Over the Transmission Hurdle

Assessing electrical transmission constraints for the Southern African Power Pool (SAPP) in PLEXOS

Jarrad Wright Pr.Eng M.Sc.Eng.(Elec.)[1]

Leading the field in Energy Market Modelling

1 Introduction

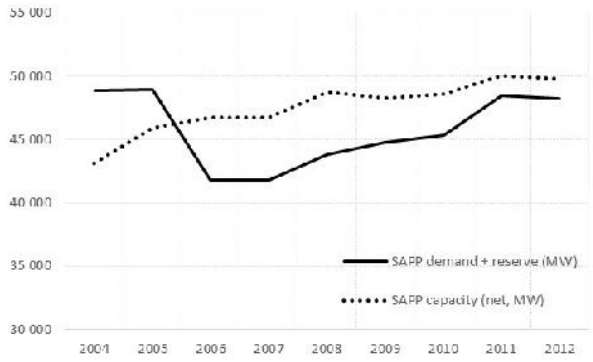
1.1 SAPP establishment and development

The Southern African Power Pool (SAPP) was formed in 1995 to promote trading of electricity between nations in the Southern African Development Community (SADC) [1]. Initially, the national utilities of each SADC country were included as SAPP members to co-operatively trade electricity (via bilateral contracts and a Short Term Energy market (STEM)). The STEM was replaced in 2009 with a competitive trading market (the Day Ahead Market (DAM)) and inclusion of Independent Power Producers (IPPs) and Independent Transmission Companies (ITCs) was late allowed.

The SAPP membership of 16 (as of 2013) is shown in Table 1 [2]. It includes nine Operating Members (OP), three Non-Operating Members, two Observers, one IPP and one ITC [2]. As can be seen in Figure 2, the majority of SAPP members are interconnected with the only isolated members being ESCOM (Malawi), ENE (Angola) and TANESCO (Tanzania).

1.1 A constrained SAPP

The interconnected SAPP has been significantly constrained for generation capacity in the last decade as can be seen in



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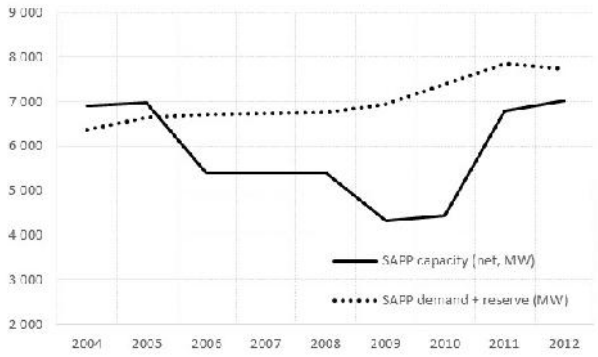

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[1] Jarrad is the Senior Consultant for Energy Exemplar (Africa)
E: jarrad.wright@energyexemplar.com
T: +27 (0) 11 881 5889
M: +27 (0) 79 527 6002
W: www.energyexemplar.com

Figure 1 where SAPP demand (incl. typical 15% reserve margin) for 2004-2012 is compared to net SAPP capacity (with/without South Africa). As can be seen, the SAPP has not had sufficient generation capacity since 2006. This trend is magnified when excluding the dominant player in the SAPP (Eskom, South Africa). Although, there are a number of rehabilitation and new generation projects currently underway to remove these constraints in the medium term (mostly in Botswana, Mozambique, South Africa, Zambia and Zimbabwe) [2].

In addition to existing generation capacity constraints, as can be seen in Figure 3, transmission capacity constraints have a significant effect on the volume of trading within SAPP (whether via bilateral contracts or DAM). For 2013/2014, on average, 70% of energy matched in the DAM was not traded and 77% of bilateral contracts granted were not traded. Again, there are a number projects in the pipeline that are far advanced to rectify these transmission constraints including the ZIZABONA project and the Central Transmission Corridor project [2]. Other notable priority SAPP transmission projects include the interconnection of NP members i.e. Namibia-Angola Interconnector, Mozambique-Malawi Interconnector and Zambia-Tanzania-Kenya Interconnector [2].

