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Effect of Distributed Energy Resources in Energy Hubs on Load and Loss Factors of Energy Distribution Networks

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Abstract

In this paper, an attempt has been made to introduce a new control strategy including Plug-in Hybrid Electric Vehicle (PHEV) and Diesel engine generator to control the voltage and frequency of autonomous microgrids. The proposed control strategy has multiple advantages over the recent control methods in microgrids. The proposed method applies the primary and secondary frequency control strategy, simultaneously. However the secondary voltage control scheme is obligatory. In present study, Artificial Neural Networks (ANN) has been implemented for training and validating the advanced droop control (ADC). After ADC unit training, the inverter based DG can be installed in complex microgrids consist of several DGs and loads. Simulation results indicate the effectiveness and applicability of proposed method in controlling the voltage and frequency in autonomous microgrids.

Keywords: Multi Carrier Energy Networks, Energy Hub, Distributed Energy Resources, Loss Factor, Load Factor

Indices

h	Hour

Parameters

α_e^{ch}	Charge efficiency of electric storage
α_e^{dis}	Discharge efficiency of electric storage
η_{gh}^{B}	Gas to heat efficiency of boiler
η_{gh}^{C}	Gas to heat efficiency of CHP
η_{ge}^{C}	Gas to electric efficiency of CHP
α_e^{shdo}	Maximum shift down of the demand
α_e^{shup}	Maximum shift up of the demand
η_{ee}^{T}	Electricity to electricity efficiency of transformer
$\pi^{e}(h)$	Hourly electric price
π^{g}	Gas price
$L_e(h)$	Hourly electric demand
$L_h(h)$	Hourly heat demand
P^{B}	Boiler maximum capacity
P^{CHP}	CHP maximum capacity
P^{T}	Transformer maximum capacity
P_e^{NetMax}	Electric network capacity
P_g^{NetMax}	Gas network capacity
$P_e^{wind}(h)$	Hourly wind power
S_e^{Max}	Maximum capacity of electric storage

Binary Variables

$I_e^{ch}(h)$	Charge of electric storage
$I_e^{dis}(h)$	Discharge of electric storage
$I_e^{shdo}(h)$	Shift down of demand response
$I_e^{shup}(h)$	Shift up of demand response

Variables

$P_e^{DR}(h)$	Electricity demand change by demand response program
$P_e^{Net}(h)$	Purchased network power
$S_e^{ch}(h)$	Charge energy of electric storage
$S_e^{dis}(h)$	Discharge energy of electric storage
LF	Load factor
LOF	Loss factor
$P_g^{NetB}(h)$	Purchased gas power for boiler
$P_g^{NetC}(h)$	Purchased gas power for CHP
$P_e^{shdo}(h)$	Shifted down of electric demand
$P_e^{shup}(h)$	Shifted up of electric demand
$S_e(h)$	Electric storage energy
OF	Objective function

1. Introduction

Recently, one of the most significant challenges of electric distribution networks is supplying energy demands by electric distribution companies. Therefore, energy distribution company owners have decided to implement a plan in order that energy distribution networks are efficiently operated. A great idea to solve the problem was utilization of different energy networks together.

The utilization of different energy networks not only makes the operation of the resources efficient, but it also provides opportunity to reduce the operation costs reduction.

The idea for integration of electricity and gas networks has been considered in some recent works. One approach to utilization of different energy networks are “Micro Grid”, which is discussed in [1]. “Hybrid Energy Hub” as another idea is discussed in [2]. The inspiring approach, Energy Hub, is debated in VOFEN (Vision of Future Energy Networks) project [3].

Energy Hub is defined as a super node in electric power system. It receives electricity and gas from the networks to supply electricity and heat demands. Different technologies are used to convert input energy carriers to output energy carriers. Hence, Energy Hub duty is deciding which technology should be operated and turned on to produce the hub requirements. In doing so, the hub requirements are satisfied in order that the operation costs of the hub owners and customers reduce.

