EU-India Collaboration for Smarter Microgrids: RE-EMPOWERED project

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Abstract: Recent technical, economic, social and environmental challenges related to global energy transition have gained increased interest from research institutes and industrial companies from all across the world. RE-EMPOWERED is a joint research program, in which European and Indian partners have joined forces to demonstrate innovative solutions for effective energy management, power forecasting techniques, added grid resilience, grid stable operation, energy sector integration, digitalization and power electronics control. The developed tools will be tested in four demo sites in Europe and India aiming to shed light on these timely research areas in the reign of power networks dominated by distributed and renewable sources generation.

Keywords: microgrids, energy management, energy efficiency, EU, India

I. INTRODUCTION

In recent years, growing consumption across the world made the energy sector accountable for about 40 percent of global CO2 emissions [1]. In 2014, the need for decarbonization became even more prominent and this led to the adoption of EU's climate and energy framework (revised in 2018) which targets "at least 40% cuts in greenhouse gas emissions (from 1990 levels), at least 32% share for renewable energy and at least 32,5% improvement in energy efficiency for the period 2021- 2030"[2]. UNFCCC reached a landmark agreement in December 2015, that has defined among others the future and roadmap for the evolution of the energy system, known as the Paris Agreement [3]. To deliver on the EU's Paris Agreement commitments, in February 2015 the Energy Union strategy was published as a key priority that targets to build an energy union providing EU consumers -households and businesses - with secure, sustainable, competitive and affordable energy [4], which was updated in 2022 in the Fit for 55 plan [5]. EU has undertaken a number of policy initiatives to formulate international cooperation and partnerships with ultimate goal to support and ensure sustainable development in global level. Similarly, India has undertaken ambitious policies and strategies such as reducing emission intensity of

its GDP by 33% – 35% from 2005 level by 2030 and achieving 40% of its installed power capacity from renewables in its Intended Nationally Determined Contribution (INDC) in 2015 under the Paris Agreement.

From a technical point of view, new techniques, control schemes and infrastructure are needed for enhanced technically feasible and economically affordable uptake of renewable energies. This includes the upgrade of distribution grid infrastructure and the adoption of intelligent networks. Microgrids, a topic in which extensive research efforts have been made over the last years, are defined as single entities consisting of various components such as distributed energy resources, interconnected loads and battery energy storage systems that can operate in grid connected and islanded modes [6], [7]. The increased share of RES and their control units operating in a wide range of frequencies, the significantly reduced inertia due to the lack of rotating machines and the short lines in microgrids infrastructures, pose new challenges which are being addressed with intelligent control functions for voltage and frequency regulation [8] along with control architectures involving communications protocols such as centralized, distributed and decentralized mode [9] [10].

Additionally, an emerging trend that is gaining more and more attention is the energy sector integration, meaning the linking of the various energy carriers, electricity, heating and cooling, gas, solid and liquid fuels and mobility, also with end-use sectors, such as buildings, transport and industry. This is clearly stated in the ETIP-SNET "Vision 2050"[11]. Exploiting the synergies among the various energy carriers together with energy conversion technologies and storage (electrical, but also thermal, gas and liquid fuel storage) transforms the electrical system to an interoperable energy system that can be optimized more efficiently as a whole, while increasing the possibilities for increased RES integration [12]. This leads the way to carbon free generation system in the year 2050.

The introduced challenges are not only technical, but also socio-economical. New business models and market mechanisms are needed to support the decentralization trend. Moreover, in the new energy system, consumers assume a central role in the energy transition, they become prosumers and they actively participate in decision-making procedures [13]. Local energy communities empower citizens to play a major role and facilitate this energy transition. Digitization, ICT technologies and automation are key enabling factors for the operation of this extremely complicated integrated systems operation. For example, consumers need to be provided with comprehensive information, on the electricity costs, energy performance of heating and cooling systems, etc. to allow them to exercise their individual choices regarding renewable energy and avoid technology lock-in.

