OPTIMAL OBSERVABILITY OF PMU'S USING ANALYTIC HIERARCHY PROCESS (AHP) METHOD

Sebastian ANGHELESCU[1], Gianfranco CHICCO[2]

Lucrarea propune o nouă abordare în vederea plasării unităților de măsurare a defazajelor, cu scopul de a monitoriza starea funcționării sistemului electroenergetic. Monitorizarea rapidă şi în timp real cu ajutorul dispozitivelor phasor measurment unit (PMU) implică o optimizare a plasării acestor dispozitive. Prin plasarea unui numar cât mai mic de unități de măsurare a defazajelor aplicația devine mai rapidă, acest lucru determină ca intervenția asupra sistemului să fie una mult mai eficientă. Metoda propusă este exemplificată pe un studiu de caz: un sistem IEEE de 14 noduri, urmând ca aceasta să poată fi testată pentru întreg sistemul electroenergetic din România.

*The article proposes a new approach for method for the optimal placement of the PMU with the aim of monitoring the working of the power system. Fast and real time monitoring by PMU, involves a optimal placement of phasor measurement units***.** *Through the placement of a minimum number of PMUs, the application becomes faster, which determines a more efficient intervention on the system. The proposed method is exemplified by a case study representing a 14 nodes IEEE system, furthermore this method can be tested for the entire Romanian power system.*

Keywords: process bus, phasor measurement units, integer linear programming, analytic hierarchy process

1. Introduction

Lately, the control-protection system suffered a continuous evolution, which leads to a complete digitalization with the help of the non-conventional transformers or bricks and also by using process bus. These PMUs which are presently physic devices shall be transformed in future into individual application apart from the control and protection system. The method is applicable for both situations of the control-protection system.

The method uses three different criteria, whose main aim is to sort these 14 buses by using the analytic hierarchy process. In first step of the proposed a multi-criteria approach method, based on three criteria, knowing the pairwise comparation scale:

[1] Eng., CN Transelectrica, Electric Transmission Branch, Bucharest, Romania, e-mail: anghelescu.sebastian@transelectrica.ro, emil_seby@yahoo.com
[2] Prof. PhD, Electrical Engineering Department, Polytechnic University of Torino

1. the vulnerability criterion
2. the minimum cost criterion
3. the observability criterion

The vulnerability criterion was created with the ETAP soft, which has the transient stability analysis function. With this soft a power network of 14 buses was simulated with the aim of analysing the frequency of each bus and sorting the buses. A fault for each line was simulated in order to find the maximum vulnerability. The frequency of each bus is obtained with the help of the transient stability analysis function.

The minimum cost criterion consists of sorting the buses according to the cost of each bus from the power system. It is known that the PMUs have a higher price for those buses that contain more channels which are proportional with the number of branches connected to that bus.

The buses, which connect with the generator, have a higher weight according to the observability criterion because these are already observable.

Through the analytical hierarchy process method the described pairwise criteria are compared, bearing in mind also the different conditions of these criteria. The result of the AHP method is to sort the buses of the power system having in mind the weight of each criteria.

2. Paper Contents

The method is studied on the IEEE 14 buses system and are presented in Fig. 1.

The system is made up 5 generators, 5 consumer. Three phase fault is created on all the transmission line, in which the fault simulation is composed for a duration 0.1 sec, beginning fault in 0.02sec and clear fault is realized in 0.12sec, total simulation time is 1 sec.

For the first criteria use the simulation, which was realized in ETAP soft version 5.03Z. In which researched frequent at every bus obtained from the “Run transient stability” function. The maximum frequent at each bus from run transient stability results for every line disturbance showed that for line disturbance on line 13-14.

