Adaptive Zoning in Coordinated Voltage Control System Applications for TNB Network System

Nira Saadun
nira@tnbr.com.my

Ir. Sheikh Kamar Sheikh Abdullah
sheikh@tnbr.com.my

Mohd. Khairun Nizam Mohd. Sarmin
knizam.sarmin@tnbr.com.my

Muhamad Tarmizi Azmi
muhamad.tarmizi@tnbr.com.my

Department of Power System
TNB Research Sdn. Bhd
Bangi, Selangor Darul Ehsan, Malaysia

Abstract — Optimal management of voltage devices and reactive power resources is one of the most challenging tasks in power grid operation. A Coordinated Voltage Control (CVC) scheme is a hierarchical voltage control structure that used to coordinate and optimize the voltage control in order to improve security, quality and economy in system operation. The hierarchical voltage control structure is consists of Tertiary Voltage Control (TVC), Secondary Voltage Control (SVC), and Primary Voltage Control (PVC) modules. This paper will focus on one of the key area in Tertiary Voltage Control (TVC) module which is known as Adaptive Zone Division (AZD). The AZD module capable to divide the power grid into decoupled control zones according to the power grid operation condition. Hence, a hierarchical clustering algorithm is the key method to solve the problem of power network zone division. Furthermore, this paper presents the method to identify pilot bus for each control zone. The simulation of adaptive zone division and pilot bus identification is tested on several snapshots of TNB network system by using adaptive zoning in Coordinated Voltage Control system application. The idea of CVC and AZD implementation in TNB network system has contributed huge benefits especially toward the efficiency of system operational control.

Keywords - Coordinated Voltage Control; Tertiary Voltage Control; Adaptive Zone Division; Hierarchical Clustering Algorithm; Pilot Bus.

I. INTRODUCTION

Tenaga Nasional Berhad (TNB) is the largest power utility company in Malaysia which responsible for power generation, transmission and distribution for the peninsular Malaysia with the generation capacity of 21,600 MW and the maximum demand of 16,500 MW. The transmission grid system in Malaysia is divided into four voltage control regions, namely North, Central, South, and East. Faced with the evolution of the network and operating conditions, a better management of the voltage profile and reactive power is essential in order to optimize the security of the electric power transmission system and the use of reactive resources. Hence, the idea of CVC generates potential in improvement of voltage control in Malaysia.

In the previous century, the hierarchical coordinated voltage control system has been widely deployed especially in Europe. In France, Secondary Voltage Regulation (SVR) has been adopted based on zone divisions and pilot buses concept [1]. At higher hierarchical control architecture, Tertiary Voltage Regulation (TVR) is applied as a kind of system-wide optimization control and provides reference voltage to pilot buses. This architecture was extended to Italy. In Italy, the closed-loop of voltage and VAR control is realized by National Voltage Regulator (NVR), Regional Voltage Regulator (RVR), and power plants Voltage and Reactive Power Regulator (REPORT). TVR is used to increase power system operation efficiency by coordinating RVRs in real-time [2]. At RWE, a two-level system-wide AVC system based on optimal reactive power flow (ORPF) without zone division was implemented in Germany [3]. Other power grids that are implementing automatic voltage control system including in Tokyo Electric Power Company (TEPCO) [4] and South Africa [5]. Recent years in China, a closed-loop, automatic voltage control (AVC) technique has been developed. The control zones of hierarchical AVC system are determined based on online AZD which allows the control zones to be redefined adaptively according to the variation of power systems [6].

II. VOLTAGE CONTROL PRACTICE IN TNB

In Malaysia, the transmission voltage networks are 500kV, 275kV and 132kV, whilst the distribution voltages are 33kV, 11kV and 400/230 Volts. However, in the case of certain parts of Johor and Perak the distribution voltages may include 22kV and 6.6kV. Malaysia National Grid is also interconnected to the transmission network of the Electricity Generating Authority of Thailand (EGAT) through a 117 MVA, 132 kV Single Circuit Line, which has since been...
upgraded to a HVCD line. The Grid also is connected to Singapore Power Limited (SP) through a capacity of 250 MVA – 230 kV transmission lines and submarine cables. These significant connections provided TNB the first evidence of rudimentary ASEAN grid on the map.

