An Environmental Constrained Active-Reactive OPF to Consider The Congestion Effect on Consumers Allocated Cost and System Emission

M. Pourakbari-Kasmaei, M. J. Rider, and J. R. S. Mantovani
Department of Electrical and Electronic Engineering
UNESP
Ilha Solteira, Brazil
mahdi.pourakbari@ieee.org

***Abstract*— In this paper considers the congestion effect on emission and consumers' allocated cost. In order to consider some environmental and operational effects of congestion, an environmental constrained active-reactive optimal power flow (AROPF) considering capability curve is presented. The famous Aumann-Shapley method is used as a pricing methodology to allocate the congestion cost. Two case studies such as 14-bus and 118-bus IEEE test systems are conducted. Results demonstrate although the line outage in power systems leads to increase the total cost, the amount of emission depending on the place where the outage occurs can be more than, less than or equal to the normal conditions' emission. Also results show that although from power sellers' viewpoint the well-known Aumann-Shapley method is a precise pricing method and will shows the real effect of congestion on consumers' cost, from consumers' viewpoint it is not a good method for cost allocation as some consumers will face with cost increment and some others will face with cost decrement.**

Keywords- Aumann-Shapley pricing; active-reactive OPF; regional emission limit; system emission limit; congestion.

I. INTRODUCTION

According to fast growing power demand associated with the fuel cost increase, economic-oriented tools such as economic load dispatch (ED) and optimal power flow (OPF) have become crucial issues in power system operation. As the ED and OPF are used in real-time energy management, they have been considered as the kernel of a power system [1], [2]. In order to have a proper power system considering operational and environmental constraints, the role of a robust and precise tool is completely undeniable. The primal objective of an OPF is to minimize the total cost of active and/or reactive generation considering active and reactive power balance, power flow limits, and active and reactive power generation limits. On the other hand, the profound effect of reactive power on power system security is the inseparable part of a proper power system, as it affects the voltage profile of the system and also it has a close relation with active power generation, where the generation and transfer of reactive power yields to active power loss and hence consumes energy.

There are lots of methodologies to find a solution for OPF where some of them are analytical, and the others are heuristic search methods such as linear programming (LP) [3], Newton-Raphson (NR) [4], nonlinear programming (NLP) [5], quadratic programming (QP) [6], interior point [7], genetic algorithm (GA) [8], miscellaneous artificial intelligent (MAI) [9], evolutionary programming (EP) [10], ant colony optimization (ACO) [11], particle swarm optimization (PSO) [12], fuzzy logic (FL) [13], etc.

Recently, electricity power pricing has become a crucial issue in restructured power system. Spot or real-time pricing of electricity has provided the economic structure for many of new service options. In the literature most of the studies focused on reactive power pricing builds on marginal cost theory, which has been applied in the spot price for real power [14], and this method of electric power pricing does not consider some concepts such as block rate, demand charges, backup charges, and so on, and in this regard the role of energy marketplace is important. The spot price depends on supply and demand conditions at that spot [15], [16]. Real-time pricing of reactive power in most researches are based on active power pricing.

Also in these days there is a growing concern on harmful environmental impacts of generating electricity focusing on pollution [17], [18]. Since 1990 the clean air act amendments (CAAA), the utilities are to modify their design or operational strategies to deplete the pollution and atmospheric emissions [19], [20]. The limitation on producing emission can be considered as system emission limit (EMS) and regional emission limit (EMA) as well.

Power system congestion will effect on pricing and also on amounts of regional and system emission. Transmission congestion occurs when there is not sufficient transmission capacity to meet the transmission service constraints among busses or within a region. In other word a power system will face with a congestion condition when a transmission line flow does not meet the reliability limits. One of the methods that can

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help to increase the line flow and consequently may alleviate the congestion limitations is producing more reactive power to increase the transmission of active power in lines, and then the role of reactive power and its optimal dispatch is very important. Moreover, the electricity cannot be stored economically, and transmission congestion may prevent a free exchange among control areas, then in power systems considering the optimal active and reactive power flow and allocating the congestion cost among consumers are considered as two important problems. The well-known Aumann-Shapley (A-S) pricing method which is based on a game-theoretic framework is a good approach for price allocation [21].

