BENEFIT OF INTERCONNECTION OF KINGDOM OF SAUDI ARABIA'S ELECTRIC UTILITIES

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ABSTRACT

The Kingdom of Saudi Arabia is currently served by four major electric utilities. Current plans, by the Ministry of Electricity and Industry, calls for the eventual consolidation of these four electric networks into one interconnected national grid. At the moment only two of the major utilities are interconnected. An interconnected Saudi Arabian electric power supply system could provide many benefits.

Generation expansion plans were developed for the participating utilities without the proposed interconnections to meet specified reliability criteria. Using reliability analysis, the optimum interconnection link capacities were evaluated. The generation expansion plans of the utilities with the optimum links were then developed. The reduction in generation capacity resulting from the interconnection were evaluated and the economic benefit quantified. At a discount rate of 5%, the savings in generation capacity including operation and maintenance savings is amounted to SR 8,248 million.

This paper will review the electric power systems of the four electric utilities, major expansion plans will be discussed. Assumption and methodology adopted for this study will also be discussed. The benefits obtained by interconnecting the Saudi electric power system will be presented.

Keywords: *Generation expansion planning, Generation reliability evaluation, Interconnection planning and studies, Interconnection benefits, Costing and economic evaluation*

الملخص

تخدم المملكة العربيّة السّعوديّة حاليا بأربعة مرافق كهربائيّة رئيسيّة , أي , الشّركة الكهربائيّة السّعوديّة – فرع المنطقة الشرقيةّ ، الشّركة الكهربائيّة السّعوديّة – فرع المنطقة الوسطى , الشّركة الكهربائيّة السّعوديّة – فرع المنطقة الغربية و الشّركة الكهربائيّة السّعوديّة – فرع المنطقة الجنوبية . تطالب الخطط الحاليّة , بوزارة الصّناعة والكهرباء بالتّدعيم النّهائيّ لهذه الشّبكات الكهربائيّة الأربعة في شبكة واحدة متصلة. هنالك فقط في هذه الإثناء اثنتان من المرافق الرّئيسيّة

متصلتان وهما , الشّركة الكهربائيّة السّعوديّة – فرع المنطقة الشرقيةّ و الشّركة الكهربائيّة السّعوديّة – فرع المنطقة الوسطى. يمكن أن يمدّ الربط الكهربائي لنظم القدرة الكهربائيّة العربيّة السعوديّة بفوائد كثيرة .

لقد تم تطوير خطط زيادة التوليد الكهربائي للمرافق المشاركة دون إلزام الربط الكهربائي المقترح بالمعايير الاعتمادية المحدّدة . لقد تم من خلال استعمال تحليل الاعتمادية تقيم لأفضل سعات وصلات الترابط الكهربائية. وقد تم تطوير خطط زيادة التوسع في التوليد مع افضل وصلات الترابط للمرافق. وتم تقيم الخفض في سعات التوليد الناتج عن الترابط الكهربائي وتحديد قيم المنفعة الاقتصادية. ويتوقّع أن يتسبّب الترابط الكهربائي بمدّخرات متراكمة للمنشأة الكهربائية بحدود ٢،٧٥١ ميغا وات. هذه المدّخرات تراكميّة من السّنة ٢٠٠٣ , السّنة الأولى للترابط , إلى سّنة ٢٠٢٣. وبمعدّل خفّض ٥ % ,وأن المدّخرات في قدرة التوليد متضمّنًا التشغيل الصّيانة تصل إلى ٨،٢٤٨ مليون.

سوف تعرض هذه الورقة نظم القدرة الكهربائيّة للمرافق الأربعة, وسوف تناقش خطط الزّيادة الرّئيسيّة. وسوف تناقش أيضًا الفرضيات و علم المنهج المتبنى لهذه الدّراسة. وسيتم تقديم الفوائد المحصلة من خلال ربط نظام القدرة الكهربائيّة السّعودية.

