Mitigation of Network Congestion Resulting from On Grid PV System

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Abstract— Grid congestion problem is an event where the existing transmission and/or distribution lines are not capable to accommodate all required load. Congestion can be appeared in many ways, among this ways the surplus of the photovoltaic systems (PV) system. In this paper, the congestion problem resulting from the PV systems surpluses can be solved by disconnecting one or more PV unit with its client from the grid. This paper will present the problem solving by manipulating it as Knapsack Problem with proposed Greedy Algorithm (GA). The paper proved that, the greedy algorithm cannot find the optimum solution comparing by using another optimization technique, "Particle Swarm Optimization Technique (PSO)". The results find that the PSO is better than the GA. In the meantime alleviating the congestion by disconnection the client from the grid produces islanding mode with its relative problem. Several researches handled the islanding mode problem. Avoiding this mode can be done straight forward by proposed cancelling the disconnection process for the selected PV units controlling the output power to be stored locally. In which this avoiding will be investigated as a future work.

Keywords— Network Congestion, On Grid PV Surpluses, Greedy Algorithm, Knapsack Problem, Particle Swarm Optimization Technique (PSO).

I. INTRODUCTION

Congestion is a state where there is insufficient capacity to transport all dealings at the same time due to the few unforeseen emergencies. Generally, it appeared in both regulated and deregulated power system but more occurs in deregulated way because of opposition in energy producers and consumers [1]. The congestion may be appeared in several ways: Week organized relation between generation and transport utilities, installation of the customer may increase the fault or current rating of network equipment, sudden increase in load demand, power surpluses may be created by installed solar units.

Thus, it is necessary to manage the problem of congestion to determine the priorities of transactions and a commitment to a schedule such that will not overload the network. The ways to manage congestion for distribution networks can be classified into two groups, indirect control groups and direct control groups [2]. The indirect groups consist of dynamic tariff, distribution capacities, and shadow price. The direct control groups consist of system reconfiguration, control of reactive power, and control of active power. Optimal location of the generators and scaled power system networks had been reviewed in [3] as a system reconfiguration for maximizing the congestion relieving in which the appropriate size and location of the generating unit distribution are necessary. Some of the available congestion management techniques based on power flow tracing approach for selection and generation rescheduling have been presented in [4]-[5]. In [6] the optimal rescheduling of active powers of generators utilizing Particle Swarm Optimization (PSO) and Chaotic Particle Swarm Optimization (CPSO) has been solved. Other option to manage congestion is to operating Flexible AC Transmission System (FACTS) devices on transmission lines. This operation of FACTS devices considers both technical and economic considerations which are presented in [7]-[8]. Congestion in the transportation lines can be mitigated by operation and planning of connected distributed generation systems [9]. Also, networks congestion may occur by the penetration of Distributed Energy Resources (DERs) at load bus such as (PV systems), wind power systems (WPS), Electric Vehicle (EV) and heat pump (HP) in which this penetration represents a big challenge to the grid planners and operators. Recently, the congestion was studied due to the inverse power of solar panels in the distribution network especially after creation of feed in tariff policy. This policy is created to develop active investment in and production of renewable energy sources. It allows the government to ensure a certain price for producing energy to encourage the productivity in the renewable energy area. The purpose of the feed-in tariff is to provide certainty in prices for long-term contracts. The electrical distribution companies are committed to buy the produced electricity from Renewable Energy power plants at the prices declared, 25 years for the PV plants, and 20 years in the wind plants. As a result, the Egyptian government has put the necessary policy and procedures for implementing the projects of the Renewable Energy Feed-in Tariff for the PV scheme from the generated power capacity point of view as follows:

- Regulations for implementation of Renewable Energy Feed-in Tariff projects up to 500 kW.

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- Regulations for implementation of Renewable Energy Feed-in Tariff projects above 500 kW.

The congestion due to PV surpluses can be solved by several ways such as: sell the surpluses when consumption is low, store surplus energy as much as possible for later use, and disconnect number of investors with its PV units from the grid. In this research a proposed algorithms will be presented to disconnect number of investors with its PV units among clients from the grid for solving congestion in the distribution grid.

