Fuel Consumption and Emissions Reduction through Advanced Microgrids Control System

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***Abstract* – Efficiency is what matters today. First microgrid installations had to prove the technical feasibility of the combination of various energy resources. That being done a while ago, the next generation of microgrids, which puts much higher demands on the site efficiency, reduction of fuel and emissions, is coming of age and advanced smart microgrids control is a must in performance optimization.**

Maximized output of the renewable energy resources and accordingly optimized regulation of the diesel gen-sets operation, while maintaining the safety and reliability of power supply, is a common practice these days. Nevertheless, fuel and emissions reduction require more complex approach and algorithms. Consideration of the real gen-sets fuel consumption curves in the microgrid control scheme increases the gen-sets operation efficiency and maximizes the diesel savings leading to reduction as a matter of fact. However, how significant the difference can be?

Keywords - microgrids, hybrid microgrids, control system, diesel gen-set, renewable energy resources, Dynamic Spinning Reserve, fuel consumption, emissions production, efficiency

I. Introduction

Hybrid microgrids, which consist of more than two different energy resources, one of them being renewable energy resource and the other conventional energy resource, for instance grid or diesel gen-set(s), became mainstream of late. They are reliable, can be operated independently on the rest of the power system, thus providing power supply security, and in addition, they can relatively easily incorporate quite a large portion of renewable energy without a negative impact on the grid stability.

Therefore, they are considered the future power system. Nevertheless, there is surely much more than the ability to run various power resources in parallel.

To reflect current trends, also microgrids require optimization, such as reduction of fossil fuel consumption and the amount of produced harmful emissions.

Simulations and mathematical models must be used for analysis of the microgrid conditions based on which the control system should be designed, but can neural networks, load and weather predictions and high-power BESS (Battery Energy Storage System) used for peak shaving increase the efficiency even more? Or shall we rather focus on the energy consumption leverage?

This paper discusses and compares various optimization tools with respect to the improvement of a microgrid control efficiency and presents results from case studies which were subject to the control algorithms optimization.

II. Fuel consumption

Fuel consumption has always been a subject matter in the operation of diesel-only sites, as the operational costs for the fuel are often a major part of the overall expenses of the site operation. But it is not only about the costs. Independence on a fuel supply, protection against power cuts due to severe weather conditions or mitigation of future price increase of on-grid electricity are the other attributes which are in favor of microgrids. However, efficiency, which is often related to minimum fuel consumption, could be perceived contradictory to a reliability. It is a widely spread bias that spinning reserve must be equal to the actual power output from the renewable energy resources. This assumption is by no means valid if a microgrid is correctly designed (meaning that the rated power of individual resources is designed according to the load profile, which has been measured over a few months, and the features that individual resources offer) and the control algorithm is customized to the site, considering the conditions of gen-sets. One solution that would fit all types of applications is just a compromise and would never provide maximum efficiency of the site operation, therefore only a good knowledge of the working conditions on a site and fit-to-purpose design of control mechanism can ensure the highest yields.

The Dynamic Spinning Reserve (DSR) which contributes severely to the overall consumption can be significantly minimized by various means, as explained below

A. Advanced Power Management

Gen-set fuel consumption is influenced by several factors – it is not only about their rated capacity and loading level, but there are other influences, external as well as internal - their age, running hours and operational history (loading) which have an impact on their ability to start, and the readiness to pick up load. In addition, altitude, temperature, and quality of fuel plays a role which cannot be neglected, too.

Optimized genset control must take into account the optimum loading level (acc.to the state of the art it´s around 85% of its nominal installed power and it is a level at which the fuel consumption is the lowest per kW generated), but also a real fuel consumption measured in real time, which can differ from the declared fuel consumption curves. The real values can be provided by the Engine Control Unit (ECU) and must be processed and evaluated in the gen-set control system. Regular power management does not take into account the real consumption and that is, where the approach differs.

According to ComAp a.s.´s simulations, site dispatch that incorporates real-time consumption values can save additional 5% of fuel compared to standard power management which does not evaluate real-time values.

B. Load and weather predictions

Frequent starts and stops have eminent impact on the gen-set wear and tear, they shorten maintenance periods and are energy demanding – heating and cooling of the gensets also contribute to the increase of the fuel consumption. Therefore, long-term history records of site load profiles should be evaluated, and the control mechanism should reflect them in the control algorithm. In addition, should the local weather forecast (from 15 min to 24 hours) be available, the control logic should reflect it too and work with the gen-sets dispatch in a way that avoids frequent starts and stops, but at the same time avoids longer loading dips leading to underloading and peaks leading to overloading which would harm the gen-sets.

Neural networks or other forms of artificial intelligence have an important contribution to the algorithm optimization as it improves the control dispatch over time and smooths the loading curves of the gen-sets, and so reduces the fuel consumption.

C. Utilization of a high-power Battery Energy Storage System (BESS)

Utilization of a high-power BESS in hybrid microgrids may significantly contribute to the fuel consumption reduction as it enables covering of the surplus or shortage of power during load drops or peaks and thus avoids unnecessary start or stop of a gen-set. There are several conditions that must be considered in the design of control algorithm, such as the rated capacity, State of Charge (SOC), remaining capacity, speed of power provision, etc.in order to use the storage as efficiently as possible. Even though BESS can significantly reduce the operation expenses, thorough economic analysis must be performed to prevent the high upfront investment to outweigh the benefits of the BESS installation. If the load fluctuations are not frequent, neither significant, and there is no additional charge for power peaks covered from the grid, the investment into BESS will not pay off.

