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The Transformer-less Unified Power Flow Controller (TUPFC) for Power Flow Control at Normally-Open Primary-Ties

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SUMMARY

Increased electrification and the rapid onset of distributed energy resources (DERs) bring significant technical challenges to the operation of aging power distribution system infrastructure. These challenges include: the inability to accommodate increasingly varied load demand, DER hosting capacities, and the increase of outages due to increased storm severity and frequency. Existing tools focus on legacy technologies, cap banks, reclosers, new substations, reconductoring, and the application of demand response strategies.

These solutions are not sufficient because they either require large capital investment or result in lost revenue for the utility while requiring a change of behavior from the consumer side. Advances in power electronics can provide a paradigm shift, which can resolve many of these problems while conserving energy, managing power quality and deferring infrastructure upgrades. This can be accomplished by transforming normally open points (NOPs) to soft open-points (SOPs) via cost-effective power electronics. The power electronic unit which will be deployed in the fourth quarter of 2019 in Georgia Power's distribution system is a transformer-less, unified power flow controller (TUPFC) which is capable or regulating real and reactive power flow. The ultimate objective of this project is proving out its capability in anticipation of a potential system wide deployment in the primary distribution system with the vision of operating the distribution system like the transmission system with bidirectional power flow capabilities. This paper will give an overview of the projected benefits of deploying the TUPFC in distribution systems along with an analysis of the planned deployment project.

KEYWORDS

Reliability, Resiliency, Non-Wires Alternatives, Demand Growth, DG Hosting, Power Flow Controller, Looped Distribution System.

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INTRODUCTION

There are many power electronics candidates that can be used to transform NOPs to SOPs. These are, STATCOMs, Back-to-Back converters (B2B), multi-terminal DC systems (MT), universal power flow controller (UPFC), or the transformer-less unified power flow controller (TUPFC) which is also referred to as the Tie Controller (TC) in this paper. Many of these technologies share benefits, while some include superior performance that enables additional benefits for utility operators and end users. Table 1 shows a comparison of the benefits of each technology.

The TUPFC is a patented device [1] which is unique because it does not require a bulky, expensive zig-zag transformer (usually required for traditional UPFCs [2]). This was accomplished through the utilization of cascaded-multi level inverter technology which resulted in a much smaller and lower cost device. The technology can be scaled to any voltage level, but medium voltages, from 4kV to 34.5kV, are most ideal from a size and cost perspective. In addition to power flow control, the TUPFC is capable of isolating circuits with disturbances and limiting fault currents.

The TUPFC offers very similar benefits to the B2B system while being much more cost-effective due to the semiconductor device power rating (SDPR) being much lower for the TUPFC [3]. In the following sections benefits of UPFC, STATCOM and B2B are presented. Then a case study simulating the TUPFC to increased demand allowance is presented. After that, analysis of the application of the TC on Georgia's Power distribution system is presented.

Table 1. Comparing the different power electronics technologies for the SOP application

	STATCOM	B2B	MT	SSSC	UPFC	TUPFC
Feeder Connection	None	DC-Link (async.)	DC-Link (async.)	Direct (sync.)	Direct (sync)	Direct (sync.)
Active Power Exchange	N	Y	Y	Limited	Y	Y
Post-Fault Restoration	N	Y	Y	Y	Y	Y
Reactive Power Support	Y	Y	Y	Limited	Y	Y
Partially Rated Converters	Y	N	N	Y	Y	Y
Additional Feeders Required	N	Y	Y	Y	Y	Y
No Transformer	N	N	N	N	N	Y
Isolates Circuit with Disturbance	N	Y	Y	N	N	Y
Limits Fault Current	N	Y	Y	N	N	Y
VSCs in Series	0	2	2	1	1	1
VSC in Shunt	1	0	0	0	1	1
VSCs per Device	1	2	>3	1	2	2

INCREASED DEMAND ALLOWANCE

Load growth has been relatively stagnant in the last ten years, but the potential for the rapid deployment of electric vehicles and increased electrification could cause the system to violate its voltage and thermal constraints in some areas. Many utilities solve this problem by incentivizing changes in customer behavior through demand response functions or through constructing new lines or substations. While these solutions may be necessary under certain circumstances, they are resource intensive taking a significant amount of human capital, cash, and time. A paradigm changing approach is the intelligent routing of electric power by utilizing power electronics technologies as mentioned above. This is done by balancing two feeders as shown in Figure 1.