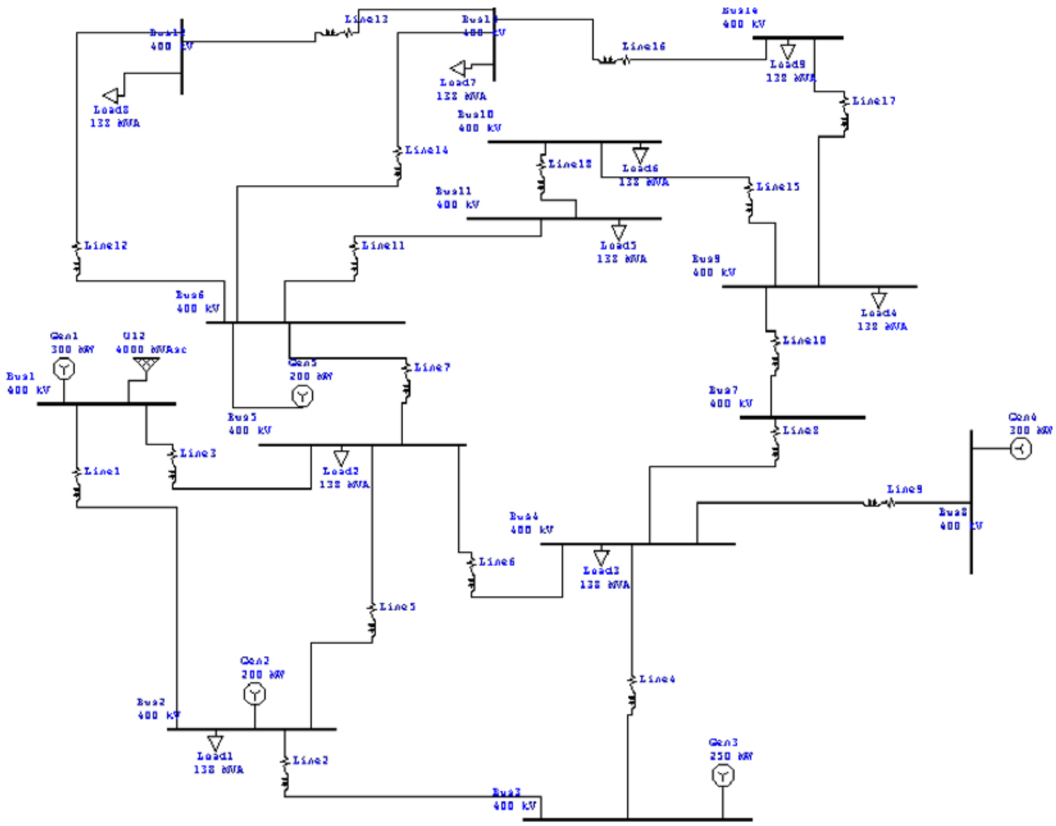

Fig.1 The IEEE 14 buses system

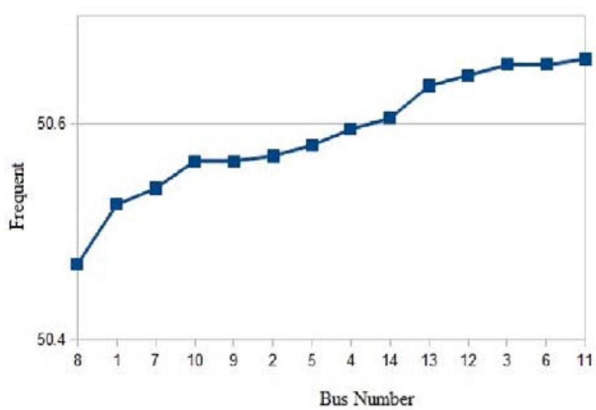

Fig.2. Frequents for each buses for line disturbance 13-14

The 14 bus network can be represented as a 14x14 size square matrix. The diagonal of the matrix represent the buses contained by the proposed system while the others represent:

$$A_{i,j} \begin{cases} 1 \text{ if } i=j \text{ (that means node or bus)} \\ 1 \text{ if } i \text{ and } j \text{ are connected (that means branch between two nodes)} \\ 0 \text{ if otherwise (none of those)} \end{cases}$$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	1	0	0	1	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	0	0	0	0	0	0	0	0	0
3	0	1	1	1	0	0	0	0	0	0	0	0	0	0
4	0	1	1	1	1	1	0	1	0	0	0	0	0	0
5	1	1	0	1	1	0	0	0	0	0	0	0	0	0
6	0	0	0	0	1	1	0	0	0	0	1	1	1	0
7	0	0	0	1	0	0	1	1	1	0	0	0	0	0
8	0	0	0	0	0	0	1	1	0	0	0	0	0	0
9	0	0	0	1	0	0	1	0	1	1	0	0	0	1
10	0	0	0	0	0	0	0	0	1	1	1	0	0	0
11	0	0	0	0	0	1	0	0	0	1	1	1	0	0
12	0	0	0	0	0	1	0	0	0	0	0	1	1	0
13	0	0	0	0	0	0	1	0	0	0	0	1	1	1
14	0	0	0	0	0	0	0	0	1	0	0	0	1	1

Fig.3 Matrix A of IEEE 14 buses

The second criterion is based on the weights nodes of the system. The cost of a PMU varies with the number of channels, so the vector B represents number of channels for each node of the system.

$$B=[2\ 4\ 2\ 5\ 4\ 4\ 3\ 1\ 4\ 2\ 2\ 2\ 3\ 2] \quad (1)$$

That means the node 4 will have the highest cost of the system, because he will need 5 channels.

The third criterion keeps of the nodes connected at the generators. So, C will be a vector make up by 1 if a generator is connected at a node, and 0 otherwise.

$$C=[1\ 1\ 1\ 0\ 0\ 1\ 0\ 1\ 0\ 0\ 0\ 0\ 0\ 0] \quad (2)$$

It is important to ensure the system during his functionality through place the PMUs on a set of selected unobservable buses from system thus it uses three different criteria to find the unobservable buses. With those three criteria it is necessary to use a multi - criteria decision making (MCDM) model for selecting a subset of PMUs to be placement in system. For calculating the weights of different criteria uses analytic hierarchy process (AHP). Pair-wise comparisons are used to establish the relative priority of each criterion. The pair-wise comparisons use a scale that ranges from equally preferred to extremely preferred.

Tabel 1

1	-	Equally preferred
2	-	Equally to moderately preferred
3	-	Moderately preferred
4	-	Moderately to strongly preferred
5	-	Strongly preferred
6	-	Strongly to very strongly preferred
7	-	Very strongly preferred
8	-	Very to extremely strongly preferred
9	-	Extremely strongly preferred

	Case 1	Case 2	Case 3	3^{rd} root of prod	Eigenvector
Case 1	w1/w1=1	w1/w2=1/5	w1/w3=1/9	0.28	0.063
Case 2	w2/w1=5	w2/w2=1	w2/w3=1/3	1.18	0.265
Case 3	w3/w1=9	w3/w2=3	w3/w3=1	3	0.672
Sum	15	4.2	1.4	4.46	
SUM*PV	0.94	1.11	0.97	3.029	
lamba max	3.029				
Cons index	0.014				

Fig 4. Pair-wise matrix for weight calculation

REMEMBER:

Case 1 is "extremely strngly preferred" over case1, as shown in the third row, first column of the matrix.

Case 2 is "strongly preferred" over case 1, as shown in the second row, first column of the matrix.

Case 3 is “moderately preferred” over case 2, as shown in the third row, second column of the matrix.

The third-root-of-product values in each row are calculated as follow:
Case 1: (1x1/5x1/9)=0.022(1/3) =0.28;
Case2: (5x1x1/3)=1.667(1/3) = 1.18;
Case3: (9x3x1)=27(1/3) = 3.

Each pf the aforementioned third-root-of-product values are then added together to equal (0.28+1.18+3)=4.46

Calculating and checking the Consistency Ratio (CR), which tells the decision-maker how consistent he has been when making the pair-wise comparisons.

Consistency index is calculated with the formula CI=(lamba max-n)/(n-1), where n is the number of criteria ; The table of random Index (RI) is shown below:

Tabel 2

N	Random Index
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45

Consistency Ratio (CR)=Consistency Index (CI)/ Random Index (RI)

CR=CI/RI=0.014/0.58=0.025

Consistency Ratio 0.025 <0.1, that means the decision maker's pair-wise comparisons are relatively consistent.