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1. INTRODUCTION

The Kingdom of Saudi Arabia is currently served by four major electric utilities, namely, Saudi Electric Company - Eastern Branch (SEC-ERB), SEC-CRB (Central Branch), SEC-WRB (Western Branch) and SEC-SRB (Southern Branch). Current plans, as envisioned by the Ministry of Electricity and Industry, calls for the eventual consolidation of these four electric networks into one interconnected national grid [Electricity Corporation, 1995]. At the moment only two of the major utilities, SEC-ERB and SEC-CRB, are interconnected. The interconnection between these two utilities was established primarily to provide firm exports of electric energy from the Eastern Province to the Central Province.

International experiences have indicated that, an interconnected electric power supply system could provide many benefits [Kanev, D. and Kanchovsky, S., 2001, Belayaev, L.S. et al, 2000, Tiberini, A. and Amthauer, E., 2000, Ardito, A. et al, 1998, Ibrahim, E.S., 1996]. These include, among others, reduction in the investment in generation capacity requirements, improved system reliability, spinning reserve sharing, reduction in operation and maintenance costs of power plant, emergency assistance from neighboring generators and energy trading based on marginal production cost differences. SEC-WRB and SEC-SRB systems are electrically isolated from each other and from the SEC-ERB – SEC-CRB interconnected system. A study [KFUPM/RI, 1999] was conducted to evaluate the benefits of interconnection of SEC-WRB and SEC-SRB to the SEC-ERB – SEC-CRB system.

This study relies mostly on data supplied in a study, "*Update Long Term Electrification Plan (ULTEP) for Saudi Arabia - Generation Plan Report* [Electricity Corporation, 1998]. That

study, which was conducted by the Ministry for Electricity and Industry, Riyadh provides an update to an earlier report "*Long Term Electrification Plan (LTEP) for Saudi Arabia*" [Electricity Corporation, 1995] also conducted by the same ministry.

1.1. Load demand and energy forecast

Table 1 shows the demand and energy forecasts for the four major utilities at some snapshot years as obtained from the ULTEP report. As may be observed from this table, the Saudi systems are projected to evolve into three, comparably sized utilities (SEC-ERB, SEC-CRB and SEC-WRB) and a smaller one (SEC-SRB) by the year 2023. In relation to the system peaks, the energy use is highest in SEC-ERB due to the concentration of heavy industry in the Eastern Province.

1.2. Generation expansion plan

The ULTEP report provides the generation expansion plans for all four utilities. A summary of the expansion plans developed for these utilities is also shown in Table 1. The figures shown are based on "reference" generation plans developed in the ULTEP study. These reference plans represent the most likely expansion scenario as envisaged in the plan.

Table 1. Peak load demand, generation expansion plans and energy forecast.

Year	SEC-ERB			SEC-CRB			SEC-WRB			SEC-SRB		
	Load (MW)	Gen. (MW)	Ener. (GWh)	Load (MW)	Gen. (MW)	Ener. (GWh)	Load (MW)	Gen. (MW)	Ener. (GWh)	Load (MW)	Gen. (MW)	Ener. (GWh)
1999	8,065	9,754	43,538	5,982	6,059	29,145	6,261	6,768	35,437	1,575	1,405	8,488
2000	8,694	10,354	47,612	6,450	6,407	31,442	6,819	6,908	38,279	1,721	1,601	9,375
2005	10,710	12,434	60,195	9,938	9,938	43,259	8,745	10,019	49,031	2,282	2,901	12,639
2010	12,580	14,337	70,834	10,335	11,707	51,703	10,659	12,292	59,439	3,077	3,787	17,026
2015	14,341	16,155	80,475	12,224	13,770	61,624	12,632	14,525	70,087	3,988	4,822	21,966
2020	16,057	18,013	89,524	14,793	15,998	72,229	14,793	17,259	81,643	5,075	6,031	27,740
2023	17,181	19,069	95,576	15,464	17,382	78,811	16,112	18,941	88,644	5,666	6,656	30,827

SEC-ERB load and generating plans include export to SEC-CRB.

