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An Integrated System Wide Reactive Power Management Strategy for Transmission and Distribution System based on Techno Economic Analysis

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ABSTRACT

This paper presents a methodology to determine the economic power factor at the point of power transfer between transmission and distribution (T & D) system for a vertically integrated utility company. An integrated reactive power management strategy is developed to optimize the planting up of reactive power compensation devices in the transmission and distribution system. The transmission and distribution network is modelled and simulated using commercially available software to analyse the transmission network losses, capacity released and voltage stability due to capacitor plant up. Economic analysis on the total cost of ownership of capacitor banks is used to determine the economic benefits of technical losses reduction and capacity. released in transmission and distribution equipment through the planting up of capacitor bank. The proposed methodology can be used by a vertically integrated power utility where a single utility own both the transmission and distribution system. A software base data analytic, power system automation and economic analysis tool was developed to facilitate the planning engineer in reactive power planning and management.

Keywords: Reactive power management

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INTRODUCTION

Reactive power management in transmission network aims at addressing issues related to voltage stability in a power system under normal operating conditions. Inadequate reactive power in the transmission system could lead to voltage collapse (U.S.-Canada Power System Outage Task Force, 2014). In the distribution system, the main objective of having adequate reactive power is to minimize technical losses and to release equipment capacity. Voltage management based on reactive power control in the distribution system is not as effective when compared with transmission system due to the nature of distribution system where the X/R ratio is high. The total costs of ownership for capacitor banks depends on the voltage and its manufacturer. As such, capacitor plant up in transmission and distribution system is optimized based on the selection of capacitor bank according to its voltage level and design under technical constraints such as physical space, network topology and availability. An integrated approach in reactive power planning and planting up can help to save costs and benefit a vertically integrated utility company.

Various methods have been proposed by researchers to optimize the management of reactive power (Singh & Srivastava, 2012); (Shourvarzi, Vaziri Mirzaei, Mehdizadeh Afroozi, & Rostami, 2012). In recent years, many publications have focused on optimal location, sizing and control strategy of reactive power management in the network with distributed generation or renewable energy resources (Hu, Dong, Lu, Xu, & Lianjie Lv, 2012). A comprehensive literature survey on the European practices in voltage and VAR control is published in (Mousavi & Cherkaoui, 2011).

Majority of the publications are focused on the optimal reactive power management on either transmission or distribution system. The methods proposed in the literature are applicable for deregulated electricity market where the coordination between transmission and distribution is minimal, and distribution operator adopted the concept “pay as you use” for reactive power. Furthermore, the proposed solution for optimal reactive power management involves complex optimization technique and heavy computation.

This paper describes an integrated approach in capacitor bank plant up for a transmission and distribution system. The first step is to establish the economic power factor at the point of power transfer between the transmission and distribution system. By applying total costs of ownership for each type of capacitor bank of different voltage level, economic benefits in terms of reduction in technical losses and capacity released in equipment is optimized by calculating the internal rate of return of each case of capacitor bank plant up. The optimum strategy is based on techno-economic analysis and network availability. Parameters required for the proposed methodology includes transmission and distribution network data, peak load demand data, unit cost of energy, and unit savings from capacity release.

METHODOLOGY

Typically, in a power system, most of the reactive power is consumed by the electrical loads. Reactive power transfer between the transmission and distribution system is recorded by energy meters installed on the secondary side of power transformers in the Main-In-Take substations. In this study, system wide power factor profile is first established by analysing the owner factor at each of the Main-In-Take substation. Power system studies were done on the transmission network to determine the optimal power factor at the Main-In-Take substation that yields the highest economic benefits.

