Analysis of Fault Effect Propagation on Power System using TSAT simulation
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Abstract — This paper presents an analysis of fault effect propagation on power system using Transient Security Assessment Tool (TSAT). This simulation tool provides various indices for analyzing power system transient state. Among these indices, Transient Stability Index (TSI) which is related with generators angle separation and Voltage drop/rise Duration Index (VDI) which is concerned with time duration for which the voltage drop/rise threshold is violated are used for analyzing the fault effect propagation. This analysis shows how much fault effect propagates to the power system when transmission line fault occurs by generator trip and the degree of voltage dip.

Keywords — Power system stability, Transient Stability Index, Voltage Drop/Rise Duration Index, TSAT

I. INTRODUCTION
The fault analysis of a power system is required in order to determine the equipment insulating level, setting of relays and stability of system operation. If power system fault occurs, then this fault could bring about a widespread blackout, infrastructures like transportation, water supply and communication system suffer huge losses.

Transmission fault is the most common fault because lines are exposed to the elements. Transmission fault cause congestion and transmission limit to drop. These give rise to imbalance between mechanical and electrical power, generation tripping and voltage dip.

In Italy, a wide blackout which occurred on September 28th, 2003 was caused by transmission fault. Storms attacked power line between Swiss and Italy, hence power line was tripped and power line between France and Italy was also tripped because of sudden increased demand. Due to the cascading line tripping, voltage instability and angle instability occurred over a wide area. An estimated 60 million people was affected by this blackout and amount to 180GWh was not delivered [1].

Many power systems prepare for N-1 contingency. Parallel lines fault may cause power system to be insecure. This paper analyzes fault effect propagation in Korea power system when transmission parallel lines are faulted simultaneously. TSAT was chose as simulation program. Section II explains power system stability and transient assessment method using TSAT. Section III shows how much fault effect propagates to the power system when transmission line fault.

II. THEORETICAL BACKGROUND
A. Power system stability
Power system stability is property of a power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance. This power system stability is generally classified to rotor angle stability and voltage stability [2].

1. Rotor Angle Stability
Rotor angle stability means ability that generators in power system remain synchronization [2]. The relation ship between transmitted power and rotor angle would be explained first to explain rotor angle stability.

![Fig. 1. Generator and load model](image)

\[ P = \frac{E_G E_M}{X_T} \sin(\delta) \] (1)

The rotor angle \( \delta \) represents the angle difference between generator angle and load angle. Fig. 2 shows this power relationship with rotor angle of generator.
The generator and the load may be considered in terms of equivalent synchronous machines. Rotor angle means relative position of the rotors of two machines. Within the point of maximum power, an increase in the torque of generator results in an increase of rotor angle and motor load supply more power and the motor also accelerates. On the contrary, beyond the point of maximum power, an increasing torque of the generator causes the motor to decelerate and rotor angle to increase. Therefore, these two synchronous machines lose synchronism, which rotor angle stability is violation [2], [3].

2. Voltage Stability

Voltage stability is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance [2]. As power system is larger and larger, maintaining voltage at all buses is not easy and voltage stability problem would be very important issue in power system operation. Especially, voltage of some part of power system would decrease rapidly when transmission line loading congestion occurred. This phenomenon would happen, even though the power supply is enough. And it might bring about voltage collapse that is usually the result of a sequence of events accompanying voltage instability leading to a low-voltage profile in a significant part of the power system [2].

B. Power system stability assessment method using TSAT

TSAT provides a lot of indices to analyze power system stability in contingency condition of power system. Among them, rotor angle stability and voltage stability could be assessed by transient stability index (TSI) and voltage drop/rise duration index (VDI), respectively.

1. Transient Stability Index (TSI) [4]

TDI is defined as

\[
\eta = \frac{(360-\delta_{\max})}{(360+\delta_{\max})} \cdot 100 \quad -100<\eta<100 \quad (2)
\]

\(\delta_{\max}\) is the maximum angle difference of any two generators in the post fault response. If \(\eta\) is positive, the generators are stable and if \(\eta\) is negative, the generators will be tripped from the power system and it would bring about blackout to some part of the power system. Fig. 3 shows the definition of this index.

2. Voltage drop/rise Duration Index (VDI) [4]

Among TSAT indices, voltage drop/rise duration index is related with voltage stability. This index is a standard which decides that voltage is in a permissible range during transient state. Definition of maximum voltage drop/rise duration (\(T_{\text{Vdrop}}/T_{\text{Vrise}}\)) is shown in Fig. 4.

\(T_{\text{Vdrop}}\) and \(T_{\text{Vrise}}\) would be defined by the power system operator. In this paper, voltage drop threshold and \(T_{\text{Vdrop}}\) are set 0.8 p.u. and 0.4 seconds, respectively, that are related to the parameters of low voltage relay. Because this paper simulated only low voltage case, voltage rise threshold and \(T_{\text{Vrise}}\) would not be mentioned.
III. EXPERIENCE METHOD

Korean power system which was made by KEPCO in 2007 is used for analyzing the fault effect propagation. The number of facilities in simulation system is as in the following Table I.

