Sizing of Rooftop PV Array and Community-Run Battery Storage for an Energy Cooperative in Prosumer Cluster

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Abstract

A standalone system can address the problem of uncovered electricity from the grid. The cost of energy storage for installing renewable energy systems is one of the issues of such a system. This paper introduces and investigates the optimal capacity of a novel energy cooperative system with prosumer clusters and a community battery bank as typical energy storage. The system's function is formulated to minimize the investor's annual expenditure. The proposed energy cooperative system uses actual annual solar insolation data and the electric load demand of houses in the optimization process. The model, as mentioned above, is applied to two system configurations – energy cooperative without and with Prosumer to Prosumer (P2P) energy sharing. The reliability factor Loss of Power Supply Probability (LPSP) from the Cooperative Energy Sharing algorithm is taken as a constraint in the formulation. The comparison of the two configurations brings out the importance of P2P energy sharing in a standalone Energy Cooperative system. Particle

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Swarm Optimization (PSO) algorithm is used to achieve this optimization. The PSO results show that the proposed Energy Cooperative configurations are promising to facilitate the system's reliability.

Keywords: Energy cooperative, community battery bank, energy sharing, optimization.

Nomenclature

AIE	Annual Imported Energy	LPSP	Loss of Power Supply Probability
AEE	Annual Exported Energy	P2P	Prosumer to Prosumer
AEF	Annual Energy Failure	PSO	Particle Swarm Optimization
AOMC	Annual Operation and Maintenance cost	O&M	Operation and Maintenance
AC_{EF}	Annual Energy Failure cost	RTPV	Rooftop Photovoltaic
CBB	Community Battery Bank	PV	Photovoltaic
CESA	Cooperative Energy Sharing Algorithm	IE	Imported Energy
DERs	Distributed Energy Resources	INR	Indian Rupees
EG	Excess Generation	UMD	Unmet Demand
EE	Exported Energy	SoC	State of Charge
EC	Energy Cooperative	C_{EF}	Cost for Energy Failure
CRF	Capital Recovery Factor	IC	Investment Cost
I	Interest Rate	P_{gen}^{N}	Power generation by house N
Y	Project Year	P_{dem}^{N}	Power Demand of house N
t	Time in hours	P_{dch}^{CB}	Discharging Power by CBB
N	Number of Houses	P_{ch}^{CB}	Charging Power of CBB
j	Number of Prosumer	A_g	Ageing Factor of Battery
i	Number of Consumer	LF	Load Factor of Battery
TH	Total Houses	p	Percentage of IC factor
E_b	SoC of Battery	T_P	Temperature Factor
E_{dch},	Discharging Energy of CBB	E_{ch}	Charging Energy of CBB
$\mathrm{IC}_{\mathrm{PV}}^{N}$	Investment Cost for PV of N house	$\mathrm{IC}_{\mathrm{CBB}}$	Investment Cost for CBB

$\mathrm{UIC}_{\mathrm{PV}}^{N}$	Unit Investment Cost for PV of N house	$\mathrm{UIC}_{\mathrm{CBB}}$	Unit Investment Cost for CBB
$\mathrm{N}_{\mathrm{PV}}^{N}$	Number PV panels for house N	$\mathrm{N}_{\mathrm{CBB}}$	Number of CBB
P_{annual}^{N}	Annual Average Demand	C^{CB}	Capacity of Battery Bank
PR	Performance Ratio	η_{PV}	Efficiency of the PV Panel
A	Area of PV Panel	$\mathrm{I}_{\mathrm{rad}}$	Solar Irradiation
net	Net energy of the house	Net	Net energy of the Energy cooperative
$E_b\max$	Maximum limit of SoC	$E_b min$	Minimum limit of SoC
E_{gen}^{N}	Energy generation by house N	E_{dem}^{N}	Energy Demand of house N

1 Introduction

The increase in the country's population increases the country's demand for power. At present 2.4% of Indian households remain unelectrified due to the unelectrified households [1]. The country's electricity demand rises quickly which is unpredictable in the years to come and consequently results in limited economic growth in the future [2]. The geographical location of the customer premises, demerits of a conventional electricity system, difficulty in transmission equipment installation and O&M cost (42% of the electrical network's total cost) result in the commissioning of isolated microgrids [3]. The energy sector is the most existing process a widespread extrude that has redefined the industry's attitude [4].

The energy sector focusing on achieving "Power for all" has enhanced capacity accumulation within the country. Global demand for energy is rapidly increasing, arising from population and economic growth, especially in emerging market economies, which will account for 90% of energy demand growth in 2035 [5]. Decarbonized Distributed Energy Resources (DERs) have become the backbone of power generation due to the exponential growth in the electrical field because of the government's policy-driven targets. India has an efficient solar potential owing to the geographically tropical nature of the country [6, 7]. India has commenced an ambitious shift towards building a sustainable energy economy and aspires to have 450 GW of renewable energy by the year 2030, which will lead to a paradigm change in India's energy mix [8]. DERs allow flexibility in power generation and eliminate grid disturbances with the rapid decline in PV costs and this led to driving more prosumers in the future electrical system. DERs cover electricity supply in nonelectrified areas [9].

A standalone microgrid plays a vital role in satisfying the energy demand of isolated remote places and a well-organized system's net demand is satisfied by local power generation [10]. Green energy generators may not satisfy the energy demand due to the intermittent nature of natural resources but combined energy storage with a photovoltaic generator can eliminate the above difficulty [11, 12]. The usage of renewable energy sources in remote places is becoming very common, due to the reducing prices of PV panels; these PV generations require energy storage to balance generation and demand [13]. An energy storage system with green energy generators can reduce hydrocarbon emissions with reliability and quality, especially at the residential level [13,14].

