WHITE PAPER

by Hassan Obeid

Minimizing Fuel Consumption and Increasing Longevity for Paralleled Generator Sets

Reducing fuel consumption, maintenance cost, and generator set wear by controlling the power generation capacity to match load needs are attractive features to owners of prime and standby power systems. This paper discusses how such features can be attained at minimal cost while still maintaining the reliability of the power system.

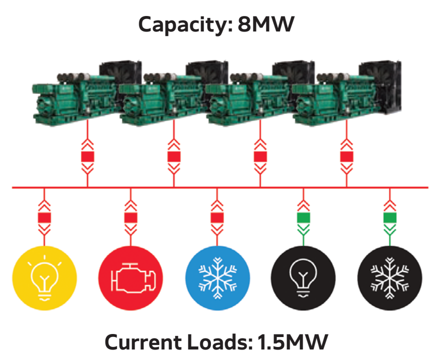

Figure 1. Capacity vs. loads

Generator sets are essential for providing backup power and prime power to both critical and non-critical loads. Depending on the size of the power system, the number of generator sets which can be paralleled together on single or multiple buses vary from a few units to dozens of units. Since this generating capacity varies, there are situations in which not all loads are connected to the system at any given time and the online power capacity is much greater than what the loads are demanding.

For example, if the system is comprised of multiple paralleled generator sets with a total capacity of 8 MW (2MW/generator set) and a total connected load of 1.5MW, Figure 1, then in this situation only one generator set is needed to power the loads while three generator sets can be shut off to reduce fuel consumption, engine runtime and wear and tear on the generator sets. Additionally, the operating unit(s) will be at a more efficient load level than if all the units were operating unnecessarily.

To match generation capacity as closely as possible to load consumption, a control algorithm needs to determine total load on the AC bus, available capacity of operating generator sets, and available capacity of non-operating generator sets. The algorithm processes this information and matches the generating capacity to the load requirement by starting/stopping generator sets to run the minimum number of generator sets required to operate the loads thereby running the generator sets more efficiently, conserving fuel, and prolonging the life expectancy of the generator sets. Another advantage of not running all the generator sets is the increased load factor on the connected sets thereby preventing the connected units from operating at lightly loaded conditions which causes wet stacking over time. In the example in Figure 1, if all the generator sets are operating with only 1.5MW of load, the generator sets would be 18% loaded.

The control algorithm can be referred to as load demand. In Figure 2, load demand stops three generator sets since the load is only 1.5MW and the generating capacity is 8MW. In this instance, the one operating generator set would be 75% loaded.

In some applications the user might want to trade fuel efficiency and decreased wear and tear for higher redundancy (N+1) to prevent exposure to failure of a single generator set. In this situation, the load demand algorithm allows the operator to create an N+1 or more configuration. For example, in Figure 3, two generator sets are running (N+1 configuration) to power the 1.5MW loads to provide redundancy and the operating generator sets would be approximately 37% loaded.

