International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-5, January 2020

Determination of Optimal Energy Sharing Pair for Local Energy Community

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***Abstract**: This paper presents a method for the maximization of Renewable energy production at the Prosumer (Seller) premises considering the technical constraints, enabling energy sharing with the neighbors in a prosumer based community. In this method a transaction is simulated between the Prosumer (Seller) and Prosumer (Buyer) and between Prosumer (Seller) and consumer by the aggregator and the number of congested lines / cables is identified to determine the optimal energy sharing pair. The technique has been tested on a benchmark low voltage distribution system and the results are presented.*

Keywords : Prosumer, consumer, peer to peer, energy trading.

I. INTRODUCTION

According to Energy access outlook more than 14% of global population lacks access to electricity [1]. The national grids are not able to suffice the needs of growing electricity demands with conventional generation. As well as they are also not able to reach all the electricity consumers due to financial and technical reasons. The three major components of power sector are generation, transmission and distribution [2]. Generation, transmission and distribution are bundled together in a Vertical Integrated Utility (VIU). Till the end of 18th century, most of the country's national grid leans on VIUs for their electricity demand. In the early 1900s, restructuring of electricity sector takes place in the generation sector allowing bulk independent power producers to penetrate the electricity market with the focus of maintaining the growing consumer demand. One rapid consequence of restructuring the power sector at generation level is that the bulk consumers at transmission and sub transmission level are able to make direct commercial contract in a unidirectional way with the bulk independent power producers. But the increasing population and growing electricity necessitates restructuring at all levels in the power sector. Due to administrative and technical reasons restructuring at transmission level is not viable and is not implemented anywhere globally.

In the power sector value chain, distribution system is the most vital component as it links directly with the consumers. Restructuring at distribution level has motivated the Distributed Energy Resources (DERs) to penetrate in to the

evolved power system over years in the for micro or mini grids to satisfy the consumers at distribution level itself [3]. The simultaneous advent of Information and Communication technologies (ICTs) with the penetration of DERs has led to the progressive transition of the role of consumer [4]. As most of the DERs are sporadic in nature, it is difficult to fit in the distribution system. The injection of DERs into distribution systems also results in instability [5]. The consumers who generate electricity are called as prosumers. The prosumers in the retail electricity market at distribution level will inject their surplus energy into the utility grid. The customers will procure energy from the utility. In this mechanism of energy sharing at distribution level the prosumers and consumers are restricted with less number of choices. Though restructuring at distribution level has reduced the burden on utility to a certain extent, the market participants suffers with price gap and number of options [6].

The consumers have transformed their role from not only consuming electricity but also by generating electricity within their premises by using DERs, for instance solar rooftop PV. In the conventional restructured trading model the prosumers and consumers can trade only with the utility.

This necessitates a new energy management model at distribution level where the prosumers and consumers within a local energy community can trade/share energy among themselves [7, 8] called as Peer to Peer (P2P) energy trading/sharing . With the advancement in storage technologies, the surplus energy in the prosumer premises can be stored in the battery and can be made available for themselves or other consumers [9, 10]. In P2P energy trading accurate prosumer – consumer integration is mandatory [11 – 13]. Each prosumer and consumer in P2P enabled energy community act as individual entity and compete among themselves and with the utility for better trade and price [14, 15].

Manuscript published on January 30, 2020.
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In this paper, the maximum penetration level of prosumer is determined by maximizing the rooftop solar PV at the prosumer premises and the optimal energy sharing pair are determined using powerworld simulator without violating the technical constraints.

II. PROBLEM FORMULATION

The objective is to determine the energy sharing pair in a prosumer based community at low voltage distribution level. The optimal energy sharing pair is the one when the energy transaction is done between the prosumer and consumer no technical constraints like the thermal constraints of the line/cable and voltage limits are not violated.

A. Selection of Prosumer (seller)

The objective function to maximize the rooftop solar PV generation at the prosumer premises P_G^{PV} is as follows:

Maximize

$$P_G^{PV} \tag{1}$$

Subject to

Equality constraints

The basic load-flow equations are modified to include the power generation by rooftop solar PV is as follows:

$$(P_{Gi} + P_G^{PV}) - P_{Di} = \sum_{j=1}^{N_P} |V_i||V_j||Y_{ij}|\cos(\delta_i - \delta_j - \theta_{ij}) \tag{2}$$

$$Q_{Gi} - Q_{Di} = \sum_{j=1}^{N_P} |V_i||V_j||Y_{ij}|\sin(\delta_i - \delta_j - \theta_{ij}) \tag{3}$$

Inequality constraints

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \tag{4}$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \tag{5}$$

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{6}$$

$$S_{ij} \le S_{ij}^{\max} \tag{7}$$

Where $P_{Gi}^{\min}$ and $P_{Gi}^{\max}$ are the minimum and maximum real power generation limits. $Q_{Gi}^{\min}$ and $Q_{Gi}^{\max}$ are the minimum and maximum reactive power generation limits. The minimum and maximum voltage limits at the nodes are $V_i^{\min}$ and $V_i^{\max}$. The power flow in line/cable thermal S_{ij} and the maximum thermal limit of the line/cable is $S_{ij}^{\max}$.

B. Selection of Consumer (buyer)

A transaction is simulated within the benchmark low voltage distribution system with the prosumer - seller at the location j and the prosumer - buyer at the location k, where k and j is varied from 1 to N_P and j is not equal to k. The Prosumer – seller at the bus j has to supply the additional load demand at bus k through the existing distribution system without violating the network constraints. The power flow program is run with utility generator being held at fixed optimal setting of base case using RPF.

The *objective function* is to identify the best transaction pairs within the community.