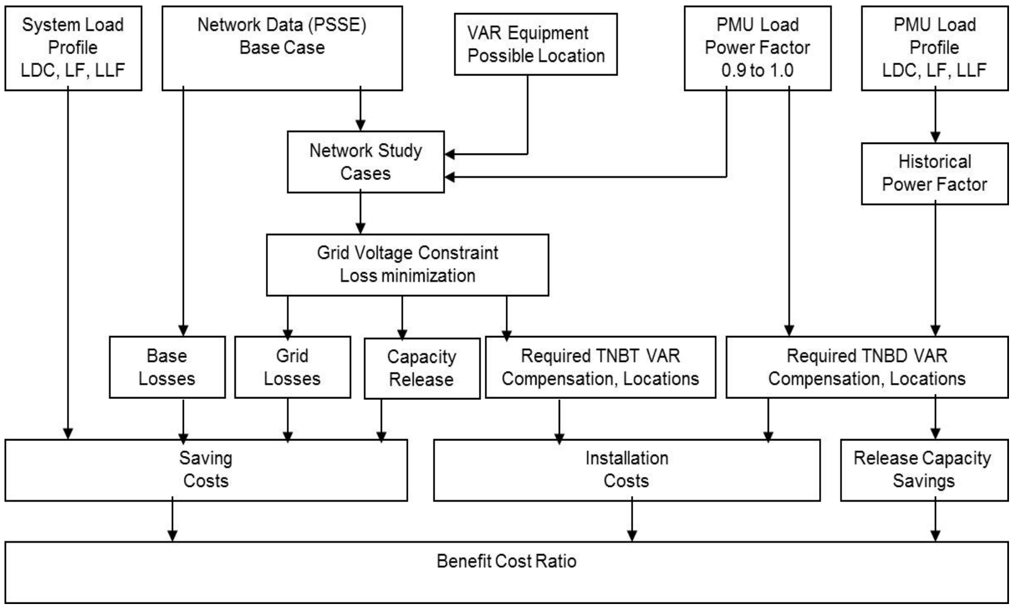

Figure 1. Process flow for integrated reactive power management

The quantum of capacitor banks to be planted in the distribution system is determined based on the optimal power factor at the Main-In-Take substation. Three different types of capacitor bank are considered; medium voltage (MV) capacitor bank, ground mount (GMLV) low voltage capacitor bank and low voltage pole top (LVPT) capacitor bank. Economic benefits based on internal rate of return are calculated for each of the three types of capacitor bank. Figure 1 shows the process flow of the integrated capacitor plant up based on the economic power factor to be maintained at the PMUs.

TECHNICAL ANALYSIS

In the technical analysis, the network data, load demand and existing power factor for the load was obtained from the utility company. The entire transmission network is modelled in the power system simulation software with optimal power flow (OPF) and the results (technical losses and total loading in MVA) are saved as base case. The OPF is repeated using different power factor from 0.9 to 1.0. The result of OPF at different power factor is compared to the technical losses and loading in MVA for the base case. The difference is the saving/benefit obtained from reactive power management. Figure 2 shows the example of capacity release at different power factor.

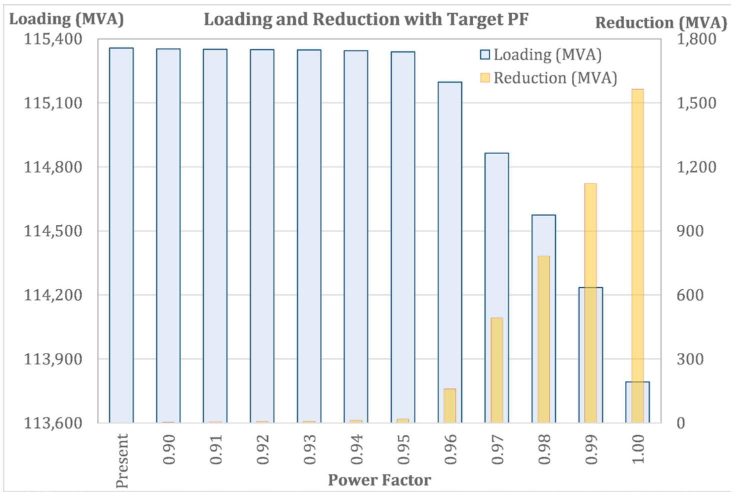

Figure 2. Example of capacity release chart

ECONOMIC ANALYSIS

From the technical analysis, the studies were able to establish the technical losses reduction, capacity released and capacitor bank required to achieve the target power factor. Financial savings is taken from the product of capacity released and energy losses multiply by its respective dollar/unit ($/MVA and $/kWh).

Capacity Released

The capacity released would benefit utility companies in terms of deferment of investment in new infrastructure, which typically consists of construction costs of new substations, transformers and auxiliary equipment. In addition, by releasing the transformer capacity the utility company would be able to minimize risk of power interruption to customers through demand management in the event of a fault in the system.

Technical Losses Reduction

Technical losses indicate the energy efficiency of the transmission and distribution system in supply power to customer loads. Operating at economic power factor by placing capacitor banks at strategic locations in the power system are effective and economical ways to minimize technical losses.

