COMPUTER AIDED MODELLING OF POWER SYSTEM IN REAL-TIME MODE

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ABSTRACT

The use of modern computer systems in control centers of the power systems has made it feasible to update system configuration and to evaluate the current state of the system by using a real-time model. This real-time model can be used to assess the security of system by implementing on-line contingency analysis, to improve system monitoring and to check out possible control strategies. In this paper, the step by step procedures for implementing the model from the real-time measurements data and the network connectivity database are described. These steps include the topology processor determination, a topologically based observability check and measurement placement using real-time telemetered measurements, treatment of network unobservability and power system state estimation. The developed real-time model has been applied to a part of the 66 KV Alexandria subtransmission system including the heavy loaded city control area.

Keywords: Computer-aided real-time modelling, Control centers of power systems, Network topology.

1. INTRODUCTION

By available process computer control and modern theories of automatic control there is now a tendency to employ computers for control tasks in load dispatching centers and power stations. This trend owing to increased demands with regard to the security of the supply and economics of generation and distribution of power, is the expression of a real need. Generally speaking, the monitoring of the system conditions is the most important step in order to keep the system reliable and secure, since this monitoring provides the system operators with pertinent up-to date information on the conditions of the system.

The security of a power system can be defined as its ability to withstand contingencies. The contingency analysis has to be done on a model of the power system. For off-line studies, this model is specified by the user through the input data. For on-line contingency analysis, the model must reflect the present conditions of the power system. Thus the model must be built from the real time measurements before contingencies can be analyzed [1].

Although on-line contingency analysis is the major motivation to develop methods for real-time modeling, there are several other uses of the real-time model. It can be used for better monitoring of the system by detecting erroneous as well as estimating the incorrect or missing measurements. It can be used to study possible control strategies like switching operations, Volt-VAR coordination, economic operation within security constraints, and many others.

This paper is mainly concerned with presentation of a computer aided modelling of power system in real-time mode. The developed model is tested through its application to a part of the 66 KV subtransmission network of Alexandria including its heavy loaded control area.

2. STEPS FOR BUILDING REAL-TIME MODEL

The power system model needed for contingency analysis is a solved power network described in terms of buses and branches. ***The model is built in two parts :***

i) Part one represents the internal system from which the control center receives telemetered data.

ii) Part two consists of the rest of the interconnected system.

The step by step procedures for building each part is illustrated in the flowchart of Figure (1). These programs are supported by a database that contains the description of the network in terms of its parameters such as branch impedances and connectivity.

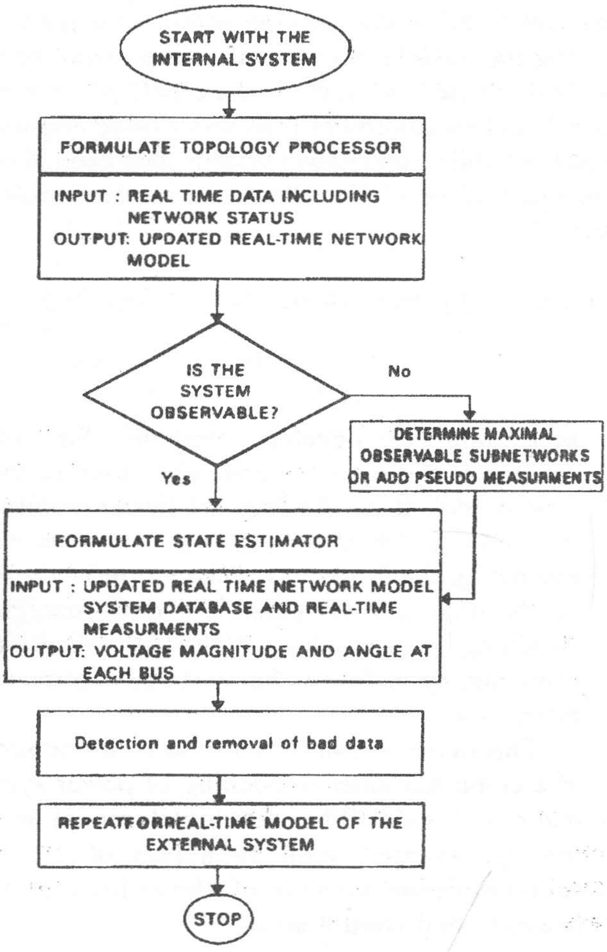

Figure. 1. Step for Building Real-Time Model.

