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New Power Flow Controller for Congestion Management and Reliability in Transmission and Distribution System

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SUMMARY

Power-flow controllers which allow dynamic power flow control can reduce the need for building new distribution and transmission assets. Traditional technology solutions for controlling power flow on distribution and transmission corridors are either slow or very expensive. There is a need for new devices, which are economical and allow higher utilization of the network while maintaining the required reliability levels. Under the ARPA-E GENI program, Varentec has developed a low-cost compact dynamic phase angle regulator (CD-PAR) that can be used for distribution system and can eventually be also scaled for sub-transmission and transmission systems. The developed CD-PAR is a stand-alone device that integrates a relatively small-rated 3-phase transformer with an electronic power converter module that can be inserted in series with any transmission line. The device can control both active and reactive power flow in the line and is rated at a fraction of the power it can control. The CD-PAR is expected to be available at a significantly lower price compared with traditional FACTS devices.

This paper presents a succinct description of the CD-PAR technology and numerical examples to illustrate its application and benefits on transmission and distribution systems. Simulations were performed using EPRI's Open DSS and Siemens PSSE® simulation platforms. A fundamental frequency CD-PAR model for power-flow and transient stability analysis was developed in PSSE® and a detailed 3-phase model was developed for analysis in OpenDSS.

KEYWORDS

Power-flow controller, power electronic, congestion management, active power control.

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INTRODUCTION

High penetration of green energy sources, as dictated by Renewable Portfolio Standards, will dramatically increase the spatial and temporal variability on the grid, requiring significant new investment in transmission and distribution under current technology and policy. Dynamic power flow control technology is a viable solution enhancing grid utilization and enabling reliable integration of renewable generation. Traditional technology solutions for power flow control have been too slow or too expensive. Under the ARPA-E GENI program, Varentec has developed a low-cost compact dynamic phase angle regulator (CD-PAR) for distribution systems that can be scaled for sub-transmission and transmission system. The CD-PAR is a stand-alone device that integrates a relatively small-rated 3-phase transformer with a power converter module (mainly switches and capacitors) which can be inserted into any T-junction where a transmission line is tapped. The power converters and the custom-wound transformers, both with ratings that are a fraction of the power controlled, are designed for long life and maintenance-free operation. The 3-D schematics of the device and its topology as well as active and reactive power control range is shown in Figure 1. Currently, the prototype is sized and tested for the 12.47 kV voltage level with an active power control range of 1-2 MW. However, the device can eventually be scaled, once certain technological challenges have been overcome, for use at 69 kV to 230 kV transmission voltage level with a much larger active power control range [1][2][3].

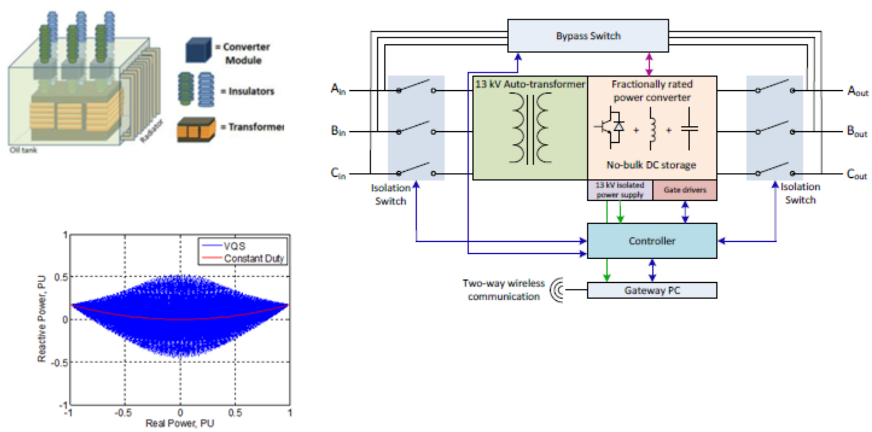

Figure 1: Conceptualized realization of CD-PAR with a thermal management system shared by both the magnetics and the converter and the P/Q Control Range.