Energy hub can be integrated to renewable, energy storages and other distributed generations to decrease hub operation costs.

Energy storages are modeled in multi carrier energy infrastructures in [4-5]. Energy storage and demand response programs are utilized to smooth renewable generation fluctuations in multi carrier energy networks in [6-7].

This paper is aimed to evaluate effect of distributed energy resources on energy distribution networks. CHP, wind, energy storage and demand response programs are integrated to the distribution networks in order that effect of them can be evaluated on the distribution networks. Loss factor and load factor as two important elements of electric distribution networks are analyzed by integration of the aforementioned technologies.

Energy Hub approach is employed to simplify the integration of the resources to energy distribution networks. The rest of the paper is organized as follows: The proposed Energy Hub is presented in section II. Section III formulates the mentioned problem. Details of simulation results are debated in section IV. Finally, conclusion is explained in section V.

2. Method

Fig. 1 shows the integration of the distributed energy resources to energy distribution networks. An Energy Hub is modeled to utter this integration. Wind, energy storage and demand response programs are integrated to energy distribution networks. Energy storage is charged when electricity demand is low and the price of electricity is high, then it is discharged when electricity price and electricity demand is high.

Demand response programs are also integrated to reduce the electricity demand or to increase the electricity demand in required times. CHP is used to simultaneously produce heat and electricity to supply electricity and heat demands. Boiler as CHP backup is used to produce heat in the times when CHP is not beneficial to be utilized.

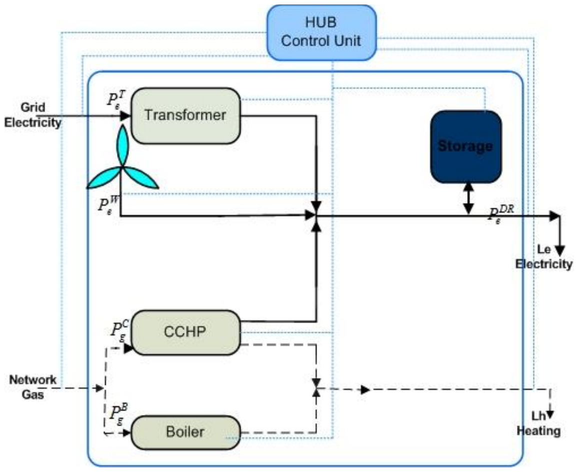

Fig. 1. Scheme of the work

3. Method

In this session, problem is formulated based on an objective function (1) and its constraints (2) through (19).

Objective function (OF) includes purchased energy carriers through their prices. Gas for CHP and boiler with gas price as well as electricity for transformer with electricity price are considered in the objective function.

$$OF = \pi^{g}(P_g^{NetB}(h) + P_g^{NetC}(h)) + \pi^{e}(h)(P_e^{Net}(h)) \quad (1)$$

Electricity demand can be supplied by network wind or CHP or electric storage or demand response programs in (2). Heat demand can be supplied by CHP or boiler in (3).

$$L_e(h) = \eta_{ee}^{T} P_e^{Net}(h) + \eta_{ge}^{C} P_g^{NetC}(h) + P_e^{wind}(h) + P_e^{DR}(h) + S_e^{dis}(h) - S_e^{ch}(h) \quad (2)$$

$$L_h(h) = \eta_{gh}^{C} P_g^{NetC}(h) + \eta_{gh}^{B} P_g^{NetB}(h) \quad (3)$$

Network gas should be limited by CHP and boiler in (4). Purchased gas from network, purchased electricity from network should be constrained in (5) and (6) in sequence.

$$P_g^{Net}(h) = P_g^{NetC}(h) + P_g^{NetB}(h) \quad (4)$$

$$P_g^{Net}(h) \le P_g^{NetMax} \quad (5)$$

$$P_e^{Net}(h) \le P_e^{NetMax} \quad (6)$$

Transformer, CHP and boiler are correspondingly restricted by (7), (8) and (9).

