Multicriteria Methodology to Assess the Market Power in the Secondary Regulation of Peruvian Electric Frequency

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***Abstract*— The ancillary services markets for the electric power system have been increasing relevance the last decade. Inside, the secondary regulation market is increasing because the electric generation sources based on power electronics converters produces a decrease in the inertia of the electric power system, instability of the frequency and changes in the automatic generation control systems.**

This research evaluates the market power for secondary regulation reserve and quantify it through the Herfindhal-Hirschman index. The methodology of grey clustering and entropy weight allows distinguishing which generation companies gather the market power and quantify it according to five criterions: total duration accumulated during the annual regulation, average energy of the maximum registered reserve during the annual regulation, maximum reserve capacity registered during the annual regulation, minimum reserve capacity registered during the annual regulation and average reserve capacity during the annual regulation. Moreover, the result shows a multicriteria Herfindhal-Hirschman index calculation.

***Index Terms*— Assessment, Electricity Market, Secondary Regulation Reserve, Market power, Grey Clustering, Entropy Weight**

I. INTRODUCTION

Beyond the normal operation of electrical power systems, there are periods of imbalance between generated and consumed power due to sudden and unforeseen changes in electrical demand or a decrease in generation whose most likely cause is a failure in the generating units. In any situation, the electricity system is protected against these sudden and natural variations in load and generators by means of electric frequency control mechanisms [1].

The electric frequency control is made up of several levels of control. Each level has activation times ranging from seconds to hours of operation. The activation of these controls is a mix of automatic control and manual control, which ensure that the operation of the electrical system is close to the reference electrical frequency [2].

Within electric frequency control there is secondary frequency regulation (SFR), it is an automatic control, i.e. it comes from a supplementary control restricted to an assigned active power band or reserve. Despite the present technical advances in controllers (fuzzy controllers, model based predictive controllers among others), most of the electrical companies trust the elaboration of the control effort to the traditional control (Proportional integrative controllers, PI) [3] due to its excellent performance and easy parameter tunning also its compatibility with modern techniques of auto-tunning.

In most electricity markets today, secondary regulation reserve belongs to an energy and power parallel market. This is not always true as there are countries for which it is an obligation and no payment is made for the service, naturally in these countries the amount of renewable generation is minimal. In Perú this service is paid.

The secondary regulation reserve is required for the secondary frequency regulation and has two different objectives: to return the primary reserve to its neutral state and to normalize the power flow on the interconnections to the programmed one. In terms of payment, this is a service that assigns a capacity or band of power. The band is assigned in a monthly period usually, the band usually includes the range of rise and fall, i.e., is symmetrical. The way in which this electricity market is transacted is usually based on bilateral [4] contracts negotiated between distribution companies, commercial-industrial consumers, and generation companies directly and through non-public negotiation.

Finally, it should be noted that with the current impact of renewable energies [5] (in Perú, using measures each 30 minutes

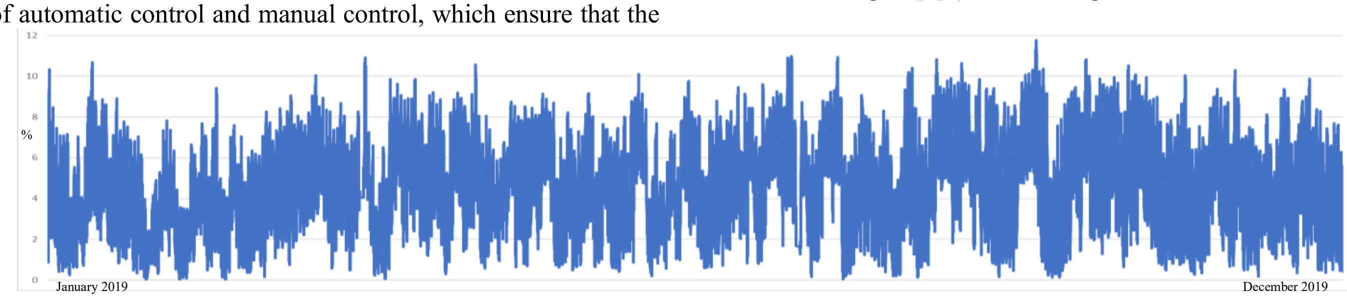

Fig. 1 Percentage of wind and solar electricity generation in Peru with regard to the total generation, during the year 2019. The maximum value is 11.79 %

Fig. 1), the market for ancillary services is finally beginning to take on greater relevance. This research will contribute to evaluate shared market of secondary frequency regulation in the multicriteria way i.e. using Grey clustering and entropy weight (GC & EW) method and then calculating the Herfindhal-Hirschman Index (HHI) using the weighted results.

