THE EFFECTS OF UNFORESEEN CHANGES IN AGGREGATED LOAD SCHEDULING ON TRANSMISSION SYSTEM OPERATION

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ABSTRACT

Transmission systems are already operated at or near their transmission limits due to geographical distances and the costs associated with the new lines to be built. The aggregator notion and electricity markets are adding more complexity to the operation of the system. The operational problems and external attacks, such as cyber-attacks, on communication system that exist between aggregators and consumers participating in demand response can jeopardise the success of demand response. The attacks can change the simultaneity factor that may cause system overloading. Thus, outages may occur in the system due to over current protection. We propose to study the effect of the sudden and/or unplanned changes, especially those that arise because of a cyberattack, in a given load management program at the load buses on the transmission level on a test system. An IEEE test system is used to demonstrate the impact of unforeseen changes in aggregated load scheduling.

Keywords:
power transmission, unforeseen changes, demand response

1. INTRODUCTION

Power system operation has become more complex due to the recent changes; such as the restructuring of power system, the competitive environment that exists between the electricity market players, the use of distributed energy resources, and the increase in the renewable resource based power generation.

Traditionally, the large-scale power plants using conventional technologies based on fossil fuels (natural gas, coal, oil, etc.) used to supply almost all of the power demand. However, today the renewable energy, such as wind and solar, contribute substantially to the total demand and they have been thought to be the most feasible way to reduce the emissions of various pollutants. The contribution to the total power demand by the renewables has been steadily increasing. On the other hand, since the power generation from both the wind and the solar power plants depends strongly on weather conditions, unpredicted or sudden changes in generation can occur, which can cause power output to fluctuate at timescales ranging from minutes to hours.

Transmission System Operators (TSOs) reliably transfer power generated by the large-sized power plants to electricity distribution operators (DSOs). Hence, they must monitor on a real-time manner the voltage levels, the line flows, and the voltage frequency to insure the compliance with network operational constraints. TSO tries to operate transmission system by dispatching generation units to meet the scheduled demand. The dependent variables, operation cost and reliability, are important factors in the scheduling. The unforeseen changes in a system load must be satisfied by using spinning reserves. The operating capacity deficiencies can also change system conditions [1].

The unforeseen changes in the load and generation frequently occur in a system, and TSO sends commands to generation units to use spinning and operating reserves to meet these unplanned changes [2]. If there is no sufficient dispatch flexibility to maintain the balance between load and generation, some loads or generators are then shed.

Changes in the temperature forecast highly affect the dispatch schedule and the emissions. When reserves are invoked to compensate variations, generator outputs vary to maintain power balance. A quick change in generator outputs may results in additional emissions. Using energy storage-based reserves and demand response applications can improve the system operation and thus reduce CO_2 emissions [3-4].

In a smart grid environment, there are several methods for forcing consumers to participate in Demand Response (DR) energy management programs. In the future, it is expected that the number of aggregated consumer will be an important part of the total load. Incentive cloud-based demand response programs can be used by aggregators. Therefore, any unforeseen changes due to a cyber-attack or a program malfunction in aggregated load scheduling will strongly affect power grid.

Thus, we propose to study the effect of sudden and/or unplanned changes, especially those as a result of cyberattack, in a given load management program at the load bus on the transmission level using a test system. The problem was, to a degree, studied on the distribution level; however, it was not dealt with at the transmission level. This is considered an important problem since any sudden change in the load may cause cascading outages in an-already heavily loaded system [5].

Transmission systems are already operated at or near their transmission limits due to geographical distances and/or costs. Smart Grid applications, load control programs, and demand management programs add more complexities to the understanding the operation of the system as a whole. When the other issues such as aggregator notion and electricity markets are added to those complexities one needs to construct many scenarios and simulate the system at hand. To this end, we plan to study the effect of cyberattacks and program malfunctions on demand management participants. The study of the effects on a transmission line due to these unforeseen changes in aggregated load scheduling that are prone to make a big and a sudden change in the load on a load bus is the main subject of this paper.