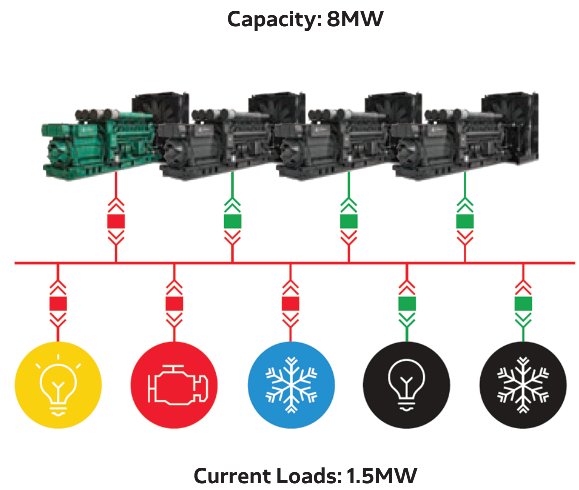

Figure 2. Load demand concept

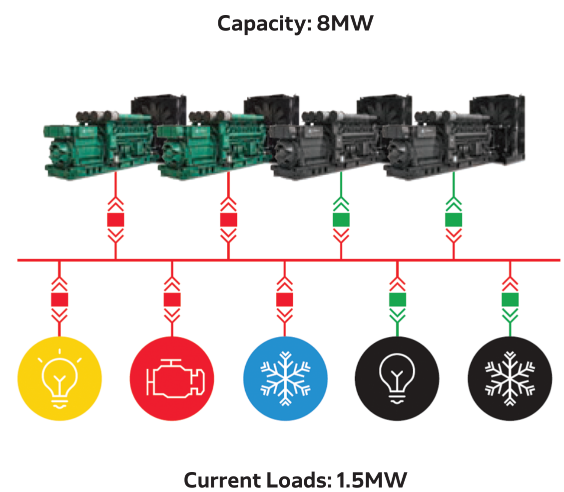

Figure 3. N+1 Configuration

LOAD DEMAND VERSUS LOAD CONTROL

Load demand is not the same as load control. Load demand refers to capacity management-simply put starting and stopping generator sets. Load control (or load add/shed) refers to load management connecting and disconnecting loads. Load add/shed is a load control algorithm which stages loads on to the power system after normal power to the loads has been interrupted. This staging of load ensures that power quality is maintained and generators do not become overloaded during the application of loads. In addition to the orderly addition of loads, the load control algorithm also monitors the generator sets, e.g. an under-frequency signal, and removes lower priority loads from the system if the generators become overloaded keeping the system and higher priority loads energized.

If load control is not available, the operator can have extra generator sets online to accommodate overloading conditions. The tradeoffs of this configuration are reduced fuel efficiency and increased wear and tear on the generator sets.

For the best possible load demand performance, the operator must have a good understanding of the load profile, load priorities, largest load steps, and specific site needs. Using this information, the operator then can optimize the load demand settings for best performance.

The load demand algorithm can either be implemented in a PLC-based master control or it can be an integral part to the generator set paralleling control. The latter may be referred to as Masterless Load Demand (MLD). Cummins offers load demand on both platforms: digital master and the PowerCommand autonomous microprocessor-based generator set control. Whether implanted in a PLC-based master or in a generator set control, load demand must always maintain the integrity of the power system:

- Upon system start, all generator sets must be started and brought online to verify their availability and ensure that all loads can be accommodated. Then load demand can trim the online capacity accordingly.
- If an overload condition is detected, then all generators sets must be brought back online as quickly as possible.
- The algorithm should automatically assign a low priority to a set with an active fault even if the set was next in line in the startup sequence.
- Load demand settings should be adjustable while the system is operating without compromising system integrity.
- If a shutdown condition takes down a generator set that is running, then all other sets in the system should start immediately.
- Allow for redundancy configuration: N+1, N+2, N+n, etc.

HANDLING LARGE LOAD STEPS

In some applications there might be a need to step very large loads such as single loads that are rated 25% or higher of the rating of a single generator set and the owner/ operator may still want to optimize fuel efficiency and reduce wear and tear without jeopardizing the reliability of the system. This can be accomplished in two ways. One straightforward method is to have more generator sets connected on the bus so that the large block of load can always be picked up.

However, this scenario can compromise fuel efficiency. A sophisticated way of optimizing fuel efficiency and reducing wear and tear is to have a load anticipation input in the control system that is activated just before the load is to come on. This will cause the algorithm to decide whether or not more generator sets should be brought on first then the control system sends a signal back to the load when it is ready to take the load step.

GENERATOR SETS STARTING AND STOPPING PRIORITIES

The load demand algorithm to decide which generator sets to start and stop can be accomplished in multiple ways. The algorithm must allow the operator to select the shutdown/restart thresholds, time delays, and other parameters for maximum system optimization. Two control methods are discussed herein:

- Fixed priority sequence
- Run hours equalization of generator set

Fixed priority sequence is often used in prime power applications so that not all the generator sets require service at the same time. In this setup, the generator sets can be serviced one at a time at varying intervals and never get to the point where they all need service simultaneously. Alternatively, run hours equalization is used when it is desired to have a more efficient service simply by performing maintenance on all the generator sets in one service call. Figure 4 shows a setup screen from a generator set integrated load demand algorithm with some of the parameters that can be adjusted such as time delays and percent and actual kW set points for starting/ stopping generator sets. These parameters give the owner/operator the flexibility to optimize the power generation capacity while still maintaining the power system reliability.

