Serving Low Load Levels by Derating Line Voltage Using Step Down Transformers

Popi Melato
University of Johannesburg
Faculty of Engineering and the Built Environment
Johannesburg, South Africa
melatope@eskom.co.za

Nhlanhla Mbuli
University of Johannesburg
Faculty of Engineering and the Built Environment
Johannesburg, South Africa
mbulin@eskom.co.za

Jan-Harm Pretorius
University of Johannesburg
Faculty of Engineering and the Built Environment
Johannesburg, South Africa
jhcpretorius@uj.ac.za

***Abstract* – Steady state voltage problems in power systems are those associated with undervoltages resulting from increasing loads. Steady overvoltages can also arise when loads served by networks are reduced, and the problem can be exacerbated if lines supplying load centres are long. This paper reports on a study that was conducted to assess the impact of derating voltage of lines, by using step down transformers on the lowest load a network can accommodate without overvoltages. A program written in Python and using PSS/E to perform loadflows, was used to perform analyses at various load levels. The study showed that with derating transformers installed, voltages in the system were better, there was less reactive power flow, and active power losses were lower. Derating lines using step down transformers is therefore a potential solution for serving low load levels.**

Index Terms- *Active power losses, Power System Simulator for Engineering (PSS/E), Python Programming Language, steady state overvoltages, step down transformers.*

I. INTRODUCTION

Utilities have to ensure that an adequate amount of power is delivered to customers [1] and that the power delivered meets acceptable levels of quality [2]. Voltage supply is one aspect of quality of supply and it must be maintained within limits and not exceed upper limits, as prescribed by the regulatory codes [3]. The IEEE 1159 [4] standard, describes the steady overvoltages as long-duration voltages which have durations of 1 minute or longer and can arise under light loading conditions.

In network capacity planning, the common problem is that of ensuring that increasing amounts of load can be adequately served by the networks, with undervoltages normally being a concern. However, there are instances where a load served can diminish, e.g. when mines are decommissioned as ore can no longer be mined economically. Lowly loaded networks are prone to experiencing steady overvoltage problems. This problem can be compounded if lines supplying the load centre are relatively long, resulting in the relatively-high generation of capacitive reactive power.

Shunt reactors are one of the solutions used to remedy steady overvoltages and keeping the operation of the network within acceptable upper limits [5]. Additional control of voltage can be achieved from transformer tap changers [5]. Another means of controlling reactive power in the system is through the variation of the generator voltage set point [5, 6], switching out of lines, switching in shunt reactors and ensuring synchronous machines are operated [6] in under excited mode.

In this paper, the authors study the use of step down transformers to derate the operating voltage of the lines between these transformers, to solve steady overvoltage problems and accommodate reduced load levels in the network. The rest of the paper encompasses the following sections. Section II discusses how the step down transformers are expected to reduce the steady overvoltages.

In Section III a brief description of the program written in Python to automate loadflow calculations is described. The details of a case study carried out are covered in Section IV. Section V presents and discusses the results of the case study. The conclusions of the study are drawn in Section VI.

II. IMPACT OF DERATING LINE VOLTAGE USING STEP DOWN TRANSFORMERS ON STEADY STATE PERFORMANCE

Consider a simple two bus system, as shown in Fig. 1, with the load, $P_R + jQ_R$, connected at the end of the transmission line.

978-1-4673-9682-0/15/$31.00 ©2015 IEEE

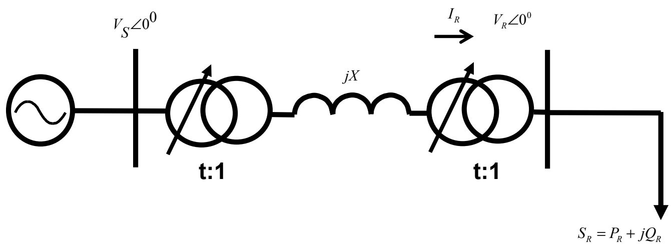

Fig. 1: Transmission line supplying a load through a Simple 2-bus system.

