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Impact of optimal controls in a microgrid

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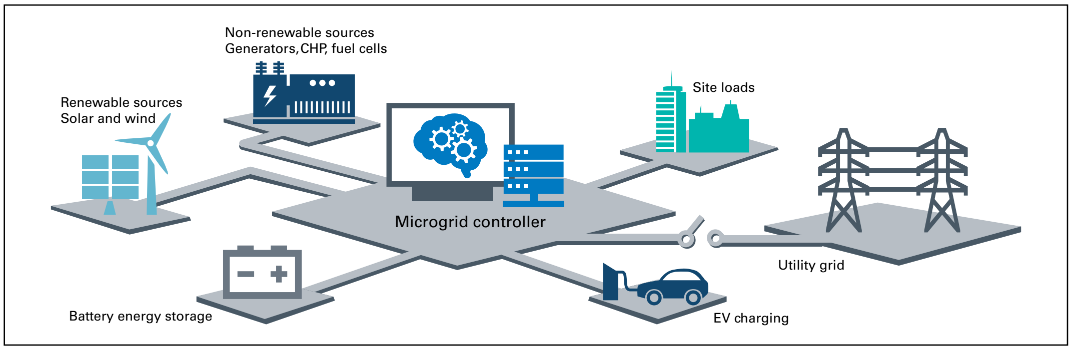

Figure 1. A typical C&I microgrid installation

Introduction

Microgrids are being widely deployed by electrical utilities, commercial and industrial (C&I) establishments, and the military due to their economic, environmental, and resiliency benefits. The U.S. Department of Energy defines a microgrid as an interconnected system of loads and distributed energy resources within a specified geographical and electrical boundary. A microgrid installation helps C&I establishments reduce their electricity costs, meet their carbon emission targets, and deliver a high degree of resiliency. A typical C&I microgrid is shown in **Figure 1**.

A typical C&I microgrid consists of renewables such as solar photovoltaic (PV) and wind energy plants, as well as conventional generation sources and battery energy storage systems (BESS). The C&I microgrid predominantly operates in grid-connected mode wherein it supports the facility load through renewables and BESS in conjunction with the electrical utility. In case of a utility outage, the microgrid islands itself from the main grid and supports the load through renewables and BESS in conjunction with conventional sources.

To achieve the aforementioned benefits, proper planning and operation of a microgrid is essential. A microgrid controller such as Eaton's Power Xpert Energy Optimizer™ is the brain of the microgrid system that enables efficient microgrid control.

In a grid connected mode, the objective of microgrid operation is to maximize renewable power and enable participation in behind-the-meter (BTM) applications such as peak shaving, energy arbitrage, and ancillary services. Such an operation results in reduction of electricity cost to the C&I facility. In an islanded mode of operation, the objective is to meet the resiliency targets while minimizing operation cost.

Microgrid control strategies

The control algorithms inside the microgrid controller are what enables the microgrid operation objectives to be achieved. Popular control techniques include rule-based (RB) and optimal dispatch (OD) algorithms. The RB algorithms operate a microgrid based on expert rules defined by per-site operating objectives. These algorithms are typically deployed using Eaton's Substation Modernization Platform (SMP) series of controllers (SG-4250/4260 and SMP 4/DP). RB algorithms are site-specific and unique for each site. RB algorithms need real-time feedback of system operating conditions, such as metered active and reactive powers of each asset, BESS state of charge, solar irradiation levels, and DER fault states, etc.

In comparison, the OD algorithms are standard optimization-based algorithms typically deployed using a cloud or computer system such as Eaton's SMP SC-2200. These algorithms incorporate the control objective functions and operational constraints. The mathematical model of different DER assets are incorporated along with the overall optimization framework that captures the modeling of the entire problem with the objectives and constraints.

The OD algorithms take the inputs of load and renewable forecasts, along with a feedback of system operating conditions, and generate a dispatch schedule for the defined time interval horizon. In general, OD algorithms are robust and more effective as compared to RB algorithms to achieve the microgrid control objectives, but OD algorithms have more computational and input data requirements.

Hardware-in-Loop (HIL) testing of microgrid control strategies

Before deployment on a field microgrid, it is imperative to perform detailed and thorough testing of the control strategies. A setup consisting of commercial HIL systems such as Typhoon HIL along with a real microgrid controller provides a convenient way of testing microgrid control strategies. Such testing is also referred to as Controller Hardware in Loop testing (C-HIL). The IEEE® 2030.8-2018 Standard for the Testing of Microgrid Controllers recommends C-HIL as an appropriate method for testing microgrid controller dispatch functionality. **Figure 2** shows such a C-HIL setup.

