

Implementation of peer-to-peer energy auction based on transaction zoning considering network constraints

Hyun Joong Kim, Yong Hyun Song, Seung Wan Kim & Yong Tae Yoon

To cite this article: Hyun Joong Kim, Yong Hyun Song, Seung Wan Kim & Yong Tae Yoon (2019) Implementation of peer-to-peer energy auction based on transaction zoning considering network constraints, Journal of International Council on Electrical Engineering, 9:1, 53-60, DOI: [10.1080/22348972.2019.1619254](https://doi.org/10.1080/22348972.2019.1619254)

To link to this article: <https://doi.org/10.1080/22348972.2019.1619254>



© 2019 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.



Published online: 30 May 2019.



[Submit your article to this journal](#)



Article views: 468



[View related articles](#)



[View Crossmark data](#)



Citing articles: 1 [View citing articles](#)

Implementation of peer-to-peer energy auction based on transaction zoning considering network constraints

Hyun Joong Kim, Yong Hyun Song , Seung Wan Kim and Yong Tae Yoon

Department of Electrical and Computer Engineering, Seoul National University, Seoul, Korea

ABSTRACT

This paper presents a peer-to-peer (P2P) energy auction mechanism based on transaction zoning in a distribution system with a number of distributed generators. A transaction zone can be configured by the power flow monitoring method using the bids and offers from auction participants. In this study, the power flow monitoring method was applied to check how much power flow passes through branches and divide the whole network into sub-networks based on branched with small power flows. Energy trading in the transaction zone configured in this manner has no significant effect on other zones in terms of power flow because only little power flow passes through the branch, which is connected in adjacent to the transaction zone. Therefore, supply and demand can be balanced in the transaction zone and energy trading can be established without violating network constraints. To verify the effectiveness of the transaction zoning, the proposed P2P trading environment was simulated with an IEEE 37-node test feeder. Simulation result shows that P2P energy transaction using transaction zone does not violate network constraints.

ARTICLE HISTORY

Received 11 November 2018
Accepted 10 May 2019

KEYWORDS

Peer-to-peer energy auction;
transaction zone;
distribution network; power
flow monitoring method

1. Introduction

Distributed generation based on renewable energy is rapidly spreading worldwide. Most distributed generators with small size capacities are generally connected to a distribution network.

Consumers who own various types of distributed generators are changing into energy prosumers [1]. Prosumers conventionally arrange a fixed-price contract with a utility in the form of the power purchase agreement or subscribe a net metering tariff. However, this monolithic transaction scheme is considered a critical barrier in spreading distributed generation and establishing decentralized and autonomous trading environment [2]. Accordingly, Park and Young [3] emphasized the necessity of creating a free-trading environment between individual prosumers.

On the other hand, because the marginal cost of the renewable energy resources is closed to zero, it may not be appropriate to set the price such as system marginal price or locational marginal price which are calculated in consideration of variable cost in the existing wholesale energy market. As an alternative, it is proposed to design prosumer Peer-to-Peer (hereafter P2P) transaction as an auction-based market in a distribution network. The International Energy Agency (IEA) 2017 report [4] has

analysed that transactions with distributed generation are changing into an auction market around the world.

To design power trading and market rules among prosumers in smart grid, Ilic et al. [5] proposed an energy market similar with a real-time stock trading based on communication technology and showed simulation results of the proposed transaction method. However, when a large number of distributed generators are connected to the distribution network, voltage violations and distribution line congestions may occur, which can deteriorate the reliability of the distribution network [6]. To consider network constraints in power trading, Greve et al. [7] suggested an energy trading method based on high computing power and real-time reconfiguration. This method is performed by setting an optimum trading combination in accordance with bids and offers and repeatedly examining the constraints in the network for combination. However, this transaction scheme seems difficult to be applied in the present distribution network because it uses high technology, such as real-time network configuration and high computing power.

This study proposed the auction-based P2P energy transaction scheme, which does not cause network constraints, by applying a realizable method in practice.

The rest of the paper is organized as follows: **Section 2** describes the transaction zone for P2P energy auction and its formation using a practical method instead of high computation and real-time reconfiguration of the network, which are assumed in the previous study. **Section 3** presents the mechanism of the auction-based P2P energy auction. **Section 4** shows the case study of the P2P energy auction, which is simulated on an IEEE 34-node test feeder. **Section 5** discusses the result analysis of the case study. Lastly, **Section 6** provides the conclusion of this study.