Table I

<table>
<thead>
<tr>
<th>Facilities</th>
<th>Number</th>
<th>Transmission voltage level</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td>240</td>
<td>765kV</td>
<td>7</td>
</tr>
<tr>
<td>Load</td>
<td>784</td>
<td>345kV</td>
<td>205</td>
</tr>
<tr>
<td>Load bus</td>
<td>748</td>
<td>154kV</td>
<td>1490</td>
</tr>
</tbody>
</table>

In this research, there are some transmission line faults which cause similar effect propagation to the particular region of Korean power system. We called this region to Zone. And, in our simulation result, there are four fault effect propagation Zones in Korean power system.

IV. RESULT AND ANALYSIS

Among the selected 117 fault conditions which explained the previous section, TSI violation is happened in 49 cases and VDI violation is happened in 31 cases. VDI violation arises in all cases of TSI violation occurred. In TSI violation, due to generator tripping, voltage also drops and VDI violation occur. In VDI violation, though generators do not trip, long duration of voltage drop causes transmission lines tripped and gives rise to blackout.

Fig. 6 shows the result of transmission line fault between Seoincheon and Sinbupyeong in Zone A. 51 generators including Seoincheon ST, Seoincheon GT, Hanhwa GT, Kyeongin #2 ST are tripped. The reason of many generators tripping is that generators are gathered around generation complex. Thus, when generation complex is tripped, all generators in generation complex are tripped. Generator voltage also drops because of tripping. Voltage dip occurs over a large area. Blackout happens near the spot where the accident took place. Fig. 7 shows effect propagation near the fault.

Fig. 5 shows analysis process of fault effect propagation. Choose contingency and then simulate it by using TSAT. Then determine whether the system is stable or unstable. If system is unstable, decide the place damaged by fault and analyze fault effect propagation.

In this paper, line-to-ground fault of transmission line is simulated for analyzing fault effect propagation. Korean power system is designed to maintain the system against N-1 contingency. Therefore the fault effect propagation analysis of Korean power system is carried out in N-2 contingency condition. However, in the case of 154 kV transmission line, the degree of fault effect propagation is unremarked even if N-2 contingency occurred, because transmission lines of this voltage level are made up circular network. Therefore, simulation scenario is selected as fault of parallel transmission lines which voltage level is more than 345 kV.
In Zone B, 16 generators including Gangneung GT, Donghae GT, SeoincheonGT are tripped by transmission line fault between Singapyeong and Sintaeback. Through this line many power flows from Gangwondo to Seoul metropolitan region. Due to transmission limit decreasing, generators violates TSI and are tripped continuously. The result of this fault may affect a half of Korea. It is important to prevent this fault. Fig. 8 and Fig. 9 show this effect.

Fig. 7. Zone A contingency : a voltage contour line by Seoincheon~ Sinbupyeong(345kV) fault

Fig. 8. Zone B contingency : generator angle and bus voltage by Singapyeong~ Sintaeback(765kV) fault

Fig. 9. Zone B contingency : a voltage contour line by Singapyeong~ Sintaeback(765kV) fault

Fig. 10 shows fault effect propagation by transmission fault between Sinnamwon and Singwangju in Zone C. 6 generators are tripped. The result shows that the system is related with Seoul metropolitan region weakly. But it has a great influence on south west area in Korea. Fig. 11 shows a contour line of this fault effect propagation.

Fig. 10. Zone C contingency : generator angle and bus voltage by Sinnamwon~Singwangju(345kV) fault

Fig. 11. Zone C contingency : a voltage contour line by Sinnamwon~Singwangju(345kV) fault
Finally, analyze Zone D contingency. Transmission line between Bukbusan and Sinulsan is in Zone D. 25 generators including Gori G, Yeongnam G are tripped. Fig. 12 and Fig. 13 show this effect. The characteristic of this fault is that voltage dip spreads Dongseoul bus. Though the voltage drops to 0.85 p.u., it cannot recover after fault clear. Another characteristic of this fault is that rotor angle decreased gradually. The reason is that generators produce more reactive power to keep voltage. But voltage does not recover. Therefore angle drops by degrees. In this case anticipate additional generator tripping and blackout due to low voltage.

Fig. 12. Zone D contingency: generator angle and bus voltage by Bukbusan~Sinulsan(345kV) fault

V. CONCLUSION

In this paper, using simulating the transmission fault, analyze Korea power system fault effect propagation. Through the result, when transmission line where many power flows is damaged, the system is influenced greatly. In Korea, many power flow from Gangwon to Seoul. Thus transmission line fault between Singapyeong and SintaebacK(765kV) has a great effect. It is important to prevent that fault occur there and protective equipment will work appropriately if this fault occurs. And the effect is smaller the region is farther from fault than the near region. Though the system does not violate TSI, the system can go through blackout. Because VDI violation can cause tripping transmission line by low voltage relay, the system falls into blackout.

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