If own energy storage is used, it leads to high procurement, operation, and maintenance costs for the investor [14]. Optimization of battery storage size can result in a reduction in the total energy cost of PV mounted homes [15]. But a common storage system acts as an aggregator and plays a dynamic part in organising user's charge and discharge decisions by controlling the energy sharing; thus, maximising the social welfare [16]. A tabulation of available literature relevant to the investigation is found in Table 1.

A community electricity system that functions as a cooperative is needed. Energy cooperative is one way to meet the objectives of the expansion of RES and resident's energy communities. Energy cooperatives are also proposed to increase the energy independence and economical conditions of rural areas;

Table 1 Survey report on restrictions of existing work

	Energy Sharing		Sizing Component	
Reference	Without $P2P$	With $P2P$	Battery	PV
[17]	Yes	Not discussed	Yes	Yes
[18]	Yes	Not discussed	Yes	Yes
[19]	Yes	Not discussed	Yes	Not discussed
[20]	Not discussed	Yes	Not discussed	Not discussed
[21]	Not discussed	Yes	Not discussed	Not discussed
[22]	Not discussed	Yes	Not discussed	Not discussed
[23]	Not discussed	Yes	Not discussed	Not discussed
[24]	Not discussed	Yes	Not discussed	Not discussed
[25]	Not discussed	Yes	Not discussed	Not discussed
Proposed Work	Yes	Yes	Yes	Yes

increase deployment of renewable resources [27, 28]. The sizing of individual RTPVs in such a cooperative energy system has not been taken up so far. Prosumer-based standalone microgrids play a critical role in the isolated energy sector [29].

Energy sharing between prosumers reduces the unreliable operation of standalone energy investors. Energy sharing is anticipated to inspire users to participate in energy management and reduce dependence on dispatchable resources, and it leads the flexibility on the demand side. This can achieve the same disutility and flexibility as centralized dispatch [30]. P2P energy sharing technology promotes the transformation of a consumer into a prosumer operation [31]. The sizing problem is critical, especially in rural communities, because incorrect results can mislead decision makers when structuring the new energy system [32].

Furthermore, the potential benefit of investing in the optimal sizing of energy cooperative components is critical for the efficient operation of the energy network. Load and generation uncertainties must be considered in the analysis for a stable standalone system planning. This can be achieved through a cooperative sharing algorithm. Furthermore, a comparative assessment of the Energy Cooperative's reliability for the annual period is also taken into account for efficient planning of a standalone system. It can be found from Table 1 that the sizing algorithm of PV array and battery storage for peer to peer sharing has not been taken up so far. Hence, this article aims to optimize the size of green energy generators and energy storage systems in the energy cooperative. In this study, two configurations of energy cooperative designs are analysed. The contribution of this study is as follows:

- Awareness to prosumers about the benefits of green electrification.
- Energy sharing techniques are motivating the consumer to become a prosumer.
- Adequate infrastructure to extend the electrical system to the unreachable area.
- Promoting the Energy Cooperative system with the community-run storage named Community Battery Bank (CBB).

2 Energy Cooperative Formulation

The mission of the Energy Cooperative system is to discover the electrical load demand of the residential customer from the existing sources in the community rendering to a predefined operation approach. Therefore, the

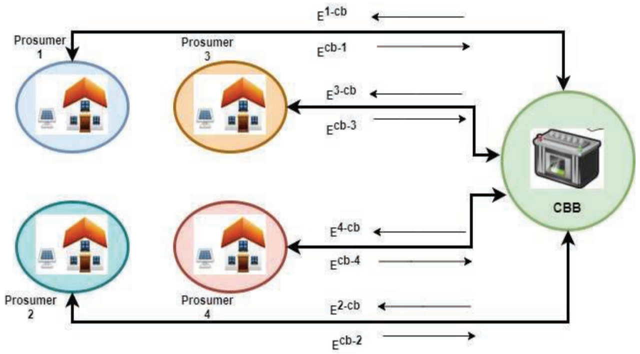

Figure 1 Proposed energy cooperative configuration without P2P.

energy cooperative works to gratify and ensuing power balance equation at each instant (t):

$$\sum_{N=1}^{TH} P_{gen}^{N}(t) + s \cdot P_{dch}^{CB}(t) = \sum_{N=1}^{TH} P_{dem}^{N}(t) + \overline{s} \cdot P_{ch}^{CB}(t) \qquad (1)$$

The binary operator $s, \overline{s}$ in (1) used to express charging and discharging are simultaneous events. Two different Energy Cooperative systems are discussed below.

2.1 Configuration-Without P2P

In this configuration, the output power from the prosumer PV array can satisfy their self-sufficient energy requirements and the excess generation (EG) is sent to the CBB without P2P. The system requires a high-capacity CBB, and the battery's maintenance plays a vital role. This configuration is shown in Figure 1.

2.2 Configuration-With P2P

In this configuration shown in Figure 2, the output power from the installed RTPV array aims to discover the electrical load demand of the house once self-sufficiency of the energy balance is achieved, P2P operation will take place in the community for satisfying the load demand of another prosumer whose load demand is unmet by its own generation.