2. Transaction zone and zoning methodology

2.1. Concept of transaction zone

Transaction zones were configured based on a criterion on weak electrical connectivity in a distribution network. They form a sub-network of the distribution network of nodes participating in energy auction with consideration of network constraints. Through this technique, inter-trading beyond each zone was carried out using untraded energy after trading inside the zone is completed first. Transaction zoning can satisfy consumer demands and avoid network congestion caused by excessive generation at some nodes. In addition, transaction zones were configured by only using the bidding information of energy prosumers. Hence, transaction zoning is much effective because it does not require high computing power in finding all possible trading cases and selecting the feasible ones [7].

Figure 1 shows the simple example of the P2P Energy Auction using transaction zoning. Let us

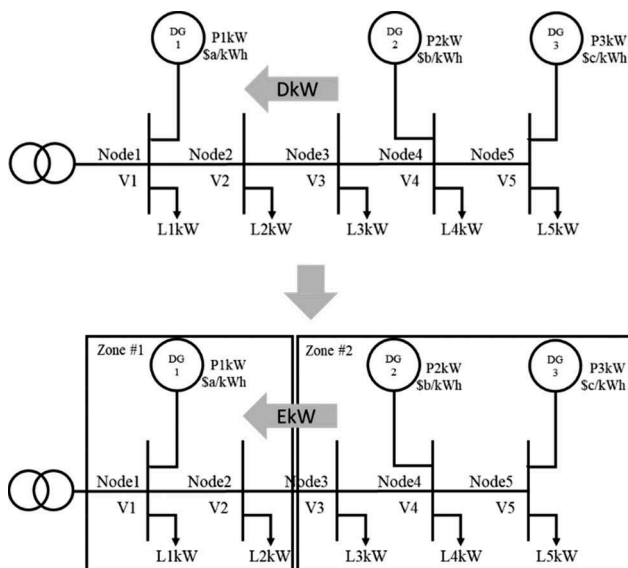


Figure 1. Conceptual figure of P2P transaction using transaction zoning.

assume that there are three distributed generators DG1, DG2 and DG3 with bid $(P1|\$a)$, $(P2|\$b)$, and $(P3|\$c)$, respectively ($P3 > P2 > P1$ and $a > b > c$).

Without transaction zoning, according to bid prices, generation outputs of DG1, DG2 and DG3 are determined as it was originally submitted. If the summation of P2 and P3 is greater than the summation of L3, L4 and L5, the power D may exceed the line capacity flows from node3 to node2. In addition, the reverse power flow due to excessive power generation from DG2 and DG3 causes increases in ending-nodes of the network ($V5 > V4 > V3 > V2 > V1$).

If zone#1 and zone#2 are configured because of transaction zoning using bidding information, transactions are performed at each zone first. In the zone#1, DG1 trades electricity with consumers at the node1 and node2. In the zone#2, DG2 and DG3 provide electricity to consumers at the node3, node4 and node 5. Because of transaction using zoning method, DG2 and DG3 are not able to produce excess power unlike the case without zoning and the network can avoid line capacity violation from node3 to node2 and abnormal voltage profile due to excessive generation of DG2 and DG3.

2.2. Transaction zoning methodology

To configure transaction zones, power flow monitoring method to check a branch flow and graphical representation method proposed in [7] were used. Power flow monitoring method was used to distinguish a branch where the power flow is passing through and to divide the whole network into sub-networks based on the branch with a power flow that is smaller than the threshold value. The process of configuring transaction zones shown in **Figure 2** is as follows and simple corresponding example is shown in **Figure 3**:

- (1) The amounts of supply and demand at each node are collected from the bidding information submitted by energy prosumers.
- (2) Finding out power flow from each branch by calculating power flow equation based on bidding information.
- (3) After filtering the calculated power flow in each branch whether it is bigger than the threshold value or not, the electrical connectivity between nodes is expressed in terms of power flow by representing it on a graph.
- (4) By checking the connectivity between nodes in the graph, the transaction zones can be configured.

