

MAXIMUM POWER TRANSFER SYSTEM EVALUATION ON DISTRIBUTION CIRCUITS

California State University, Fresno

Electrical and Computer Engineering Department



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AUTHORS:

KERRY D MCBEE, PE

IZAR FAREEZ

OVERVIEW

The theoretical benefits of Maximum Power Transfer System (MPTS) were first identified by Moritz von Jacobi in 1840 with his development of the maximum power theorem. Since this time many engineers have applied this law widely in communication applications to maximize signal transmission. Prior to 2010 many manufacturers attempted to develop a larger MPTS devices to maximize power demand for industrial and commercial facilities. Unfortunately, due to the dynamic characteristics of loads, which fluctuate in real-time, developing a practical MPTS to maximize power demand seemed impossible. However, thanks to advances in computer technology in the last 20 years, companies have been able to develop functioning MPTS devices that provide more benefits to customers than originally identified by Jacobi Law.

By 2021, numerous industrial and commercial companies have experienced the benefits of installing MPTS applications. Since 2010, end-users have witnessed MPTS devices reducing their kW and kVA demand, while also improving their power quality. While many industrial and commercial customers have been willing to take a chance on the new technology, many utility companies are hesitant to fully embrace the benefits of widespread implementation of MPTS devices. Much of the doubt surrounding implementation of these devices center around their unknown performance on a large scale. As a result, utility companies are asking the following questions regarding MPTS implementation and operation:

- *What is the maximum amount of power that can be reduced with widespread implementation of MPTS devices on a single circuit?*
- *How does MPTS penetration rate affect operational benefits?*
- *How does circuit topography impact the operational benefits of widespread implementation MPTS devices on a distribution circuit?*
- *What are the benefits of controlling a network of MPTS devices on distribution system?*

The goal of the research was to identify answers to these questions. Utilizing the MPTS operation benefits identified from multiple end-users, the operational benefits were quantified utilizing the IEEE 13 Node Test Feeder, which was modeled in MATLAB Simulink. The analyses results suggest utilities companies can greatly benefit from widespread implementation. The remainder of this report addresses each operational benefit as a function of MPTS penetration rate.

PERFORMANCE ANALYSIS

MPTS devices reduce operational costs by reducing kW demand, dynamically correcting for power factor, and eliminating losses at harmonic frequencies. The research evaluates each of these operational benefits independently so that engineers can predict the operational benefits as a function of circuit and load characteristics. To establish performance guidelines for individual customers, the researchers utilized operational data from commercial or industrial customers who have installed MPTS devices. Evaluated customers include school districts, well known government agencies, and hospitals.

KW REDUCTION

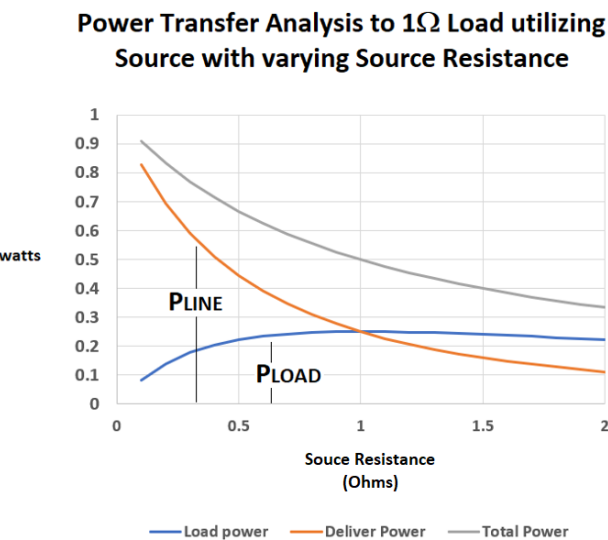


Figure 1: Power requirement for 1Ω load.

Jacobi’s Law states that power is maximized when the source impedance is equal to the conjugate of the load impedance. As illustrated in Figure 1, power delivered to a 1Ω load is maximized when the source and load resistance are equal. Applying this relationship has proven beneficial in numerous communication applications. However, the optimal operational configuration for “power delivery” must account for the load demand (P_{LOAD}) and power losses (P_{LINE}) through the system. As illustrated in Figure 1, the overall system efficiency ($P_{LOAD} + P_{LINE}$) can be increased if the “Load Resistance” to “Source Resistance” ratio is manipulated. MPTS devices possess the ability to dynamically adjust this resistance ratio to maximize overall system efficiency. The result is an overall reduction in kW demand for the system as P_{LINE} is minimized to serve a mostly constant P_{LOAD} .

