POWER POOL TRANSFER LIMITS: STANDARDISED PROCESS

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Abstract: The Southern African Power Pool (SAPP) is a pool of interconnected electrical utilities in southern Africa. The SAPP hosts a workshop annually between all its constituents to determine the power transfer limits for the interconnected network for the following year. These limits ensure that the power pool remains stable and does not experience a blackout. Consistent processes have led to accurate and consistent results; therefore the aim of this research was to identify the gaps in the SAPP transfer limits studies process compared to international best practice processes. The inconsistencies identified translate to the identified potential process improvements that can be made to the consistency of the SAPP process and therefore the accuracy of the results produced.

Key words: Transfer limits studies, transfer limits, Southern African Power Pool (SAPP), electrical system stability, case study.

1. INTRODUCTION

There are two elements of electrical supply that are important to customers: price and security of supply. For electrical utilities to remain popular among their customers, they are required to supply electrical energy at low cost with maximum levels of reliability [1]–[7]. The security of electrical supply is directly dependent on the stability of the electrical system from which it is supplied. System stability can be described as the condition in which an electrical power network is able to sufficiently supply all the loads connected to it, even under the worst system contingency conditions, i.e. if there is a fault or disturbance on the network [1], [3], [7]–[14].

If a system becomes unstable after all stability resources of the network have been exhausted, a blackout will occur. A blackout is the situation where an electrical network collapses and all load and generation connected to the network are lost [1], [7], [10], [15]. This happened in Canada and Italy in 2003 [1], [16].

A method of increasing system stability is to form an electrically interconnected power pool between neighbouring utilities. This provides additional resources to all the utilities connected, benefiting from the concept of pooled resources. In southern Africa there is a power pool between the neighbouring countries, each of which has its own national electrical utility. This power pool, as any power pool in the world, is operated within certain stability limits. The stability limits referred to in this research are the power transfer limits implemented on the interconnecting electrical transmission lines between the utilities.

Figure 1 indicates the geographical layout of the SAPP as well as the encircled interconnecting transmission (tie) lines to which the SAPP transfer limits studies results apply.

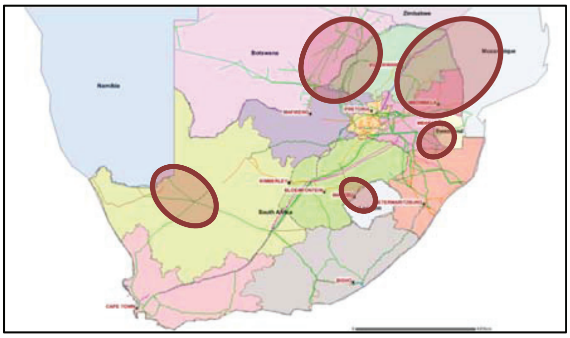


Figure 1: SAPP and tie lines highlighted from the Eskom Transmission Spatial Information System (TxSIS)

A process is required to determine the transfer limits between the utilities. The exercise of determining the transfer limits is conducted annually in the SAPP and these transfer limits are then used to trade electrical power for the rest of the year [17]–[19]. The SAPP consists of the interconnected national utilities of Zimbabwe (Zimbabwe Electricity Supply Authority – ZESA), Namibia (Namibia Power – NamPower), Botswana (Botswana Power Corporation – BCP), Mozambique (Electricidade de Moçambique – EdM), Zambia (Zambia Electricity Supply Corporation – ZESCO), Swaziland (Swaziland Electricity Company – SEC), Lesotho (Lesotho Electricity Company – LEC) and South Africa (Eskom) [17]–[21].

The consequences of inaccurate transfer limits can be devastating; the security of all the utilities connected to the power pool would be at risk [6], [9], [10], [15], [20], [22]–[26], particularly in southern Africa, where there are still-developing world infrastructure and processes and no strong neighbouring sources of electrical power; thus it could take up to a few weeks to black start (restore the power supply). The socioeconomic implications of a large population (southern Africa) without electrical power for a few weeks would include industries closing, mass loss of data, communication links down, extensive food spoilage, lack of transportation and lack of sewerage or water supply services to meet basic human needs [9], [15]. If a transfer limit is under-estimated, the interconnected utilities could become unstable and the entire network lost [23]. If the transfer limits are over-estimated, the profits between the utilities in the process of buying and selling electrical power are not maximised, or future network expansion plans initiated to increase system stability are rendered redundant [24], [27].

The purpose of determining transfer limits in a power pool is to ensure that the power pool remains stable even under contingency conditions. The undesirable effect of a system blackout points towards the importance of accurately calculated transfer limits. Research indicates that consistent processes will lead to more consistent and accurate results; thus the results of the SAPP transfer limits studies process could have improved consistency and accuracy as a result of a consistent process followed.

One of the challenges in this research was to establish the best way to accurately describe the execution of the transfer limits process best practice (internationally) and in the SAPP. This was so that the comparison between the two processes would be valid, producing reliable results for this research. The first challenge was overcome through a thorough investigation of a number of methodologies employed throughout interconnected utilities all over the world and consolidated into a single process that could be compared to the process described by the SAPP. The way in which the challenge in establishing the SAPP process was overcome was by using a case study research methodology with which to represent the execution of the SAPP transfer limits studies process (stemming from a number of data sources) and finalising the SAPP transfer limits studies process from the empirical data collected. Rival hypotheses were developed in arguing the contrary view that a consistent process leads to more accurate results and these were tested once all data had been collected and analysed.

This research is directed at the SAPP and other power pools that conduct transfer limits studies. Implementing the findings from this research both in the international standard process of transfer limits and the actions that can be taken by the SAPP could lead to improved transfer limits studies results. The stability of the interconnected power pool has an effect on every electricity consumer within the power pool, in this case in southern Africa. More consistent transfer limits studies results could minimise the probability of the devastating socioeconomic consequences of a power pool blackout that affects every electricity consumer in the region. It would also ensure maximum profits for the electrically connected utilities buying and selling power from one another.

This paper is structured into three parts: first, the compilation of the literature best practice transfer limits studies process, second, the case study research methodology revealing the SAPP transfer limits studies process, and finally, the identification of the gaps between the processes through results analysis. These gaps reveal the relevant recommendations applicable to the SAPP, concluding the research aim. The gaps revealed also point towards additional research that could be conducted in the field.

