COORDINATED VOLTAGE CONTROL IN LV GRID WITH SOLAR PVS: DEVELOPMENT, VERIFICATION AND FIELD TRIAL

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ABSTRACT

The increasing share of distributed renewable energy resources may lead voltage violation problems in low voltage network. Though a number of smart grid solutions are developed, only very limited number of solutions are being implemented in real field. Therefore, in this paper, on-load tap changer based smart solution is verified using a real rural LV network in Slovenia. The field trial revealed that redundancy and cyber security are the main concerns for distribution system operator, which are addressed in this field trial.

INTRODUCTION

As countries try to achieve their green energy related targets, the share of distributed renewable energy resources (DRES) in low voltage (LV) networks increases. Since the existing LV networks are designed in a passive way with the uni-directional power flow from centralized power generation to the customers, the increasing share of DRES from the customer premise with possible bi-directional flows creates some technical problems e.g. overvoltage [1], [2]. Distribution system operators (DSOs) are putting effort to mitigate the overvoltage problem in their LV network in order to meet the quality of supplied power according to EN 50160 [3].

Besides using grid reinforcement or reactive power control or storage, recently, DSOs prefer using on-load tap changer (OLTC) equipped distribution transformer due to its affordable cost and less time consuming [4]. However, the conventional OLTC control based on the voltage at the substation busbar cannot completely solve voltage variations in the downstream LV network [5]. In this paper, a control concept called overlaying control for OLTC is proposed to solve the simultaneous overvoltage and undervoltage problem that occur in different feeders. The overlaying control acquires the real-time voltage measurements from the end busses of all feeders, and coordinates OLTC and power injection of solar PVs to maintain the voltages within EN50160 limits.

In [6], the proposed control is verified using the software simulation. In this paper, the proposed control is verified using a real rural LV network in Slovenia. The interviews with the experts from DSOs indicate that the main concern for DSOs is redundancy and cyber threat. Therefore, the following features are identified as requirements in order to test the proposed control in a real field trial, which are: cyber security and redundancy for communication failures. The cyber security concern is addressed by following the cyber security concept called "physical air gap separation" [7]. Whereas, the redundancy in case of communication failures is provided by coordinating the local control of transformer and the proposed overlaying control.

In this paper, the practical implementation challenges while implementing a new smart OLTC control is developed and experimentally tested. The test results are described in this paper.

PROBLEM FORMULATION

The limitation of the conventional control

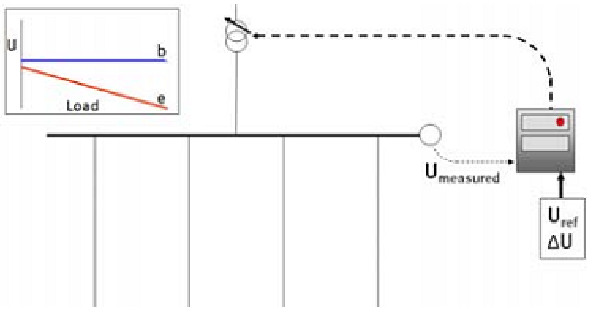


Fig. 1 A typical example for voltage regulation using OLTC

In this section, a classical control methodology of the OLTC equipped transformer is described. Let assume a transformer is equipped with an on-load tap changer, which is controlled by an automatic voltage regulator (AVR). This regulator measures the voltage at the secondary side of the transformer (U_m) and compare it with a reference voltage (U_{ref}). When the voltage difference crosses a deadband (ΔU) and it sustains for a predefined time period, the taps of the transformer are adjusted to regulate the voltage level [8], [9]. If a LV network consists of a feeder mostly connected to DRES and another feeder mostly connected only to loads. More details about this voltage problem is defined in [6].