In this paper in order to make a good price allocation, some practical and environmental constraints via a modified OPF is used, where the capability curve, EMS, and EMA are taken into consideration. Effect of congestion on regional and system emission limits is taken into account, and also via the Amann-Shapley pricing method its real effect on consumers allocated cost are considered and the drawback of this method to allocate cost among consumers is considered. In this regard two IEEE test system such as 14-Bus and 118-Bus systems as case studies are conducted.

The present paper is organized as follows: Section II formulates the environmental constrained active-reactive OPF and cost allocation approach; in section III, case study and result are presented, and section IV presents the concluding remarks.

II. Environmental Constrained Active-reactive OPF and Cost Allocation Approach

In this section to consider the effects of congestion on consumers allocated cost and also on regional and system emission, at first a formulation for environmental AROPF under normal and congestion condition is presented and then a method for cost allocation via environmental AROPF is taken into consideration.

A. Environmental Constrained Active-Reactive OPF

The objective function of an OPF in normal operation condition is as follows:

$$Min\ f_N = \sum_{i=1}^{ng} C_i(Pg_i) \qquad (1)$$

where, *ng* is the number of generator, and $C_i(Pg_i)$ is the cost of active power and approximated by a quadratic function such as (2).

$$C_i(Pg_i) = a_i(Pg_i)^2 + b_i Pg_i + c_i \qquad (2)$$

where a_i, b_i, and c_i are cost coefficients and P_{g_i} is the active power generation.

System operating constraints are as follows:

$$Qg_i - Qd_i - Q_i\ (V,\delta\ ,t) = 0,\quad i = 1,\ldots,ng \qquad (3)$$

$$Pg_i - Pd_i - P_i\ (V,\delta\ ,t) = 0,\quad i = 1,\ldots,ng \qquad (4)$$

$$\left| fl_{ik}(V,\delta\ ,t)\right| \le fl_{ik}^{\max},\quad i,k = 1,\ldots,nl \qquad (5)$$

$$V_i^{\min} \le V_i \le V_i^{\max},\qquad i = 1,\ldots,ng \qquad (6)$$

$$Pg_i^{\min} \le Pg_i \le Pg_i^M(Qg_i),\qquad i = 1,\ldots,ng \qquad (7)$$

$$Qg_i^{\min} \le Qg_i \le Qg_i^{\max},\qquad i = 1,\ldots,ng \qquad (8)$$

$$t_{ik}^{\min} \le t_{ik} \le t_{ik}^{\max},\qquad i,k = 1,\ \ldots, nl \qquad (9)$$

$$\sum_{i\in A} Em_i \le EMA \qquad (10)$$

$$\sum_{i\in ng} Em_i \le EMS \qquad (11)$$

where Qg_i is reactive power generation, Qd_i, and Pd_i are active and reactive demand, Q_i and P_i are active and reactive injection, V_i is voltage magnitude, t_{lk} is transfer tap, $Pg_i^M(Qg_i)$ is the maximum active power limit based on the reactive power generation, Em_i is the generation's emission calculate by (12), EMA and EMS are regional and system emission limits. The amount of emission is calculated by a quadratic function as (13).

$$Em_i(Pg_i) = \alpha_i(Pg_i)^2 + \beta_i Pg_i + \gamma_i \qquad (12)$$

where, α_i, β_i, and γ_i are the emission coefficients.

The $Pg_i^M(Qg_i)$ limit is imposed by the capability curve and turbine, where it has three different portions as it has shown in Figure 1.