Scenario 1: Transmission System Application

For transmission systems, the primary application of the CD-PAR is to reduce congestion on the grid by routing power flow through partially-loaded sub-transmission and transmission lines. Because the CD-PAR can control the power flow in a transmission line very fast, it can be used to quickly divert power flow from congested lines through partially-loaded sub-transmission and transmission lines right after a critical contingency has occurred (post-contingency or remedial control). Thus, CD-PARs reduce the need to constrain the power flow on key transmission lines in the pre-contingency state or normal operating conditions (preventive control). The device can also help in reducing loop flows, improve flexibility as well augmenting the Total Transfer Capability (TTC) on an interface. Besides the ability to control the flow of power in steady state mode, which is the main objective, the CD-PAR can also be used to enhance power system stability. For example, with addition of a properly-tuned power oscillation damping control loop, low-frequency oscillations in the system could be damped. The scenario presented in this sub-section illustrates benefits of using CD-PAR as a viable option to accommodate wind generation in a transmission-constrained power system [4][5]. The Alberta Interconnected Electric System, obtained from Alberta Electric System Operator (AESO) website, is used as an example study system [4] . The AESO's system model is open access and can be downloaded from their website www.aeso.ca. For demonstration of CD-PAR applications, a hypothetical wind interconnection scenario was considered. An interconnection request from an Independent Power Producer (IPP) for 350 MW of wind generation at Bus 267 (as shown in Figure 2) was assumed. Typically, as per wind interconnection feasibility studies, the limit of wind injection is evaluated under normal and contingency conditions. The power injection at any point in the network could be limited due to thermal overload, voltage violation, or any stability issues. For purpose of this analysis, only thermal constraints were considered. For any additional injection, system upgrades such as reconductoring or power routing would be required. The amount of wind injection is examined under representative contingencies at the locations indicated by ‘X’ in Figure 2. It was found that the outage of the 138 kV transmission line between Bus 267 and 674, as marked by blue ‘X’ in Figure 2, limits the wind generation injection to 215 MW due to thermal overload of the 138 kV transmission line between bus 267 and 266. One possible option to increase wind injection without overloading that line is to insert a CD-PAR in series with the line, as shown in the Figure 3, to divert power flow during contingency conditions through other lines with spare capacity. With such a control strategy, the wind injection can be increased from 215 MW to 335 MW.