2. LITERATURE

System security has been improved in many ways in the electrical industry. One such method, implemented worldwide, is the establishment of power pools – interconnected electrical utilities [1], [7], [10], [15], [23]. The interconnection of the utilities adds system stability to the overall power pool by pooling resources. The power pool can provide:

- Excess generation when needed;
- Excess load for frequency balancing;
- Inertia for additional dynamic security;
- Fault ride through assistance; and
- Blackstart facilities to provide for a blackout due to the system becoming unstable.

Stability in a network is defined by thermal, voltage and dynamic stability. Thermal and voltage stability are taken in this research as the limiting factors that power pools consider when determining the stability limits through power transfer. Thus these are the two factors to consider as defining stability when determining transfer limits [6], [7], [22]–[24], [27]–[33]. The stability of a network is also dependent on the network topology and the loading and generation in each of the interconnected networks in the power pool. Figures 2 and 3 describe thermal and voltage stability concepts, respectively.

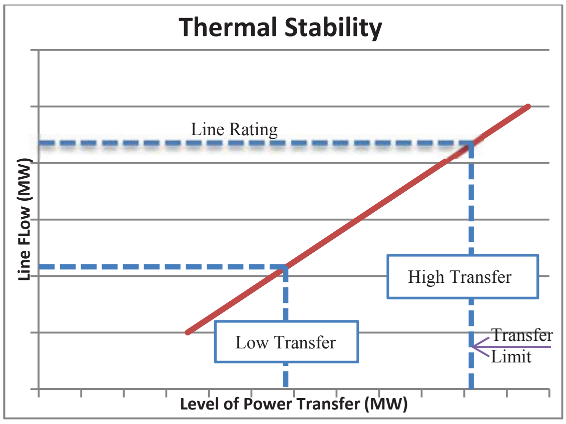


Figure 2: Thermal stability transfer limit

Thermal stability is dependent on the power flow on the line with regard to its physical components and terminal equipment power ratings [1], [8], [10], [14], [19]. The thermal transfer limit is the limiting power flow (incrementally increasing in the figure) that the transmission line can carry before damage occurs to any of the equipment through which it flows. The transfer limit point, as indicated by the arrow in Figure 2, is the transfer limit for thermal stability of a network [7], [20].

The concept of voltage stability on an electrical network is illustrated in Figure 3. Figure 3 is post-contingency as the network is required to be N-1 stable [7], [20]. The figure indicates the slow decline in voltage of the network as the incremental power transfer between two interconnected utilities is increased. The first point on the graph is the 95% voltage transfer limit. This is the point at which a busbar in the network reached the minimum operating voltage in pu (0.95 pu). In some networks busbars are operated below the minimum 0.95 pu mark. In these examples or under more serious contingency conditions, the decline in voltage as the transfer is increased can surpass the 95% transfer limit and the busbar voltage tends towards voltage collapse. Voltage collapse is the point at which the electrical network is rendered unstable and blacks out [6], [7], [23]. Thus the voltage collapse transfer limit for a network is taken at 95% of the power transfer at this point to ensure that there is always a 5% safety margin with which to operate in a network.

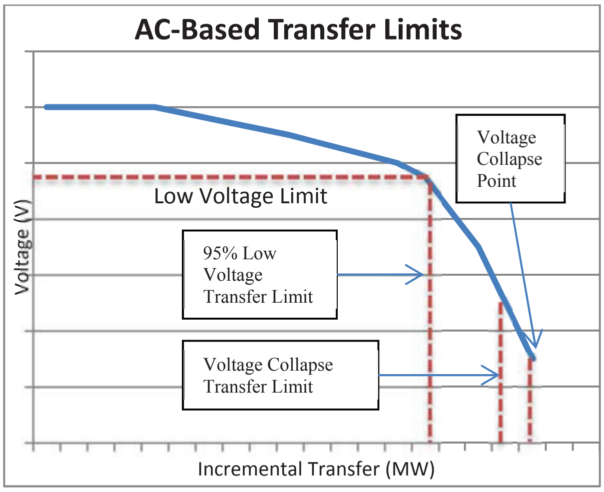


Figure 3: Voltage collapse and 95% safety margin transfer limits

Understanding thermal and voltage stability is imperative in determining transfer limits. This is because the power flows for which thermal or voltage stability points are reached on a network are the points within which the network has to be operated to maintain system stability in preparation for the next worst contingency [3], [23], [30]. A process has to be followed by the utilities to establish the operating limits specified above [6], [22]–[24], [31].

The literature describes a process as a means of creating outputs from specified inputs under the restrictions of certain standards or guidelines (controls) [34]–[37]. These standards or guidelines are used to ensure the reliability of the outputs achieved. Literature indicates three phases of transfer limits studies: the planning and design phase, the execution phase and the monitoring and evaluation phase [5]–[7], [20], [22]–[24], [26], [30], [31], [33], [38]–[40]. Each of these phases has the necessary inputs that are processed to produce useful outputs contributing towards the setup, execution and continuous improvement of the transfer limits studies process. Figure 4 is a summarised process, derived from literature, of the international best practice transfer limits studies [4]–[7], [22]–[24], [26], [31]–[33], [38], [41].

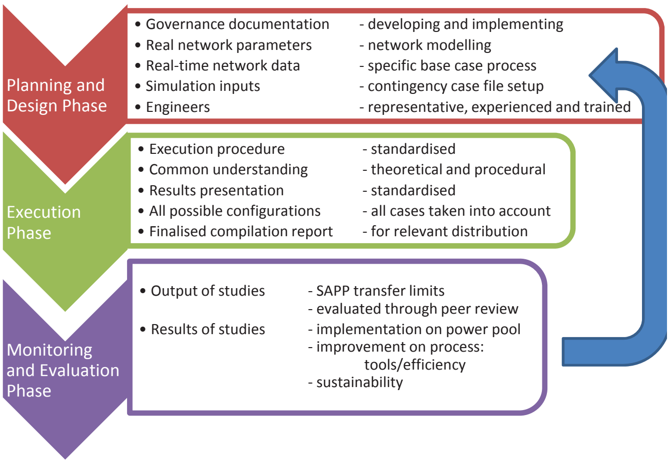


Figure 4: Process of transfer limits studies

2.1 *Planning and Design Phase*

The planning and design phase prepares all the elements required in the execution phase to produce the actual transfer limits for the network [33], [40]. Governance documentation is required to stipulate the various operating guidelines required for the power pool in question [19], [33]. The output from the governance documentation in the planning and design phase is creating a standardised knowledge base from which the transfer limits studies can be conducted [19], [33].