$$\eta_{ee}^{T} P_e^{Net}(h) \le P^{T} \quad (7)$$

$$\eta_{ge}^{C} P_g^{NetC}(h) \le P^{CHP} \quad (8)$$

$$\eta_{gh}^{B} P_g^{NetB}(h) \le P^{B} \quad (9)$$

Electrical energy storage is restricted by available energy, charge energy and discharge energy of it in (10) [5]. Electric storage amount should be limited by its maximum capacity in (11). Charge and discharge of the storage are limited in (12) and (13) in sequence. Binary variable of charge and discharge are used to prevent charge and discharge simultaneously (14).

$$S_e(h) = S_e(h-1) + S_e^{ch}(h) - S_e^{dis}(h) \quad (10)$$

$$0 \le S_e(h) \le S_e^{Max} \quad (11)$$

$$0 \le S_e^{ch}(h) \le (1/\alpha_e^{ch}) S_e^{Max} I_e^{ch}(h) \quad (12)$$

$$0 \le S_e^{dis}(h) \le \alpha_e^{dis} S_e^{Max} I_e^{dis}(h) \quad (13)$$

$$0 \le I_e^{ch}(h) + I_e^{dis}(h) \le 1 \quad (14)$$

Demand response programs should be limited based on [7]. Demand shifting is restricted by sum of shifted up and sum of shifted down in demand shifting program in (15). Amount of shift down and shift up should be respectively limited by (16) and (17). Binary variables of shift down and shift up prevent the performance simultaneously (18).

$$\sum_{h=1}^{24} P_e^{shup}(h) = \sum_{h=1}^{24} P_e^{shdo}(h) \quad (15)$$

$$0 \le P_e^{shup}(h) \le \alpha_e^{shup} L_e(h) I_e^{shup}(h) \quad (16)$$

$$0 \le P_e^{shdo}(h) \le \alpha_e^{shdo} L_e(h) I_e^{shdo}(h) \quad (17)$$

$$0 \le I_e^{shup}(h) + I_e^{shdo}(h) \le 1 \quad (18)$$

Load factor is defined average of electrical load (in a duration of time) to maximum load (in that duration of time) (19). Loss factor is defined average of loss power to maximum loss in a duration of time (20) [8]. Here, the load factor as well as loss factor is taken into account for the effect of the renewable and energy storages on the technical factors. P^{Max} denotes maximum value of the load in the duration.

$$LF = \frac{(\sum_{H=1}^{24} P^{Net}(H))/24}{P^{Max}} \quad (19)$$

$$LOF = 0.7LF^{2} + 0.3LF \quad (20)$$

4. Simulation Results

Simulation is applied the proposed hub in Fig.1. GAMS software is employed to solve the aforementioned problem. Problem is modeled through objective function (1) and the mentioned constrains (2) to (19).

Mixed Integer Linear Programming (MILP) is considered for solving the problem. The proposed hub elements are given in Table I. Wind power is given in Fig.2. Hourly electricity price is also given in Fig. 3. Furthermore, electrical and heat demands are presented in Fig. 4.

Five different cases are introduced to evaluate effect of distributed energy resources on electricity distribution network.

Load factor and loss factor are calculated by equations (18) and (19). Case 1 introduces integration of all the distributed energy resources. CHP, wind, energy storage and demand response programs are applied on the energy distribution networks. In case 2, all distributed energy resources are integrated to the networks except CHP.

Case 3 includes CHP, energy storage and demand response programs. In case 3, integration of wind turbine is deposits from the network. Case 4 encompasses CHP, wind and demand response programs.

This case lacks the integration of energy storage. In case 5, all distributed energy resources are integrated to the energy distribution networks except demand response programs.

Effects of the aforementioned cases are illustrated in Table.2 , Table.3 and Table. 4. Table.2 and Fig5 show the operation costs in different cases. Table.3 and Fig. 6 include evaluation of loss factor in different cases. Table.4 and Fig. 7 show the effect of the mentioned cases on load factor.

