

RESEARCH ARTICLE



OPEN ACCESS

Received: 22-06-2020

Accepted: 20-07-2020

Published: 31-07-2020

Editor: Dr. Natarajan Gajendran

Citation: Mallikarjunaswamy S, Sharmila N, Maheshkumar D, Komala M, Mahendra HN (2020) Implementation of an effective hybrid model for islanded microgrid energy management. Indian Journal of Science and Technology 13(27): 2733-2746. <https://doi.org/10.17485/IJST/v13i27.982>

*Corresponding author.

S Mallikarjunaswamy

Associate Professor, JSS Academy of Technical Education, Bangalore, 560060, Karnataka, India.
Tel.: +91-9036337480
pruthvi.malli@gmail.com

Funding: Technical Education Quality Improvement Programme (TEQIP) of Visvesvaraya Technological University (VTU), Belagavi for technical and financial support

Competing Interests: None

Copyright:

© 2020 Mallikarjunaswamy, Sharmila, Maheshkumar, Komala, Mahendra. This is an open access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Published By Indian Society for Education and Environment (iSee)

Implementation of an effective hybrid model for islanded microgrid energy management

S Mallikarjunaswamy^{1*}, N Sharmila², D Maheshkumar³, M Komala⁴, H N Mahendra⁵

¹ Associate Professor, JSS Academy of Technical Education, Bangalore, 560060, Karnataka, India. Tel.: +91-9036337480

² Assistant Professor, RNS Institute of Technology, Bangalore, 560060, Karnataka, India

³ Associate Professor & HoD, JSS Academy of Technical Education, Bangalore, 560060, Karnataka, India

⁴ Associate Professor, SJB Institute of Technology, Bangalore, 560060, Karnataka, India

⁵ Assistant professor, JSS Academy of Technical Education, Bangalore, 560060, Karnataka, India

Abstract

Objective: To propose an effective hybrid model for predictive control (EHMPC) to efficiently manage demand and supply of energy for a microgrid operating in islanded mode operation. Due to the intermittent nature of renewable energy sources and variation in load in the microgrid, maintaining the system stability and reliability along with the economy is a critical issue to be addressed. In the islanded mode of operation, the voltage and frequency have to be monitored in addition to managing energy storage units. The different uncertainties occurring at various stages of microgrid should be taken into account to operate the microgrid with reliability under critical condition **Methods:** This paper proposes an effective algorithm to efficiently control the operation of microgrid and to operate it with optimal efficiency and reliability. In this work, we have proposed a three-stage control of the microgrid where the first stage consists of the arbitrarily distributed generation (ADG) stage, the second stage has energy storage unit (ESU), and the final stage has the energy management scheme (EMS). **Finding:** A case study has been carried out and the proposed method is found to be better in performance, economical and robust in comparison with the conventional two-stage model predictive control (MPC) optimization approach. Further important parameters have been analyzed. **Novelty:** To overcome the limitations of conventional MPC algorithm, we propose a three-stage EHMPC algorithm it consists of three stages, ADG had the first stage of the algorithm the main features of this stage. To optimize the placement, sizing, power factor, minimize network losses and maximize DG integration. The second stage has ESU, the main features of this stage to improve control strategy for optimal power management of microgrid and the final stage has the EMS, to improve tested analysis for a real-time islanded microgrid under various load conditions.

Keywords: Energy management; microgrid; renewable Energy; islanded mode; predictive control

1 Introduction

Research oriented to harness energy from the renewable resources has gained importance in the past few years. The renewable energy can be used as distributed generated (DG) units to obtain balance between supply and demand. The limitation in implementation of these sources lies in their intermittency and operational difficulties, variation in voltage, magnitude, and imbalance between active and reactive power. Implementation of integration of these resources into the conventional grid involves enhanced automation techniques, advanced control strategies and efficient voltage management techniques. The emerging potential of DG can be efficiently utilized by using system approach which views generation and loads as a sub-system, termed as a microgrid (MG). A MG can be operated along with the utility grid in grid connected mode or independently in islanded. The proposed microgrid consists of an Energy storage unit (ESU) and distributed generation unit including PV panels, wind turbines, sea water desalination generators, a water tank and few loads as shown in Figure 1. The islanded microgrid has considerable renewable sources which causes less or zero pollution minimizes depletion of ozone layers, ensures sustainability. Due to use of renewable sources which are intermittent and dilute in nature, the energy storage system should efficiently operate in storing the energy generated by the renewables. Proper co-ordination of loads, generation units and the energy storage units are required to have efficient operation of the system. Initially the objective of the microgrid is to provide a robust scheduling of the system by considering the forecast uncertainties. The microgrid operator should further ensure the minimal real-time operation cost and optimal scheduling process.

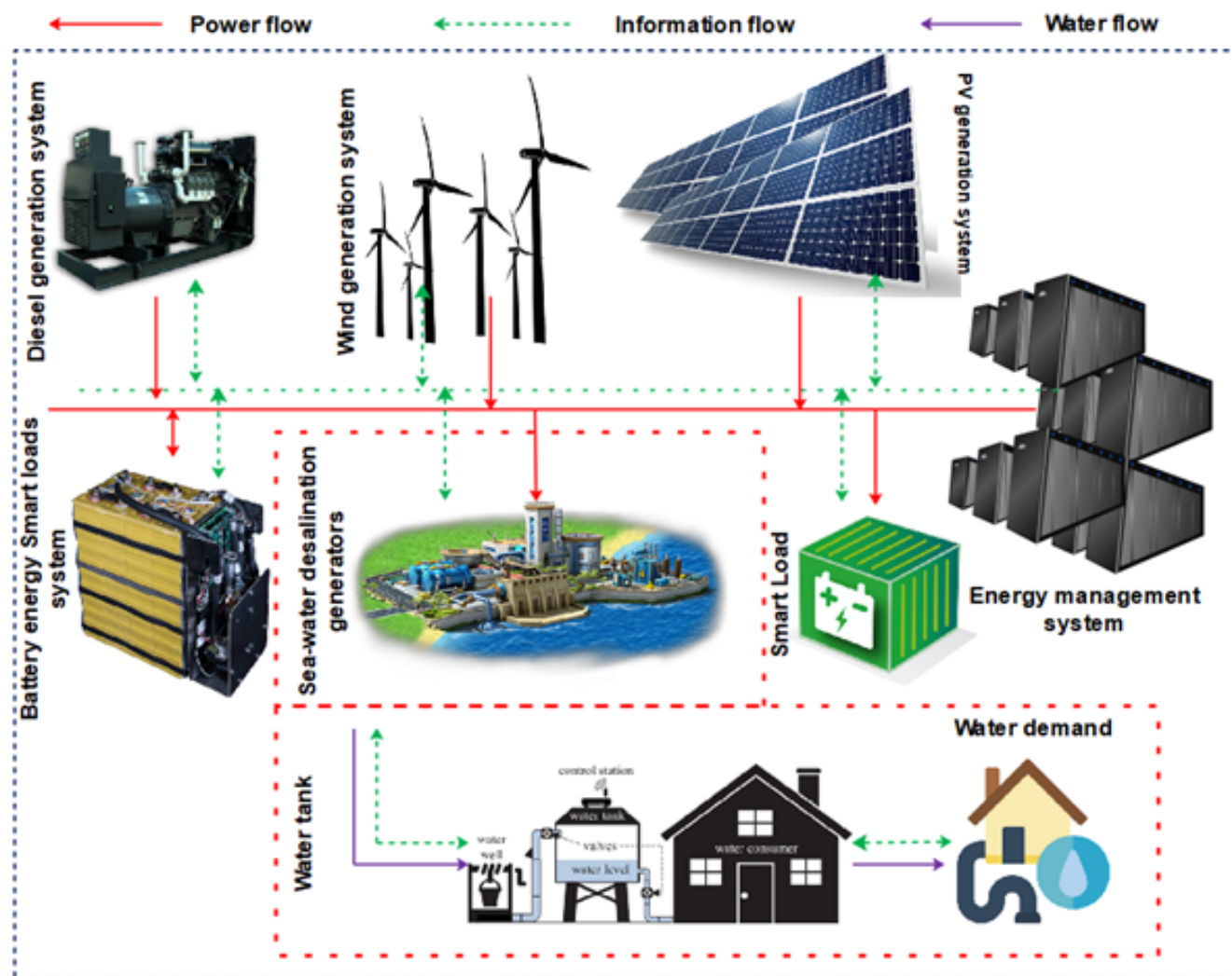


Fig 1. The fundamental island microgrid energy management system

A microgrid comprises of multiple generation units, Energy storage units and critical/non-critical loads as shown in Figure 2. The point of common coupling (PCC)^(1,2) is used to connect microgrid to the utility grid. All the distributed generation units have PEI connection in order to attain control protection, metering objectives in addition to plug-in feature, whether in grid connected or islanded mode. If the microgrid is connected to utility grid, it can give away the surplus power to the utility. The microgrid can change its mode of operation

from grid connected to islanded mode in case of disturbance or failure in the utility grid. The critical loads are first supplied by the microgrid under any circumstance. A microgrid central controller (MGCC) controls all these operations along with local controllers (LC)⁽³⁾. The system performance and sustainable development has been considerably improved by effective coordination of Distributed Energy Resources (DERs) and energy management in microgrid⁽⁴⁾.