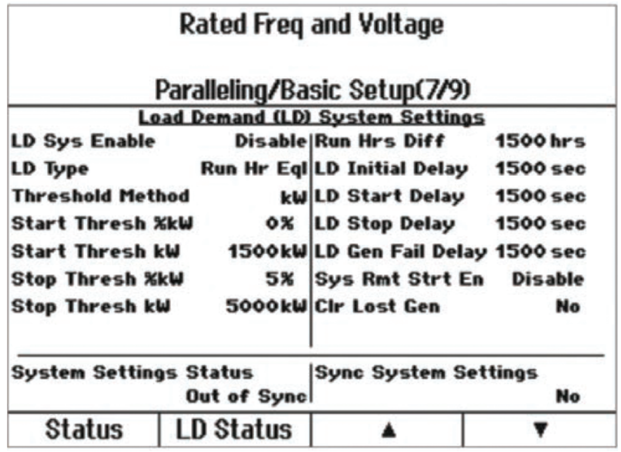

Figure 4. Load demand setup screen

FIXED PRIORITY SEQUENCE

The load demand method called fixed priority sequence allows the generator set priority to be manually assigned by an operator. Therefore, each generator set is assigned a fixed priority: 1, 2, 3, 4, etc. This sets the sequence of starting or stopping the generator sets as system load increases or decreases. For example, the unit which is assigned to be Lead as shown in Figure 5, or assigned Priority1 as shown in Figure 7, never shuts down. Figure 6 shows that Unit 4 (D) will shut down first, then Unit 3 (C), then Unit 2 (B). And the Masterless Load Demand screen in Figure 7, shows that a generator assigned to be Priority16 will stop first, followed by the generator set assigned Priority15, et.

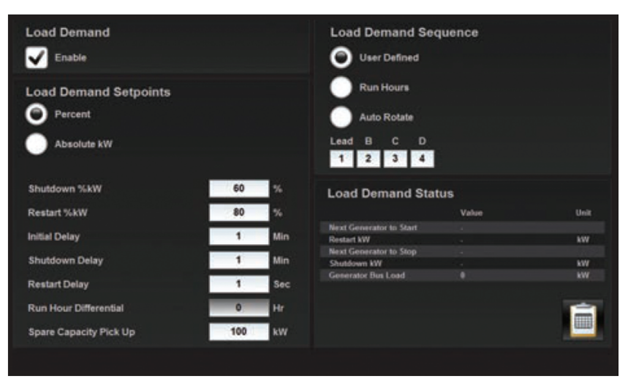

Figure 5. PLC-based load demand setup (four generators)

RUN HOURS EQUALIZATION OF GENERATOR SET

The load demand method run hours equalization works to balance the number of run hours of the generator sets. The generator sets with the lowest number of run hours will have a higher priority to run compared with the sets with a higher number of run hours. This can be accomplished by monitoring the engine run hours and monitoring a run hours differential parameter. When the difference in run hours between the next generator to stop and the next generator to start exceeds the run hours differential, the system starts up the generator set with the lower number of running hours and shuts down the one with the higher number of hours.

LOAD DEMAND IN A PLC-BASED MASTER VERSUS IN THE GENERATOR SET CONTROL

As stated before, load demand can either be implemented in a PLC-based master control or it can be integrated to the generator set control (MLD). Having load demand part of either of those two options, as Cummins does, gives the system designer a higher level of flexibility to choose which method to implement depending on the application.

In applications where a digital master system level control is not required such as simple paralleling and rental applications, and the owner would still like to benefit from the fuel cost savings and other advantages of load demand. Using MLD would be a significant advantage since it is integral to the generator set control and no external controllers are required. Figure 8 shows a power rental application with multiple paralleled generator sets where MLD is used for load demand.

For applications where a digital master is required for a complete system level control, the system designer can utilize the load demand function of the digital master. Additionally, as the digital master is PLC based, the load demand algorithm can be more customizable to fit the needs of the application if fixed sequence and run hours are not suitable or if the system is comprised of multiple generator sets with dissimilar controls that cannot communicate with each other.