2.1 *Network Topology Processor Determination :*

The topology processor picks up the status of circuit breakers and switches from the real-time data and using the connectivity data from the database, to determine the present network topology. The method is based on a modified topological technique of Sasson's basic tree search algorithm referred to as the Configuration Analysis Program (CAP) [2]. A flowchart of the CAP-program structure showing the main program and subroutine is given in Figure (2).

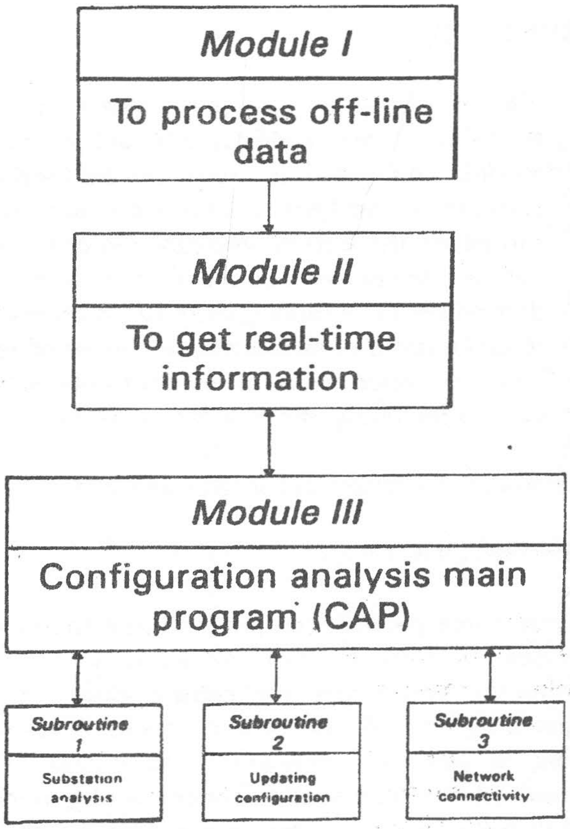

Figure 2. Network as viewed by modified CAP technique.

Some modifications to the CAP technique are proposed in [3] and are summarized in this paper so as to give better performance for preparing power system model in real-time mode, as follows :

(i) Processing the injection measurements in addition to the flow measurements so that the resulting system configuration can be used by any state estimation algorithm. These measurements will highly increase the probability of system observability. Moreover, they will contribute in the treatment of unobservability by adding pseudo injection measurements to the system. Even if the system is observable by flow measurements these injection measurements will increase the state estimation measurement redundancy leading to better accuracy and bad data detection.

(ii) The proposed modification deals with the measured and unmeasured network lines. Line terminal with lost data can be treated in the state estimation procedures.

(iii) Preparing lists of available voltage pseudo measurements using past estimates or generator voltage regulator settings data. Each non-voltage measured island will consider one pseudo measurement of voltage at one of its nodes. The only disadvantage of this method is that pseudo measurement accuracy can vary widely than that of telemetered data. This means that the added voltage is likely to be corrupted by gross errors which will affect the resulting state. These errors along with high redundancy that characterizes power system measurements will tend to give satisfactory estimates since without these pseudo measurements no existing estimate of these islands can be provided.