Table 1: SAPP membership (2013)

Entity	Status	Abbreviation	Country
Botswana Power Corporation	OP	BPC	Botswana
Electricidade de Mocambique	OP	EdM	Mozambique
Hidro Electrica Cahora Bassa	OB	HCB	Mozambique
Mozambique Transmission Company	OB	MOTRACO	Mozambique
Electricity Supply Corporation of Malawi	NP	ESCOM	Malawi
Empresa Nacional de Electridade	NP	ENE	Angola
Eskom	OP	Eskom	South Africa
Lesotho Electricity Corporation	OP	LEC	Lesotho
NamPower	OP	NamPower	Namibia
Societe Nationale d'Electricite	OP	SNEL	DRC
Swaziland Electricity Company	OP	SEC	Swaziland
Tanzania Electricity Supply Company	NP	TANESCO	Tanzania
ZESCO Ltd	OP	ZESCO	Zambia
Copperbelt Energy Corporation	ITC	CEC	Zambia
Lunsemfwa Hydro Power Company	IPP	LHPC	Zambia
Zimbabwe Electricity Supply Authority	OP	ZESA	Zimbabwe

OP = Operating Member

NP = Non-Operating Member

OB = Observer

ITC = Independent Transmission Company

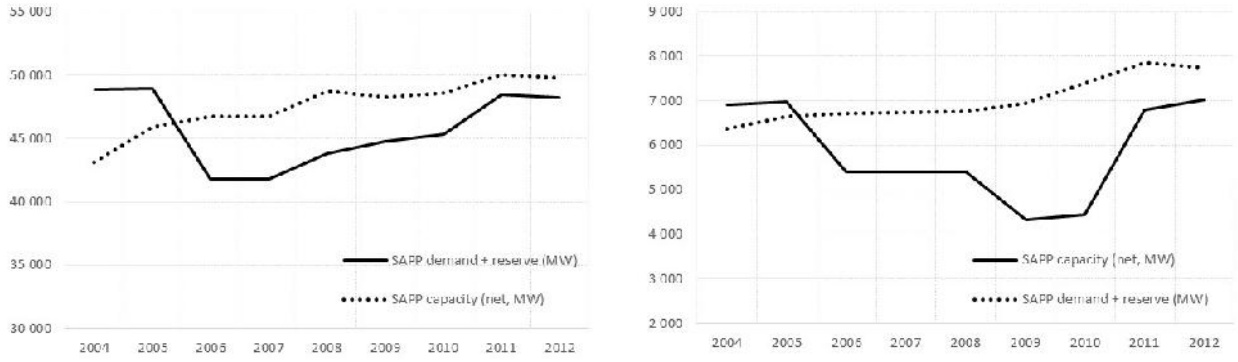

Figure 1: SAPP historical interconnected capacity, peak demand and reserve margin (2004-2012) (a) incl. SA (b) excl. SA