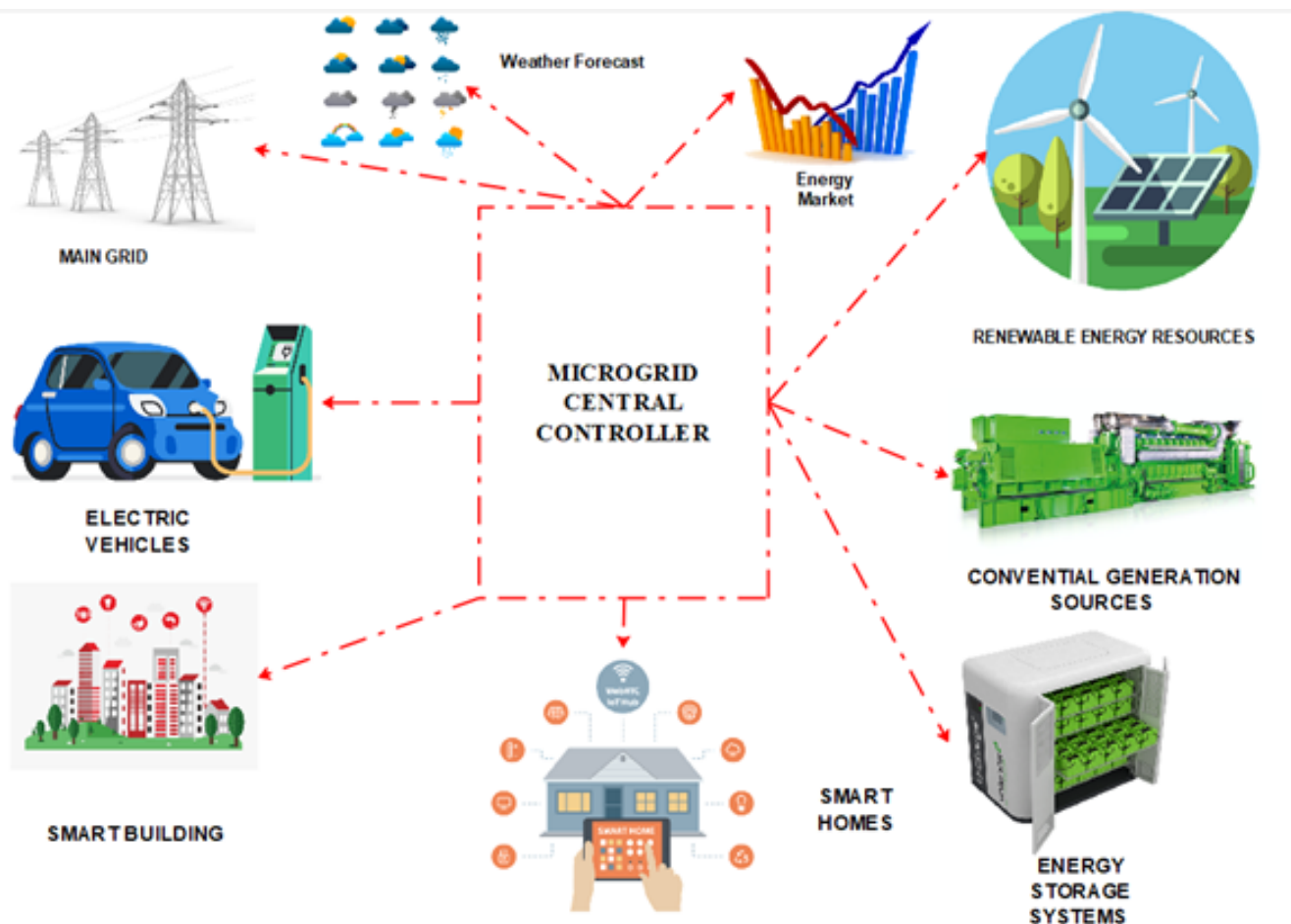


Fig 2. Microgrid architecture

Microgrid can operate in grid connected or islanded mode. Controlling of microgrid in grid connected mode is easier than islanded mode since the frequency of microgrid in grid connected mode is regulated by utility bus frequency. Another important criterion to be monitored in islanded operation is the nature of ADG resources. If the resources of energy used are renewable in nature, their intermittent and dilute nature pose problems in the working of the grid^(5,6). For the effective energy management of micro grid, a large number of studies and models have been developed referring to all previously carried out research work, the research can be categorized into 3 types: Day- Ahead Scheduling (DAS)^(7,8), real time dispatch energy optimization⁽⁹⁾, and model predictive control (MPC)^(10,11). In implementing the strategy of real time power adjustment, the changes in future is not considered and only the present status of the grid is taken for account. In DAS approach, it is open-loop scheduling method, and as is the case with open-loop systems, Due to prediction error it will deviate the original values over a large period of time in optimal resultant result. To enhancement of energy management by adopting closed loop feedback time scheduling methods where the updated iteration probability is saved during the energy optimization procedure. Performance of optimal time period for microgrid comparison with conventional DAS it shows the better result in terms of efficiency, flexibility with respect to economy point of view^(12,13). The limitation of uncertainties & intermittency of renewable energy sources are addressed in previous works by stochastic programming approach. However, this approach has a limitation that the input data entered should abide by certain rules which is not possible in reality⁽¹⁴⁾. In this paper, a study is made on energy management scheme of islanded micro grids which consider the uncertainties in the renewable energy sources.

2 System model

The islanded Microgrid consists of Arbitrary distributed generators (ADG), Energy Storage Unit (ESU) and loads. The Energy Management System [EMS] controls and co-ordinates all these components of Microgrid^(15,16).

t	Timing Index
i	Equipment Index
y	Predictive zone (h)
Δt	Time Interval of each period (h)
$\alpha_{ESU,i}$	Energy Storage unit self- discharge rate (kW)
N_{load}	Number of flexible loads
$\gamma_{load}^{max}, \gamma_{load}^{min}$	Maximum and Minimum Restriction of flexible loads (%).
$\sigma_{load,i}(t)$	Penalty factor (₹/kWh)
$E_{ESU}^{max}, E_{ESU}^{min}$	Energy Storage Unit Maximum, Minimum energy level (kWh)
$C_{ESU}^{max}, C_{ESU}^{min}$	Maximum Charge / Discharge levels of Energy Storage Unit (kW)
$\eta_{ESU}^c, \eta_{ESU}^d$	Energy Storage unit charging and Discharging efficiency
UM_{ESU}	Utilities and maintenance of Energy Storage Unit (₹/kWh)
N_{ADG}	Number of arbitrary distributed generator
$P_{ADG,i}^{max}, P_{ADG,i}^{min}$	Maximum and minimum power outputs with respect to ADG (kW)
$V_{ADG,i}(t)$	Fuel utilization cost function of ADG (₹)
$\Delta P_{ADG,i}$	ADG Ramp power (kW)
x_i, y_i, z_i	Cost coefficient of $V_{ADG,i}(t)$
$\tau_i^{up}, \tau_i^{down}$	Timiest up/Down time interval (h)
$UM_{ADG,i}$	ADG Utilities and maintenance costs(₹)
$V_{ADG,i}^{up}, V_{ADG,i}^{down}$	Startup, shutdown cost of ADG (₹)
$S_{power}(t)$	Solar power production (kW)
$f_{load}(t)$	Flexible load demand (kW)
$C_{load}(t)$	Critical load demand (kW)
$W_{power}(t)$	Wind power production (kW)
$\beta_{ADG,i}(t)$	ADG on/off status
$\delta_{load}(t)$	Flexible loads curtailment (%)
$P_{ADG,i}(t)$	Power output of ADG (kW)
$\beta_{ESU}(t)$	ESU charge / discharge status
$CD_{ESU}(t)$	ESU charge / discharge rate (kW)
$E_{ESU}(t)$	ESU energy level (kWh)