The modified power system network topology processor determination technique can be summarized in three sequential steps :

Step 1 Substation analysis: In step 1 substation in which changes occur will be examined independently. If all breakers are closed, a list of all circuits belonging to the substation is prepared and is sent to next step. If there are open breakers, lists of circuits belonging to all possible closed breaker paths are prepared and sent to the next step. When initializing the program every substation and circuit breaker has to be processed in this step. After that only substations in which breaker status changes have taken place need to be processed. Since the number of status changes during each cycle is normally quite small this will reduce the time of operation of the topology processor determination which is very suitable for on-line implementation.

Step 2 Network configuration: The second step will determine:

(i) Opened and closed lines and transformers,
(ii) substations separation into nodes,
(iii) isolated buses, and
(iv) network islands.

Step 3 Equipment tables: In the third step two tables will be produced. The updated configuration table (Table 1) gives :

(i) Connectivity of the network buses by branches,
(ii) real-time line flow measurements, and
(iii) network islands.

However, the updated injection table (Table 2) gives all nodes (old and new) with their injection measurements status.

If there is a status change, the three steps outlined above are executed to obtain the new topology.

2.2 Network Observability test:

Because availability of the measurements as well as network topology may vary with time, it is necessary to perform an observability test every time there is a change in the set of available measurements or in the network topology. If the network is observable, state estimation may proceed. Otherwise, it is necessary to determine which buses are unobservable. These unobservable buses have to be either removed from the state estimator calculation or to be made observable by adding pseudo-measurements. It is possible to have several observable islands of buses and the separate state estimators are capable of solving all the islands by providing a reference bus for each [3].

A topologically based algorithm for determining the observability and measurement placement of a real-time network topology processor has been used by the authors in a computer package programs [3]. The method is based on a graph-theoretic observability algorithm published by Clements et.al in [4-6]. The algorithm provides a tool which may be used to solve the following questions :

What parts of the network are observable ? and what measurements should be added to render the entire network observable ?

Before the state estimator attempts to calculate a state estimate, the topologically based observability and measurement placement algorithm should be run to perform the following three functions:

i) It uses the actual and virtual measurements to construct a maximal forest F of full rank with measurement assignment.

ii) It labels all measurements processed so far as critical for those measurements which are necessary for observability, or noncritical for those measurements which are redundant. This function should be accomplished by identifying, for each redundant measurement m, an observable measured subnetwork O_m whose measurement set $M(O_m)$ is a minimal dependent set of measurements that contains m.

iii) It tests additional pseudo measurement sites for inclusion in the measurement set. The result of testing a pseudo measurement P should be either : (a) the addition of a branch to the maximal forest F, or (b) the identification of an observable measured subnetwork O_m whose measurement set $M(O_m)$ is a minimal dependent set of measurements.

Alternative (b) allows the identification of any additional measurements made uncritical by the inclusion of m in the measurement set. These additional uncritical measurements consist of all previously critical measurements that belong to $M(O_m)$.

The application of the third function (iii) should continue until the maximal forest F is filled out to form a spanning tree which renders the entire network X_m to be observable.

2.3 Power system state estimation :

Evaluating power system state estimation is one of the most significant functions in modern power system control centers. This estimation process is the first step in controlling power system operations.

Power system state estimator (PSSE) aims to determine the system states (bus voltage magnitudes and their phase angles) from the data base distributed throughout the system. Therefore, the PSSE is a collection of digital computer programs which convert telemetered data into a reliable estimate of the transmission network by accounting for :

(i) Small random metering and communication errors.

(ii) Uncertainties in system parameter values.

(iii) Bad data due to transients and meter communication failures.

In short, PSSE employs a data processing algorithm which combines the telemetered data with the information representing the system model to provide the best estimate of the system state. It will do so by "*smoothing out*" small random errors in meter reading, "*detecting*" and "*identifying*" gross measurement errors, and "*filling in*" meter readings that have failure.

The PSSE is determined by using an efficient hierarchical state estimation algorithm [7].

3. APPLICATION

3.1 System description:

The power system studied is shown in Figure (3). We have considered transformers of 220/66 KV as direct injections to the 66 KV network and any connections to the external system were removed since all research work is concentrated on the internal system model. The system data are included in Appendix A.