2. STUDY ASSUMPTIONS AND METHODOLOGY

This section presents the basic assumptions and methodology used in conducting the study. The basic assumptions on which this current study was based are as follows:

2.1. Study assumptions

The assumptions adopted in this study are in line with those used with ULTEP study. Demand forecast, reference generation plans, planning year, power supply options, fuel supply availability, forced outage rates, maintenance schedule, generation planning standard,

capital cost of plant, operation and maintenance costs, cash flows and service life of generating units and transmission equipments are same as those adopted by ULTEP. A few more assumption were adopted for the current study and are as follows:

Study Horizon: In this study, a horizon of 2003-2023 was used. Most of the new generating units, which have not been commissioned as yet, will appear around 2003 and beyond.

Earliest Year of Interconnection: The earliest year for interconnection was assumed to be the year 2003 for both the SEC-WRB – SEC-CRB and the SEC-SRB – SEC-WRB interconnections. The year 2003 provides opportunities for generation plant savings as well as sufficient lead time for the interconnections to be realized.

Interconnection Benefits: The benefits from the proposed interconnection are determined from (a) the savings in generation plant reserves and (b) savings in operation and maintenance costs.

Existing SEC-ERB – SEC-CRB Transmission Capacity: It was assumed that the existing transmission capacity between SEC-ERB and SEC-CRB would not change during the study horizon. Currently, contractual shipments are limited to a maximum of 1,200 MW from SEC-ERB to SEC-CRB. Excess capacity available from this interconnection is known to be 1,000 MW. For planning purposes, the available capacity for this link was assumed to be 2,200 MW total.

Economic Parameters: The reference year for all costs is January 1, 1999. All costs are expressed in constant money and in Saudi Riyals (SR) based on a fixed exchange rate of 3.75 SR to the US dollar. A base discount rate of 5% is used for economic evaluation. Rates of 3% and 7% were used for sensitivity analysis.

2.2. Methodology

One of the principal benefits of interconnecting power systems is the reduction in the amount of generation capacity needed to achieve a given level of reliability. In order to quantify this benefit, it is necessary to estimate the plant requirements of each system without the proposed interconnection. The difference in plant requirements before and after the proposed interconnection yields the generation capacity benefits (savings). The following sections illustrate in details the methodology used.

3. MODIFIED REFERENCE GENERATION PLANS

In order to quantify the generation capacity savings attainable through interconnection, it is first necessary to estimate the plant requirements of each system without the proposed interconnection. The basic plant data used in this analysis was extracted from the ULTEP report. This study provides detailed information of the separate system expansion plans for all

the four major utilities. Ordinarily, this information should have been the starting point for carrying out the interconnection study. However, due to changes in systems' load profile, modeling assumptions and some computer program parameters used, it was found necessary to obtain modified, separate system generation plans. These plans are hereinafter referred to as the modified reference generation plans. This section presents the modified reference generation plans for SEC-ERB, SEC-CRB, SEC-WRB and SEC-SRB. In carrying out these studies the following assumptions were made:

The modified generation plans are expected to be not significantly different from those obtained in the ULTEP study. Consequently, ULTEP plans were modified on the basis of reliability studies alone. The generation unit types, sizes, operating characteristics used in the ULTEP were adopted. Firm plans were observed. However, future additions were advanced or delayed when the reliability calculations indicated that plans must be modified.

3.1 Methodology

A generation plan is prepared for each utility for each year beginning from 2003 to 2023. The plans start from the ULTEP separate system (reference) generation plans for the four utilities. For each utility and each year, reliability analysis was carried using a multi-area reliability software, MAREL [PTI, 1993] to determine the Loss-of-Load-Expectation (LOLE) index. The LOLE is defined as an expected value of the number of hours/days per year of capacity deficiency. Except for units on firm installation schedule, plants were advanced or delayed in order to meet the criterion of not exceeding the assumed LOLE index of 4.8 hours per year. The same LOLE standard are adopted by the Kingdom's utilities and is also used by ULTEP study [Electricity Corporation, 1998].