Currently, primary voltage controls in the Grid are carried out automatically by using generating units, SVCs, and on-line automatic transformer tap changers. Only limited number of this equipment can be controlled directly from the National Load Dispatch Centre (NLDC) and therefore, in the usual practice, system control operators would instruct station operators to perform the control locally.

For secondary voltage controls, several means are available including manual switching in and out of shunt capacitors/reactors, reconfiguration of network, and manual controls of transformer tap-changers. Secondary voltage controls are carried out by control operators based on a set of guidelines and taking the necessary actions accordingly. Since the guidelines are broad in nature, control actions could vary from one operator to another depending on experience, system information and knowledge.

In TNB, the transmission voltages are maintained within the operational range of 1.0 to 1.05 per unit during steady state and 0.95 to 1.10 per unit during emergency condition. The 500/275 kV and 275/132 kV auto-transformer tap changers are sparingly adjusted to ensure reactive power flows from high voltage side to the low voltage side and the reactive flows are kept to be minimum. In addition, tap changer controls are applied when voltages are observed at the extreme of the declared ranges. Meanwhile, generator units are operated to continuously maintain their terminal voltages via automatic voltage regulators (AVR). If required, the generator transformer on-load tap changers will be adjusted to achieve the desired high-side bus voltages.

In conjunction with the fast growing network, more equipment is required to be coordinated and controlled. With respect to reactive power and voltage control resources, the operator at TNB control center currently has access to the following equipment:

- 129 generating units.
- 61 shunt capacitor banks.
- 67 shunt reactors.
- 2 Static VAR Compensators.
- More than 250 transformers with on-load tap-changers.

Analysis of voltage profile across the network revealed a large variation in voltage magnitude geographically which would result in significant reactive power transfer incurring additional losses. A CVC system based on AZD refers to an approach in which secondary voltage control is carried out automatically using a control system that would coordinate the various voltage control equipment to achieve a desired pilot bus voltages. Therefore, CVC system is chosen to improve voltage control practice, voltage profile and hence to further enhance TNB system operation.

III. METHODS AND TECHNIQUES

A. Identify the Optimum Zone Number and Zone Division

The AZD module capable to divide the power grid into decoupled control zones according to the power grid operation condition. The method for dividing a power grid into weak – coupled control zones starts by finding the optimum number of zone division. Based on the sensitivity of voltage with respect to reactive power output, the electrical distance between two nodes is calculated. Hence, a hierarchical clustering algorithm is the key method to solve the problem of power network zone division. It is a method of merging the zones step by step according to the zone distance. These procedures are characterized by the construction of a hierarchy or tree-like structure. It is interesting to notice that reasonable number of control zones can be determined automatically according to characteristics of variation merging distance through clustering process. For the best zone division result, each zone partition should have sufficient reactive power resources to control its own voltage. In addition, the control action in a zone should have limited influence to the voltage outside its region. In this paper, the hierarchical clustering method is carried out by initially each node is a zone and in each step, the closest two zones where in terms of zone distance are merged into one until all nodes have finally been merged into a single zone.

To identify the generators which participate in regulating the voltage within the zones, it proposed to use of information on the sensitivity of voltage to reactive power change. Each generator should only be participating in one voltage control zone and it is associated with one or multiple pilot node. At the same time, the more generators participating in voltage control, the better the voltage regulation performance would be.

