International Journal of Smart Electrical Engineering, Vol.4, No.2, Spring 2015
ISSN: 2251-9246
EISSN: 2345-6221
pp.59:64

# Determination of Composite System Adequacy Equivalents Using a Reduction Technique: a Case Study on a Regional Electric Company

Reza Keypour [1], Hessam Golmohamadi [2], M. S. Jahan [3], Saeed Saeedi[4], Asghar Akhundi [5]

[1,2,3] Faculty of Electrical Engineering, Semnan University Semnan, Iran rkeypour@semnan.ac.ir
[4,5] Regional Electric CompanySemnan, Iran

**Abstract**

Reliability evaluation of a large-scale composite power system faces to numerous events/outage and consequently imposes an extensive burden of calculations. In order to simplify the problem, determination of an equivalent system for large-scale power system is inevitable. This paper proposes a framework as reduction technique to separate a composite power system to three areas: external area, optimization area and equipment outage area. This separation enables policy makers of power systems to evaluate reliability of large-scale power systems with less time of calculation and extraordinary precision. The reduction technique is applied to composite power system of Iran with more than 4600 buses to determine an equivalent network for reliability evaluation of Semnan Province network. Comparative discussions and simulations for case study are presented at the end.

*Keywords:* AC load flow; DigSILENT; Reduction technique; Reliability indecies; Separation area.



## 1. Introduction

Reliability evaluation in a large-scale power system is a problem with time-consuming calculations. Consequently, reduction techniques are used widely to determine an equivalent network. Reduction techniques involve the problem to find an equivalent/simplified model for a large-scale composite power system which facilitates reliability and adequacy evaluation studies. The reduced network reduces the dimension of the large-scale power system and therefore reduces the required time calculations for reliability evaluations. It should be pointed out that the equivalent networks are not only effective in time calculation side, but also they must be effective in precision side. Therefore, an appropriate equivalent/reduced network should strike a right balance between time calculation and precision.

Many studies proposed reduction techniques, which are directly or indirectly related to determination of equivalent network for a large-scale power system. In [1] the reduction techniques are divided into two categories. The first type deals with finding an equivalent network for a portion of a system. Simplification of the reliability evaluation is the main focus in the second type.

Over the last few decades, many papers have used load flow for determination of equivalent reduced network. In these papers a static equivalent for a large-scale power system is obtained through performing AC load flow in base mood of power system [2-11]. The base mood of power system involves loads at peak value and all the circuit breakers of power system are in normal operation state; moreover, there is no fault or forced outage for power system elements. In paper [1] the presented methods to determine static equivalents based on AC load flow are divided into three categories:

- Ward equivalent [3, 4].
- Radial, equivalent and independent (REI) network [5, 6].
- Three-area separation [7, 8].

Determination of Ward equivalent for a power system involves three main stages. First of all, power injections in external buses are converted to current injection. Secondly, external buses are omitted through using Gaussian reduction. Finally, in third step, the current injections are converted to power injections again [1, 4].

In a REI network, some or all of the power injections at the external buses are substituted by one equivalent power injection. At least one equivalent generation node and one equivalent load node are usually assigned for generators and loads, respectively [1, 5].

In three-stage separation approach which is presented in [7, 8], the large-scale power system is divided into three main areas: (1) equipment outage area (2) optimization area (3) external area. In this approach, all the reliability characteristics are fully considered for power system elements which are located in equipment outage area. This area involves a full representation of the random behavior of transmission and generation elements. The second area, larger, network involves representation of all its elements for load flow and remedial action analysis [7]. Finally, the third network connects to previous optimization network and includes the equivalent of the remaining components of the original system. The generators and loads are fixed in this network [7, 8]. Table I summarizes some novel approaches which have been studied reduction techniques in recent years. The novelty of the manuscript is that the proposed technique of partitioning is applied to the large-scale power system of Iran with more than 4600 buses. The main distinguishing feature of this study is the large-scale dimension of case study in comparison with the other studies which are described in table I.