The main output produced from the planning and design phase is the range of contingency base cases. Each network configuration (topology) has to be studied and the transfer limits determined for each one, so that the worst case scenario can be taken as the limiting factor for the interconnection [5]–[7], [10], [20], [22]–[24], [26], [30], [31], [33], [38]–[40].

In the planning and design phase of the overall transfer limits studies process, an accurate network model would have to be obtained [6]. An accurate representation of the physical network would best represent real-life scenarios and therefore offer the most realistic results [10].

Standardisation should be ensured in this phase: the software package used to model the interconnected networks (from each utility) should be the same and the respective engineers should be familiar with it [42], [43]. Different network configurations will change the transfer limits of the system [5]–[7], [20], [23], [39].

The engineers should similarly be skilled in executing the overall process; consistency is introduced when their understanding of the method of executing the transfer limits studies is the same [7], [19], [33].

Figure 5 represents the overall process in creating the necessary contingency base cases [5]–[7], [10], [20], [22]–[24], [26], [30], [31], [33], [38]–[40]. The software package simulation network is often known as a case file. These resulting case files would be used to determine the transfer limits between utilities in a power pool in the execution phase. To create an accurate base case, the process begins with the requirement of an accurate transmission network model represented on the simulation package (case file) [10]. The specific loading and generation scenario of the network to which the transfer limits are meant to apply (worst case) then needs to be modelled [7], [23]. This entails the active and reactive power flows on the transmission network in a specific season or on a specific day, under the relevant network configuration [7], [20], [23], [38].

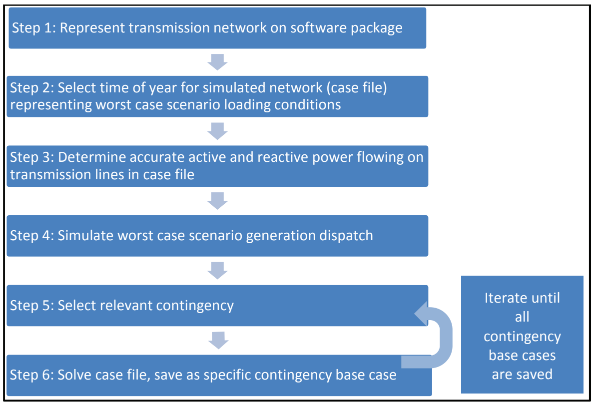


Figure 5: Contingency base case process

This base case or case file represents the system healthy network condition: all the voltages and transmission path flows are within voltage and thermal limits [23], [38], [39].

The relevant contingency (plant out of service) that causes a limitation to the transfer limits between the utilities in the power pool should then be selected and the contingency taken out of service. This process continues until all contingencies that limit the transfer between interconnected utilities are considered [33].

If there is a voltage or thermal violation in the system healthy base case, the load flow has to be changed so that the power transfer is reduced, ensuring that the network is operated within limits [23], [33], [38]. A number of base cases have to be simulated to ensure that all threatening network conditions for transfer limits are addressed [23].

These inputs ensure that the most accurate contingency base cases are set up to represent real network conditions, revealing results as close to realistic network reactions as possible [1], [3], [6], [23].

The final requirement of the planning and design phase of transfer limits studies as indicated by international best practice is the consistent experience of the engineers required to perform the studies. These engineers have to appropriately represent all areas of the power pool and should be knowledgeable in the theory, tools used and processes of transfer limits studies [7], [19], [33], [42], [43].

2.2 *Execution Phase*

The execution phase of the overall process identifies the output of the process: the transfer limits for the power pool. This requires a standard procedure and common understanding of the engineers regarding thermal and voltage stability and identifying the relevant transfer limits on the simulation package outputs. The results from this process are compiled into a single report, in a standard format, that is distributed to the relevant stakeholders. A step-by-step indication of the transfer limits studies as indicated in international best practice is presented below [5]–[7], [20], [22]–[24], [26], [30], [31], [33], [38]–[40]:

Step 1: Determine the load to be incrementally increased and the rate of increase (in MW): This involves establishing the corridor for which the transfer limits are going to be determined and defining the relevant loads that are going to be scaled to detect where the thermal or voltage stability limits lie [5]–[7], [20], [22]–[24], [26], [30], [31], [33], [38]–[40].

Step 2: Increase the identified load by the step increase: Continual power flow simulation tools are used to conduct this process automatically using linear solving techniques [5]–[7], [22]–[24], [26], [33], [38]. However, the process can be conducted manually [23], [38].

Step 3: Observe the electrically interconnected networks for voltage or thermal violations: The limit ensures that once a disturbance has occurred on the network and the disturbance on the network settles, the network remains in a stable state [7].

Step 4: If there are no system violations, repeat steps 2 and 3; if there is a violation, switch back the next worst contingency and record the transfer limit: System stability, as has been mentioned, refers to the sustainability of network stability even under the next worst contingency on the network. Therefore the network must be operated within the limits of the next worst contingency. It is therefore important to take a pre-contingency transfer limit to ensure the stability of the network even after the next worst contingency occurs on the network [30]–[33], [40].

This process is repeated for each contingency case file to find the corresponding transfer limit for each possible contingency pair on the network [5]–[7], [20], [22]–[24], [26], [30], [31], [33], [38]–[40]. In most studies, the worst case contingency is used as the transfer limit, i.e. the lowest power transfer, to eliminate the need to conduct the transfer limits studies on a regular basis every time the network configuration changes [32].

The outputs of the transfer limits process, whether conducted automatically or manually, can be tabulated or represented on a power voltage (PV) curve or plot.