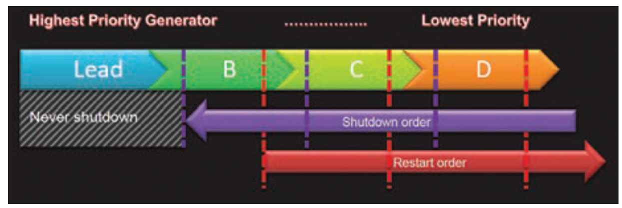

Figure 6. Load demand start/stop sequence

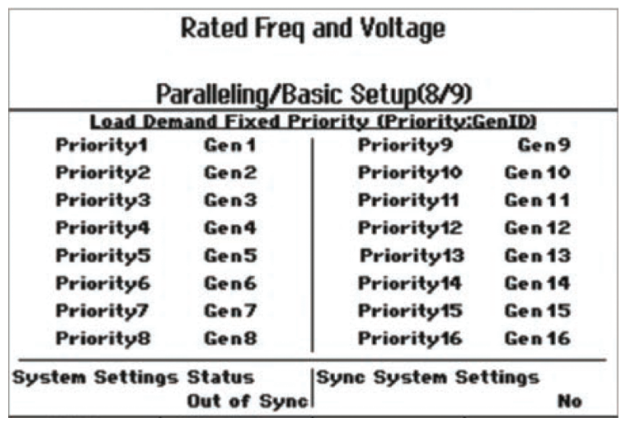

Figure 7. Generator set priority sequence

Figure 8. MLD rental application

GENERATOR SET FUEL CONSUMPTION AND EFFICIENCY

The electrical energy power output efficiency of a generator set depends on multiple factors such as fuel quality, generator set loading, site conditions, and how well the generator set is maintained. While the owner cannot improve operating efficiency by adjusting site conditions, efficiency can be improved by the use of appropriate fuels and fuel maintenance, avoiding operation at light load levels for extended periods of time, and by operating the generator system at optimum efficiency levels based on the load of the system. Figure 9 shows typical fuel consumption of a 2000kW generator set and Figure 10 shows that fuel efficiency is highest for the same generator set when running near rated load. The plot in Figure 10 is the electrical energy power output per chemical energy input versus percent load (kWh/gal versus % load).

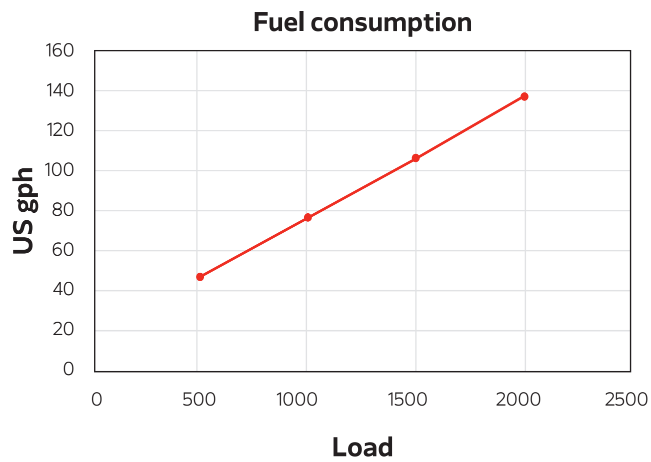

Figure 9. Typical fuel consumption of a 2000kW generator set

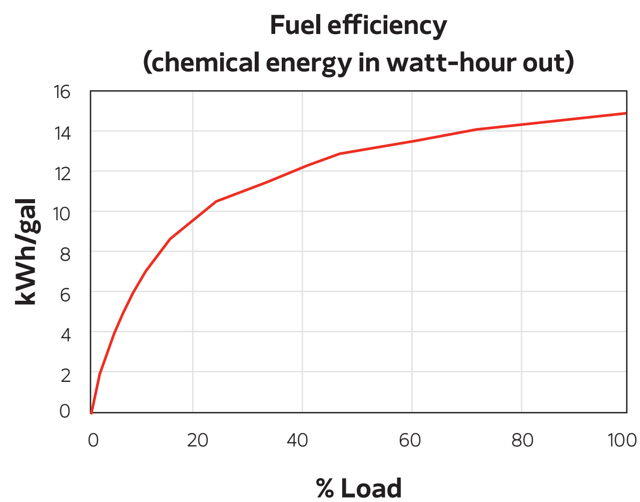

Figure 10. Typical diesel generator set fuel efficiency

LOAD DEMAND EXAMPLE

The daily load profile for this prime power application example is shown in Figure 11. The system is comprised of four 2MW generator sets (8MW total capacity) and the fuel efficiency characteristics for each generator set is shown in Figure 10. Without a load demand feature, the four generator sets run continuously regardless of the load profile. However, with load demand set as, e.g., 60% and 80% for shutdown and restart threshold respectively Table 1, the number of generator sets connected to the system bus varies between one and four depending on the load. The difference in gallons of fuel consumed along with savings are tabulated in Table 2 for a 365 days operation. Figure 12 shows the total system efficiency with and without the load demand feature over a 24-hour period. In addition to the fuel savings, the total engine runtime is reduced when load demand is utilized, Table 3, which translates into capitol cost savings, increased generator sets longevity, and operational cost savings due to less frequent maintenance intervals.