This paper proposes a framework to determine an equivalent network for reliability evaluation in power system of Semnan Province. The proposed framework is based on partitioning of power system to three areas. The main under studied network is the large-scale power system of Iran. Reliability evaluation of the entire power network in Iran is difficult and time-consuming. For this reason, Iran network is divided to three different areas according to the electrical connection between Semnan Province and other provinces. In this approach, each tie line is cut at its mid-point and virtual loads and generators are added at this point in order to simulate active and reactive power flows under normal conditions. According to various ways of partitioning, 5 different reduced networks are obtained in this paper. Making a comparison between the resulted networks, the best reduced network with respect to time of calculation and precision of reliability indexes is obtained.

## 2. Implementation of Network Reduction Approach to Iran Network

The large-scale power system of Iran is considered as the under studied network in this paper. The aim is to find an appropriate equivalent network to reduce the time burden of the reliability evaluation studies for a special area of Iran network as Semnan Province. It should point out that in spite of calculation time of the problem, the reduced network must have a military precision in reliability indices. Consequently, the ultimate aim is to find an equivalent network for power system of Semnan Province to strike a right balance between calculation time burden and precision of the reliability evaluation problem. In this approach, the power system of Iran is partitioned into three main areas as following [7]:

- equipment outage area
- optimization area
- external area

Table.1.
Review of recent studies about reduction

| Reference | Year of Publication | Reduction Technique | Case Study |
|---|---|---|---|
| **[12]** | 2010 | Power Transfer Distribution Factor (PTDF) | 6-bus Test System |
| **[13]** | 2011 | Gauss Elimination | IEEE-RTS 96 |
| **[14]** | 2012 | Aggregation of Buses | IEEE 30-bus and 118-bus Systems |
| **[15]** | 2013 | Mathematical Model | A Test System with 130 nodes |
| **[16]** | 2014 | Balanced Truncation | Swedish power system-52 buses |
| **[17]** | 2015 | Krylov Subspace Theory | IEEE 123-node System |

Fig. 1 shows the partitioning form of power system in this paper. In this figure, the dashed line describes borders of entire power network in Iran.

In order to make practical model in large-scale power network of Iran, the power system is partitioned into three different areas as following:

- First area: involves power system in Semnan Province
- Second area: the power systems in provinces which are connected directly to Semnan Province power network. This area involves the power networks in Tehran Province, Mazandaran Province and Khorasan Province.
- Third area: the power networks in all provinces which are connect indirectly to Semnan Province network. This area involves all the networks in Iran except the power networks in Tehran Province, Mazandaran Province and Khorasan Province.

According to the presented approach the power network of Iran is partitioned into three main areas as Fig. 2.

Considering different states for three main areas in power network of Iran, 5 reduced networks can be proposed to study the reliability indices of power network in Semnan Province. AC load flow calculations and reliability analysis studies are carried out by commercial software DigSILENT 14.1 [18]. The proposed 5 reduced network are presented as following:

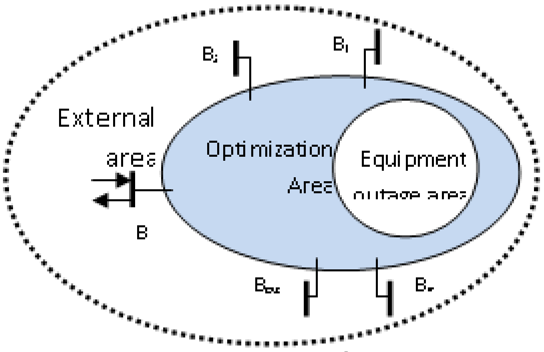


Fig. 1. Power system partitioning into three main areas

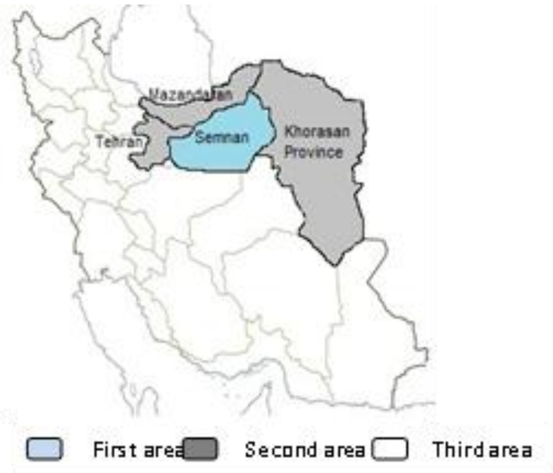


Fig. 2. Network depiction for large-scale power system of Iran

**Reduced network N01:** in this proposed network, power network of first area (Semnan Province) is considered as equipment outage area. The optimization area is second area in power network of Iran including Tehran, Khorasan and Mazandaran Province. The external are is considered the third area including all the remained provinces of Iran network (all the provinces except Semnan, Tehran, Khorasan and Mazandaran). In DigSILENT software, load flow calculation is done for large-scale power system of Iran and the information for module of reliability analysis is entered for first area of Iran network (Semnan Province).