3.2 Off-line data preparation :

If all circuit breakers are closed there will be 10 substations (nodes) prior to any changes in breaker status. Lines are coded from 1 to 17, non-measured voltage nodes (or buses) are coded from 18 to 32 and voltage measured nodes are coded from 33 to 35. Tie line is considered as an injection and new circuits 36 and 37 are now produced. Some circuits have negative signs since they are connected to more than two breakers; like for example circuit 33 connected to C.Bs 1, 5, 6 and 7. Phantom circuit breakers around tie points are defined [2]; this condition arises with C.Bs 42, 43 and 44.

3.3 Network topology determination :

Figure (3) shows the network as viewed by the modified CAP technique used to determine network topology. The real-time data case studied including the maneuvering of opening CBs 18, 20, 24, 26, 29, 33 and 36.

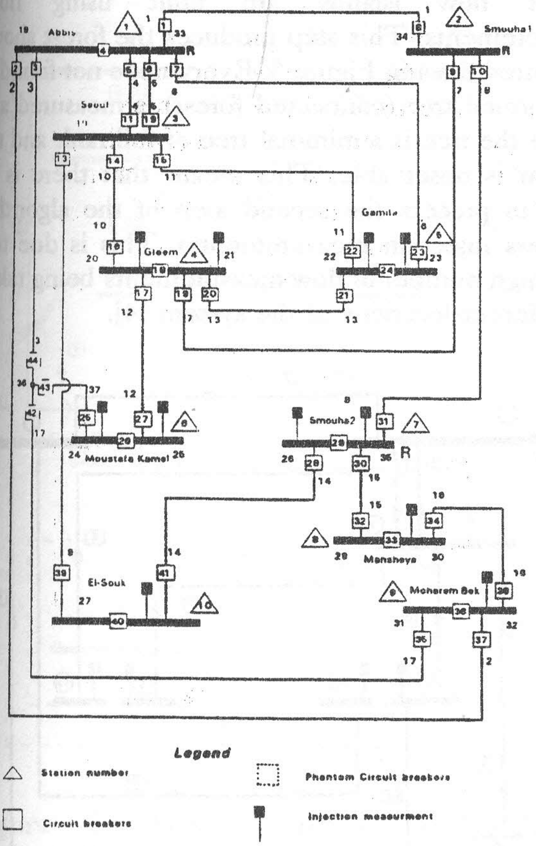

Figure 3. Network as viewed by modified CAP technique.

Table (1) presents real-time data of the tested network; while Tables (2) and (3) present input (and updated output) Configuration and Injection tables of the modified CAP technique.

Figure (4) shows the output of the network topology processor. The system is now composed from 16 nodes and 16 lines; where line #13 is removed from the system configuration by C.Bs opening. The system is still connected and consists of one island.

Table 1 : Real-time Data Table

C.B. Code	C.B. Connected to Circuits		Substation Code	C.B. Status
	Circuit #1	Circuit #2		
1	1	-19	1	0
2	-18	2	1	0
3	3	-18	1	0
4	-18	-19	1	0
5	-19	4	1	0
6	-19	5	1	0
7	6	-19	1	0
8	-20	1	2	0
9	-20	7	2	0
10	8	-20	2	0
11	4	-21	3	0
12	5	-21	3	0
13	-21	9	3	0
14	-21	10	3	0
15	-21	11	3	0
16	10	-22	4	0
17	-22	12	4	0
18	-22	-23	4	1
19	-23	7	4	0
20	-23	13	4	1
21	13	-24	5	0
22	-24	11	5	0
23	25	6	5	0
24	-24	25	5	1
25	26	37	6	0
26	26	27	6	1
27	27	12	6	0
28	28	14	7	0
29	28	-29	7	1
30	-29	15	7	0
31	-29	8	7	0
32	32	15	8	0
33	32	33	8	1
34	33	16	8	0
35	34	17	10	0
36	34	-35	10	1
37	-35	2	10	0
38	-35	16	10	0
39	30	9	9	0
40	30	31	9	0
41	31	14	9	0
42	17	-36	6	0
43	-36	37	6	0
44	-36	3	6	0

Status : 0 indicates closed C.B & 1 indicates open C.B

C.B Code : C.Bs are coded according to the order in which breaker status information comes into computer.