If an EG exists after satisfying the above conditions, there insiter the remaining EG was charging in the CBB without violating the battery state

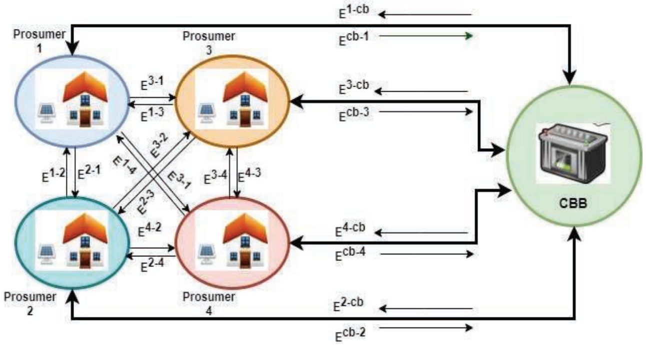

Figure 2 Proposed energy cooperative configuration with P2P.

of charge (SoC) condition or discharge of power/energy from the CBB when unmet demand (UMD) exists in the community zone. Either charging or discharging happen in CBB at an all-time instant without violating the SoC. Otherwise, the battery is disconnected from the energy-sharing operation. In this learning, the energy sharing operation strategy and economic factors are used to optimize the Energy Cooperative system along with the specific operation constraints. The operation strategy for the operation of P2P and CBB is described in the fore-coming section.

3 Methodology

In this methodology, the Energy Cooperative is formed with residential prosumers and CBB. The CBB is active throughout the day with a pro-rated value of energy limits. The following objective highlight the important elements of the cooperative energy sharing technique utilised and used to exert the new one. The system is free from the grid, and there is no tariff – the surplus energy generation by the prosumer charging the CBB. A new model of P2P gives a reliable supply for Energy Cooperative. CBB reduces the cost of storage units for the investors. The proposed methodology is composed of a comprehensive study and gives the optimum size of the energy cooperative system.

3.1 Development of Preliminary Combination

The limiting factor of installation of the PV generator is decided by the daily average load of the house with the availability constraints. Calculation of average daily load demand of the house can be calculated from the annual demand data of the house as follows [33],

$$P^N_{Annual} = \sum_{t=1}^{8760} P^N_{dem}(t) \tag{2}$$

$$P^N_{monthly,avg} = \frac{\sum_{t=1}^{8760} P^N_{dem}(t)}{12} \tag{3}$$

$$P^N_{daily,avg} = \frac{P^N_{monthly,avg}}{30} \tag{4}$$

The capacity of the CBB can be calculated from the following formula, with the consideration of ageing factor A_g, load factor LF and temperature factor T_P of battery [34, 35].

$$C^{CB} = \frac{\left(\sum_{n=1}^{N} P^N_{daily,avg}\right)_{max} \cdot (1 + Ag) \cdot (1 + LF) \cdot Tp}{DoD} \tag{5}$$

Each population of the optimization gives different combinations of the size of the RTPV array and CBB. A different combination size of the Energy Cooperative can be checked by the CESA.

3.2 Cooperative Energy Sharing Algorithm

The hourly solar energy output of the PV array $P^N_{gen}(t)$ in $[kWh]$ for the Nth house(H) at time instant (t) can be estimated as [36].

$$P^N_{gen}(t) = N^N_{PV} \cdot I_{rad}(t) \cdot PR \cdot A \cdot \eta_{PV} \tag{6}$$

where, N^N_{PV} is indicates the number of panels used in the array with panel area $A[m^2]$. Solar irradiation from the sun is taken as $I_{rad}(t)$ in $[kwh/m^2/day]$. The performance ratio of the solar panel is taken as (various from 0.5 to 0.9) 0.7 with 15% panel efficiency η_{pv}.

The PV output power of the Energy Cooperative during the instant of time at $t \in (1, 2, \ldots T)$ and PV energy generation with the time sample $\Delta t = 1hr$ are expressed as:

$$P_{gen}(t) = [P^1_{gen}(t)\ P^2_{gen}(t)\ \ldots\ P^N_{gen}(t)] \tag{7}$$

$$E_{gen}(t) = P_{gen}(t) \cdot \Delta t \tag{8}$$

Total output power and energy by the prosumer at (t) expressed as,

$$P_{gen}^{total}(t) = \sum_{N=1}^{TH} P_{gen}^{N}(t) \tag{9}$$

$$E_{gen}^{total}(t) = \sum_{N=1}^{TH} E_{gen}^{N}(t) \tag{10}$$

The power and energy demand of the Energy Cooperative during the instant (t) are expressed as:

$$P_{dem}(t) = [P_{dem}^{1}(t)\; P_{dem}^{2}(t)\; \ldots\; P_{dem}^{N}(t)] \tag{11}$$

$$E_{dem}(t) = P_{dem}(t) \cdot \Delta t \tag{12}$$

The total power and energy demand of the community consumer during (t) are expressed as,

$$P_{dem}^{total}(t) = \sum_{N=1}^{TH} P_{dem}^{N}(t) \tag{13}$$

$$E_{dem}^{total}(t) = \sum_{N=1}^{TH} E_{dem}^{N}(t) \tag{14}$$

UMD or EG of the houses calculated from the Equations (8) and (12) and from the Equations (10) and (14) net energy in the clusters of prosumers can be calculated. Net Energy is a decision parameter for changing the state of the battery. The positive value of net energy leads to selling power to the CBB, negative net energy flow leads to buying energy from the CBB.

$$Net(t) = E_{gen}^{total}(t) - E_{dem}^{total}(t) \tag{15}$$

$$net^{N}(t) = E_{gen}^{N}(t) - E_{dem}^{N}(t) \tag{16}$$

From the Equation (16) the status of the (H) can be estimated if the value is positive $(EG, net(t) > 0)$ subscriber act as a prosumer (j) or negative $(UMD, net(t) < 0)$ subscriber act as consumer (i) at the instant of the time t.