II. Knapsack Problem-KP

Knapsack problem is a combinational optimization problem which has been studied widely during the past four decades [10]-[11]. In such problems, we try to maximize (or minimize) some quantity while satisfying some constraints. The Knapsack Problem can be presented as follows: "suppose taking a trip by carrying a backpack which it has a certain capacity. Given a set of elements, each element has some weight and some value, define the number of each element to include in a backpack in which the total weight is less than a certain limit and the total value is as much as possible" [12].

Vector $w = (w_1, w_2, \dots, w_n)$ contains n items' weights, and other vector $v = (v_1, v_2, \dots, v_n)$ contains their values, where v_i and w_i are integers. To find other n-dimension decision vector $x = (x_1, x_2, \dots, x_n)$ make the total maximum value under the limit of knapsack. The related math equation can be described as following:

Maximize:
$\sum_{i=1}^{n} v_i x_i$
Subject .to:
$\sum_{i=1}^{n} w_i x_i \leq W$
$x_i \in \{0,1\}$, $i=1,2,\dots,n$

The i^{th} item put into knapsack if $x_i = 1$, the i^{th} item not put into knapsack if $x_i = 0$. So the problem called the 0-1 knapsack problem. In this problem, fraction amount cannot be taken in which the items must be taken or left totally.

III. Problem formulation and proposed knapsack greedy algorithm

We consider N client with installed PV solar units. Each client is symbolized by n, n = 1, 2,. . .,N, and its PV unit is symbolized by X_n. client n may (not) consume power in KW through solar power generation, its demand symbolized by $P_{D,n}$. The power surplus from client X_n is (not) found when the produced power in kW is (lower) greater than it is needed, the surplus is an integer and symbolized by $P_{S,n}$.

In the distribution grid the congestion issue can be considered as a type of knapsack problems. Which the client either remains joined to the grid or disjointed from the grid. Therefore, we take a 0/1 KP in which the client n is off the grid the $X_n = 0$ and the client n is on the grid the $X_n =$ 1. Then, the total number of joined clients can be calculated:

$$U = \sum X_n \quad , x_n \in \{0,1\} \tag{1}$$

The goal is to maximize the number of joined clients corresponding to a certain capacity that the grid can accommodate the surpluses of joined clients.

$$\text{Maximize:} \quad \sum X_n$$

$$\text{Subject .to:} \quad \sum P_{s,n}.X_n \leq P_{ATC} \quad , x_n \in \{0,1\} \tag{2}$$

From power point of view, when a large number of clients joined to the grid a large number of investor will use their solar power, also can be sell the power surplus to the grid.

Also maximize the value of total power demand while meeting the capacity requirement is our target

$$\text{Max:} \quad \sum P_{D,n}.X_n$$

$$\text{S .t:} \quad \sum P_{s,n}.X_n \leq P_{ATC} \quad , x_n \in \{0,1\} \tag{3}$$

Residual capacity of the physical transmission network is measured by index (ATC) "Available Transfer Capability" [13]. It has been an implement used to manage congestion for power marketers business in rival electric market. The ATC value is given by:

$$ATC = TTC - TRM - CBM - ETC \tag{4}$$

The Total Transfer Capability (TTC) is the maximum quantity of energy that can be passed over the grid in a reliable way while satisfying all safety constraints, i.e., voltage, thermal, and stability boundary; Transmission Reliability Margin (TRM) is the quantity of transmission capacity to guarantee the grid is safe under reasonable limits of uncertainties in network conditions and (ETC) Existing Transmission Commitments, Capacity Benefit Margin (CBM) is the quantity of transmission transfer capability booked up by load serving entities for generation reliability requirements, it booked up for emergency when energy generation is not enough in one zone which needs to be provided with purchased energy from other zones [14].

From other hand and in our study and expectation for the future after spreading the feed in tariff policy, selling of power surplus will be by auctions. This means, the clients with lower tariff will remain connected, the higher are disconnected. Consequently, the proposed algorithm will achieved the ultimate target of having less power surplus flowing to the network, more units joined to the grid and minimum tariff for the joined units. Greedy algorithm is proposed to solve the Knapsack Problem (KP).