Subject to

$$(P_{Gi} + P_{Gj}) - (P_{Di} + P_{Dk}) = \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}|\cos(\delta_i - \delta_j - \theta_{ij}) \tag{8}$$

where

P_{Gj} Prosumer - Seller power at jth location (P_G^{PV})

P_{Dk} Prosumer - Buyer power at kth location

Here $P_{Gj} = P_{Dk} + P_{loss}$

where

P_{loss} Line losses in MW

The power flows on all the lines/cables are calculated and are compared with the respective power transfer limits $S_{ij}^{\max}$ of each line/cable in order to identify the lines which are overloaded. The buyer is selected based on the criteria with minimum number of lines gets overloaded while simulating the transaction j-k.

III. A BENCHMARK MULTI – FEEDER LOW VOLTAGE MICROGRID NETWORK

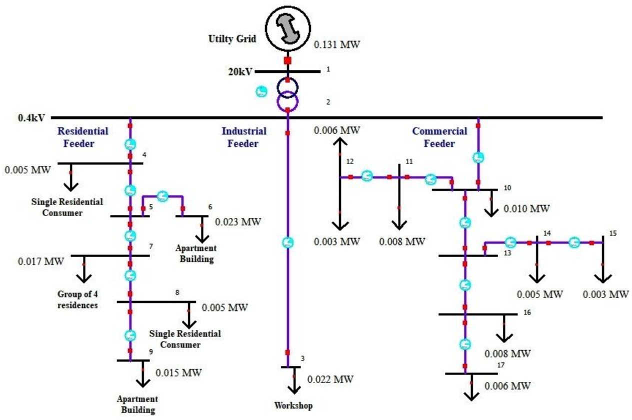

Fig.1. A typical benchmark multi feeder low voltage microgrid.

A typical benchmark multi feeder low voltage microgrid network is shown in Fig.1. It consists of Residential, Industrial and Commercial feeder. The residential feeder is an overhead transmission line which serves two numbers of single residential consumers, two numbers of apartment building and a group of 4 residences. The industrial feeder is an underground cable which feed the workshop. The commercial feeder serves both single phase and three phase loads [16]. The typical benchmark multi feeder low voltage microgrid network is created in powerworld simulator.

Powerworld simulator is an effective and interactive power system tool to analyse the competitive electricity market with the penetration of DERs [16]. The residential, industrial and commercial consumers are connected to the utility grid at Point of Common Coupling (PCC). In this paper the benchmark system is considered as a local energy community in which all the prosumers and consumers are equipped with bidirectional meter to assess their power injection / withdrawal over a period of time [17].

IV. RESULTS AND DISCUSSION

The different types of consumers fed by residential, industrial, and commercial feeders in the benchmark system are attached with rooftop solar PV generation at their premises, one at a time considering them as prosumer. The rooftop solar PV generation is maximized using powerworld simulator without violating the technical constraints as listed from equation (4) to equation (7). The rooftop solar PV generation at the prosumer premises, P_G^{PV} is incremented in steps of 0.001 MW till the optimum is reached using power world simulator without violating the network constraints. The prosumers are then arranged in the order of maximum PV penetration. The prosumer with maximum PV penetration in the order is taken as Prosumer (Seller). Table 1 shows the result of the maximum penetration level of each consumer acting as a prosumer without violating the network constraints.

It is evident from table 1 that at location no 8 (single residential consumer) the PV penetration is maximum and is selected as an optimal prosumer (Seller). The power injected at location number 8 should be withdrawn as load at some other location within the local energy community.

Table I: Level of PV penetration

Location No	PV Generation (MW)	Increased PV Generation (MW)	Level of PV Penetration (MW)
8	0.004	0.211	0.207
6	0.02	0.225	0.205
17	0.005	0.21	0.205
9	0.013	0.217	0.204
10	0.008	0.21	0.202
14	0.004	0.206	0.202
15	0.002	0.204	0.202
11	0.007	0.208	0.201
7	0.015	0.211	0.196
12	0.007	0.202	0.195
16	0.007	0.202	0.195
3	0.02	0.121	0.101

In order to identify the optimal energy sharing pair for the single residential consumer at location no 8 transactions are simulated between the optimal prosumer at location no 8 and consumer at all other locations using powerworld simulator. The numbers of line/cable violations are noted down. Table 2 shows the number of overloaded line/cables within the local energy sharing community.

The best optimal consumer (buyer) for the optimal prosumer (seller) is determined based on the status and number of overloading line/cables when energy is shared between them. Table 3 shows the best optimal energy sharing pairs where there is no overloading of line/cable.

Table II : Energy sharing from optimal prosumer at location no 8 to other locations

Other consumers at locations	Number of overloaded lines
4	4
5	0
6	0
7	0
9	0
3	6
10	6
11	7
12	8
13	7
14	8
15	9
16	6
17	9

It is evident from table 3 that there are no overloaded lines/cables when the surplus energy from the optimal prosumer at location no 8 with maximized PV penetration is shared with consumers at locations 5, 6, 7 and 9. Hence {8 – 5}, {8 – 6}, {8 – 7} and {8 – 9} are determined as the optimal energy sharing pairs. The same methodology can be applied for the next prosumer with maximum level of PV penetration and the optimal energy sharing pairs can be determined.

V. CONCLUSION

The energy sharing model for a decentralized distribution system is detailed for the next generation power system. The renewable energy penetration at the prosumer premises is maximized. The maximum levels of PV penetration at all prosumer locations are determined. The interaction between the prosumer and consumer are simulated within a local energy community to examine the benefits of peer to peer energy trading. The paper also proposed a power flow based method to determine the optimal energy transaction pair without violating the network constraints, thereby reducing the utility grid dependency. The results show that by identifying the optimal energy transaction pairs the likeliness of the network congestions within the local energy community and with the distribution system can be alleviated.

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