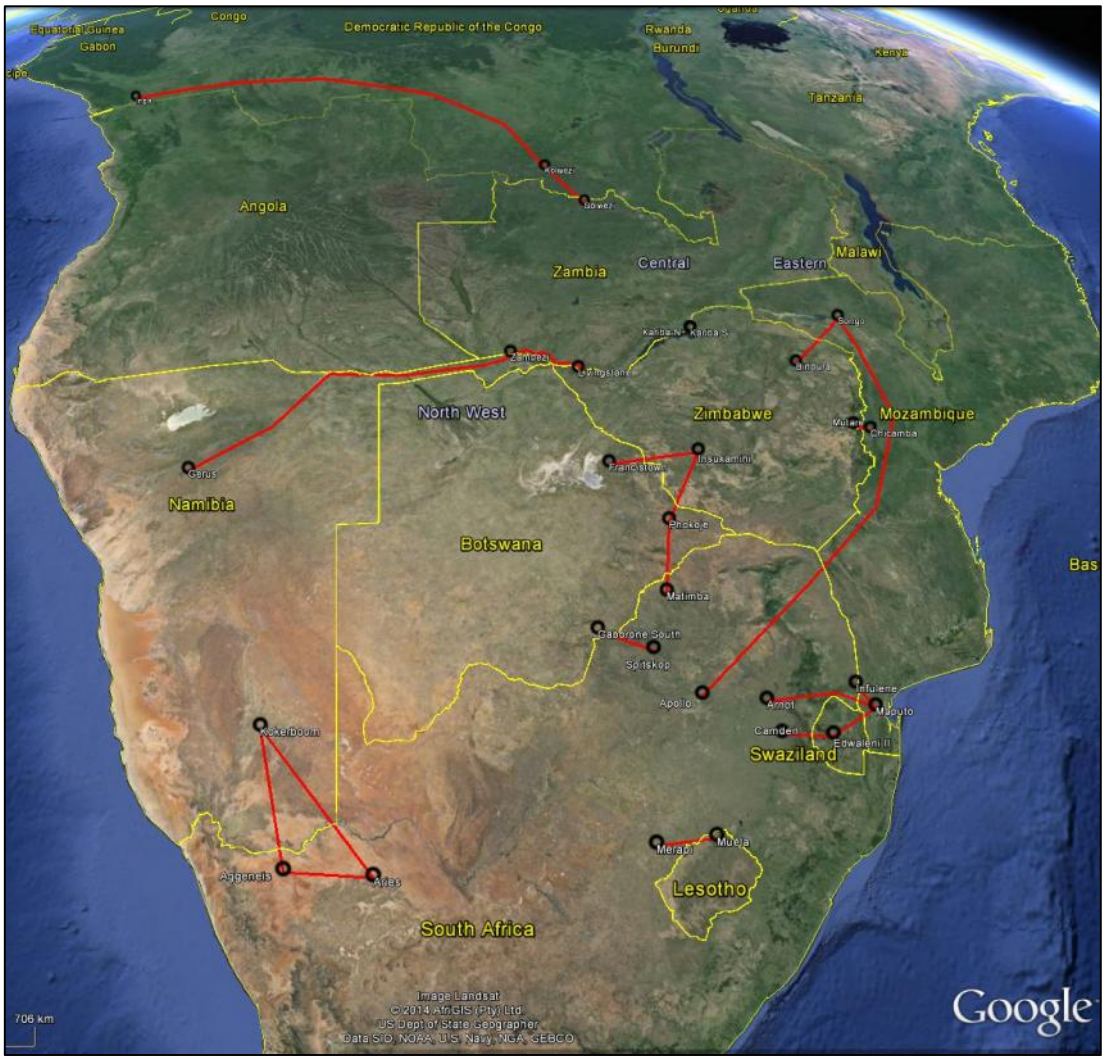

Figure 2: SAPP interconnectors (simplified line routes)

