Identifying the Rating of the Unified Power Controller According to Unbalanced Distribution System Requirements

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- Intro
  - The main goal of the distribution system is to efficiently, affordably, and reliably transmit and distribute electrical energy to customers.
  - Technical indicators of the network include harmonics, phase balance, voltage regulation, rapid voltage rise, electrical losses, system security, and supply reliability.
- Unbalanced Loading
  - The most common cause of voltage imbalance in electric power systems.
  - Occurs when a three-phase electrical system has different amounts of current flowing in each phase.
  - Can cause problems such as voltage fluctuations and negative-sequence currents.
  - Can damage or reduce the efficiency of electrical equipment.
- Prevention
  - Unbalanced loads should be avoided as much as possible.
  - Voltage unbalance at the point where different systems are connected should not be more than 3%, according to Gost 2014 standard.

Unified Power Control (UPC)

One of the solution to the unbalanced condition is using the UPC.

- The UPC uses a device that is designed to generate balanced currents based on the load mode of operation.
- The symmetrical-component method is used to develop requirements and determine the UPC rating.
- Power flow analysis, employing the Newton-Raphson method, is conducted to deduce the device rating.

Main Contribution

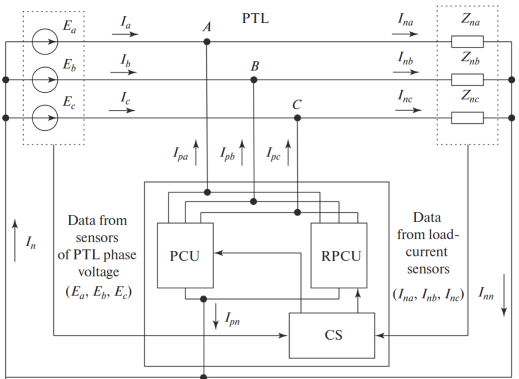
The main contribution of this paper is the determination of UPC rating. Therefore, the unbalanced distribution system is evaluated under different loading condition to assess its maximum need for power balancing provided by UPC. The effect of UPC may be only the balancing of active and reactive power between phases or the balancing of active power and the compensation of total reactive power required by the UPC-connected load. This paper evaluates the rating of the UPC in both modes of operation.

Agenda

3. Principle of Operation of the Designed UPC
4. Design Methodology of UPC
5. Case Study
6. Results and Implementation
7. Symmetrical Components
8. Conclusions

Principle of Operation of the Designed UPC

1. This device consisted of two units: PCU and RPCU.
2. These units are managed by a main CS
   1. measures the voltages and currents in the load phases
   2. calculate their powers and set control actions
   3. generate controllable parameters for uniform redistribution of active-load powers
3. Independent analysis is performed for each selected PCU and RPCU circuit.



Power Balancing Modes

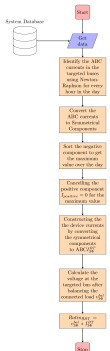
The first mode when the UPC compensates only the negative and zero current components, this leads to balanced active and reactive power flow.

$$\begin{aligned} P^*_{eq(a)} = P^*_{eq(b)} = P^*_{eq(c)} = \frac{P_t}{3}; \\ Q^*_{eq(a)} = Q^*_{eq(b)} = Q^*_{eq(c)} = \frac{Q_t}{3}; \end{aligned} \tag{1}$$

The second mode when the RPCU is activated through the compensation of the reactive part of the positive current component.

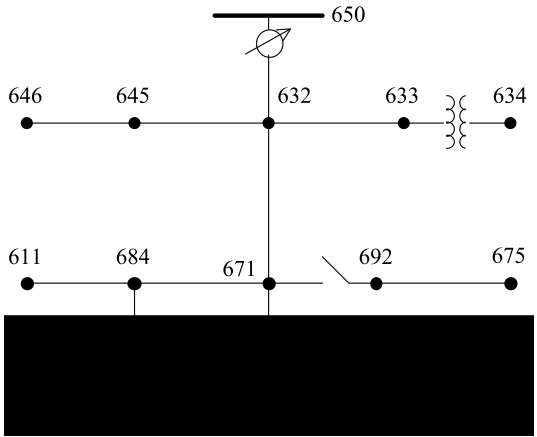
$$P^*_{eq(a)} = P^*_{eq(b)} = P^*_{eq(c)} = \frac{P_t}{3}; Q_t = 0 \tag{2}$$

- The rating of the balancing device is the apparent power determined from the maximum required currents and the maximum applied voltage of the device.
- the rating of reactive power part of UPC is defined by the maximum load reactive power.