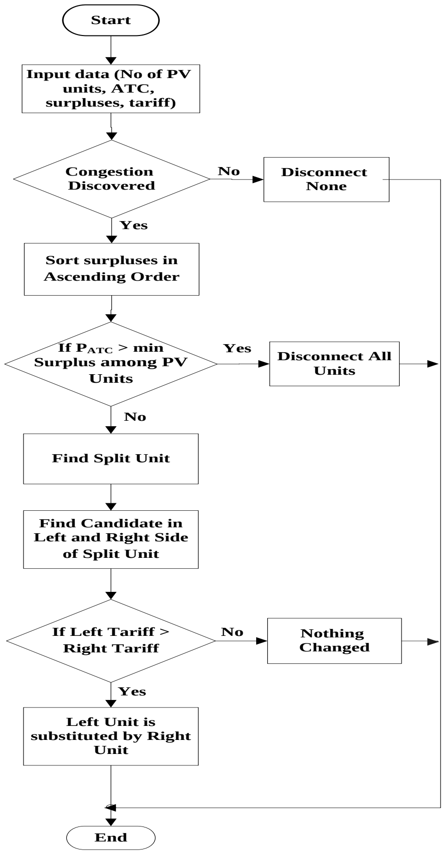

Fig. 1. Flow chart for proposed knapsack greedy algorithm

Fig.1 shows the greedy algorithm constructed which data information about the ATC and clients (number of clients (PV units), surpluses and tariff) have been collected. While the network is not congested no clients are disconnected. The (overload) congested condition of the network is finding out when subtracting the capacity boundary by the total surplus of N clients.

$$P_o = \sum P_{s,n} - P_{ATC} \quad (5)$$

By discovering the congestion (i.e, $P_O > 0$), the surpluses are arranging in ascending order.

$$P_{S,1} \leq P_{S,2} \ \ldots\ldots \leq \ P_{S,n} \qquad n \in N \quad (6)$$

If P_{ATC} more than the minimum surpluses, all clients will be disconnected. After some iteration when congestion is detected, i.e.,

$$\sum_{n=1}^{s-1} P_{s,n} \leq P_{ATC} \ \text{ and } \ \sum_{n=1}^{s} P_{s,n} > P_{ATC}, \quad n=1, 2, \quad (7)$$
$$n=s, s+1, \ldots$$

Observe that the capacity constraint will be exceeded if the $P_{S,s}$ was added. Unit (client) S is set to be the split one. Which divided the solution to n = 1; 2; ; s –1(left) and for n = s; s +1; . . . ; N (right).

The split surplus value is defined as $P_{S,s}$. By adding the split surplus value the overflowed power (P_E) will be known, the number of candidate units in left and right of split unit will be considered for a one-to-one substitution.

$$P_E = \sum_{n=1}^{s} P_{s,n} - P_{ATC} \quad (8)$$

IV. CASE STUDY

By using the Electrical Transient Analyzer Program (ETAP), a case study had been modeled for consumer demand of 600kw (8consumers) feeding from power transformer (1000KVA), six of consumers with load power (200kw) owned PV units accommodate to ATC (200kw) as in Fig.2. When load flow of the system is implemented, the power of the PV units can meet the load of consumers. The excess power (surpluses=216kw) can return to the grid which they to feed other users. Because the line capacity cannot accommodate the residual surpluses which is above the ATC value, disconnecting some of the consumer is our process for congestion avoidance. By applying the proposed knapsack greedy algorithm using a Matlab program as shown in Fig.3, the inputs will be surpluses in KW, the ATC in KW and the tariff in pilasters.