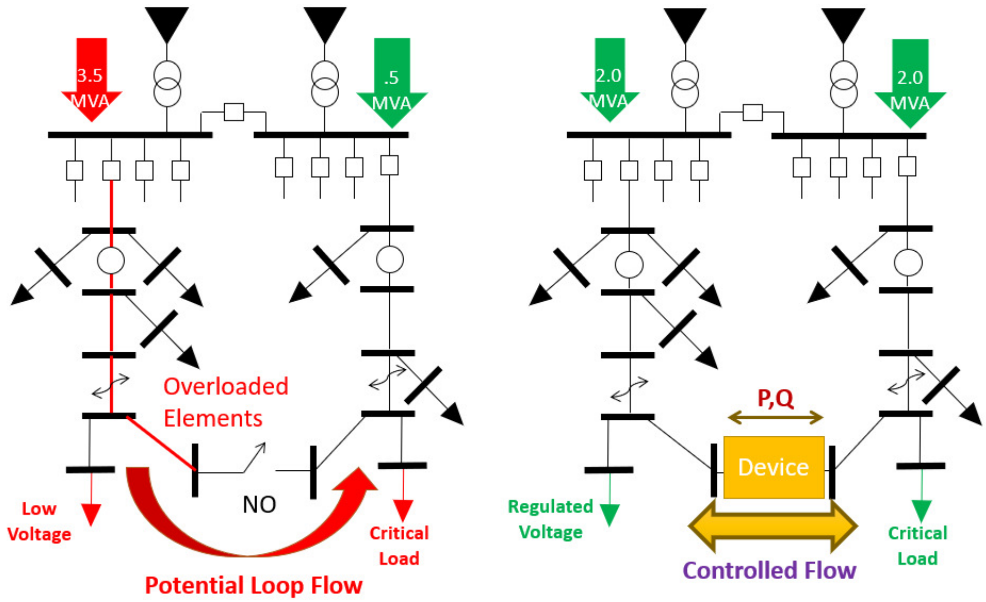

Figure 1. Feeder balancing by transforming NOPs to SOPs via power electronics devices

Monetary savings and system benefits can be accomplished when SOPs are implemented to regulate power flow. The monetary savings are accomplished as a result of deferring major system upgrades as demand grows. A study was performed by [4] to determine the allowable increase in customer demand with the use of different power electronics to form SOPs. In the systems studied, the allowable increase without SOP was 7% of existing peak allowance. With the use of SOPs the allowable system demand more than tripled as shown in Figure 2.

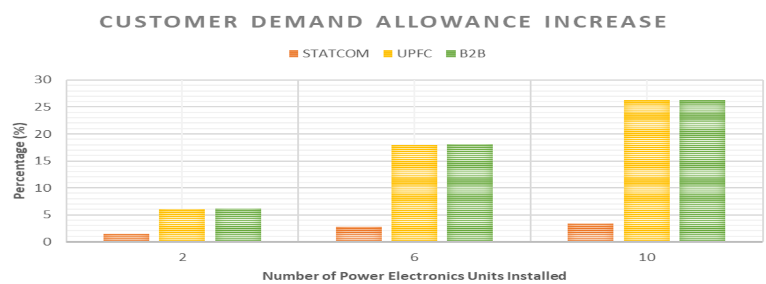

Figure 2. Marginal increase in customer demand allowance

DISTRIBUTED ENERGY RESOURCE INTEGRATION AND ENVIROMENTAL BENEFITS

Transforming normally open points (NOPs) to soft open-points (SOPs) via power electronics can bring tremendous benefits to the environment by enabling the system to increase its distributed, renewable energy hosting capacity. This is accomplished with the intelligent routing of power between feeders.

Hosting capacities of traditional distribution networks are limited by various physical and regulatory constraints such as feeder capacity, thermal constraints, and voltage regulations. Those limits can be stretched using power electronics SOPs without the need for reconductoring or substation upgrades. A study was performed by [5] to determine the amount of distributed generation allowance increase if SOPs were deployed at various levels. Figure 3 shows the potential percentage increase of renewable energy penetration levels for various technologies for different quantities of SOPs. The results obtained are for different sized networks. The sizes are shown with respect to their original hosting capabilities without SOPs (2.03 MW, 3.24 MW, and 4.88 M).