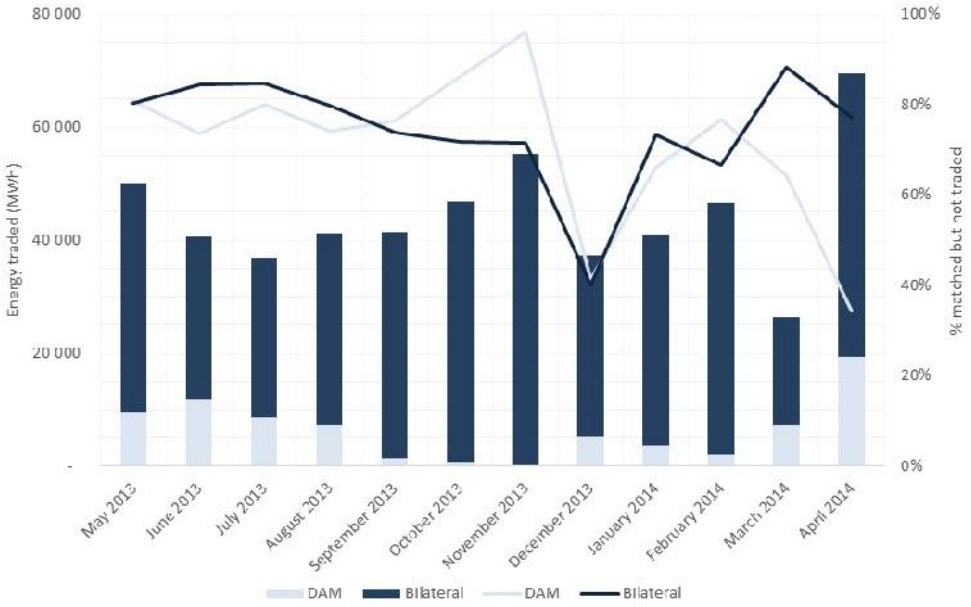

Figure 3: 2013/2014 SAPP bilateral contracts and DAM trading along with percentage of energy matched but not traded (transmission constraints)

1.2 Assessing SAPP opportunities now and into the future

A view of the SAPP including integrated gas-electric transmission and generation in the short term, medium term and long term has not been possible in the past. However, to fully assess the risks and opportunities to existing national utilities and regulators as well as prospective IPPs and ITCs in the SAPP, this will be required. This is where a software tool like the *PLEXOS Integrated Energy Model* ® ("PLEXOS") excels.

The focus of this paper is the assessment of the aforementioned transmission constraints that exist in the SAPP via the use of a developed PLEXOS transmission model for SAPP.

2 SAPP modelling with PLEXOS

Based on only public domain information and generally accepted industry practice, a regional level SAPP transmission dataset has been developed in PLEXOS. In summary, the dataset includes:

- A node per SAPP country (with the exception of Mozambique and DRC which have separate interconnected systems). All SAPP member hourly loads are modelled with assumed load profiles based on peak demand and energy forecasts from 2010 to 2025.
- Existing transmission interconnectors between SAPP nations including:
  - Maximum and Minimum transfer capacity
  - Line impedances (resistance and reactance)
  - Forced Outage Rates (FORs) and Mean Time To Repair (MTTR)
- Existing major generators in each SAPP nation including:
  - Hydro and pumped storage (including annual firm energy constraints)
  - Thermal coal
  - OCGT (natural gas, diesel, HFO, LFO driven)
  - Reciprocating engine (diesel, natural gas driven)
  - Onshore wind

    - Solar PV and CSP
    - Landfill gas

  Properties modelled for generators include max capacity, de-rating, heat rate, variable O&M costs, minimum stable level, min up/down time and max ramp up/down time as applicable.
- Storages for pumped storage generators
- Fuels for generators e.g. country specific HFO, LFO, diesel, natural gas and coal
- Emissions from generators e.g. CO_2

The transmission components of the PLEXOS SAPP dataset are shown geographically in Figure 4 (extracted directly from PLEXOS mapping interface) with the SAPP interconnectors summarised in Table 2 [3]. The assumed existing bilateral contracts defining the base flows between SAPP members are taken from [4].

Table 2: Existing SAPP interconnectors modelled in PLEXOS dataset

From	To	Voltage Level (kV)	Transfer capacity (MW)
Botswana	South Africa	400	190
Botswana	South Africa	132	425
Botswana	Zimbabwe	400	220
Botswana	Zimbabwe	220	205
DRC	Zambia	330	247
DRC	Zambia	500 kV HVDC	560
Lesotho	South Africa	132 kV	90
Mozambique (Central)	Mozambique (North)	110 kV	30
Mozambique (South)	South Africa	533 kV HVDC	1920
Mozambique (South)	South Africa	110 kV	67
Mozambique (South)	South Africa	400 kV	1100
Mozambique (South)	Swaziland	400 kV	1000
Mozambique (North)	Zimbabwe	330 kV	220
Mozambique (Central)	Zimbabwe	110 kV	38
Namibia	South Africa	400 kV	380
Namibia	South Africa	220 kV	195
South Africa	Swaziland	400 kV	1100
South Africa	Zimbabwe	132 kV	15
Zambia	Namibia	350 kV HVDC	180
Zambia	Zimbabwe	330 kV	428