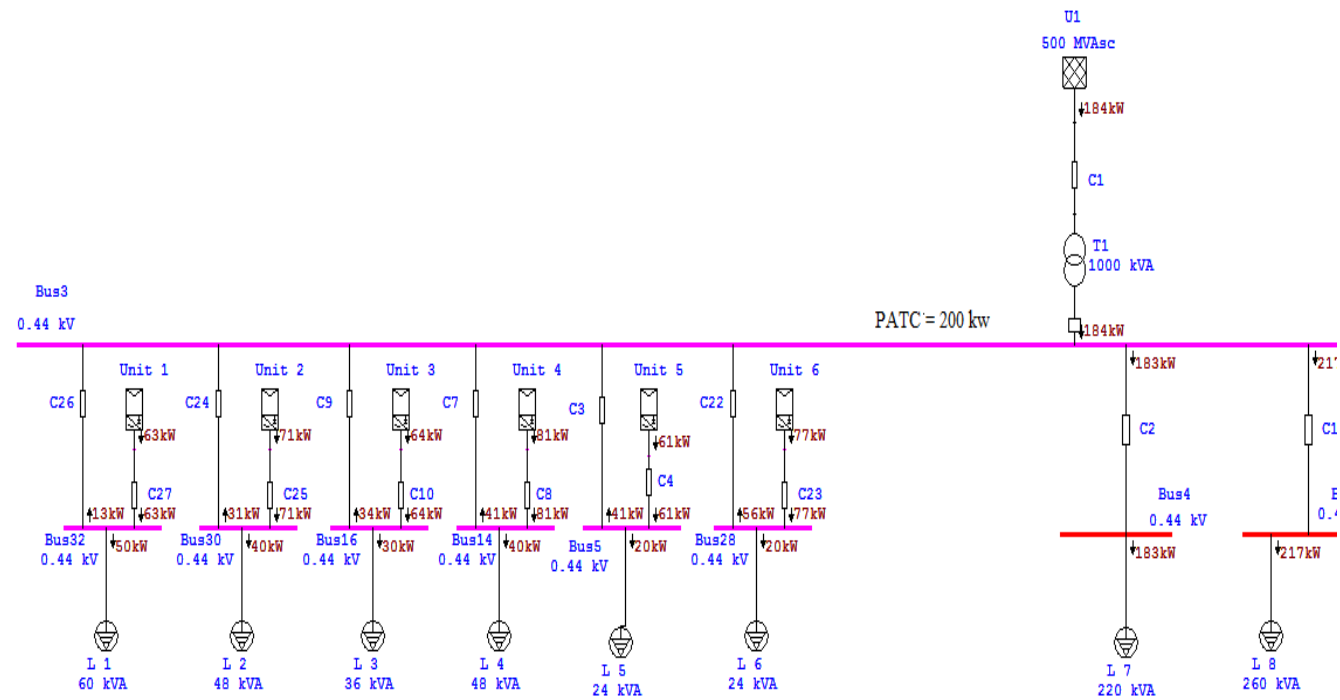

Fig. 2. Case study load flow

```
N=6;                                 % Number of units
pATC=200;                            %Available transfer capability
psn=[13 31 34 41 41 56 ];            %Surpluses in each units (n)
Tariff=[40 60 60 70 80 120];         %Tariff of each units
ps=sum(psn);
po=ps-pATC;                          %over load power
 for y = 1:n
  units(1,y) = y;         % Assign index for each tested candidate
   if patc>=ps
       units(2,y) = psn(y);   % Get its associated surplus value
   end
 end
units
if po<=0
else
psi=sort (psn);                      %Sort surpluses in ascending
```

Fig. 3.Sorting surplus in ascending order

```
for i=1:N
            if psi(i)<=c
                c=c-psi(i);
                x(i)=1;
            else
                s=i          %split unit
                break
            end
        end
    end
end
w=s-1;                          % The last unit to be selected
pss=0;
for j=1:s
    pss=pss+psi(j);
    end
z=pss;
pE=z-pATC                       % over load power
```

Fig. 4.Finding the split unit

Fig 4 shows applying the algorithm for the split unit which the unit 6(whose surplus value is 56) may be found to be the split one. Adding the split surplus value to the aggregation of first five units would make the sum 216 and result in overload.

The algorithm calculates the overflowed power (P_E) value. While knowing P_E=16, this means that any surplus values more than or equal to 16 in left side of the split unit (i.e., units 2) are qualified for substitution which presented in Fig. 5. Unit 2 whose surplus value is 31 gets the lowest tariff value among others (60 pt).

```
for d = 1:w
      leftCand(1,d) = d;                % List for each tested candidate
      if pE <= psi(d)
            leftCand(2,d) = psi(d);          % Associated surplus value
            leftCand(3,d) = Tariff(d);       % Associated tariff value
            else
            leftCand(2,d) = NaN;           % Set NaN value for the un
qualified unit
            leftCand(3,d) = NaN;           % Same here
      end
end
leftCand        % Display the Unit table for Left-Hand candidates
```

