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Impact of New Voltage Optimization Strategies on Power Distribution System

Authors: Rahul Jha,[1] Deepak Tiwari,[1] Aleksandar Vukojevic[1] and Jeff Chapman [2]

[1] Commonwealth Edison Company
[2] 1898 & Co., Part of Burns & McDonnell

Presenter: Rahul Jha

Background

- Increased penetration of distributed energy resources (DERs) in distribution system
- DERs can create adverse conditions in sub-cycle time
- Conventional voltage control devices are slow operating devices, hence, we require faster voltage control devices
- DVAR-VVO is a device which can operate in sub-cylce
- Conservation voltage reduction (CVR) objective is to flatten the voltage towards lower voltage limit for energy saving
- Investigation of effects of single-phase capacitor banks over three-phase switching for CVR
- Combined control of DVAR-VVO with three-phase and single-phase switching for CVR

Introduction

- To increase energy saving, we need to expand our voltage optimization (VO) algorithm
- Current VO controls voltage regulator and capacitor banks (gang-operated)
- Single-phase capacitor bank switching controls each phase separately
- DVAR-VVO is a power electronics-based shunt-connected Static VAR Compensator devices
- DVAR-VVO has the capability to absorb and supply continuous reactive power
- This device can operate in multiple control modes like
    - VOLT-VAR curve mode
    - Voltage control mode
    - Power factor control mode
    - Reactive power mode
- This paper investigates only the VOLT-VAR curve mode
- The location of DVAR is based on the short circuit impedance of the node

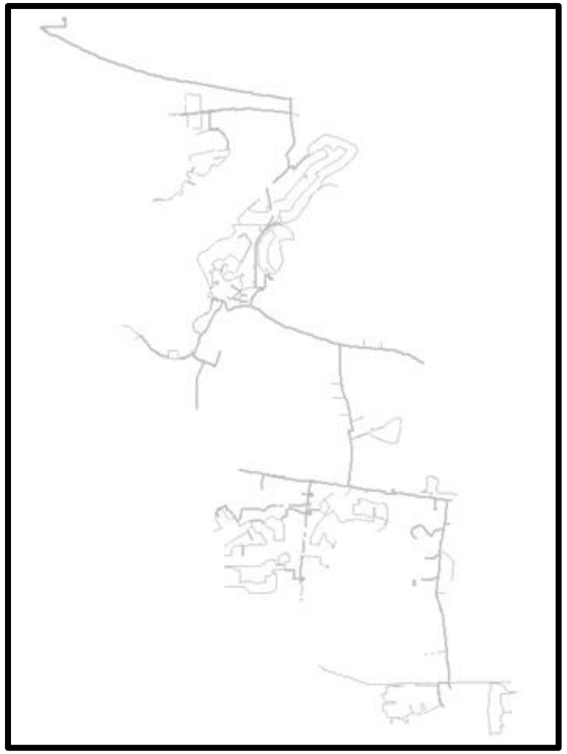
Different VO Techniques

- To evaluate the performance of different controllable devices following tasks are performed:
    - ➢ Baseline without advanced VO techniques
    - ➢ VO with three-phase capacitor bank switching
    - ➢ VO with Single-phase capacitor bank switching
    - ➢ DVAR-VVO and VO with three-phase capacitor bank switching
    - ➢ DVAR-VVO and VO with Single-phase capacitor bank switching