International best practice suggests that a way in which consistency can be introduced into the process is through monitoring and re-evaluating the process on a regular basis. This also provides for continual process improvement.

2.3 Monitoring and Evaluation Phase

The monitoring and evaluation phase attempts to increase the reliability of the process. Methods such as peer reviews, investigations into more powerful simulation tools and training of the engineers could be used [1], [7], [10], [23]. Sustainability is introduced to the process by training younger engineers. In this way there is a clear knowledge path and sufficient experience in the theoretical background, processes and required tools in annual transfer limits studies.

The consolidation of the literature available on the topic of transfer limits studies processes internationally revealed the best practice process implemented as well as the methods by which the processes are governed and standardised. As a result, a process with inputs, processes and outputs was constructed in tabular format (see appendix, Table 6). This table was pattern matched against the empirically collected data describing the process followed by the SAPP.

2.4 SAPP – Southern African Power Pool

This research was centred on the Southern African Power Pool, a power pool that comprises neighbouring national utilities in southern Africa. Involved are the national utilities of South Africa, Namibia, Botswana, Lesotho, Swaziland, Zimbabwe and Mozambique [17]–[19]. The South African utility is the largest with the most interconnections. It is therefore split up into different grids, each with an assigned network operations engineer. There are generally 18 people present at the SAPP transfer limits studies workshop on an annual basis. The engineers that study the grids interconnecting to neighbouring utilities participate in these studies with each corresponding network operations engineer – forming sub-workgroups [17]–[19], [44]. The workshop forms part of the SAPP transfer limits study process [17]–[19], [44]. The SAPP process aims to achieve reliable outputs from the various inputs into the process, which is governed by guidelines and standards [17]–[19]. This process was compared to international best practice so that discrepancies could be identified and the overall process improved.

3. METHODOLOGY

The method in determining the way in which the empirical data should be collected had to be reliable and valid. As a result of the research aim, the focus on a contemporary problem and the resources available, a case study research methodology was selected [45]–[48]. This was also motivated by access to the relevant resources available and respondents for a questionnaire adequately representing the annual workshop participants. In this way the data collected from the respondents was representative of the workshop (case study). Thus the conclusions drawn from this data, combined with the documentation available, as well as the participant observation views from the researcher who participated in the workshop before, can be taken as accurately representing the process followed during the SAPP transfer limits studies. Further motivation of reliable and valid data according to the case study methodology was the formulation and subsequent rejection of rival hypotheses in the case [45]–[48].

Figure 6 is an illustration of the overall case study research methodology, compiled in an effort to ensure there was construct validity in the process, leading to accurate empirical data conclusions [45].

The case study was set up to represent the annual SAPP transfer limits studies workshop in which the transfer limits are determined for the rest of the year for trading and system security in the SAPP. The more sources of data for a case study research methodology, the more reliable and valid the results of the research will be [45], [46], [49]. Thus the case study consisted of four types of data collection, as shown in Figure 6:

- A questionnaire completed by engineers that had participated in the workshops in the past and had experience in the field;
- The SAPP documentation relevant to the transfer limits studies – governance and procedural documentation;

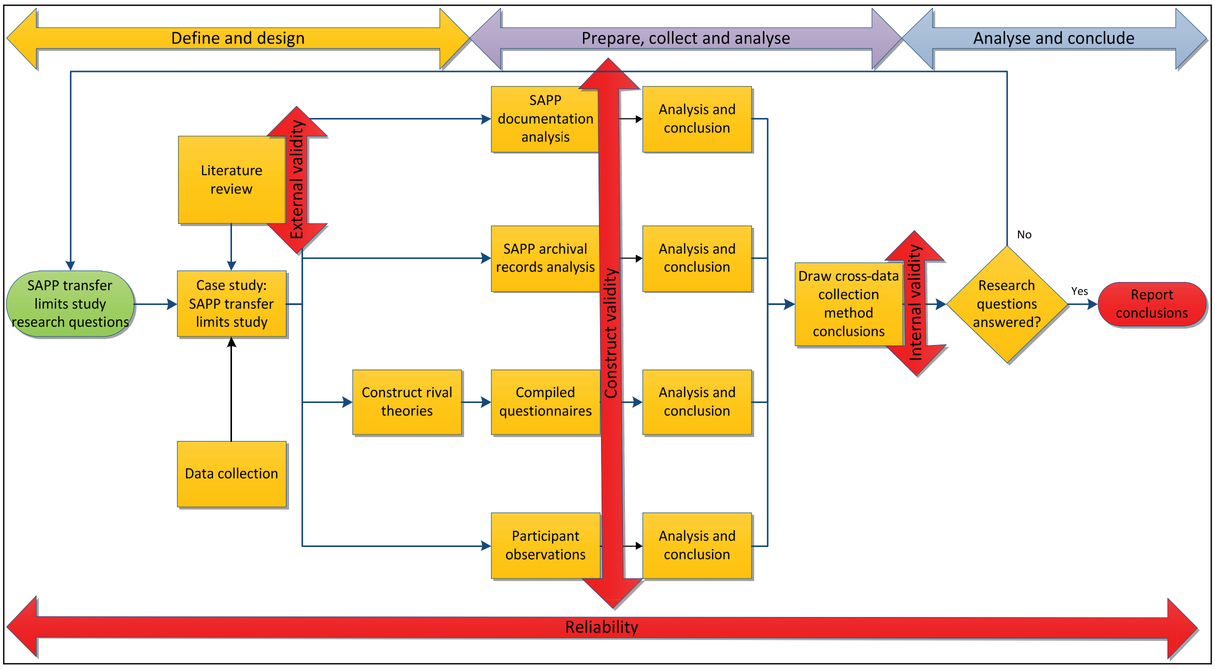


Figure 6: SAPP transfer limits case study methodology

- The SAPP archival records – previous reports on SAPP transfer limits studies results; and
- The participant observation views from the researcher – who had also participated in the workshop previously.

The most important element in collecting empirical data from which to draw conclusions is to ensure that once the data analysis exercise has been conducted, the conclusions can be considered relevant, valid and reliable [45], [46], [49]. From the figure it is clear that the ways in which the empirical data was collected were decided upon before the data collection process began in a clear research trail that could be followed, thus discouraging any research bias [45], [46], [48]. This aimed to increase the validity and reliability of the research results. Hence, the findings in the research process could contribute to the relevant field of knowledge.