II. State of the Art

Multi-criteria evaluation began with Saaty's work on the analytical network process, ANP, around 1980 with the Analytic Hierarchy Process, AHP [6]. Recently, numerous researches related to renewable energy, energy planning based on multi-criteria methodologies have been taken up again. By their type of research and chronologically: energy planning using Fuzzy VIKOR [7], evaluation of supply alternatives and decision making in renewable energy using VIKOR [8], analysis of environmental conflicts and social impact solved with grey clustering methodologies GCEW (Grey clustering and entropy weight) [9], power quality using grey relational analysis [10], decision making using AHP-PROMETHEE [11], energy planning using VIKOR [12], renewable energy using AHP [13], decision making using ANP-VIKOR [14]. As for the assessment of market power, the Hirschman index is a generally accepted indicator [15].

III. Methodology

The GCEW methodology consists of using triangular functions (Fig. 2) to calculate a table of grades. The maximum value of the triangular function is 1 and the minimum value is 0. In order to increase the understanding of the grade, consecutive triangular functions are created (1)-(3), the restrictions represent domains for the piecewise function. The vertices of each triangular function are designed and coincide with the classes gray k = 0, 1, ..., s, s + 1→ λ_k is selected for each parameter and stored in Table II. Each class gray represents a value of units equal to the parameter to be evaluated. The way each gray class is chosen can be subjective or rule-based. If it is subjective, it should be intended that the triangular functions enclose the measurements of the table of aggregated values, Table I. For gray classes with s + 1 = 4 then k_{max} = 3, which indicates three triangular functions. Likewise, the first triangular function will limit in minimum magnitudes (1) and the last in maximum magnitudes (3).

TABLE I. Aggregated values for each criterion for each secondary regulation power plant during 2019 year

COES Code	Generation company, genco (C1)	Code	Electric power plant (C2)	C3[a]	C4[b]	C5[c]	C6[d]	C7[e]
URS-CLP-001	CELEPSA	1	(G1) C.H. PLATANAL	5061.2	226549.9	83.4	12.0	44.9
URS-ENL-001	ENEL GENERACION PERU S.A.A.	2	(G2) C.H. HUINCO	6127.2	517302.8	188.0	12.0	85.4
URS-ENL-002	ENEL GENERACION PERU S.A.A.	2	(G3) C.H. MATUCANA	4476.7	182012.0	109.0	12.0	40.8
URS-STK-002	STATKRAFT	3	(G4) C.H. MALPASO	1455.5	25469.4	24.0	12.0	17.1
URS-STK-004	STATKRAFT	3	(G5) C.H. CHEVES	1732.8	76545.1	80.0	12.0	44.3
URS-ENG-001	ENGIE	4	(G6) C.T. CHILCA UNO	4104.5	310194.3	298.0	0.0	71.7
URS-KALL-003	KALLPA GENERACION S.A.	5	(G7) C.H. CERRO DEL AGUILA	3626.7	331052.4	298.0	12.0	90.9
URS-EGN-002	ORAZUL ENERGY PERÚ	6	(G8) C.H. CARHUAQUERO	1377.2	30758.3	58.0	12.0	22.3
URS-KAL-001	KALLPA GENERACION S.A.	5	(G9) C.T. KALLPA	5600.8	768804.4	266.4	35.2	127.0
URS-KAL-002	KALLPA GENERACION S.A.	5	(G10) C.T. LASFLORES	1713.8	106636.8	73.1	0.0	61.5
URS-EGN-001	ORAZUL ENERGY PERÚ	6	(G11) C.H. CAÑON DEL PATO	551.0	27522.1	64.0	12.0	49.5
URS-STK-003	STATKRAFT	3	(G12) C.H. CAHUA	9.4	37.4	4.0	4.0	4.0
URS-ENL-004	ENEL GENERACION PERU S.A.A.	2	(G13) C.T. SANTA ROSA 2	57.1	1924.7	44.2	22.5	33.0
URS-CHI-001	CHINANGO S.A.C.	7	(G14) C.H. CHIMAY	147.3	3199.9	25.0	12.0	22.0

[a] Total time registered and accumulated (h). Source: SFR COES [16]

[b] Average energy of the maximum registered reserve (MWh).

[c] Maximum reserve capacity registered (MW).

[d] Minimum reserve capacity registered (MW).

[e] Average reserve capacity registered (MW).