IEEE 13 Bus System

The studied system is the standard IEEE-13 bus unbalanced system where the branch data and load data are fetched from sources. There are eight loads distributed over the system.



Proposed Location and Unbalancing Ratio

- The proposed devices are proposed to be installed at two buses according to the load flow study.
- The two three-phase buses that are heavily loaded in this system are buses #634 and #675.
- The method used in this study is the Newton-Raphson method to get the power flow study.
- The ratio between the voltage negative component and the positive component (unbalancing ratio) is used to assess the unbalanced ratio for the IEEE 13 bus system.

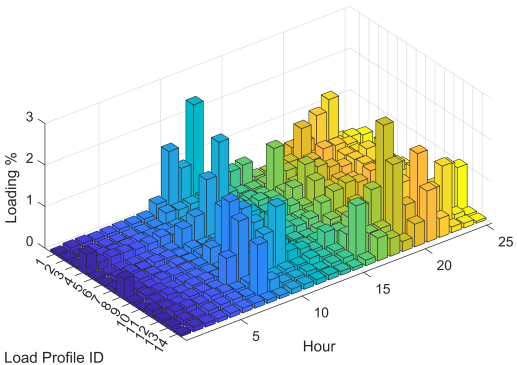
The unbalancing ratio is calculated as:

$$K_{Un} = \frac{\text{negative voltage component}}{\text{positive voltage component}}$$

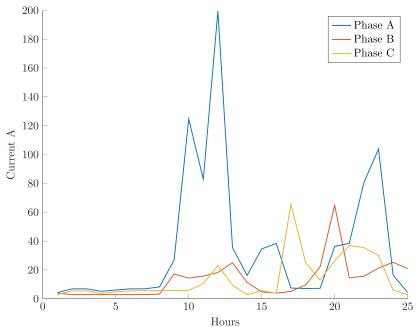
Adopted Standard Loads Profiles

The IEEE-13 loads are calculated every hour by multiplying the load profile with load profile ID by the base loads which are fetched from sources.

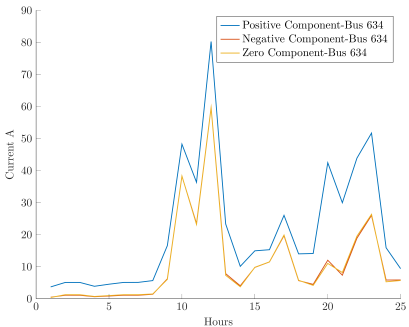
bus	Ph_A	Ph_B	Ph_C
634	1	2	3
675	5	6	7
671	10	11	12
645	4	-	-
652	14	-	-
646	-	9	-
611	-	-	8
692	-	-	13



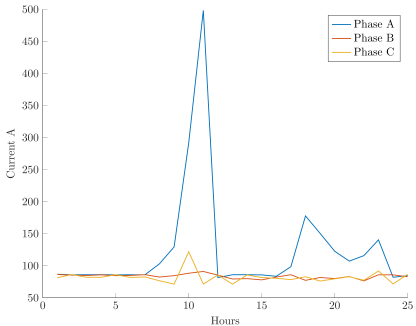
Three phases Currents in ABC at the bus 634



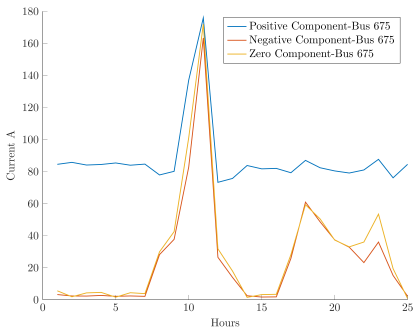
Symmetrical Components of the phases currents at the bus 634



Three phases Currents in ABC at the bus 675



Symmetrical Components of the phases currents at the bus 675



Results and Implementation I

1. The maximum negative component for the buses 634 and 675 are occurs at the hour 12 and 11, so at those hours the designing process will be executed.
2. The currents are determined in ABC, those currents for bus 634 are $(199.4503\angle -37.89°, 18.21\angle -157.74°, 23.15\angle 82.42°$ in A) and for bus 675 are $(498.37\angle -21.99°, 91.02\angle -35.88°, 71.31\angle 160.76°$ in A).
3. then they will be transformed to symmetrical components (positive, negative and zero). Those currents for bus 634 are $(80.27\angle -37.85°, 59.63\angle -39.299°, 59.58\angle -36.55°$ in A) and for bus 675 are $(175.9366\angle -5.38°, 163.4\angle -36.83°, 172.04\angle -24.7984°$ in A).
4. the positive current is cancelled to get the device currents in symmetrical components.