The correct nominal capacity of the BESS is paramount to maintain the economic benefits – there are several software tools that enable the users to design the site according to the load profile and gen-sets present on the site.

III. EMISSIONS REDUCTION

The global initiatives towards significant reduction of the greenhouse gas emissions have an impact also on the hybrid microgrids. Stricter standards on the amount of emitted gases has been applied primarily on the diesel gen-sets, but environmental standards put on the microgrid as a whole can be anticipated very soon. The larger portion of renewable energy within a microgrid can certainly reduce the total amount of emitted gases, however in moments of renewable energy unavailability or due to high, non-optimized DSR, the gen-sets emissions production must not make up for the entire measured period.

Therefore, sustainable approach towards the gen-set emission production must be implemented also in the control algorithm design. ComAp a.s. has conducted extensive measurements of the emissions of diesel, gas and bi-fuel (combination of diesel and gas fuel) gen-sets operation of various rated power and at different load levels. The results revealed that the production of emissions is influenced by a number of factors – among a few can be named the condition of the gen-set, the amount of oxygen present in the combustion process, altitude of the site, quality of fuel, etc. The CO2 emissions, which are usually used as a benchmark to compare different pollutants should not, however, be considered as the only criterion as there are many other emissions which impose severe threath to health, such as NOx, SOx, PM, CO, HC, CH4, etc. The CO2 emissions pollution is linked directly to the amount of burnt fuel, hence the more loading of a gen-set is required, the more CO2 will be produced. At lower loading levels the CO2 is indeed lower, but the other emissions gain significance.

Natural gas, which is in some regions considered less harmful for the environment than diesel is in fact less fuel-efficient than the diesel gen-set, and on top of that, burning gas produces CH4 which is for the environment far worse than just CO2 itself. Gen-sets that must comply with the latest Tier standards are optimized on stable NOx production at all loading levels, but they are usually worse in the CO production which is usually associated with imperfect combustion. Fuel mixture of diesel and gas can decrease the amount of emitted NOX by 50%, but the CO2 increases significantly, up to three times.

IV. OPTIMIZATION OF THE MICROGRID CONTROL

Despite the requirement of late, on the reduction of fuel consumption as well as harmful emissions production, it is impracticable to design such a control algorithm which would reduce both. It is always a trade-off between these two requirements and microgrids operators usually need to choose the relevant requirement as per their region.

The requirements on isolated islands, which are fully dependent on the diesel supplies, call for minimum diesel consumption to decrease their dependence on external suppliers, but they are not disturbed by environmental restrictions on the amount of emissions production as there are usually none in place. Unlike cities in populated countries where limitations on emissions production are strict, but the pressure on diesel consumption reduction is not so significant.

ComAp a.s.has been working on a development of such Advanced Power Management that will dispatch the individual gen-sets according to their real fuel consumption or emissions produced. The input values can be measured on site and based on the evaluation; the control algorithm will be designed. The Advanced Power Management is an improved algorithm on top of the Load Demand Swapping control scheme which selects the optimum combination of gensets according to their rated power.

Customized control maximizes the genset lifetime, avoids unscheduled downtime, shortens maintenance intervals, ensure slow loading and soft unloading and optimize the number of starts to stops, all of which ensure reliability and power supply stability with the lowest operational costs. Load fluctuations have also a negative impact on the smoothness of the fuel consumption curve, as well as on the amount of emitted emissions, which is another variable that must be taken into account.

V. Case studies

ComAp a.s. has conducted simulations as well as real site testing to confirm the assumptions about the necessity to consider real-time values which might differ significantly from the datasheet values. Even though, it is a lengthy process to design such optimized control solution because the measurements should be conducted over a few months to reflect on seasonality, and the variables which play a role in the process are many, it is worth to spend the time on proper control algorithm creation, as the effort will pay off in the results of fuel consumption and emissions production. Especially on sites which run 24/7 and have different gen-sets types and rated power.

On sites with exactly the same gen-sets with equal rated power is the saving not significant, as the usual power management ensures optimum operation of the gen-sets, taking into account their running hours.

VI. Conclusion

Maximized yields from renewable energy resources is a must. The other, dispatchable resources must be controlled in a way that ensures accommodation of the higher renewable energy yields without negative impact on the stability and reliability of the site. That has been always the paramount criterion for hybrid microgrids when the costs and emissions optimization was not yet required, and the biggest challenge was the technical feasibility. But this has changed. Inefficient, even though working, hybrid microgrid is a subject of the past. Maximum usage of the renewable energy yield must be ensured. It is no more acceptable to oversize the renewable energy component on a site to increase the yields, and limit their actual output to prevent gen-sets from overloading, or to keep high DSR. Droop cannot be, by any means, considered appropriate approach to the hybrid microgrid control as it does not maximize the utilization of the renewable energy resources. It is very simple and easy to implement control solution, but it is surely not an efficient one.

Smart site design and consequent resources dispatch which maximizes the utilization of renewable energy while not jeopardizing the stability and reliability, and at the same reducing fuel consumption and emissions production, is only viable through thorough understanding of all the variables in the microgrid that matters.

In modern microgrids, DSR that would equal to the actual renewable energy output is a matter of past. Real-time collection of consumption and emissions data which is then used for a control mechanism design which can on top use artificial intelligence to learn and improve the control itself, is the matter of future.

References

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