Where $\beta_{ADG,i}(t)$ and $\beta_{ESU,i}(t)$ are binary variables to satisfy the following conditions. It shown in equation (1), (2).

$$\beta_{ADG,i}(t) = \begin{cases} 1, & P_{ADG,i}(t) > 0; \text{ ADG on} \\ 0, & P_{ADG,i}(t) = 0; \text{ ADG off} \end{cases} \tag{1}$$

$$\beta_{ESU}(t) = \begin{cases} 1, & CD_{ESU}(t) > 0; \text{ Charging} \\ 0, & CD_{ESU}(t) \leq 0; \text{ Discharging} \end{cases} \tag{2}$$

2.1 Equipment model

ESU plays a major role in the Microgrid. It acts as a load to store excess power generated and as a standby power supply during deficiency of power from energy sources. The energy storage charging / Discharging power limit, energy storage capacity, supercapacitors storage limit, relation between charging and discharging power are the parameters used for modeling the ESU the constraints of ESU can be described by the following equations (3), (4), (5), (6).

$$C_{ESU}^{min} \leq CD_{ESU}(t) \leq C_{ESU}^{max} \tag{3}$$

$$E_{ESU}^{min} \leq E_{ESU}(t) \leq E_{ESU}^{max} \tag{4}$$

$$E_{ESU}(k+1)_e = E_{ESU}(t) + \eta_{ESU} C D_{ESU}(t) \Delta\tau - \alpha_{ESU} \Delta\tau \tag{5}$$

where

$$\eta_{ESU} = \begin{cases} \eta_{ESU}^c, P_{ESU}(t) > 0 \\ \eta_{ESU}^d, P_{ESU}(t) \leq 0 \end{cases} \tag{6}$$

$E_{ESU}(k+1)_e$ are the constraints of ESU

A battery, is the basic unit in the battery storage system shown in Figure 3 . An energy storage unit [ESU] consisting of batteries can store excess generated energy and dispatch as and when required if the grid operates at maximum capacity, the ESU stores excess energy^(17,18). If there is shortage of power generated due to intermittency of ADG units, the storage energy in ESU can be made use of the ESU also helps in achieving reliable power transfer to all the loads connected. The components in a battery storage system includes battery, monitory and control equipment, power converters and auxiliary units and simulation result of energy storage unit as shown in Figure 4 . Cell base battery units contain packs made up of several modules which, in turn are made up of multiple cells.

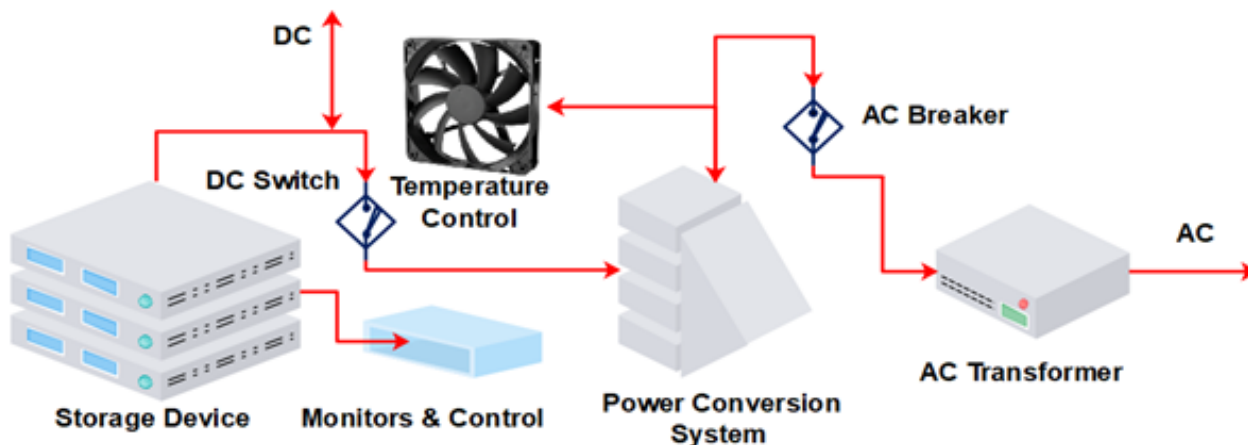


Fig 3. Efficient energy storage unit for islanded microgrid energy management

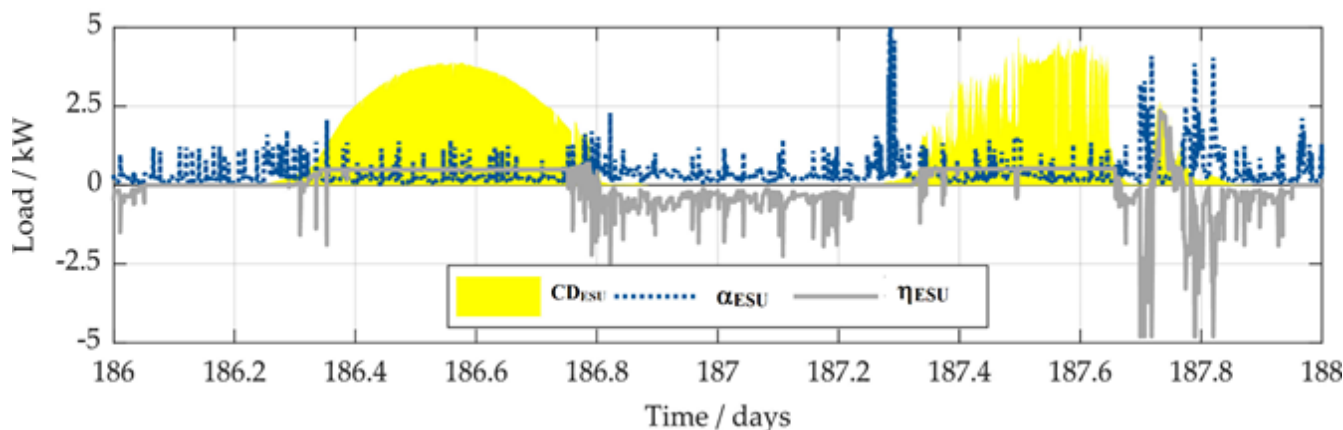


Fig 4. Simulation result of Energy storage unit for islanded Microgrid Energy Management

The mixed logic dynamic (MLD) approach makes the reduction of prediction control error by adopting the scrambling process into a mixed integer programming problem⁽¹⁹⁾. Equation (5) is thus equivalent to the following equations (7), (8), (9), (10), (11), (12), (13).

$$E_{ESU}(k+1) = E_{ESU}(t) + \left(\eta_{ESU}^c - \frac{1}{\eta_{ESU}^d} \right) z_{ESU}(t) \Delta \tau + \frac{1}{\eta_{ESU}^d} P_{ADG,i}(t) \Delta \tau - \alpha_{ESU} \Delta \tau \tag{7}$$

$$-P_{ESU}^{min} \beta_{ESU}(t) \leq P_{ESU}(t) - P_{ESU}^{min} \tag{8}$$

$$P_{ESU}(t) + \sigma \leq (P_{ESU}^{max} + \sigma) \beta_{ESU}(t) \tag{9}$$

$$z_{ESU}(t) \leq P_{ESU}^{max} \beta_{ESU}(t) \tag{10}$$

$$z_{ESU}(t) \geq P_{ESU}^{min} \beta_{ESU}(t) \tag{11}$$

$$z_{ESU}(t) \leq P_{ESU}(t) - P_{ESU}^{min} (1 - \beta_{ESU}(t)) \tag{12}$$

$$z_{ESU}(t) \geq P_{ESU}(t) - P_{ESU}^{max} (1 - \beta_{ESU}(t)) \tag{13}$$

Where $z_{ESU}(t) = \beta_{ESU}(t) P_{ESU}(t)$ and σ is a tolerant positive value. The Utilities and maintenance costs of the ESU with respective time various can be analyze by equation (14).

$$V_{ESU}(t) = [2z_{ESU}(t) - P_{ESU}(t)]UM_{ESU} \Delta \tau \tag{14}$$

The ADG units can have diesel, steam generation, renewable sources like solar, wind, biomass etc. equation (15) and (16) represent the power output limit and ramp power limit. The minimum up and minimum down time constraints are satisfied by using equation (17) and (18).

$$\beta_{ADG,i}(t) P_{ADG,i}^{min} \leq P_{ADG,i}(t) \leq \beta_{ADG,i}(t) P_{ADG,i}^{max} \tag{15}$$

$$\Delta P_{ADG,i} \Delta \tau \leq P_{ADG,i}(t) - P_{ADG,i}(t-1) \leq \Delta P_{ADG,i} \Delta \tau \tag{16}$$

$$\beta_{ADG,i}(t) - \beta_{ADG,i}(t-1) \leq \beta_{ADG,i}(\epsilon_1) \tag{17}$$

$$\beta_{ADG,i}(t-1) - \beta_{ADG,i}(t) \leq 1 - \beta_{ADG,i}(\epsilon_2) \tag{18}$$

Where $\epsilon_1 = t + 1, \dots, \min(t + \tau_i^{up} - 1,)$, $\epsilon_2 = t + 1, \dots, \min(t + \tau_i^{down} - 1,)$ and ϵ_1, ϵ_2 are the supplementary variables in the constraints⁽¹⁹⁾.