Proposed solution

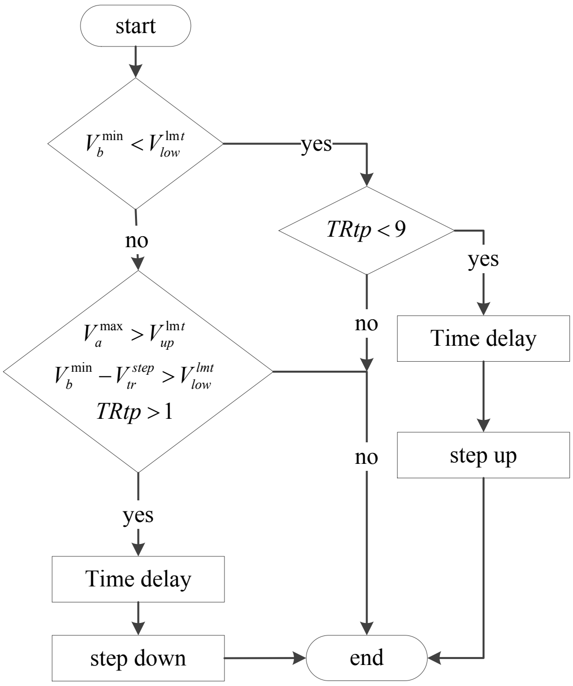


Fig. 2 The proposed overlaying control for OLTC

where V_a^{max}, V_b^{min} are the maximum and minimum voltages of the feeders (a,b - represents different feeders); $V_{up}^{lmt}, V_{low}^{lmt}$ are the predefined higher and lower voltage limits; V_{tr}^{step} is the voltage change per OLTC's tap position; $TRtp$ is the current tap position.

As can be seen from Fig. 2, the main function of this control method is that: if minimum voltage is lower than the limit, the OLTC is step up. In case the maximum voltage is higher the limit, there will be a check if step down will cause minimum voltage lower than limit. Since the OLTC can only be controlled symmetrically, therefore the positive sequence voltage is taken into account in the control algorithm. The calculation for the voltage is described as below with the assumption that three phase voltages are balanced with 120 degree angle between any two voltages.

CASE STUDY

Network

The single line diagram of the network under testing is shown in the following figure. The distribution transformer is 400 kVA 20/0.4 kV transformers that are equipped with 1.5% OLTC and 9 tap positions. Whereas, the installed capacity of PV systems is 210 kW_p. The PV connections points and few demand points are being monitored remotely using the network analyzers which are shown in the following figure.

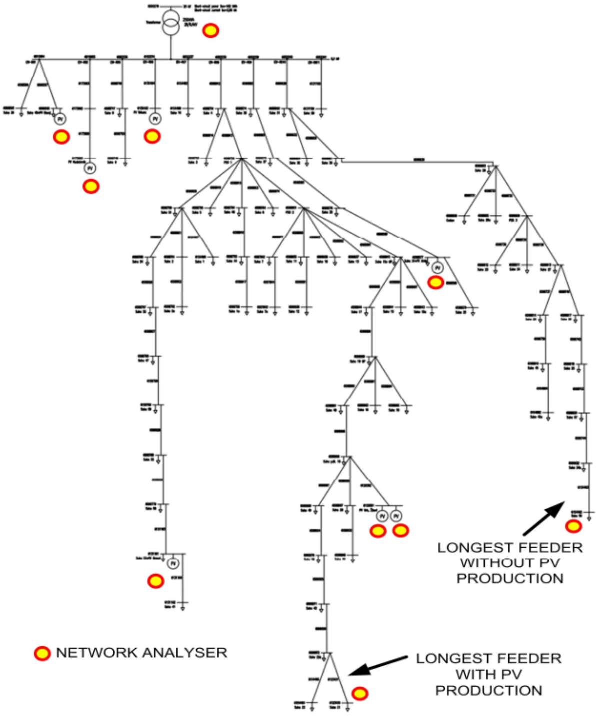


Fig. 3 The single line diagram of field trial

Implementation

Different communication protocols are used in the field trial. It is learned that the protocols used differs with manufacturers. In the field trial, the following protocols are used: DNP 3.0, WIMAX and OPC UA. Fig. 4 shows the communication link among devices in the field trial. The proposed control is embedded in a computer called TU/e PC that is connected to the SCADA system of DSO using OPC UA protocol.

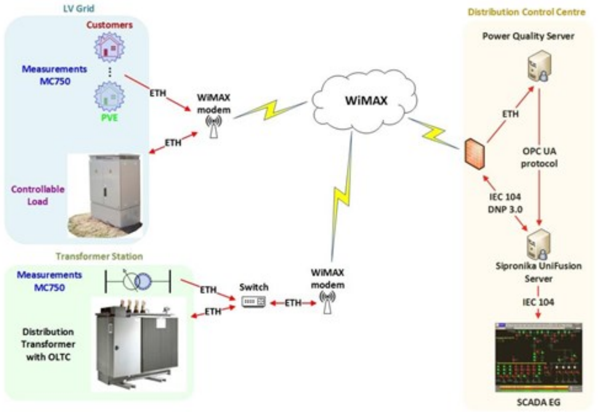


Fig. 4 Communication network of the field trial

A java-based OPC UA package is chosen to receive and send the monitoring and control signals respectively. Moreover, the JAVA programming language is chosen for the development because it is platform independent. Thus, it can be used easily implemented in other computers.