Capacitor Cost

Capacitor bank is a low cost reactive power compensation device compared to other technology such as STATCOM. Therefore, capacitor bank is widely used by power utility. Capacitor bank rated at different voltage level has different capacity, life span and maintenance cost. To have a fair comparison, total cost of ownership (TCO) is introduced to compare the most optimum reactive power compensation strategy. TCO is calculated based on the formula below: -

$$TCO\ (RM) = [\text{Initial cost} + \text{Maintenance cost} + \text{Disposal cost} - \text{Less value}]\ \ \text{unit cost} \tag{1}$$

RESULTS AND DISCUSSION

The benefit cost ratio is calculated based on ratio of overall cost saving to total cost of capacitor installation. The result in figure 3 shows the most economic power factor to be maintained at Main-In-Take Substation which is 0.97. Consequently, this 0.97 power factor is used to determine system wide strategies in capacitor bank plant up in the distribution system.

In this study, it has been determined that 120 MVAR of capacitor bank should be planted per year over the next 8 years in the distribution system to mitigate the deficit in reactive power requirement based on 0.97 economic power factor at PMU. Plant up of 120 MVAR per year is taking into consideration of practicality at site such as outage requirement, civil work, cabling and installation work.

A sample result on capacitor bank plant up in the distribution system is shown in Table 1. In this example, 75% of the total 120 MVAR required will be planted up at 11kV (5 MVAR capacitor bank). This is equivalent to approximately 90 MVAR or 18 units of 5 MVAR 11kV capacitor bank. This is follow by 10 % of GMLV capacitor bank and 15% of LVPT capacitor bank. With the plant up as shown in Table 1, it is expected that the quantum of reactive power transfer from transmission to distribution system would be gradually reduced. Consequently, the whole generation, transmission and distribution system would be more energy efficient as the distribution system is capable of meeting its reactive power demand locally which is achievable in year 2023.

Figure 3 shows the overall optimization chart from the reactive power optimization study. It is shown that the most economic power factor in between transmission and distribution system is 0.97. This is because the benefit over cost ratio at power factor of 0.97 is the highest.

Table 1
Plant-up Strategy in Distribution System based on 120 MVAR/YR

5 MVAr 11kV Cap Bank		180 kVAR GMLV Cap Bank		18 kVAR LVPT Cap Bank	
Percentage	No of Units	Percentage	No of Units	Percentage	No of Units
75%	18	10%	67	15%	1,000

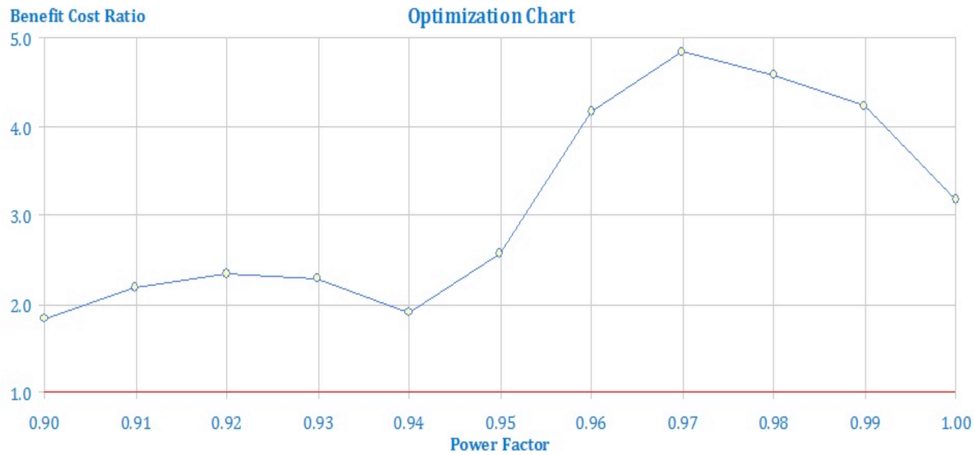

Figure 3. Benefits over cost ratio at different targeted power factor

CONCLUSION

An integrated VAR management methodology based on techno economic analysis is proposed to determine the economic power factor in transmission and distribution networks. The proposed methodology is suitable where transmission and distribution system belongs to the same utility company. A Microsoft Access data based and automation tools was developed for short term and long term reactive power planning and analysis.

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