This setup is comprised of a Typhoon HIL system that is used to model microgrid loads and DERs, along with Eaton's SMP SG-4250 controller and SC-2200 computer. Communication between the Typhoon HIL, SG-4250, and SC-2200 is accomplished via Modbus® over TCP protocol. A computer system is also included to monitor and control the simulation process. The computer system communicates with the rest of the setup hardware through Ethernet.

Impact of control strategies on the microgrid

The control strategies are designed to meet the primary objective of the microgrid. The objective can be economic, resilience, and sustainability based. This section elaborates on the impact of control strategies for each of these objectives.

Economic objective

Eaton has installed a microgrid at its industrial manufacturing facility in Wadeville, South Africa. This microgrid consists of a 200 kW PV plant and a 275 kW, 200 kWh Li-ion-based Eaton xStorage BESS. This industrial microgrid is simulated in the HIL setup in **Figure 2** and controlled with the objective of reducing electricity cost. Three control strategies are evaluated:

- Rudimentary control: The output of the PV plant is maximized to meet the facility load without back feeding to the utility. The BESS is used to store excess PV generation during low load periods.
- Rule-based control: The PV+BESS combination is used to perform BTM applications such as peak shaving, energy arbitrage, and excess PV recovery based on fixed rules.
- Optimal economic dispatch: The PV+BESS is controlled using the OD strategy described above to optimally derive the economic benefits and minimize electricity costs.

The monthly electricity cost savings and payback period are estimated considering deployment of each of these strategies. The electricity cost savings are delivered by peak shaving, energy arbitrage, and excess PV storage applications. The savings are calculated considering a base case in which the entire facility load is served by electricity from a distribution utility. The payback period is calculated by dividing typical CapEX investments needed with the estimated annual savings possible.

The simulation results are shown in **Figure 3** and **Figure 4**.

RB control strategy would improve monthly savings by 8% over rudimentary controls and OD strategy would provide an additional 5% savings over RB control savings. This would result in payback period improvement by one year over rudimentary controls in this case. The overall savings that could be achieved through optimal controls depends on multiple factors such as the tariff structure, DER size, load, PV profile of the site, and any other policy-based incentive schemes applicable to that geographic location.

OD control strategies require load and renewables forecast for the selected prediction horizon. Typical forecasting algorithms have errors in the predicted values, thereby necessitating their inclusion while performing economic analysis. Considering 10% error in load and PV forecast, the monthly savings are typically expected to reduce by 5–10%.

