A Load Flow Analysis of the IEEE 33-bus with Grid-Edge Control PF-ONE

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Abstract:
The present paper discusses the impact of the low voltage grid-edge device PF-ONE has on power flow analysis of the IEEE 33-bus test feeder. The green economy is asserting more pressure on utilities to deliver more power over existing transmission and distribution networks. An example being able to accommodate Electrical Vehicles (EVs) power demands over existing distribution networks.

As distribution networks are loaded, voltage regulation decreases at the end user load point. Traditional voltage compensation methods are inadequate to meet these challenges. The PF-ONE grid-edge device is located at the meter socket, corrects and improves voltage regulation. PF-ONE uses active shunt currents to compensate reactive power demand and mitigate harmonic load currents to meet power quality standards of distribution systems. A brief overview of the PF-ONE grid-edge technology and its operational benefits are presented with load flow analysis of the IEEE 33-bus test feeder.

The present analysis will showcase PF-ONE and its intrinsic capabilities to reduce aggregated transmission and distribution losses (ATC), increase voltage stability, increase power transfer capacity of existing networks and improve transient stability limits. An 2.0 pu overloaded demonstration case is presented, contrasting PF-ONE results with the standard configuration showing benefits to the end user and utility alike.

Introduction

Their has been much talk about power electronics at the grid edge to solve many tough voltage stability and capacity issues on distribution networks. Introducing the PF-ONE, the first grid edge device to meet the last mile challenge. PF-ONE increases distribution capacity, improves voltage regulation, and reduces transmission losses. Adaptive shunt currents shape varying reactive and harmonic load currents to maintain a power factor and power quality as viewed from the utility side. This is only one of the many modes the PF-ONE can operate in. Paper [1] discusses increasing power flow on distribution lines up to 3 pu and beyond if, the power factor of loads can be adjusted in proportion with distribution network loading. This is one of many applications that PF-ONE can accomplish, without SCADA connections or communications.

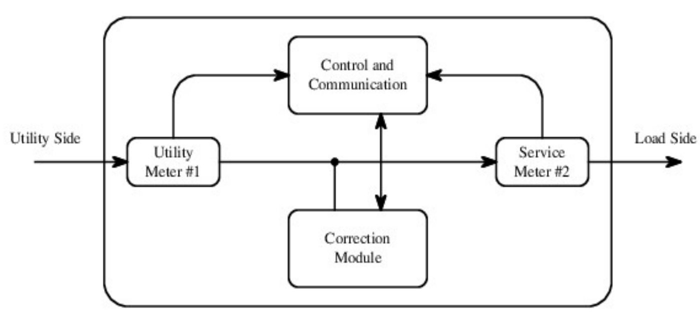

Figure 1: Block diagram of PF-ONE

The architecture of PF-ONE is shown in Figure 1. On the left is the utility side meter and on the right the service side meter. There is a direct connection of the utility to the service side, nothing to hinder the free flow of power to loads. The PF-ONE compensation module is connected in-between the utility and service sides, this is the corrective current injection point. The PF-ONE control measures real and reactive currents both on the utility and service sides. Then a compensation current is calculated to meet the desired result and passed to the correction module to inject the corrective current. The unique dual meter configuration enables the control to react to fast changing load currents, measure compensation performance and effectiveness in one package. With this two meter arrangement global metering standards for billing are met. With every service having a PF-ONE, reliability is increased and costs are minimized. The unique dual meter structure enables: operation without communication, records compensation costs, measures effectiveness of compensation, and more.