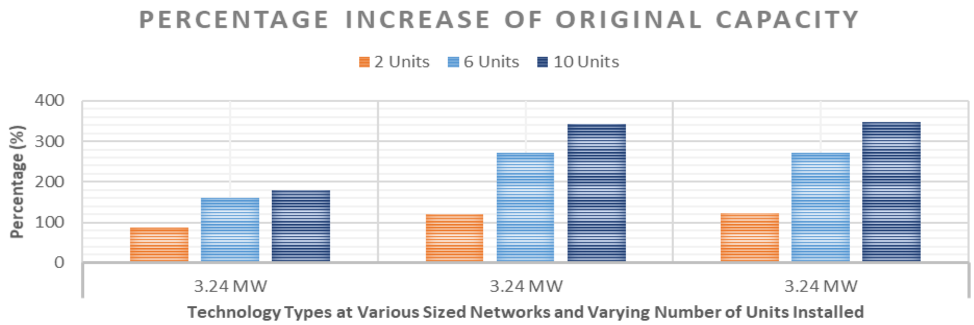

Figure 3. Increase in distributed generation hosting capacity

The following remarks can be implied from these figures:

- Installation of 10 power electronic units to form 5 UPFCs at a network that originally hosts 4.88 MW of renewable energy can triple the initial hosting capacity.
- Installing 1 UPFC can double renewable energy hosting capacities.
- UPFC performs significantly better than STATCOMS and performs similar to B2B.

RELIABILITY ENHANCMENT

The Tie Controller can offer significant reliability enhancement to the distribution system. This is made possible by the ability of the TC to tie circuits together and provide a second source of electricity to users in the event of an upstream fault. This effectively transforms open loop and radial with tie systems into N-1 systems from a reliability perspective. This can reduce SAIFI by a third assuming a midpoint recloser and assuming the number of customers are equal in both feeders. A study was done by [7] on the IEEE123 system, and it was shown that having multiple normally closed (NC) points can reduce SAIFI by around 25% in that system. Note that this study did not take into account active power flow control and the ability of the controller to increase reliability by riding through temporary interruptions.

TEST CASE SIMULATION STUDY USING THE TUPFC

The previous case studies were performed with the traditional UPFC which showed relatively superior performance to the other technologies. Since the UPFC is bulky, relatively expensive, and largely unavailable commercially for distribution system applications, the TUPFC was developed to perform a similar function with smaller size, lower cost, and added functionalities (such as current limiting). Switched Source's TUPFC was modelled in a co-simulation environment utilizing both MATLAB and OpenDSS. To demonstrate increased demand allowance, two IEEE13 node feeders were connected together while varying the load and line length on one of the feeders to throw the system off-balance. Figure 7 shows the voltage profile without the TC and Figure 8 shows improved voltage profile after adding the TC and setting its P and Q set points to the optimal points (with respect to maximum demand growth). Figure 4 shows the voltage profile before applying the TC, and Figure 5 shows the voltage profile after adding the TC with optimal setpoints. We can see that the voltage profile has shifted away from the ANSI limit to which can increase demand growth potential. It can be seen in Figure 6 that the TC can increase demand allowance by 20% (up to 1.2 p.u.) before the ANSI voltage limits (1.05 p.u. and 0.95 p.u.) are violated.

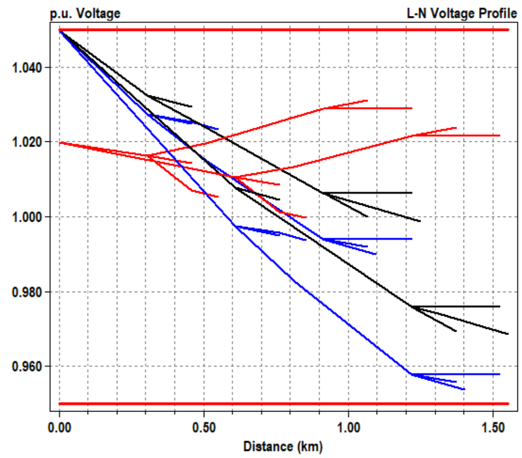

Figure 4. Voltage profile of two IEEE13 node systems connected together (without TC)