Circuit Model and Characteristics

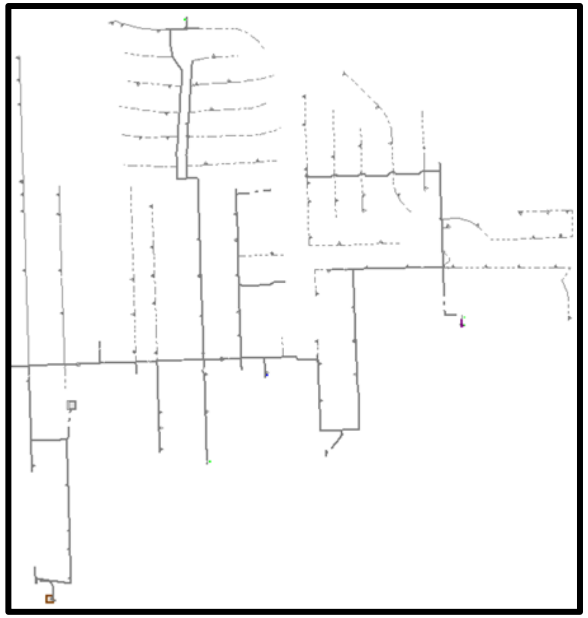
Circuit Selection

- **Feeder X**:
  - suburban/rural circuit operated at 12.47 kV
  - two Capacitor banks (1200 kVAR) and one line voltage regulator
  - substation load tap changer is modelled in CYME
  - total of 1853 nodes with 314 spot loads



- **Feeder Y:**
  - suburban comprises of both underground and overhead lines operated at 12.47 kV
  - total number of nodes 1150 with 256 spot loads
  - two Capacitor banks (1200 and 600 kVAR)
  - two wo-phase and one three-phase line voltage regulator
  - substation LTC is modelled in CYME

- **Feeder Z:**
  - densely populated urban circuit operated at 12.47 kV with two 4.16 kV section
  - total of 442 nodes with 136 spot loads
  - no line voltage regulators
  - six Capacitor banks (600 and 450 kVAR)
  - substation LTC is modelled in CYME



Optimization

- Conservation Voltage Reduction (CVR) from CYME is used for optimizing tap position and capacitor switch
- CVR objective – minimize active power demand, remove abnormal conditions
- CVR constrains – reactive power constrain at substation $0 \leq Q \leq 600$ kVAR
- DVAR is operating locally based on the Volt-Var curve
- Analyzed for a day in Summer, Winter, Spring and Fall

Results and Discussion

Feeder X

Season	Peak active demand (pu)	Peak active loss (pu)	VBI (%)	# Regulator Switching	# Capacitor Switching
Basecase					
Summer	6.153	0.103	0.47	7	-
Winter	2.395	0.102	0.18	2	-
Fall	2.539	0.102	0.24	4	-
Spring	2.187	0.102	0.20	1	-
VO with Three-Phase Capacitor Switching					
Summer	6.149	0.098	0.47	55	1
Winter	2.394	0.099	0.18	3	4
Fall	2.537	0.099	0.26	4	4
Spring	2.187	0.099	0.22	2	1
VO with Single-Phase Capacitor Switching					
Summer	6.149	0.098	0.48	57	2
Winter	**2.396**	0.098	0.21	2	0
Fall	2.539	0.100	0.41	8	24
Spring	**2.188**	0.099	0.42	2	24
DVAR VVO and VO with Three-Phase Capacitor Switching					
Summer	**6.164**	0.098	0.49	50	4
Winter	**2.397**	0.099	0.21	1	0
Fall	**2.541**	0.099	0.25	4	0
Spring	**2.189**	0.098	0.21	2	0
DVAR VVO and VO with Single-Phase Capacitor Switching					
Summer	**6.154**	0.098	0.66	58	11
Winter	**2.396**	0.098	0.39	2	2
Fall	**2.539**	0.098	0.32	2	1
Spring	**2.188**	0.098	0.29	2	1

Discussion for Feeder X

- Increase in regulator tap changes from 7 to 50-60 times in a day during Summer
- In case III, for Fall and Spring there is increase in # of capacitor operation to 24 in a day
- Peak demand increased from base case as well as energy consumption increases with the introduction of DVAR
- Operation of cap banks and regulators are not impacted significantly with DVAR
- Loss at peak is reduced, however there is increase in energy loss for a day
- Increase in the active power demand and loss from case IV and V
- Voltage profile are tighter at cap location with the introduction of DVAR and single-phase capacitor switching
- Not much of the reactive power support by the DVAR
- Annually, peak demand increased from base case as well as energy consumption increases with the introduction of DVAR.

