – men play cards, women visit neighbors, relatives visit and stay longer as there is light, fans and coolers, and relish quality family time. Women are the happiest lot as they can now complete chores at their pace and don't have to depend on the sunlight. Local businesses have started to emerge. Two farmers have invested some of their savings to run a rice and flour mill. Grocery stores have reported that their business runs till late evening, fetching additional income. Farmers want to switch from diesel to electric pumps for irrigation and practice agriculture all year round. And to top it up, the villagers who have seen grid electricity off in the towns and cities, prefer microgrid over the grid systems, for its quality, consistency and dependability.

A cyber-physical digital platform was developed to manage the microgrids and related assets in these villages, as shown in Figure 3. The system has performed well for monitoring and managing the microgrid. However, it still lacks the interaction with the customers and does not include the social behavior of the customers/communicates. Several individual decision

support models were built to evaluate, design and validate the interaction of microgrids with the communities.

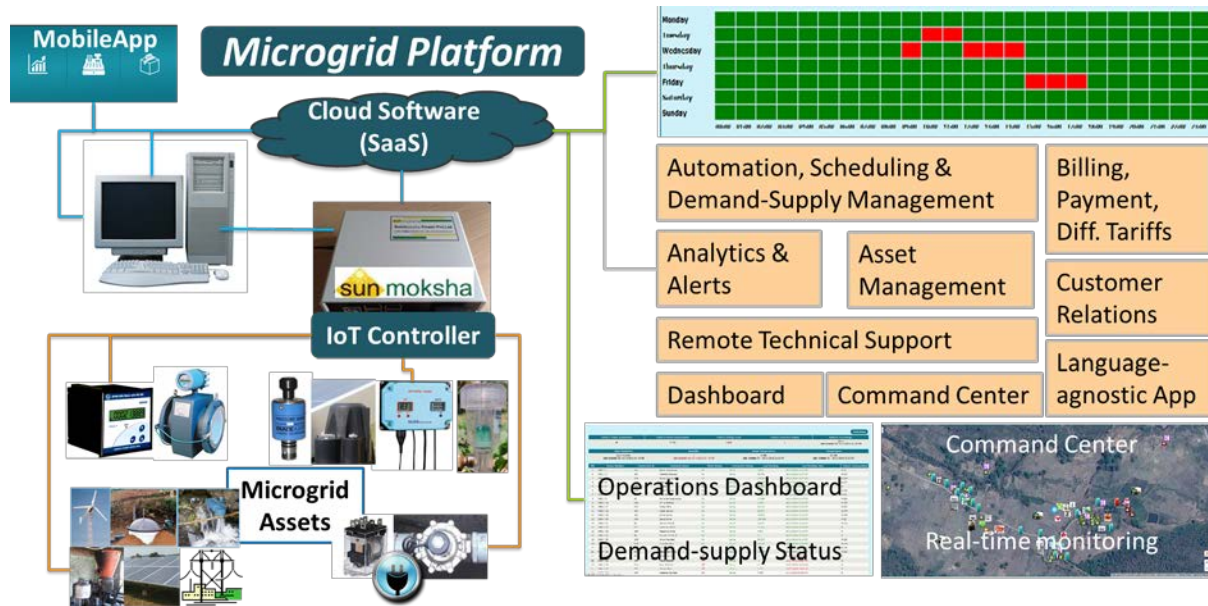


Figure 5: SunMoksha's Cyber-Physical Platform for Social Development

For the technologies deployed by SunMoksha in the Indian villages, cyber-physical-social models were developed for a few of these villages to measure, assess and evaluate: (1) the impact of the technologies on the quality of life (Suk. et al., 2020); (2) decision making of the beneficiaries for further adoption of the solutions (Guo. et al. 2020); and (3) identify key factors and value propositions to ensure sustainability of the technologies (Karkaria. et al. 2021).

As a result, we found that the relationship between the quality of life and the system operation are needed in solutions to efficiently support sustainable development of the rural communities. Furthermore, with multiple scenario-planning through System Dynamics and Agent Based Models, we realized that the social influence plays a crucial role in adapting to new solutions and ensuring their sustainability in the developing communities. Through several analysis at different timeline of the installed solutions, we concluded that the combination of IoT/Cloud solutions – cyber, installed microgrids – physical and the active participation of the beneficiaries – social, lead to an efficient and sustainable microgrid solution.

Next Steps: The Digital Platform for Microgrids with cyber-physical-social models

A Digital Platform for Microgrids (DPM), anchored in cyber-physical-social models, is proposed that supports social (customer) interactions and the ability for customers to better define and manage their own energy requirements. The current solutions have generally ignored this. This capability is aligned with Environmental, Social and Governance (ESG) factors. Delivering advanced technologies to historically underserved communities, which is central to our design, ensures their full participation in evolving energy markets.

