Power Transfer Limit of Rural Distribution Feeder

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Abstract

Western Power is concerned about planning to avoid voltage collapse issues on long rural feeders. Hence, Western Power wishes to explore reinforcement options to increase power transfer on rural feeders. The main objective of this project is to determine power transfer limitations on rural distribution feeders, in order to maintain voltage stability. This project also examines the Voltage versus Power characteristic (graph between receiving end voltage and power) with different reinforcement options like Static Synchronous Compensators (STATCOMS), Static VAR compensators (SVC), capacitor banks, series capacitors and voltage regulators across distribution feeders. This will provide better feeder utilization and improve the use of long rural distribution feeders without exceeding power transfer limits. In turn, this will increase the reliability to customers and maintain Key Performance Indicators of System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) to acceptable. This will lead to efficient and prudent network investment decisions.

***Keywords**: Power Transfer Limit, Voltage collapse, Reactive power, FACTS, STATCOM, SVC, Distribution Feeders, Stability*

1. Introduction

Reactive power compensation is generally required to reduce MVAr flow via the network to improve voltage regulation and also to reduce the resulting power losses. In order to maintain voltage stability it is essential to determine the power transfer limits on rural distribution feeders. The control of voltage and reactive-power is one of the important control measures for achieving the following outcomes described by Kundur P (Kundur P, 1994).

- Voltages at the consumer end in the network are within acceptable limits.
- System stability is enhanced to maximize the utilization of the distribution network.
- The reactive-power flow is minimized so as to reduce power losses.

The problem of maintaining voltages within the required limits is complicated because it is associated with reactive-power requirements of the distribution network.

Improved utilisation of the existing power system is provided through the application of advanced control technologies. Power electronics based equipment, such as Flexible AC Transmission Systems (FACTS) allows operation of power system with minimal infrastructure investment, environmental impact, and implementation time compared to the construction of new lines. (Gregory et. al, 2002)

Voltage collapse in power system affects optimal distribution of power and leads to instability in the system. The effective voltage control with various reinforcements and FACTS devices like capacitor banks, voltage regulators, Static Synchronous Compensator (STATCOM), Static VAr Compensator (SVC) leads to increase in power transfer limits, reduced losses and voltage stability.

In order to reduce voltage collapse Western Power wants to explore alternative methods to maintain stable distribution network. The rural distribution feeders were analysed using computer modelling and taking into consideration different voltage control options.

STATCOM is like a synchronous machine running without a prime mover or mechanical load. By controlling the firing angle, it can be made to either generate or absorb reactive power. SVCs are shunt-connected static VAR compensators whose outputs are varied so as to control reactive power in the system; unlike SVC have no moving or rotating components (Kundur P, 1994).

The project results will provide Western Power with an appreciation of power transfer limits and the different reinforcement options available for enhancing the power transfer limits for rural feeders. If the project is not carried out, the increase in electricity demand may lead to instability and voltage collapse in some edge of grid locations.

The main objective of this project was to determine power transfer limitations on rural distribution feeders in order to maintain voltage stability and to examine the effects of different reinforcement options on power transfer across distribution feeders and the associated voltage stability limits.

The Gnowangerup, Kalbarri, Quangellup and Dandaragan feeders were selected for case study. Successful completion of this project is expected to yield the following benefits to Western Power:

- Improve reliability on rural feeders.
- Increased asset utilisation which will lead to deferral of expensive capital investment
- Reduce risk of exceeding power transfer limits.

The project's findings and recommendations, in relation to power transfer and voltage collapse is expected to influence Western Powers distribution planning process. That is all reinforcement options will need to be considered in terms of meeting steady state voltage regulation requirements, as well as supporting power transfer so as to avoid voltage instability.

2. Process

In the power system, active power and voltage at the receiving end is related by the power transfer equation. The distribution line is represented by an equivalent single-phase model which is often known as Π (pie) circuit model.

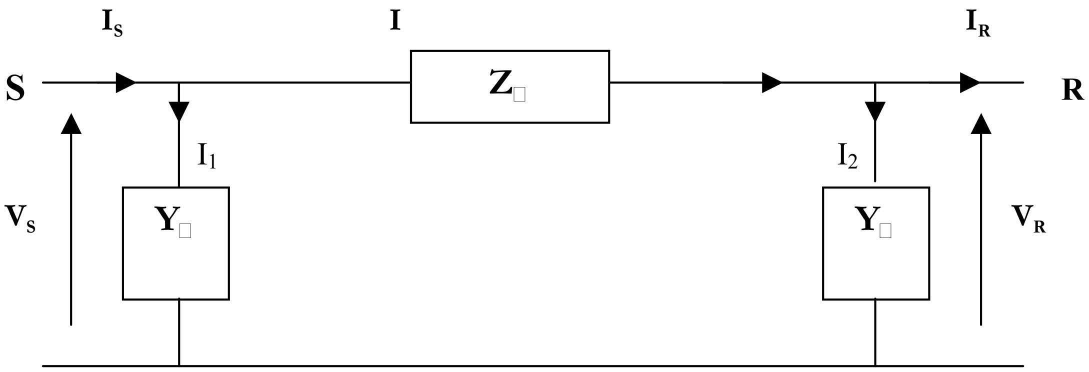

Figure 1 Π circuit Model (Nguyen T. T., 1992)