The zoning in the distribution network is conducted by establishing separated transaction zones based on

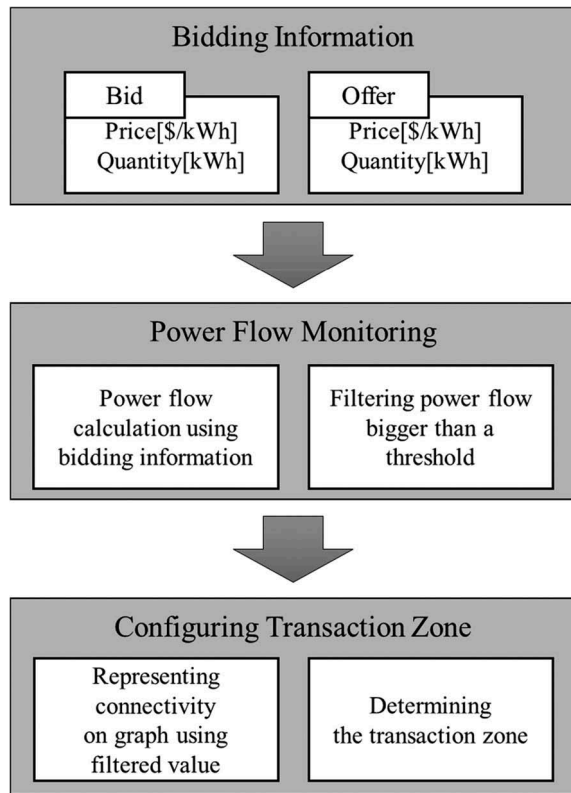


Figure 2. Zoning process using power flow monitoring method.

the point where branch flow is less than prescribed a threshold value. A proper threshold value is selected through the trial and error method used in [8]. The transaction zone configured in this manner has no significant effect on other transaction zones in terms of power flow.

3. P2P transaction mechanism based on transaction zoning

Several assumptions were considered in designing the P2P transaction mechanism: (1) P2P energy auction is very competitive that the prices submitted by a bidder should be very close to the other bidder's price; (2) The P2P transaction is restricted to the times within each transaction zone, and inter-zone transaction is performed once for those not traded in the transaction zone; (3) Demand that is not traded during all transactions is supplied by retail service providers and is settled at a fixed tariff. The process of P2P energy auction within transaction zone is described as follows:

- (1) A distribution system operator (DSO) opens an energy auction before energy is delivered.
- (2) Prosumers who own distributed generators and consumers who want to participate in the

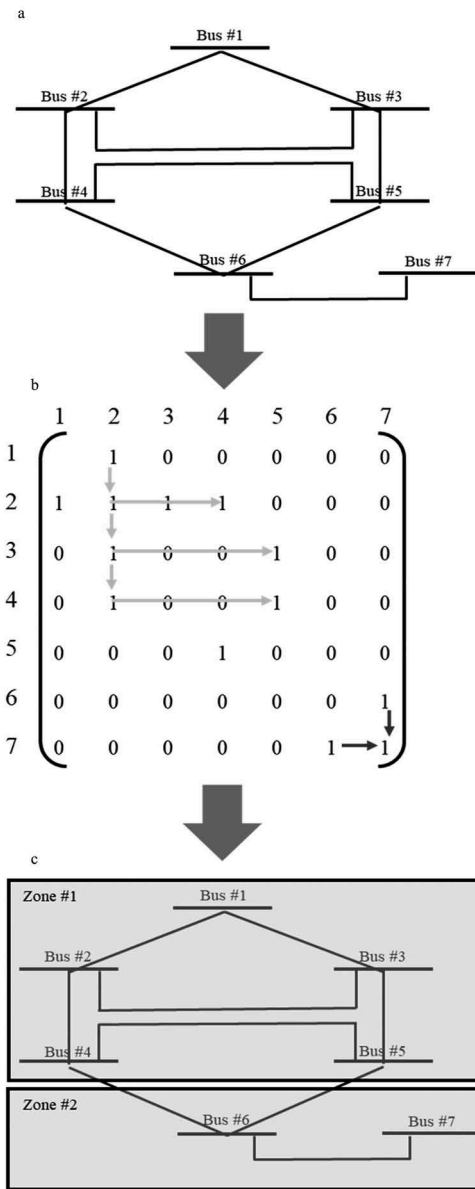


Figure 3. Simple zoning example (a: seven bus network, b: showing filtered value branch value and zoning the node, c: representing the transaction zone).

auction should submit the quantity to sell or purchase with bid price to DSO.

