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A framework for assessing economic and environmental benefits from transmission line rehabilitation investments

Sener Salci

Department of Economics, Queen's University, Kingston, Ontario, Canada

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A B S T R A C T

The analytical challenges in the evaluation of the impacts of transmission line investments have vexed practitioners and energy regulators. This study provides a compact analytical framework to improve the accuracy and predictability of such impacts from transmission line rehabilitation investments. The proposed approach is suitable for the evaluation of projects that are implemented in a broken electricity network. In such cases, the demand for electricity is deterred and the supply of the electricity is unreliable.

1. Introduction

In many developing countries, an inefficient and poorly maintained and operated transmission system usually suffers from significant technical losses (e.g., power flow losses, line blackouts, etc.) and non-technical losses (e.g., theft, fraud, uncollected bills, etc.) (World Bank, 2009a, 2009b). Not surprisingly, these losses substantially cost the electric utility companies. Although reliable data on the actual amounts of technical (mechanical) grid losses are readily available, these losses can reach up to 30% in developing countries (Jiménez et al., 2014; World Bank, 2014, 2016). Therefore, for reliable transmission of electricity to the areas served from power station(s) to demand nodes, transmission lines require restoration, insulation, and grounding with safe and reliable capacity (World Bank, 2009b).

Also, the high cost of electricity charges for a limited supply of service and crippling electricity breakdowns force consumers to rely on self-generation of electricity in developing countries (Alby et al., 2012; Steinbuks and Foster, 2010). Although some customers use costly and inefficient self-generation to avert power failures, many of them (mostly large industrial customers) still prefer to disconnect from the power grid and self-generate their electricity (Oseni and Pollitt, 2015). This averting behavior of consumers potentially prevents the electric utility companies from achieving a higher level of economy of scale in electricity generation. Consequently, it also affects the financial condition of the electric utilities and increases the cost of service to grid-connected consumers. The unreliable and inadequate electric power supply significantly reduces investment in productive capacity by firms, and also discourages the independent private energy investors for their investments in these countries (Eberhard et al., 2011). These efforts need to be tackled at the institutional level before reaching to utility level applications. Hence, in order to strengthen the operations of the electric utility and power network, retaining these consumers in the power grid would simultaneously require regulatory reforms and investments to improve reliability in the provision of the service (World Bank, 2009a, 2009b).

In the case of transmission line projects, the measurement of all the widespread and diverse impacts on an integrated network presents analytical challenges in developed countries (Chang et al., 2013). Such diverse impacts and their measurements in the context of developing countries are not the exception, however. Focusing on the current situation in a typical broken electricity network, this study presents an analytical approach to identify and estimate such benefits from the rehabilitation of the transmission line.[1,2]

Ensuring the reliability of the cost to consumers in the transition to a

E-mail address: ssalci@econ.queensu.ca.

[1] Earlier studies dealing with transmission rehabilitation projects in a similar fashion include Jenkins et al. (1999), and more recently by Salci (2017). In recent study, the replication data and economic model for a typical transmission rehabilitation project undertaken in broken electricity network is also available to public.

[2] Also, see Chang et al., 2013.

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low-carbon power system in a broken electricity network is a very complex task. First, developing countries are capital-constrained. Secondly, the large volume of energy losses is also a major concern for many electric utilities due to the lack of infrastructure quality and grid maintenance. Thirdly, persistence of low levels of electrification and energy poverty create serious obstacles for the economic development of these countries. These are inter-linked energy challenges. Therefore, this paper hopes to prove useful for detecting energy and emission savings resulting from improved transmission infrastructure; it can be used to as a tool when comparing energy and emission savings from alternative investment options (e.g., grid-connected wind, solar installations) so that scarce capital resources are optimized in their energy sector related infrastructure investments.

2. Transmission system reliability metrics

Based on integral coordination between generation facilities, the transmission network, and the distribution grid, power system reliability considers the performance of the electricity network as a whole. The transmission lines transfer bulk amounts of power from the power-generating stations to the distribution grids. The primary factors that are considered for electricity transmission investments (e.g., upgrades or rehabilitation of existing facilities and new expansions) are either reliability of the transmission system or interconnection of new generation facilities into the grid, or both (Hogan, 2011; Mazer, 2007).

