

# Optimal Allocation of Wind Turbine in Multi Carrier Energy Networks Improving Loss and Voltage Profile

Samaneh Pazouki<sup>1</sup>, Amin Mohsenzadeh<sup>2</sup>, Mahmoud-Reza Haghifam<sup>2</sup>, and Mohammad Ebrahim Talebian<sup>3</sup>

<sup>1</sup>Islamic Azad University, South Tehran Branch, Tehran, Iran  
samanehpazouki@gmail.com

<sup>2</sup>Tarbiat Modares University, Tehran, Iran  
a.m@modares.ac.ir, haghifam@modares.ac.ir

<sup>3</sup>Managing Director (MD) of Neka Power Plant, Mazandaran, Iran  
metalebian@gmail.com, www.neka.power.plant.ir, www.dr.talebian.ir

## Abstract

Smart grid enables Distributed Energy Resources (DERs); wind, energy storage and demand response through advanced technologies. Combined Heat and Power (CHP) is great example of the technologies which allows coupling of independent energy networks together. Energy Hub (EH) has been originated as a new approach to optimal planning and operation of combined networks in recent years. Wind turbine as an important of distributed generation in the world as beenh integrated to electricity network over two past decades. Optimal placement of wind turbine in multi carrier energy network in presence of CHP as another distributed produce source originates novel challenge which is considered in this paper. A multi objective function is formulated to solve the optimization problem with considering multi carrier energy network operation costs, loss and voltage profile. Simulation carries out a 33 bus radial distribution network which is supplied with CHP in some buses. CPLEX solver of GAMS and Genetic Algorithm of MATLAB is employed to solve the problem. Simulation results reveal optimal allocation of wind turbine in multi carrier energy networks in presence of CHP. Results demonstrate that optimal placement of wind turbine in the systems improves operation costs till 8% and loss power till 5%. It also enhances voltage profile till 0.5%.

## 1. Introduction

Smart grid enables DERs with advanced technologies in distribution network levels. Integration of the resources to the network can prevent huge investment costs of transmission line expansion and electrical power plants establishment. Customer operation costs could be also improved by installation of the technologies. In addition, loss reduction and voltage profile improvement would be results of DERs installation which could be beneficial for distribution network companies. CHP is a great example of the technologies which has potential to convert one energy carrier such as gas to different energy carriers such as electricity, heat and cooling. CHP allows integration of independent energy networks such as electricity, gas, district heat and etc with its significant benefits on economic, efficiency and reliability improvement.

Integrated energy systems have been considered recently as “Micro Grid” [1], “Hybrid Energy Hub” [2], the latest approach originates in VOFEN (Vision of Future Energy Network) project [3] which defines “Energy Hub” as a super node in

electrical power system to receives varying energy carriers such as gas and electricity in its input, then strongly schedules when and how much of which carrier should be purchased and stored to provide hub required demands. EH facilities optimal planning and operation of multi carrier energy networks (See [4], [5] for hub and interconnected hub optimization both in operation and planning). The approach could be flexibility extended by DERs [6] in big buildings, industrial plants, bounded geographic areas and island systems. Optimal power flow of multi carrier energy networks in hub and interconnected hubs is examined in [4], [7-8] which optimization planning isn't studied in the papers. Multi carrier energy networks is optimally operated in an EH with DERs integration in [9-10] which planning problem isn't considered in the paper. An optimal power flow problem between interconnected EHs with distributed energy resources integration is solved in [11] which optimal planning isn't researched in the paper. Multi carrier energy networks are optimally operated in an EH in [5], [12-14] which optimal size of EH technologies is recognized in the papers. An EH with potential of voltage management is optimally operates in [15] which optimization planning isn't researched in the paper.