Results and Implementation II

5. To get the operational voltage for the device, the load flow study is performed under the condition of balanced loads at the targeted buses.

Table: Devices Currents and Voltages

	Bus 634		Bus 634	
Phases	I_{abc}^{device} (A)	V_{abc}^{device} (V)	I_{abc}^{device} (A)	V_{abc}^{device} (V)
A	94.00596-73.25664i	2494.6538-60.308477i	286.9612-170.1143i	2472.6235-101.66923i
B	57.4968+23.3597i	-1263.5945-2084.6448i	175.6171+90.08145i	-1370.3114-2021.4342i
C	-7.92083-56.5663i	-1146.0471+2179.1744i	5.952997-136.4432i	-1087.0207+2188.4788i

Results and Implementation

The resultant rating for the both of PCU is 0.589 MW or 0.6 MW for bus no 634, while the PCU for bus 675 is 1.64 MW, RPCU is designed to be equal to the installed load reactive power or higher at the bus. So, for bus 634, RPCU rating is 0.4 MVAR and for bus 675 is 0.6 MVAR.

Phasor diagram for the currents at the bus 634

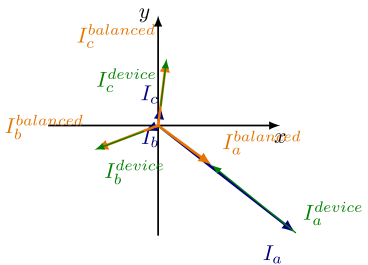


Figure: Phasor diagram for the currents at the bus 634 (blue is the load current, orange is the load current after balancing the operation, and green is the device current).

Positive, negative, and zero components at bus 634

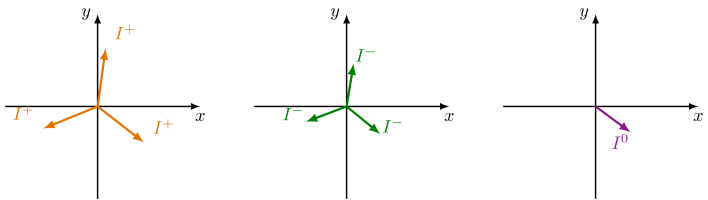


Figure: Positive, negative, and zero components at bus 634.

Phasor diagram for the currents at the bus 675

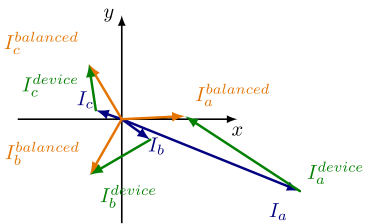


Figure: Phasor diagram for the currents at the bus 675 (blue is the load current, orange is the load current after balancing the operation, and green is the device current).

Positive, negative, and zero components at bus 675

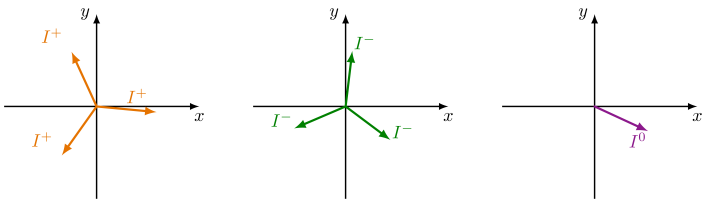


Figure: Positive, negative, and zero components at bus 675.

Conclusions I

- The design methodology of UPC device for power balance and reactive power compensation has been developed.
- This design methodology mainly depends on the identification of the unbalanced distribution system requirements.
- The distribution system requirements have been identified based on Newton-Raphson method.
- The developed methodology is used to determine the rating of both PCU and RPCU.
- The UPC device may be designed for only one purpose or multiple purposes (power balancing or reactive power compensation or both).
- The UPC rating identification has been applied on a standard IEEE-13 bus system loaded by standard load profile.

Conclusions II

- The developed methodology is represented as a general technique to be applied on any unbalanced distribution system if the essential system data (voltage levels, system configuration and load profile) are available.

Thank you!

Ready for questions.

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