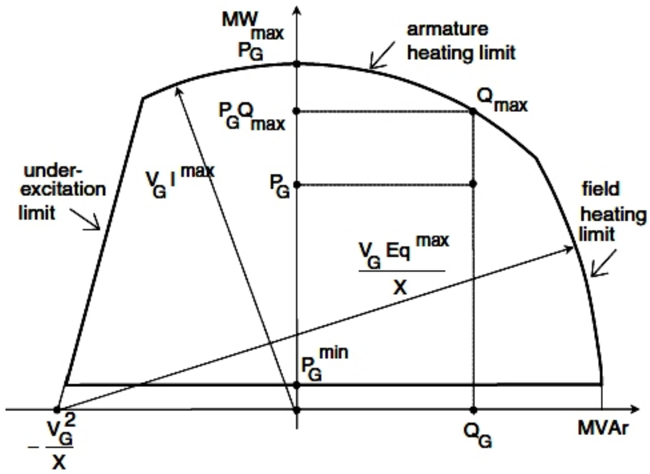

Figure 1. Capability curve of synchronous generator

$$Pg_i^M(Qg_i) = \begin{cases} \left(\dfrac{Pg_i'}{Qg_i' - Pg_i^{\min}}\right)(Qg_i - Qg_i^{\min}), & Qg_i^{\min} \le Qg_i \le Qg_i' \\ \sqrt{Sg_i^2 - Qg_i^2}, & Qg_i' \le Qg_i \le Qg_i'' \\ \dfrac{\sqrt{V_i^2(E_i^{\max})^2 - (Qg_i Xs_i + V_i^2)^2}}{Xs_i}, & Qg_i'' \le Qg_i \le Qg_i^{\max} \end{cases} \qquad (13)$$

$E_i^{\max}$ as the maximum excitation voltage is calculated by (14).

$$E_i^{\max} = \sqrt{\frac{(Xs_i Pg_i'')^2 + (Xs_i Pg_i'' + V_i^2)^2}{V_i^2}} \quad (14)$$

When the congestion occurs, the optimal solution will change based on the power system rebalancing. In this paper in order to consider the transmission line outage, the following formulation is used.

$$Min\ f_C = \sum_{i=1}^{ng} C_i(Pg_i^C) \quad (15)$$

where $C_i(Pg_i^C)$ is the cost of active power as (16).

$$C_i(Pg_i^C) = a_i(Pg_i^C)^2 + b_i Pg_i^C + c_i \quad (16)$$

where Pg_i^C is the active power generation at congestion event.

System operating constraints are as follows:

$$Qg_i^C - Qd_i - Q_i^C(V^C, \delta^C, t^C) = 0, \qquad i = 1,...,ng \quad (17)$$

$$Pg_i^C - Pd_i - P_i^C(V^C, \delta^C, t^C) = 0, \qquad i = 1,...,ng \quad (18)$$

$$\left| fl_{ik}^C(V^C, \delta^C, t^C) \right| \le fl_{ik}^{\max}, \qquad i,k = 1,...,nl \quad (19)$$

$$V_i^{\min} \le V_i^C \le V_i^{\max}, \qquad i = 1,...,ng \quad (20)$$

$$Pg_i^{\min} \le Pg_i^C \le Pg_i^M(Qg_i^C), \quad i = 1,...,ng \quad (21)$$

$$Qg_i^{\min} \le Qg_i^C \le Qg_i^{\max}, \quad i = 1,...,ng \quad (22)$$

$$t_{ik}^{\min} \le t_{ik}^C \le t_{ik}^{\max}, \qquad i,k = 1, ...,nl \quad (23)$$

$$\sum_{i \in A} Em_i^C \le EMA \quad (24)$$

$$\sum_{i \in ng} Em_i^C \le EMS \quad (25)$$

B. Cost allocation Approach

Sometimes congestion in power system occurs after a sudden increase in demand, sometimes because of a transmission line outage or generally it occurs when there is not sufficient transmission capacity to meet the transmission service constraints. Real-time congestion pricing can show the effect of congestion on consumers. The allocated congestion price is calculated by (26).

$$C_Q = [\overline{Pd_i}\ \ \overline{Qd_i}] \begin{bmatrix} \overline{\eta}_{Pd_i} \\ \overline{\eta}_{Qd_i} \end{bmatrix} \quad (26)$$

In order to find the pricing factors, a well-known, robust and powerful game theoretic method of Aumann-Shapley is used. The pricing factors are defined using marginal costs, then at first the short-run active and reactive marginal cost of power consumers located at node *i* are computed by (27) and (28) [10].

$$\lambda_{Pd_i} = \frac{\partial(f_N)}{Pd_i}, \quad \lambda_{Qd_i} = \frac{\partial(f_N)}{Qd_i} \quad (27)$$

$$\lambda'_{Pd_i} = \frac{\partial(f_C)}{Pd_i}, \quad \lambda'_{Qd_i} = \frac{\partial(f_C)}{Qd_i} \quad (28)$$