The ADG units have initial cost, Utilization and maintenance costs equation (19) shows the fuel consumption cost function of ADG⁽²⁰⁻²²⁾. The startup cost and shut down loss of the DG units should satisfy (20)-(21). The DG operation cost is represented by equation (22).

$$V_{ADG,i}(t) = x_i P_{ADG,i}^2(t) + y_i P_{ADG,i}(t) + z_i \Delta \tau \tag{19}$$

$$\chi_{ADG,i}^{up}(t) \geq V_{ADG,i}^{up} (\beta_{ADG,i}(t) - \beta_{ADG,i}(t-1)) \tag{20}$$

$$\chi_{ADG,i}^{down}(t) \geq V_{ADG,i}^{down} (\beta_{ADG,i}(t-1) - \beta_{ADG,i}(t)) \tag{21}$$

$$\chi_{ADG,i}^{up}(t) \geq 0, \chi_{ADG,i}^{down}(t) \geq 0 \tag{22}$$

Where $\chi_{ADG,i}^{up}(t)$ and $\chi_{ADG,i}^{down}(t)$ are the startup and shutdown cost in time interval t, respectively. Fuel utilization cost function of ADG given by equation (23).

$$V_{ADG}(t) = \sum_{i=0}^{N_{ADG}} [\beta_{ADG,i}(t) + UM_{ADG,i} \beta_{ADG,i}(t) \Delta \tau + \chi_{ADG,i}^{up}(t) + \chi_{ADG,i}^{down}(t)] \tag{23}$$

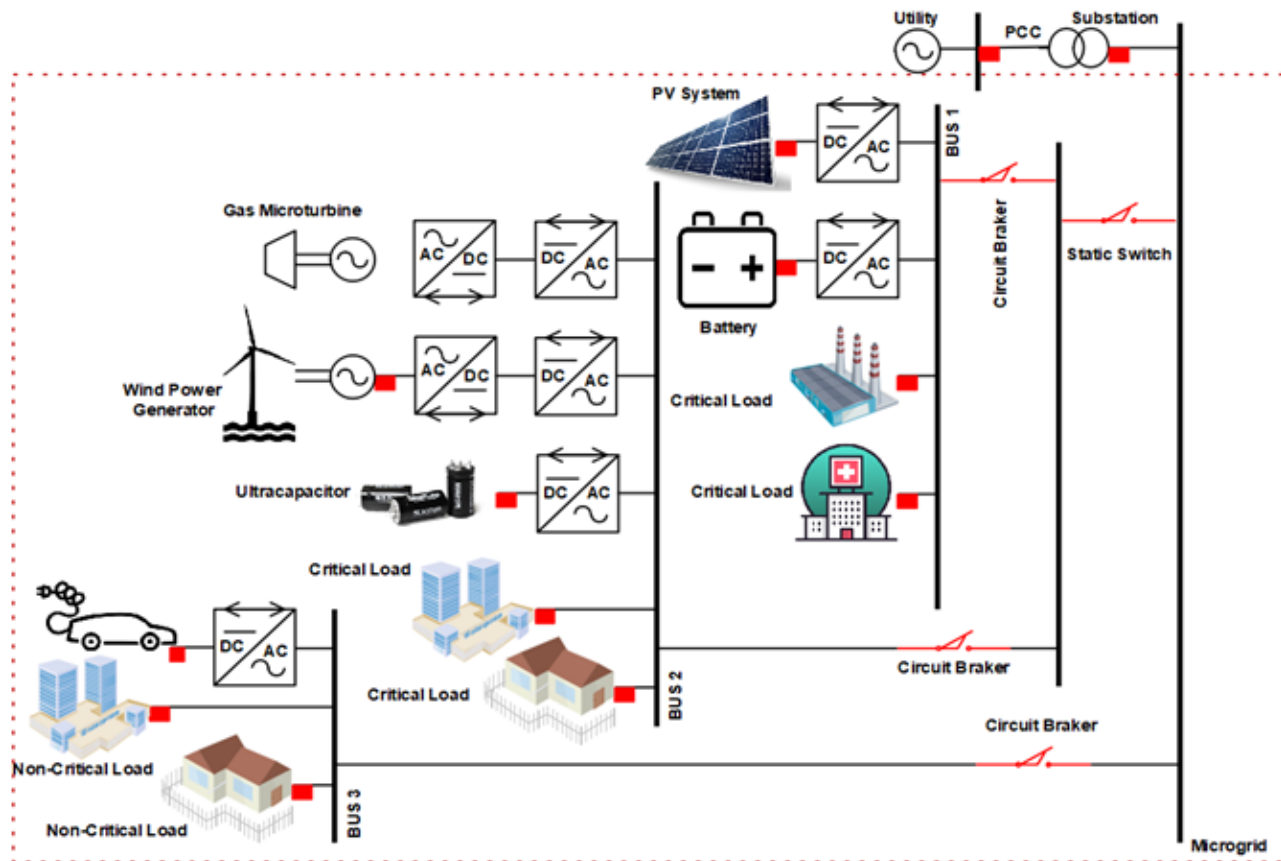


Fig 5. Fundamental microgrid structure for critical and non-critical loads

Ac microgrid is a popular type and follows the traditional electric power system structure. Ac microgrids can be easily designed and implemented by utilizing the available AC network infrastructure which includes distribution transformers and protection this AC microgrid also proves to be reliable in operation. An example of AC microgrid structure is shown in Figure 5. The microgrid structure has 3 buses/AC feeders Two of the three buses have Distributed Generation, Energy Storage System and Critical Loads. The third bus is connected to only non-critical loads. The circuit breaker helps in changing the topology of the microgrid in order to enable the microgrid to cater to the change in demand. A static switch helps in connecting microgrid to the utility grid. In critical condition including poor power quality this switch can disconnect the microgrid and operate it in islanded mode. In islanded mode of operation, the loads are fed from both distributed generation and energy storage device. This designed model categorizes loads as critical and non-critical the critical load has to be met during operation management equation (24) gives the limit for the curtailment of flexible loads. Equation (25) is the penalty cost that is required during the curtailment.

$$\delta_{cloud,i}^{min} \leq \delta_{cloud}(t) \leq \delta_{cloud,i}^{max} \tag{24}$$

$$V_{cloud}(t) = \sum_{i=1}^{N_{cloud}} \sigma_{rload,i}(t) \beta_{cloud,i}(t) f_{load,i}(t) \Delta \tau \tag{25}$$

2.2 Power balance constraint

A microgrid comprises multiple generation units, Energy storage units and critical/non-critical loads as shown in Figure 6. the point of common coupling (PCC) (15) is used to connect microgrid to the utility grid. All the distributed generation units have PEI connection in order to attain control protection, metering objectives in addition to plug-in feature, whether in grid connected or islanded mode. If the microgrid is connected to utility grid, it can give away the surplus power to the utility. The microgrid can change its mode of operation from grid connected to islanded mode in case of disturbance or failure in the utility grid.

The critical loads are first supplied by the microgrid under any circumstance. A microgrid central controller (MGCC) controls all these operations along with local controllers (LC) (23-25). The system performance and sustainable development has been considerably improved by effective coordination of Distributed Energy Resources (DERs) and energy management in microgrid. A battery, is the basic unit in the

battery storage system shown in Figure 6. An energy storage unit [ESU] consisting of batteries can store excess generated energy and dispatch as and when required if the grid operates at maximum capacity, the ESU stores excess energy. If there is shortage of power generated due to intermittency of ADG units, the storage energy in ESU can be made use of the ESU also helps in achieving reliable power transfer to all the loads connected. The components in a battery storage system includes battery, monitory and control equipments, power converters and auxiliary units. Cell base battery units contain packs made up of several modules which, in turn are made up of multiple cells. In order to maintain the balance between demand and supply of energy, steps should not only focus on the usage of pumped storage power generation or large number of units but also on distributed generation units on demand side. The innovative laboratory makes a study on managing energy by the use of optimization techniques on supply and demand side including the controller part Hence it has made a tremendous name in home energy management systems. In Figure 3 . The centralized and decentralized energy management systems work in unison to balance the supply and demand and also to address all the needs of the power system. The power sector fore sees the demand in service area, determines the optimal load dispatch in centralized system of energy management.