RE-EMPOWERED is a research program, funded by European Commission and Department of Science and Technology of India, which addresses the aforementioned topics with a view to provide solutions and real experiences that will be shared with the whole world. Its consortium involves 13 world known experts in energy islands from 5 different countries (9 R&D and academic, 2 industrial, 1 NGO and 1 professional services company) which combined with the differentiated focus and development level of the four pilot cases render this project an ideal EU-India platform for knowledge exchange and use case replicability.

In this paper, the aim and the main objectives of RE-EMPOWERED project are discussed in Section II. Moreover, a detailed analysis of the ten innovative solutions which are currently developed and upgraded along with initial results are presented in Section III. In Section IV, an overview of the four demo sites, in which the tools will be deployed, is provided. Finally, the conclusions are drawn in Section V.

II. RE-EMPOWERED PROJECT

The overarching goal of RE-EMPOWERED is to develop a set of solutions for efficient, decarbonized and RES-intensive multi-energy local energy systems. Special focus is given on increasing demand flexibility through customer engagement using digitization that fosters an active energy community via sustainable business plans and investments and exploiting synergies among energy vectors.

The solutions of the toolset are tailored to the specific needs of four pilot sites in the EU and India, but aim at a wide target group for replication and exploitation in both the developed and developing world. Bornholm (Denmark) focuses on unlocking the demand flexibility for higher RES utilization in grid-connected islands; Kythnos (Greece) targets at increased whole system efficiency and digitization with reduced imported fuel and RES curtailments for non-interconnected islands. Kythnos demo also includes the Gaidouromantra microgrid, a 100% RES system, which will be upgraded. Ghoramara (India) explores a newly built 100%-RES standalone system for the island, aiming at improved energy access

for sustainable community development. Keonjhar (India) examines the upgrade of the existing rural microgrid towards higher energy availability and affordability and improved local air and water quality. RE-EMPOWERED objectives are organized in the 3 following pillars:

A. Increased energy efficiency, RES utilization and reliability

The objective is to achieve a highly efficient and reliable energy system with increased RES penetration and high flexibility, that exhibits competitive performance over available commercial solutions.

B. Fostering sustainable and economic community development

The ambition of RE-EMPOWERED is to provide to the community the tools for economic and social development, through a sustainable energy system based on local resources that protects the local environment and delivers unhindered energy access, health benefits and a good return on investment.

C. Exchange, replicability and scalability in EU and India

The RE-EMPOWERED consortium aims to create a long lasting network involving world known experts in energy islands from EU and India.

III. TOOLS

In order to tackle the aforementioned objectives a set of solutions is developed. The partner of the Consortium who leads the group that is responsible for the tool's development and maintenance is stated within the brackets. Each team consists of European and Indian partners who collaborate and hold frequent meetings in order to product results through fruitful discussions.

A. ecoEMS (Institute of Communication and Computer Systems NTUA)

ecoEMS is an Energy Management System aiming at optimizing the overall performance of isolated and weakly interconnected energy systems by increasing the share of RES. ecoEMS considers storage facilities and provides advanced on-line security functions, both in preventive and corrective mode. More specifically, ecoEMS is a modular system comprising load and RES Forecast, Unit Commitment and Economic Dispatch and on-line Security Assessment functions. The goal of ecoEMS is the full exploitation of the RES potential (i.e. RES penetration levels above 40%) at reasonable costs in isolated electricity systems.

B. ecoMicrogrid (Institute of Communication and Computer Systems NTUA)

ecoMicrogrid is an Energy Management System for microgrids where advanced management algorithms are deployed to optimize the performance, taking into consideration synergies with different energy vectors like water management and cooling systems. ecoMicrogrid monitors the state of microgrid components, such as RES production, flexible loads' consumption, and battery storage charge level and predicts its short-term development. An optimization procedure dictates the required actions like load shedding, diesel generator start-up/shutdown and RES power curtailment according to the desired optimization goals.