To compute the prices to calculate consumers' costs, the active and reactive demands at each bus is divided to small quantities and usually divided by a large number, *K*.

$$\Delta Pd_i = \frac{Pd_i}{K} \quad (29)$$

$$\Delta Qd_i = \frac{Qd_i}{K} \quad (30)$$

The procedure of sequentially solving the objective functions of f_N and f_C for *K* times, where the amount of demands are defined by (31) and (32).

$$Pd_i(k) = k \cdot \Delta Pd_i, \qquad k = 1,...,K \quad (31)$$

$$Qd_i(k) = k \cdot \Delta Qd_i, \qquad k = 1,...,K \quad (32)$$

As the destination is to find the reactive power pricing then the differences between marginal costs of two aforementioned steps is taken into account as it shown by Eq. (28) and Eq. (29).

$$\eta_{Pd_i} = \frac{1}{K}\sum_{k=1}^{K}[\lambda'_{Pd_i}(Pd_i(k)) - \lambda_{Pd_i}(Pd_i(k))] \quad (33)$$

$$\eta_{Qd_i} = \frac{1}{K}\sum_{k=1}^{K}[\lambda'_{Qd_i}(Qd_i(k)) - \lambda_{Qd_i}(Qd_i(k))] \quad (34)$$

where, the $\lambda_{(\cdot)}(\cdot)$ is the marginal cost of active/reactive at demand level *k* defined in Eq. (26) and Eq. (27).

III. CASE STUDIES AND RESULTS

Two case studies are considered in order to show the effects of congestion on consumers' allocated cost, regional emission, and system emission. The first case is the IEEE 14-Bus test system with two regional emission limits and the second one is the IEEE 118-Bus test system with 2 regional emission limits. In both cases the power factor is held as 0.9. The presented approach finds the optimal solution using a modeling language for mathematical programming (AMPL) [22].

A. IEEE 14-Bus system

This system contains 11 load busses, 5 generators with 20 transmission lines [23]. The environmental active-reactive OPF is applied to this system and the incurred cost by congestion is allocated between consumers. For this system, in normal condition (NC) and congestion condition (CC), three different cases such as: system without emission limits (NL), system with regional emission limit (EMA), and system with regional and system emission limits (EMA&EMS) are taken into consideration. For this case study, EMS is supposed to be 150 kg. The transmission line outage is taken place for the line between busses 1 and 2. The additional data of this system are given in Table I.

TABLE I. ADDITIONAL DATA, IEEE 14-BUS SYSTEM

Bus	α_i	β_i	γ_i	S [p.u]	Xs	*EMA*	
						Region	*Limit(Kg)*
1	0.007	-0.52	25.8	3.324	0.825	1	115
2	0.007	-0.54	26.9	1.4	0.925		
3	0.004	-0.49	30.1	1.0	1.098	2	190
6	0.004	-0.53	25.3	1.0	1.098		
8	0.008	-0.40	23.9	1.0	1.098		

TABLE II. GENERATION AND ALLOCATED COSTS UNDER NORMAL AND CONGESTION CONDITION FOR NL, EMA, AND EMA&EMS CASES, IEEE 14-BUS SYSTEM

Bus	Cost of NC ($)			Cost of CC ($)			Allocated Cost ($)		
	NL	EMA	EMA&EMS	NL	EMA	EMA&EMS	NL	EMA	EMA&EMS
1	5511.917	3824.8406	3513.0006	4110.4806	3824.274	3451.2309	0	0	0
2	1071.5526	1132.2144	1094.7796	1215.4209	1221.5089	1203.5589	47.2174	35.0936	31.3149
3	1158.4625	1735.4751	1744.3555	2342.0499	2448.0479	2311.4580	163.8474	122.4735	106.6760
4	0	0	0	0	0	0	66.6554	42.7693	37.8867
5	0	0	0	0	0	0	9.0726	5.0922	4.4850
6	0	415.1848	1134.8879	0	0	665.9238	13.7327	7.8737	7.5750
7	0	0	0	0	0	0	0	0	0
8	339.2537	1105.4673	790.0664	817.1306	997.1544	888.9455	0	0	0
9	0	0	0	0	0	0	41.6857	26.9688	22.6970
10	0	0	0	0	0	0	12.5418	8.0005	6.8448
11	0	0	0	0	0	0	4.5872	2.7872	2.5000
12	0	0	0	0	0	0	7.5157	4.2902	4.0753
13	0	0	0	0	0	0	17.0482	9.9269	9.2830
14	0	0	0	0	0	0	20.2710	12.5458	11.0007
Total	8081.1858	8213.1822	8277.09	8485.082	8490.9852	8521.1171	404.1751	277.8217	244.3384