2. UNFORESEEN CHANGES IN AGGREGATED LOAD SCHEDULING

To improve reliability and efficiency of power systems that have high penetration rates of the renewable energy sources, such as solar or wind, demand response can be used to balance demand and supply. A definition of Demand Response (DR) is given by FERC (Federal Energy Regulatory Commission) as follows [6];

"*Changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized*."

To plan and manage the transition towards the wide use of DR applications, it is important to understand its impacts on a power system. In practice, it is required that a command is directly issued to the customers/loads for providing more flexibility into the power grid operation, thus, DR requires additional investments in information and communication technologies (ICT) to enable the engagement of thousands or millions of loads. An electricity retailer or a Demand Side Response Aggregator (DSR Aggregator) needs to setup of large information network in conjunction with a sophisticated communication infrastructure to control thousands of devices [7-9]. A DSR Aggregator, which is usually a third-party company specializing in electricity demand side participation, works on a shared revenue model taking a certain percentage of the DSR's revenue earned by the participating end-user's site [10].

In demand side response, it is important to determine the suitability of an end-user site by DSR Aggregators. A wrong determination of the suitability of end-user sites or unforeseen responses may cause undesired system operation. For example, desired amount of load reduction may not be obtained under critical loading conditions and the system may have a low reliability level due to over loading conditions.

The DR programs can be categorized as time-based programs and incentive-based programs [11]. Incentive based programs encourage consumers to reduce/increase their consumption by offering special rewards to manage their demand. One way to ensure consumer participation to the DR programs is to use demand response messages, such as electricity pricing and events specification via some end point communication methods. The problems and attacks on the communication link between the aggregators and the consumers participating in DR can jeopardise the success of demand response. DR programs are not only important for customers but also for both the efficiency and the stability of the system since they improve system operation by balancing the load. A vital part of ensuring reliability is securing the grid from cyber-physical attacks.

The information contained in a load curve that can be drawn by using meter readings, is analysed to determine some load characteristics such as the time of occurrence of peak demand, the percentage of total electrical energy use occurring during the off-peak hours, etc.

An example of the daily load curve is given in Figure 1. As can be seen in this Figure, the load profile varies with the hours. The curve with solid line is actual demand variation (undesired), the curve with dashed line is desired demand by using demand response. The dotted line represents unforeseen demand change due to an attack such as sending a low-price signal instead of actual high energy price. The attacks can change the simultaneity factor that may result in the system overloading and outages may occur in the system due to over current protection.

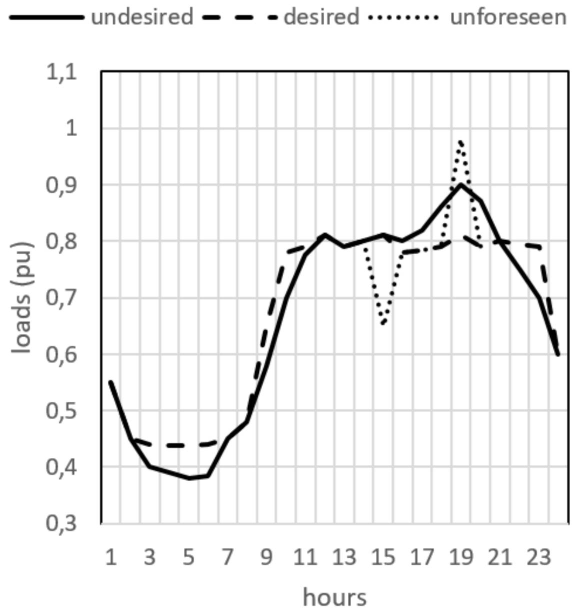

Fig. 1. The effect of DR on a daily load curve.