Figure 4: Existing SAPP transmission model in PLEXOS (geographical)

3 Case Studies

The developed SAPP dataset was used to assess the case studies outlined in Table 3.

Table 3: Case studies assessed with PLEXOS SAPP transmission model

Reference	Model name	Description
1	2012: SAPP as-is	Existing SAPP system with existing bilateral contracts
2	2012: SAPP Free	Existing SAPP system with interconnectors free to trade between countries openly (ignoring bilateral contracts)
3	2012: SAPP Unconstrained	Existing SAPP system with no transmission constraints between all SAPP countries (all countries interconnected)

4 Selected results and insights from case studies

4.1 Energy balance

Based on the SAPP transmission model developed and case studies previously outlined, the energy balance for all SAPP countries for 2012 is as shown in Table 4. As can be seen, NP members of SAPP (members not interconnected) cannot import from other SAPP members resulting in significant energy imbalances (most notably for Malawi). The overall SAPP energy imbalance is 5 850 GWh (~1.7%) as a result of transmission constraints.

The benefits of free trade of electricity between SAPP nations is clear with a reduction in the energy imbalance in SAPP of ~75% (down from ~1.7% to ~0.4%). Furthermore, a completely unconstrained SAPP transmission system results in no energy imbalance in the SAPP for the assessed year. Notable exporters of power include DRC, northern Mozambique, Tanzania and South Africa while notable importers of power include Botswana, Malawi, Lesotho, southern Mozambique, Swaziland and Zimbabwe.

4.1 Interconnectors (the central corridor example)

The central corridor of the SAPP (Botswana-Zimbabwe-Zambia) is known to be a significant transmission constraint (more specifically the Botswana-Zimbabwe interconnector and internal Zimbabwe transmission network). This can be seen in Figure 5 where a typical days' power-flows taken from the PLEXOS SAPP model are shown. As can be seen, when free trade is allowed, the South Africa-Botswana interconnector gets pushed to its maximum capacity. Some of this power is used in Botswana but a considerable amount is wheeled via the Botswana-Zimbabwe interconnector further north especially when no transmission constraints are imposed.