The relationship between the sending end voltage, the receiving end voltage, and the complex load can be expressed as [7]

$$V_S\angle\delta = V_R\angle 0^0 + \frac{XQ_R}{V_R} + j\frac{XP_R}{V_R} \quad (1)$$

where V_S is the sending end voltage (in kV), V_R is the receiving end voltage (in kV), S_R is the apparent power (in MVA), P_R is the active power in (in MW), and Q_R is the reactive power (in MVAr).

From the above expression, the voltage drop at the end of the line is proportional to the load, $P_R + jQ_R$, and the receiving end voltage, V_R , is inversely proportional to the load. Thus, a decrease in load will result in lesser reactive power being drawn, leading to less voltage drop, and a higher voltage at the receiving end.

In addition to the above factor, it has to be taken into consideration that due to the capacitance formed between phases and between phases and ground, transmission lines have capacitive characteristics that lead to the generation of capacitive current which can be written [8] as

$$I_C = YV \quad (2)$$

where I_C is the capacitance charging line current (in kA), Y is the shunt admittance per unit length in Siemens, and V , is the operating voltage of the line.

The reactive power produced because of the capacitive current can be written as

$$Q_C = BV^2 \quad (3)$$

where Q_C is the charging reactive power produced by the lines (in MVar), B is the line suceptance of the line (in Siemens), and V , is the operating voltage of the line.

Considering the active power losses, they can be expressed as

$$P_{loss} = I^2R \quad (4)$$

where P_{loss} is the active system power loss (in MW), I is the current along the line in (kA), and R is the resistance of the line (in Ω).

When the networks become lowly loaded, there will be a consumption of reactive power to offset the production of capacitive reactive power by the transmission line. Consequently, there will be a higher total current flow in the network, resulting in increased active power losses.

Next, the introduction of step down transformers at the ends of the lines is considered. They impact on the characteristics of the network in a number of ways. Firstly, they contribute additional reactance into the system. Due to the added reactance, there is an increase in voltage drop along the lines, leading to lower voltages being realized at the end of the lines, resulting in a reduced potential for steady overvoltages.

Secondly, the introduced reactance will consume some of the capacitive reactive power in the network, thereby helping to offset the generated reactive power. This will also ensure a reduced possibility of overvoltages in the system and will lead to a decrease in current flows, resulting in less active power losses.

Finally, the step down transformers have an additional benefit of the load tap changers into the system. The tap changers provide an additional means of voltage regulation as they have the capability to buck voltage rises in the system, helping to curb steady state voltage rises.

III. ALGORITHM FOR LOAD FLOWS AT VARIOUS LOAD LEVELS

In order to assess the impact of derating transformers, it is of interest to determine the lowest load that can be accommodated by the network without violating voltage limits and thermal capacities of lines. Further, it is desirable to have a feel of how reactive power flow will be affected. It is also of interest to see how this use of transformers will affect active power losses. To obtain data that can provide information on these questions, it is necessary to run load flow analysis for networks (I) with and (II) without the proposed solution of step down transformers. This has to be done at various load levels, with load in the network being gradually reduced to a point where the desired, lowest load is reached.

Performing power system analysis at various load levels to gather information required to do the above-mentioned assessment would be laborious, time-consuming, and cumbersome. In order to effectively perform the study, it was decided that a program be written to help with the automation of the studies. The authors chose Python Programming

Language [9] to implement the program.

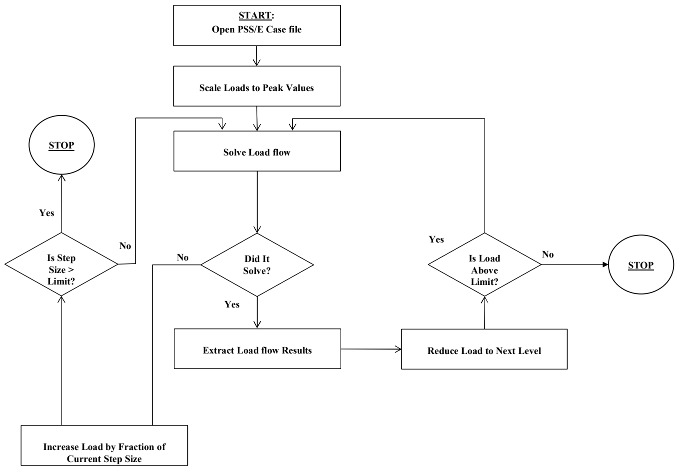

Fig. 2: Flow chart showing steps for load flow studies at various load levels.