Table 2. COFIGURATION Table.

Line Code	Line connected between nodes				Flow measurement status		On-line availability status		Area Number	
	node#1		node#2		i/p	o/p	i/p	o/p	i/p	o/p
	i/p	o/p	i/p	o/p						
1	1	1	2	2	0	0	0	0	1	1
2	1	1	9	16	0	0	0	0	1	1
3	1	1	6	6	1	1	0	0	1	1
4	1	1	3	3	0	0	0	0	1	1
5	1	1	3	3	0	0	0	0	1	1
6	1	1	5	12	0	0	0	0	1	1
7	2	2	4	11	0	0	0	0	1	1
8	2	2	7	14	0	0	0	0	1	1
9	3	3	10	10	0	0	0	0	1	1
10	3	3	4	4	0	0	0	0	1	1
11	3	3	5	5	0	0	0	0	1	1
12	4	4	6	13	1	1	0	0	1	1
13	4	-4	5	5	1	1	0	1	1	OU
14	7	7	10	10	0	0	0	0	1	T
15	]7	14	8	8	0	0	0	0	1	1
16	8	15	9	16	1	1	0	0	1	1
17	9	9	6	6	0	0	0	0	1	1
										1

Status: 0 indicates available item & 1 indicates unavailable item

Line Code: Line-ends are not coded but are ordered according to the order in which real-time line flow measurements and measurement status infomation is entered into computer.

i/p & o/p: indicates input (and updated output) real-time data of the modified CAP technique.

OUT: indicates that line is cleared by C.Bs opening.

Table 3 : INJECTION Table

Node Code		Injection measurement status	
i/p	o/p	i/p	o/p
1	1	1	1
2	2	1	1
3	3	1	1
4	4	0	0
5	5	0	0
6	6	0	0
7	7	0	0
8	8	0	1
9	9	0	1
10	10	0	0
	11		0
	12		0
	13		0
	14		0
	15		0
	16		0

3.4 Observability check :

First flow islands are built using flow-measurements. This step produces the forest shown by dotted lines in Figure 5. Every node not found in the formed tree (connected forest) is measured and hence the tree is a minimal tree of full rank and the system is observable. This means that there is no need to process the second step of the algorithm (process injection measurements). This is due to a very high number of flow measurements being taken in different locations of the system [4].