Table.2 and Fig.5 show that when all the technologies are integrated to the energy distribution networks, the operation costs are reduced. Wind has the most important effect on the operation costs. CHP is also has a remarkable effect on the operation costs. Energy storage and demand response program has some effect on the operation costs.

The result of Table.3 and Fig.6 is very interesting since integration of energy storage and demand response to the energy distribution networks increases loss factor. Wind and CHP have more remarkable effects on loss factor reduction.

Table.1.
The proposed energy hub parameters

α_e^{ch}	0.93	π^g	4	η_{ee}^T	0.98
α_e^{dis}	0.93	P^B	1000	α_e^{shup}	0.1
η_{gh}^B	0.9	P^{CHP}	700	α_e^{shdo}	0.1
η_{gh}^C	0.4	P^T	1200	η_{ge}^C	0.35
S_e^{Max}	500	P_e^{NetMax}	1200	P_g^{NetMax}	1200

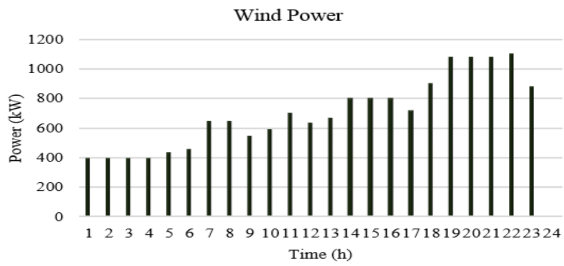

Fig. 2. Hourly wind power

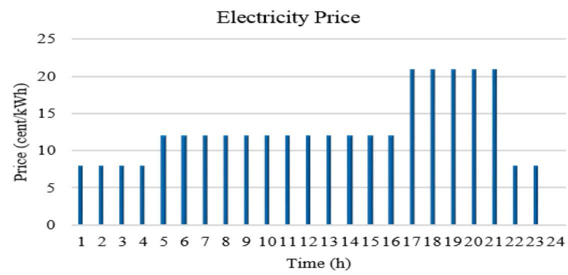

Fig. 3. Hourly electricity price

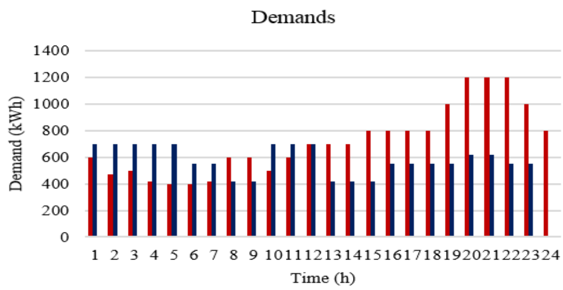

Fig. 4. Electrical and heat demands of the proposed hub

Table.2.
Results of operation costs in different cases

	CHP	Wind	Energy Storage	Demand Response	Operation Costs
Case.1	+	+	+	+	1368
Case.2		+	+	+	1723
Case.3	+		+	+	2539
Case.4	+	+		+	1432
Case.5	+	+	+		1452

Table.3.
Results of loss factor in different cases

	CHP	Wind	Energy Storage	Demand Response	Loss Factor
Case.1	+	+	+	+	0.074
Case.2		+	+	+	0.256
Case.3	+		+	+	0.439
Case.4	+	+		+	0.069
Case.5	+	+	+		0.066

Table.4.
Result of load factor in different cases

	CHP	Wind	Energy Storage	Demand Response	Load Factor
Case.1	+	+	+	+	0.175
Case.2		+	+	+	0.428
Case.3	+		+	+	0.606
Case.4	+	+		+	0.166
Case.5	+	+	+		0.161

The result of Table.4 and Fig. 7 show that CHP and wind have more interesting effects on load factor reduction. Furthermore, when all the technologies are integrated to the energy distribution networks, load factor is sensibly reduced. The interesting result is observed when energy storage and demand response programs are departed from the energy distribution networks in case 4 and case 5.