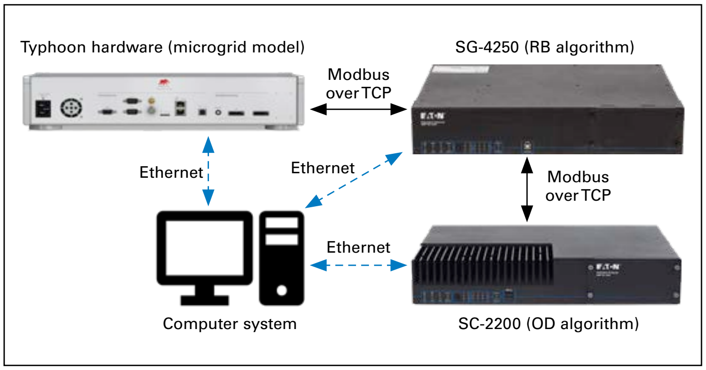

Figure 2. C-HIL setup for testing the microgrid control strategies

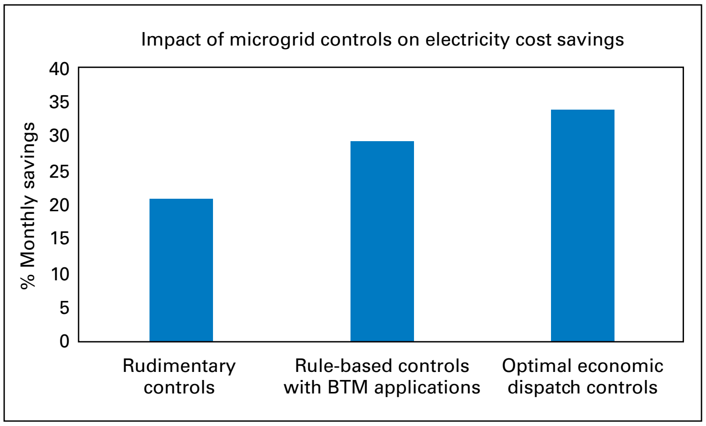

Figure 3. Impact of control strategies on monthly savings

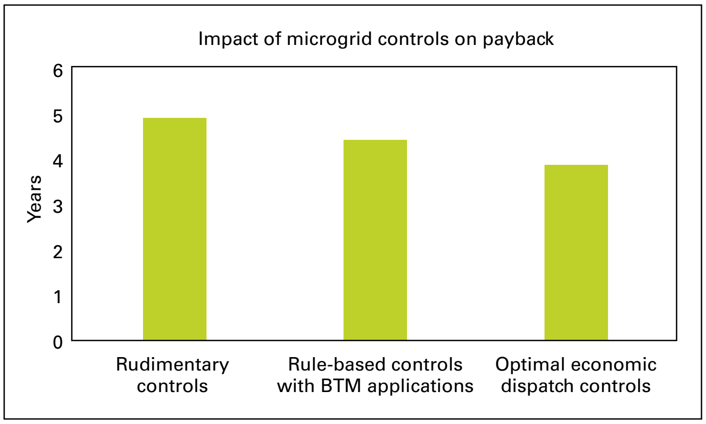

Figure 4. Impact of control strategies on payback period

The RB and OD control strategies were deployed in the actual field microgrid and the operation is shown in **Figure 5**.

The optimal peak shave limit is set at 260 kW and it can be observed that the BESS is discharged when the net load of the microgrid exceeds this limit. The BESS is also used to perform energy arbitrage during high tariff hours in the morning and evening. The BESS is charged during off-peak night and afternoon hours. The OD dispatch judiciously uses BESS while maximizing PV to avoid excessive degradation of BESS and can perform the economic objectives of peak shaving and energy arbitrage.

Resilience objective

Another example where OD control results in significant performance improvement is a microgrid that Eaton installed at one of its critical infrastructure facility customers. This microgrid consists of PV, BESS, and diesel generator and it is to be operated for an extended duration of time in off-grid mode.

Some of the challenges in this microgrid operation include:

- Operating the microgrid in islanded mode for extended duration of time (>7 days) without any grid support
- Ensuring continuous availability of power for the loads during all times of the year
- Presence of a heater load with on-off controls
- Maintaining system voltage and frequency within limits.
- The diesel generator is to be out of service for maintenance every 450 hours resulting in planned outages

The benefit of OD controls over RB controls is shown in **Figure 6**. The OD control effectively manages the system and ensures power availability, even when the diesel generator requires a maintenance outage, whereas RB controls may result in loss of some critical load.