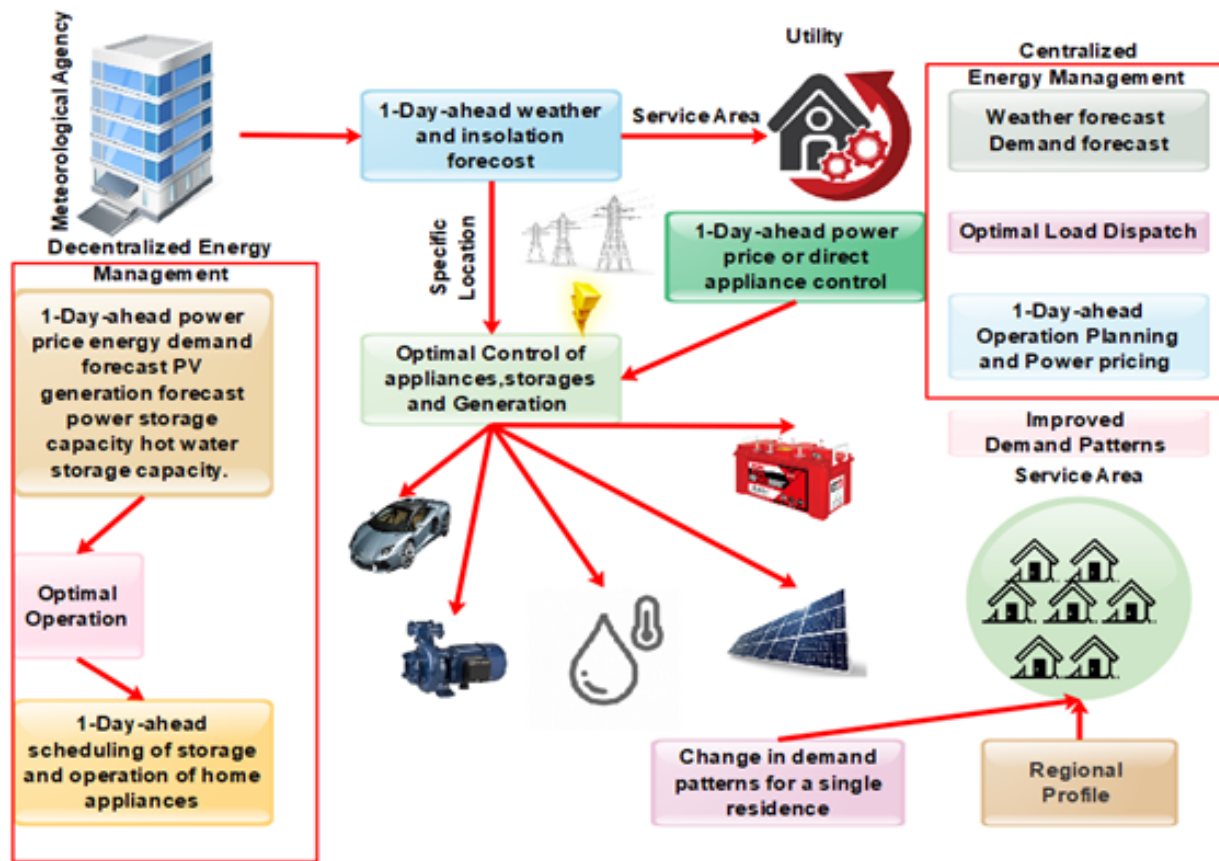


Fig 6. Power Balance Constraint Architecture

During all the time internals considered, the electricity generated should satisfy corresponding demand equation (26) represents the power balance constraint.

$$\sum_{i=1}^{N_{cloud}} f_{load,i}(t) (1 - \delta_{cloud,i}(t)) + C_{load}(t) + P_{ESU}(t) S_{power}(t) + W_{power}(t) \sum_{i=1}^{N_{cloud}} P_{ADG,i}(t) \tag{26}$$

2.3 Objective constraint

To accomplish energy management in islanded Microgrid it is important to maintain a low cost of the entire operation in the whole “predictive zone” equation (27) gives the objective functions and its solutions provide the control action.

$$\begin{aligned} \text{Minimize } V_{total}(t) = & \sum_{i=1}^{N_{cloud}} V_{ADG,i}(t) + U M_{ADG,i} \beta_{ESU}(t) \Delta \tau + \chi_{ADG,i}^{up}(t) + \chi_{ADG,i}^{down}(t) + \\ & \sum_{i=1}^{N_{cloud}} \sigma_{rload,i}(t) \gamma_{load,i}(t) f_{load}(t) \Delta \tau + (2z_{ESU}(t) - P_{ESU}(t)) U M_{ESU} \Delta \tau \end{aligned} \tag{27}$$

3 Proposed EHMPC-Based Reconfigurable workstation Model

3.1 The efficient mathematical model for reconfigurable workstation

Figure 7 shows flowchart the steps involved in the EHMPC based optimization approach. The uncertain forecasts can be solved by considering the solution of robust linear optimization formulation (25-28). An economic dispatch model has to be considered to solve the real time optimization problem by obtaining the actual data. Further an EMS framework is also incorporated to minimize the conservativeness. Certain parameter in the model such as $S_{1power}(t)$, $W_{1power}(t)$, $C_{1load}(t)$ and $f_{1load}(t)$ are delt by utilizing robust optimization approach⁽²⁶⁻²⁸⁾. In this work, we have define a parameter ζ , as the degree of uncertainty. ζ takes values in the interval $[0, |U|]$ where U represents set of uncertain parameters. If ζ is varied, then the robustness of the video can be adjusted against conservation levels of the solution. For the constraint presented in (25), the uncertain parameter $S_{power}(t)$, can take values in the range $[S_{power}(t) - S_{1power}(t), S_{power}(t) + S_{1power}(t)]$, where $S_{power}(t)$ and $S_{1power}(t)$ represent expected solar power production and maximum deviation from extracted production respectively. Similar are the uncertain parameters $W_{power}(t)$, $C_{load}(t)$ and $f_{load}(t)$. We first change the constraint (25) and (28). EHMPC-Based Optimization Strategy: This strategy is proposed in the work based on feedback control law obtained from EHMPC control framework, the robust optimization is offered to the forecast uncertainties as shown in Figure 8. model design and implemented by using MATLAB Simulink.

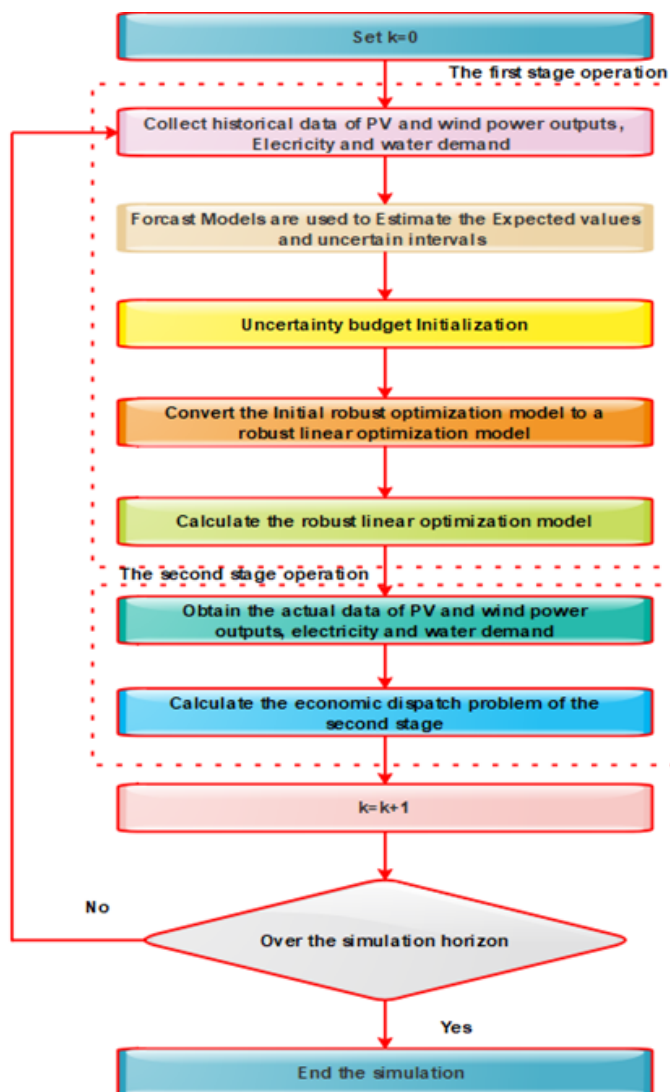


Fig 7. Flow chart of the proposed energy management system algorithm

$$\sum_{i=1}^{N_{\text{load}}} f_{\text{load},i}(t) (\mathbf{1} - \delta_{\text{load},i}(t)) + C_{\text{load}}(t) + P_{\text{ESU}}(t) \leq S_{\text{power}}(t) + W_{\text{power}}(t) + \sum_{i=1}^{N_{\text{ADG}}} P_{\text{ADG},i}(k) \tag{28}$$