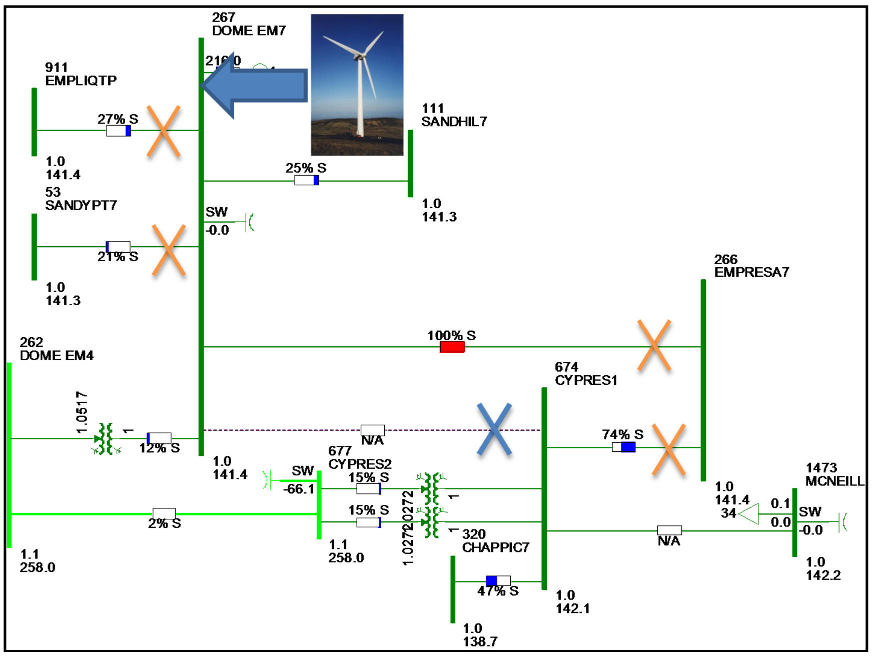

Figure 2: Single Line Diagram & List of Contingency

With CD-PAR, the limiting contingency is now changed as indicated by blue ‘X’ in Figure 3 and limiting element as marked by red ‘box’. Figure 4 shows the assumed hourly power output of a 350 MW wind plant. The wind data is obtained from National Renewable Energy Lab’s ‘Eastern Wind Dataset’. It must be noted that the wind output is not an indicator of actual performance of a wind plant in the study region within AESO footprint. The hourly power characteristic is used to quantitatively show the benefits of CD-PAR when used in wind integration planning. The red horizontal line in the Figure 4 shows the injection limit without the CD-PAR i.e. 215 MW and the green horizontal line show the injection limit with CD PAR i.e. 335 MW. With CD-PAR operating during N-1 conditions, the annual wind curtailment can be reduced from 174 GW to approximately 1 GW. However, this is possible only if CD-PAR operates during normal (N-0) conditions as well. During normal (N-0) conditions, the limit of wind injection is 300 MW as compared to 335 MW (with CD-PAR) during N-1 conditions due to thermal overload of transmission line between Bus 266 and 267. The injection limit is lower during normal condition as compared to the N-1 condition due mainly to the fact that long term emergency (LTE) thermal rating of the transmission lines used during an N-1 condition is much greater than the normal thermal rating of the line. To achieve the 335 MW limit, the CD-PAR must control the flow during the normal conditions every time power flow on the congested line exceeds the normal thermal rating. Thus, CD-PAR devices reduce the need to constrain the power flow on the transmission in the pre-contingency state or normal operating conditions. This case study highlights one of the most distinctive and important characteristics of CD-PAR, which is the ability control power flow not only on a very fast mode but also as frequent as needed.

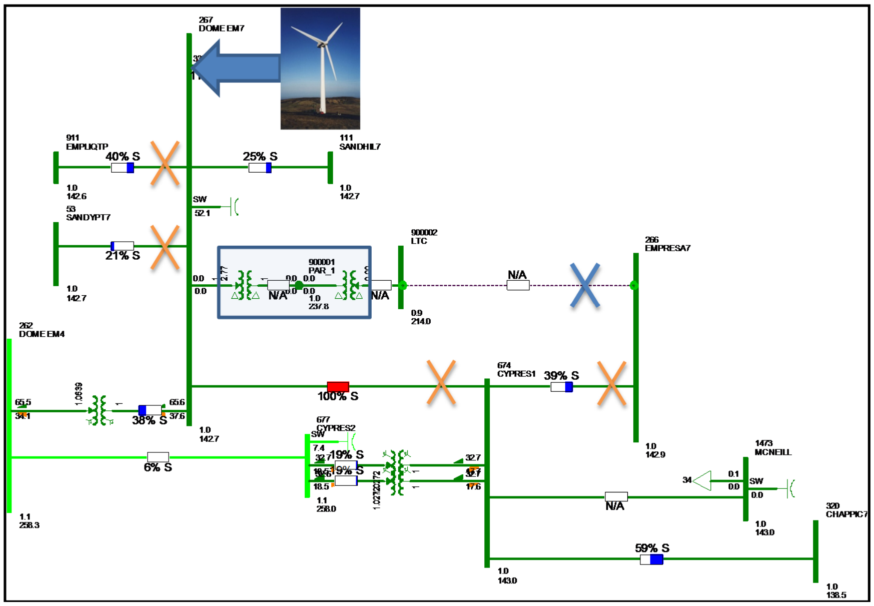

Figure 3: Wind Injection with CD-PAR under N-1 conditions.