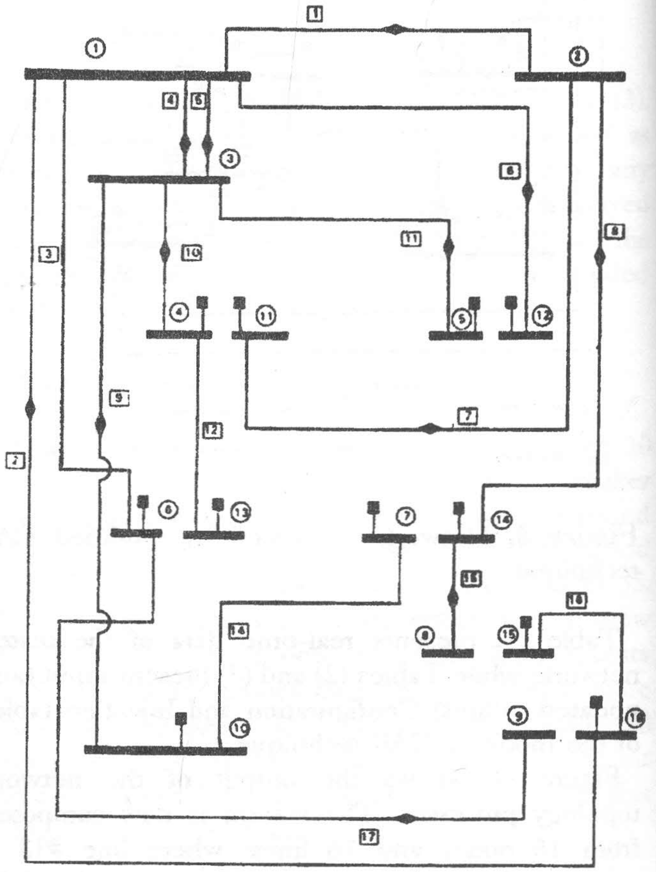

Figure 4. O/p of the modified CAP technique & I/p to observability check.

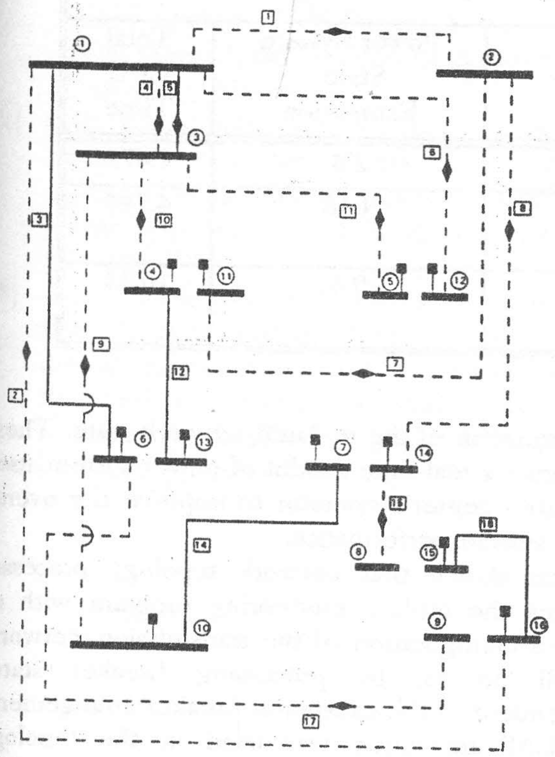

Figure 5. Maximal forest constructed by observability check.

3.5 State estimation:

The final step is to estimate voltages (magnitudes and angles) of the system from the set of measurements shown in Figure (6) by using a new hierarchical PSSE algorithm [7]. High measurement redundancy leads to an accurate estimate of the system state. The real-time model of the studied system is given in Figure (7).

3.6 Test models :

Several tests were carried out using the heavy loaded 66 KV subtransmission network of Alexandria central area (Alex-C) (16 bus and 16 lines), IEEE 30 bus and Alexandria city 66 KV network (45 bus and 47 lines) [7] systems to show the effectiveness of the developed software computer package programs. The programs were executed on 80486 DX2, 66 MHz,IBM compatible PC-computer and the execution times in seconds are given in Table 4.