End-users have experienced significant reductions in kW demand after installing MPTS devices. Figure 2

Plastic Injection Molding Factory		
24 hour application		
Data from the Customer's Utility Bill		
	2013	2014
	KW Demand on the bill	KW Demand on the bill
April with MPTS (partial)	507.6	453.6
May with MPTS	514.8	446.4
June with MPTS	464.4	500.4
July with MPTS	500.4	514.8
August with MPTS	504.0	482.4
September with MPTS	478.8	442.8
October with MPTS	468.0	428.4
November with MPTS	468.0	453.6
December with MPTS	406.8	406.8
January with MPTS	457.2	410.4
February with MPTS	414.0	428.4
March with MPTS	399.6	468
Average	465.3	453.0

Figure 2: Monthly kW demand for plastic manufacturer

illustrates the monthly kW savings for a plastic manufacturer before and after installing MPTS devices. The average monthly kW savings after installing MPTS devices was 3.9% for the system.

A more thorough view of the demand reduction can be seen from data provided by a major hospital in Denver, who installed MPTS devices on their HVAC system in 2013. As illustrated in Figure 3, installation of MPTS devices reduce the monthly maximum current demand by 21.6% (June), 17.80% (July), 21.10% (August), and 19.82% (September).

Data from the plastic manufacturer and hospital suggests that kW savings are a function of the load type, system configuration, and seasonal variations. Based upon measured data, an end-user can expect a kW reduction between 2% - 20%.

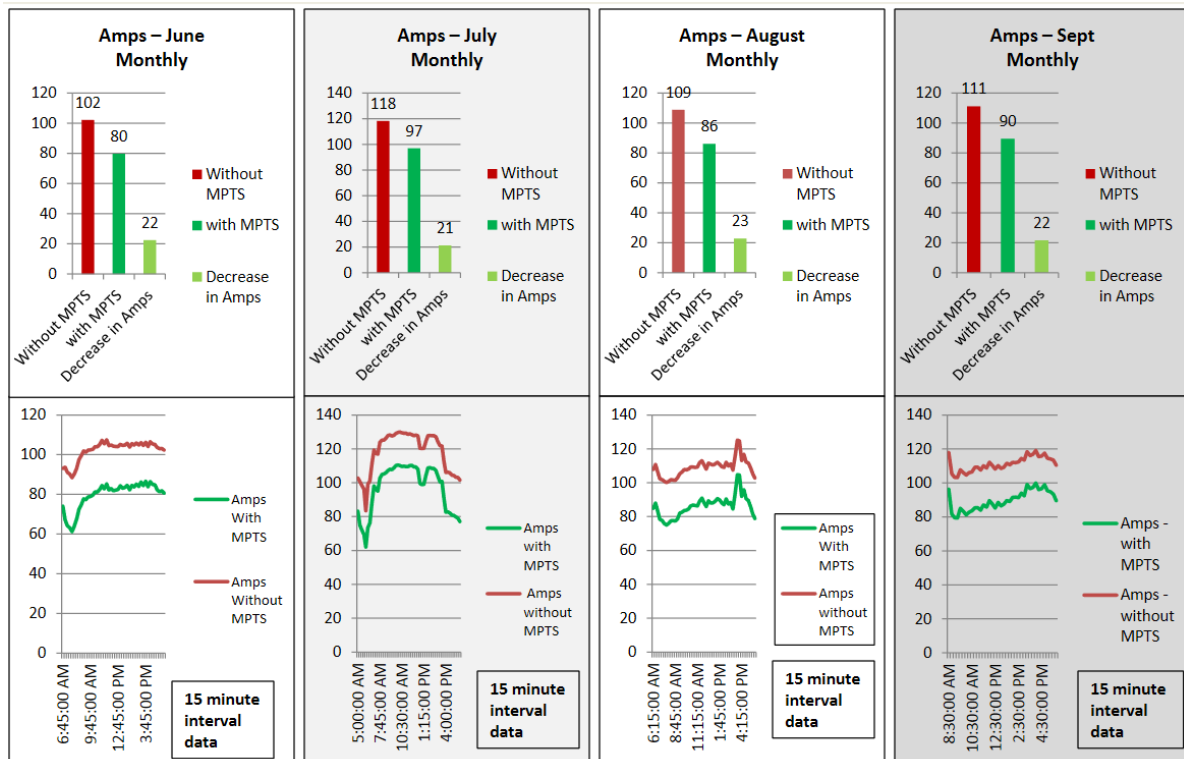


Figure 3: Monthly kW demand for plastic manufacturer

DYNAMIC POWER FACTOR CORRECTION (KVA REDUCTION)

The MPTS device performs dynamic power factor correction in real-time, which allows the device to provide dynamic VAR support. According to the Jacobi Law, power is maximized when the reactive components of load and source of equal in magnitude, but opposite in reactive component. This action brings the overall load power factor closer to 1, which reduces the overall kVA demand. Since most systems are inductive, the MPTS device performs similar to a dynamic capacitor bank.

