21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2013 Grid of the Future Symposium

Deploying Power Flow Control to Improve the Flexibility of Utilities Subject to Rate Freezes and Other Regulatory Restrictions

S. RAMSAY, J. COUILLARD, J. MELCHER, C. THOMAS, F. KREIKEBAUM[1]
Smart Wire Grid, Inc.
US

SUMMARY

The U.S. electric power sector is undergoing changes in generation type, generation location, environmental regulations, and load patterns. These uncertainties not only increase the hurdle rate for investment in new infrastructure, prioritizing projects with short payback periods, they also increase the need for flexibility in the infrastructure already implemented. At the same time, utilities in 19 states are facing a combination of revenue decoupling, rate indexation, or rate freezes. In these states, utilities have an acute incentive to deploy solutions with short payback periods.

This paper demonstrates the potential for power flow control to reduce congestion and increase asset utilization of a test system within a short payback period. The analysis consists of a cost-benefit analysis based on the costs of the power flow controllers and the reduced power system production costs. Power system production costs are computed using a multi-period simulation.

KEYWORDS

Revenue decoupling
Rate indexation
Rate freeze
Power flow control
Optimal power flow
Production cost
Congestion
Transmission

---

[1] frank.kreikebaum@smartwiregrid.com

INTRODUCTION

Investor-owned utilities (IOUs) in at least 19 states face some combination of revenue decoupling, rate indexation, or rate freeze, creating the potential for the impacted IOUs to improve asset utilization and reduce costs [1] by increasing operating flexibility. However, given the uncertainty of the electric sector and the frequent update of ratecases, a project to improve utility flexibility is more likely to be implemented if the payback period is short.

A number of technologies exist to increase flexibility and reduce costs. This paper focuses on power flow control, as it is emerging as a viable solution following the development of new, reliable, and cost effective power flow controllers. Only congestion reduction is quantified in the analysis. Power flow control may have other benefits, which can reduce costs, or improve reliability and system security.

METHODOLOGY

For demonstration purposes, a three-bus, two-generator system was setup. The system is simulated under two cases, one with power flow controllers and one without power flow controllers.

The peak bus loadings are 100, 500, and 100 MW for Buses 1, 2 and 3 respectively, with Bus 2 corresponding to the load center. Hourly loads were assigned for two weeks using data from the IEEE 24 Bus Reliability Test System (RTS) [2]. Specifically, the week containing the annual hourly minimum load as well as the week containing the annual hourly maximum load were selected. Peak loads were mapped to hourly loads using the relationships between hourly loads and peak loads as defined in the RTS. Reactive power loads were adjusted to maintain a power factor of 0.9 lagging at all buses and at all time steps. A total of 336 hourly time steps were simulated.

The system is supplied by two generators, a legacy coal plant remote from the load center at Bus 1 and a new open-cycle gas turbine (OCGT) at Bus 2. The generator variable costs are modelled using linear heat rates and O&M costs representative of these plant types and vintages [3,4,5]. Fuel costs are EIA projections for US electric-sector costs for 2014-2023 [6,7]. The resulting variable costs for the coal and gas plant are $29.86/MWh and $64.56/MWh respectively.

The system is solved with an AC optimal power flow (ACOPF) algorithm. The algorithm minimizes the production cost for each hour by dispatching generator output to operate within system limits. System limits include branch flows ratings, minimum and maximum voltage limits, power balance at each bus, and constraints on generator power levels. For the case with power flow controllers, the OPF dispatches both the generators and the power flow controllers.

Distributed series Reactors (DSRs) are the implemented power flow controller, with a rating of 47 μH per DSR. DSRs are faster to deploy than other solutions, such as switchable air core reactors. They also require no substation space or permitting, reducing project lead-time and project cost. Each DSR is bi-modal, injecting 47 μH in series with the line when dispatched or a negligible inductance when not dispatched. If one DSR is deployed per phase per mile on a typical 138 kV line, the line impedance can be controlled between 100% and 102% of the natural line impedance. Additional DSRs can be added to increase the control range. The power flow controllers were sited by manual inspection on the second branch connecting Bus 2 and Bus 3. The number of power flow controllers was determined iteratively to maximize the production cost savings.