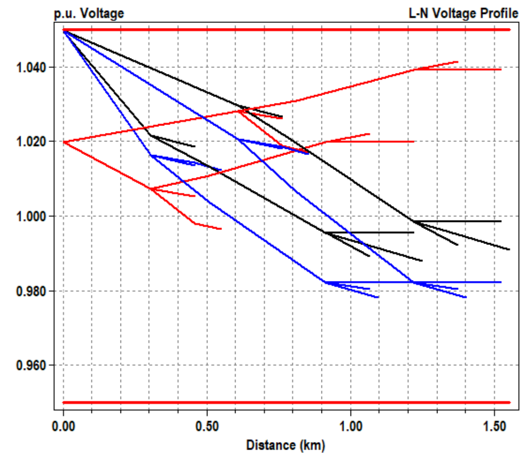

Figure 5. Voltage profile of two IEEE13 node systems connected together (with TC and optimal P & Q setpoints)

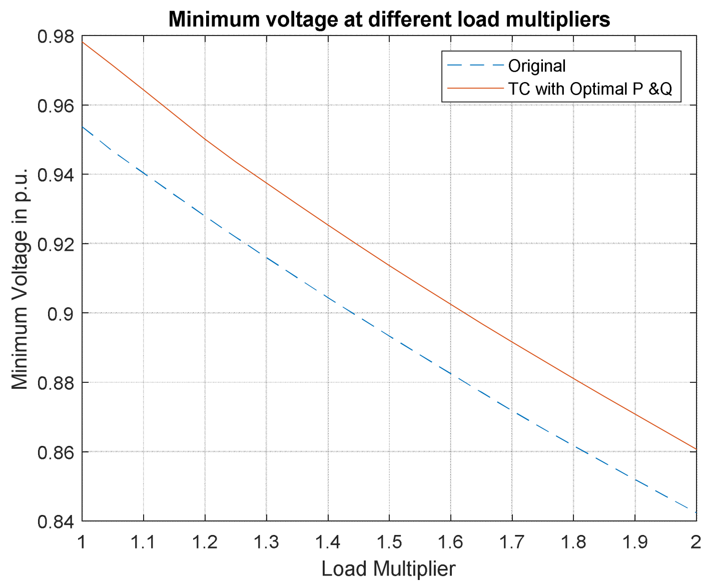

Figure 6. The lowest point of the system voltage for various load growth multipliers

DEPLOYMENT CASE ANALYSIS

Southern Company has been exploring the potential of a power electronics enabled distribution grid for over 10 years through supporting both internal and external research efforts mainly through the Power Delivery group in Southern's own Research & Development department. Southern Company leverages its relationships with universities and research entities to stay on the cutting edge of new technology in the utility space. Southern R&D aggressively seeks out technologies to test that can improve the way the grid is operated at all levels including distributed volt-VAR controllers, smart inverter functions, and distribution scale power flow controllers like the Switched Source device.

Southern R&D previously tested another distribution-scale power flow controller. The tests yielded positive results, however the vendor of the device decided not to pursue the technology for distribution applications. The Switched Source device has more capacity and capabilities than the device tested previously.

A growing number of utilities around the country are starting to pursue non-wires alternatives (NWAs) in their planning processes, mostly on distribution-scale projects. NWAs can provide lower cost options for alleviation of capacity or voltage issues on distribution lines and can include energy storage, targeted demand response, or advanced power electronics like the TUPFC. NWAs allow the utility to have more flexibility in how they provide lowest cost power to consumers.

The selected site outside of Savannah, GA is ideal for this device as it has already had to be reconfigured once for capacity issues. The two circuits that will be tied together both operate at 13.2kV and have a combined load greater than 15 MW. There is even a solar installation planned on one of the feeders, an occurrence more and more common in rural parts of Georgia. The Switched Source TUPFC is the most advanced power flow controller available, and Southern R&D is proud to help prove out this technology with a real-world field demonstration.

The demonstration is scheduled for six months of testing as we try to control power flow on active feeders in a new way that could provide more flexibility on the distribution system than ever before. A six-month testing window will provide opportunity for testing in different seasonal and loading conditions. At the end of the testing period, Georgia Power will have the option to keep the device for an additional cost.

CONCLUSION

Innovative solutions to the aging power system are necessary to efficiently operate the distribution grid especially while successfully integrating large numbers of DER. Through the advancement of power electronics, it became possible to build transformer-less power flow controllers that can be applied economically to transform normally open points to soft open points and regulate the power flow in distribution systems. Studies have shown that SOPs can help solve many of the problems that the grid currently faces. Demand allowance, DER hosting capacities, and reliability can all be increased significantly without expensive infrastructure upgrades. A simulation case study on TUPFC showed up to a 20% increase in demand growth is possible with the TUPFC and existing infrastructure, and currently a TUPFC is planned to be deployed in Georgia Power's distribution system by the end 2018.

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