As a result, optimal operation problem of multi carrier energy networks through one hub or between in EHs is seen in the papers. Optimization planning of EH elements has been also researched in the papers. Optimal operation problem of integrated DERs to multi carrier energy networks in one EH or between intercommoned EHs is also solved in above papers. But optimal placement of DERs in multi carrier energy networks based on EH approach isn't seen in the papers and it is an open problem in interconnected EHs. This paper is organized to solve optimization placement of wind turbine in interconnected multi carrier energy networks based on EH approach as follow: Problem is formulated in one objective function considering loss, voltage and operation costs in section 2. Section 3 states methodology of problem. Simulation results are discussed in section 4. Finally, conclusion is debated in section 5.

## 2. Problem Formulation

In this section, optimal placement of wind turbine is mathematically formulated in objective function with its constraints as follow:

### 2.1 Objective Function

Installation  $Ct^{Ins}$  and maintenance  $Ct^M$  costs of wind turbine together with operation costs  $Ct^{Op}$  of multi carrier energy

networks are applied in the function. Loss cost  $Ct^{loss}$  and voltage penalty  $Ct^V$  are also considered in the function.

Multi carrier operation costs and Energy Not Supplied (ENS) costs due to DR implementation are formulated in objective function (1). Cost Present Value Factor (CPVF) is applied on operation, loss and voltage costs for conversion of project future costs to present time value in (2). PVF states Present Value Factor (3),  $EL$  expresses Economic Life of Project,  $if$  and  $ir$  introduce inflation rate and interest rate [16].

$$of = Ct^{Ins} + Ct^M + Ct^{Op} + Ct^{loss} + Ct^V \quad (1)$$

$$CPVF = \frac{(PVF)^{EL} - 1}{PVF - 1} \quad (2)$$

$$PVF = \frac{1 + if}{1 + ir} \quad (3)$$

## 2.2 Wind

Wind power ( $P_e^W$ ) is produced by wind turbine which starts to produce power in minimum wind speed ( $W_{ci}$ ). Turbine produces power till rated wind for turbine ( $W_r$ ). If wind speed increases, wind turbine will produce power in its rated power ( $P_r^W$ ) till handling maximum wind speed ( $W_{co}$ ). It would be off for more wind speed.  $Z$ ,  $y$ ,  $x$  are related to wind turbine characteristic in [9], [17]:

$$P_e^W(h, d, s) = \begin{cases} 0, & w < W_{ci} \\ P_r^W(z - y * w(h, d, s) + x * w^2(h, d, s)), & W_{ci} \leq w \leq W_r \\ 0, & P_r^W W_r \leq w \leq W_{co} \\ & w \geq W_{co} \end{cases} \quad (4)$$

## 2.3 Operation Costs in Multi Carrier Energy Networks under EH approach

Hub decides to when and how much of which energy carrier should be purchased in required times to satisfy its required demands in response to minimization of operation costs.

Electricity power  $P_e^{Net}$ , gas powers for CHP  $P_g^{NetCHP}$  and for boiler  $P_g^{NetB}$  are purchased according to electricity  $\pi_e^{Net}$  and  $\pi_g^{Net}$  gas prices. Additional produced electricity and heat  $P_h^{Netsold}$  with electricity and  $\pi_h^{Net}$  heat prices are also sold to grid to achieve revenue in order to reduce operation costs (5).  $h$  shows hours indices for one year and  $b$  introduces bus numbers in the function.

$$of = \sum_{b=1}^B \sum_{h=1}^{8760} [\pi_e^{Net}(h) P_e^{Net}(h)] + [\pi_g^{Net}(P_g^{NetCHP}(h) + P_g^{NetB}(h))] - [\pi_h^{Net} P_h^{Netsold}(h)] \quad (5)$$

Hub required electricity demands  $P_e$  could be supplied by network electricity power in required times. CHP can also produce electricity power from converting imported gas power to electricity through its gas to electricity efficiency  $\eta_{ge}^{CHP}$ . Wind power  $P_e^W$  could be able to produce free and clean electricity power through its efficiency  $\eta_{ee}^{con}$  in (6).

Hub required heat demands  $P_h$  could be supplied by produced heat by CHP through its gas to heat efficiency  $\eta_{gh}^{CHP}$  or boiler through its gas to heat efficiency  $\eta_{gh}^B$  in (7).