TABLE I. ADDITIONAL DATA, IEEE 14-BUS SYSTEM

Bus	α_i	β_i	γ_i	*S* [p.u]	*Xs*	*EMA*	
						Region	*Limit(Kg)*
1	0.007	-0.52	25.8	3.324	0.825	1	115
2	0.007	-0.54	26.9	1.4	0.925		
3	0.004	-0.49	30.1	1.0	1.098	2	190
6	0.004	-0.53	25.3	1.0	1.098		
8	0.008	-0.40	23.9	1.0	1.098		

Table II contains the fluctuations of generation and allocated costs of 14-bus system under normal and congestion conditions for NL, EMA, and EMA&EMS cases. Results demonstrate that for both NC and CC, when emission limits are taken into account, the total generation cost is increased. On the other hand, after considering emission limits the allocated costs have decreased; when the emission limits taken into account the gap between the generation costs under NC and CC conditions for the limited cases of EMA and EMA&EMS will decrease, then this is why the allocated costs have faced with a decrease.

TABLE III. PRODUCED EMISSION UNDER NORMAL AND CONGESTION CONDITION FOR NL, EMA, AND EMA&EMS CASES, 14-BUS SYSTEM

Bus	Emission of NC (Kg)			Emission of CC (Kg)		
	NL	EMA	EMA&EMS	NL	EMA	EMA&EMS
1	189.12	98.51	84.43	112.22	98.49	81.75
2	16.51	16.49	16.50	16.51	16.51	16.50
3	19.32	16.44	16.40	15.14	15.10	15.17
6	25.30	20.24	13.54	25.3	25.3	17.61
8	21.09	18.95	19.13	19.08	18.90	18.97
Total	271.34	**170.63**	150.00	188.25	**174.30**	150.00

Table III shows the produced emission under different conditions for NL, EMA, and EMA&EMS states. Results show that as it was expected, based on the conflicting objectives of cost and emission and by considering the increasing order of total cost for NL, EMA, and EMA&EMS states, the amounts of emission for these states are sorted in decreasing order. Although considering NL and CC for EMA&EMS state shows that the CC's cost has increased (Table II), in both NC and CC the amounts of emission has kept constant and hit the upper limit. The bold face numbers in this table reveal that although in Table II the cost of EM state after congestion has faced with an increase about 278 $ (8213.18 $ for NC, 8490.98 $ for CC), the corresponding emission has faced with an increase about 4 Kg (170.63 Kg for NC, 174.30 Kg for CC). The reason is based on the place where the outage has occurred and expounding Table III reveal that it has led to emission increase on busses 2, 6, and 8 which are highlighted part of the table. This issue is discussed in detail via the IEEE 118-bus test system.

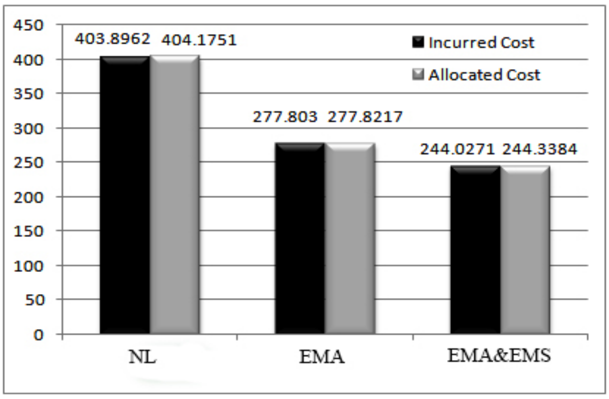

Figure 2. Allocated cost for NL, EMA, and EMA&EMS ($), IEEE 14-Bus system

Figure 2 compares the incurred cost and the allocated cost of NL, EMA, and EMA&EMS. Results show that the allocated cost can cover the incurred cost while the allocation errors for NL, EMA, and EMA&EMS cases are 0.069%, 0.0067%, and 0.1276% respectively which are acceptable errors.