On or after the argument of net energy flow in the community promises both a configuration can be analysed with its Coopearative Energy Sharing

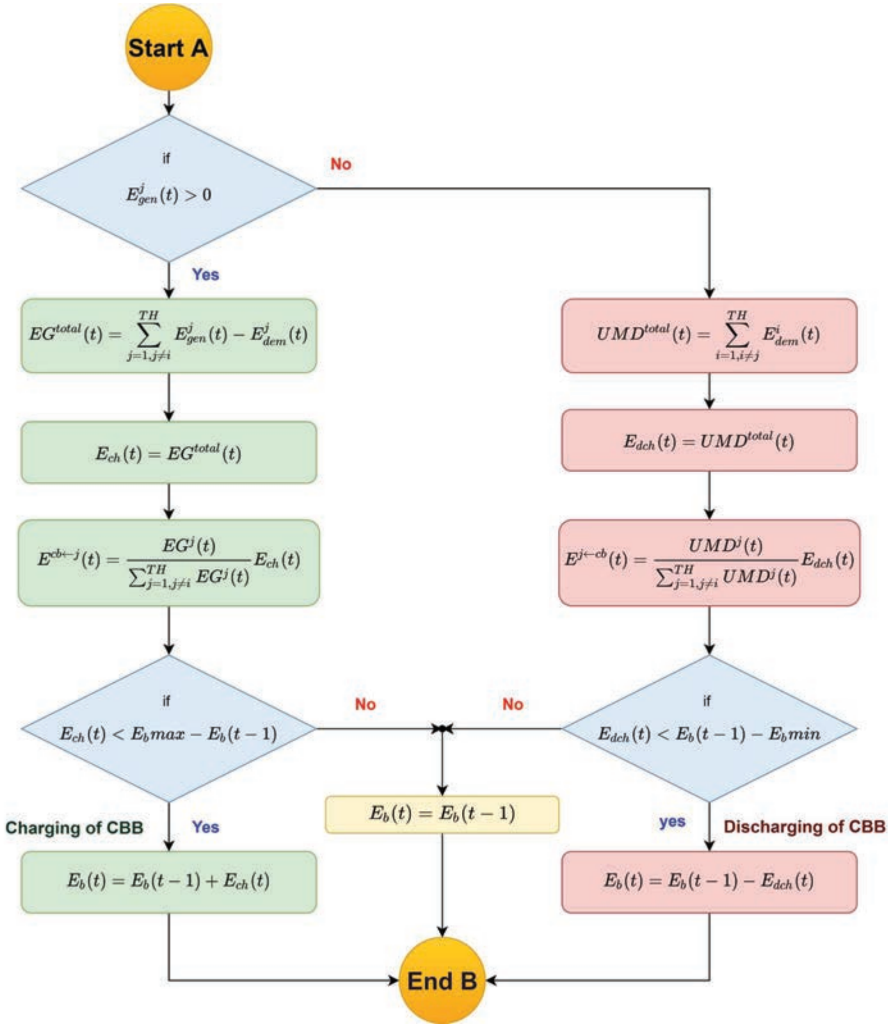

Figure 3 Coopearative energy sharing algorithm for energy cooperative without P2P.

Algorithm. The CESA of each configuration are discussed in the following flow diagram.

Repeat this process for the entire period of time. The cooperative energy sharing algorithm (CESA) starting at point A gives a detailed energy sharing of each actors (both CBB and houses) in the cooperative zone. The end (after point B in flowchart) of the CESA imported energy (IE) and exported energy (EE) of each actor was evaluated.

