GENERAC INDUSTRIAL POWER

WHITE PAPER

Rich Burn Generation in Today's Power Grid

BY NASH WHITNEY, DIRECTOR OF SALES
Generac Industrial Power

INTRODUCTION

Distributed generation is the future of the electric grid. The term, distributed generation, generally means it is distributed across the grid, rather than in centralized power plants. Why is this a good thing? This paper is intended to focus on the method and rationale for why distributed generation is important, efficient and economical for the safe and reliable operation of an electric grid, and what technologies are best positioned to support it.

LAYING THE GROUNDWORK

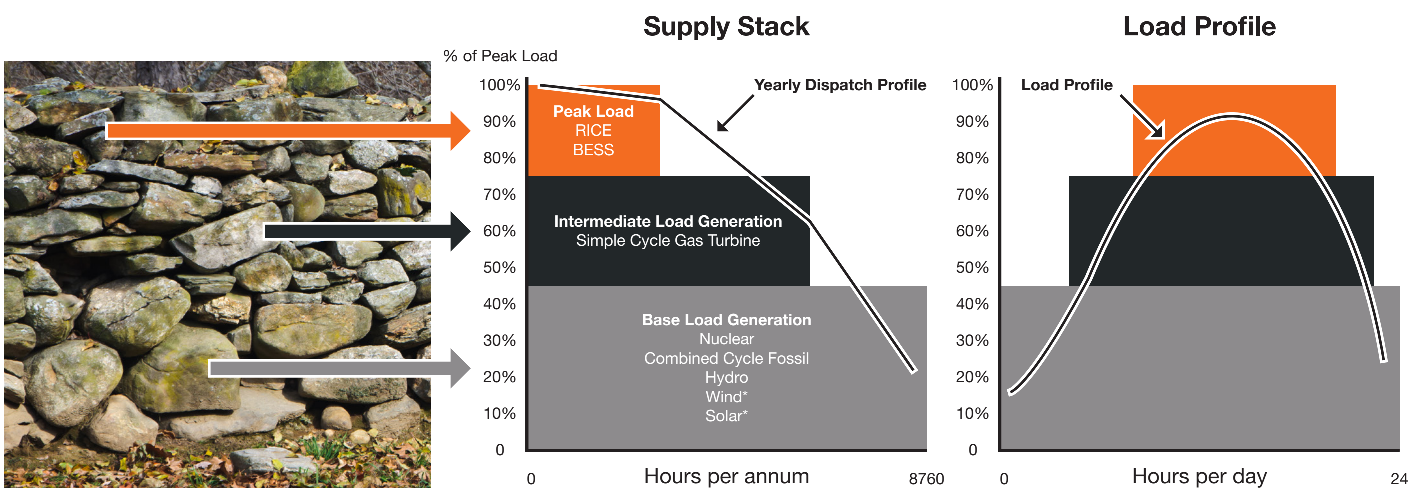
We start with a comparison of producing power on an electric grid to building a stone wall on a hill. The hill represents the collective demand of power, and the stone wall represents the generation required to meet that demand. The goal is to build a stone wall that as closely follows the contour of the hill as possible. If you build the wall too high in areas, and you have wasted stone and the labor to build it. Build it too low, and you risk the wall's integrity, or things jumping over the wall. The wall should be uniform, smooth and level across the entire hill.

When building, the largest stones are placed at the base of the wall, aligned and stacked, utilizing their natural shapes. These stones represent base-load generation, which is generating power approximately 60-90% of the time and is usually produced in blocks of hundreds of megawatts at a time. They account for the majority of the volume of the wall, and the foundation for the remainder of the wall to be built.

These stones are what enable the wall's profile to mirror the contour of the hill, and ensure that the wall is the appropriate height across its entire length, regardless of its location on the hill. These stones represent peak load and distributed generation. Distributed generation is able to shore up any gaps in the demand for electricity in the market, and is able to do it dynamically, with ever changing ratios of electric production and its demand. If you take a cross section of our completed wall, which is comprised of large base-load generation stones, medium intermediate generation stones, and small-distributed generation stones, this represents what is termed a supply stack, or the quantity and corresponding level of different generation assets that are available to serve a grid's demand.

Hopefully, this story paints somewhat of a clear, simplistic picture of the difference in generation types in our electric grid as it exists today.

Figure 1.