The process to identify optimum number of zone starts with the sensitivity of the $i$th node’s voltage with respect to the $j$th reactive power source’s output and is denoted as $S_{ij}$. The reactive power control space is defined as a $g$ – dimensional Euclidean space spanned by the $g$ reactive power sources, and each load node can be described by a coordination vector $(x_{i1}, x_{i2}, x_{i3}, \ldots, x_{ig})$ in this space, where $x_{ij}$ is defined as:

$$ x_{ij} = -\log_{10}(|S_{ij}|) $$  \hspace{1cm} (1)

For two nodes $m$ $(x_{m1}, x_{m2}, \ldots, x_{mg})$ and $n$ $(x_{n1}, x_{n2}, \ldots, x_{ng})$ the electrical distance $D_{mn}$ is then defined as:

$$ D_{mn} = \sqrt{|x_{m1} - x_{n1}|^2 + \ldots + |x_{mg} - x_{ng}|^2} $$  \hspace{1cm} (2)

The reasonable number of control zones can be determined automatically according to the variation in the average zone distance $AD_k$, which is defined as:

$$ AD_k = \frac{\sum_{I=1}^{K} d_{I,J}^2}{K} \quad I = 1, \ldots, K - 1; J = I + 1, \ldots, K $$  \hspace{1cm} (3)

where $K$ is current number of zones.
Through the hierarchical clustering process, the buses can be grouped into same set of reactive power resources to solve the problem of power network division based on the optimum number of zones. Each group or control zone should consist of generators, shunt capacitors or reactors, OLTC, and pilot bus.

B. Identification of Pilot Buses

The identification of pilot bus for each control zone is part of AZD module. The selection of pilot bus should be the strongest bus in the zone whereas the nodes impose their voltages to the load nodes electrically close to them. The pilot bus represents the key factor for the voltage control effectiveness of the CVC system.

The technique to identify the best pilot bus is based on short circuit level method. Through the sensitivity of load bus with the other load buses (SDD) in the power network, the result of short circuit level can be determined. The diagonal from the sensitivity matrix is sorted from smallest to largest value. The diagonal shows the largest sensitivity of the reference bus to the other buses. In this condition, the node with the strongest short circuit capability in this zone is selected as the pilot bus candidates. Since the zones are identified, the determination of pilot nodes also is simply can be formalized by using electrical distances. Few nodes from pilot bus candidates that have most center position among load buses in its respective area are selected as pilot buses. Such process is carried out by using the calculated electrical distance. The center node in the area can be considered as pilot bus whereby it represents degree of influence of the bus to the network system in its respective area. In practical operation, the appropriate number of pilot bus is usually more than one.

The other ways to validate and check the best candidate of pilot node by observation from the network diagram. If the pilot bus located among the radial feeds, the reconsideration of selection pilot node should be taken.

IV. ADAPTIVE ZONING APPLICATIONS

As mentioned earlier, the power grid system in Malaysia is divided into four voltage control regions, namely North, Central, South, and East. The adaptive zoning and pilot bus identification is tested on TNB network system by developed adaptive zoning in CVC system application. A typical human machine interface (HMI) of TNB CVC system is shown in Figure 1. Some adaptive zoning application results are presented below.
Logically, the smaller the value of electrical distance between two nodes, the closer the node is. However, the operational scheme must be taken into consideration whereby it gives influence to the determination of optimum number of zone and zone division. Figure 2 shows the zone distance variation curve. This curve provides a precious indication for the best choice of number of zone for TNB network. The changes in the slope of this curve correspond to a deterioration of the quality of the grouping performed. The selection of optimum zone number is very subjective such as it can be obtained through the flat segment from the variation curve. The flat segment in the variation curve represents the point of weak coupled of control zones. Optimum number of zone also can be determined by finding the number of control zones with the largest average zone distance. For this test, the flat segment can be observed in between 5 to 8 zones. In order to minimize frequent changes of zone division in the power network, 8 zones is selected as the optimum zone number. However, the optimum zone number also can be selected based on the experience of the system operator.

B. Control Zone Division

In general, the zone division shows the coupled characteristic between buses. Strong coupled buses will contain in the same control zone and the division or boundary of zone is created when they are weak coupled to each other. The same snapshot is used to analyze the result of the zone division. Figure 3 and Figure 4 shows network topology for both snapshots. Table I and Table II shows the result of the zone division by showing some of control bus for the respective zones.