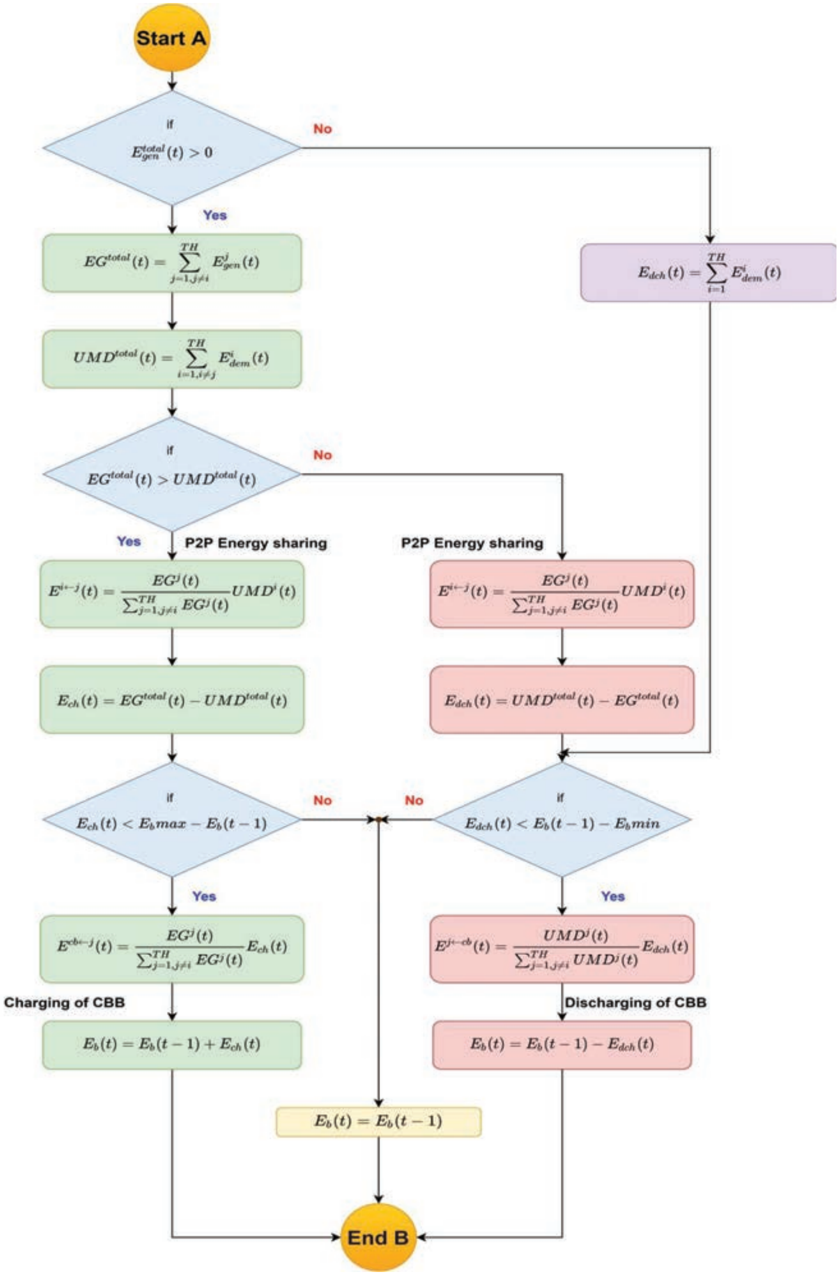

Figure 4 Coopearative energy sharing algorithm for energy cooperative without P2P.

The imported and exported energy of the prosumer for the time instant (t) are expressed as,

$$IE^{N}(t) = \sum_{N=1,N\neq i}^{TH} E^{N\leftarrow j}(t) + E_{dis}^{i\leftarrow cb}(t) \tag{17}$$

$$EE^{N}(t) = \sum_{N=1,N\neq j}^{TH} E^{i\leftarrow N}(t) + E_{ch}^{cb\leftarrow N}(t) \tag{18}$$

The Annual Imported Energy (AIE) and Annual Exported Energy (AEE) of the prosumer are expressed as,

$$AIE^{N} = \sum_{t=1}^{8760} IE^{N}(t) \tag{19}$$

$$AEE^{N} = \sum_{t=1}^{8760} EE^{N}(t) \tag{20}$$

3.3 Reliability Analysis

The final phase of the optimization is called reliability-based optimization. Because of the reliability factors taken as the important constraint for the design of community P2P market component design. The global variable of PSO is taken as the optimum design value of the community P2P components. Various combinations were evaluated by reliablity parameters such as LPSP is investigated for accomplishing operative sizing of an array in the cooperative energy network. The optimum condition met by the combination with the least tolerance can be assigned as an optimum combination of cooperative P2P.

4 Objective Function Formulation

An accepted optimization method known as Particle Swarm Optimization (PSO) was used for the formulated problem of the Energy Cooperative optimization model. In this study, a high number of populations (100) and iterations (100) are considered with (20) runs in order to guarantee a global optimal solution by the PSO algorithm [37].

4.1 Objective Function

The work's main objective is to increase the reliable Energy Cooperative system by optimize the total annual expenditure of the investor who participated in the cooperative energy market with increase the generation of the prosumer – the novel approach is taken as an objective function of this problem. The reliability and various technical constraint should be satisfied with allowable tolerance; for design the size of installed capacity RTPV and CBB in the Energy Cooperative network.

$$\begin{aligned} Min(F_{obj}) = {} & \sum_{N=1}^{TH} (IC_{PV}^{N} + AOMC_{PV}^{N} + AC_{EF}^{N}) \\ & - EE^{N} \cdot \frac{(IC_{PV}^{N} \cdot CRF_{PV} + AOMC_{PV}^{N})}{8760 \cdot CF} \\ & + (IC_{CBB} + AOMC_{CBB}) \\ & - E_{dch} \cdot \frac{(IC_{CBB} \cdot CRF_{CBB} + AOMC_{CBB})}{8760 \cdot CF} \end{aligned} \tag{21}$$

Indices PV and CBB represent the prosumer (PV installation) of Nth number of house and CBB, respectively.

The components of the objective function can be expressed as below. Initial investment cost of the PV generator-based prosumer IC_{PV}^{N} and CBB IC_{CBB} can be expressed as,

$$IC_{PV}^{N} = UIC_{PV} \cdot N_{PV}^{N} \tag{22}$$

$$IC_{CBB} = UIC_{CBB} \cdot N_{CBB} \tag{23}$$

The annual operation and maintenance cost of the prosumer who install the RTPV array and maintenance cost of the CBB is denoted as p. The value of p (generally 2–3) percentage of investment cost of the components, the annual operating and maintenance cost of the prosumer $AOMC_{PV}^{N}$ and the CBB $AOMC_{CBB}$ can be expressed as,

$$AOMC_{PV}^{N} = p \cdot UIC_{PV} \cdot N_{PV}^{N} \tag{24}$$

$$AOMC_{CBB} = p \cdot UIC_{CBB} \cdot N_{CBB} \tag{25}$$

EE^{N} exported energy from the surplus generation can be calculated for the Nth house expressed in the Equation (34). EE_{CBB} exported energy from the CBB otherwise called total discharging energy of the community battery can be obtained by CESA. The energy failure cost is an important parameter for designing the new power project in the economic model. An annualized cost of Energy failure of energy cooperative AC_{EF}^{EC} can be calculated as:

$$AC_{EF}^{EC} = C_{EF} \cdot \sum_{t=1}^{T} ((E_{dem}^{total}(t) + E_{ch}(t)) - (E_{gen}^{total}(t) + E_{dch}(t))) \tag{26}$$

Annual energy failure cost AC_{EF}^{N} calculated by each house can be expressed as follow.