The annualized production costs are generated by scaling the two-week production costs.

RESULTS

For each case, the simulation time was less than 10 s or less than 30 ms per time step. Figure 1 shows operation of the system at peak load without power flow controllers. Figure 2 shows the operation of the system at peak load with power flow controllers. Both figures display the locational marginal price (LMP) of each bus. The contour map displays the gradient of LMPs across the system. Figure 3 shows the legend for the contour maps. Total production cost is displayed in terms of $/hr. In Figure 2, the icon on the second circuit connecting Bus 2 to Bus 3 represents the utilization of the DSRs. The numerical values adjacent to the icon indicate the number of installed DSRs per phase and the number of dispatched DSRs per phase. Note that the output of the high-cost generator at Bus 2 is decreased in the case with power flow controllers, resulting in a lower system production cost.

The resulting annualized operation costs are displayed in Table 1.

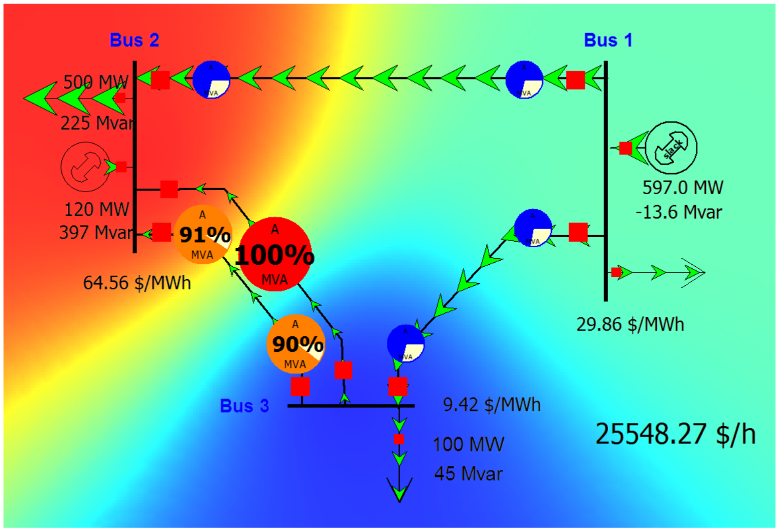

Figure 1 : Dispatch at the annual peak load hour for the case without power flow controllers

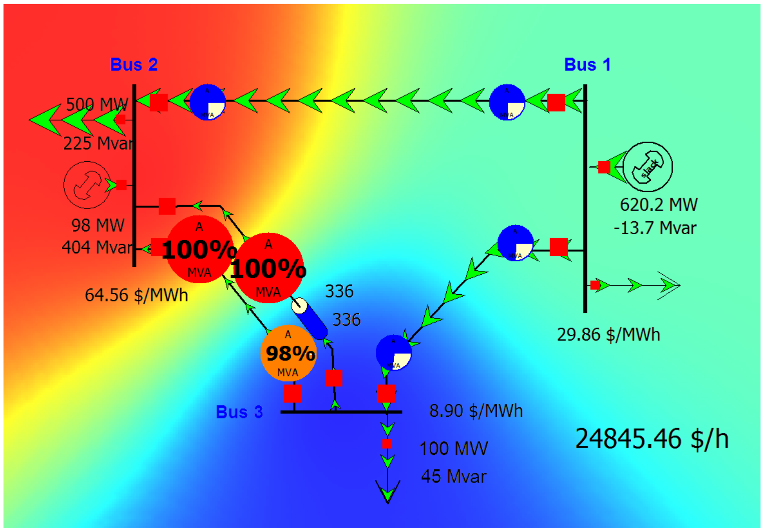

Figure 2 : Dispatch at the annual peak load hour for the case with power flow controllers