On June 2015, new 500kV transmission lines from JMJG to BTRK were established. Previously, JMJG was determined in the Northwest area as shown in zone division result on May 2013. However, after the network topology regulation, JMJG is currently contributing its reactive power
towards central area. As a result, the members of control bus for a few control zones are different in two snapshots. This is happened due to the different generation, load demand and network topology for both snapshots. As discussed earlier, the operational condition and variation of network topology plays the important role for the zone division changes.

C. Pilot Bus Results

<table>
<thead>
<tr>
<th>TABLE III: PILOT BUS FOR EACH CONTROL ZONE ON 14TH MAY 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
</tr>
<tr>
<td>Northern</td>
</tr>
<tr>
<td>Northeast</td>
</tr>
<tr>
<td>Northwest</td>
</tr>
<tr>
<td>Southern 1</td>
</tr>
<tr>
<td>Southern 2</td>
</tr>
<tr>
<td>East-South</td>
</tr>
<tr>
<td>East-North</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE IV: PILOT BUS FOR EACH CONTROL ZONE ON 16TH JUNE 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central North</td>
</tr>
<tr>
<td>Central South</td>
</tr>
<tr>
<td>Northern</td>
</tr>
<tr>
<td>Northeast</td>
</tr>
<tr>
<td>Northwest</td>
</tr>
<tr>
<td>Southern 1</td>
</tr>
<tr>
<td>Southern 2</td>
</tr>
<tr>
<td>Eastern</td>
</tr>
</tbody>
</table>

Similar snapshots are used to demonstrate the selection of pilot bus for each control zones. Table III and Table IV show the selection of pilot bus for each control zone. Most of the selected pilot bus is among 500/275kV buses whereby it can provide a better and less variation of voltage profile in the network. However, the selections from 132kV buses can be also considered by undergo another pilot bus selection approach.

From the simulation on 16th June 2015, TNB southern area is divided into 2 control zones, thus 2 pilot buses is selected from the southern area network. From the analysis as well, the pilot node cannot be selected among buses at radial feeds as mentioned earlier. This is due to high reactive power requirement and its inability to control the bus voltages in the same control zone.

V. CONCLUSIONS

This paper presents the adaptive zoning and pilot bus identification techniques deployed in CVC system application. The benefits of these findings are the improvement of voltage control and thus minimize the transmission losses. Normally, the control resource is essentially based on the largest generators within the control zone that have the maximum regulating sensitivity on the pilot node [7]. In CVC system application for TNB network, generators and shunt compensators were considered as main reactive power resources to be controlled. However, the voltage control in each control zone also can be supported by adjusting OLTC tap changer [8].

The results describes in this paper are very encouraging. Through the simulation results, the control zones of the network system are not fixed in accordance with variations in the grid structure. Therefore, adaptive zoning that based on hierarchical clustering algorithm can automatically adapt to structural changes in power system proportional with the rapid growth of power grid.

In France and China, shunt capacitors were installed at extra high voltage level network and it is not overlapped with the medium voltage level power grid. In TNB network, transmission power grid consists of 500kV, 275kV, and 132kV voltage level and most of the shunt capacitors were installed at 132kV substations. Due to this network topology, adaptive zoning by using hierarchical clustering method similar in [6] has been improved to ensure it can be implemented into TNB system. As result, better voltage control performance is obtained by effective determination of reactive power resources for each control zone. The voltage control is more reasonable hence the reactive power transmission between different control zones is greatly reduced.

In conclusion, the idea of adaptive zoning and implementation of CVC system in TNB network is feasible and hence it influenced the efficiency of voltage control performance for the TNB power grid.

ACKNOWLEDGMENT

The authors thank the Tenaga Nasional Berhad for providing national system network data used in this study.

REFERENCES