Installation of MPTS devices has proven to provide rapid power factor correction in multiple applications. Figure 4 illustrates the “before” and “after” MPTS installation for a public school. As illustrated, the devices push the power factor near unity for the large periods of the day.

The number of benefits associated with dynamic VAR compensation are a function of the existing load characteristics. If the power factor is poor at high loading levels, the savings can be significant. If power factor is good during high loading conditions, the savings will be small. Utilities can identify the potential savings by identifying the existing power factor performance on the circuit.

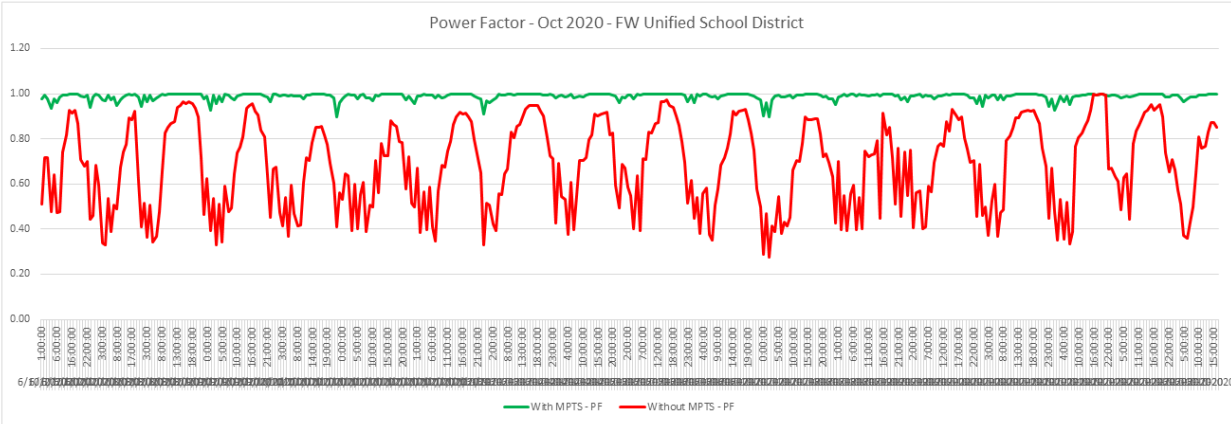


Figure 4: Power Factor for public school before and after MPTS installation.

FEEDER EVALUATION

Although MPTS applications can provide operational benefits for the loads they are serving, the benefits associated with wide-spread implementation on a utility distribution circuit can vary based upon the type of customers and penetration rate of implementation. A distribution circuit can serve up to 5000 individual customers, or end-users, all of which can demand an individual P_{LOAD} . The operational benefits associated with MPTS implementation increase as more P_{LOAD} 's are served by MPTS devices. To identify operational benefits for utilities companies, the individual operational benefits identified by individual end-users was applied to the IEEE 13 Node Test Feeder. Operational benefits were evaluated as a function of MPTS penetration rate.

kW REDUCTION

A distribution circuit in the US can serve anywhere from 1 to 5000 end-users. The total amount of kW reduction will be a function of the type of customers and the MPTS implementation rate (penetration rate). As previously identified, the kW reduction for single installation can range between 2% and 20% depending upon the type of load and delivery infrastructure. As the number of customers utilizing MPTS devices on a circuit increase, the more operational benefits utilities experience at the substation transformers. Figure 5 illustrates the kW reduction as a function of penetration rate, which is measured by identifying the kW demand that is served by MPTS devices. For example, for a 50% penetration rate the expected kW reduction can range between 1% - 10%. In addition, the type of customers can also greatly impact benefits experienced by utilities.