- (3) The DSO constitutes a zone where transactions will take place using power flow monitoring method based on the bid amount.
- (4) The DSO conducts the first auction for prosumer nodes within each transaction zone.
- (5) After the first auction is completed, the second transaction within each transaction zone is performed for the prosumers who cannot sell or buy an energy as much as they bid at the first auction. Before starting the second auction, prosumers can update their bidding price.

- (6) After all auctions within each transaction zone are completed, the prosumers who have not traded within the zone transaction process are traded with those in the adjacent transaction zone, which is called inter-zone auction. However, the inter-zone auction must only be conducted within the network constraints.

4. Simulation

4.1. Description of the test system

To simulate the P2P energy auction, the single-phase balanced IEEE 37-node test feeder in [9] was modified and analysed, as depicted in Figure 4. The test system is described as follows:

- (1) To set the line capacity limit at each branch, a base condition assumes that each node has a specific demand value and no distributed generator. The line capacity limit is presented in Table 1.
- (2) A total of 16 nodes are set as prosumer nodes participating in the transaction. These nodes submit bids to purchase or sell, and they are allocated the amount of electricity to purchase or sell according to the transaction results.

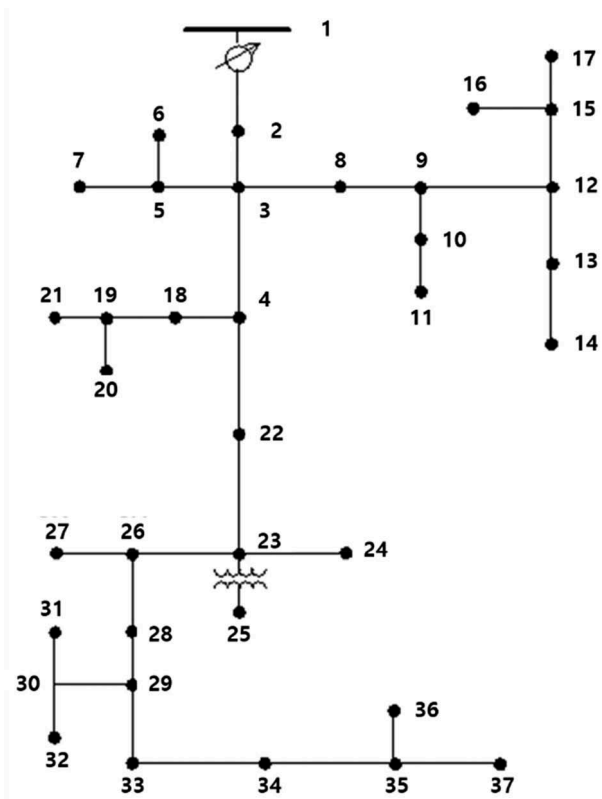


Figure 4. Modified IEEE 37-node test feeder.

Table 1. Line capacity limit.

From	To	Flow limit (kW)
3	5	100
3	8	250
4	18	100
4	22	350
9	12	150
23	26	250
28	29	200
29	30	100
29	33	100

- (3) Lastly, all nodes other than the prosumer nodes have a fixed amount of demand.

Under the base condition, transactions were made as follows. Prosumer nodes make selling offers or purchasing bids. Transaction zones were configured by the power flow monitoring method reflecting the bid amount of prosumer nodes. After configuring the transaction zones, P2P energy auction was performed according to the transaction mechanism. After all, transactions were completed, the amount of winning bids was reflected on each prosumer nodes, and network violation was checked through power flow analysis.

4.2. Case study

To conduct a transaction, prosumer nodes bid the amount to sell or purchase as a supply or demand. Table 2 shows the specific bidding information of the case.

The power flow analysis was performed based on the bidding amount of each prosumer node. The analysis results showed that the transaction zone was configured using the power flow monitoring method. The threshold value used in the power flow monitoring method was 30 kW. Two transaction zones were configured in the test system, and the results are illustrated in Figure 5.

Table 2. Submitted offers and bids.