Defining:

$$Z_\Pi = |Z_\Pi|\angle\psi \qquad Y_\Pi = |Y_\Pi|\angle 90^\circ \qquad \text{where, } Z_\Pi \neq Y_\Pi$$

Receiving End Voltage, $V_R = |V_R|\angle 0^\circ$ (Reference)

Sending End Voltage, $V_S = |V_S|\angle\delta$

Power at the Receiving End R

$$P_R + jQ_R = V_R \cdot I_R * \tag{1}$$

But From Π circuit model we know,

$$I_R = \frac{V_S - V_R}{Z_\Pi} - Y_\Pi V_R \tag{2}$$

$$P_R + jQ_R = V_R\angle 0^\circ \cdot \left[\frac{(V_S\angle -\delta) - (V_R\angle 0^\circ)}{Z_\Pi\angle -\psi} - Y_\Pi V_R\right] \tag{3}$$

Hence,

$$P_R = \frac{|V_S|\cdot|V_R|}{|Z_\Pi|}Cos(\psi - \delta) - \frac{|V_R|^2}{|Z_\Pi|}Cos(\psi)$$

$$Q_R = |Y_\Pi||V_R|^2 + \frac{|V_S|\cdot|V_R|}{|Z_\Pi|}Sin(\psi - \delta) - \frac{|V_R|^2}{|Z_\Pi|}Sin(\psi) \tag{4,5}$$

Rearranging Equations 4&5 we get,

$$\left[\frac{1}{V_S^{\,2}}\left[V_R^{\,4}(X)+V_R^{\,2}(Y)+Z_{\Pi}^{\,2}(P_R^{\,2}+Q_R^{\,2})\right]\right]^{1/2}=0 \qquad (6)$$

Where X & Y is given by:

$$X = 1+Z_{\Pi}^{\,2}Y_{\Pi}^{\,2}-2Z_{\Pi}Y_{\Pi}\cdot Sin\psi$$

$$Y = 2Z_{\Pi}\left(P_R\cdot Cos\psi+Q_R\cdot Sin\psi\right)-2Q_RZ_{\Pi}^{\,2}Y_{\Pi}$$

The power transfer capability can be determined by the power transfer equation, because with variation in admittance and PF, the power transfer limits in a network changes.

The following methodology and analysis was carried out.

2.1 Power flow analysis Using PSS/ADEPT (Power System Simulator/ Advanced Distribution Engineering Productivity Tool) and MATLAB

The PSS/ADEPT software was developed for Engineers and technical personnel who design and/or analyse electrical distribution systems. PSS/ADEPT enables the users to graphically create, edit and analyse power system models and diagrams. (Power Technologies INC, 2002)

In this software, a feeder network diagram was taken from the software Distribution Facilities Information System (DFIS) or from a folder where exported feeder diagrams were saved. This network diagram contained all the information about line, load, transformer, switches and Voltage regulators. The impedance parameters of the line are obtained from the Construction Dictionary (i.e. data sheet where parameters for different types of conductors are stored).

Where the network model was not available in the folder (where new models are saved), the graphical network model was created through a data extraction process. The load flow analysis was done by clicking Load Flow on the main window of PSS/ ADEPT.

After the successful load flow analysis, the line and load parameters were uploaded into the Power Flow software of Matlab to get the desirable PV curves. The PV curve gave the relation between receiving end voltage and receiving end power.

2.2 Power flow analysis using DIgSILENT (Digital Simulation and Electrical Network Calculation Program) Powerfactory

The calculation program Powerfactory, as written by DIgSILENT, is a computer aided engineering tool for the analysis of industrial, utility, and commercial electrical power systems. It has been designed as an advanced integrated and interactive software package dedicated to electrical power system and control analysis in order to achieve the main objectives of planning and operation optimization (DIgSILENT Germany, 2007).

The network models were either created manually or imported to Powerfactory. The models from the DFIS or from PSS/ADEPT were converted from PSSU model to .dz format. After the model was converted, a link was created with the construction dictionary to obtain line parameters.

The load flow analysis was performed by clicking the load flow button. The load flow was found to fail due to error in the network diagram, which is shown in the output window. After correcting the error, the load flow was run and the PV curve was obtained by running the PV script. In Powerfactory software there is an inbuilt DPL script for plotting the PV curve.

The comparison was done based on the result obtained from both analyses to arrive at a technical decision for distribution of power. The application of a suitable reinforcement option (SVC, STATCOM, capacitor bank, series capacitor) to increase power transfer on rural feeders was then recommended.