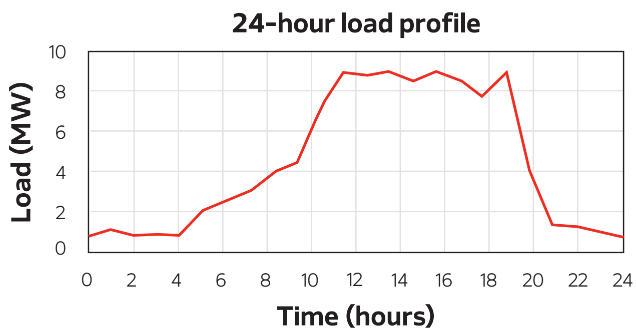

Figure 11. 24-hour load profile

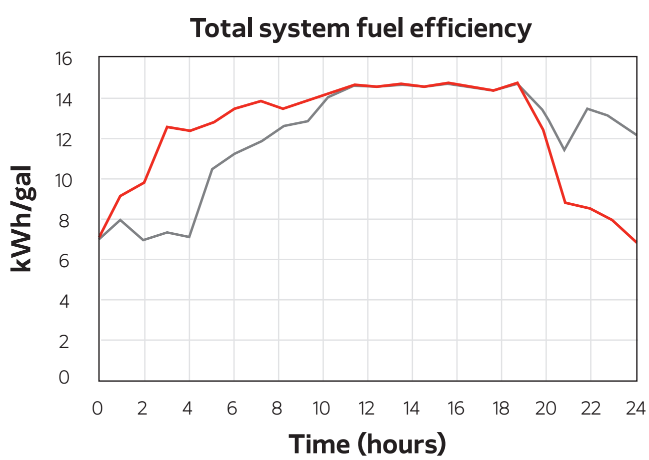

Figure 12. Total system efficiency

Units online	Bus capacity	Shutdown kW 60%	Restart kW 80%
1	2000	-	1600
2	4000	2400	3200
3	6000	3600	4800
4	8000	4800	6400

Table 1. Generator sets shutdown and restart

Gallons/running generator set over 365 days	
Gallons used without load demand	63,936,560
Gallons used with load demand	58,853,951
Gallons difference	5,082,609
Savings	
Diesel price/gallon ($2.557)	$12,996,231

Table 2. Fuel consumption comparison thresholds

Engine runtime over 365 days	Hours
Without load demand	35,040
With load demand	24,455
Runtime difference	10,585

Table 3. Engine runtime comparison

CONCLUSION

The concept of a load demand control algorithm is to run the minimum number of generator sets required to energize the connected loads while still maintaining the overall integrity of the power system. By doing this, there will be fuel savings as well as benefits such as prolonging the life expectancy of the generator sets. These attractive features allow load demand to be used in a variety of applications ranging from military to mining to data centers to healthcare. The power system operator can find the right balance between fuel savings, reduced wear and tear, and redundant online capacity when configuring the load demand feature. To fully utilize the load demand control feature and maximize the fuel savings, the operator must understand the sites total loads, largest step loads, generator fuel consumption rate, load priorities, and redundancy needs.

About the author

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Hassan Obeid is a Senior Global Technical Advisor – Energy Management Solutions at Cummins Power Generation focusing on technical vision, business strategy and solving a wide range of complex problems. Hassan has been with Cummins since 2007 in a variety of roles: power systems design engineering, project engineering and applications engineering. Hassan has designed power systems involving switchgear, controls, paralleling, transfer switches, generator sets, renewable DERs, microgrids and digital solutions. He has developed and conducted technical power seminars on several topics and products involving paralleling, grounding, power systems and controls. Hassan received his bachelor's degree in Computer Science and master's degree in Electrical Engineering from Minnesota State University, Mankato.

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