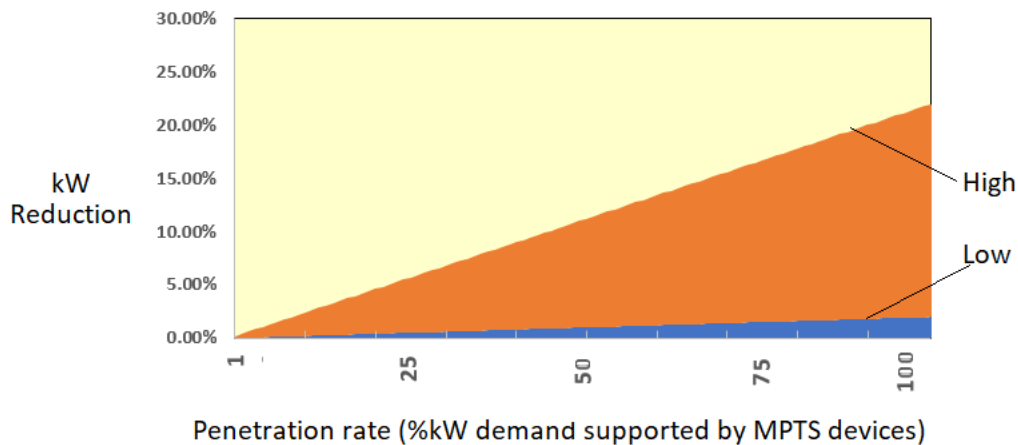


Figure 5: kW reduction as a function of MPTS penetration rate.

A distribution circuit typical serves three types of customers (Residential, Commercial, Industrial). Although each type can greatly influence the operation on a distribution circuit, MPTS benefits are typically limited to industrial and commercial customers. The smallest MPTS device is 100 kW, which is larger than numerous residential premises. As such, installing MPTS devices on low demand residential facilities may not be cost beneficial. Therefore, to evaluate the practical potential of MPTS installation engineers must apply the penetration rate to the end-users applicable to MPTS installation. Figure 6 illustrates the kW reduction as a function of penetration rate on a distribution circuit where 70% of the demand is drawn by commercial or industrial customers.

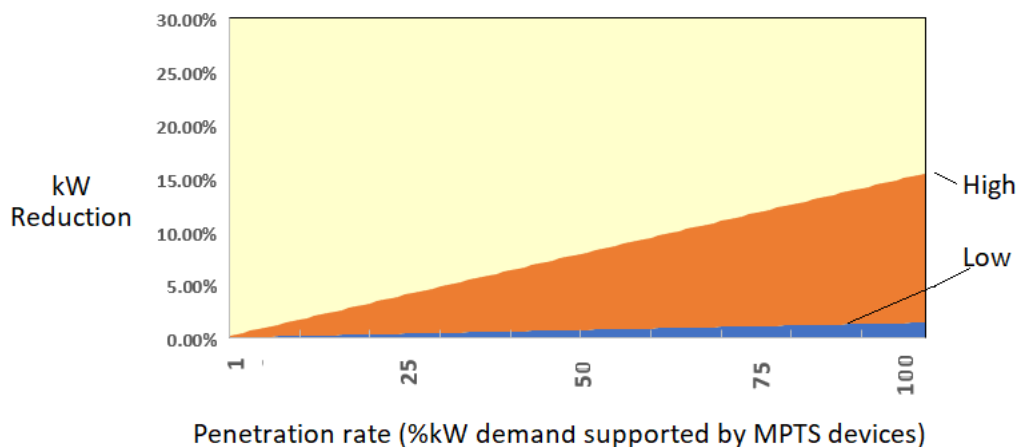


Figure 6: kW reduction as a function of MPTS penetration rate on circuit serving 70% industrial/commercial customers.

The IEEE 13 Node test feeder demands a total of 3266 kW for the spot loads. Assuming that 70% of the load is the demand of residential and industrial customers results in a total demand of 2286 kW for the circuit. Assuming 50% MPTS penetration rate for industrial and residential customers, the total kW reduction will range between 22.9 kW and 228.6 kW depending upon the types of loads. Since most of

the VAR compensation on the circuit is due to capacitor banks providing voltage support, it can be assumed that with a kW reduction, the VAR compensation will also reduce. Applying the kW reduction to the VAR compensation reduction results in kVA reduction on the system of 7.1%, reducing the original 3827 kVA to 3555 kVA.

DYNAMIC POWER FACTOR CORRECTION

The benefits associated with dynamic power factor correction are dependent upon the existing levels of power factor on the distribution circuit. Utilities routinely employ capacitor banks to improve the feeder's power factor and/or voltage profile. Widespread implementation of MPTS devices on a feeder could indirectly provide the same benefits as numerous capacitor banks installed throughout the circuit. However, operation performance with a high penetration of MPTS devices could be more responsive than traditional VAR compensation systems.