The empirical data collection methods and analysis aimed to:

1. Find conclusive data that provides direct answers to the research questions; and
2. Reject the rival hypotheses based on the research questions.

From Figure 6 the questions to be asked in the questionnaire were developed by testing the theoretical and process knowledge of the respondents regarding the SAPP transfer limits studies. Rival hypotheses were formulated as a validity check for the research results from the questionnaires [45], [46]: if conclusions found from the empirical data answered the research question but also sufficiently rejected the rival hypothesis relevant to a particular element in the overall process, the results from the analysis could be concluded as reliable. The results of the questions asked are revealed in the data analysis section. These results were summarised in tabular format (using Table 6 in the appendix as a basis) according to the process identified from the literature so that a triangulation exercise could be conducted on all the empirically collected arrangements of data to form a single empirically collected data conclusion. This final conclusion was used as a comparison to the international best practice process from which to identify possible gaps in the process.

The documentation used for data analysis was from the SAPP, relevant to the process of transfer limits studies. This documentation was analysed within the same tabular format so that the relevant conclusions could be drawn.

The researcher has had the opportunity to participate in the SAPP transfer limits studies. It was thus important that all the preparation for the research and the analysis of the research were done so that the opinion of the researcher did not skew the data [45]–[47]. The observations of the participant observation data from the researcher were not viewed as concrete as the raw empirical data collected from the respondents to the questionnaires, nor the documentation from the SAPP [45]–[47]; thus the results from the studies were only enhanced from the participant observation views of the researcher.

The final observation in Figure 6 relevant to this research is the triangulation process required of all the collected data to ensure internal validity of the results in forming overall report research conclusions [45], [46], [48]. The multiple sources used to devise the case study were triangulated and then used as an overall empirical data collection case study view. This, in turn, was used for pattern matching comparison to the study processes discovered from international best practice.

4. RESULTS

In this section the results from the various empirical data sources are described.

It is important for research to ensure that its sources are valid and reliable. Before this research could be analysed and conclusions drawn from it, validations were required for the data sources used.

In order to use the information from the questionnaire, respondents had to represent elements of the workshop conducted by the SAPP to determine the transfer limits. The profile of the respondents that completed the questionnaire is indicated in Table 1.

Table 1: Relationship between study experience and professional working field

Study experience	Professional field			Total
	Network operations	Expansion planning	Other	
Electrical engineering degree	8	1	1	10
Other engineering degree	1	0	0	1
Total	9	1	1	11

The results analysis from the questionnaires distributed to engineers was seen as reliable and valid, because the 11 respondents (out of a full workshop of 17 less the researcher) represented three utilities and the SAPP. Thus, the engineers were found to have enough experience in the relevant fields to represent the workshop and could be used to draw accurate conclusions. From Table 1 it is clear that the respondents from different utilities in the SAPP all had engineering degrees, with the vast majority holding electrical engineering degrees and with experience in network operations.

The analysis of the documentation from the SAPP was conducted with reference to Figure 7, which is linked directly to Figure 4 from the literature. The background described in the documentation proves that the information observed from the documentation is an accurate representation of the SAPP transfer limits process. Thus conclusions drawn from the SAPP documentation will be applicable to conclusions drawn overall about the empirically collected data for the case study.

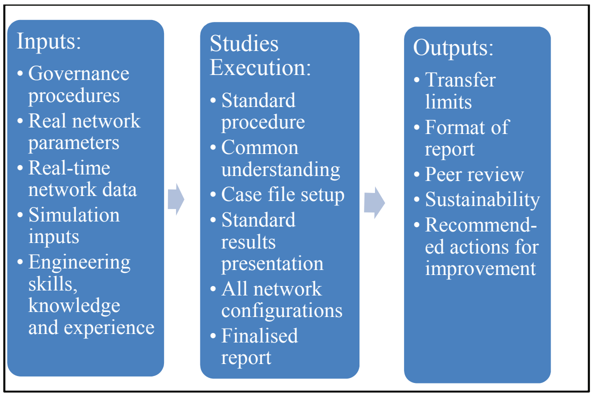


Figure 7: Inputs, processes and outputs of the SAPP transfer limits studies process

There was a possibility that the views of the researcher as a participant in previous studies could introduce bias in the results. These views were therefore only used to reinforce conclusions drawn from the triangulation of the above resources.

Data analysis was conducted in accordance with the three phases of transfer limits as indicated by the literature. The following findings were revealed:

4.1 Planning and Design Phase

Theoretical, Tools and Procedural Training for Engineers: Results from the questions in the questionnaire that tested the knowledge of the respondents in the field of thermal and voltage stability reveal that the respondents' understanding of stability was not sufficient. Respondents were asked to identify the thermal and voltage transfer limits (0.95% and voltage collapse) as illustrated in Figures 2 and 3.

82% of the respondents were able to accurately display the thermal transfer limit, but as seen in Figure 8, the superimposed answers reveal that the engineers did not convincingly identify the correct positions of A – the voltage collapse point, B – the 0.95 pu voltage transfer limit and C – the voltage collapse transfer limit (taken at 95% of the collapse point).

The randomised collection of responses from the individuals indicated in Figure 8 clearly illustrates that there are problems in the understanding of voltage stability in the context of transfer limits studies by the engineers required to conduct the studies.

Information from the documentation analysed indicated that all the correct procedures and theoretical explanations are present in the governance and procedural documentation applicable to the SAPP. This therefore further suggests that either this documentation is not implemented correctly or the understanding of the engineers conducting the studies is lacking.