Fig.8 shows when different cases are applied on the energy distribution networks what changes are observed. The results show that when all the technologies or distributed resources are connected to the energy distribution networks, the least electricity is purchased from the network. Since the least electricity is purchased from the network, the operation costs are remarkably decreased. The most electricity is purchased when CHP and wind are departed from the energy distribution networks. Therefore, the operation costs remarkably increases. Energy storage and demand response programs approximately decrease purchasing electricity from the relevant network.

Fig. 9 illustrates that the least gas is purchased from the network when CHP is removed from the energy networks. The most gas is purchased from the gas network when CHP is connected to the grid. It confirms that the proposed hub tends to supply its heat and electricity demands by CHP.

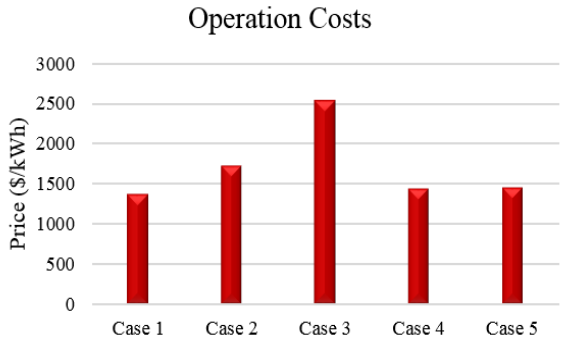

Fig. 5. Results of operation costs in different cases

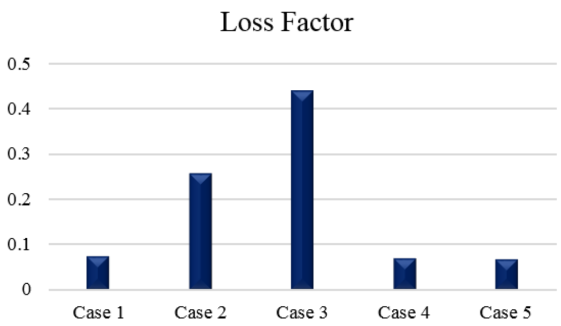

Fig. 6. Results of loss factor in differernt cases

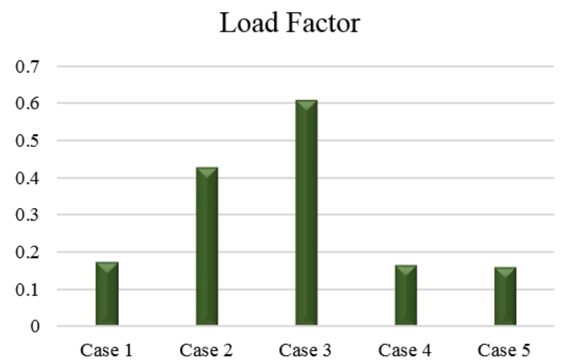

Fig. 7. Results of load factor in differernt cases

5. Conclusion

In this paper, effects of distributed energy resources such as CHP, wind, energy storage and demand response programs are evaluated on the operation costs, loss and load factors in energy distribution networks. Gas and electricity networks are modeled in this work. An energy hub was proposed to model integration of distributed resources to electricity and gas networks. Electricity and heat demands are supplied in the proposed hub. GAMS software was used to solve the proposed MILP model of the hub.

The results show that however the integration of distributed energy resources declines the hub operation costs for customers; it increases the loss factor and load factors of electric distribution network. Hence, electric distribution network companies should consider the challenges while integrating the distributed resources to the networks. Furthermore, the results show that the least electricity is purchased from the network when all the distributed resources are integrated to the networks. Also, when the energy networks are connected to CHP, the proposed hub prefers to supply its demands by gas network to reduce the operation costs.