Source: Marsden Jacob Associates' analysis (2011)

The next layer is comprised of slightly smaller stones that are stacked on top of the larger ones, enabling the wall's contour and profile to begin to take shape. These stones represent intermediate generation, or power that is produced about half of the time; or when the demand for power exceeds the capacity of base-load generation. This happens on a daily basis, mostly during daylight hours. Pausing for a few moments, we see that our wall and its two layers of stone have somewhat of a jagged and lumpy shape. The profile of the wall is not yet smooth, and there are areas that must be filled in with yet smaller stones, ensuring that the wall is uniform on its face, and able to mirror the contour of the hill. The final layer of stones are much smaller than either our large base-load generations stones, or our medium intermediate generation stones, and are numerous in quantity. They are placed according to their size, so that they fill the space.

MARKET FUNDAMENTALS

Now transition from our stone wall to an electric grid. The electric grid's demand curve and corresponding supply stack realize that each point on the demand curve has a corresponding cost. This cost then determines the supply stack so that it satisfies each point. In other words there is a cost, comprised of base-load, intermediate load and distributed generation assets to produce power able to meet that demand.

In an ideal world, there would be an exact equivalency between the supply and demand for power. This would be an efficient allocation of available resources. However, there are gaps between supply and demand, and it is always a surplus. If it were a shortage, there would be rolling brownouts across the entire grid, as the supply of power would not satisfy the demand.

CONTINUED

This is the specific area of focus to understand distributed generation better along with its advantages. For every kilowatt-hour of power that is generated, but not used, there is a cost that doesn't have a corresponding revenue or sale. In economic terms, this is categorized as a deadweight loss to the producer, or an inefficient allocation of resources. This occurs because supply does not equal demand in quantity or price. The cost of this deadweight loss is carried across all generation types and is distributed to ratepayers on their bills, embedded in the levelized cost of electricity ($/kW-hr).

As a matter of regulation and oversight, there is a required supply margin for electric grids to maintain, ensuring that there is sufficient power left in reserves to account for spikes in demand and mitigate rolling outages. For purposes of this discussion, the combination of the real consumer demand and the required supply margin equals total demand for the system. The challenge is to as closely as technologically possible, mirror the dynamic changes in total demand with an efficient allocation of generation assets. In other words, to minimize the deadweight loss observed and reduce the costs associated with the oversupply of power.

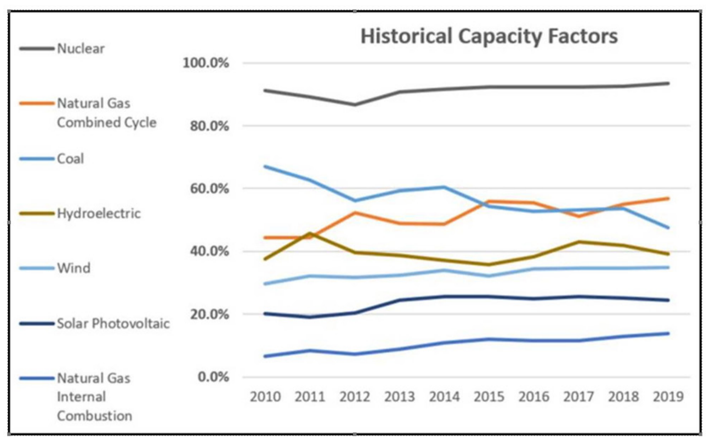
BALANCING CAPACITY

Thinking back to our allegory of the stone wall, if you used only large stones, your wall would be lumpy, jagged and not uniform. Although using more stones, the same could be said if you used only medium sized stones. If you were to use only small stones, you would be able to achieve the desired profile. In each scenario, the materials and labor required to build a wall with only a single type of stone would not be an efficient allocation of either labor or materials. The same can be said for organizing the supply stack of power. The ideal configuration is the appropriate use and placement of each type of generation, in a manner that equivalently reflects the true demand of the system. The method to determine what type of generation should be used and where it should be used is based on two key factors that are closely intertwined, the capacity factor and the levelized cost of electricity of each type of generation in the system.

The capacity factor is the ratio of the amount of generation produced from an asset divided by the total available generation it can produce, but more importantly, it represents the minimum threshold for a generation asset to be profitable. According to the EIA, in 2019 the capacity factor of nuclear plants is 92%, meaning that they are producing power at least 92% of the time they are capable of producing power while combined cycle gas turbines are about 55%. Internal combustion engines are approximately 13%. Similarly, the levelized cost of electricity (LCOE) is effectively the normalized value of generating electricity for each type of technology. This is comprised of fixed capital costs, fixed operating costs and variable operating costs, discounted over the life term of project. Technologies with higher capacity factors have lower LCOE's. Technologies with lower capacity factors have higher LCOE's. Each of these components integrate themselves into the market prices published across both regulated and deregulated markets. There are differences in how those prices manifest between the different market types, but the cost of generation is generally similar.