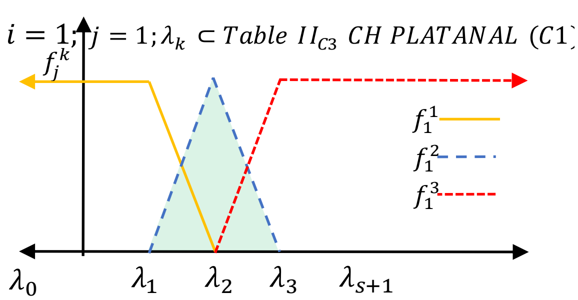

Fig. 2. Grey clustering of triangular functions for each central grey class k=1,2,3 considering the expansion values in upper grey class λ_{s+1} and the expansion in lower grey class λ_0. Ilustrated for C.H. Platanal

$$f_{1=j}^{1=k}(x) = \begin{cases} 1, & x \in [\lambda_{k-1}, \lambda_k] \\ \dfrac{\lambda_{k+1} - x}{\lambda_{k+1} - \lambda_k}, & x \in [\lambda_k, \lambda_{k+1}] \\ 0, & x \notin [\lambda_{k-1}, \lambda_{k+1}] \end{cases} \tag{1}$$

$$f_{1=j}^{2=k}(x) = \begin{cases} 0, & x \notin [\lambda_{k-1}, \lambda_{k+1}] \\ \dfrac{x - \lambda_{k-1}}{\lambda_k - \lambda_{k-1}}, & x \in [\lambda_{k-1}, \lambda_k] \\ \dfrac{\lambda_{k+1} - x}{\lambda_{k+1} - \lambda_k}, & x \in [\lambda_k, \lambda_{k+1}] \end{cases} \tag{2}$$

$$f_{1=j}^{3=k}(x) = \begin{cases} 0, & x \notin [\lambda_{k-1}, \lambda_{k+1}] \\ \dfrac{x - \lambda_{k-1}}{\lambda_k - \lambda_{k-1}}, & x \in [\lambda_{k-1}, \lambda_k] \\ 1, & x > \lambda_k \end{cases} \tag{3}$$

TABLE II. COMPONENTS OF THE GREY CLASSES λ

Evaluation Parameter	λ_0	λ_1	λ_2	λ_3	λ_{s+1}
C3	-inf	100	1500	5000	inf
C4	-inf	100000	200000	500000	inf
C5	-inf	64	150	250	inf
C6	-inf	5	22.5	30	inf
C7	-inf	33	71.7	90.9	inf

The evaluation made by triangular functions is a repetitive step for each electric power plant i. The results for C.H. Platanal and using (1)-(3) for each parameter is stored in Table III. The impact assessment (4) produces Table IV in percentages respectively for C2 and the grey classes

$$IA_{kj} = \frac{100k f_j^k(x_{ij})}{k_{max}} \tag{4}$$

TABLE III. TRRIANGULAR FUNCTIONS RESULTS FOR C.H. PLATANAL

	C3	C4	C5	C6	C7
$f_1^1(x)$	0.00	0.00	0.77	0.60	0.69
$f_1^2(x)$	0.00	0.91	0.23	0.40	0.31
$f_1^3(x)$	1.00	0.09	0.00	0.00	0.00

TABLE IV. IMPACT ASSESSMENT FOR C.H. PLATANAL

	C3	C4	C5	C6	C7
Low	0.00	0.00	25.83	20.00	23.05
Normal	0.00	60.77	15.01	26.67	20.57
High	100.00	8.85	0.00	0.00	0.00

For summarize the results of impact assessment for generation units use (5) to generate Table V

$$z_{ij} = \sum_{k=1}^{k_{max}} IA_{kj} \tag{5}$$

TABLE V. TOTAL IMPACT ASSESSMENT FOR ALL ELECTRIC POWER PLANTS (%)

C2	C3	C4	C5	C6	C7
G1	100.00	69.62	40.84	46.67	43.62
G2	100.00	100.00	79.33	46.67	90.43
G3	95.02	60.67	50.78	46.63	40.01
G4	65.61	33.33	33.33	46.67	33.33
G5	68.88	33.33	39.53	46.67	43.03
G6	91.47	78.91	100.00	33.33	66.66
G7	86.92	81.23	100.00	46.67	100.00
G8	63.74	33.33	33.33	46.67	33.33
G9	100.00	100.00	100.00	100.00	100.00
G10	68.70	35.55	36.87	33.33	57.90
G11	44.07	33.33	33.33	46.67	47.51
G12	33.33	33.33	33.33	33.33	33.33
G13	33.33	33.33	33.33	66.67	33.37
G14	34.46	33.33	33.33	46.67	33.33

This step is required to achieve the entropy weight values w_j (8), previously H_j (6) and div_j (7) should be calculated. For WNVIA a sum of a product element by element is done between w_j rows and the rows of Table VII.

