Volatility Prediction and Management by Active Network Management & Future Generation Management

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Abstract— **The growing penetration of renewable generation in distribution network is upcoming area of focus for monitoring and controlling of the network by the operators. The frequent changes in distribution network are common, it becomes important not only to know if and when the volatility is going to happen but also to know whether the operator can resolve the volatility by available controls and resources.**

This decision making is fairly complex process for the operator if not supported by appropriate calculation and monitoring tools. Distribution System State Estimation and Active Network Management are essential components to assist the operator to execute this workflow. With the fairly accurate generation and load forecasting it is possible to estimate the current status of the network as well as to estimate the state of the system for following period of time.

A semaphore model is used to represent the network state in more effective visual and logical presentation. It uses three discrete semaphores with different colors to reflect the state of the system and to alert the operator indicating how relatively fast the operator has to response in order to resolve the actual and anticipated volatility.

Keywords- ***distribution system state estimator, Active Network Management, semaphore, distriubuted generation***

I. CURRENT SITUATION IN DISTRIBUTION GRIDS IN INDIA AND THE CHALLENGES WITH UPCOMING RENEWABLE TRENDS

The current majority of distribution network in India has the 11kV distribution feeders originating from a substation transformers like 33/11 kV, 132/11 kV and etc. The substation has well telemetry at voltage levels 132 or 33 etc and 11 kV substation feeders are monitored. This telemetry includes the Active Power, Reactive power, voltages and digital statuses and is made available in SCADA at control center for monitoring. The substation is equipped with measuring and transmitting equipments while the below network is not completely equipped with the measuring and the transmitting equipments. The distribution generation is expected to penetrate more and more in future distribution network. This factor becomes important when the direction of power flow in the network is bidirectional at different time instances arising from the power contribution by the distributed energy sources.

II. DISTRIBUTION SYSTEM STATE ESTIMATION

Distribution System State Estimation (DSSE) as a part of a Distribution Management System control center runs 24/7. The Distribution System State Estimation provides state information about the network in real time. Distribution System State Estimation is triggered by any topological or significant measurement value change. As a primary output Distribution System State Estimation provides detailed current, voltage and power information about every single element in the network [2]. Other than this, as the most relevant data for the dispatcher i.e. distribution network operator, secondary results are given providing a big picture of the network status.

Those data include:

- Alarms – Critical network states which require immediate dispatcher intervention
- Limit Violations – Subset of equipment which might have voltage or thermal violation
- Total Power P and Q – Energy exchange with the Transmission Grid Operator
- Power factor – Energy exchange with the Transmission Grid Operator
- Reserve state – Ability to provide ancillary services

A. Distribution System State Estimator Algorithm

The estimation problem is mathematically defined as a minimization of the objective J described by the equation (1). The goal is to provide nearest estimates to given measurement set consisting of power measurements (1st row), pseudo power measurements at load groups (2nd row), current magnitude measurements (3rd row) and voltage magnitude measurements (4th row). Additionally the following equality constrains must be fulfilled:

- Sum of estimated active power within the area including estimated power at real and pseudo measurements and active power contributed by generators covers power losses (2)
- Sum of estimated reactive power within the area including estimated power at real and pseudo measurements and reactive power contributed by capacitors covers power losses (3)
- For each measurement area having a P and Q pair calculated from current magnitude measurement estimated PcE , QcE , IcE and Vc must fulfill (4).

$$\mathrm{J} = \min \begin{bmatrix} \sum_{i=1}^{NPQ}\left[W_i^{PM}(P_i^E - P_i^m)^2 + W_i^{QM}(Q_i^E - Q_i^m)^2\right] & + \\ \sum_{i=1}^{NLG}\left[W_i^{P,LG}(P_i^{E,LG} - P_i^{LG})^2 + W_i^{Q,LG}(Q_i^{E,LG} - Q_i^{LG})^2\right] & + \\ \sum_{i=1}^{NI} W_i^{IM}(I_i^E - I_i^m)^2 & + \\ \sum_{i=1}^{NI} W_i^{VM}(V_i^E - V_i^m)^2 & \end{bmatrix} \quad (1)$$

$$\sum_{i=1}^{NMK} P_i^E + \sum_{i=1}^{NGK} P_i^{Gen} - \sum_{i=1}^{NLGK} P_i^{E,LG} - P_{loss}^k = 0 \quad (2)$$

$$\sum_{i=1}^{NMK} Q_i^E + \sum_{i=1}^{NGK} QP_i^{Gen} - \sum_{i=1}^{NLGK} Q_i^{E,LG} - Q_{loss}^k = 0 \quad (3)$$