C. ecoPlanning (Institute of Communication and Computer Systems NTUA)

ecoPlanning serves as a tool for supporting the decision-making process for the deployment of new electricity generation units (conventional and renewable) in the electrical systems of Non-Interconnected Islands (NIIs) in a mid-term horizon. ecoPlanning performs the following types of studies: 7-Year Energy Planning for assessing the deployment plan of new conventional production units; RES Hosting Capacity for assessing the hosting capacity of Renewable Energy Sources in the electric system; Interconnection Assessment by performing steady state simulations of the electric system to evaluate the interconnection advantages. It reports the operation of the production units and several results pertaining to the energy production in terms of quantity, fuel consumption and cost, CO2 emissions, etc.

D. ecoDR (CSIR-Central Mechanical Engineering Research Institute)

ecoDR tool focuses on the development of advanced metering infrastructure (AMI) with inbuilt load controller and protection functionalities. In addition to measurement and billing of household energy

consumption, it will facilitate remote monitoring and control of non-critical loads based on user preference. This tool is capable to communicate with ecoPlatform tool to access services such as demand-side management, to implement scheduling of critical/non-critical loads via load shedding and to access dynamic electricity pricing tariffs for computation of the energy cost of residential loads.

E. ecoPlatform (Danmarks Tekniske Universitet)

ecoPlatform is a lightweight, cloud-based platform with the primary objective of providing the RE-EMPOWERED tools with a secure and reliable interface to the deployed distributed energy infrastructure. In addition, ecoPlatform is capable of managing, processing and handling the heterogeneous data and command stream from the RE-EMPOWERED tools, metering infrastructure, SCADA systems, MGCC and selected controllable assets. ecoPlatform provides a Platform as a Service (PaaS) that can integrate all the solutions in one software structure.

F. ecoMonitor (CSIR-Central Mechanical Engineering Research Institute)

ecoMonitor tool focuses on the surveillance and monitoring of drinking water quality parameters and the deployment of water purification plants. Within the RE-EMPOWERED project, the water samples are collected and based on water quality analysis, a community level solar powered water purification plant is deployed to provide safe drinking water to the residents in the Indian demo sites. Furthermore, water quality parameters such as conductivity (salinity), dissolved oxygen, and ORP/Redox etc., water temperature and pH level etc. are monitored periodically.

G. ecoCommunity (Imperial College London)

ecoCommunity is a digital platform aiming to enhance citizen engagement, active participation and technology acceptance in the four demo sites. The main functionalities of ecoCommunity are dynamic pricing mechanism for residential loads, management of non-critical loads, electronic billing, payment, and a feedback portal. ecoCommunity contains advanced functionalities and is tailored to the special requirements of energy-disadvantaged communities.

H. ecoResilience (CSIR-Central Mechanical Engineering Research Institute)

ecoResillience tool focuses on the development of cyclone resilient support structures for both ground-mounted solar PV arrays and wind turbines. It aims to optimize the PV configuration to reduce the aerodynamic wind loads through numerical simulations, wind tunnel testing, and field tests. For wind turbines, cyclone resistive hybrid structure will be designed for extreme weather conditions. The small wind turbine is manufactured locally, with the assistance of local technicians and community members using the available resources of the region, thus allowing for maintenance to be performed quickly with reduced down time and increased resilience.

I. ecoConverter (Indian Institute of Technology Kharagpur)

ecoConverter deals with the development of power electronic converters and their control, for dc/ac microgrids. Two power electronic converters, a 30 kW DC/AC inverter and a 50kW DC/DC Partial Power Converter (PPC) for multi-string PV architecture, are developed. The purpose of these converters is to form a local AC grid providing ancillary services and extracting the maximum power from PV panels under partial shading conditions. The converter is modular, plug-and-play, reliable and compact with functions like, built-in communication, protection, remote control, and display option.

J. ecoVehicle (Visvesvaraya National Institute of Technology, Nagpur)

ecoVehicle considers the development and deployment of two charging stations, each with six 1.5kW charging points, to facilitate green transportation within Ghoramara island and to nearby islands. Moreover, four electric three wheelers and an e-Boat are going to be deployed, which will allow locals to utilize the e-mobility infrastructure and improve local transportation.