The main reason for the choice of Python lies in the fact that to carry out the load flow analysis, the authors used the Power System Simulator for Engineering (PSS/E) [10]. Python is able to interface with PSS/E using the Application Program Interface (API) [11]. The software code can be programmed in Python and communication between Python and PSS/E is made possible by using APIs. Python is able to send commands to PSS/E via these APIs, and in this way Python is able to write information into and extract information from PSS/E files, in addition to being able to instruct PSS/E to perform some functions (e.g. run load flow calculations, reduce loads, etc.).

The pseudo-code of the program is presented in Fig. 2. The Python code first instructs PSS/E to open a file containing data required for load flow analysis. Thereafter, PSS/E receives an instruction to scale the load in the network to its peak value, after which a load flow is solved. If there is a successful solution, load flow results at the current load level are extracted and stored in data arrays.

The data of interest include voltages for selected busses, reactive power flowing in selected lines, reactive power in the network and active power losses in the system.

If at any stage the solution of the load flow is unsuccessful, the program attempts to obtain a solution by reducing the step size, checking if the step size is not less than some lowest size desired, adding the new step size and attempting the loadflow solution.

IV. ILLUSTRATIVE EXAMPLE

To evaluate the impact of line derating using the step down transformers, a case study was conducted using the IEEE 14 bus system, and its single line diagram is shown in Fig. 3. The parameters of these lines are available in [12].

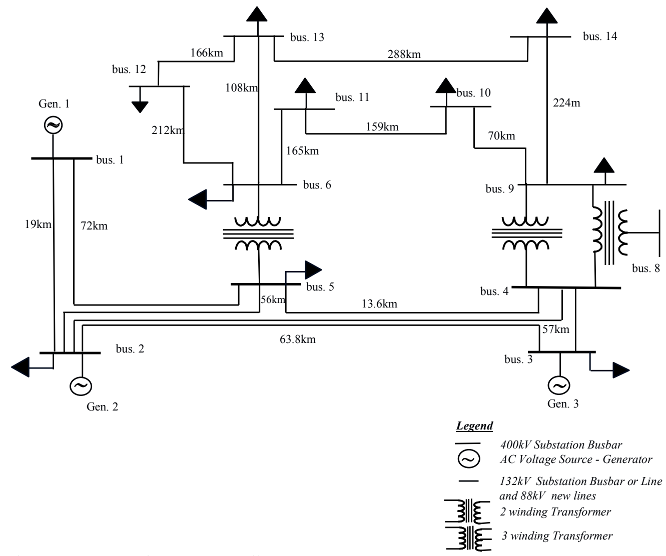

Fig. 3: IEEE 14-bus system diagram.

The Python program which was written, and is described in the previous section, was used in running the simulations, effecting adjusted loading of the changes to the network and extracting data from the PSS/E network case file. The starting load was 120MW and was reduced in steps of 1MW down to the lowest load of 1MW.

System healthy load flow studies were conducted at each of the load levels, with voltages (at busses 6, 9, 10, 11, 12, 13 and 14), reactive power flow (in the system and flowing through lines 6-11, 6-12, 6-13, 9-10, 9-14, 10-11, 12-13 and 13-14, and active power system losses recorded at each load level.

V. RESULTS AND DISCUSSIONS

In Fig. 4 the results of the variation of steady state voltage at bus 10 with system load are plotted. In the case of the network the voltage increases with load reduction, exceeding the acceptable limit without line derating, at initial system load level of 120MW, the voltage at bus 10 is 1.03 per unit of 1.05 per unit when the load drops below about 48 MW. In the case of derated lines, the voltage starts at about 1.0 per unit, is around 1.035 per unit at the lowest load level, and is never always below the upper, steady state limit.