**Reduced network N02:** in this network, the equipment outage area is considered for first and second areas of Iran network including Semnan, Tehran, Khorasan and Mazandaran Province. The optimization area is considered as all the remained networks in the other provinces of Iran network (except the mentioned provinces). Regarding DigSILENT software, load flow calculation is done for large-scale power system of Iran and the information for module of reliability analysis is entered for first and second areas of Iran network.

**Reduced network N11:** in this network, the equipment outage area is considered as first area (Semnan network) in power network of Iran. The optimization area is considered as the second and third areas of Iran network. In DigSILENT software, load flow calculation is done for first and second areas in power network of Iran. Moreover, the information for module of reliability analysis is entered for first area of Iran network.

**Reduced network N12:** in this network, the equipment outage area and optimization area are considered as first and second areas in power network of Iran, including Semnan, Tehran, Khorasan and Mazandaran Province. The external area includes the networks of provinces which are connected to Semnan network indirectly (all the provinces except Semnan, Tehran, Khorasan and Mazandaran). In DigSILENT software, load flow calculation is done for first and second areas in power network of Iran. Moreover, the information for module of reliability analysis is entered for first and second areas of Iran network.

**Reduced network N2:** in this network the equipment outage area and optimization area are considered as first area in power network of Iran, including Semnan Province network. Consequently, the external area involves the second and third area in power network of Iran, including all the provinces except Semnan network. In DigSILENT software, load flow calculation is done for first are in power network of Iran. Similarly, the information for module of reliability analysis is entered only for the first area of Iran network.

In module of reliability analysis in DigSILENT software, the information about the power network of Semnan Province, including transmission lines, sub-transmission lines and power transformers are submitted in accordance with table II and III. In the tables, TTR and TTF describe parameters of Time to Repair and Time to Failure respectively. In addition, the parameter $\lambda$ describes outage rate in Markov model of maintenance scheduling [19].

It is worth mentioning that the information of outage rate for transmission/sub-transmission lines and power transformers of Semnan network is obtained through cooperation of power system operators at Semnan Regional Electricity Company.

## 3. Simulation Results

The ultimate aim in this paper is to find the reduced network optimized from prospective of time calculation and precision of reliability indices. To achieve this goal, 5 different reduced networks are proposed in this paper in accordance with partitioning of Iran's network into three main study areas. Input data for reliability module of DigSILENT software are entered according to tables II and III. As a result, table IV describes the results of contingency analysis for 5 proposed reduced networks.

Table IV reveals that decreasing in network dimensions has been a noticeable reduction in time burden of calculations. Therefore, reduced network

N2 has the least time calculation as 14 seconds for reliability analysis in power system of Semnan Province. Adversely, it is most evident that the reduced network N02 has imposed the most time burden of calculations as 1320 seconds to reliability studies. The reason is that the network N02 has the most dimensions in comparison with the other 4 reduced networks.

Table.2.
Information of transmission

| Voltage (kV) | Number | Number of Outages | Time of Outage (s) | TTR (h) | TTF | λ |
|---|---|---|---|---|---|---|
| **400/230** **400/63** | 5 | 16 | 10893 | 12.96 | 2.1413 | 0.4669 |
| **230/63** | 14 | 59 | 29836 | 9.7503 | 1.6459 | 0.6075 |
| **63/20** | 39 | 197 | 29652 | 2.6858 | 1.2714 | 0.786 |

Table.3.
Information of power transformers

| Reduced Network | Time Burden of Calculations (s) | Number of Buses | Number of Contingencies | Reliability Study (Area) |
|---|---|---|---|---|
| **N01** | 357 | 4600 | 137 | 1 |
| **N02** | 1320 | 4600 | 578 | 1,2 |
| **N11** | 29 | 609 | 139 | 1 |
| **N12** | 110 | 609 | 575 | 1,2 |
| **N2** | 14 | 114 | 138 | 1 |

Fig. 3 shows the variation of reliability index TCIT for 5 reduced networks. Regarding the figure, TCIT index has a similar value for reduced networks N01, N02, N11 and N12 approximately. As regards reduced network N2, the reliability index TCIT climbed from just under 2.24 to over 5.4 dramatically: more than twofold increase. It means that the precision of reliability index TCIT in the reduced network N01, N02, N11 and N12 is reasonable. In contrast, despite the fact that the reduced network N2 has reduced time burden of reliability calculations noticeably, precision of reliability index is very low. It can be implied that the reduced network N02 is an inappropriate equivalent network for Semnan Province.