K. Tools interconnection

The design of the whole toolset aims at creating an ecosystem of tools that constitute an integrated solution for the operation and upgrade of smart grids. To this end, the approach (mostly for software tools) is the one of developing an Enterprise Service Bus (ESB) through which the other services (ecotools) can interact. The ESB is part of the ecoPlatform tool, described in the following section. This

approach stems from the state of the art approach in software development, of the microservices approach instead on monolithic tools, that are customized applications, but more difficult to expand in future work. Figure 1 presents the main architecture for the RE-EMPOWERED tools. At the bottom level (field and process level), there are the ecoMicrogrid and ecoEMS tools which directly communicate with the system assets. Part of these assets are the ecoConverter and ecoVehicle tools. At the top level, there are the higher level tools, the ecoPlatform and ecoCommunity. The responsible entity for the interaction between these two levels, is the ESB which is being developed as part of the ecoPlatform tool, using MQQT brokers.

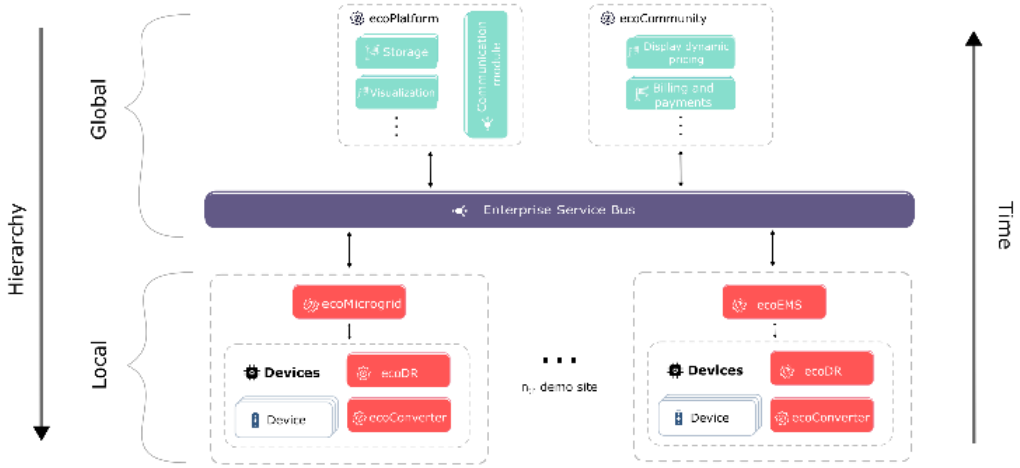

Figure 1 RE-EMPOWERED tools interconnection.

IV. DEMONSTRATION SITES

The solutions that are under development in the RE-EMPOWERED project will be deployed and tested in 4 demonstration sites: 2 in Europe and 2 in India.

A. Bornholm Island

The Danish Island of Bornholm has embraced the green agenda for over 30 years, aiming to become a CO2 neutral island in 2025, and a zero-emissions and climate-friendly community by 2035, while it had been awarded with the 1st Prize of RESponisble Island. Bornholm (40.000 inhabitants – 589 km2) is a whole community consisting of one municipality with hospital, police station, court of justice, educational institutions and utility companies. All sectors of society are engaged in a penta-helix model, bringing together science, public institutions, business and civil society. Bornholm connects to the Scandinavian electricity grid through a submarine power cable to Sweden, but is also capable of running the electric system off grid [14]. The energy system combines proven technologies and innovative solutions, system integration, local biomass and an advanced simulation model. On Bornholm a group of citizens, with support from the municipality, are now developing a 100 MW Windturbine park (offshore) based on local funding, to be ready in 2025. This means that in the near future the sea cable to the mainland will not have enough capacity to export electricity produced from RES in Bornholm, when the production from wind and sun is high.