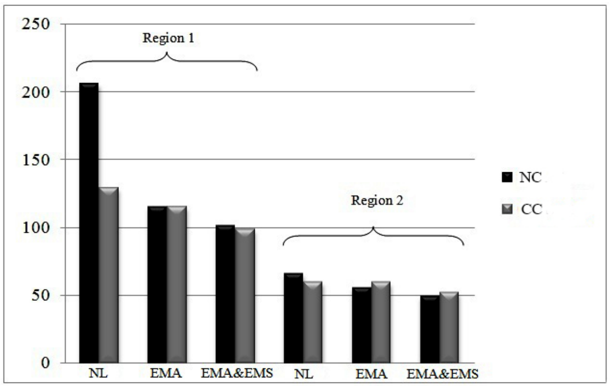

Figure 3. Regional emission for NL, EMA, and EMA&EMS (Kg) , IEEE 14-Bus system

B. IEEE 118-Bus system

This system has 99 Load busses, 186 transmission lines, 54 generators, and 2 critical emission regions. The first region contains generators of busses 70, 73, 74, 76, 77, and 80 and the second region contains generators of busses 89, 90, 91, and 92. In this case study we focus on the places where the congestion occurs; two different study in congestion is taken into account, where in each study three outages of transmission lines are considered. The regional and system emission limitations are 1250 kg and 7500 kg respectively.

1) Normal lines outage: in this case the outage of three normal lines are considered; these lines are called normal lines because they do not transmit high amount of active and reactive power. The outaged lines and the active and reactive transmitted powers of these lines under normal condition and for both of NL and EMA&EMS conditions are in Table IV. In this case, for normal condition (NC) and contingency condition (CC) two studies on NL and EMA&EMS conditions are considered. Costs and the amounts of emission in region 1 (R1), region 2 (R2), and the total system cost and emission system are in Table V.

TABLE IV
TRANSMITTED POWERS OF CANDIDATE LINES FOR OUTAGE, IEEE 118-BUS SYSTEM

Case	Candidate Lines					
	from 69 to 77		from 80 to 81		from 94 to 96	
	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
NL	72.48	-11.91	7.67	-60.20	14.99	-2.88
EMA&EMS	73.78	-13.02	-4.26	-59.48	15.95	-3.13

From Table V, it is clear that in NL condition and for R1, R2, and total consideration, amounts of emissions have faced with an increase in CC comparing with NC, also the corresponding costs have faced with an increase. For EMA&EMS case, amounts of emission for CC is more than or equal to NC's emission. The difference part of Table V confirms that the outage of aforementioned lines yield to increase in cost and emission. Also the considerable impact of this outage is related with the cost of first region while for NL and EMA&EMS cases its effect on this region are respectively 1228.57 % and 978.82 % more than its effect on the total costs.

TABLE V
RESULTS OF NORMAL LINES OUTAGE

Case	Condition	Emission (Kg)			Cost ($)		
		R1	R2	Total	R1	R2	Total
NL	NC	1434.4	1360.4	8209.0	14107.8	14185.9	129660.7
	CC	1525.4	1399.5	8255.8	15130.8	14443.5	129737.7
	Difference	91.0	39.1	46.8	1023.0	257.6	77
EMA& EMS	NC	1250.0	1244.5	7500	14042.6	13406.5	129756.6
	CC	1250.0	1250.0	7500	15122.5	13441.1	129856.7
	Difference	0.0	5.5	0	1079.9	34.6	100.1

The allocated costs of normal outage case under NL and EMA&EMS conditions are respectively 78.03 $ and 101.2 $ corresponding to 77 $ and 100.1 $ of incurred costs. In this case the allocation errors of NL and EMA&EMS are %1.34 and %0.92 respectively.

Figure 4 shows the congestion allocated cost between consumers under NL condition. Expounding this figure from consumers' viewpoint reveals that, congestion can have a positive or negative effect on their cost. In this figure, the consumers with negative congestion allocated cost will face with a decrease in cost, whereas the consumers with positive congestion allocated cost will face with an increase on their cost. This happens as in outage condition, some areas will face with more limitation to receive or transmit the power to other area, then the optimal solution will change and consequently the additional allocated cost among consumers of some areas are negative, and on the other hand some consumers will face with positive additional allocated cost.