3.1.1 MAREL Computer Application Program

The generation capacity savings were quantified using a multi-area reliability analysis program, MAREL. MAREL is a well known program within the electric utility industry. This program assesses the reliability of an isolated or interconnected electric power system. It calculates standard reliability indices, which can be used to develop generation expansion plans. Standard indices such as the Loss-of-load expectation (LOLE), the Expected-energy-not-served (EENS), and area deficiencies are generated.

3.2. Separate System Plans

A separate system plan is developed for the four major utilities. These plans show the year-by-year installation schedules for future generating units and the retirement schedules of existing units. The plan also provide the total load demand, the plant reserves available in each year. In developing these plans, firm plans for the installation of new plant were not modified. A closer look at these reference plans and those of the ULTEP report shows some slight differences between the two results. These differences are due to load profile changes and program parameter differences.

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4. INTERCONNECTION TIE CAPACITIES

This section presents the interconnection studies and the results of the analyses conducted to determine the most appropriate tie capacities between SEC-WRB, SEC-CRB and SEC-SRB. In order to determine the appropriate interconnection tie capacities between these three utilities, it is first necessary to remove all capacity benefits that can be attributed to the existing SEC-ERB - SEC-CRB interconnection. The generation capacity savings attributable to the existing interconnection and the method used in quantifying them are described in the section that follows.

4.1. Generation Capacity Savings due to Existing SEC-ERB – SEC-CRB Interconnection

The existing interconnection between SEC-ERB and SEC-CRB allows for firm power shipments from East to Central. The capacity of this link is about 2,200 MW that is 1,000 MW higher than the existing maximum contractual transfer. In trying to quantify generation capacity benefits arising out of new interconnections, it is necessary to remove the reliability benefits coming from this available excess capacity. To determine the generation capacity savings due to the existing East-Central interconnection, new generation plans were developed for SEC-ERB and SEC-CRB that recognize the extra transmission capacity available from this link. Generation plants were removed or added, where necessary, in order to satisfy the LOLE criterion of not more than 4.8 hours per year. These studies were carried for each year from 2003 to year 2023. Where generation plants were removed, priority was given to gas turbines (GTs) since they have the highest per kW owning cost. Combined cycle plants (CCs) were removed only when there were not available GTs in that year. These CCs were brought back in whenever the opportunity to do so arose.

The cumulative generation capacity savings amounts to 1,701 MW. This capacity credit is due to the extra transmission capacity available from the existing SEC-ERB to SEC-CRB interconnection. The modification, when added to the reference plans developed earlier yields the optimum generation plan for the SEC-ERB - SEC-CRB interconnected system. Optimum is used here in the sense of maximizing the generation capacity saving benefit.

4.2 Optimum Interconnection Capacity For Generation Plant Savings

The method used in determining the optimum capacity between systems is as follows. First, the systems are assumed to be interconnected by a link of infinite capacity. The systems here refer to the modified reference generation plans without the new interconnection and with the East-Central transmission capacity credit taken out. In actual simulation the link is assigned a large transmission capacity. Consider for example a two-area system. Having an infinite tie between them in effect makes the two systems behave as a single area system. Reliability analysis of such an interconnected system will show a much lower LOLE. Consequently, generation plant capacity can be removed to bring the LOLE standard closer to but not exceeding 4.8 hours per year. The amount of plant capacity removed represents the potential

reserves that can be shared by the two systems. This shared reserve is in effect the transmission capacity that is required to link the two systems. For systems with multi-year generation plans an average value must be found.

The average potential reserve sharing benefits were evaluated by conducting reliability analysis at five-year intervals starting in year 2003. At those snapshot years, generation plant capacity was removed to satisfy the 4.8 LOLE criterion. The potential savings obtained in those snapshot years were then averaged to obtain the required interconnection capacity. Having determined the interconnection capacity, new generation plans were developed for the proposed interconnected system. Year-by-year modification of the reference generation plans were conducted to determine the actual plants that must be removed or shifted to satisfy the reliability standard.