$$H_j = -\frac{1}{\ln(i_{max})} \sum_{i=1}^{i_{max}} P_{ij} \ln(P_{ij}) \tag{6}$$

$$div_j = 1 - H_j \tag{7}$$

$$w_j = \frac{div_j}{\sum_{j=1}^{j_{max}} div_j} \tag{8}$$

TABLE VI. CALCULATION OF ENTROPY, DIVERGENCE AND WEIGHTING OF ENTROPY w_j FOR THE TRIANGULAR FUNCTIONS RESULTS

	C3	C4	C5	C6	C7
H_j	0.97	0.96	0.96	0.98	0.96
div_j	0.03	0.04	0.04	0.02	0.04
w_j	0.16	0.25	0.27	0.11	0.22

Table VII is calculated using (9) for normalize

$$P_{ij} = \frac{z_{ij}}{\sum_{i=1}^{i_{max}} z_{ij}} \tag{9}$$

TABLE VII. NORMALIZED IMPACT ASSESSMENT FOR ALL ELECTRIC POWER PLANTS

C2	C3	C4	C5	C6	C7
G1	0.10	0.09	0.05	0.07	0.06
G2	0.10	0.13	0.11	0.07	0.12
G3	0.10	0.08	0.07	0.07	0.05
G4	0.07	0.04	0.04	0.07	0.04
G5	0.07	0.04	0.05	0.07	0.06
G6	0.09	0.10	0.13	0.05	0.09
G7	0.09	0.11	0.13	0.07	0.13
G8	0.06	0.04	0.04	0.07	0.04
G9	0.10	0.13	0.13	0.15	0.13
G10	0.07	0.05	0.05	0.05	0.08
G11	0.04	0.04	0.04	0.07	0.06
G12	0.03	0.04	0.04	0.05	0.04
G13	0.03	0.04	0.04	0.10	0.04
G14	0.03	0.04	0.04	0.07	0.04

TABLE VIII. WEIGHTED NORMALIZED VALUES IMPACT ASSESSTMENT

C1	C2	WNVIA
CELEPSA	C.H. PLATANAL	0.07
ENEL GENERACION PERU S.A.A.	C.H. HUINCO	0.11
ENEL GENERACION PERU S.A.A.	C.H. MATUCANA	0.07
STATKRAFT	C.H. MALPASO	0.05
STATKRAFT	C.H. CHEVES	0.06
ENGIE	C.T. CHILCA UNO	0.10
KALLPA GENERACION S.A.	C.H. CERRO DEL AGUILA	0.11
ORAZUL ENERGY PERÚ	C.H. CARHUAQUERO	0.05
KALLPA GENERACION S.A.	C.T. KALLPA	0.13
KALLPA GENERACION S.A.	C.T. LASFLORES	0.06
ORAZUL ENERGY PERÚ	C.H. CAÑON DEL PATO	0.05
STATKRAFT	C.H. CAHUA	0.04
ENEL GENERACION PERU S.A.A.	C.T. SANTA ROSA 2	0.05
CHINANGO S.A.C.	C.H. CHIMAY	0.05

IV. RESULTS AND DISCUSSION

The Herfindhal-Hirschman Index, HHI is used to evaluate an electricity market. Notice GCEW was used to improve the HHI calculation, contributing with WNVIA multicriteria Table VIII, through the product between normalized impact assessment for all generation units and w_j (Table VI), which represents a shared market calculated using multicriteria methodology. To calculate the HHI use (10).

Table I is made with public data and calculated from excel spreadsheets. The authors detected errors in some reports and tried to fix them manually. Finally, Table I should be considered as an unofficial reference. The authors do not take responsibility for the data in Table I, the purpose of this paper is purely theoretical and exemplary.

According the United States Department of Justice and Federal Trade Commission, the markets are considered moderately concentrated for (11) between 1500 and 2500 points [15].

$$HHI_{genco} = WNVIA_{genco}^{2}$$
$$WNVIA_{genco} = \sum WNVIA \;\forall\; C2 \in genco \quad (10)$$

$$HHI = \sum\nolimits_{gencos} HHI_{genco} = 1930.35 \quad (11)$$

V. Conclusions

This research concludes in this case, there are an emerging market power concentration for the secondary frequency regulation evaluated, based on the Herfindhal-Hirschman Index, the result is moderately concentrated and could reflect a vulnerable market.

The contribution of multicriteria methods (GCEW) is valuable because includes relevant aspects like time, energy and size of reserves in the Herfindhal-Hirschman Index calculation, also the methodology could work with more criteria.

The moderated result could not be bad, it depends a lot in the quality of service and client's satisfaction, a moderated market power could be a best support for a country or the opposite, this ambivalence is dangerous and should be reason for continuously study topics like this also add multicriteria techniques (this research is a partial example) in the future include the client satisfaction, prices, it means the other dimensions not considered here.

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VII. Biographies

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