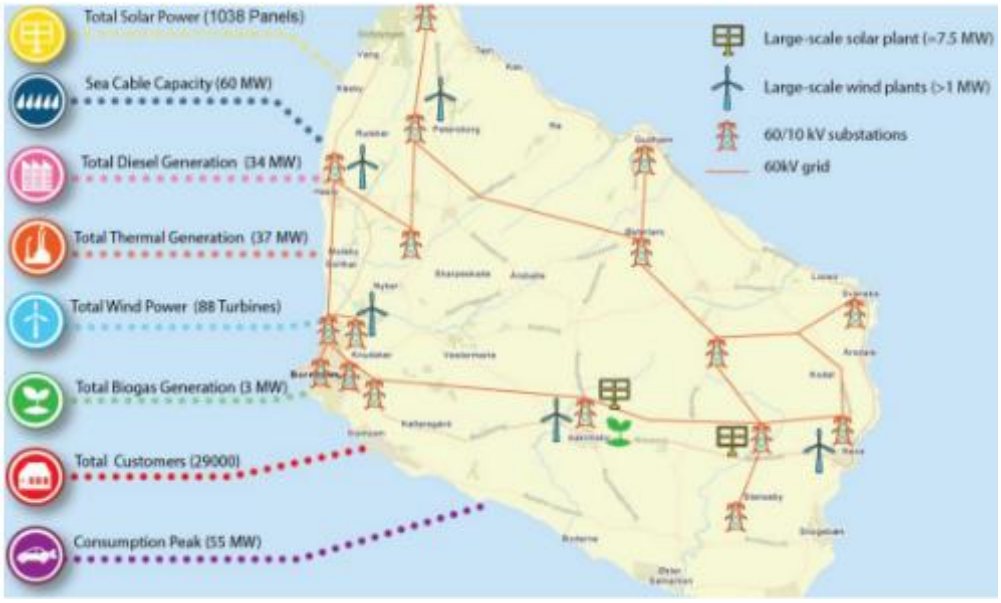

Figure 2 Bornholm power system

The demonstration will explore the synergies of integrating the energy vectors: Electricity, District Heating and Biomass, by forecast, balancing, and integration of increasing PV-production via the heat plant and District Heating Network (DHN). Local services of power control, peak shaving and optimized use of renewable biomass and solar power, will be demonstrated by means of intelligent control capability.

B. Kythnos Island

Kythnos is a Greek island, (100.2km2 – 1,456 inhabitants) part of the Cyclades complex in the Aegean Sea with a long history in sustainable energy installations. It hosts the first wind farm in Europe constructed in 1982 and the first microgrid in Europe in 2001, in Gaidouromantra, a small valley next to the coast, in the southern part of Kythnos, has been a versatile live testbed for smart grid technologies, which have been developed in the framework of several European projects. Based on this past experience and since it is non-interconnected to the mainland electrical grid, leading to constraints in RES penetration, Kythnos provides an ideal demonstration site. The Gaidouromantra islanded microgrid electrifies a settlement consisting of 14 houses with 100% renewable energy coming from PVs and batteries since 2001 [15]. Besides being the first microgrid in Europe, in the Kythnos settlement advanced decentralized techniques for DSM techniques were demonstrated for the first time.

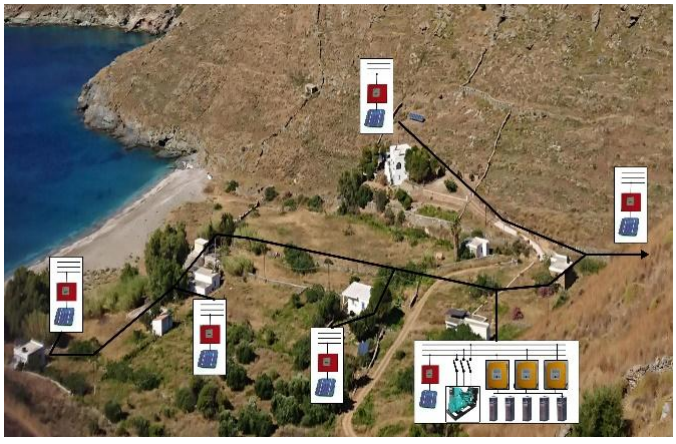

Figure 3 Overview of Kythnos Microgrid..

"RE-EMPOWERED" will accelerate the digitization and energy transition of Kythnos' energy system. Building on the existing experience and proven technologies developed within past EU projects, the tools and business models that will be upgraded and demonstrated in the framework of "RE-EMPOWERED" will lead to higher technological and efficiency level and moreover it will increase the maturity level to develop a structured energy community with active engagement in its core. The demonstrated solutions,

tools, strategies, business models in Kythnos will synthesize an economically sustainable and attractive multi-layer architecture that will be replicable in all non-interconnected islands in Greece and elsewhere.