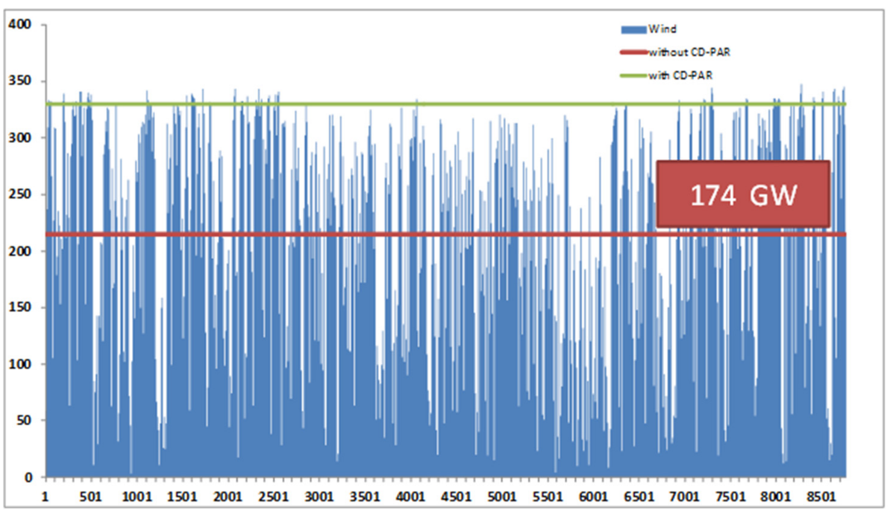

Figure 4: Hourly Output of a 350 MW Plant & Curtailment with and without CD-PAR

Scenario 2: Distribution System Application

For distribution systems, a CD-PAR device can be used to balance substation transformer loading. A common practice of utilities is to build two-transformer substations to serve 4 to 8 distribution feeders. This is done to improve reliability. For example, if one transformer is out of service the load can be transferred temporarily to the other ensure continuous supply of power to customers. An issue with this design often arises as the loading on one transformer exceeds it normal rating while the other transformer is loaded below rating. A CD-PAR device can be used at the bus-tie location to balance the loading on the two transformers either indefinitely or until additional capacity can be built. In addition, a CD-PAR device can be used to reduce loop-flows and negative flows in the distribution feeders. For demonstration, a CD-PAR was modeled in the OpenDSS software platform along with two models of actual distribution feeders [7]. The OpenDSS CD-PAR model consists of a full 3-phase transformer model connected as a phase shifter with continuously-variable taps to represent the smooth control action of the power converter. The two feeders are served from the Substations A and B as shown in Figure 5. The present condition of the feeder design has the two feeders tied together at a 480 V service to provide more reliable service to the customer with critical load at that location. Network protectors are installed on both feeders near the tie point to prevent power from flowing in the reverse direction into either feeder. The CD-PAR has the potential to replace the network protectors by providing more balanced, regulated power flow into the 480 V service. With the 480 V tie modeled ''closed', varying substation power flow can result in negative flows into one of the feeders at times. This will cause a nuisance trip of one of the network protectors and expose the critical load to less reliable service. Both the feeders are overcompensated with capacitor banks. Sub A load is slightly smaller than that on Sub B and is more overcompensated. Individual loads on both feeders have an average of 0.94 lagging power factor.