Base Case

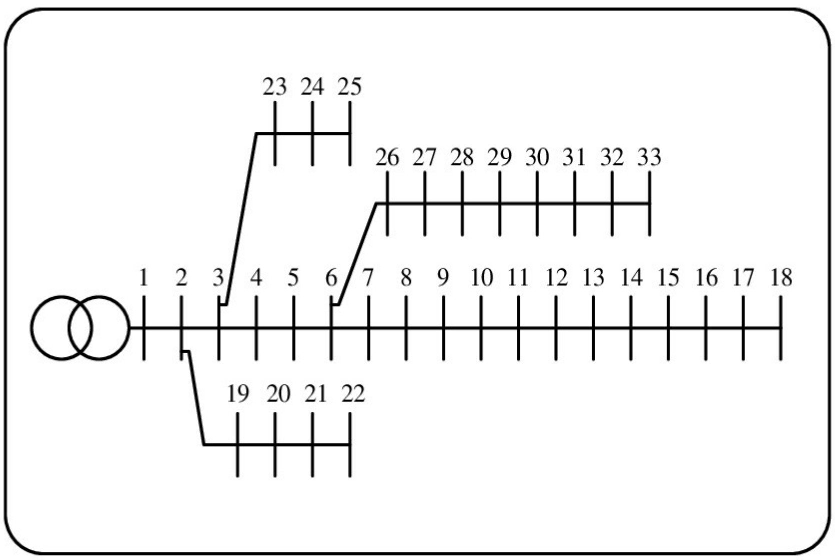

Figure 2: Topology of IEEE 33-bus

As an example of PF-ONE capabilities the IEEE 33-bus example is simulated (see figure 2 above) using Mat-power[2] and 'case33bw'. We will show how to edit the Standard case to represent the PF-ONE on the network and publish the results of comparative simulations between the Standard case and PF-ONE. The base case is the original case33bw vs PF-ONE with PF=1.0. The PF-ONE file, Var loads are set to zero or a power factor of one. The PF-ONE compensation costs are represented as additional watts used at each bus in proportion to the amount of Vars required at each bus. Results shown in Figure 3 show voltages for the Standard case vs the PF-ONE at each bus. The overall voltages at each bus have seen an improvement as well as the rate of decline along each branch is reduced. As an example bus voltages at #6 to #18 seen a decline of 0.037 pu in the Standard case but only a decline of 0.027 pu with the PF-ONE case.

Referring to table 1, results show that the MVA load on the generator is reduced by over 15%, increasing transient stability margin. This excess generation capacity can be reassigned to active power production, yielding better efficiencies and revenue from existing assets. The lowest voltage is raised by 0.026 pu to 0.939 pu. PF-ONE increases the stable range of tap changer voltages that may be used to meet peak demands. Transmission costs are equal at 204Kw.

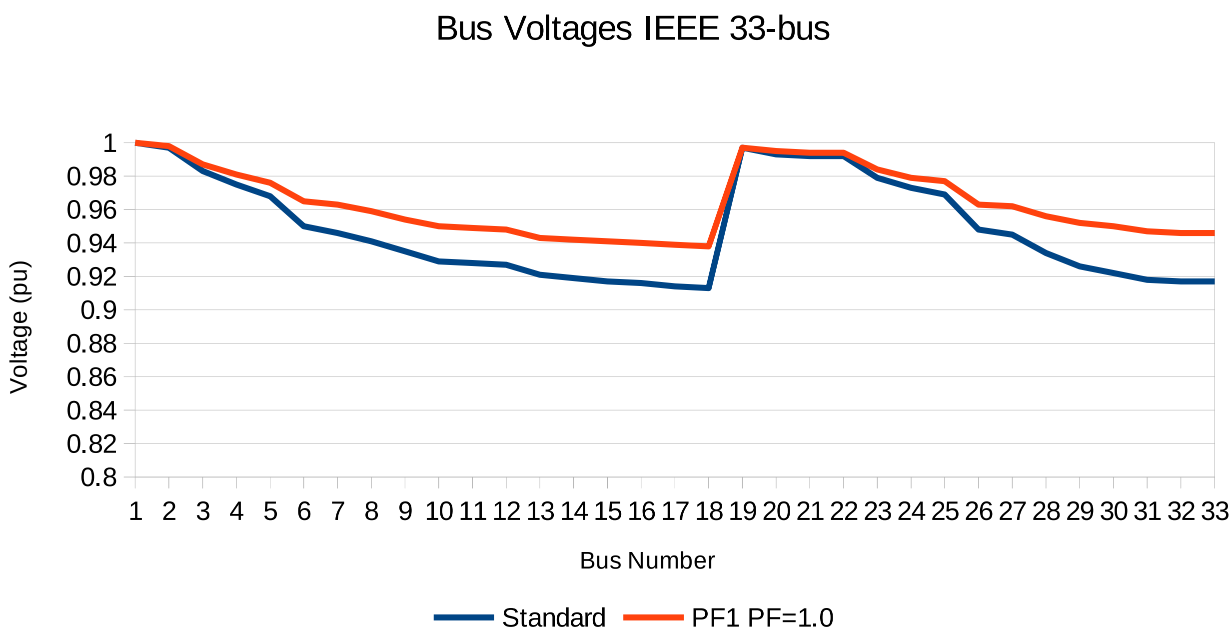

Figure 3: Bus Voltages of IEEE 33-bus Standard vs PF-ONE with PF=1.0

Table 1: Comparison of Standard vs PF-ONE of base IEEE 33-bus case.