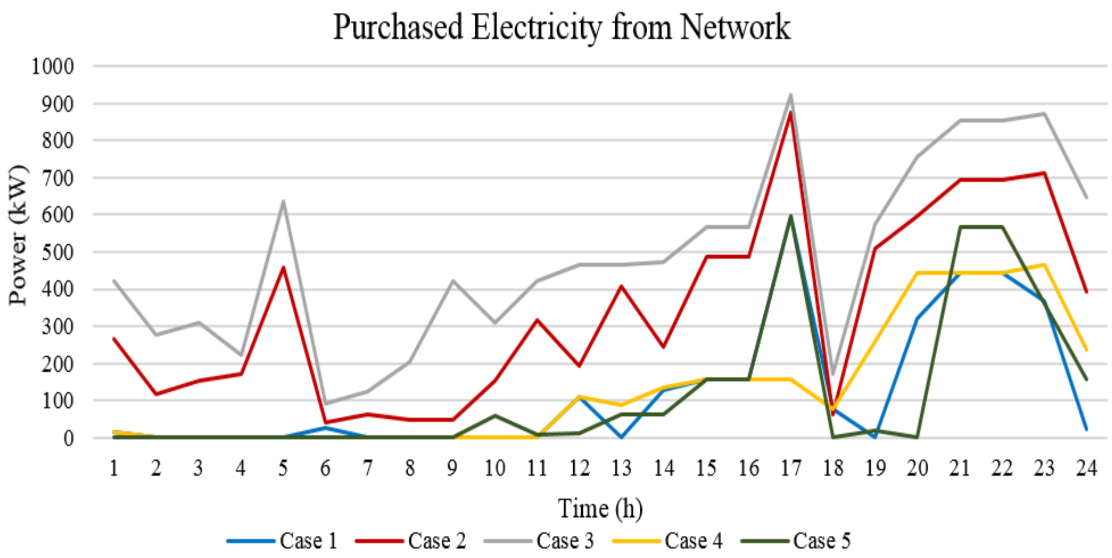

Fig.8. Results of purchased electricity from electricity network in different cases

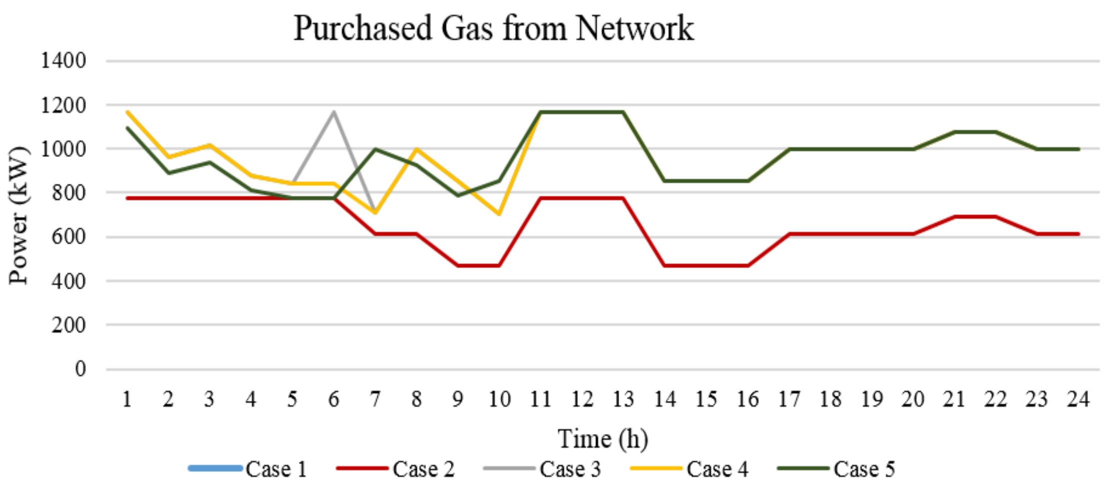

Fig. 8. Results of purchased gas from gas network in different cases

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