Sum of imported gas power for CHP and boiler should be restricted by gas network constraint  $P_g^{Net}$  in (8). Imported gas power for CHP and for boiler could be respectively limited by CHP  $P^{CHP}$  and boiler  $P^B$  capacities in (9) and (10).

$$P_e(h, b) = [P_e^{Net}(h, b)] + [\eta_{ge}^{CHP} P_g^{NetCHP}(h, b)] + [\eta_{ee}^{con} P_e^W(h, b)] \quad (6)$$

$$P_h(h, b) = [\eta_{gh}^{CHP} P_g^{NetCHP}(h, b)] + [\eta_{gh}^B P_g^{NetB}(h, b)] \quad (7)$$

$$P_g^{Net}(h, b) = P_g^{NetCHP}(h, b) + P_g^{NetB}(h, b) \quad (8)$$

$$\eta_{ge}^{CHP} P_g^{NetCHP}(h, b) \leq P^{CHP} \quad (9)$$

$$\eta_{ge}^B P_g^{NetB}(h, b) \leq P^B \quad (10)$$

## 2.4 Loss

Loss power of electricity network could be evaluated by several methods. Due to high ratio of  $R_{br}$  (resistance of each branch) to  $X_{br}$  (reactance of each branch), Backward/Forward sweep method is used to calculate current of each branch  $R_{br}$  which is wholly formulated in [18]. Calculation of loss power cost is stated as follow:

$$Ct^{loss} = \sum_{br=1}^{Br} \sum_{h=1}^{8760} \pi_e^{Net}(h) R_{br} i_{br}^2(h, br) \quad (11)$$

## 2.5 Voltage Penalty

Optimal place of distributed generation is main solution for voltage profile improvement in distribution network. Due to variable consumption of customers, feeder's voltage in every bus  $V_b$  will change in a specific range  $V_r$  which is standard voltage and  $V_m$  is voltage limit which are too high or low.  $c$  shows an exponent for function slope. Here, due to deviation from rated voltage (1 p.u), utilities are obliged to pay penalty to customers based on Voltage Penalty Function VPF [19].

$$Ct^V = \sum_{b=1}^B \left( \frac{V_r - V(b)}{V_r - V_m} \right)^c \quad (12)$$

## 2.6 Network Constraints

Electrical grid  $P_e^{Netmax}$ , gas network  $P_g^{Netmax}$ , thermal limits of each branch  $S_{br}^{max}$  and voltage of each bus  $V_b^{min}, V_b^{max}$  constraints should be applied in the problem in equations (13), (14), (15) and (16) in sequence.

$$\sum_{h=1}^{8760} P_e^{Net}(h, b) \leq P_e^{Netmax} \quad (13)$$

$$\sum_{h=1}^{8760} P_g^{Net}(h, b) \leq P_g^{Netmax} \quad (14)$$

$$S_{br} \leq S_{br}^{max} \quad (15)$$

$$V_b^{min} \leq V(h, b) \leq V_b^{max} \quad (16)$$

## 3. Methodology

The main goal of proposed modeling is to determine proper locations of Wind turbines by minimizing objective function.