4.2.1 Rules for Plant Addition or Removal

The following rules were followed in evaluating the potential capacity sharing benefit among the systems.

- Firm generation installation plans were not removed.
- Where plants were available for removal, priority was given to gas turbines (GT) since they have higher per kW owning cost than steam (ST) or combined cycle (CC) units. Whenever a steam or combined cycle unit was removed because of the unavailability of a sufficient number of gas turbines, this unit was brought back in whenever the opportunity arose.
- Plants were removed from the systems in relation to their sizes (peak load).
- Each utility has to maintain a minimum reserve equal to the largest unit

4.2.2 Results of Tie Capacity Evaluation Studies

The results of tie capacity evaluation studies are shown in Tables 2 and 3. The average capacities shown exclude the year 2003. Not much plant was available for removal because of firm, committed units. On the basis of the results obtained a capacity of 1,400 MW was adopted for the West to Central link and 1,000 MW for the South to West link. These adopted capacities which are about 10 percent higher than the calculated averages, are to allow for the impact of the Royal Commission for Jubail and Yanbu (RCJY) network interconnection to SEC-WRB and the economic lifetime of the proposed interconnection. The 30-year transmission equipment life would favor the higher values found in the later years (2018-2023).

Table 2. Potential Capacity Savings: East - Central to West Interconnection.

Year	Interconnected System LOLE	Capacity savings (MW)			
	(hrs/year)	Total	East	Central	West
2003	0.07	106	0	106	0
2008	3.96	1,181	408	423	350
2013	4.57	1,288	360	529	399
2018	4.32	1,230	240	477	513
2023	4.66	1,454	240	530	684
Average		1,289	312	490	487

Table 3. Potential Capacity Savings: East - Central -West to South Interconnection.

Year	Interconnected System LOLE	Capacity Savings (MW)				
	(Hrs/Year)	Total	East	Central	West	South
2003	0.09	228	0	0	0	228
2008	3.67	635	0	0	350	285
2013	4.01	855	0	0	342	513
2018	4.67	969	0	0	456	513
2023	4.14	1,140	0	0	456	684
Average		900			401	499

5. INTERCONNECTED SYSTEM GENERATION PLANS AND GENERATION CAPACITY SAVINGS

In section 4, the tie capacities that maximize generation plant savings were presented. In this section the generation plans developed for all four SECs using these interconnection tie capacities are presented. In general, the interconnected system plans require less plant capacity than the reference plans. In addition to the requirement that the system LOLE after interconnection should be at least as good as before interconnection, and constraints on the acceptable reserve margin for each system were also imposed. The interconnected system generation plans are presented in the following sections.

5.1 Results of study

The study involves the interconnection of SEC-WRB to the East-Central system followed by the interconnection of SEC-SRB. Detailed year-by-year generation expansion plans were

developed using the adopted link capacities. The savings in generation capacity were evaluated as the difference in installation plans before and after interconnection.

5.1.1 Interconnection of SEC-WRB to the SEC ERB-CRB System (Stage 1)

For this interconnection study, a new link of capacity 1,400 MW was placed between SEC-WRB and the SEC-ERB – SEC-CRB system. As a result of this interconnection, all three affected utilities benefit from generation capacity savings. The savings for each utility are discussed below.

SEC-WRB: In Table 4 the summary generation plans for SEC-WRB with and without interconnection are presented at 5-year snapshots. It can be observed that except for the year of interconnection (2003), the interconnection leads to a reduction in generation plant reserves in all other years. In year 2023 this amounts to a reduction of about 4.6%. The plant reserve is in excess of the minimum requirement imposed. The yearly savings in generation capacity for SEC-WRB shows a reduction in plant capacity which amounts to a total of 741 MW by the 2023. This is made up of gas turbines. The interconnection allows the installation of 350 MW steam plant in year 2005 to be delayed until 2011. This delay provides additional economic benefit.