Another way to think about this is in terms of 'Merit Order'. Thinking back to Figure 1 that shows the % of peak load satisfied by different generation types: replace '% of peak load' with 'Price' in $/kW-h. The order of dispatch is based on the $/kW-h that can be achieved in the market. When prices go higher, more expensive generation technologies come online (higher prices are able to cover their higher operating costs). Of course, this metric can become incredibly complicated through factoring in the cost of externalities, moving commodity prices, and congestion and transmission charges that can affect the clearing price of electricity, but this concept should enable the reader to better understand the role that different categories of generation play with respect to the prices they can capture in the market, and the costs they incur to create electricity. The reason that this paper is focused on distributed generation is that this segment of the

Figure 2: **EIA Capacity Factor Data for Last 10 Years**



supply stack is not only the mortar that will hold the next generation of electric grid together, but it is the most efficient and the lowest cost method for reducing the gap between the dynamic changes in demand and the lumpy response of supply. This is best illustrated by trying to use a large stone to fill a small gap in our stone wall. It can be done, but the result again is an inefficient allocation of resources; working to fit a bulky object into a small opening requires additional labor and additional tools that are not necessary when compared to using small stones. This is identical to picking the wrong type of technology from Figure 2 to fill a small gap in supply and demand. If for instance there is a relative shortage of 20 MW of electricity predicted for this afternoon, a combined cycle power plant with a capacity factor of 55% and a nameplate generation of 60 MW will be much more expensive than utilizing ten 2 MW internal combustion, distributed generation, engine plants. For a combined cycle power plant to operate at 1/3 capacity, the plant must derate its output. When any plant derates its output, it operates at a less efficient operating point. This means that the variable operational costs spike and the levelized cost of electricity is much higher. This cost is distributed to the ratepayers resulting in expensive electricity bills.

The alternative is using technology that is less prone to derating due to fact that the amount of power that it produces is lower. Although a distributed generation asset has a heat rate much higher than a combined cycle plant, the amount of derate and corresponding increase in the combined cycle plant's heat rate would exceed that of the distributed generation plant. The result of electing to use distributed generation over a derated combined cycle plant, or any other technology with a higher capacity factor, is that the cost of the specific quantity of electricity produced is much lower. Although ratepayers are still paying a premium when compared to the cost of base-load generation, the cost is still much lower than the alternative.

Finally, distributed generation's place in an electric market is dynamic. Distributed generation is a category of assets, it is not a program or an incentive passed on by utilities. As an asset, distributed generation can be used to fill gaps across the supply stack and price index, and its usability is defined by its operating profile and the risk its operators want to take. For instance, the use of distributed generation in demand response (DR) programs can be found across the country. Similarly, distributed generation assets can be used as peaking plants that generate based on market signals and an established strike price. They can be enrolled in grid services programs, used as remote power for oil and gas or used as captive call options leveraged by commodity suppliers working to hedge their futures position on electric contracts. The application of distributed generation is diverse, which underscores its importance in day-to-day grid operation.

A REVIEW OF RICE TECHNOLOGY

The technologies available in the lower, distributed generation portion of Figure 2 are numerous, but none more appropriate than internal combustion engines. Reciprocating internal combustion engine, or RICE technology dates back further than 120 years. The technology has continually evolved since its advent in the late 19th century, and has become resoundingly more robust and efficient. Within RICE technologies there are two primary segments, each with their own unique advantages. These technologies are rich burn and lean burn. Natural gas engines can be both rich burn and lean burn. Diesel engines are always lean burn. Rich burn means that an equivalent amount of fuel and air are combusted in the ignition cycle. Lean burn means that a far greater amount of air is used for the same amount of fuel. Rich burn engines produce more emissions at the engine outlet, but handle changes in load much more efficiently. Lean burn engines produce fewer emissions at the exhaust port, but are unable to handle load swings as effectively. The key difference between rich burn engines and lean burn engines is that rich burn engines have the ability to provide superior load following ability while also producing less net emissions. Rich burn engines are able to accomplish this due to the inclusion of non-selective catalysts in their exhaust systems. Non-selective catalysts are different from selective catalysts, which are required for lean-burn engines. They are less sophisticated, less expensive, and easier to maintain, as the chemistry of the catalyst is able to account for a broader range of exhaust constituents. This focus on emissions is important, as it is the greatest and most consistently encountered barrier for all fossil generation technologies that aim to participate in electric markets.