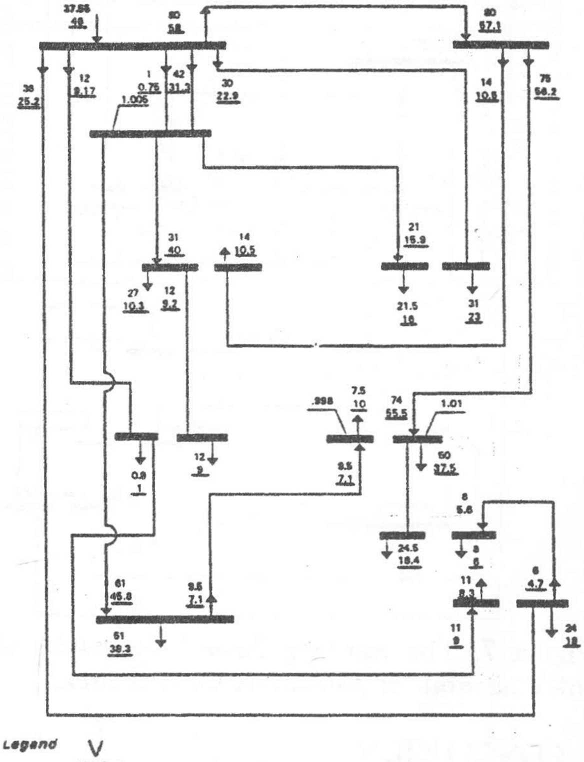

Figure 6. Input set of measurements to the estimator.

Table 4.

Test System	CPU Time (sec)			
	Topology Processor Determination	Observability Test	Power System State Estimation	Total CPU Time
Alex-C	0.022	0.0549	2.4	2.477
IEEE 30 bus	0.044	0.2197	4.48	4.744
Alex. 66 KV net.	0.110	0.8239	9.4	10.33

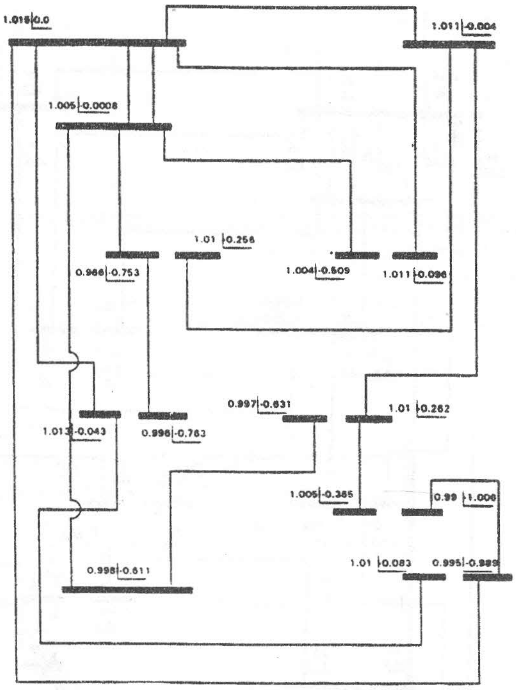

Figure 7. The resulting Real-Time model of the 66KV network of Alexandria Central Area.

4. CONCLUSION

A model that tracks the real time network conditions using real time measurements was developed. This modeling has the advantage that it needs minimum numerical calculations and a reduced computational time (Table 4); which would be of great importance in on-line implementation.

The various steps in constructing the model were described. These steps include the determination of network topology, the check for observability and the estimation of the updated network state. These steps give a real-time model of power system used by control center's operator to improve the overall power system performance.

It was shown that network topology processor provides the on-line monitoring program with an updated configuration of the transmission network. It will do so, by processing breaker status independent of the substation breaker arrangement. The CAP technique was used in the topology processor determination after adding some modifications to give a complete system configuration which may be used by any state estimator and to comply with next steps of the model.

To verify the effectiveness of the proposed real-time model, several test models including IEEE 30 bus system and the practical 66 KV subtransmission network of Alexandria city (45 bus and 47 lines) have been selected for computer simulation. By investigation the model presented herein can be used for real-time modelling of power systems in EM and SCADA control centers.

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6. APPENDIX A

Table A1 : Data Of 66 (KV) Network Of Alex. Central Area.

Line Code	Ser. Imp. (p.u)	Line Code	Ser. Imp. (p.u)
1	.0017 + j.0085	10	.008 + j.019
2	.021 + j0.07	11	.003 + j.006
3	.010 + j0.014	12	.002 + j.003
4	.009 + j.026	13	.002 + j.006
5	.015 + j.042	14	.006 + j.008
6	.006 + j.010	15	.010 + j.015
7	.004 + j.006	16	.007 + j.009
8	.0004 + j.0010	17	.010 + j.014
9	.005 + j.008		