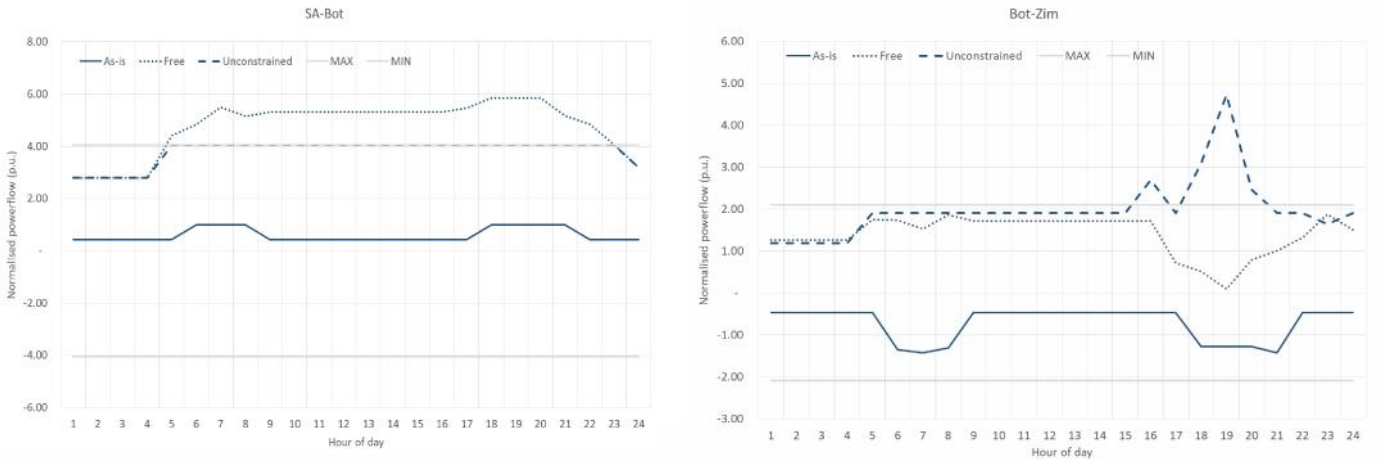

Figure 5: SAPP central corridor power-flows over a typical day

Table 4: Energy balance in SAPP (2012) based on developed PLEXOS transmission model for case studies assessed

Country	Load (GWh)			Generation (GWh)			Net injection (imports-exports) (GWh)			Energy imbalance (GWh)		
	As-is	Free	Unconstrained	As-is	Free	Unconstrained	As-is	Free	Unconstrained	As-is	Free	Unconstrained
Angola	7 565	7 565	7 565	7 269	7 269	6 063	0	0	1 521	297	297	-
Botswana	3 293	3 293	3 293	1 368	732	657	1 217	2 605	2 710	709	-	-
DRC	6 075	6 075	6 075	6 712	7 196	7 617	-1 081	-1 207	-1 529	448	92	-
Lesotho	624	624	624	456	456	456	171	171	185	1	-	-
Malawi	2 071	2 071	2 071	1 274	1 274	1 255	-	-	818	797	797	-
Mozambique (central)	875	875	875	248	248	248	434	534	634	202	104	-
Mozambique (north)	489	489	489	17 434	18 185	18 185	-16 520	-17 230	-17 434	3	-	-
Mozambique (south)	2 298	2 298	2 298	82	-	-	2 213	2 303	2 387	15	-	-
MOTRACO	7 884	7 884	7 884	-	-	-	8 032	8 032	8 034	-	-	-
Namibia	3 497	3 497	3 497	1 514	3 018	3 018	1 990	511	549	-	-	-
South Africa	284 377	285 160	285 633	283 924	289 921	295 762	1 008	-4 117	-9 723	-	-	-
Swaziland	1 385	1 385	1 385	177	98	98	624	1 293	1 294	585	-	-
Tanzania	5 217	5 217	5 217	5 217	5 217	5 274	-	-	-42	-	-	-
Zambia	12 887	12 887	12 887	10 615	10 069	9 975	-307	2 739	2 952	2 592	104	-
Zimbabwe	14 051	14 051	14 051	11 684	9 688	6 564	2 203	4 343	7 608	203	66	-
TOTAL	**352 589**	**353 372**	**353 844**	**347 973**	**353 370**	**355 172**				**5 850**	**1 459**	**-**

5 Conclusions

PLEXOS has been used to develop a regional level transmission model of the SAPP. This model includes all major generators, loads and load profiles, transmission interconnectors, storages for pumped storage generators, country specific generator fuels and CO_2 emissions from generators.

The developed PLEXOS model was used to assess the impact of existing transmission constraints and bilateral contracts in SAPP. These case studies revealed that existing energy imbalances in SAPP countries can be significantly reduced if interconnectors are freed up to allow for the most optimal trade of electricity between SAPP nations. In addition, in a scenario where all SAPP nations are assumed to be interconnected and no transmission constraints exist, energy imbalances are removed completely.

References

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[3] Southern African Power Pool, "SAPP TRANSFER LIMITS - 2013 (NORTH TO SOUTH WHEELING)," 2013. [Online]. Available: http://www.sapp.co.zw/tlimits.html. [Accessed 26 July 2014].

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