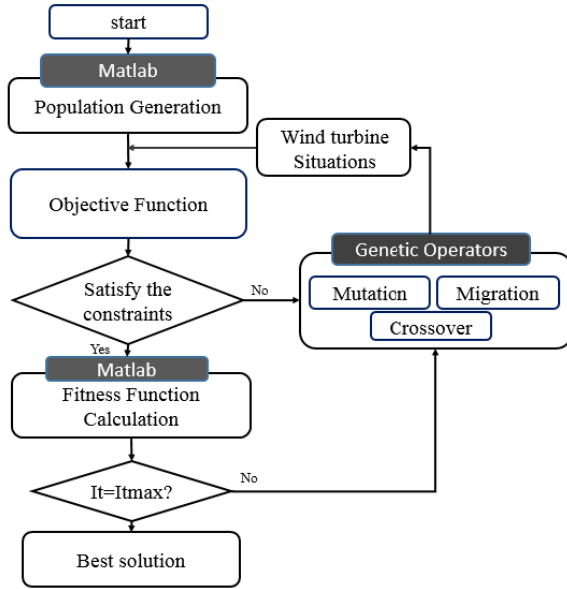


Fig. 1. Proposed method under multi objective function

Number of candidate location

0	1	1	1
0	0	1	0
.	.	.	.
.	.	.	.
.	.	.	.
1	0	1	0

Fig. 2. Proposed chromosomes

Wind turbine placement in distribution network based on Genetic Algorithm [20] can be done as following steps:

1) Initial population is generated. Each Chromosome is defined as a string, which contain 0 and 1. The proposed chromosomes are shown in Fig. 2.

0 : wind turbine is not installed  
1 : wind turbine is installed

2) Genetic algorithm of MATLAB software proposed a population of wind turbine situation. Next steps the strings will be used for computing objective function.

3) wind turbines are located in case study and terms of objective function and they are calculated as described below:

3.1) Utilities can schedule optimal operation program in a distribution network to achieve minimum operation cost with satisfying techno-economic constraints. To this end, heat and electrical demand, wind turbine situation, gas and electricity price are considered as inputs of GAMS software to determine optimal operation program of proposed network. After mathematical calculation,  $P_{CHP}$ ,  $P_{Net}$ ,  $P_{Boiler}$  and  $L_{hSold}$  are obtained as outputs.  $P_{CHP}$ ,  $P_{Net}$  will be used as inputs for the next steps.

Other terms of objective function are voltage and loss. As mentioned in previous section, backward forward load flow is used to compute voltage and current of each node and branch. Therefore, line characteristics such as R and X, DER outputs and electrical demand are considered as inputs of load flow. Due to

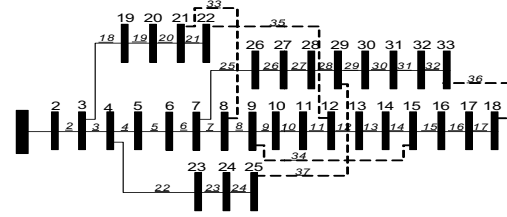


Fig.3. Radial distribution network under study

Table 1. Information of radial distribution network under study

Bus No.	2	3	4	5	6	7	8	9
Load(kW)	36	185.3	42.8	21.4	21.4	7.1	72	21.4
Bus No.	10	11	12	13	14	15	16	17
Load(kW)	21.4	16	354	21	42.8	21.4	21.4	21.4
Bus No.	18	19	20	21	22	23	24	25
Load(kW)	32.1	32.1	32.1	32.1	253	32.1	151.2	593.2
Bus No.	26	27	28	29	30	31	32	33
Load(kW)	21.4	21.4	21.4	43.1	72	55.9	605	21.4

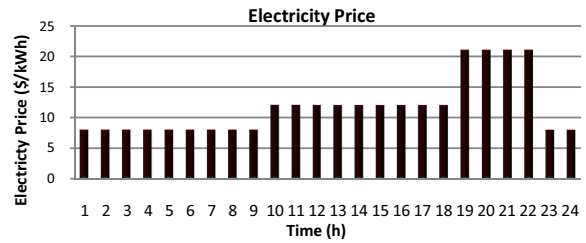


Fig. 4. Network electricity price at 24 hours a day

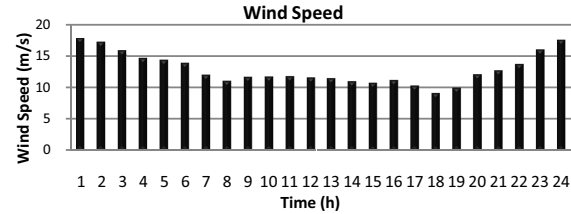


Fig. 5. Wind speed at 24 hours a day

voltage of each node and voltage penalty function, the cost of violation from standard rate is determined. Moreover, the hourly loss cost based on hourly branches current and hourly price are calculated.