The variation of reactive power flowing in line 6-13 with the reduction in load is plotted in Fig. 5. In the original case, the reactive power flow in the system increases from 12.5MVar to 21MVar as the load is reduced from the peak value to the lowest size. When step down transformers are introduced, the reactive power is kept within the 0-5MVar capacitive range. A similar observation is made in Fig. 6, where the system reactive power ranges between 271 and 320 MVar in the case without step down transformers, but is kept between only 208 and 252MVar when derating transformers are incorporated.

The total system active power losses calculated at various load levels are plotted and presented in Fig. 7. The active power losses range from 2.5MW at 120MW load level, to 1.75 MW around 50MW load level, to 2.0MW at the lowest load level. In the derated case, the losses vary from 2.5MW at peak load to 0.6MW at the lowest load level. It can also be seen that there is a difference in losses for the two scenarios, with this difference increasing from near 0MW during peak to a peak of around 2.5MW at lowest load levels, with lower losses in the derated case.

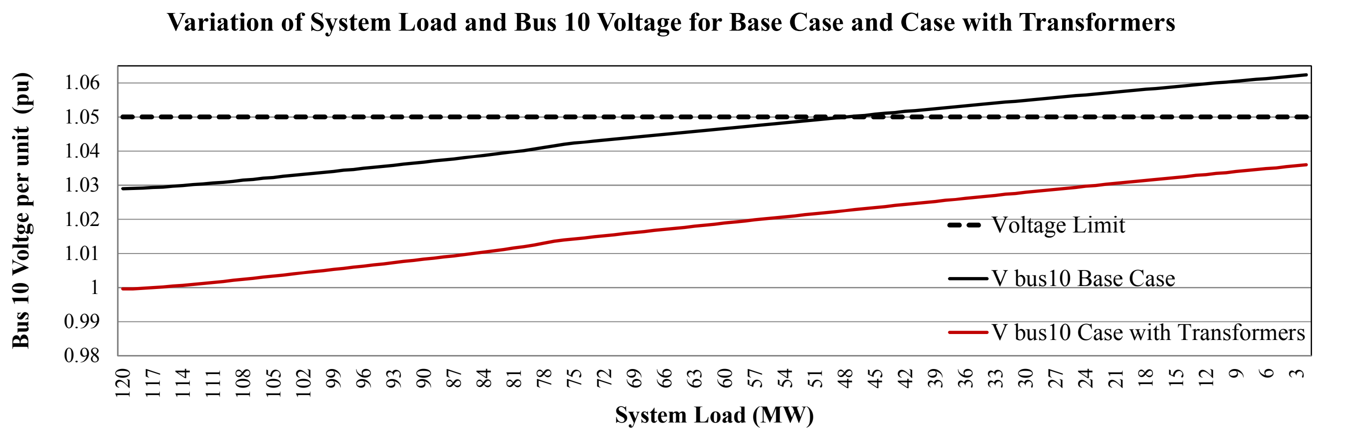

Fig. 4: Variation of voltage at bus 10 with active power load in the system for (I) case without step down transformer and (II) case with transformers.