At the optimal solution, the optimization ensures that the constraint becomes equality first stage operational equation (28) can be reformulated as follows second stage operational equations (29), (30), (31), (32), (33), (34), (35), (36), (37), (38):

$$\sum_{i=1}^{N_{\text{load}}} C_{\text{load}}(t) (\mathbf{1} - \delta_{\text{load},i}(t)) + z_{\text{balance1}}(t) S_{\text{balance1}}(t) + \sum_{i=1}^{N_{\text{load}}} \mathcal{H}_{\text{balance1},i}(t) + z_{\text{balance2}}(t) S_{\text{balance2}}(t) + \sum_{i=1}^3 \mathcal{H}_{\text{balance2},i}(t) \tag{29}$$

$$\leq S_{\text{power}}(t) + W_{\text{power}}(t) - C_{\text{load}}(t) - P_{\text{ESU}}(t) + \sum_{i=1}^{N_{\text{load}}} P_{\text{ADG},i}(t) - y_{\text{balance1},i}(t) \leq \mathbf{1} - \delta_{\text{load},i}(t) \leq y_{\text{balance1},i}(t) \quad i = \mathbf{1}, \mathbf{2}, \dots, N_{\text{load}} \tag{30}$$

$$z_{\text{balance1}}(t) + x_{\text{balance1},i}(t) \geq C_{\text{load},i}(t) y_{\text{balance1},i}(t) \quad i = \mathbf{1}, \mathbf{2}, \dots, N_{\text{load}} \tag{31}$$

$$z_{\text{balance2}}(t) + \mathcal{H}_{\text{balance1.1}}(t) \geq S_{\text{power}}(t) \tag{32}$$

$$z_{\text{balance2}}(t) + x_{\text{balance2.2}}(t) \geq W_{\text{power}}(t) \tag{33}$$

$$z_{\text{balance2}}(t) + x_{\text{balance2.3}}(t) \geq c_{\text{load}}(t) \tag{34}$$

$$x_{\text{balance1},i}(t) \geq 0 \quad i = \mathbf{1}, \mathbf{2}, \dots, N_{\text{load}} \tag{35}$$

$$x_{\text{balance2},i}(t) \geq 0 \quad i = \mathbf{1}, \mathbf{2}, \mathbf{3}, \mathbf{4}, \dots \tag{36}$$

$$z_{\text{balance1}}(t) \geq 0 \tag{37}$$

$$z_{\text{balance2}}(t) \geq 0 \tag{38}$$

Where $\mathcal{L}_{\text{balance1}}(t)$, $\mathcal{H}_{\text{balance1},i}$, $y_{\text{balance1},i}(t)$, $Z_{\text{balance2}}(t)$, $z_{\text{balance2}}(t)$ auxiliary decision variables are introduced in the model, meanwhile $\zeta_{\text{balance1}}(t)$ and $\zeta_{\text{balance2}}(t)$ take a value in $[0, N_{\text{load}}]$ and $[0, 3]$ respectively.

- In the similar manner, the objective function (27) has to be dealt for the uncertain parameter $f_{\text{load}}(t)$
- To summarize the robust counterpart of the model can be defined as:

$$\text{Minimize } z_{\text{Aux}}(t) = \sum_{i=1}^{N_{\text{load}}} \sigma_{r\text{load},i}(t) \delta_{\text{load},i}(t) f_{\text{load},i}(t) \Delta \tau + V_{\text{ESU}}(t) + V_{\text{ADG}}(t) - z_{\text{Aux}}(t) \leq 0 \tag{39}$$

s.t. (1)-(2), (5)-(26).

Here $z_{\text{Aux}}(t)$ is the auxiliary variable. The following equations (40), (41), (42), (43), (44) hold good for the new constraint in (39).

$$\sum_{i=1}^{N_{\text{load}}} \sigma_{r\text{load},i}(t) \delta_{\text{load},i}(t) f_{\text{load},i}(t) \Delta \tau + V_{\text{ESU}}(t) + V_{\text{ADG}}(t) - z_{\text{Aux}}(t) + z_{\text{cload}}(t) \zeta_{\text{cload}}(t) + \sum_{i=1}^{N_{\text{load}}} f_{\text{load},i}(t) \leq 0 \tag{40}$$

$$z_{\text{cload}}(t) + f_{\text{load},i}(t) \geq \sigma_{\text{cload},i}(t) f_{\text{load},i}(t) y_{\text{cload},i}(t) \Delta t \quad i = \mathbf{1}, \mathbf{2}, \dots, N_{\text{load}} \tag{41}$$

$$-y_{\text{cload},i}(t) \leq \delta_{\text{cload},i}(t) \leq y_{\text{cload},i}(t) \quad i = \mathbf{1}, \mathbf{2}, \dots, N_{\text{load}} \tag{42}$$

$$f_{\text{cload},i}(t) \geq 0 \quad i = \mathbf{1}, \mathbf{2}, \dots, N_{\text{load}} \tag{43}$$

$$z_{\text{cload}}(t) \geq 0 \tag{44}$$

Where $\zeta_{\text{cload}}(t)$ takes a value in $[0, N_{\text{load}}]$.

To summarize, the proposed model has the robust counterpart shown in section II which can be described as: $\text{min} z_{\text{Aux}}(t)$ s.t. (1)-(2), (5)-(25), (29)-(38), and (40)-(44).

The parameters representing the degree of uncertainty in the model are subjected to normalization and uniformly represented by $\zeta \in [0, 1]$. If $\zeta=1$, then the model has the strongest robustness and the model (43) degeneration into (25) if $\zeta=0$.