C. Ghoramara

Ghoramara island is located 92 km south of Kolkata, in the Sundarban Delta complex of the Bay of Bengal. The island is roughly five square kilometres in area and as of 2016 has 3,000 inhabitants. The residents live in very poor conditions while the island is affected by severe cyclonic storms every 5-10 years which leave the people in distress due to snapping off electricity (roof-top PV panels) and unavailability of other livelihood items. This fact makes it very difficult to restore normality after any such situations.

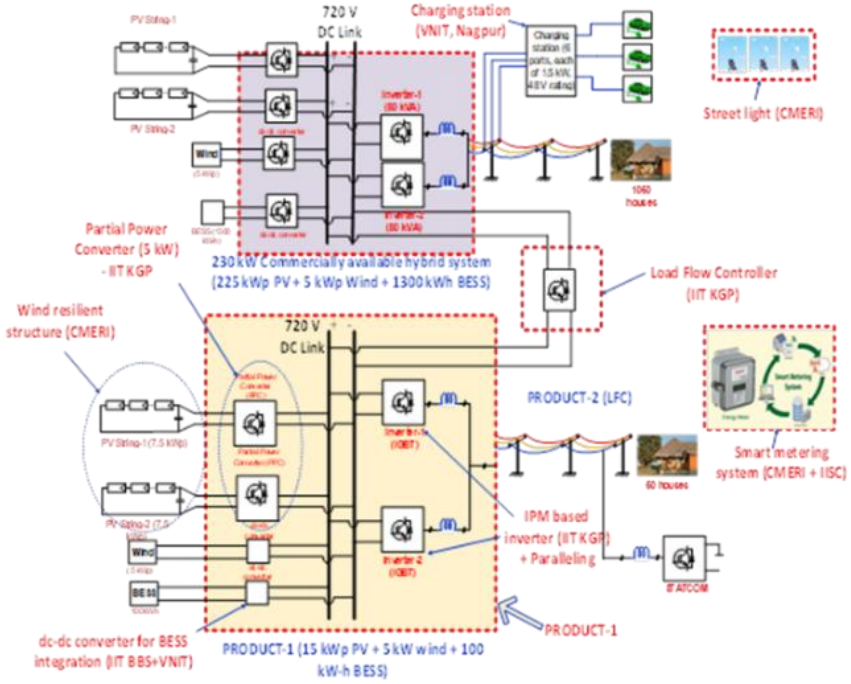

Figure 4 Configuration of the microgrid to be formed in Ghoramara island

An isolated DC/AC microgrid will be built to electrify several houses of the island. Layout of the electrical network is shown in the figure, which comprises a central dc-grid surrounded by ac grids. At the initial stage, it is estimated that around 300 houses will be supplied by electricity. A similar model will be utilized for future upgrade to provide electricity to the rest of the houses. Both single-phase and three-phase options will be provided to the end-users. There will be a total of four ac microgrids each of which provides power to ¼ th of the houses, which is approximately 75 houses. Two PV-arrays, 50kWp each, will be installed for power generation. A small wind turbine (3 kWp) will also be installed. Power electronic converters will be used for the PV integration, while smart meters will be deployed in each house and other important locations. The smart metering technique will be coordinated with protection technique for reliable operation of the grid. App based GUI enabled payment gateway system will be established not only to serve customers to pay bills, but also to allow them to choose various options related to dynamic pricing . Electric four-wheeler and electric boat will be developed with indigenous electric motor and associated control system to provide easy mobility on and around the island. A PV based charging station will be installed at some convenient locations within the island from where both electric boat and electric four-wheeler can charge their own storage systems. Energy from RES will be used to electrify water purification system which is very important for the drinking needs of the residents. Moreover, fishing is one of society's main business activities and part of their daily diet, making cold storage another important energy carrier to exploit for synergy.