3.2) Sum of these terms (voltage penalty cost, electrical losses and operation cost) demonstrates value of each proposed chromosome. This cost will be used for fitness function calculation in next steps.

4) After calculating cost of each initial chromosome, chromosomes with lower profit are eliminated. Remain chromosomes are selected for genetic operation.

5) Selected chromosomes participate in genetic operation to crossover, migration and mutation. New population is proposed.

6) Final cost of chromosomes is calculated in current population and record the best individual.

7) If yes is determined for end of iteration, output will be optimal value, if not, then it goes to step (2).

Proposed method based- multi objective is shown in Fig. 1.

## 4. Simulation Results

Simulation is applied on a 33 bus radial distribution network [21] in Fig.3 considering its load in Table. 1. 12, 25 and 32

**Table 2.**Parameters

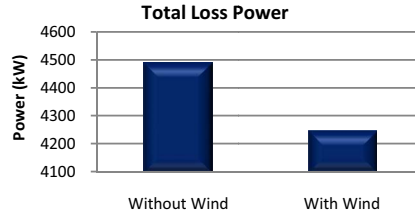
$P^{CHP}_{b12}$	0.4MW	$P_r$	0.2MW	$P^{Netmax}_a$	6MW
$P^{CHP}_{b25}$	0.6MW	$\eta_{ee}^{con}$	0.9	$P^{Netmax}_g$	5.5MW
$\eta_{ge}^{CHP}$	0.4	$w_{ci}$	4	$\pi_g^{Net}$	5Cent
$\eta_{ge}^{CHP}$	0.35	$w_r$	10	$\pi_e^{Net}$	10Cent
$P^B$	1.5MW	$w_{co}$	22	$V_m$	210-250
$\eta_{gh}^B$	0.9	$x$	0.07	$V_r$	220
$C_t^{Ins}$	1500(\$/kW)	$y$	0.01	$c$	3
$C_t^M$	0.01(\$/kW)	$z$	0.03	if,ir,EL	0.12,0.14,20

**Table 3.** Simulation Results

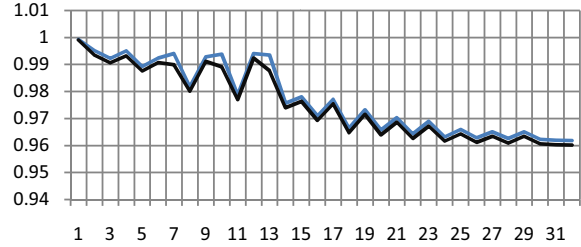
Costs(\$)	Without Wind Placement	With Wind Placement
Operation	12475.14	11487.09
Loss	747.68	709.18
Voltage	2111.8	1987.7

buses are also supplied by another source. CHP produces some part of electrical demands with importing and converting network gas to electricity demand. In addition to preparing some parts of electrical and heat demands, CHP has ability to sell its additional heat and electricity to grid. CHP characteristics are depicted in Table. 2. Boiler is utilized as CHP back up for serving heat demands. Its aspects are also shown in Table. 2. Network electricity prices are illustrated in Fig. 4. Wind turbine aspects are shown in Table. 2. Potential of wind speed of region is employed from world weather website in Fig. 5 [22]. Voltage penalties function and other network parameters are shown in Table.2. Simulation results are summarized in Table.3. Optimal place of wind are recognized. Operation ,loss costs and voltage penalties are also compared with and without turbine in the network. Loss power and voltage profile are compared with and without wind allocation in Fig.6 and Fig.7 in sequence.