	Node #	Quantity (kWh)	Price (\$/kWh)	
Demand	5	35	5	
	7	35	4	
	11	30	6	
	18	30	5	
	20	30	6	
	21	25	5	
	24	30	6	
	27	35	5	
	Supply	12	65	5
		14	60	6
16		70	5	
17		65	6	
28		35	9	
31		40	8	
32		30	7	
34		40	7	
36		50	7	

Table 5. Checking voltage violation in no-transaction zoning case.

Node	Voltage magnitude (P.U.)	Violation check (>1.05 P.U.)
1	1.05	-
14	1.049	X
16	1.052	O
17	1.053	O

Note: Node 1 is the main transformer in this distribution network.

Table 7 shows the result of the second auction after re-bidding and re-offering. In the transaction zone 1, node 7 can obtain full transaction from node 16 because it lowered the offering price to \$4. In transaction zone 2, the transaction between nodes 24 and 32 was fully completed. However, node 27 in transaction zone 2 did not make any transaction although the supply nodes lowered their offering price.

After completing the second auction, the inter-zone auction was carried out. The node that has untraded energy can bid and offer, as shown in Table 8. Node 27 in the transaction zone 2 bid \$6

for 30 kWh of electricity and made a deal with node 17 located in transaction zone 1. However, after considering the network constraints, this transaction cannot be completed.

In the case of using the transaction zone, the line congestions are not found, as shown in Table 9. The transactions were made in each transaction zone in advance. Nodes 12, 14, 16, and 17 had to make transactions in transaction zone 1 and then acquire a chance to make a transaction with the nodes in transaction zone 2. However, while the auction in transaction zone 1 was carried out, the other auction was made in transaction zone 2 according to the P2P transaction mechanism. In other words, the total generation of nodes 12, 14, 16, and 17 decreased from 225 kW to 185 kW, which reduced line flow from node 12 to node 9.

Furthermore, any voltage violation in the auctions with the transaction zone was not found, as shown in Table 10. In the auctions without a transaction zone, the voltage violation occurred in nodes 16 and 17 where the voltage of each node was larger than main transformer voltage of

Table 6. First auction results using the transaction zone.

Zone	Bidding quantity (kWh) (Node#)			Price (\$/kWh)	Offering quantity (kWh) (Node#)		
#1				9			
				8			
				7			
			30 (11)	6	60 (14)	65 (17)	
		25 (21)	30 (18)	5	65 (12)	70 (16)	
			35 (7)	4			
		Trading volume		150 kWh		Trading value	\$810
#2				9	35 (28)		
				8	40 (31)		
				7	30 (32)	40 (34)	50 (36)
			30 (24)	6			
			35 (27)	5			
				4			
		Trading volume		0 kWh		Trading value	\$0

Note: The quantities highlighted in dark gray and light gray refer to fully traded and partially traded, respectively.

Table 7. Second auction results using the transaction zone.

Zone	Bidding quantity (kWh) (Node#)			Price (\$/kWh)	Offering quantity (kWh) (Node#)		
#1				9			
				8			
				7			
				6			
				5	65 (17)		
			35 (7)	4	45 (16)		
		Trading volume		35 kWh		Trading Value	\$140
#2				9			
				8	35 (28)		
				7	40 (31)		
			30 (24)	6	30 (32)	40 (34)	50 (36)
			35 (27)	5			
				4			
		Trading volume		30 kWh		Trading value	\$180

Note: The quantities highlighted in dark gray and light gray refer to fully traded and partially traded, respectively.

Table 8. Inter-zone auction results sing the transaction zone.

Bidding quantity (Node#)	(kWh)	Price (\$/kWh)	Offering quantity (Node#)
		9	
		8	35 (28)
		7	40 (31)
		6	40 (34) 50 (36)
	35 (27)	5	65 (17)
		4	10 (16)
Trading volume	0 kWh	Trading value	\$0

Note: The quantities highlighted in dark gray and light gray refer to fully traded and partially traded, respectively.

Table 9. Checking line congestion in transaction zoning case.

From	To	Flow limit (kW)	Power flow (kW)	Congestion check
3	5	100	95.3	X
3	8	250	-39.2	X
4	18	150	106.3	X
4	22	350	137.9	X
9	12	150	-145.6	X
23	26	250	12.1	X
28	29	200	-82.1	X
29	30	100	-3.0	X
29	33	100	1.0	X

Table 10. Checking voltage violation in the transaction zoning case.