Case	P (MW)	Q (MVAR)	MVA	Min V(pu)	Costs
Standard	3.900	2.400	4.600	0.913	203KW
PF-ONE	3.900	0.100	3.900	0.939	204KW
Difference	**0**	**-2.3**	**-0.7 (-15.2%)**	**0.026 (+2.8%)**	**~0**

Double P and Q Case

In this example every load of the Standard case is doubled both in P and Q. The PF-ONE buses are edited to represent zero Vars again, the PF=1.0 case. In the PF-ONE Adjusted case, all buses are set to PF=1.0 except for buses 11 to 18 and 30 to 33 which are set to 100KVar leading for a total of 1.2MVars leading injection. Loads and the costs of generating these Vars is added to each bus. Resultant bus voltages are shown in Figure 4 below. The unaltered base or Standard case at 2.0 pu loading has many

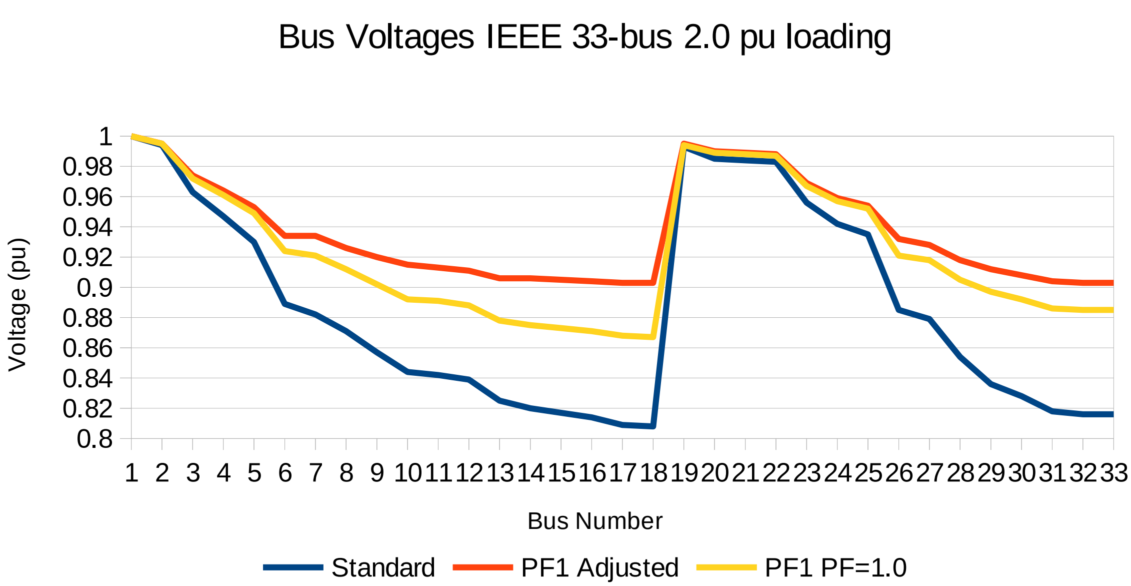

Figure 4: Bus Voltages of IEEE 33-bus at 2.0 pu loading. Standard vs PF-ONE with PF=1.0 vs PF-ONE Adjusted.

buses below 0.9 pu. The PF=1.0 case also has several buses below 0.9 pu but not as many nor as severe as the base case. The PF-ONE Adjusted case with an injection of 1.2 MVars leading at select buses has no bus voltages below 0.9 pu.

Table 2 below shows system data for the Standard and the PF-ONE adjusted case, both at 2.0 pu. Lower real power generation is required for the PF-ONE case and MVA is reduced by 11.5% leaving some transient stability margin. While in the Standard case generation is near it's maximum of 10 MVA. The voltage minimum for the PF-ONE Adjusted case is just over the set minimum of 0.9 pu, while the Standard case is well below at 0.808 pu. Transportation costs are reduced with PF-ONE Adjusted by over 150KW and voltage is within regulation.

Table 2: Comparison of Standard vs PF-ONE Adjusted for IEEE 33-bus 2.0 pu loading case.

Case	P (MW)	Q (MVAR)	MVA	Min V(pu)	Costs
Standard	8.400	5.300	9.930	0.808	976KW
PF-ONE	8.300	0.400	8.310	0.903	821KW
Difference	**-0.1**	**-4.9**	**-1.62 (-11.5%)**	**0.095 (+9.5%)**	**-155KW**

Conclusions

Initial load flow simulations using the IEEE 33-bus model shows that PF-ONE has a very positive impact on distribution networks. Stability, voltage regulation, and transportation costs are all improved. PF-ONE enables other opportunities to improve existing asset efficiencies and demand management. With the spectre of distribution networks asked to contend with increased solar penetration and electric vehicle charging, the distributed abilities of the PF-ONE will be a welcomed addition to the tools of the distribution engineer.

References

[1] Rohit Kumar, Akshay malik, and Gaurav Dalakoti , "Power Flow & Voltage Stability Analysis using MATLAB, International Research Journal of Engineering and Technology (IRJET)", Jan-2017.

[2] R. D. Zimmerman, C. E. Murillo-Sanchez, and R. J. Thomas, "MATPOWER: Steady-State Operations, Planning and Analysis Tools for Power Systems Research and Education", Power Systems IEEE Transactions on, vol. 26, no. 1, pp. 12-19, Feb.2011.