Fig. 5. Determination the number of candidate units in left

Fig.6, shows applying the algorithm for finding the units in right side of the split unit that satisfy the requirement. The outcome displays the candidates in right side to become unit 6. As a result, unit 6 is replace by unit 2 whose tariff is the smallest, without override the limit of the capacity, i.e., $\sum_{n=1}^{5} P_{s,n} = 160 \leq P_{ATC}$.

```
lastUnit = length(psn);            % Equal to variable 'n'
count = 1;
for i = s:last unit
      RightCand(1,count) = i;          %Index for each tested candidate
            if (psi(i)-psi(s)) <= (psi(leftCandId) - pE)
            rightCand(2,count)= psi(i);       % Get its associated surplus
            rightCand(3,count) = tariff(i) ; % Get its associated tariff
                  else
            rightCand(2,count) = NaN;        % But NaN value for the
   unqualified unit
            rightCand(3,count) = NaN;        % Same here
           end
      count = count + 1;
end
RightCand                  % Display the unit table for right-hand candidates
```

Fig. 6. Determination the number of candidate units in right

The results of applying the proposed knapsack greedy algorithm are show in Table 1 which shows the selected units to be disconnected. It's shown that unit (6) is selected to be disconnected at P_{ATC}=200kw keeping more units connected to the grid and minimum tariff for the connected units.

Table I. Selected Unit by Greedy Algorithm at (P_{ATC} =200KW)

***Units* Number**	***Surpluses* (kw)**	***Tariff* (pt)**	***Selected units***
1	13	40	1
2	31	60	1
3	34	60	1
4	41	70	1
5	41	80	1
6	56	120	0

In another case as shown in Table 2, for P_{ATC} =60KW, unit 3 is found to be the split one (with surplus value is 30) while the first two units have sum of surplus values of 50. Adding the value of split surplus will make the total 80 and result in overload. by knowing PE =20, unit 1, 2 are determined to be candidate in left side of split unit. Subsequently, the outcomes when searching for candidates in right side of split unit are units 3, 4. As a result, the selected units are 1, 4 without override the limit of the capacity i.e,

$$P_{S,1} + P_{S,4} = 60 \leq P_{ATC}.$$

In this situation the selecting units are 1and 4 whose tariff 60, 20. But it is obvious from the Table 2 that, when selecting units 2, 3 without override the limit of the capacity, i.e., $P_{S,2} + P_{S,3} = 60 \leq P_{ATC}$, whose tariff, 30, 40 is the better, that the greedy algorithm is not optimum solution. So we will present the particle swarm optimization algorithm for searching the best solution.

Table. II. Selected Unit by Greedy Algorithm at (P_{ATC} = 60KW)

***Units* Number**	***Surpluses* (kw)**	***Tariff* (pt)**	***Selected units***
1	20	60	1
2	30	30	0
3	30	40	0
4	40	20	1
5	60	70	0
6	70	40	0

V. PARTICLE SWARM OPTIMIZATION (PSO)

Particle swarm optimization algorithm was developed by Kennedy and Eberhart [15]. It is inspired by the social movement of a swarm of birds searching for food. The algorithm is simple, easy to implement, powerful and robust [16]. The algorithm works by the presence of a swarm of particles, these particles are moved to a good region searching for a food. The particles movements are guided by their own best known place with definite speed in the search-space. The velocity can be regulated dynamically due to its personal flying experience and flying experience of other particles. Better positions are discovered; these will then come to guide the movements of the swarm. The particle have two capabilities, their memory of their own best position - local best (P_b) and knowledge of the global or their neighborhood's best - global best (g_b) [17]. The position and velocity of particle i^{th} are represented as $X_i = (x_{i1}, x_{i2}, x_{iD})$ and $V_i = (v_{i1}, v_{i2}, v_{iD})$, the best position is called p_{best} and the best position among the whole population called g_{best}. Particles update their speeds and positions according to (8) and (9) until find two extreme points as shown in Fig.7.

$$v_i(t+1)=w\ v_i(t)+c_1(p_{best}(t)-x_i(t))+c_2\ (g_{best}(t)-x_i(t)) \quad (9)$$

$$x_i(t+1)=x_i(t)+v_i(t+1) \quad (10)$$

Where,
i is the particle index
w is the inertial coefficient
c_1, c_2 are acceleration coefficients, $0 \leq c_1, c_2 \leq 2$
r_1, r_2 are random values ($0 \leq r_1, r_2 \leq 1$)