The objectives of these investments are to improve the operational performance of the electric utility for a more efficient and reliable electricity supply and enhance the transmission capacity of the grid in terms of expansion planning. The reliability of the transmission system is measured in terms of the transmission system availability (i.e., percentage of full load hours net of the total of a number of planned line outages and unplanned line outages) and the transmission line losses during actual operation, when a line is available for power transfer (Hogan, 2011; Harris, 2006).

2.1. Transmission line availability

To maintain network reliability as well as extend the useful life of transmission lines, it is essential for transmission lines to undergo (planned or scheduled) regular outages for the purpose of maintenance. This is a regular recurrent process that imposes fixed non-available hours required for planned maintenance. Generally, the regular maintenance of the transmission lines is scheduled during off-peak load hours, when they are not heavily congested. The improved/rehabilitated transmission lines always require less time and effort for regular maintenance.

The rehabilitation of the line also increases reliability by minimizing the number of unplanned line outages, especially during peak-load hours, in addition to the planned outages; therefore, the annual availability of the transmission line further increases. This reflects an increase in the supply of electricity during peak-load hours. The availability of transmission line increases during both peak-load and off-peak load hours of system operations consider both planned and unplanned transmission line outages—hence, transmission lines carry more electric power from power stations to distribution lines during both demand loads.

2.2. Transmission line losses

The energy dissipated in the conductors and equipment used for transmission, transformation, and distribution of power causes losses in the technical lines. Generally, transmission lines are congested and mostly constrained-off during peak hours. For instance, this might result in a higher frequency of line losses and even blackouts during peak-load hours. When the transmission lines are under operation, energy losses during peak-load hours increase exponentially as power lines become heavily loaded in these hours. The line losses with the project are much lower than the losses occurring with the existing (unimproved) transmission line because of the lower electrical resistance of the new conductor.

The incidents of technical transmission line losses during both peak-load and off-peak-load hours decrease "with" the project scenario. However, these technical line losses are not static. Line losses increase because of the depreciation of the lines over time. As anticipated, the unimproved transmission line depreciates at a faster rate than that of the improved line. This adjustment prevents the overestimation of benefits from the rehabilitated transmission line. Therefore, the quantities of both off-peak-load energy and peak-load energy delivered change over time at the same quantities of energy generated "with" and "without" the project, considering the changes in transmission line reliability indicators.

3. Identified benefits and valuation technique

The reductions in technical transmission line losses and the increase in transmission line availability are used to calculate the annual incremental energy transmissions. According to the nature of the rehabilitation projects, the analysis must compare the situation "with" the rehabilitation of the line with a business as a usual scenario where there is no rehabilitation (i.e., "without" project).

With the project, the load-serving capability from generation to delivery will increase by improving the efficiency of the transmission system. The project offers the following benefits: (1) incremental energy transmission by reducing transmission line losses at a higher transmission line availability and (2) additional power delivered by the enhanced transmission capacity.

3.1. Assumptions underlying the benefits

This section provides a concise and precise description of the assumptions underlying the estimated benefits.

3.1.1. Supply of electricity

In this study, the existing hydro plant with a given firm capacity, for example, 50 MW, is considered as the energy production technology connected to the (unimproved) transmission line. The available spare capacity of the existing (unimproved) transmission line would allow the electric utility to expand the generation capacity, for example, by an additional amount of 20 MW (i.e. total generation capacity at 70 MW). The electric utility is able to expand generation by adding an additional 10 MW hydrogeneration capacity into the grid because of the expansion of the transmission line capacity "with" the project.

The electricity generation from either the 50 MW existing hydro plant or the 20 MW planned hydro capacity will not change "with" the project. The amount of electricity transmitted from the same levels of electricity generation will increase in both load hours, however. The calculations of incremental peak and off-peak energy supplied from these hydrogeneration capacities are based on reliability parameters used "with" and "without" the project. The incremental benefits from the additional 10 MW generation capacity, in the form of the net additional energy flow in the transmission line, depend on line availability and line losses of the improved transmission system.

3.1.2. Demand for electricity

The total firm generation capacity of the network is assumed to be sufficient to meet the current off-peak energy demand, and future investments elsewhere in the generation will cover the need for off-peak energy demand over time.

On the other hand, the total firm generation capacity is insufficient to meet the current peak energy demand. It is assumed that the electricity consumers will purchase all incremental peak-load energy delivered by the electric utility. This is a reasonable assumption because