So comparing apples to apples, rich burn engines equipped with a non-selective catalyst have a lower capacity factor and LCOE than a lean burn engine with a selective catalyst. This means that they are cheaper to install, cheaper to operate, and are able to maintain profitability at a lower cost than lean burn.

THE CASE FOR RICH BURN RICE AS DISTRIBUTED GENERATION TECHNOLOGY

To tie this all together, let's start with a problem statement with a little more detail than the previous example of a 20 MW shortage being filled by a 60 MW combined cycle gas turbines plant.

Tomorrow is expected to be a record day for the projected heat index and an electric grid expects a 20 MW spike in demand during the peak period from 1 p.m. to 6 p.m. Calls to independent power producers within the system are made and spinning reserves are accounted for. All base-load and intermediate load generation are expected to be online and operating at full power, and peak efficiency, reducing the expected shortage to 5 MW. However, during the morning of an event, there is an unexpected outage at a combined cycle gas turbine facility that suddenly drops the active supply stack by 50 MW. The grid operators now have a 55 MW shortage and the system will be at risk of rolling outages to mitigate against a full system blackout. As a response, the grid operators notify all of the captive demand response participants that they should expect to curtail loads per contract. Consequently as a response, the wholesale real-time market prices for power start to ratchet higher, signaling peaking plants to be ready to start. About 30-minutes prior to the start of the 5-hour peak period, wholesale market prices spike to $350/MW-hr and lower LCOE peaking plants begin to ramp up. At 1 p.m., all demand response customers curtail contracted load, which puts slight downward pressure on real-time prices, however, they are still above the strike price that most peaking plants require to operate. At 4:30 p.m., demand exceeds the grid operator's expectations and wholesale real-time prices shoot up to $1500/MW-hr. As the prices climb, the strike price required for higher cost peaking plants is achieved and they also ramp to production. At 6 p.m. demand and consequent real-time prices begin to subside, slowly ratcheting downward the number of peaking plants that are online, as the market price begins to fall below the strike price for varying peaking plants, and the trend continues until the system is back under peak-demand conditions. Demand response participants have fulfilled their obligation, peaking plants have successfully achieved their generation targets and the system was spared from experiencing rolling outages or blackouts. To add complexity to this scenario also consider that, retailers also exercised their optionality on varying distributed generation plants to mitigate their own risk of procuring power at expensive real-time rates.

Every incremental change in capacity, whether a curtailment or a generation, has an effect on price, regardless of markets. It is important to consider and realize that the signals that prices provide to investors, private organizations, independent power producers and utilities indicate the types of generation and their corresponding costs that are needed, and which ones can provide the most cost-effective and efficient production of electricity.

CLOSING

The quality and quantity of power on the grid today indicates a substantial need for distributed generation. These examples paint only a limited picture of electric grid operation. Further amplifying these are the downward pressures on new conventional base-load fossil generation, barriers against new nuclear base-load, and the combination of incentives and pressure for cleaner renewables. Together, the trend of our electric grid's supply stack and the signals that price and policy are providing paint a landscape that only distributed generation, but specifically rich burn combustion engines can satisfy. This should not be considered a rebuke of the current trend of our electric ecosystem, but rather a chance to highlight technology that can provide safe, efficient power at rates that are not susceptible to renewable intermittency, or the costs of sophisticated electronics. Distributed generation is the spider silk that holds together the sophisticated web of system balancing, and can provide a resilient, reliable and environmentally friendly basis for continuing to build out the electric grid of tomorrow.

ABOUT THE AUTHOR

Joining Generac in May of 2019 and based out of Texas, Nash is the Director responsible for leading the Energy Management and Utilities team for Generac, developing new business across the country. Focusing on cultivating Demand Response and other Beyond Standby opportunities, Nash works to drive programmatic solutions for end customers, utilities, cooperatives and energy market participants. Nash is a graduate of Principia College with a B.S. in Physics and of Rice University with a Masters of Energy Economics.

Generac Power Systems, Inc.
S45 W29290 Hwy. 59, Waukesha, WI 53189 | 1-844-ASK-GNRC (1-888-275-4672) | 201903018

GENERACINDUSTRIALPOWER.COM