D. Keonjhar

Kanheigola, Nola and Ranipada are small Villages/hamlets in Harichadanpur-Tehsil reserve forest in Keonjhar District of Odisha State, India. They are located 54km towards South from District headquarters Keonjhar and 180km from state capital Bhubaneswar. At present these villages are not connected to the

main utility grid. The proposed site is ideal as a test bed and demonstration site as it already has some basic renewable energy facilities. These will be upgraded and coupled with various available energy vectors to improve the living standards of the community.

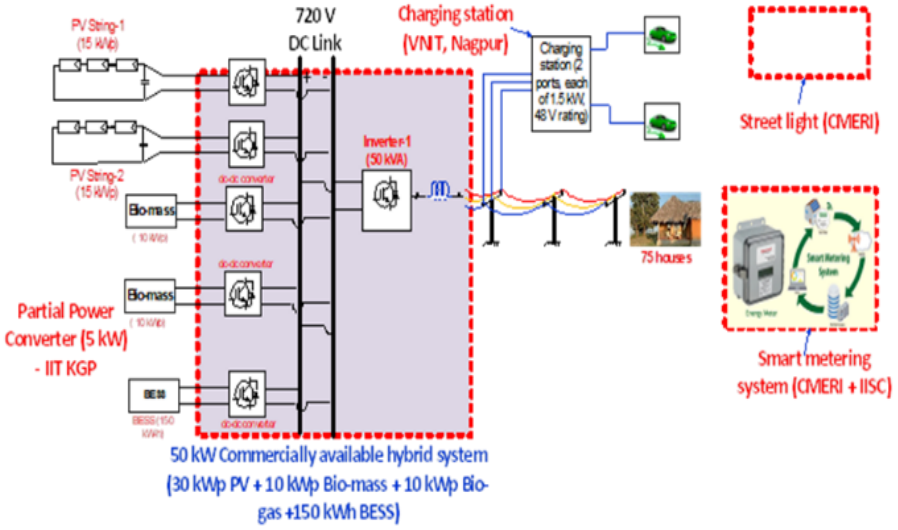

Figure 5 Configuration of microgrid system in Keonjhar demo

In this demo site various energy vectors such as solar PV, biomass, storage, e-mobility and water purification will be integrated with the existing PV system. The proposed 40 kWp microgrid system will be primarily used for livelihood activities apart from household supply. The main challenge is to design power converters with high efficiency at low power range. The field test is anticipated to demonstrate optimized use of renewable PV solar and biomass power by means of stiff DC-link control capability in standalone mode. The demonstrated solutions, tools, strategies, business models in Keonjhar will enable the development of a socio-economically sustainable model which can be easily replicated in other remote villages in India.

The partners of the Consortium have finalized the design of the Use Cases, the definition of the architecture of the IT tools as well the definition of the Key Performance Indicators. Pilot sites are being prepared, equipment is specified and procured. Furthermore, regulatory conditions are explored, the development of the various tools is progressing and soon results will be published.

V. CONCLUSIONS

New policies and legally binding agreements aiming to combat climate change are accelerating the energy transition globally. RE-EMPOWERED provides a complete set of tools addressing the challenges related to high penetration of RES, advanced forecasting techniques, optimal operation of microgrids, energy sector integration and digitalization, electric grid resilience, and a strong focus on power electronic devices operation.

Through this joint project strong bonds have been forged between leading research institutes and businesses in the two continents and effective communication channels have been successfully established. This cross-boundary framework provides an adequate platform to exchange knowledge and lessons between the EU and Indian partners. RE-EMPOWERED will ensure the transfer of expertise, knowledge and the lessons learnt from both the European and the Indian demo sites in order to support energy experts in powering an energy sustainable future.

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BV, PROtection Applications & Studies Industrial Services S.A. *PROTASIS*, Deloitte Advisory, S.L. *DelAdv*, Network of Sustainable Greek Islands *DAFNI*, IIT Bhubaneswar *IIT BBS*, Visvesvaraya National Institute of Technology, Nagpur *VNIT,* CSIR-Central Mechanical Engineering Research Institute *CMERI,* Indian Institute of Science *IISc,* Indian Institute of Technology Delhi *IIT Delhi and* Lab Concern (India) *LCI.*

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