$$(P_c^E)^2 + (Q_c^E)^2 + (V_c I_c^E)^2 = 0 \quad (4)$$

NPQ , NI	total number of power and current measurements respectively
NLG , $NLGK$	total number of load groups and load groups in area k
NMK	number of P-/Q- pairs converted from currents in area k
NGK , NCK	number of generators and capacitors in area k respectively
w_i^{PM} , w_i^{QM} , w_i^{IM}	weighting factors for active, reactive power and current measurements
P_i^E , Q_i^E , I_i^E ,V_i^E	estimated active and reactive power, current and voltage related to the i-th measurement respectively
P_i^m , Q_i^m , I_i^m ,V_i^m	measured active and reactive power, current and voltage respectively
$_{wi}P, LG$, $_{wi}Q, LG$	weighting factors for active and reactive power of i-th load group
k_i^P , k_i^Q	estimated scaling factors for power of i-th load group
P_i^{LG} , Q_i^{LG}	active and reactive power of i-th load group
P_i^{Gen} , Q_i^{Gen}	active and reactive power of the i-th generator
P_{loss}^k , Q_{loss}^k	power losses in area k
V_c , P_c^E , Q_c^E , I_c^E	voltage and estimation results for a current converted to power

III. LOAD AND GENERATION MODELLING

A. Data sources

Load data is usually obtained from several different sources such as Accounting data, Sampling and load classification, Automated Meter Readings (AMR) and Advanced Metering Infrastructure (AMI). Except for the AMR and AMI sources which are accurate but come late to the system, load data is mostly unreliable, and not well maintained. Although the State Estimator handles even very large discrepancies between initial load values and the real/estimated measurements, this difference should be as small as possible. The Short Term Load Scheduler (STLS) is utilized to reduce the number of iterations in the subsequent estimation process. Most important to note is that STLS works with real time Distribution System State Estimation (DSSE) in negative feedback, see Figure 1. STLS is also considering the reliability of DSSE results by calculated trust factor.

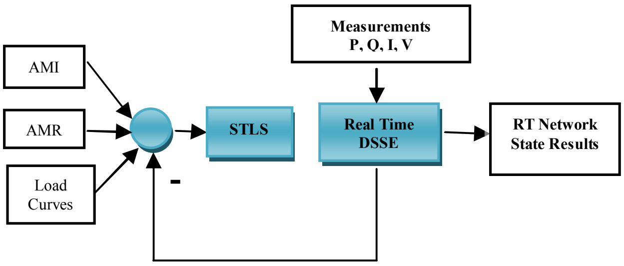


Figure 1 - Load data preparation in STLS

Figure 2 shows data for one load and the difference between the static data and STLS profile [4]. A Distribution System Operator can make fairly good load scheduling for the entire network, but with STLS application it is done for every single load which makes the end result of the whole network much more precise.

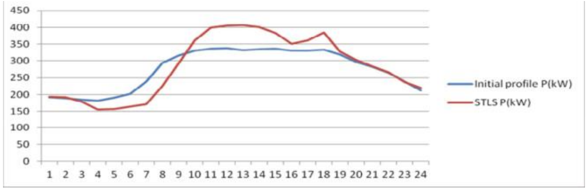


Figure 2 - Comparison Graph showing a difference between scheduled and STLS data after several weeks period

B. Load weight factors

The STLS constantly updates the load group values and improves the load group curves as see in fig 2. However it requires a classification of loads which can allow different grades of freedom to update the load group values. This is achieved by classifying the loads and assigning the weighing factors to the active and reactive part of loads.

Load Type	**Weighing P**	**Weighing Q**
Non-conforming Load	High	High
Conforming Load	Low	Low

C. Generation Model

While in the past all loads were supplied by large central plants with the increase of renewable more and more generation is available in the distribution networks. This is mainly related to wind, photovoltaic and biomass. Considering a limited number of such plants in the past mostly a modeling for renewable generation was applied as it was performed for loads, a static curve model. But with the increasing amount of renewable generation, weather conditions are more and more influencing production and so load flows. Integration of generation forecast data into the

Distribution System State Estimation provides high additional value with regard to accuracy of results.

IV. ACTIVE NETWORK MANAGER

While Distribution System State Estimation provides an actual status of the grid, the task remains to check if one will be able to resolve potential network instabilities and to select the countermeasures. This is the task of Active Network Management (ANM). The Volt/Var Control (VVC) [5] [6] application of Active Network Management calculates and simulates all required control actions to achieve the given objective functions.