CPLEX solver of GAMS is employed to model and optimally operate multi carrier energy networks powers. Genetic Algorithm of MATLAB is used to optimal place of wind turbine with considering loss and voltage improvement in objective function. GAMS and MATLAB interface comment is used to transfer power exchanges with multi carrier networks. Observing Table.5 reveals that the result of minimized costs in objective function is recognizing bus 6 and bus 22 as optimal place for wind turbine. It occurs because cumulation of electrical demands are together with operation costs increase. Rising electrical demands cause power loss and voltage drop increase in distribution electrical network. On the other hand, more power loss and voltage drop cause increasing loss costs and voltage penalties in networks. Objective function finds a best solution for wind turbine placement for improving above terms. Evaluation of operation, loss costs and voltage penalties shows that installation of wind turbine mostly effect on operation costs reduction till 8%. Loss power reduction till 5% and operation costs reduction is sensibly seen after wind turbine optimal placement. Comparison of above terms costs shows that less impact occurs in voltage profile improvement. Wind turbine tends to place where electrical demands cumulation is more at end of feeder in order to improve voltage profile till 0.5%. Due to CHP place at end of feeder and situation of candidate places near to CHP, wind turbine is optimally placed far from CHP and near to candidate places with more demands cumulation. Hence, voltage profile is improved less than operation costs and loss.



**Fig. 6.** Total loss power before and after wind turbine placement



**Fig. 7.** Voltage Profile before and after wind turbine placement

### 5. Conclusion

Nowadays, common energy infrastructures such as gas and electricity networks are utilized independent of each other. Smart grid enables DERs to advanced technologies. CHP is a great example of distributed generation which allows integrating electricity and gas networks with its significant benefits; reliability, efficiency and operation costs improvement. Energy hub has been originated as a new approach to cope with optimal operation and planning of combined networks. Wind is one of the important resources which is utilized in the world as a free and clean energy more and more. Optimal placement of wind turbine in multi carrier energy networks in presence of CHP originates novel challenge which is taken into account in this paper. A multi objective function is formulated to find optimal placement of wind turbine in multi carrier energy networks. Multi carrier networks operation costs, loss cost and voltage penalties are considered in the function. Simulation carries out a 33 bus radial distribution network which is also supplied with CHP in some buses as another electricity produce source. CPLEX solver of GAMS and Genetic Algorithm of MATLAB was employed to solve the problem. Simulation results reveal optimal location of wind turbine in multi carrier energy networks in presence of CHP. Results show that optimal placement of wind turbine occurs in location with cumulation in electrical demands and improves operation costs till 8% and loss costs till 5%. It shows the importance of wind turbine installation on operation costs. Results also demonstrate optimal place of the turbine can improve voltage profile and voltage penalties till 0.5 %. Voltage profile improvement occurs less than operation and loss costs because the turbine tends to place in the location with cumulation of electrical demands at the end of feeder. Whatever wind turbine capacity increases, operation and loss costs decrease. In addition, candidate places have been situated at the end of feeder which is near to CHP. Therefore, CHP usually serves related buses. Hence, wind turbine is placed in cumulative places with electrical demands instead of locating at the end of feeder. Therefore, voltage profile is improved less

than operation and loss costs. Generally speaking, wind turbine is optimally allocated in multi carrier energy networks in presence of CHP with improving operation costs, loss and voltage profile.