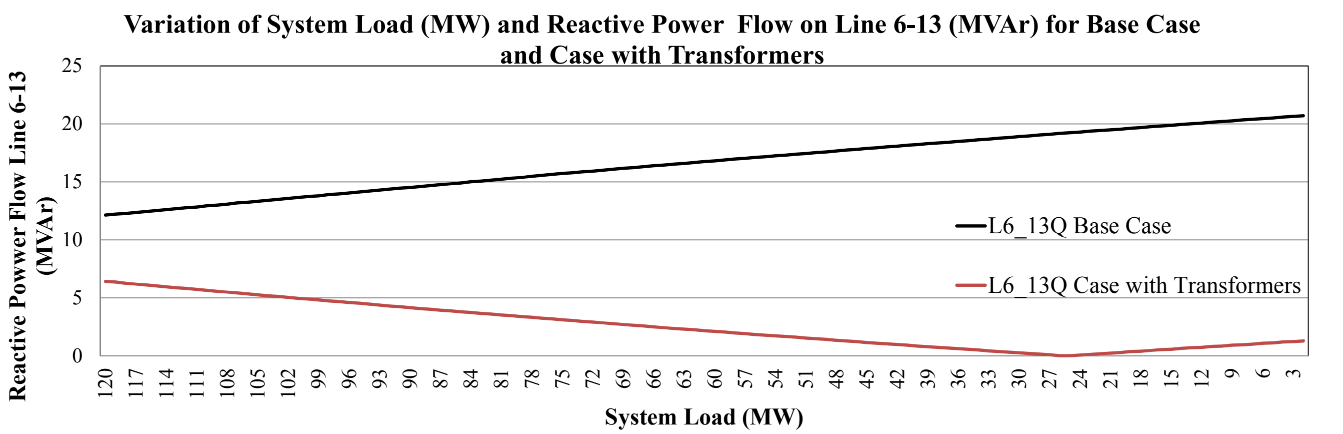

Fig. 5 Variation of reactive power in the network with the active power load in the system for (I) case without step down transformer and (II) case with transformers.

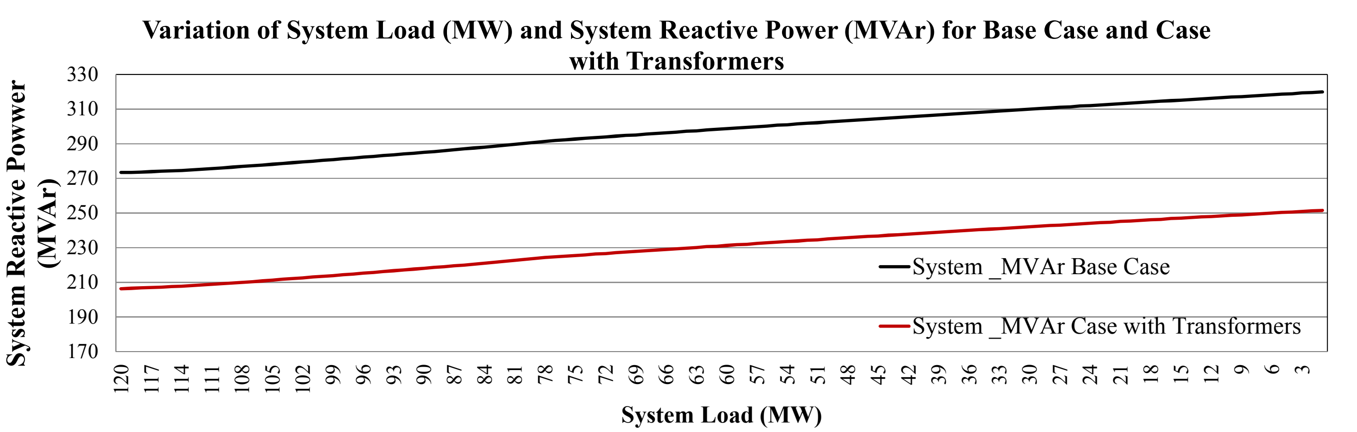

Fig. 6: Variation of system reactive power with active power load in the system for (I) case without step down transformer and (II) case with transformers.