A. VVC

VVC control equipment includes generators, on-load tap changers, capacitor banks, batteries and controllable loads. Volt/ Var Control is a mathematically reduced dynamic gradient method used for the optimization procedure. The objective function value is determined from the power flow solution given the settings of the control variables. Optimization consists in minimizing an objective function of one major and several minor sub-objectives:

1. Minimal limit violation (the mandatory basic sub-criterion)
2. Combination of the two – minimal limit violation and one of the following:
    - Minimal power losses.
    - Minimal active power (or demand) consumption.
    - Minimal reactive power (or demand) consumption.
    - Maximal revenue

Furthermore, minimal limit violation presents the basic sub-criterion and consists of following:

- Minimal voltage deviation.
- Minimal transformers overload.
- Minimal feeder overload.
- Minimal power factor violation
- Minimum cost of corrective actions

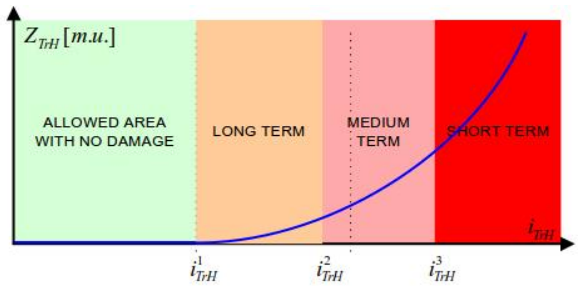


Figure 3 - Minimal Transformer overload sub-criterion

Based on this sub-criterion, the quantification of deviations from optimal values is performed. Optimal values are considered to be the ones that are within allowed limits (e.g. within technical limits). Figure 3 shows transformer violation areas. Values that are violating limits can be classified as follows:

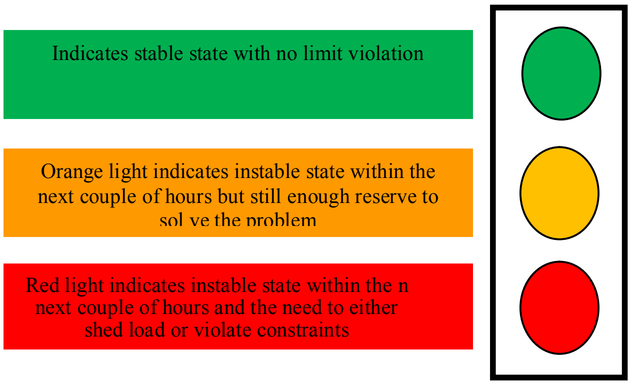
- Long-term violations - Values are allowed to violate limits for long period
- Medium-term violations - Values are allowed to violate limits for specified period
- Short-term violations - Values have to be corrected very fast.

Based on how serious deviations from optimal values are, penalty factors (e.g. cost) are defined. The penalty factors values for the medium term areas are greater than the values for the long term areas, and are less than the values in the short term areas.

V. VISUALIZATION CONCEPT

A. General approach

A semaphore model is used both as logical and visual presentation to mediate the obtained network state information in a user friendly and comprehensive way. The three discrete states reflect the network state and Distribution System Operator’s ability to resolve the actual and anticipated volatility. This semaphore model is reflecting the so-called semaphore concept and is both concerned about the current and the near future (predicted) state. The colored semaphore indicates the relativity of the speed of the response by the operator for securing the network operation. The signal states can be defined as follows:



Indicates stable state with no limit violation

Orange light indicates instable state within the next couple of hours but still enough reserve to solve the problem

Red light indicates instable state within the n next couple of hours and the need to either shed load or violate constraints

The calculation of the semaphore status is shown in Figure-4. As long as the network state is in green zone, only DSSE simulation is done (Step 1). If a potential volatile network state is determined, VVC is simulating counter measures by engaging available controllers, such as remote load tap changers, capacitors, batteries as well as controllable loads and distributed energy resources. If these countermeasures resolve the network state the semaphore is set to orange. If it is not possible to resolve the network state, an alarm is issued for the operator and all necessary information is provided for further analysis. The process of generating the semaphore can be expressed mathematically through a discrete objective function as shown in (5). The total objective function is calculated as normalized figure and based on the predefined border value Gzone a semaphore state is determined.

The process of determining the semaphore state is done through the network state simulation algorithm which is shown on Figure 5. Here it can be seen that in Step 1, and as long as the network state is in green zone, only Distribution System State Estimation simulation is done. When a potential volatile network state is determined, Active Network Management is engaged to simulate the control equipment. Active Network Management will try to resolve the given state whether it is limit violations or something else, by engaging available controllers, such as remote load tap changers, capacitors and batteries. If Active Network Management succeeds to bring back the network state into green zone the semaphore is shown in orange state and a timestamp of the simulation is saved. If Active Network Management is unable to resolve the network state, an alarm is issued for the operator which then needs to analyze the data and find a solution.