### References

- [1] R. H. Lasseter, "Micro grid," in *Proc. 2002 IEEE Power Engineering Society Winter Meeting Conf.*, New York, USA.
- [2] R. Frik, P.Favre-Perrod, "Proposal for a multi-functional energy bus and its interlink with generation and consumption", High voltage Laboratory, ETH Zurich, 2004.
- [3] M. Geidl, G. Koepfel, P. Favre-Perrod, B. Klockl, G. Andersson, K. Frohlich, "Energy hubs for the future," *IEEE Trans. Power and Energy Magazine*, vol. 5, no.1, pp. 24-30, 2007.
- [4] M. Geidl, G. Andersson, "Optimal power flow of multiple energy carriers," *IEEE Trans. Power Systems*, vol. 22, no.1, pp. 145-155, 2007.
- [5] M. Geidl, G. Andersson, "Optimal coupling of energy infrastructure," in *Proc. 2007 IEEE Power Tech Conf.*, Lausanne, Switzerland, pp. 1398-1403.
- [6] M. Schuzle, L. Friedrich, M. Gautschi, " Modeling and optimization of renewable: applying the energy hub approach, in *Proc. 2008 IEEE Sustainable Energy Technology Conf.*, Singapore, pp. 83-88.
- [7] T. Krause, F. Kienzle, L. Yang, G. Andersson, "Modeling interconnected national energy systems using an energy hub approach," in *Proc. 2011 IEEE Power Tech Conf.*, Trondheim, Norway, pp. 1-7.
- [8] M. Salimi, H. Ghasemi, S. Vaez-zadeh, " Iran's electricity and natural gas networks modeling by means of energy hubs," in *Proc. 2012 IEEE Environment and Electrical Engineering Conf.*, Venice, Italy, pp. 648-654.
- [9] S. Pazouki, M. R. Haghifam, "Market based operation of a hybrid system including wind turbine, solar cells, storage device and interruptible load," in *Proc. 2013 IEEE, Electric Power Distribution Network Companies (EPDC)*, Kermanshah, Iran.
- [10] S. Pazouki, M. R. Haghifam, "Market based short term scheduling in energy hub in presence of responsive loads and renewable resources," in *Proc. 2013 IEEE 22nd International and exhibition on Distribution Network Conf.*, CIRED, Stockholm, Sweden, in press.
- [11] M. Arnold, G. Andersson, "Modeling and optimization of renewable; applying the energy hub approach," in *Proc. 2010 IEEE Power and Energy Society General Meeting Conf.*, Minneapolis, MN, pp. 1-8.
- [12] A. Sheikhi, A. M. Ranjbar, and H. Oraee, "Financial analysis and optimal size and operation for a multi carrier energy systems," *Elsevier, Energy and Building*, vol. 48, pp. 71-78, 2012.
- [13] A. Parisio, C. D. Vecchio, and A. Vaccaro, "A robust optimization to energy hub management," *Elsevier, International Journal of Electrical Power and Energy Systems*, vol. 42, pp. 98-104, 2012.
- [14] A. Shahmohammadi, M. M. Dalvand, M. S. Ghazizade, A. Saliminia "Energy hubs structural and operational linear optimization with energy storage elements," in *Proc. 2011 IEEE Power and Energy Conversion Systems Conf.*, Sharjah, United Arab Emirates, pp. 1-6.
- [15] L. Carradore, R. Turri, "Modeling & simulation of multi vectorenergysystems," in *Proc., 2009 IEEE Power Tech Conf.*, R omania, Bucharest, pp.1-7.
- [16] A. K. Basu, S. Chowdhury, S. P. Chowdhury, "Impact of strategic deployment of CHP-based DERs on micro grid reliability," *IEEE Trans. Power Delivery*, vol. 25, no. 3, July 2010.
- [17] H. Falaghi, M. Ramezani, C. Singh, M. R. Haghifam, "Probabilistic assessment of TTC in power systems including wind power generation," *IEEE System Journal*, vol.6, No.1, pp. 181-189, March 2012.
- [18] M. Moradijoz, M. Parsa. Moghaddam, M. R. Haghifam, E. Alishahi, "A multi-objective optimization problem for allocating parking lots in a distribution network," *Elsevier, International Journal of Electrical Power and Energy System*, " vol. 46, pp. 115-122, 2013.
- [19] M. Lehtonen, M. Jaonen, K. Uusitalo, "Customer voltage density function in distribution system voltage monitoring and control," in *proc. 2002 PSCC Conf.*, Sevilla, Spanish.
- [20] A. Mohsenzadeh, M.R. Haghifam, "Simultaneous placement of conventional and renewable distributed generation using multi objective optimization," in *Proc. 2012 IEEE, Integration of Renewables into Distributed Grid Workshop, CIRED*, Lisbon, Portugal.
- [21] M. E. Baran, and F. F. Wu, "Network reconfiguration in distribution systems for loss reduction and load balancing," *IEEE Trans. Power Delivery*, vol. 4, no. 2, pp. 1401-1407, 1989.
- [22] Available at <http://www.accuweather.com/>