With those three cases it is necessary to calculate percent for each buses of system as shown in tabel 3.

Tabel 3

No. bus	Case 1	Case 2	Case 3
1	0.29	0.75	0
2	0.53	0.25	0
3	0.97	0.75	0
4	0.66	0	1
5	0.58	0.25	1
6	0.97	0.25	0
7	0.37	0.5	1
8	0	1	0
9	0.5	0.25	1
10	0.5	0.75	1

11	1	0.75	1
12	0.92	0.75	1
13	0.87	0.5	1
14	0.71	0.75	1

There are two different cases to find the priority vector: a) using unequal weights (uw) to each criterion calculated and b) using equal weights (ew).

Tabel 4

No.bus	Pvuw	Pvew
1	0.217	0.346
2	0.099	0.259
3	0.26	0.575
4	0.712	0.553
5	0.774	0.610
6	0.128	0.408
7	0.827	0.623
8	0.265	0.333
9	0.769	0.583
10	0.901	0.750
11	0.933	0.917
12	0.928	0.890
13	0.858	0.789
14	0.915	0.820

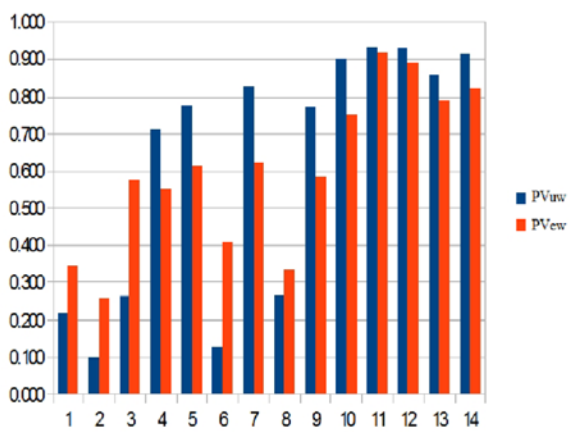

Fig 5. The evolution priority vector unequal and equal weights

For start, to ensure the system's complete observability with minimum numbers of PMUs, it is necessary to regard some few rules:

1. assign a current phasor measurement to each branch incident to a bus provided a PMU;
2. Assign a pseudo-current measurement to each branch connecting two buses known voltage;
3. Assign a pseudo -current measurement to a branch whose current can be inferred by using Kirchhoff 's current law.

To find optimal placement of the PMU needs to knowledge the priority vector with unequal weights, and learn the maxim node priority vector. The logic begin with this maxim node priority vector and further needs to ensure the rules.

If the node became PMU will be marked with the numeral 3 and otherwise with the numeral 2. So the matrix will modify into like fig.

Optimal observability of PMU's using analytic hierarchy process (AHP) method

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	2	2	0	0	3	0	0	0	0	0	0	0	0	0
2	2	2	3	2	3	0	0	0	0	0	0	0	0	0
3	0	2	3	2	0	0	0	0	0	0	0	0	0	0
4	0	2	3	2	3	0	0	3	0	0	0	0	0	0
5	2	2	0	2	3	0	0	0	0	0	0	0	0	0
6	0	0	0	0	3	2	0	0	0	0	3	2	3	0
7	0	0	0	2	0	0	2	3	3	0	0	0	0	0
8	0	0	0	0	0	0	2	3	0	0	0	0	0	0
9	0	0	0	2	0	0	2	0	3	2	0	0	0	2
10	0	0	0	0	0	0	0	0	3	2	3	0	0	0
11	0	0	0	0	0	2	0	0	0	2	3	0	0	0
12	0	0	0	0	0	2	0	0	0	0	0	2	3	0
13	0	0	0	0	0	2	2	0	0	0	0	2	3	2
14	0	0	0	0	0	0	0	0	3	0	0	0	3	2

Fig 6. The matrix

The optimal placement of PMUs is obtained for both cases unequal/equal weights to follow nodes:

$$PMU= [3\ 5\ 8\ 9\ 11\ 13\ ] \quad (3)$$

3. Conclusion

The proposed method aims at optimizing the number of the PMU placed into a network of 14 buses, so that the system becomes completely observable. This method respects the (N-1) principle, which means that the system is ensured in case that a fault into a PMU appears. The main contribution of this article is the application of the AHP method at the optimization of the number of the PMU in the power system. The advantage of this method is the installation of the PMU on the buses which are considered suitable from the point of view of the applied criteria.