$$AC_{EF}^{N} = C_{EF}^{N} \cdot \sum_{t=1}^{T} ((E_{dem}^{N}(t) + E_{ch}^{cb \leftarrow N}(t)) - (E_{gen}^{N}(t) + E_{dch}^{N \leftarrow cb}(t))) \tag{27}$$

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). The equation for the capital recovery factor is expressed for real interest rate (I) with project year (Y) as per [38]:

$$CRF = \frac{I(1+I)^{Y}}{(1+I)^{Y} - 1} \tag{28}$$

4.2 Technical Constraint

The Energy Cooperative are designed in such a way to meet the following technical constraints.

$$E_{dem}^{N}(t) = E_{gen}^{N}(t) + \sum_{N=1, N \neq j}^{TH} IE^{N}(t) \tag{29}$$

The Equation (29) expresses the total energy supplied by the Energy Cooperative which needs to satisfy its demand at each instant. It is known as demand constraint of the system. The demand of the house can be satisfied by its own generation, otherwise the demand is meet by the imported energy from the prosumers in the community at the time(t) and CBB. These constraint are related to the LPSP of the system.

$$0 < P_{gen}^{N} < (P_{gen}^{N})_{Rated,STC} \tag{30}$$

The power generation of the prosumer by the installed PV array does not exceed its nominal rating of the PV array can be expressed in (30).

$$P^{N}_{daily,avg} < U_{PV} \cdot N^{N}_{PV} < 1.2P^{N}_{daily,avg} \tag{31}$$

$$Installation\_Area^{N}_{PV} < Available\ Area^{N} \tag{32}$$

$$Investment\_cost^{N}_{PV} < Budget\ Limit^{N} \tag{33}$$

The Equations (31)–(33) represents the constraints in PV installation by the prosumers depending on the availablity of limited sources.

$$0.1 < SoC < 0.9 \tag{34}$$

$$E_{B}min < E_{B}, E_{ch}, E_{dch} < E_{B}max \tag{35}$$

$$1 \cdot C^{CB} < U_{CBB} \cdot N_{CBB} < 3 \cdot C^{CB} \tag{36}$$

Where, $U_{PV}, U_{\,CBB}$ are unit capacity of PV pannel and CBB respectively. The Equations (34)–(36) are constraint of CBB. The SoC of the CBB plays a vital role in energy cooperative operation. The SoC of battery should be within this limit for a reliable operation of battery.

4.3 Reliability Constraint

Dependening on the sunshine hours and impulsiveness of solar resources, it has an excessive effect on energy production which leads to a fly-by-night power supply. A cooperative structure is reliable if it can supply the essential power to the demand of the consumer within a specific period. LPSP is broadly used as a reliabilty estimater in standalone renewable energy system, hence is designated, in this work, as reliability measures. The LPSP over the period $T(8760)$ hours of one year takes interpretation the total energy supplying electricity in the cooperative network $E^{total}_{gen}(t) + E_{dch}(t)$ when compared with the demand of the cooperative network $E^{total}_{dem}(t) + E_{ch}(t)$ is given as [38]:

$$LPSP = \frac{\sum_{t=1}^{T} \left(\left(E^{total}_{dem}(t) + E_{ch}(t) \right) - \left(E^{total}_{gen}(t) + E_{dch}(t) \right) \right)}{\sum_{t=1}^{T} \left(E^{total}_{dem}(t) + E_{ch}(t) \right)} \tag{37}$$

The LPSP value of each prosumer can be estimated as:

$$LPSP^{N} = \frac{\sum_{t=1}^{T} \left(\left(E^{N}_{dem}(t) + EE^{N}(t) \right) - \left(E^{N}_{gen}(t) + IE^{N}(t) \right) \right)}{\sum_{t=1}^{T} (E^{N}_{dem}(t) + EE^{N}(t)} \tag{38}$$

The LPSP value is sandwiched between 0 to 1 for the reliable operation of the system enterprise. If the rate of the LPSP is greater than 1, then the system is considered to be undersized. On the other hand, a negative LPSP denotes an oversized system.

5 Case Study

The developed novel optimization model is used for the sizing of Energy Cooperative systems. Geographically isolated areas and rural networks are considered for this case study to evaluate the proposed optimization model. This section deals the with the availability of system parameters.

Figure 4 shows the monthly average load demand data of residential houses [39]. Solar-related data are taken from metrological website [40].

Table 2 shows the space availability of each house and the associated investment in INR. The data has been taken based on assumption by the authors. Table 3 lists out the load demand of the Energy Cooperative prosumers using Equation (2)–(4).

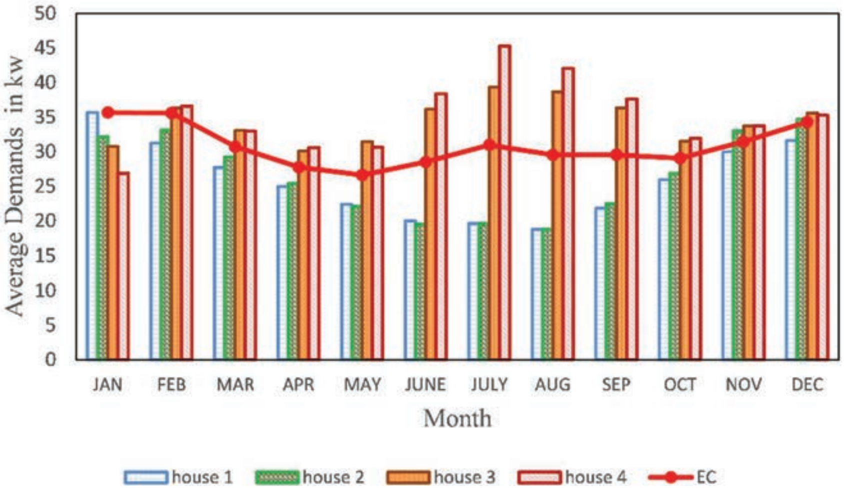

Figure 5 Monthlywise average daily load demand of energy cooperative and its customer.