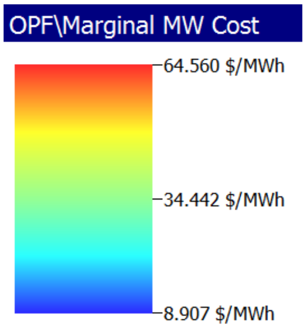

Figure 3 : Legend for the LMP contour maps

Table 1 : Annual production costs for both cases

Case	Annual Production Cost	Annual Production Cost Savings Relative to the Case w/o Power Flow Controllers	
	$M	$M	Percentage
Without Power Flow Controllers	125.12	0	0
With Power Flow Controllers	123.68	1.44	1.15

A cost-benefit analysis was performed based on the annual production cost savings. The analysis evaluated benefits over the 20 year life of the power flow controllers assuming inflation of 2% per year and a discount rate of 10% per year. Load and generation were considered unchanged over the analysis period. The overall benefit-to-cost ratio is 3.07. Discounted benefits exceed discounted costs in year four of the project.

DISCUSSION

Fuel prices, economic growth rates, environmental regulations, and regulation increase the uncertainty of investments in the US electric sector. As such, projects with low benefit-to-cost ratios or long payback periods may be difficult to realize. Given the uncertainty, some

ISOs and RTOs use a 5-10 year period to evaluate economic projects. At the same time, the ability of some utilities to deploy capital is limited, given revenue decoupling, rate indexation, and rate freezes. Solutions that are both quick to deploy and have short payback periods allow utilities to realize projects to reduce congestion, thereby reducing consumer cost.

Over time, congestion problems may become reliability problems. In the demonstration system, if loading increases without a corresponding increase in local generation capacity, the power flow control solution will decrease the amount of investment required to maintain reliability. These reliability benefits were not accounted for in the analysis.

Further, because of the uncertainties, the flexibility to increase asset utilization even after a project is implemented may provide benefits. For example, an existing generation resource may be shut down or a new resource may be added in a location that was not anticipated when investment decisions were made. The DSR fleet can be controlled to accommodate resource changes or be moved to a location of greater need. These benefits were also not accounted for in the analysis.

CONCLUSIONS

Utilities are facing increased uncertainty and regulatory challenges. This paper has demonstrated that a solution including power flow control can provide a short payback period. Such solutions can improve the flexibility of utilities subject to revenue decoupling, rate indexation, or rate freezes.

ACKNOWLEDGEMENTS

Smart Wire Grid thanks the members of the Smart Wire Focus Initiative (Southern Company, Tennessee Valley Authority, Baltimore Gas and Electric, and NRECA), the Georgia Institute of Technology, NEETRAC, and ARPA-E for their support of the DSR technology.

BIBLIOGRAPHY

[1] EEI “Alternative Regulation for Evolving Utility Challenges: An Updated Survey,” January 2013.

[2] IEEE Reliability Test System Task Force of the Application of Probability Methods Subcommittee, “The IEEE Reliability Test System-1996” (IEEE Transactions on Power Systems Vol. 14 No. 3, 1999)

[3] DOE "Assumptions to the Annual Energy Outlook 2012," 2012, Available: http://www.eia.gov/forecasts/aeo/assumptions/pdf/0554(2012).pdf.

[4] Brattle Group, CH2M Hill "Cost of New Entry Estimates for Combustion-Turbine and Combined-Cycle Plants in PJM," Available: http://www.brattle.com/_documents/UploadLibrary/Upload971.pdf.

[5] EPA "eGRID2012," 2012, 2012, Available: http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2012V1_0_year09_DATA.xls.

[6] EIA "Annual Energy Outlook 2012: Natural Gas Supply, Disposition, and Prices, Reference case," 2012, Available: http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2012&subject=8-AEO2012&table=13-AEO2012&region=0-0&cases=ref2012-d020112c.

[7] EIA "Annual Energy Outlook 2012: Coal Supply, Disposition, and Prices, Reference case," 2012, Available: http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2012&subject=7-AEO2012&table=15-AEO2012&region=0-0&cases=ref2012-d020112c.