The process of generating the semaphore can be expressed through a discrete objective function presented in (5). Total objective function is calculated as normalized with every DSSE simulation and based on the predefined border value Gzone a semaphore state is determined:

$$Ztot = W_{li} * Flimits + Wlo * Floading + WR * FR + WPF * FPF \qquad (5)$$

Where:

W_{li}, *Wlo* , *WR*, *WPF* – weighting factors for respective sub-objectives *Flimits* – V, I, P, Q and cos(φ) limit violations
Floading – Total loading of network
FR – Reserve status (e.g. battery state of charge, capacitor and load tap changer potential)
FPF – Power factor measured at feeder-head or injection source

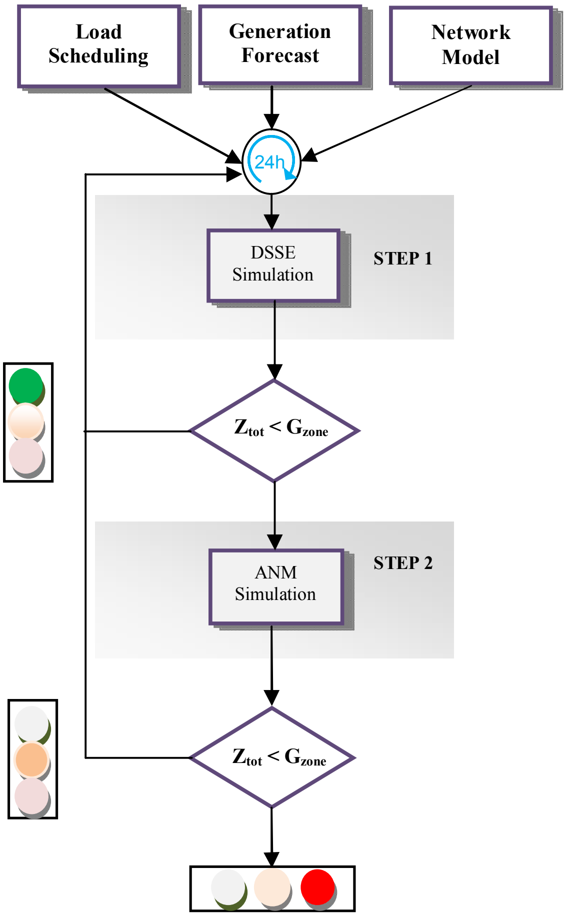


Figure 4 Calculation of semaphores

VI. SAMPLE VISUALIZATION FOR OPERATOR

The semaphore can be presented to the operator as shown in Figure 5.

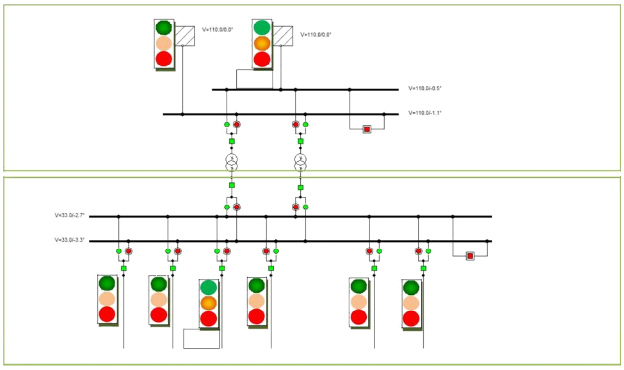


Figure 5 Operator view

Apart from the given semaphore visualization above, a Distribution Management System offers a more detailed view for the operator, where every single equipment with the violation can be shown (figure-6)

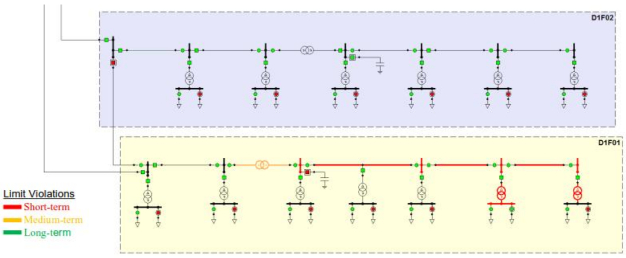


Figure 6 Detailed operator view

VII. FUTURE- GENERATION MANAGEMENT IN DISTRIBUTION NETWORK

After the implementation of automatic generation control in transmission network, the potential of generation management is foreseen in distribution network as well. In distribution network as the number of renewable energy sources increases and hence the need to optimize the renewable and non-renewable sources.

Generation Management GM controls ON/OFF statuses, active and reactive power of the distributed resources that include distributed generation and storage. The distributed generation can be renewable (e.g. solar, wind) or non-renewable (e.g. micro turbines, fuel cells, diesel generators).

The active power control strategy is primarily determined based on the operating objective provided by the user. The reactive power control strategies can be predetermined for grid connected and islanded mode of operation by the user. The GM can take actions such as increasing or decreasing generation autonomously in response to abnormal situations like low or high voltage violations in the network. The GM can be parameterized to support various active and reactive power control modes of various types of distributed resources.

In islanded mode of operation the GM can provide automatic voltage control in the microgrid. If configured, the GM can calculate regulation and control the import/export with the main grid in connected mode of operation; while in islanded mode it can provide frequency regulation.

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