Node	Voltage magnitude (P.U.)	Violation check (>1.05 P.U.)
1	1.05	.
14	1.045	X
16	1.045	X
17	1.044	X

Note: Node 1 is the main transformer in this distribution network.

1.05 P.U. According to [9], the relationship between the voltage of the distributed generator at demand side (V_{Gen}) and the voltage of the main transformer of the distribution network (V_S) is defined as

$$\Delta V = V_{Gen} - V_S \approx R(P_G - P_L) + X(\pm Q_C - Q_L \pm Q_G) .$$

The equation indicates that V_{Gen} is larger than V_S if the amount of active power generation increases with the reactive power unchanged. Without a transaction zone, the power generation at nodes 16 and 17 are 70 and 30 kW, respectively. However, after configuring the transaction zones, the power generation at nodes 16 and 17 changed to 60 and 0 kW, respectively. Hence, the amount of power generation at nodes 16 and 17 that cause voltage violation was reduced due to the transaction under the transaction zone, and voltage violation was released.

6. Conclusion

This study simulated a transaction with individuals who own distributed generators at a distribution network. In this network, a large number of distributed generators are integrated. The unpredictable generation of many distributed generators causes voltage violation and line congestion in a distribution network. Therefore, to make P2P auction with the distributed generator in consideration of these network constraints, the transaction zone is proposed using power flow monitoring methods. The proposed transaction is implemented under the IEEE 37-node test feeder. The simulation result shows that a P2P energy auction using the transaction zone was established while avoiding any network constraints.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors



Hyun Joong Kim He received his B.S. degree in Electrical and Computer Engineering from Seoul National University. His research interests include electrical power system, common power system information model, and distribution energy markets.



Yong Hyun Song He received his B.S. degree in Electrical and Computer Engineering from Seoul National University. His research interests include smart grids, renewable energy, and energy transition.



Seung Wan Kim He received his B.S. degree in Electrical Engineering and Ph. D. degree in Power System Economics from Seoul National University, Korea, in 2012 and 2018, respectively. He is a currently an Assistant Professor in the School of Electrical Engineering, Chungnam National University, Korea. His research interests include renewable energy integration, distribution system operation, and smart grid policy/regulation.



Yong Tae Yoon He received his B.S., M. Eng., and Ph.D. degrees from the Massachusetts Institute of Technology, Cambridge, in 1995, 1997, and 2001, respectively. Currently, he is a Professor in the School of Electrical Engineering and Computer Science, Seoul National University, Korea. His research interests include electric power network economics, power system reliability, and incentive regulation of independent transmission companies.

ORCID

Yong Hyun Song  <http://orcid.org/0000-0001-6860-1361>

References

- [1] Zhang C, Wu J, Cheng M, et al. A bidding system for peer-to-peer energy trading in a grid-connected microgrid. *Energy Procedia*. 2016;103:147–152.
- [2] Junfeng L, Li Z, Runqing H, et al. Policy analysis of the barriers to renewable energy development in the People's Republic of China. *Energy Sustainable Dev*. 2002;6(3):11–20.
- [3] Park C, Yong T. Comparative review and discussion on P2P electricity trading. *Energy Procedia*. 2017;128:3–9.
- [4] The IEA. 2017. Renewables 2017 – analysis and forecasts to 2022. doi:10.1787/re_mar-2017-en
- [5] Ilic D, Da Silva PG, Karnouskos S, et al. (2012, June). An energy market for trading electricity in smart grid neighbourhoods. In *Digital Ecosystems Technologies (DEST), 2012 6th IEEE International Conference on* (pp. 1–6). IEEE, Campione d'Italia, Italy.
- [6] Lopes JP, Hatziargyriou N, Mutale J, et al. Integrating distributed generation into electric power systems: a review of drivers, challenges and opportunities. *Electr Power Syst Res*. 2007;77(9):1189–1203.
- [7] Greve T, Charalampos P, Pollitt M, et al. (2016). Economic zones for future complex power systems.
- [8] Schlueter RA, Hu I-P, Chang M-W, et al. Methods for determining proximity to voltage collapse. *IEEE Trans Power Syst*. 1991;6.1:285–292.
- [9] Mahmud MA., Hossain MJ, and Pota HR. “Analysis of voltage rise effect on distribution network with distributed generation,” *IFAC Proceedings Volumes*. 2011; 44 (1); 14796–14801.