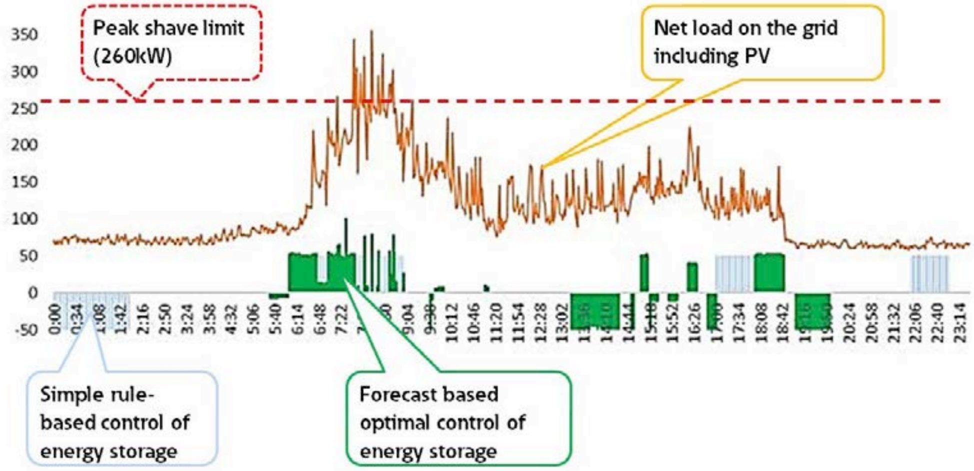

Figure 5. Field results of OD and RB controls deployment at Wadeville

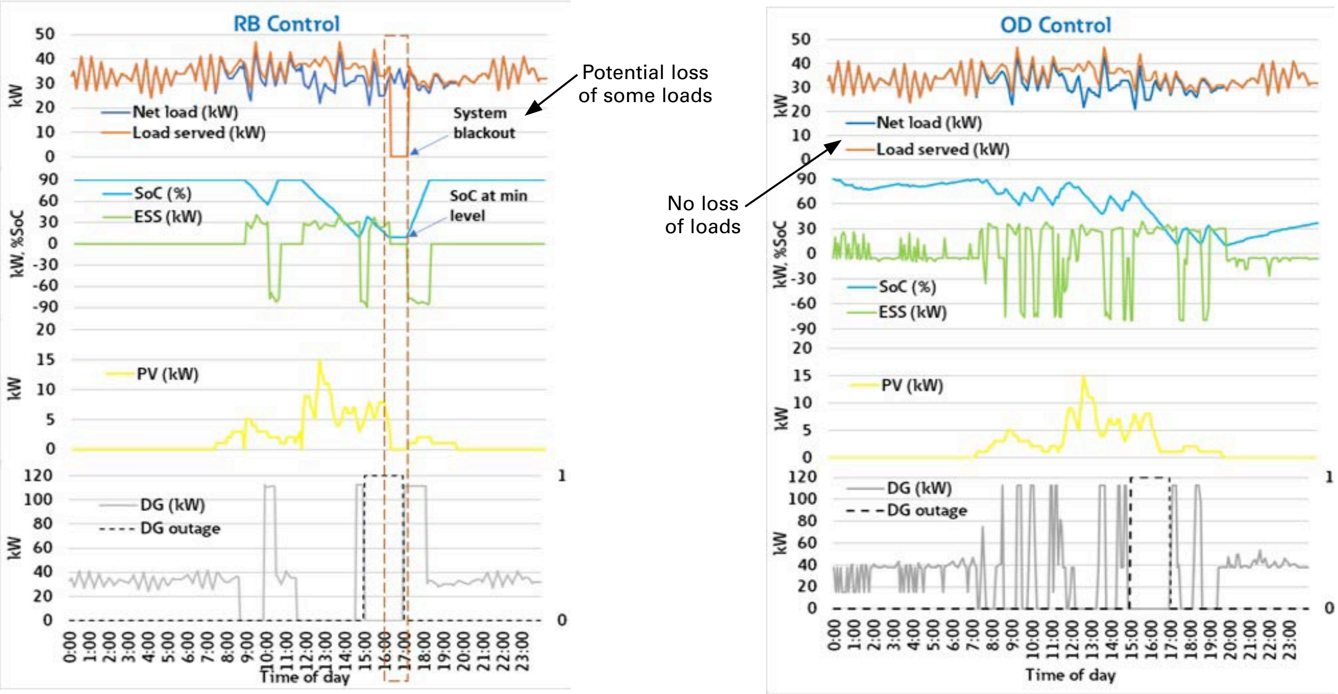

Figure 6. OD vs. RB controls comparison for microgrid in off-grid mode

Sustainability objective

Sustainability has become an important operating objective in C&I facilities. Microgrids help to achieve sustainability objectives through maximization of renewable utilization and taking advantage of marginal emission rates. One such example is a microgrid proposed by Eaton for one of its utility customers in the Western U.S. The operation objective of this microgrid is to minimize the carbon emissions from the facility based on the marginal emission rates. The microgrid consists of a 30 kW PV plant, 120 kW, 336 kWh BESS, and controllable loads. Eaton developed an OD solution along with a load-shedding scheme to minimize carbon emissions at this site. The software simulated carbon emissions reduction for various months in a year as shown in **Figure 7**.

Through an OD solution, the monthly average carbon emission reductions are expected to be reduced by 43% in a scenario with perfect load and PV forecast, as compared to a base case where the entire load is served by the electrical utility. When a forecast error of 30% is considered in the analysis, the carbon emissions are expected to be reduced by 41% as compared to a base case where the entire load is served by the electrical utility alone.

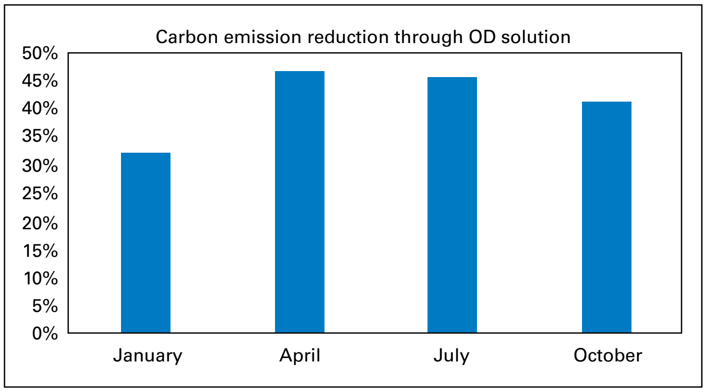

Figure 7. Carbon emissions reduction from OD algorithm

Conclusion

This white paper presents control techniques adopted for microgrid controls, namely OD and RB, and illustrates the overall impact of different control strategies on the optimal control objective. The OD control typically resides at a tertiary control layer, and the RB algorithms will form the secondary control layer followed by real-time controls. The OD control strategy is developed and applied to different use cases and the overall impact of the dispatch algorithms and their sensitivity to system forecast errors is presented. Although the OD control strategy is robust, spanning into different time horizons to capture uncertainties sufficiently to provide an optimal performance to meet different objectives, the value really depends on multiple parameters such as load variations, DER asset capacity, utility tariff structure, frequency of utility outages, and opportunity costs associated with it. The percentage savings obtained in each of the use cases presented is unique to the assumed system conditions and cannot be generalized for any system representing that particular use case.

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