Fig. 4 describes the variation trend of reliability index TCIT for 34 load points at Semnan network. As far as precision is considered, the precision of reliability index TCIT for reduced networks N01, N02, N11 and N12 follows a similar pattern. It is most evident that the network N02 has a lower precision in reliability indices calculations in comparison with the other reduced networks.

Fig. 5 shows the reliability index AID (Average Interruption Duration) for 5 reduced networks. The graph shows that the reliability index AID has a similar value for reduced networks N01, N02, N11 and N12 approximately. Adversely, the reliability index has a sharp increase for reduced network N2: an increase of 66 % approximately. It is clear from the data given that the reduced network N2 has a lower precision in reliability index calculations in comparison with the other proposed networks.

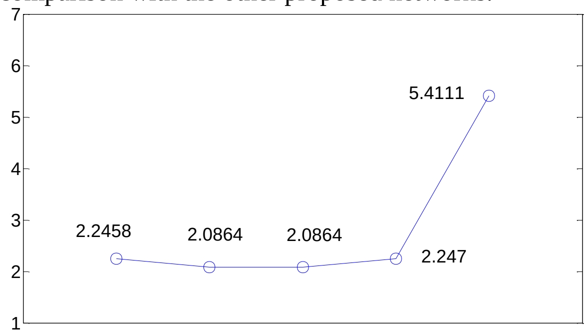


Fig. 3. Reliability index TCIT for 5 reduced networks

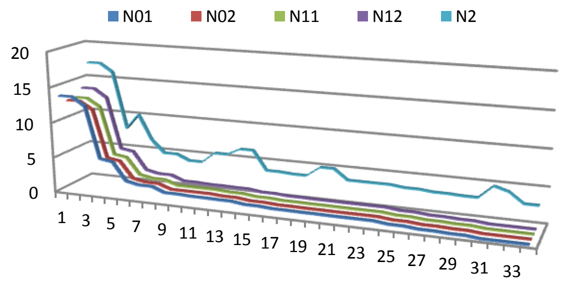


Fig. 4. General trend of reliability index TCIT for different load points

Fig. 6 describes the reliability index LPENS (Load Point Energy Not Supplied) for 5 proposed networks. Not surprisingly, this graph demonstrates that the precision of reliability calculations in network N2 is lower than the other networks. Regarding reduced networks N01, N02, N11 and N12, the reliability index LPENS fluctuates between just over 320 and 380 approximately, but the value of reliability index rises to 1205 for network N2 abruptly. Therefore, this graph demonstrates that the reduced network N2 is inappropriate for reliability analysis at Semnan network.

Fig. 7 shows the reliability index LPENS for 34 load points at Semnan network. This figure confirms that the network N01, N02, N11 and N12 have more accuracy in calculation of reliability indices in comparison with network N2. In addition, the graph reveals that calculation of reliability index LPENS follows a similar pattern for all load points at Semnan network.