Feeder Y

Season	Peak active demand (pu)	Peak active loss (pu)	VBI (%)	# Regulator Switching	# Capacitor Switching
Basecase					
Summer	5.421	0.164	0.22	12	0
Winter	2.037	0.024	0.11	4	0
Fall	4.325	0.102	0.31	15	0
Spring	3.068	0.051	0.20	1	0
VO with Three-Phase Capacitor Switching					
Summer	**5.591**	0.149	0.23	45	0
Winter	1.968	0.023	0.11	47	1
Fall	**4.335**	0.094	0.29	35	1
Spring	3.008	0.047	0.19	12	1
VO with Single-Phase Capacitor Switching					
Summer	**5.591**	0.149	0.20	45	0
Winter	1.991	0.024	0.35	39	4
Fall	4.321	0.094	0.31	32	1
Spring	3.022	0.048	0.21	23	1
DVAR VVO and VO with Three-Phase Capacitor Switching					
Summer	**5.616**	0.154	0.27	44	2
Winter	1.957	0.024	0.12	25	0
Fall	4.300	0.094	0.27	33	4
Spring	2.981	0.049	0.19	10	6
DVAR VVO and VO with Single-Phase Capacitor Switching					
Summer	**5.550**	0.152	0.53	44	0
Winter	1.957	0.024	0.12	25	0
Fall	4.290	0.094	0.37	37	12
Spring	2.977	0.049	0.24	56	21

Discussion for Feeder Y

- Increase in regulator tap changes from 12 to 44-45 times in a day
- Voltage profile are not tighter at cap location with the introduction of DVAR and single-phase capacitor switching
- Larger reactive power support from DVAR at the peak load only for Summer
- Except for Summer there is reduction in the peak active power demand and loss for all cases
- Reduction in peak active power demand, power and energy loss for Summer, Fall and Spring from case IV and V
- Annually, peak demand and energy consumption reduces from base case also there is reduction in the value from case IV to V

Feeder Z

Season	Peak active demand (pu)	Peak active loss (pu)	VBI (%)	# Regulator Switching	# Capacitor Switching
Basecase					
Summer	5.492	0.076	0.24	0	0
Winter	2.387	0.014	0.17	0	0
Fall	1.552	0.006	0.13	0	0
Spring	1.571	0.006	0.12	0	0
VO with Three-Phase Capacitor Switching					
Summer	5.400	0.069	0.28	30	7
Winter	2.287	0.014	0.18	24	36
Fall	1.476	0.00622	0.14	6	0
Spring	1.493	**0.00632**	0.13	6	0
VO with Single-Phase Capacitor Switching					
Summer	5.400	0.069.03	0.61	10	7
Winter	2.245	0.01323	0.17	2	22
Fall	1.448	0.00602	0.51	0	3
Spring	1.464	**0.00910**	0.49	0	3
DVAR VVO and VO with Three-Phase Capacitor Switching					
Summer	5.310	0.068.36	0.25	8	12
Winter	2.223	0.01277	0.17	0	4
Fall	1.459	0.00625	0.13	0	0
Spring	1.461	0.00583	0.13	0	0
DVAR VVO and VO with Single-Phase Capacitor Switching					
Summer	5.307	0.06912	0.60	11	27
Winter	2.250	0.01357	0.18	4	0
Fall	1.460	0.00608	0.13	3	5
Spring	1.462	0.00577	0.51	3	5

Discussion for Feeder Z

- For Summer and Winter there is reduction in the voltage spread for each of the capacitor
- For Fall and Spring, case V increases the voltage spread
- Only for Summer, there is large reactive power support by DVARs
- Huge reduction in the # of operation of VRs from case II in case III, IV and V
- Reduction in the peak active power demand and loss for all cases when compared to base case
- Annually, peak demand and energy consumption reduces from base case, however there is increment in the value from case IV to V

Conclusion & Future Work

- Analyzed four types of voltage control algorithms for conservation voltage reduction
- Single-phase capacitor banks switching with DVAR-VVO is most effective in reducing the voltage gaps among the phase at a node
- Single-phase capacitor banks switching with DVAR-VVO is more energy efficient compared to other methods for most cases

Future work:

- To evaluate the performance of the DVAR-VVO by including it in the optimal power flow problem
- To analyze with multiple feeders with different load mixes, DERs locations and multiple DVAR-VVO

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Thank you