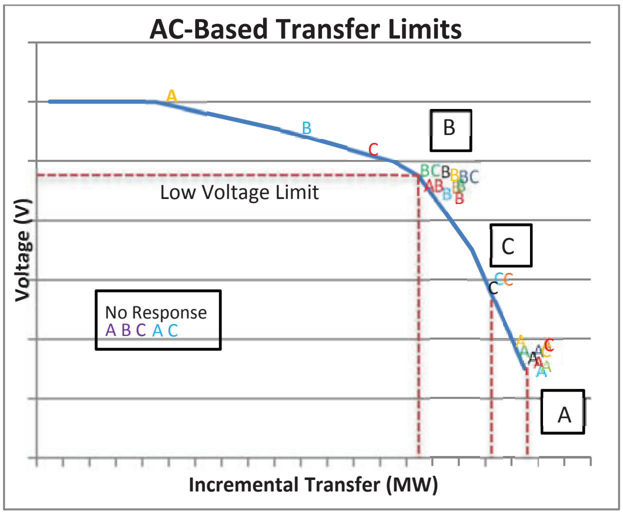


Figure 8: Voltage stability question results

Step-by-Step Documentation Instructions: Table 2 presents the results of the questions posed to the respondents on the SAPP governance documentation applicable to the transfer limits studies. The results indicate that the documents containing the SAPP transfer limits study information (governance and procedural documents) were known and available to the respondents. However, of the 11 respondents to which the execution of the available process was applicable, 67% indicated that they followed the process available, but 70% did not think that the process was adequately available in the execution phase of the transfer limits studies.

The contradicting information in the results of Table 2, combined with the clear uncommon understanding of thermal and voltage stability limits from the results analysis above, indicates that the process followed by the SAPP is faulty. It is also clear from Table 2 that the respondents felt they required training for the studies, which does not indicate confidence in their abilities to accurately conduct the studies, and therefore produce accurate results.

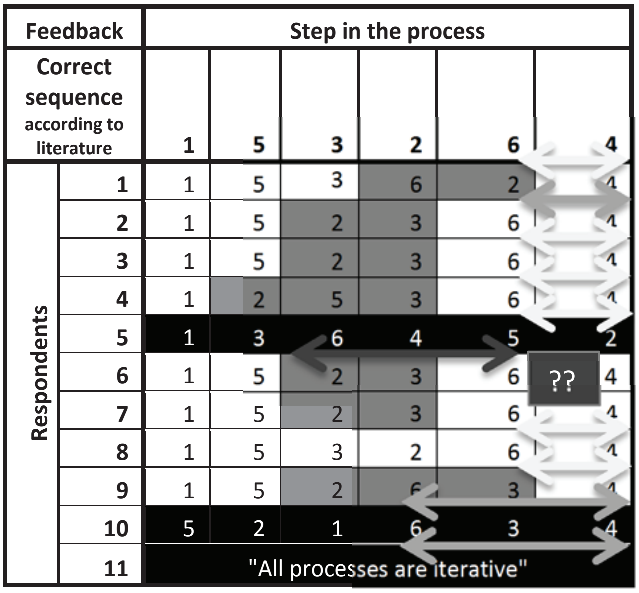
Table 2: Question results on SAPP governance

Category	Yes	No
Awareness of document	11	0
Able to access document	10	1
Follow prescribed process	6	3
Process adequately available	3	7
Training required	10	0

The SAPP documentation indicates sufficient guidelines on how to set up the inputs and conduct the studies. However, there are no specific step processes that indicate how the studies should be conducted, especially in the necessary software package.

Standard Process in Compiling the Base Case and Individual Contingency Base Cases: The questions in the questionnaire also attempted to test the process knowledge of the respondents with reference to the SAPP transfer limits studies. These questions were derived from voltage and thermal stability as well as transfer limits studies literature. The engineers were required to order the steps required in compiling a contingency base case – as indicated in Figure 5. Table 3 below indicates the responses compared to international best practice. The correctly identified process steps are indicated unshaded, faulty processes where there were faults in shaded and completely incorrect answers in black. The arrows on the figure indicate the correct identification of the iteration in the process. White represents a correct answer; light grey a partially correct answer and dark grey a completely incorrect or absent answer.

Table 3: Base case set up process



Feedback		Step in the process					
Correct sequence according to literature		1	5	3	2	6	4
Respondents	1	1	5	3	6	2	4
	2	1	5	2	3	6	4
	3	1	5	2	3	6	4
	4	1	2	5	3	6	4
	5	1	3	6	4	5	2
	6	1	5	2	3	6	?? 4
	7	1	5	2	3	6	4
	8	1	5	3	2	6	4
	9	1	5	2	6	3	4
	10	5	2	1	6	3	4
	11	"All processes are iterative"					

Each of the differing methodologies identified by the respondents in Table 3 indicates that the base cases are set up differently in each of the sub-workgroups required to complete the transfer limits studies between the relevant utilities. This introduces a clear inconsistency in the results from the overall transfer limits studies process. It is also clear from the poor understanding in the process of compiling the base cases that training is required by the respondents.

4.2 Execution Phase

Standard Execution Phase Process: The process knowledge of the respondents was further tested in a question requiring the organisation of the steps involved in executing the transfer limits studies process in the correct order. Table 4 below indicates the responses compared to international best practice. The correctly identified process steps are shaded lightly and completely incorrect answers in black.

Table 4: Execution phase process

Feedback		Step in the process			
Correct sequence according to literature		4	2	3	1
Respondents	1	4	2	3	1
	2	4	1	3	2
	3	4	2	3	1
	4	4	2	3	1
	5	4	2	3	1
	6	4	2	3	1
	7	4	2	3	1
	8	4	2	3	1
	9	4	2	3	1
	10	4	2	3	1
	11	"Depends"			

4.3 Execution process of the transfer limits studies

Table 4 is well understood by the engineers in determining the transfer limits. However, with inconsistent base cases (Table 3), the results from the studies were inconsistent nonetheless.

In the execution phase, the knowledge of the engineers fell short once again, with their inability to determine the points at which the transfer limits should be identified when voltage collapse occurs on the network or when the busbars (as stipulated in the governance documents as a requirement for SAPP transfer limits) operate below 0.95 pu (Figure 8). This finding was emphasised by the responses to a question on iteration exceeded in the relevant software package, which translates to voltage collapse in the case file, but was correctly identified by only 27% of the respondents.

Standard Study Results Format (software package included): From the questionnaire:

- 7/11 respondents (64%) preferred recording the transfer limits in a table including the corresponding conditions;
- 2/11 respondents (18%) preferred recording the transfer limits on PV curves and pointers; and
- 2/11 respondents (18%) liked both options of displaying the results.