The proposed methodology could be successfully applied on any large electrical network. The most interesting aspect of all is that the proposed approach is given by a hierarchical structure evaluation criteria model and determines the global priority weight of each criterion.

R E F E R E N C E

[1] *D. Thukaram, S.R. Kolla*,"Real-time monitoring of critical nodes with minimal number of Phasor Measurement Units", India Decembre 27-29, 2009

[2] *B. Xu, A. Abur,* "Observability analysis and measurement placement for system with PMU's "IEEE Power System Conf. And exposition, New York, **vol. 2**, USA, 2004,

[3] *C. Rakpenthai, S. Premrudeepreechacharn, S. Uatrongjit, N.R. Watson*, "An optimal PMU placement method against measurement loss and branch outage", IEEE Trans. Power Deliv, 2007

[4] *J. Zeitsman,* "Transportation corridor decision-making with multi-attribute utility theory", Int. J. Manage, Decision Making, 2006

[5] *J. McGhee, M. Goraj,* " Smart High Voltage Substation based on 61850 Process Bus and IEEE 1588 Time Synchronization", 2010 IEEE

[6] *R. Moore,* "Time synchronization with 1588", PAC World Magazine, Summer 2009 Issue.

[7] *B. Gou,* "Generalized Integer Linear Programming Formulation for Optimal PMU Placement "Power Systems, IEEE Transactions on, **Vol. 23**, Issue 3, 2008, Vol. 23. Issue 4, 2008, Page(s): 1812 – 1820

[8] *D. Dua, S. Dambhare, R.K.Gajbhiye, S.A. Soman*, "Optimal Multistage Scheduling of PMU Placement: An ILP Approach", Power Delivery, IEEE Transactions on, VOL.23, Issue: 4, 2008 , Page(s): 1812 – 1820

[9] *C. Rakpenthai, S. Premrudeepreechacharn, S. Uatrongjit, N.R. Watson*, "An Optimal PMU Placement Method Against Measurement Loss and Branch Outage", Power Delivery, IEEE Transactions on, **Vol. 22**, Issue 1, 2007, Page(s): 101 - 107

[10] *B.D. Milosevic, M. Begovic*, "Nondominated Sorting Genetic Algorithm for Optimal Phasor Maesurement Placement", Power Engineering Review, IEEE, **Vol. 22**, Issue 12, 2002, Page(s): 61

[11] *B. Milosevic, M. Begovic*, "Nondominated sorting genetic algorithm for optimal phasor measurement placement", Power Systems, IEEE Transactions on, **Vol. 18**, Issue 1, 2003, Page(s): 69 - 75

[12] *N.H. Abbasy, H.M. Ismail*," A Unified Approach for the Optimal PMU Location for Power System State Estimation" Power Systems, IEEE Transactions on, **Vol. 24**, Issue 2, 2009, Page(s): 806 – 813

[13] *R. Sodhi, S.C. Srivastava, S.N. Singh*, "Multi-criteria decision-making approach for multistage optimal placement of phasor measurement units", Generation, Transmission & Distribution, IET, **Vol. 5**, Issue 2, 2011, Page(s): 181 – 190

[14] *O.B. Alaba, I. Făgărăşan, R. Dobrescu, S.Şt. Iliescu*, "System analysis for e-learning grids", U.P.B. Sci. Bull., Series C, **Vol. 71**, Iss. 3, 2009

[15] *F. Ciauşiu, M. Eremia*, "Steady-state stability limit identification for large power systems", U.P.B. Sci. Bull., Series C, **Vol. 72**, Iss. 1, 2010.