3. Results and Discussion

The simulations were performed for all four feeders (Gnowangerup, Quangellup, Dandaragan and Kalbarri). The PV curve analysis for Kalbarri feeder is displayed below

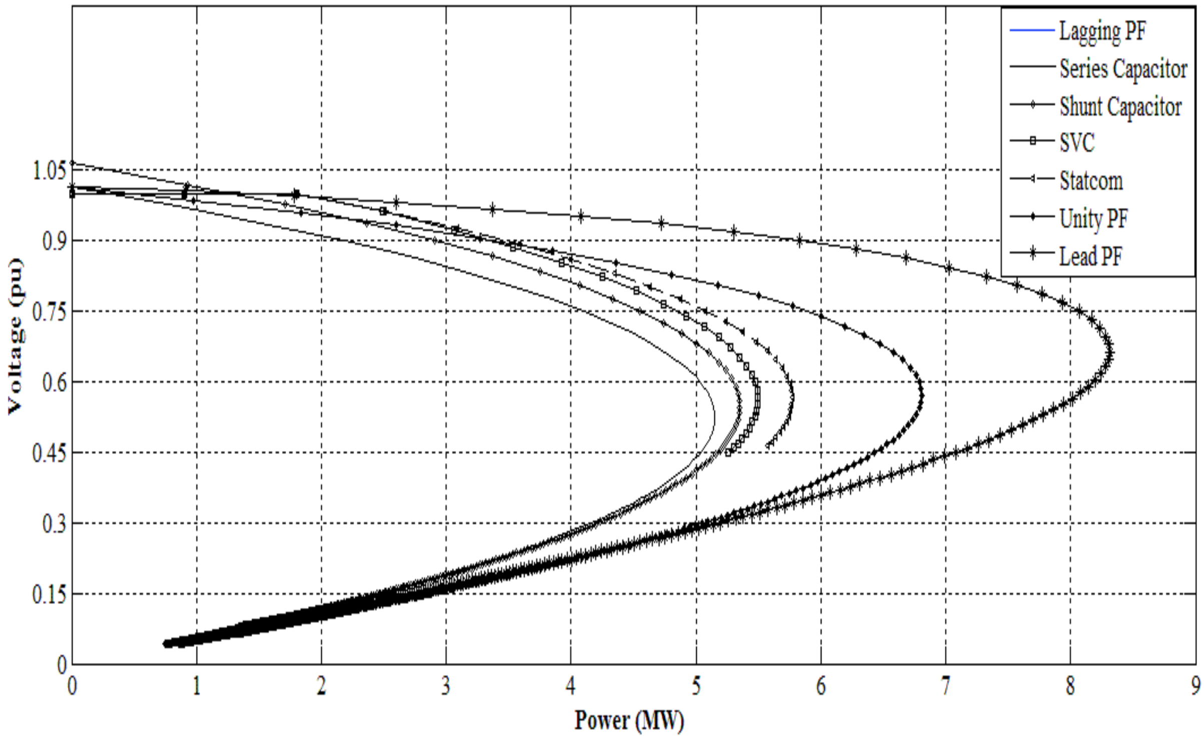

Figure 2 PV Curve for Kalbarri Feeder

The results for other feeders are tabulated below for different power factors.

Feeder	Power Transfer Limit (MW)		
	0.9 Lag PF	Unity PF	0.9 Lead PF
Kalbarri	5.2	6.8	8.3
Dandaragan	4.5	5.4	5.9
Gnowangerup	1.24	1.45	1.52
Quangellup	0.88	1.12	1.14

Table 1 Power Transfer Limit at different Power Factor

From the above results, it is clear that with effective reactive power control and power factor improvement, power transfer capability of the feeder increases.

Feeder	Power Transfer Limit (MW)				
	0.9 Lag PF	Series Cap	Shunt Cap	SVC	STATCOM
Kalbarri	5.20	5.21	5.4	5.5	5.8
Dandaragan	4.5	4.55	4.7	4.95	5.2
Gnowangerup	1.23	1.24	1.35	1.26	1.30
Quangellup	0.88	0.9	1.06	1.1	1.12

Table 2 Power Transfer Limit with different reinforcement options at 0.9 Lag. PF

The power transfer limits shown above are in reference to the knee point. However, in actual case the power is transferred with voltage within the specified range. The voltage limits according to Western Power's Distribution Planning Criteria is between 0.9 pu and 1.10 pu.

4. Conclusion

This paper has successfully assessed the power transfer limits on rural distribution feeders, in order to maintain voltage stability. This study provides a comprehensive assessment of the benefits of the options like STATCOM, SVC, capacitor banks and voltage regulators for voltage control on rural feeders to maximise the power transfer.

Application of the study results, provide better feeder utilization and improve the use of feeders without exceeding power transfer limit. In turn, this will increase reliability and quality of power supplied to customers on long rural distribution feeders. Also this will lead to efficient and prudent network investment decisions.

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