The IEEE 13 Node Test Feeder was evaluated for widespread implementation of MPTS devices to identify the impact on power factor and efficiency as a function of penetration rate. *The kW reduction identified in the previous section was ignored so that the analysis evaluates only the impact of dynamic power factor correction.* Without widespread implementation of MPTS devices throughout the circuit, the power factor at the substation transformer is 0.918 lagging. As more MPTS devices are implemented the power factor slowly improves to unity, which is reached at a MPTS penetration rate of 90%. As illustrated in Figure 7a, power factor improvement is nearly linear [0.001/ % rate increase] prior to a 60% penetration rate. As illustrated in Figure 7b, the kVA delivered through the substation is reduced from 3827 kVA to 3450 kVA, an overall efficiency improvement of 10.38%. In high penetrations, MPTS applications could provide the equivalent of 1400 kVAR, which is illustrated in Figure 7c. Additionally, it was found that the circuit topography had close to no impact on the operational benefits of MPTS widespread implementation. In other words, analysis results displayed negligible difference of MPTS implementation operational benefits when installed on either the high-end or tail-end of a feeder. The overall results suggest that widespread implementation of MPTS device could also provide voltage conservation applications for the utility companies.

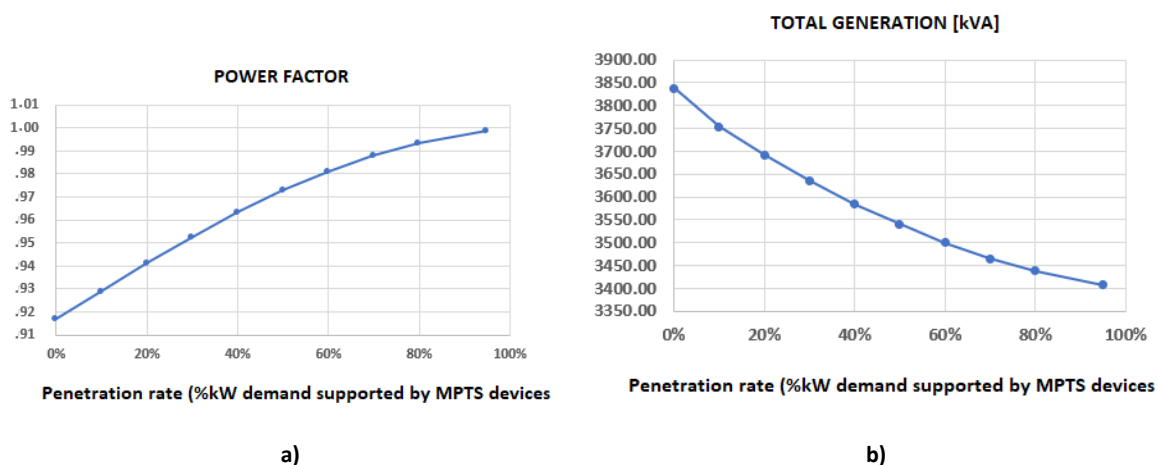


Figure 7 a) Power factor as function of penetration rate, b) kVA reduction as a function of penetration rate.

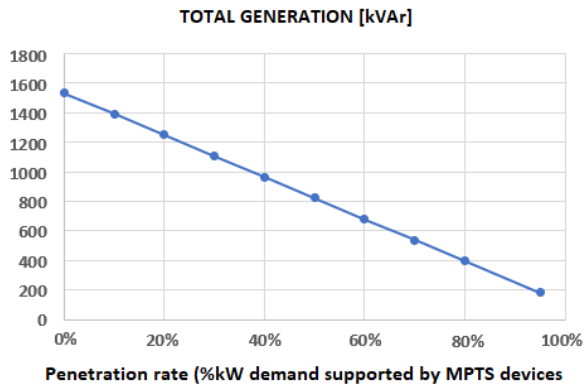


Figure 8) kVar reduction as function of penetration rate.

CONCLUSION

The analysis demonstrated that high penetrations of MPTS devices on distribution can be very beneficial to utility companies. As illustrated in Table 1, depending upon the penetration rate, the kW and kVA reduction can be significant.

Table 1: Summary of MPTS benefits on IEEE 13 Node Test Feeder	
kW Reduction Exclusively @ 50% Penetration Rate	
kW Reduced (max)	3266 kW → 3037 kW
kW Reduced (min)	3266 kW → 3243 kW
kVA Reduced (max)	3827 kVA → 3555 kVA
kVA Reduced (min)	3827 kVA → 3795 kVA
Dynamic PF Correction Exclusively @ 50% Penetration Rate	
PF Correction Improvement	0.918 → 0.973
kVA Reduced	3827 kVA → 3540 kVA

In addition, the dynamic VAr and harmonic filtering capabilities open the door for utilities to utilize a network of MPTS devices to support the following:

- 1) voltage conservation applications
- 2) power quality support
- 3) PV voltage support.

The second stage of the research will consist of evaluating these utility operational benefits.