Table 5: Cross-tabulation of software package preferences

Package	Reason for package preferences				
	User friendly	Experience/ case setup	Accuracy	Applic Tools	Total
PSS/E	5	2	3	4	14
DIgSILENT	2	1	2	3	8
VSAT	1	0	0	1	2
Total	8	3	5	8	24

As seen from the statistics above as well as the information in Table 5, the way in which the transfer limits studies results are recorded is not consistent. This information also indicates that the preference for and experience in software packages used by the respondents is not consistent. This is part of the process of the transfer limits studies.

The SAPP documentation required results to be presented in PV curves, but in the results documentation analysed, the results appear in a variety of formats, including PV curves with or without explanations or even tables of the transfer limits with or without explanations. This is a clear indication of incorrect and inconsistent execution of the studies from the governance documentation.

4.4 Monitoring and Evaluation Phase

Implementation of Better Analysis Tools: The information in the SAPP guidelines documentation sourced indicates that transient (dynamic) studies are required for transfer limits studies to assess the overall health of the system. This is not evident in the reports from the studies conducted and introduces more inconsistency concerns into the overall SAPP transfer limits process. Often the guidelines documentation on the transfer limits studies process is consistent with international best practice, but the execution of those processes indicated in the guidelines is not followed through. This is concluded by the absence of the results in the reports from the studies conducted. A further indication that dynamic studies are not conducted is that this is a recommendation from one of the respondents as a method to improve the overall SAPP transfer limits studies.

Introduce Measures of Sustainability and Process Improvement: Neither the questionnaire results analysis nor the documentation from the SAPP revealed measures of sustainability or process improvement in the overall process of the SAPP transfer limits studies.

5. DISCUSSION

The results from the data analysis were triangulated and a pattern matching exercise conducted with the international best practice process (Table 6) in an attempt to determine if gaps exist between the processes. The rejection of the rival hypotheses formulated ensured that all possible conclusions from the empirical research were addressed.

The analysis revealed that the process followed by the SAPP could be compared to the process developed from the literature as international best practice. The gaps between these two processes from the pattern-matching exercise identified the areas in which the SAPP transfer limits process could be improved. Thus, recommendations were created for the SAPP in standardising the process used to determine the transfer limits studies results to improve their consistency.

5.1 Planning and Design Phase

From the results in terms of *Theoretical, Tools and Procedural Training for Engineers*, a major finding of this research is that the engineers required to conduct the studies on which the power pool operates do not understand the process to be followed in setting up the relevant inputs (case files, networks, etc.) to be used in the execution phase of the transfer limits studies producing the actual MW transfer limits. This is despite the procedures present in the SAPP documentation on the process. Therefore the following action is recommended to be taken by the SAPP:

- *The engineers that participate in the SAPP transfer limits studies should be trained, specifically targeting the theoretical background and methodology of the studies to be conducted*.
- *The SAPP documentation (final reports of the studies) should include a short section on the competency or experience of the engineers that participate in the studies to determine the international transfer limits*.

From the information gathered in *Step-by-Step Documentation Instructions*, the process in which the base cases are set up from both sets of empirically collected data indicates inconsistency between the individual workgroups. Therefore:

- *The SAPP needs to create a procedural step-by-step document on setting up and conducting transfer limits studies (specific to the SAPP) in the appropriate software*. This recorded process would also introduce consistency from one year to the next and provide opportunities for continuous improvement.

From the information gathered in *Standard Process in Compiling the Base Case and Individual Contingency Base Cases,* it is evident that the engineers do not follow a standardised process in compiling the base cases upon which to conduct the studies. Thus:

- *All SAPP sub-workgroups performing the SAPP transfer limits studies must follow the same process in compiling the base case for their interconnection as well as the same setup parameters and processes in determining the individual contingency base cases*.

5.2 Execution phase

From the results relating to *Standard Execution Phase Process,* the processes available to the engineers to follow from the SAPP documentation are clearly not executed. Thus:

- *The engineers should be required to follow the standardised step-by-step procedure documented by the SAPP for the duration of the SAPP transfer limits studies process*.

From the results pertaining to *Standard Study Results Format (software package included)* according to the SAPP guidelines, the results should be reported in the form of PV curves from the software package used to conduct the studies. However, the results documentation indicates a number of inconsistent methods in presenting the data. From the questionnaire data, there were a number of different preferences among the respondents in how they present the results from the studies. Therefore the recommendation is:

- *Consistency should be maintained in the standard study results format for recording the SAPP transfer limits*. This also pertains to the training required of the engineers so that all engineers are capable of using the required software package tools.

5.3 Monitoring and Evaluation Phase

From results in *Implementation of Better Analysis Tools* and *Introduce Measures of Sustainability and Process Improvement,* it would be advisable for the SAPP to introduce:

- *The dynamic (transient) stability limits of the system included in the studies and the report;*
- *Human resource sustainability through young engineers participating in the training conducted and transfer limits studies process;*
- *Improved development of the overall process by observing international best practice methods and incorporating suggested tools into the process;*
- *Investigations conducted into other software packages, such as VSAT, that could conduct the studies more accurately and efficiently*.

The final recommendation, as is implemented in international best practice, which was also brought up by one of the respondents, is as follows:

- *The SAPP should strive to achieve online transfer limits, i.e. real-time studies conducted by background software onto transmission energy management systems*.

5.4 Rival Hypotheses

All rival hypotheses, bar one, were rejected based on the results of the research. This was an inconclusive finding regarding the frequency with which the transfer limits studies should be conducted for the most accurate network representations to reveal the most accurate results. The information from the questionnaire was not strong enough to draw a valid conclusion. Thus additional research on this topic could be conducted to contribute to the field of knowledge.

However, the rest of the rejections indicate from the case study methodology that all of the alternative hypotheses were addressed in the overall empirical data collection. The comparison of this data to the international best practice process can be confirmed as complete and conclusive.

5.5 Overall

Overall, the process of the SAPP transfer limits studies follows the same structure as a general process: converting supplied inputs to valid, reliable outputs through a series of actions that are controlled by certain rules or guidelines (controls).