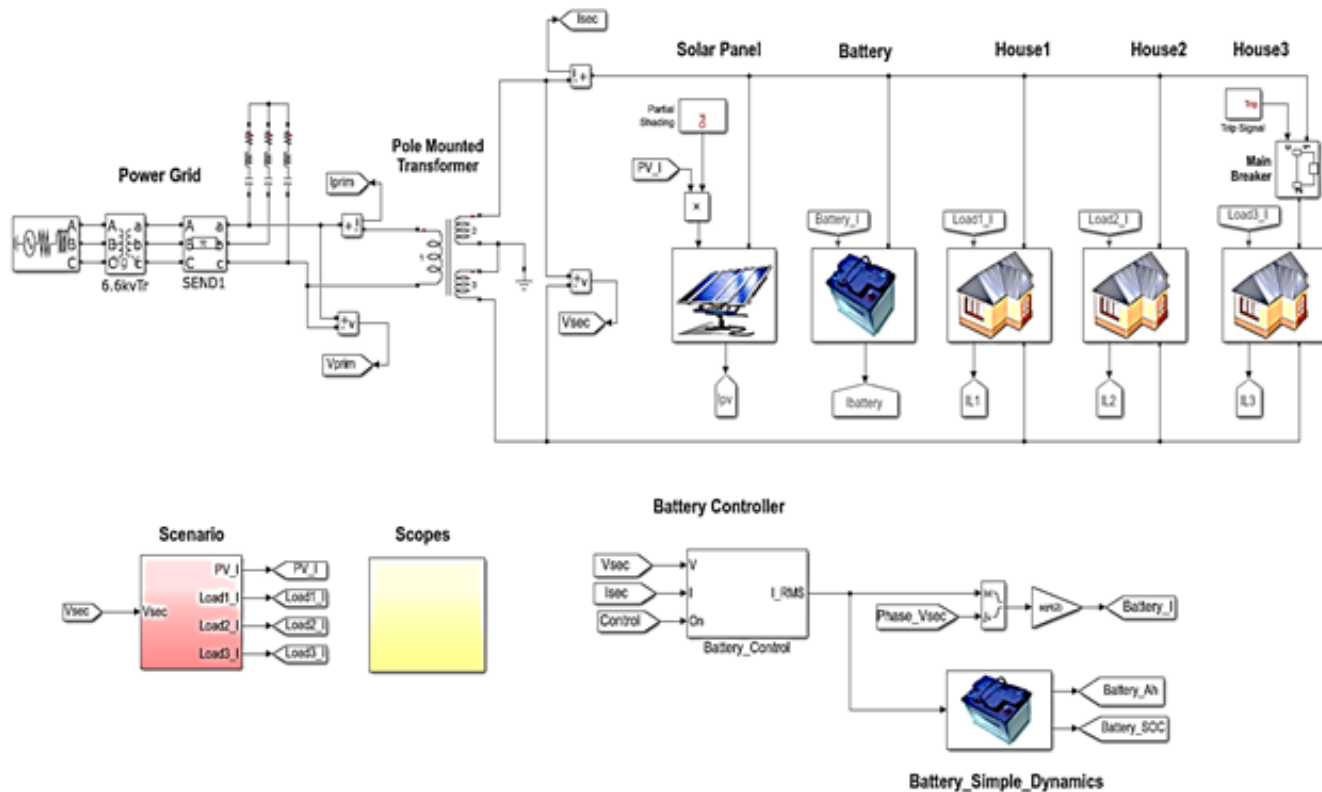


Fig 8. Proposed renewable energy management system for microgrid in islanded mode operation

3.2 MPC based strategy

Step_1: The high-speed reconfigurable energy management optimization model has been derived.

Step_2: The probabilities values updating of all automotive equipment’s in the islanded Microgrid (Including ESU energy level $E_{ESU}(t)$, DC power output $P_{ADG,i}(t)$) is obtained at the end of time interval $t-1$, the load demand and power production from renewable sources in the duration t to $t+W$. The load demand and power production from renewable sources in the duration t to $t + W$ will be forecasted.

Step_3: The control sequence is acquired by solving the limited zone ideal issue (43).

Step_4: The main thing of the control grouping must be applied the control procedure must be balanced in agreement to the real estimation of forecast parameters.

Step_5: Step_2 is implemented by making $t=t+1$.

4 Case Study

4.1 Case description

The access to the values of solar and wind energy generation output and load demand is obtained from global energy forecasting competition 2019. Here we have taken two days data. Table 1 has the parameter settings data of the ADGs and third set of data is set for emergency condition.

Table 1. ADG critical parameter settings

SI.NO	Power out limit	Ramp Power limit	Min up/ Down time	Cost co-efficient	ADG Startup, Shutdown cost
1	600/10	510	2/1	0.00048/3.2	3.2/3.38
2	760/20	550	2/1.5	0.00055/0.56/3.7	3.53/4.3
3	40/0.4	40	0.4/0.4	0.0015/0.73/2.4	1.01/1.99

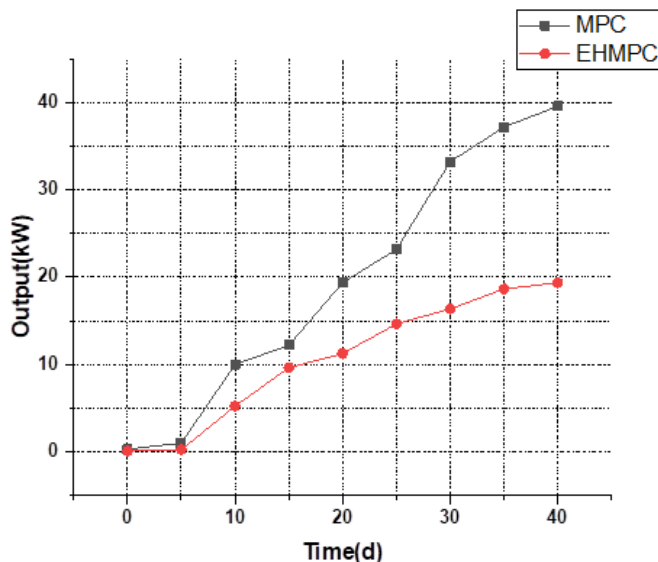


Fig 9. Output of the emergency ADG with $\zeta = 0.15$.

Curtailment of loads, during the operation of Microgrid should be avoided as far as possible unless it is an emergency. 0.2 is the maximum curtailment and the penalty cost is 5 times the average loss of power generation. Table 2 shows the four risk levels considered, which indicates the length of uncertain interval. The MPC method is utilized to make a comparison with the proposed EHMP method. The uncertainty parameter ζ is set to 0.15. The Figures 9 and 10 depicts the usage of ADG (emergency ADG) coming under 2 strategies at the level 4 risk. It is observed from these 2 Figures 9 and 10. that MPC based method requires less emergency power and load curtailment.

Table 2. Risk levels of uncertainty

Risk Level	1	2	3	4
Max predictive deviation	4.98%	9%	14%	19%

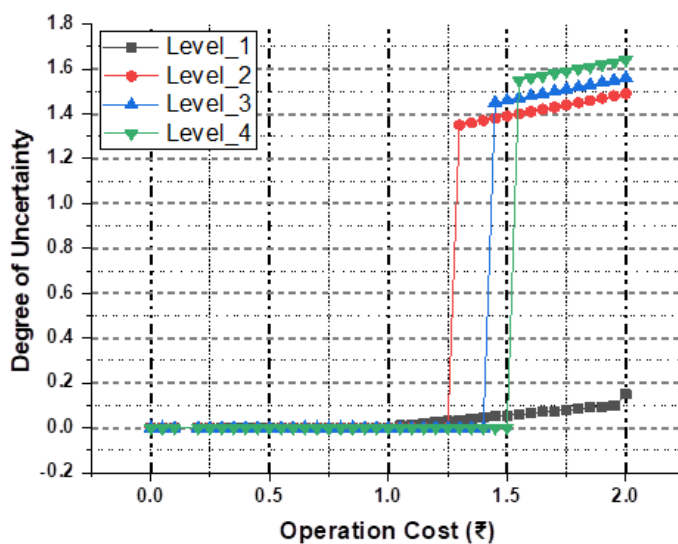


Fig 10. Operation cost with variable ζ .

Table 3. Risk levels of operation cost

Risk Level	Level_1	Level_2	Level_3	Level_4
EHMPC	14103.9	14208.8	14395.8	14657.8
MPC	14156.8	14478.1	14865.3	14656.56

From the analysis and observation of the data in Table 3 . We can conclude that the proposed work EHMPC has less operation cost compared to conventional MPC method and the risk level increases when $\zeta = 0.15$.

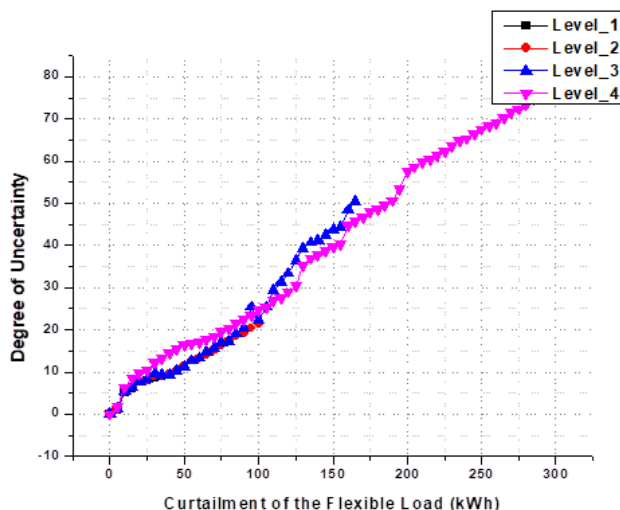


Fig 11. Curtailment of the flexible load with variable ζ .

The results shown in Figures 10 and 11 . depicts that the load curtailment decreases with increase in uncertainty parameter ζ , however, there is decrease in operation cost at first and then increases.

5 Conclusion

This work proposes the EHMPC based optimization strategy for optimal scheduling of the microgrid with PV and wind energy sources. Internal forecasting models are used to obtain the data from PV panels, wind turbines load and water demand. The primary robust optimization model can be transformed into ESU model by using robust linear methods and further the solution can be obtained using suitable software. The case study has the following observations:

- The EHMPC strategy has better predictive output efficiency with 98.23% in comparison to the conventional MPC. .
- sage of ESU increases the reliability of operation, reduces 19% of actual operation cost and capital cost of arbitrary distributed generation units.
- The reliability, flexibility and efficiency of the microgrid has increased with EMS techniques and devices being integrated into the microgrid.