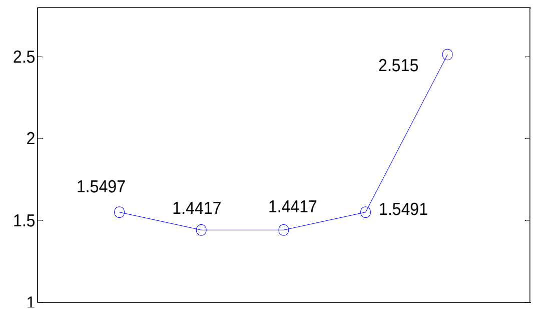


Fig. 5. Reliability index AID for 5 reduced networks

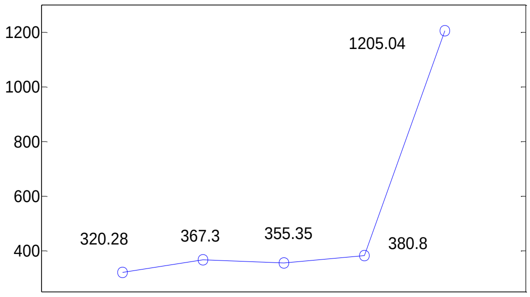


Fig. 6. Reliability index LPENS for 5 reduced networks

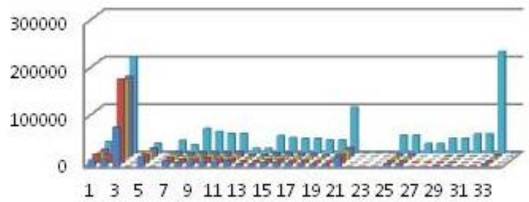


Fig. 7. General trend of reliability index LPENS for different load points

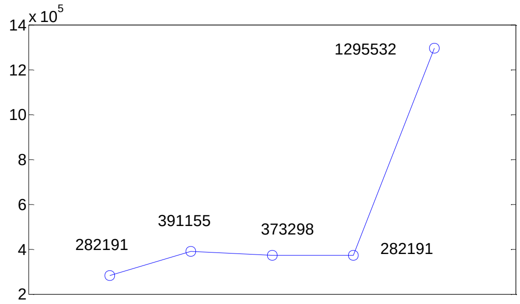


Fig. 8. Reliability index LPEIC for 5 reduced networks

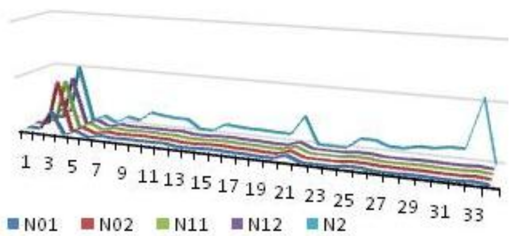


Fig. 9. General trend of reliability index LPEIC for different load points

Fig. 8 describes the reliability index LPEIC (Load Point Energy Interruption Cost) for 5 reduced networks. As can be seen from the graph, the reliability index fluctuates between 282191 and 391155 for networks N01, N02, N11 and N12. However, the value of index has jumped to 1295532 suddenly for network N2. It shows the fact that precision of reliability index for network N2 is very low in comparison with the other networks.

Fig. 9 displays the pattern of reliability index LPEIC for 34 load points at Semnan network. Based on the graph, we can say that calculation of reliability index LPEIC follows a similar pattern for networks N01, N02, N11 and N12. In contrast, the pattern for network N2 has dramatic and abnormal growth in some load points. The line graph confirms the fact that the network N2 is not an appropriate equivalent network for reliability analysis at Semnen Province.

## 4. Optimized Network

The aim in this paper is to find the reduced network optimized in terms of calculation time and precision of reliability indices. The reduced network should reduce time burden of reliability calculations; in addition, it must have a reasonable precision in calculation of reliability indices. In order to achieve this goal, 5 reduced networks are proposed in this study. First of all, time burden of reliability calculations and contingency analysis for 5 reduced networks were presented. In the second step, in order to make a comparison between different networks from prospective of index precision, the main reliability indices as TCIT, AID, LPENS and LPEIC are calculated. Considering the mentioned facts, the network N11 can be identified as the best reduced network for reliability analysis in power system of Semnan Province. Time calculation of this network is about 29 seconds; therefore, it can reduce time burden of reliability calculations noticeably. In addition, as the graphs reveal, this network has a reasonable precision in calculation of reliability indices. To sum up, reduced network N11 are proposed to the operators of power system at Semnan Regional Electricity Company to study reliability analysis.

## 5. Conclusion

This paper proposes an applicable approach for assessing reliability indices for a composite large-scale power system. Considering time burden and accuracy of computational efforts, the effects of different partitioning of primary power system into three main areas are investigated. The aim is to find the best reduced network in terms of computational time and precision. To achieve this goal, 5 reduced networks are proposed as equivalent networks for reliability analysis. The novelty of this approach is to use the partitioning of a large-scale power system to some small networks to find an optimized reduced network. For this reason, power network of Iran with more than 4600 buses are studied in this paper to show the applicability of the method. The large-scale dimension of case study is the main distinguishing feature of this study in comparison with the other studies.