Table 2 Prosumer resource parameter

Parameter	H_1	H_2	H_3	H_4
Space Availability (m^2)	60	60	80	80
Investment (INR)	2,00,000	2,00,000	2,30,000	2,50,000

Table 3 Load Demand of the houses in the cooperative zone

Load Demand (kWh)	H_1	H_2	H_3	H_4
Annual Net	9268	9967	12730	13126
Daily Average	25.39	26.48	34.87	35.96

Table 4 Technical and economical value of per unit component

Unit	Rating	Unit Cost	Panel Area	Lifespan	η
PV	250 W	8000INR	1.6m^2	25	15%
CBB	10 kWh	52000INR	–	10	85%

Table 4 list the details of the component costs for the unit component used in the system and technical details of the unit component. The values of components used in Energy Cooperative are chosen based on the Indian market prices. Hence, all prices are in Indian rupees (INR). The lifetime of the project is considered as 25 years. The SoC of the battery bank was taken as 0.1–0.9 along with the 5 years of the replacement period.

6 Result & Discussion

The proposed optimization method is applied to a distinctive proposed energy cooperative system with four prosumers and a typical CBB. Numerous analyses are performed in the two different configurations of the proposed energy cooperative system, and the reliability indices were obtained for both configurations.

6.1 Sizing of Energy Cooperative

Reliability is the main factor of standalone systems. The standalone nature of the Energy Cooperative proposed system sizing is done by measuring the LPSP of each prosumer and overall design. Energy Cooperative system RTPV sizing was obtained with 15% panel efficiency, performance ratio of 0.07 with 10% initial charge of CBB was performed using a PSO algorithm in Matlab.

The size of the RTPV array configuration without P2P sizing is lesser as compared with configuration with P2P. In both configurations, reliability also plays a vital role in the sizing of the Energy Cooperative system. The sizing of Energy Cooperative with two configuration results was listed in Table 5.

In configuration without P2P, The size of the PV array of the first prosumer is 5.0 kW_p, the second prosumer is 5.5 kW_p, the third prosumer is

Table 5 Sizing of energy cooperative

Configuration without P2P					Configuration with P2P				
$H1$	$H2$	$H3$	$H4$	CBB	$H1$	$H2$	$H3$	$H4$	CBB
5.0 (kW)	5.5 (kW)	7.0 (kW)	7.5 (kW)	300 (kWh)	6.0 (kW)	6.0 (kW)	6.5 (kW)	6.5 (kW)	260 (kWh)

Table 6 Initial charge influencing of sizing of energy cooperative

	LPSP of Configuration without P2P					LPSP of Configuration with P2P				
% Initial Charge CBB	$H1$	$H2$	$H3$	$H4$	EC	$H1$	$H2$	$H3$	$H4$	EC
10	0.0088	0.0068	0.0110	0.0073	0.0085	0.0011	0.0143	0.0048	0.0053	0.0085
25	0.0080	0.0060	0.0104	0.0069	0.0079	0.0007	0.0142	0.0042	0.0048	0.0080
50	0.0069	0.0049	0.0096	0.0060	0.0069	0.0003	0.0133	0.0035	0.0040	0.0070
75	0.0056	0.0037	0.0087	0.0052	0.0059	0.0001	0.0123	0.0028	0.0032	0.0059

7 kW_p, the fourth prosumer is 7.5 kW_p, and 300 kWh capacity of CBB. Since, there is no energy sharing among the prosumers, the IE and EE are performed between house and CBB. The IE of the house is the same as its energy discharging E_{dch} by the CBB. Similarly, the EE of the houses is charing energy E_{ch} of CBB by houses.

For configuration with P2P, sizing of the first and second prosumer capacity of RTPV is 6 kW_p, for the third and fourth prosumer with a capacity rating of 7 kW_p, along with a 260 kWh capacity rating of CBB. In this case, the IE and EE are different from charging and discharging battery energy by CBB.

The LPSP of each house connected in the Energy Cooperative are obtained as for the second configuration houses from prosumer 1 to prosumer 4 are 0.11%, 1.46%,0.48% and 0.53% respectively, with an overall Energy Cooperative system LPSP of 0.85%. The same overall LPSP of the Energy Cooperative without P2P reaches with the battery bank of $300kwh$ capacity. Capacity of CBB huge for investment point of view.

For configuration without P2P, the number of panels used for RTPV array of first house, second house, third house and fourth house is 20, 22, 28 and 30 panels respectively, its occupancies with $32m^2$, $35.2m^2$, $44.8m^2$ and $48m^2$ respectively along with the 30 units of Battery banks as a common stroage of Energy Cooperative. The configuration with P2P of first and second houses occupies $38.4m^2$ roof space with the 24 panel array in RTPV while, third and fourth houses with the 26 panels in the rooftop occupies the $41.6m^2$ space along with 26 units of battery banks as common storage.

The LPSP depends upon the CBB's initial charge condition. Configuration without P2P is fully controlled by the community run storage alone; the CBB partially controls configuration with P2P Energy Cooperative due to the energy sharing between the prosumers. Table VI lists out the influence of CBB initial charging on how to decide the sizing of the system. The higher initial charge can reduce the size of the RTPV. Designing the Energy Cooperative and the initial battery charge needs to be a primary factor.