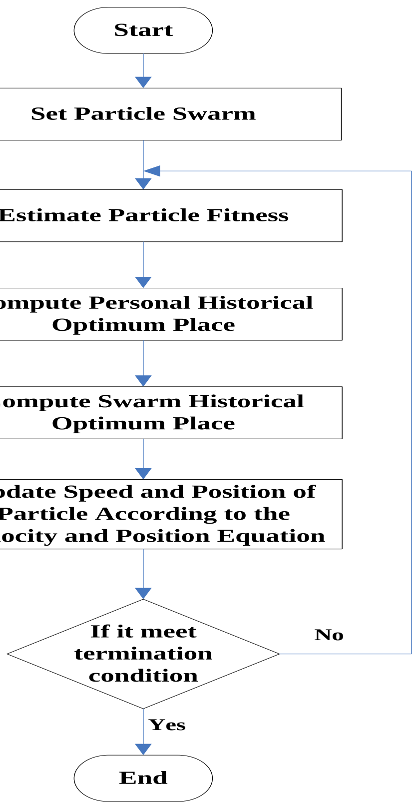

Fig. 7.Flow chart depicting the general PSO algorithm

By applying the particle swarm for our problem for PATC ≤60 comparing with greedy algorithm is shown in Table 3.

Table. III. Case 1, Selected Units by PSO and GA.

***Units* Number**	***Surpluses* (KW)**	***Tariff* (pt)**	***Selected units by greedy***	***Selected units by PSO***
1	30	20	1	1
2	30	30	1	1
3	40	40	0	0
4	50	20	0	0
5	60	70	0	0
6	70	40	0	0

Table 3 shows the same selection for the both algorithms. When applying PSO for other surpluses and tariffs with the same $P_{ATC} \leq 60$ and comparing with greedy algorithm as shown in Table 4. The result shows that the selected units with PSO are with minimum tariff more than the units selected with greedy algorithm.

Table. IV. Case2, Selected Units by PSO and GA.

***Units* Number**	***Surpluses* (KW)**	***Tariff* (pt)**	***Selected units by greedy***	***Selected units by PSO***
1	20	60	1	0
2	30	30	0	1
3	30	40	0	1
4	40	20	1	0
5	60	70	0	0
6	70	40	0	0

VI. Drawbacks of Units Disconnection and Islanding

Once congestion is detected in the power network, the notification signal packets will be sent in accordance with the above described selection schemes to isolate the associated consumer from the grid. This mode is called islanding. The system is called islanding when the distribution system isolated electrically from the remainder of the power system, after it energized by DG connected to it [18]-[19]. Although there are some profits of islanding operation such as continuity of supply at islanded zone, there are some of drawbacks as well. Some of them are:

- When the breaker has opened, the DG feeds the neighborhood load, any mismatch in real or reactive power between load and generation results the voltage magnitude and/or angle to diverge from the voltage of the grid. Subsequently, a large voltage appears across the open breaker. When the device closes again this voltage drives an inrush current, which flows between the grid and DG the. The inrush current leads to damage various components in distribution network.
- Large mechanical torque is usually produced as a result of out of phase reclosing of DGs when the networks are reconnected [20].
- In the island the utility has no control over the frequency and voltage, so there is a possibility of damage to the equipment of the customer.
- Islanding may interfere with restoration of normal services by the utility.

Therefore, the ability to detect islanding is very necessary for distributed generators.

VII. Conclusions and future work

In transmission lines there is a technical problem called congestion, this problem happened due to insufficient transfer capacity and line outages in the systems. Similarly, the problem is expected to exist in the distribution network when the number of solar units increases and when energy consumption is decreased. We formulate the congestion which resulting from the solar surplus in the distribution network as one type of knapsack problems (0/1 KP) and solve it by greedy strategies. We achieve our goals by maximizing the number of joined units on the grid and minimum tariffs for connected units. By using the greedy algorithm we find the algorithm can't get the optimum solution. We find that the proposed greedy algorithm is not the best, hence the particle swarm optimization technique is provided as optimum solution. During the connection and disconnection of the client the system will inter an islanding mode with its drawbacks. In the future work we will study the effect of islanding on the network and how to overcome this phenomenon. And provide a new technique avoiding the islanding and controlling the surpluses to be stored in different schemes.

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