Simulation results demonstrate that the reduced network N11 with time calculation 29 seconds is an appropriate equivalent network for reliability analysis. Reliability studies for main reliability indices as TCIT, AID, LPENS and LPEIC confirm that the reduced network N11 has a reasonable precision in calculation of reliability indices. To sum it up, the reduced network N11 is considered as equivalent network for reliability analysis at Semnan Electrical Regional Company.

## References

[1] A. Akhaveina, M. Fotuhi Firuzabadb, R. Billinton, D. Farokhzad, "Review of reduction techniques in the determination of composite system adequacy equivalents," Electric Power Systems Research, vol. 80, pp. 1385–1393, July 2010.

[2] T.E. Dy Liacco, S.C. Savulescu, K.A. Ramarao, "An on-line topological equivalent of a power system," IEEE Trans. Power Syst. vol. 97 (5), pp. 1550–1563, 1978.

[3] E.C. Housos, G. Irisarri, R.M. Porter, A.M. Sasson, "Steady state network equivalents for power system planning applications," IEEE Trans. Power App. Syst. vol. 99(6), pp. 2113–2118, 1980.

[4] S.C. Savulescu, "Equivalents for security analysis of power systems," IEEE Trans. Power App. Syst. vol. 100 (5) pp. 2672–2682, 1981.

[5] S. Deckmann, A. Pizzolante, A. Monticelli, B. Stott, O. Alsac, "Studies on power system load flow equivalencing," IEEE Trans. Power App. Syst. vol. 99, pp. 2301-2310, 1980.

[6] M.L. Oatts, S.R. Erwin, J.L. Hart, "Application of the REI equivalent for operations planning analysis of interchange schedules," IEEE Trans. Power Syst. vol. 5 (2), pp. 547-555, 1990.

[7] A.M.L. da Silva, L.A.F. Manso, G.J. Anders, "Composite reliability evaluation for large-scale power systems," IEEE Power Tech Conference, vol. 4, pp. 1-5, 2003.

[8] A.M.L. da Silva, L.C. Resende, L.A.F. Manso, "Application of Monte Carlo simulation to well-being analysis of large composite power systems," Probabilistic Methods Applied to Power Systems, PMAPS, pp. 1–6, 2006.

[9] K.I. Geisler, A. Bose, "State estimation based external network solution for online security analysis," IEEE Trans. Power Syst. vol. 102 (8), pp. 2447–2454, 1983.

[10] S.C. Savulescu, "Solving open access transmission and security analysis problems with the short-circuit currents method," The Latin America Power Conference, Controlling and Automating Energy Session, Mexico, 2002.

[11] M. Khodadadi, M. Khalilifar, S. M. Shahrtash, "A novel static external network equivalencing method for protection studies on Iran Transmission Grid," 9th Power Systems Protection and Control Conference (PSPC), pp. 49-54, 2015.

[12] HyungSeon Oh, " A new framework reduction methodology for power system planning studies," IEEE Trans. Power Syst. vol. 25 (2), pp. 677–2454, 684, 2010.

[13] A. Lima, N. Alguacil, O. Yauri, E. Carlos, "Network reduction schemes for transmission cost allocation in multi-area systems," IEEE Trondheim PowerTech Conference, pp. 1-6, 2011.

[14] HyungSeon, "Aggregation of Busesfor a Network Reduction," IEEE Trans. Power Syst., 27 (2), pp. 705- 712, 2012.

[15] A. Shapovalov, C. Spieker, C. Rehtanz, "Network reduction algorithm for smart grid applications," Australasian Universities Power Engineering Conference, pp. 1-5, 2013.

[16] C. Sturk, L. Vanfretti, Y. Chompoobutrgool, H. Sandberg, "Coherency-independent structured model reduction of power systems," IEEE Trans. Power Syst., 29 (5), pp. 2418- 2426, 2014.

[17] C. Wang, H. Yu, P. Li, J. Wu, " Model order reduction for transient simulation of active distribution network," IET Generation Transmission and Distribution, vol. 9, pp. 457-467, 2015.

[18] http://www.digsilent.de

[19] R. Billinton, W. Li, Reliability Assessment of Electric Power Systems Using Monte Carlo Method. Plenum Press, New York and London, 1994.