Acknowledgment

The authors acknowledge with thanks Technical Education Quality Improvement Programme (TEQIP) of Visvesvaraya Technological University (VTU), Belagavi for technical and financial support.

References

- 1) Admasie S, Bukhari SBA, Haider R, Gush T, Kim CH. A passive islanding detection scheme using variational mode decomposition-based mode singular entropy for integrated microgrids. *Electric Power Systems Research*. 2019;177:105983–105983. Available from: <https://dx.doi.org/10.1016/j.epr.2019.105983>.
- 2) Chakravorti T, Priyadarshini L, Dash PK, Sahu BN. Islanding and non-islanding disturbance detection in microgrid using optimized modes decomposition based robust random vector functional link network. *Engineering Applications of Artificial Intelligence*. 2019;85(4):122–136. Available from: <https://dx.doi.org/10.1016/j.engappai.2019.06.004>.
- 3) Ganesh C, Babu CHL, Kumar KP. Adaptive Control and Power Management in a Microgrid by using Distribution Grids. *Indian Journal of Science and Technology*. 2015;8(30):1–8. Available from: <https://dx.doi.org/10.17485/ijst/2015/v8i30/78769>.
- 4) Gayathri GS, Annapeachi V, and. A Generalized Framework for a Cost Optimization Scheme in a MicroGrid. *Indian Journal of Science and Technology*. 2019;12(24):1–6. Available from: <https://dx.doi.org/10.17485/ijst/2019/v12i24/143935>.

- 5) Padmanabhan B. Nine-level Inverter based Solar Power Generation for Micro Grid Application. *Indian Journal of Science and Technology*. 2017;10(36):1–5.
- 6) Singh I K, Mishra S. A Review on Power Management and Power Quality for Islanded PV Microgrid in Smart Village. *Indian Journal of Science and Technology*. 2017;10(17):1–4.
- 7) Prakash AC, Reddy DS. Distributed Generation Operation in Micro-Grid by using Smart Distribution Systems. *Indian Journal of Science and Technology*. 2016;9(35):1–5. Available from: <https://dx.doi.org/10.17485/ijst/2016/v9i35/97930>.
- 8) Choudhary NK, Mohanty SR, Singh RK. Active and Reactive Power Management in Microgrid: Analysis in Grid Connected and Islanded Mode of Operation. *Indian Journal of Science and Technology*. 2016;9(21):1–8. Available from: <https://dx.doi.org/10.17485/ijst/2016/v9i21/79587>.
- 9) Thakur G, Kamal K, Sharma. Power Management in Hybrid Microgrid System. *Indian Journal of Science and Technology*. 2017;10(16):1–5.
- 10) Nabatirad MR, Eghbalpour H, Rahnamafard Y, Pirayesh A. Load Sharing by Decentralized Control in an Islanded Inverter-based Microgrid using Frequency Tracking. *Indian Journal of Science and Technology*. 2015;8(27):1–11. Available from: <https://dx.doi.org/10.17485/ijst/2015/v8i27/59406>.
- 11) Pandey K, Banerjee P, Mathur D. Study and Modelling of Green Energy based Micro-Grid for Rural Area. *Indian Journal of Science and Technology*. 2016;9(21):1–6. Available from: <https://dx.doi.org/10.17485/ijst/2016/v9i21/91568>.
- 12) Bindhu VS, M D. Mary Synthia Regis Prabha, A Survey on Control and Communication of Smart Micro Grid. *Indian Journal of Science and Technology*. 2015;8(25):1–6.
- 13) Rajarajeswari R, Vijayakumar K, Swaroop PR, Ramanathan S. Simulation of Controllers for AC Microgrid. *Indian Journal of Science and Technology*. 2016;9(42):1–5. Available from: <https://dx.doi.org/10.17485/ijst/2016/v9i42/101854>.
- 14) Kodali MM, Srikanth KS. Power Management Strategy for Hybrid Microgrid System under Islanded Condition using Adaptive Droop Control. *Indian Journal of Science and Technology*. 2016;9(28):1–7. Available from: <https://dx.doi.org/10.17485/ijst/2016/v9i28/91580>.
- 15) Raju L, Milton RS, Morais AA. Autonomous Energy Management of a Micro-Grid using Multi Agent System. *Indian Journal of Science and Technology*. 2016;9(13):1–8. Available from: <https://dx.doi.org/10.17485/ijst/2016/v9i13/89294>.
- 16) Jafari A, Ganjehlou HG, Khalili T, Bidram A. A fair electricity market strategy for energy management and reliability enhancement of islanded multi-microgrids. *Applied Energy*. 2020;270:115170–115170. Available from: <https://dx.doi.org/10.1016/j.apenergy.2020.115170>.
- 17) Rezaei N, Mazidi M, Gholami M, Mohiti M. A new stochastic gain adaptive energy management system for smart microgrids considering frequency responsive loads. *Energy Reports*. 2020;6:914–932. Available from: <https://dx.doi.org/10.1016/j.egy.2020.04.021>.
- 18) Vivas FJ, Segura F, Andújar JM, Caparrós JJ. A suitable state-space model for renewable source-based microgrids with hydrogen as backup for the design of energy management systems. *Energy Conversion and Management*. 2020;219:113053–113053. Available from: <https://dx.doi.org/10.1016/j.enconman.2020.113053>.
- 19) Sinha S, Bajpai P. Power management of hybrid energy storage system in a standalone DC microgrid. *Journal of Energy Storage*. 2020;30:101523–101523. Available from: <https://dx.doi.org/10.1016/j.est.2020.101523>.
- 20) Ahmadi SE, Rezaei N. A new isolated renewable based multi microgrid optimal energy management system considering uncertainty and demand response. *International Journal of Electrical Power & Energy Systems*. 2020;118:105760–105760. Available from: <https://dx.doi.org/10.1016/j.ijepes.2019.105760>.
- 21) Parol M, Wójciszewski T, zyk KK, Wenge C, Balischeckski S, Arendarski B. Optimum management of power and energy in low voltage microgrids using evolutionary algorithms and energy storage. *International Journal of Electrical Power & Energy Systems*. 2020;119:1–13. Available from: <https://doi.org/10.1016/j.ijepes.2020.105886>.
- 22) Samadi E, Badri A, Ebrahimpour R. Decentralized multi-agent based energy management of microgrid using reinforcement learning. *International Journal of Electrical Power & Energy Systems*. 2020;122:106211–106211. Available from: <https://dx.doi.org/10.1016/j.ijepes.2020.106211>.
- 23) Nadh AP, Kishore DR. Integration of PV based DG Source in AC microgrid with interconnection to Grid. *Indian Journal of Science and Technology*. 2015;8(32):1–5. Available from: <https://doi.org/10.17485/ijst/2015/v8i32/72203>.
- 24) Khamis A, Ab MR. Modelling and Analysis Fuel Cell with Battery Storage Microgrid System Based on Green Energy. *Indian Journal of Science and Technology*. 2018;11(30):1–15. Available from: <https://doi.org/10.17485/ijst/2018/v11i30/109336>.
- 25) Singh K, Mishra S. A Review on Power Management and Power Quality for Islanded PV Microgrid in Smart Village. *Indian Journal of Science and Technology*. 2017;10(17):1–4. Available from: <https://doi.org/10.17485/ijst/2017/v10i17/103033>.
- 26) Rasheed A, Rao GK. Improvement of Power Quality for Microgrid using Fuzzy based UPQC Controller. *Indian Journal of Science and Technology*. 2015;8(23):1–5. Available from: <https://dx.doi.org/10.17485/ijst/2015/v8i23/70751>.
- 27) Sanij MD, Dehghani-Ashkezari M, Hashemi-Dezaki H. Optimum Reserve Estimation in Micro-Grids containing Renewable Distributed Generation Resources. *Indian Journal of Science and Technology*. 2015;8(28):1–9. Available from: <https://dx.doi.org/10.17485/ijst/2015/v8i28/82804>.
- 28) S. Kant SK, Inderpreet K, Balwinder S. Power System Stability for the Islanding Operation of Micro Grids. *Indian Journal of Science and Technology*. 2016;9(38):1–5. Available from: <https://dx.doi.org/10.17485/ijst/2016/v9i38/101474>.