There are 10 locations in totals as shown in Fig. 3, in which there are 10 measurement quantities of each location. The measurement data are retrieved each 10s interval. The measurements are:

- 3 phase voltage magnitude
- 3 phase current magnitude
- Total active, reactive, and apparent power
- Power factor

OPC UA client

The communication link of client to server is built as non-security and run on the local personal computer that is connected to the same LAN network of the server. The communication link is further developed to work on the 256bit secured connection in order to satisfy the cyber security concerns of DSO . The algorithm implemented by the client is described as in the following figure.

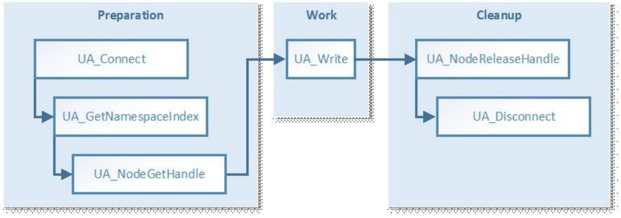


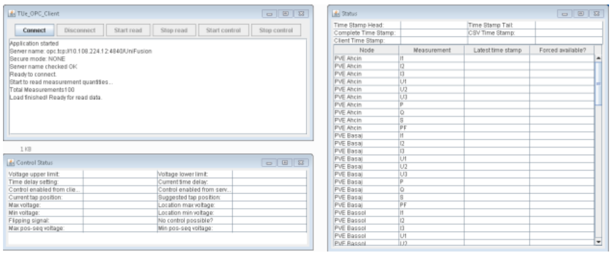
Fig. 5 OPC U/A client development

The test set up procedure

In order to carry out the test that the field, the Sipronika server is used as a central system and the client is developed using another dedicated computer for OLTC control machine located at the same network.

Client development

The OPC UA client is built with the specifications defined by the standard OPC, which composes of preparation, working (deploy control algorithm) and close the connection as shown in Fig. 2. Its graphical user interface (GUI) is shown as in Fig. 6.



```
Application started
Server name: opc.tcp://10.108.224.12:4840/UniFusion
Secure mode: NONE
Server name checked OK
Ready to connect.
Start to read measurement quantities...
Total Measurements100
Load finished! Ready for read data.
```

Voltage upper limit:		Voltage lower limit:	
Time delay setting:		Current time delay:	
Control enabled from clie...		Control enabled from serv...	
Current tap position:		Suggested tap position:	
Max voltage:		Location max voltage:	
Min voltage:		Location min voltage:	
Flipping signal:		No control possible?	
Max pos-seq voltage:		Min pos-seq voltage:	

Time Stamp Head:		Time Stamp Tail:	
Complete Time Stamp:		CSV Time Stamp:	
Client Time Stamp:			

Node	Measurement	Latest time stamp	Forced available?
PVE Ahcin	I1		
PVE Ahcin	I2		
PVE Ahcin	I3		
PVE Ahcin	U1		
PVE Ahcin	U2		
PVE Ahcin	U3		
PVE Ahcin	P		
PVE Ahcin	Q		
PVE Ahcin	S		
PVE Ahcin	PF		
PVE Basaj	I1		
PVE Basaj	I2		
PVE Basaj	I3		
PVE Basaj	U1		
PVE Basaj	U2		
PVE Basaj	U3		
PVE Basaj	P		
PVE Basaj	Q		
PVE Basaj	S		
PVE Basaj	PF		
PVE Bassol	I1		
PVE Bassol	I2		
PVE Bassol	I3		
PVE Bassol	U1		
PVE Bassol	U2		

Fig. 6 GUI of the proposed control

So far with the close cooperation between TU/e, Sipronika and Elektro Gorenjska, the overlay control method was successfully implemented and verified at Slovenian actual environment. The development process is listed as follow:

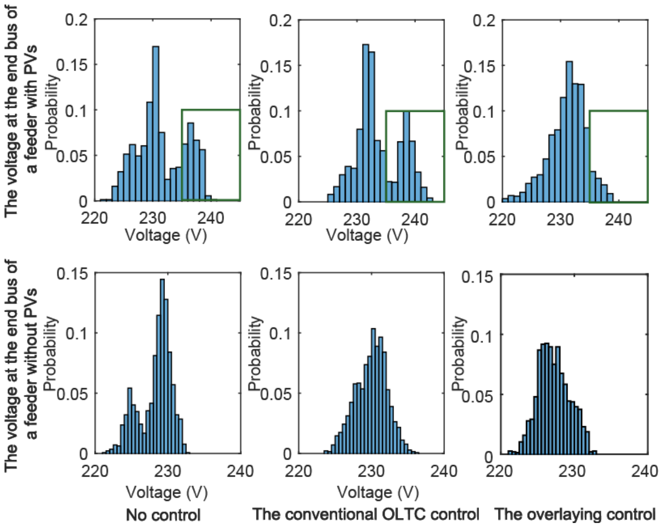
- Connect TU/e PC to the Sipronika server via OPC/UA
- Retrieve and log measurement data from Sipronika server
- Test the data quality, identify and solve possible data interruption problems
- Retrieve and log measurement data with sufficient quality
- Use the measurement data as case study material, test the OLTC control algorithm in simulation environment
- Trial overwrite OLTC position through OPC/UP protocol
- Implement OLTC control algorithm in field
- Upgrade connection from non-security to 256bit Sign & Encrypted
- Validate the outcome of OLTC control
- Modify the client to auto-start whenever PC restarts

Lessons Learned

Some difficulties faced from the beginning are the data interruption but it is soon resolved by the improvement of algorithm. For a given measurement, if the data interruption is less than 10 minutes, the missing values will be interpolated when the new data comes in. Otherwise, if the interruption is longer than 10 minutes, the measurement will be declared as unavailable until the new data comes in. In the data log the entries for the missing time stamps will be marked as NaN (not a number).

Another update at very end of progress is the reduction of 10 locations to 6 locations to be measured only. The results still show that the algorithm is easily modified to fit to the new condition and the communication problems.

4. MEASUREMENT RESULTS



No control The conventional OLTC control The overlaying control

Fig. 6 The result of the field trial

In the field trial, three different days with the same cloud cover were chosen to compare three control cases namely no control case, conventional control case and the proposed overlaying control. The corresponding results are shown in Fig.6. As highlighted by green box in Fig. 6, the overlaying control mitigated the voltage rise problem (>235 V) significantly than the conventional control. It can be noted that in case of communication failures the conventional control will take over the control of OLTC.

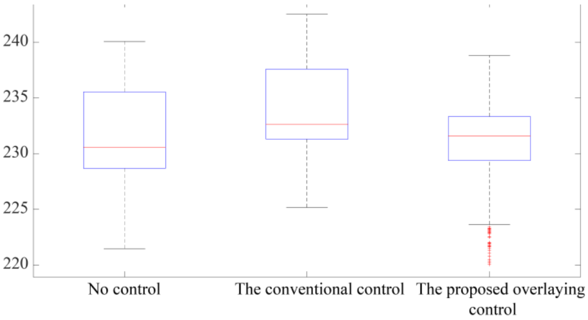


Fig. 7 The voltage at the end bus of a feeder with PVs

Fig. 7 shows that the proposed overlaying control reduces the voltage rize problem. Moreover, the number of changes in the tap position of OLTC are same for both overlating control (TU/e) and the conventional control (OLTC), which is shown in the following figure.

CONCLUSION

The field trial revealed that the new smart grid solutions should incorporate cyber security and redundancy features. Thereby, it can be deployed in real-life easily. The field trial of this paper proves that new smart grid solutions can be implemented in real-life application once the developers addresses concerns of distribution system operator. Moreover, since the proposed solution is developed using machine independent JAVA, the proposed solutions can be modified and updated easily.

In future, the field trial will be extended to test the coordination of active power output from PVs and OLTC operation.

ACKNOWLEDGEMENT

This research has received funding from the European Union's Seventh Framework Programme for research technological development and demonstration under grant agreement no 608998 - INCREASE project.

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