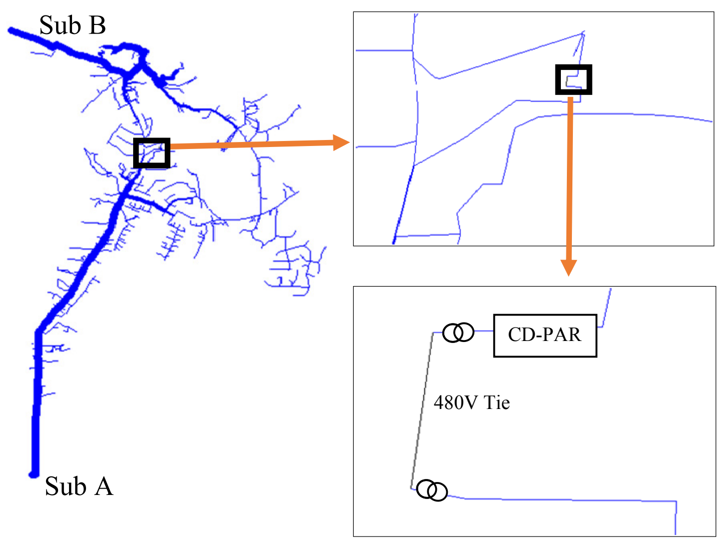

Figure 5. CD-PAR location in OpenDSS Model

There are two distribution system configurations considered for the CD-PAR application in this sub-section. The first configuration is to place the CD-PAR in series between the two feeders as illustrated in Figure 5. The second configuration is to place the CD-PAR at a substation distribution-side bus connecting two buses served from two different transformers. This configuration is illustrated in Figure 6. Even though the Sub A and Sub B feeders are not served from the same substation, they are used as the template for this configuration with the bus tie modeled open. The sensitivity study for each configuration adjusts the feeder base load, transmission voltage source phase angles, and reactive compensation to determine the capability of the CD-PAR to achieve desired power flows. The CD-PAR power flow control target for the feeder-end tie configuration (Figure 5) is set to provide equal active power to the 480 V load from both Sub A and Sub B feeders. The CD-PAR power flow control target is then modified for the connection at the substation bus. There are two methods to adjust power flow with the substation connection. The first method is to split the load evenly between the two transformers. This method is appropriate when the transformers are the same rating. The second method is to limit the power flow through one transformer. This method is appropriate when the two transformers have different ratings. The CD-PAR can transfer power when one substation transformer reaches its limit. For example, let's assume Sub B (Source) substation limit to be 9 MVA. If the required power flow is above the limit, the CD-PAR provides the difference from the other transformer. The reduction in power flow through the Sub B substation transformer, which is provided by Sub A feeder, assumes a 0.95 power factor. If the Sub B substation transformer power flow is not greater than the limit, the CD-PAR is assumed open and not controlling power flow between the two feeders.

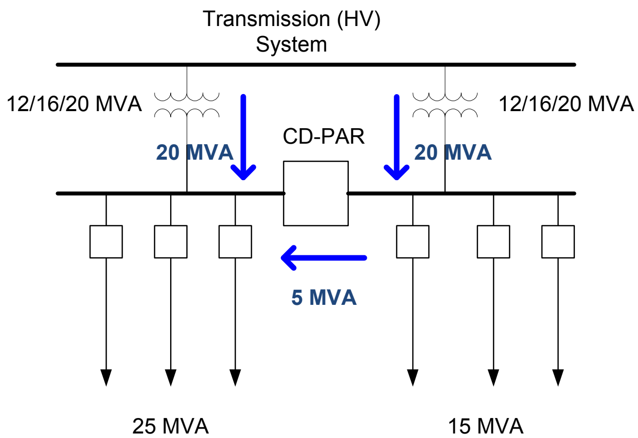

Figure 6: CD-PAR Application in a Distribution Substation

CONCLUSIONS

Under the ARPA-E GENI program, Varentec has developed a low-cost compact dynamic phase angle regulator (CD-PAR) for distribution systems, which can also be scaled for sub-transmission and transmission networks. The developed CD-PAR is a stand-alone device that integrates a small rated 3 phase transformer with switches and capacitors and can be inserted in series with any transmission line. The device can control both active and reactive power flow in the line. The CD-PAR is expected to be available at a significantly lower price compared with traditional FACTS devices. As shown above, the primary application of the CD-PAR is to reduce congestion on the grid by routing power through partially loaded sub-transmission and transmission lines. Because the CD-PAR can control the power flow on a transmission line relatively very fast, it can be used to divert power flow from congested lines through partially loaded lines after a critical fault has occurred, thus reducing the need to limit the transmission capacity of key lines during normal conditions . Therefore, the CD-PAR technology can be used to increase the transmission capacity of key transmission corridors, improving the utilization of the existing network components, and consequently reducing or deferring the need to build new transmission assets. Besides, the CD-PAR can be used to improve improving the utilization of distribution networks by balancing load among different feeders and substation transformers.

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