6.2 Energy Sharing Study

Figure 6 shows the Energy sharing of Enery Cooperative without P2P. During sunshine hours, the excess generation is transferred to CBB but during non-sunshine hours, when the Energy Cooperative needs power it draws from CBB. The reliabilty of this system is achieved with high value of CBB and low value of RTPV.

Figure 7 shows the Energy sharing of Energy Cooperative with P2P. During the sunshine hours of summer, there are prosumer clusters that do not import power from other power sources and CBB. The prosumer feeds the PV power to the total load demand of the own consumption (self-sufficient) and exports the EG power to the CBB. The prosumer PV surplus power is charging the CBB, and the charging power does not exceed the pre-rated SoC of the CBB at any time. The load power demand is satisfied by discharging the CBB for both configurations in the evening off sunshine hours to morning before adequate sunshine hours, without violating the SoC. Circles A and B indicate the P2P operation, the energy demand of the prosumer met by another prosumer.

6.3 Real-time Admonishment for Energy Cooperative

This study contributes by offering guidelines for residential prosumer renewable energy deployment. The size of the renewable energy source is

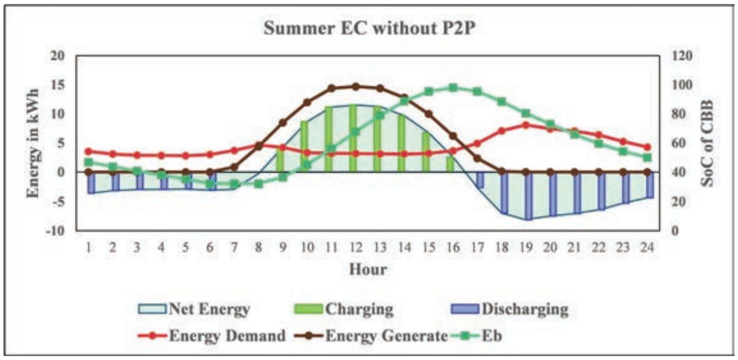

Figure 6 Energy sharing of energy cooperative without P2P.

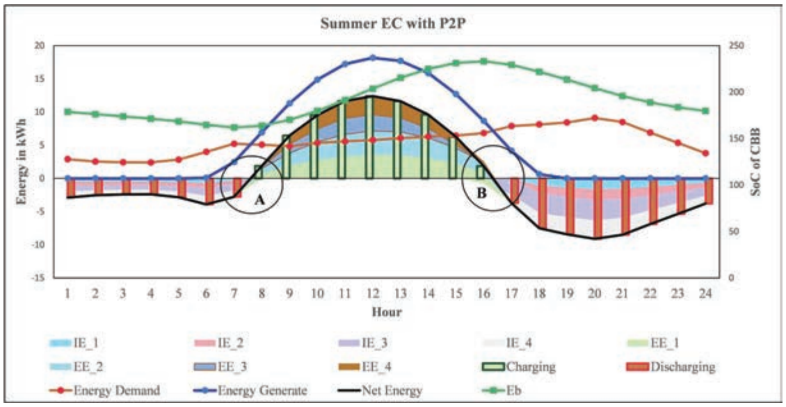

Figure 7 Energy sharing of energy cooperative with P2P.

Table 7 Annual energy sharing of energy cooperative

Energy	Configuration without P2P					Configuration with P2P				
(kW)	$H1$	$H2$	$H3$	$H4$	CBB	$H1$	$H2$	$H3$	$H4$	CBB
AEE	4639.75	5248.26	6234.70	6822.38	22981.49	6385.62	6229.43	5532.12	5399.03	23156.27
AIE	4952.53	5097.94	6386.34	6544.66	22945.10	4867.60	5051.65	6677.64	6929.891	23175.68
AEF	111.71	89.67	197.85	138.31	–	17.65	232.80	88.30	98.39	–

determined by the amount of rooftop space available, the investment budget, and the daily average electricity use for the investor who does not have access to storage. The reliability of the prosumers might be decreased if the PV array is placed without its storage unit and this can be overcome by CBB. Assuming the prosumer does not know about the enhancing reliable consumption without spending on storage. The suggested Energy Cooperative provides an answer to the preceding question. In such instances, only a PV system with a CBB subscription was suggested as being more beneficial. When this unique P2P business model is implemented between prosumers in Energy Cooperative, it allows for more flexible energy transfer between residential houses. Owning storage units is prohibitively expensive for homes with independent systems.

7 Conclusion

This study investigates the optimum size of RTPV and CBB in an Energy Cooperative. It is formulated without P2P and with P2P energy sharing configuration with reliability constraints. The P2P energy sharing involved in the

Energy Cooperative system gives an adequate sizing of the prosumer's point of view. The result shows that Energy Cooperative with P2P can produce sufficient energy because the dumping of power is less in this configuration. A novel CBB is a single community-run storage unit that can reduce the burden of prosumer own storage constraints technically and economically. The congifuration with P2P differene between charging to discharing is more optimal. Deployment of renewable energy is efficiently carried out in energy sharing with P2P operation. It will produce a low annual expenditure with a high benefit market from the investor's point of view. As a result, both configurations result in a well-structured Energy Cooperative system. An innovative CBB encourages Energy Cooperative homes to implement renewable energy sources in a consistent manner.

- The energy failure cost reduced due to the energy sharing among the prosumer various 30% to 80%.
- Off grid network of Energy Cooperative can produce 8.5% of LPSP.
- The space occupied by the PV array varies from 52% to 65% in both the configurations, utlility space of the prosumer was also optimized.
- Community battery bank reduces the installation cost of prosumer by around 40- 60%.
- The introduction of P2P in Energy Cooperative will overcome AIE bigger than AEE in the non-P2P arrangement. Energy Cooperative with P2P network stores around 20kW of annaual energy in CBB.

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