The genesis of these models lies in the ‘practice on the ground’ experience of the authors in rural India. We have implemented Smart Microgrids in inaccessible terrains. And, for the sustenance of the microgrids, it was imperative to remotely manage the operations in

real-time. Over the course of the life of microgrids and challenges faced, the energy management system has gone through multiple modifications. The modifications were restricted to the needs and management capabilities of these communities in India. State decarbonization policies are driving a rapid evolution towards a far greater reliance on distributed energy resources (DERs). Poorly served tribal areas, LMI or in state defined environmental justice (EJ) areas can leapfrog from the current energy services platform to an advanced digital platform using the cyber-physical-social framework.

With this platform, customers will not only be able to monitor their usage pattern and costs, but they will also be able to take control or change those parameters. This control, monitoring, optimization capability, is absolutely essential for optimal operations. In a remote off-grid setting these capabilities support the stable, reliable, and least-cost operation of the community grid. In more urban settings, these features allow the local community to maximize the capture of revenue streams from operating their local energy ecosystem as a dynamic asset, serving the grid. This functionality is of utmost importance. The transition to a low or net zero carbon future will be complex. It's essential that **affordability** be addressed in any decarbonization roadmap. With low- and moderate-income households in New York State already suffering a high and rising energy burden, addressing these under the Climate Law and Community Protection Act (CLCPA), energy affordability is a matter of increasing concern (Utility Dive Brief 2022).

The platform is designed for the microgrid to be managed by local community members. It also incorporates customer interaction capabilities with the microgrid which is essential in the target communities – Tribal Nations and historically disadvantaged LMI communities. The existing solutions are engineer oriented, designed and developed for the use of microgrid operators. The proposed platform aims to be operated by the indigenous people and the underserved communities. The platform allows the customers to interact with the microgrid, i.e., the customers will have access to define their own energy usage on a day-to-day basis or via scheduling based on the tariff or anticipated usage. This essential dynamic customer interaction feature is so far not available in any other microgrid management systems. In addition, hybrid power source integration and management also provide a tremendous opportunity for communities owning microgrids, small and medium enterprises in solar businesses and customers of such microgrid services to take advantage of the capabilities provided by the platform. Our hypothesis, our working philosophy, is the construction of DPM with cyber-physical-social may truly democratize the distributed energy resource (DER) transformation. If correctly planned, designed and executed, this enhanced DPM will promote local ownership, entrepreneurship, build community wealth and offer historically disadvantaged communities' full partnership in the energy revolution. The DPM is a tool for addressing *affordability* in the energy transition. LMI households and disadvantaged communities have the greatest need for infrastructure hardening to withstand the consequences of climate change. When disruptions in energy supply occur, these communities are affected in an acutely disproportionate manner.

The platform is being redeveloped for the indigenous and LMI communities in the USA

We are partnering with universities and colleges to identify energy gaps and challenges in the indigenous, low to medium income (LMI) and other disadvantage communities. As mentioned earlier, 14% of the household have no access to electricity. We are currently collaborating with Diné College on project Hope. Project Hope intends to bring empowerment and entrepreneurship opportunities to the Navajo communities for sustainable socioeconomic development. The project is spearheaded by the Diné College's center for

entrepreneurial learning. An advanced smart hybrid microgrid infrastructure is being designed based on the requirement of the communities. The project hinges around the pillars of energy, water, education (training), agriculture and employment to build strong community infrastructures. The project integrates systems designed to serve a small communities' power, water and economic needs while encouraging business growth and startups. The proposed platform would be designed such that the community can operate and maintain it locally, with remote support from SunMoksha.

Closing Remarks

The Digital Platform for Microgrids addresses access to energy for the historically underserved communities through novel applications of data science, modelling, visualization, network communication, and optimization. Integration of energy efficiency, demand flexibility, and distributed energy resources (DER) in a microgrid setting is the way forward to meet the needs of these communities. Our past international experience in designing, developing and implementing technology interventions to serve such communities are the guiding principles for this research described. We incorporate lessons learned and evolve the framework for deployment within Tribal nations, LMI communities in urban areas and poor rural/exurban communities. Future microgrids will be interactive where inclusion of social and behavioral elements of consumers is crucial for operational success and to capture the monetary benefits of highly flexible energy ecosystems as anticipated by Grid operators.

Microgrids are more reliable, robust and resilient source of power supply for the communities, and even more so especially for underserved developing and remote communities. Microgrids help achieve “energy democracy and social justice”, where communities should be able to make, profitably sell and consume their own energy. More importantly, with limited access to electricity in the off-grid systems, customer interactions are essential to maintain the reliability and sustainability of the microgrid. However, today, the communities are dependent on external resources for the microgrid systems and their management. This hampers the underserved communities from being completely self-reliant for energy, as they are not able to monitor, operate, and manage the power systems on their own.

Our past experience in implementing such technologies have shown that it is critical to manage microgrid operations both physically and digitally to make the promise of flexible, economically viable, broadly accessible microgrids achievable. Our proposed digital platform using cyber-physical-social models are geared to meet this promise.

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