Although the Aumann-Shapley pricing method is an acceptable method to cover the incurred cost, but Figure 4 shows that it is not fair for all consumers as it increases some consumers cost and decrease some other consumers' cost.

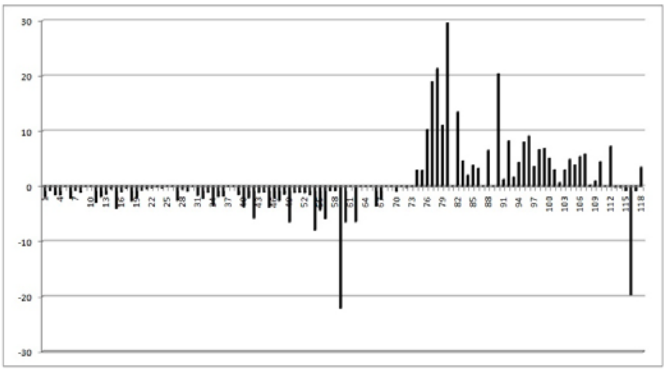

Figure 4. Additional allocated cost for normal outage case under NL condition, IEEE 118-Bus System

2) Critical Line outage: in this case two lines are under normal operation (69-77 and 80-81) but the other one (8-9) is under critical operation. The candidate lines and the active and reactive transmitted powers of these lines under normal condition and for both of NL and EMA&EMS conditions are in Table VI. Output active power of line 8-9 shows its critical role in this system.

TABLE VI
TRANSMITTED POWERS OF CANDIDATE LINES FOR OUTAGE, , IEEE 118-BUS SYSTEM

Case	Candidate Lines					
	from 69 to 77		from 80 to 81		from 8 to 9	
	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
NL	72.48	-11.91	7.67	-60.20	-394.58	-74.80
EMA&EMS	73.78	-13.02	-4.26	-59.48	-379.72	-79.01

TABLE VII
RESULTS OF CRITICAL LINE OUTAGE, , IEEE 118-BUS SYSTEM

Case	Condition	Emission (Kg)			Cost ($)		
		R1	R2	Total	R1	R2	Total
NL	NC	1434.4	1360.4	8209.0	14107.8	14185.9	129660.7
	CC	1464.0	1374.3	7759.9	14830.3	14277.7	133897.9
	Difference	29.6	13.9	-449.1	722.5	91.8	4237.2
EMA& EMS	NC	1250.0	1244.5	7500.0	13965.9	13406.5	129756.6
	CC	1250.0	1250.0	7479.9	13901.8	13444.2	133941.9
	Difference	0.0	5.5	-20.1	-64.1	37.7	4185.3

Table VII shows the regional and total costs and emissions for NL and EMA&EMS cases under normal and contingency conditions. Considering differences show that unlike Table V in this critical outage, the considerable impact is on total cost and emission where in both NL and EMA&EMS cases total costs have faced with an increase corresponding with a total decrease in emission. On the other hand, unlike the NL case which in both regional cost and regional emission has faced with an increment, in EMA&EMS case, the first regional cost has faced with a decrement corresponding with no change on environmental emission (because it has hit its limit). In this case the allocated cost for no limit condition is 4242.04 $ and for limited condition is 4188.02 corresponding with 4237.2 $ and 4185.3 $ of incurred cost respectively. The allocating errors are %1.14 and %0.64 respectively.

IV. Conclusions

In order to find the effects of congestion on regional and system emission limits and also on consumers allocated cost, two case studies has conducted. Results show that the effects of congestion have a close relation with the place, critical role, and the region of outage transmission line such that in some cases increasing in cost yields to decrease in emission and in some cases increasing cost yields to increasing in emission. Also results show that, although the Aumann-Shapley pricing method is a good, precise and robust method to cover the incurred costs which is really important from sellers viewpoint, this method is not good to allocate the incurred cost among consumers as it works based on lagrangian multipliers and in congestion condition the power flow will find another solution than normal one for demands which yields to increase or decrease in some consumers cost.

It is recommended to consider a method to allocate the incurred cost such that it satisfies the seller and consumers desired objective.

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