SEC-CRB: Table 5 shows a summary of the generation expansion plan for snapshot years. The plans for SEC-CRB with and without the new interconnection are presented at 5-year snapshots. The interconnection leads to a reduction in generation plant reserves in all years. In year 2023 this amounts to a reduction of about 7.8%. The yearly savings in generation capacity for SEC-CRB shows a reduction in plant capacity that amounts to 636 MW by the 2023. This is made up of gas turbines. The interconnection allows the installation of 285 MW combined cycle plant in year 2004 to be delayed until 2012. This delay provides additional economic benefit.

Table 4. Interconnected SEC-WRB Generation Plan.

Year	Load (MW)	I/C Installed Capacity (MW)	I/C Reserve (%)	Ref. Plan Reserve (%)
2003	8,081	9,811	21.4%	21.4%
2008	9,891	11,051	11.7%	15.8%
2013	11,830	12,955	9.5%	15.3%
2018	13,902	15,481	11.4%	15.0%
2023	16,112	17,915	11.2%	15.8%

I/C interconnected.

SEC-ERB: The plans for SEC-ERB with and without the new interconnection are presented at 5-year snapshots in Table 6. The interconnection leads to a reduction in generation plant reserves in all years. In year 2023 this amounts to a reduction of about 4.9%. The yearly savings in generation capacity for SEC-ERB shows a reduction in plant capacity that amounts to 120 MW by the 2023. The interconnection allows the installation of 408 MW combined cycle plant in year 2004 to be delayed until 2007 providing additional economic benefit.

Table 5. Interconnected SEC-CRB Generation Plan.

Year	Load (MW)	I/C Installed Capacity (MW)	I/C Reserve (%)	Ref. Plan Reserve (%)
2003	7,777	7,983	2.7%	15.4%
2008	9,690	10,046	3.7%	14.8%
2013	11,452	11,990	4.7%	14.4%
2018	13,413	14,157	5.5%	13.8%
2023	15,464	16,322	5.6%	13.4%

I/C interconnected.

Table 6. Interconnected SEC-ERB Generation Plan.

Year	Load (MW)	I/C Installed Capacity (MW)	I/C Reserve (%)	Ref. Plan Reserve (%)
2003	9,984	11,554	15.7%	16.9%
2008	11,812	12,732	7.8%	15.9%
2013	13,648	14,899	9.2%	15.3%
2018	15,376	16,765	9.0%	15.3%
2023	17,181	18,829	9.6%	14.5%

I/C interconnected.

5.1.2 Interconnection of SEC-SRB to the SEC WRB-CRB-ERB System (Stage 2)

In this study, a link of capacity 1,000 MW was placed between SEC-SRB and SEC-WRB. This results in the interconnection of all four major utilities. The results of the generation plan study show that the generation capacity savings are possible only in SEC-SRB, SEC-WRB and SEC-CRB. The savings for each utility are discussed below.

SEC-SRB: In Table 7, the plans for SEC-SRB with and without interconnection are presented at 5-year snapshots. The interconnection leads to reduction in generation plant reserves in all

years and amounts to a reduction of 11.1% in year 2023. The yearly savings in generation capacity for SEC-SRB shows a reduction in plant capacity that amounts to 627 MW by the 2023. The interconnection allows the installation of 250 MW steam plant in year 2005 to be delayed until 2006 providing additional economic benefit.

SEC-WRB: In Table 8, the plans for SEC-WRB with and without the new interconnection are presented at 5-year snapshots. Except for year 2003, the interconnection leads to reduction in generation plant reserves in all other years. In year 2023 this amounts to a reduction of about 8.5%. The yearly savings in generation capacity for SEC-WRB shows a reduction in plant capacity totaling 627 MW by the year 2023. The interconnection allows the installation of 350 MW steam plant in year 2006 to be delayed until 2010 that would provide additional economic benefit.