The documentation available for the SAPP transfer limits studies indicates that valid, reliable processes are in place to ensure the validity and reliability of the results achieved each year after the annual workshop is conducted by the relevant engineers.

The overall conclusion of the research through the analysis of the questionnaire data, the documentation data and the participant observations (triangulated) is that when matched to theoretical international best practice, the process is not consistent and therefore the results for the studies are also not consistent or accurate.

6. CONCLUSION

The research aimed at determining the gaps between the SAPP transfer limits studies process and international best practice. It can be concluded through the gaps identified that not only is the process of transfer limits studies conducted by the SAPP inconsistent, but also the results produced from the process. The gaps identified, however, also reveal the actions that can be taken by the SAPP to improve the process of transfer limits studies conducted in producing more reliable results to ensure overall network security. Actions include training the engineers that are required to conduct the studies in the theory behind transfer limits and the process to be followed to determine them. It would also be beneficial for the organisation to investigate other software tools that might streamline the process of transfer limits determination in the SAPP. Actions of continuous improvement after the execution of the process are important to maintain a high quality process and these will need to be implemented by the SAPP.

The overall conclusion to this research is as follows:

A standardised method of the execution of the SAPP transfer limits studies process can improve the consistency of the transfer limits obtained each year.

The training of the engineers in transfer limits studies will not only benefit the power pool and the countries that rely on its electricity supply, but also the engineers themselves in that they will develop more skills and understanding of the stability and appropriate operation of the network. This recommendation promotes individual growth of the utilities and the representative engineers.

The increased consistency in the process of conducting the SAPP transfer limits studies is an indication to power pools all over the world of the importance of consistency in engineering processes that produce operating guidelines on an interconnected power pool, as the consequences of instability are drastic.

Additional research opportunities lie in other methods of increasing the overall stability of a power pool, such as dynamic system studies and how these processes can be created and implemented.

It should also be noted that the sustainability issues addressed in the recommendations above would promote a process of monitoring and continual improvement for the SAPP transfer limits and therefore for the accuracy of the results of the studies. As mentioned above, this could even involve the incorporation of new tools or software, used internationally, to conduct these studies.

Future studies on a similar topic, unknown to this research, could investigate whether:

- The effects of dynamic system stability in interconnected power pools have a major influence on the transfer limits.
- The studies take into consideration each network portion’s worst case scenario setup in establishing the contingency base case.
- Human resource sustainability exists within the overall SAPP transfer limits studies process.
- The SAPP transfer limits studies process takes into account worst case contingency case file setup consistently in all sub-workgroups.
- The consistency of the results of SAPP transfer limits studies improves with more regular workshops.

The SAPP is growing fast and reliability in the operation of the power pool is imperative. The implementation of the actions listed above could ensure added system security for the operation of the SAPP providing power for Africa.

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8. APPENDIX

Table 6: Summary of the transfer limits studies process

Summary table of the transfer limits process in a power pool				
Phase	Inputs		Process	Outputs
Planning and Design [33], [40]	Governance documentation [19], [33]	Procedures and processes used to conduct transfer limits studies	Transfer limits studies	Standard knowledge base to use for transfer limits studies
	Real network parameters [6], [10]	Accurate modelled network case file with all interconnected networks represented	Network modelling – correct transmission line parameters or transformer models to represent the network in real life etc.	Accurate voltage and thermal violations identified
	Real-time network data	Correct network configuration [5]–[7], [20], [23], [39]	Worst case scenario base case setup	Most accurate base case set up to represent real network conditions, revealing realistic network reaction results
		Correct loading conditions [7], [23]		
		Correct generation conditions [7], [23]		
		Consistent simulation software package [19], [33], [42], [43]		
	Simulation inputs	Correct relevant tie lines identified [19], [22] One reference bus used for all studies [50]	Iteratively deriving worst case scenario transfer limits contingency base case [23], [33]	Most accurate contingency base cases set up to represent real network conditions, revealing results as close to realistic network reactions as possible [1], [3], [6], [23]
		Solving worst case scenario case file [23], [25], [26]		
		Selecting contingencies to be studied [23], [38]		
		Setting up software for PV curves [10], [20]		
		Determining load step increment [23], [38]		
		All voltage and thermal ratings within limits [7], [23], [38], [39]		
	Engineers	Representing all parts of the power pool [7], [19], [32]	Understanding transfer limits and required procedure introductory presentation	Standard understanding of results required from studies to be conducted in a specified way, which can be continued into the following year
		Consistently experienced in the study area and software package [7], [19], [33], [42], [43]		
		Consistently experienced in transfer limits studies [23]		
		Sustainability parties [37], [51]–[53]		
Execution [19], [33]	Standard procedure to execute studies [39], [47], [48]		Transfer limits study execution [5]–[7], [20], [22]–[24], [26], [30], [31], [33], [38]–[40]	PV curves
	Common understanding in identifying thermal and voltage violations [7], [19], [33], [42], [43]			
	Common understanding of how to record relevant transfer limit (thermal or voltage) [7], [19], [33], [42], [43]			Transfer limits, limiting contingency, limiting network violation

	Standard results presentation format/procedure [1], [10], [20], [50], [54]		
	All loading and generation configurations possible [7], [23]	Reverse case taken into account [22], [33]	Transfer limits that cover a wider variety of scenarios
	Finalised compilation of all transfer limits relevant to the interconnected power pool [33]	Distribution to all relevant system operators [17]–[19], [33]	Transfer limits implemented on electrical networks
Monitoring and Evaluation [7], [23], [33]	Output of execution process	Peer review of results [10]	More reliable results
	Combined power pool transfer limits	Compare to network operability and exceedances on the transfer limits	Power pool blackout prevented [23], [55]
		Evaluation of standardisation of transfer limits [7], [23]	Penalties incurred according to non-adherence by utilities [17]–[19], [44]
		Recalculation of transfer limits to increase accuracy and effectiveness [48]	Implement recommended procedures in the following year's process to increase effectiveness of outputs
		Analyse with the intent to implement international best practice and tools to further increase efficiency and applicability of studies [7], [23]	
		Training for future study participants, especially if study procedures or tools have to be changed for improvement of the overall process [1], [10]	More efficient process the following year, no retraining required, encourage sustainability