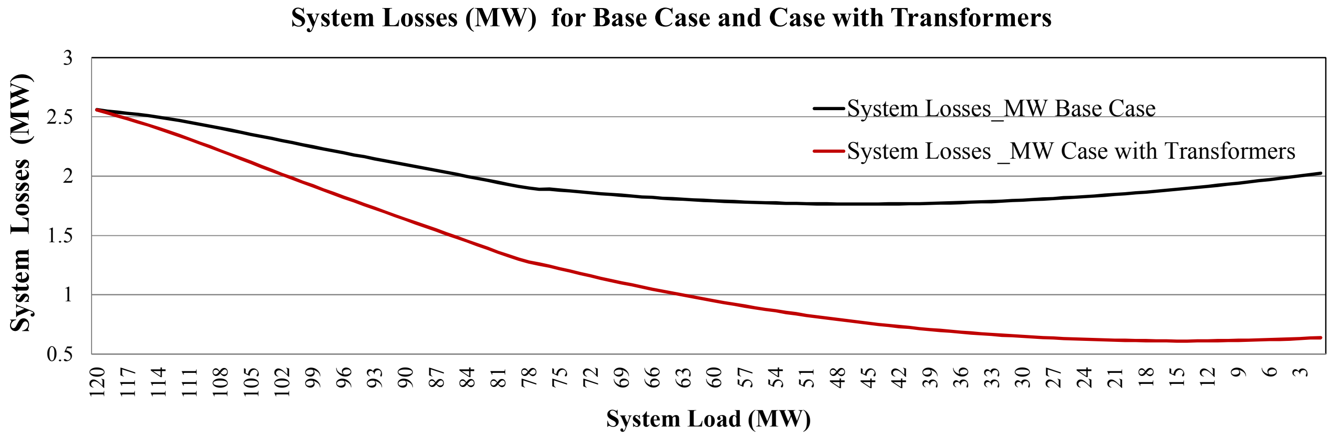

Fig. 7: Variation of system active power losses with active power load in the system for (I) case without step down transformer and (II) case with transformers.

VI. CONCLUSIONS

In this paper, an investigation into the use of line derating to accommodate lowest load in the network has been carried out. Load flows were carried out at various load levels and network performance assessed at each load level. A software program, written in Python and using PSS/E to perform calculations, was used to automate the calculations.

The study showed that the introduction of line derating, step down transformers had numerous beneficial effects on system performance as the system load was reduced. Lesser voltages, lesser reactive power flow, and lesser active power losses were realized in the case of derated lines, showing the improved capability of the system to serve low loads.

The study demonstrated that the proposed use of step down transformers could serve as an alternative solution for ensuring acceptable supply to networks serving low loads. The techno-economic merits of this solution will have to be weighed against those of other solutions.

ACKNOWLEDGMENTS

The authors wish to thank the University of Johannesburg and Eskom Holding SoC Limited for funding this study.

REFERENCES

[1] R. J. Ringlee, P. Albrecht, R. N. Allan, M. P. Bhavaraju, R. Billinton, R. Ludorf, B. K. LeReverend, E. Neudorf, M. G. Lauby, P. R. S. Kuruganty, M. F. McCoy, T. C. Mielnik, N. S. Rau, B. Silverstein, C. Singh, and J. A. Stratton, "Bulk Power System Reliability Criteria and Indices Trends and Future Needs", IEEE Trans. On Power Systems, vol. 9, no. 1, February 1994, pp. 181-188.

[2] S. Chattopadhyay, M. Mitra, and S. Sengupta, "Electric Power Quality," Springer: New York, 2011.

[3] Electricity Supply-Quality of Supply, Part 2: Voltage Characteristics, 2nd Edition, NRS 048-2: 2003.

[4] A. Moreno-Munoz, "Power Quality Mitigation Technologies in a Distributed Environment," Power System Series, Springer-Verlag London Limited, 2007.

[5] P. Kundur, "Power System Stability and Control," McGraw-Hill, Inc., New York: USA, 1993.

[6] V. A. Diachkov, A. A. Gremiakov, and V. A. Stroev, "Alleviation of Steady State Overvoltages in Electrical Power Systems," in Proc. 2003, IEEE PowerTech Conference (Volume: 3), Bologna: Italy, 23-26 June 2003, pp. 1-5.

[7] C. W. Taylor, "Power System Voltage Stability," McGraw-Hill, Inc., New York: USA, 1992.

[8] A. Moreno-Munoz, "Power Quality Mitigation Technologies in a Distributed Environment," Power System Series, Springer-Verlag London Limited, 2007.

[9] PYTHON, Online Documentation : Ver. 32 (Siemens Energy, Inc., 2009).

[10] PSS/E, Power System Simulator for Engineering: Online Documentation : Ver. 32 (Siemens Energy, Inc., 2009).

[11] Application Program Interface Power System Simulator for Engineering: Online Documentation : (Siemens Energy, Inc., 2013).

[12] P. Melato, N. Mbuli, J. H. Pretorius, "Derating Line Voltage as an Option for Reliability Enhancement of Lightly Loaded Networks," in Proc. 2014, 49th Int. Conf. Universities Power Engineering, Cluj-Napoca: Romania, 2014, pp. 1-6.