SEC-CRB: In Table 9, the plans for SEC-CRB with and without the new interconnection are presented. The interconnection leads to reduction in generation plant reserves in all years. In year 2023 this amounts to a reduction of about 7.8%. The yearly savings in generation capacity for SEC-CRB shows that there is no net reduction in plant capacity. However, the new interconnection allows some delays in the installation of a number of gas turbines. These provide additional economic benefit.

Table 7. Interconnected SEC-SRB Generation Plan.

Year	Load (MW)	I/C Installed Capacity (MW)	I/C Reserve (%)	Ref. Plan Reserve (%)
2003	2,065	2,503	21.2%	32.2%
2008	2,757	3,253	18.0%	34.5%
2013	3,605	4,218	17.0%	32.8%
2018	4,619	5,442	17.8%	28.9%
2023	5,666	6,714	18.5%	29.6%
2023	5,666	6,714	18.5%	29.6%

Table 8. Interconnected SEC-WRB Generation Plan.

Year	Load (MW)	I/C Installed Capacity (MW)	I/C Reserve (%)	Ref. Plan Reserve (%)
2003	8,081	9,811	21.4%	21.4%
2008	9,891	10,701	8.2%	15.8%
2013	11,830	12,556	6.1%	15.3%
2018	13,902	15,025	8.1%	15.0%
2023	16,112	17,288	7.3%	15.8%

Table 9. Interconnected SEC-CRB Generation Plan.

Year	Load (MW)	I/C Installed Capacity (MW)	I/C Reserve (%)	Ref. Plan Reserve (%)
2003	7,777	7,983	2.7%	15.4%
2008	9,690	10,046	3.7%	14.8%
2013	11,452	11,990	4.7%	14.4%
2018	13,413	14,157	5.6%	13.8%
2023	15,464	16,322	5.6%	13.4%

SEC-ERB: This generation plan study did not provide any reduction in capacity reserves. This is not a surprising result since most of the available plant reserves would be expected to be shaved off to account for the East-Central to West interconnection studied earlier.

5.1.3 Summary of Generation Capacity Savings

The savings due to SEC-WRB to SEC-CRB Link (stage 1) is 1,497 MW, the major contributor to the reserve savings were SEC-WRB and SEC-CRB. 1,254 MW was saved in the reserve due to the interconnection between SEC-SRB to SEC-WRB (stage 2). In this stage the saving was shared between SEC-SRB and SEC-WRB. The overall savings due to the integration of the four Saudi utilities is 2,751 MW.

6. GENERATION BENEFITS DUE TO INTERCONNECTION

The interconnection of power systems can give rise to several technical, economic and strategic benefits. In carrying out an assessment of the proposed interconnection schemes, only the generation capital and operation and maintenance (O&M) savings are considered. The generation benefits due to the interconnection were determined by comparing the costs of the reference generation expansion plans of the utilities to those plans resulting from the new interconnections. Since the reference and interconnected system plans differ in both the amount and timing of new plant capacity, the value of the saving must be determined from the effect of the interconnection on the total cost of all new generation plant capacity. The costs are based on simulation of the network from Jan.1, 2003 to Dec. 31, 2023. In order to evaluate the residual effects, the evaluation period was extended to Dec. 31, 2032. This is to account for the 30-year economic life of the new interconnection links. All benefits are assigned a present worth for January 1, 1999 using a 5% discount rate. Benefits at 3% and 7% discount rates are also presented. The generation capital cost, cash flow and O&M cost data used were adopted from ULTEP. The annual generation savings due to these interconnections were evaluated for each utility. These savings consist of generation capacity

savings and O&M savings. Summaries of the generation savings are presented in the following sections.

6.1. Generation Benefits: SEC-WRB to SEC-CRB – SEC-ERB Interconnection (Stage 1)

Table 10 shows the potential generation savings from the interconnection of SEC-WRB to the SEC-CRB – SEC-ERB system. The breakdown of these benefits at various discount rates is presented in Table 11. At a discount rate of 5%, the cumulative present worth of benefits is estimated in Saudi Riyals (SR) to be 4,594 million. Of this amount, the savings in generation investment amounts to SR 3,747 million while savings in O&M amounts to SR 846 million (Table 11). Most of the benefits are the result of the reduction in generation capacity in SEC-WRB and SEC-CRB. Together, these two utilities provide nearly 88% of the benefits. As SEC-SRB is not participating in this interconnection, no benefits are shown.

Table 10. Summary of generation benefits.

Component	Benefits	
	(SR million)	(%)
SEC-WRB	1998	43.5%
SEC-SRB	0	0.0%
SEC-CRB	2027	44.1%
SEC-ERB	569	12.4%
Cumulative P.W. Benefits	4594	100.0%

Table 11. Breakdown of generation benefits.

Component	Breakdown of benefits at various discount rates (SR million)		
	3%	5%	7%
Generation Investment	4241	3747	3366
Generation O&M	1190	846	620
Cumulative P.W. Benefits	5431	4594	3985

6.2. Generation Benefits: SEC-SRB SEC-WRB-CRB-ERB Interconnection (Stage 2)

Table 12 shows the potential generation savings from the interconnection of SEC-SRB to the SEC WRB-CRB-ERB system while Table 13 provides the breakdown of these benefits at various discount rates. At a discount rate of 5%, the cumulative present worth of benefits is shown to be SR 3,655 million. Of this amount, the savings in generation investment amounts to SR 3,000 million while savings in O&M amounts to SR 655 million (Table 13). Practically

all the benefits come from the reduction in generation capacity in SEC-WRB and SEC-SRB. These two utilities provide nearly 99.4% of the benefits.

Table 12. Summary of generation benefits.

Component	Benefits	
	(SR million)	(%)
SEC-WRB	1541	42.2%
SEC-SRB	2089	57.2%
SEC-CRB	24	0.7%
SEC-ERB	0	0.0%
Cumulative P.W. Benefits	3655	100.0%

Table 13. Breakdown of generation benefits.

Component	Breakdown of benefits at various discount rates (SR million)		
	3%	5%	7%
Generation Investment	3486	3000	2623
Generation O&M	936	655	471
Cumulative P.W. Benefits	4422	3655	3095

6.3. Summary of Generation Benefits

The total potential benefits of interconnecting all four utilities is shown in Tables 14-15. These benefits are derived by adding the benefits of Stage 1 to that of Stage 2. As Table 14 shows, the cumulative present worth of benefits amounts to SR 8,248 million at 5% discount rate. The calculated benefits at other discount rates are shown in Table 15. The breakdown of the benefits (Table 14) shows that SEC-WRB derives 42.9 % of the total. This is because SEC-WRB is involved in all two stages of the interconnection. SEC-ERB derives the least amount of benefit (6.9%) because it is already interconnected to SEC-CRB and does not have much to provide by way of generation capacity savings.

Table 14. Summary of generation benefits.

Component	Benefits	
	(SR million)	(%)
SEC-WRB	3539	42.9%
SEC-SRB	2089	25.3%
SEC-CRB	2051	24.9%
SEC-ERB	569	6.9%
Cumulative P.W. Benefits	8248	100.0%

Table 15. Breakdown of generation benefits.

Component	Breakdown of benefits at various discount rates (SR million)		
	3%	5%	7%
Generation Investment	7727	6748	5989
Generation O&M	2126	1501	1091
Cumulative P.W. Benefits	9853	8248	7080

7. CONCLUSIONS

The interconnection of Saudi Arabia's four major utilities have been subjected to detailed engineering and economic analyses to quantify the benefits that can be derived from them. The technical studies indicate that the cumulative generation plant reserve savings are amounting to 2,751 MW. The results of the discounted cash flow analysis show that, on the basis of the assumptions made of the costs and benefits, the proposed interconnection provide substantial economic benefits. At a discount rate of 5%, the savings in generation capacity alone amounts to SR 6,748 million. Including operation and maintenance the total benefits are respectively SR 8,248 million.

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