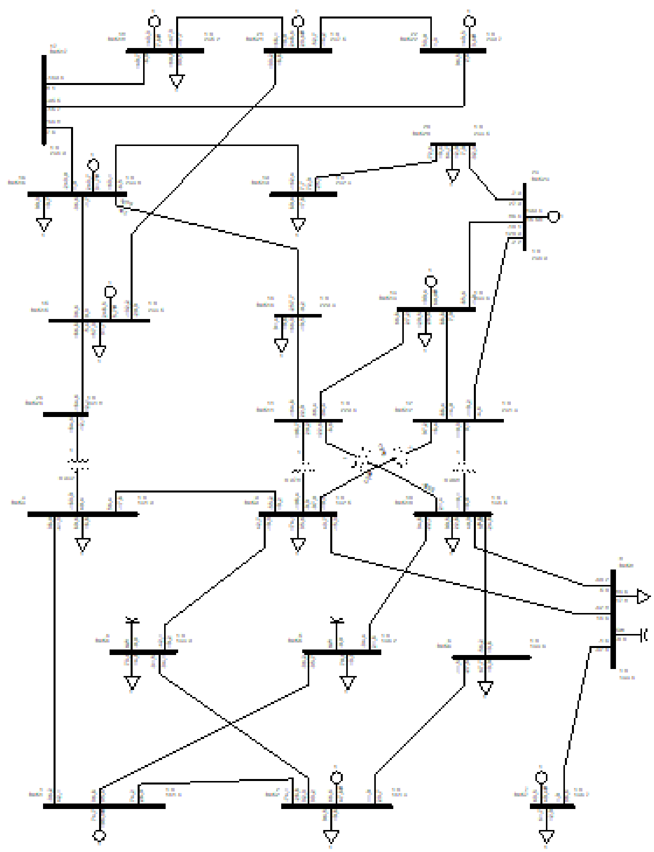

Fig. 2. IEEE 24 bus test system.

3. CASE STUDY

The IEEE 24-bus reliability test system is used to demonstrate the impact of unforeseen changes in an aggregated load scheduling [12]. The test system shown in Figure 2 consists of 10-generation buses and 37 branches. Loads and installed generation capacity are assumed to be higher than their original values. Siemens-PSSE software is used to analyse cases [13].

Different case studies were performed to show the effects of sudden load changes on the system at the peak hours. It is assumed that the system is operated under peak load condition in the simulations. The two cases simulated are:
Case 1: Loads are suddenly increased 10%
Case 2: Loads are suddenly decreased 10%

The changes of bus voltage magnitudes for the Case 1 are shown in Figure 3. A voltage sag for a short duration due to the load increase is seen clearly from the Figure 3. Depending on both the amount of the unforeseen load increase and the simultaneity of their switching, a significant voltage drop and overcurrent can cause tripping.

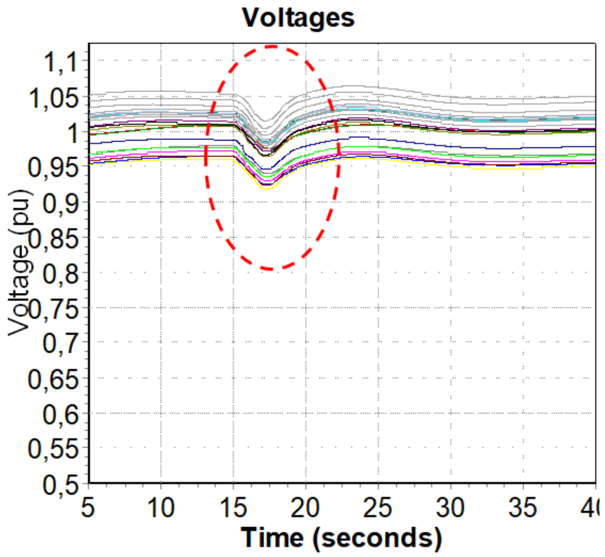

Fig. 3. The changes of bus voltage magnitudes for Case_1.

The problems and attacks on the communication link between the aggregators and the consumers participating in DR can also force consumers to reduce their consumption. In Figure 4, the changes of bus voltage magnitudes during the considered scenario Case 2 are shown. In this case, the reduction on amount of the loads can cause a voltage swell problem that is an increase in AC voltage for a short duration. Similarly, depending on both the amount of the unforeseen load reduction and the simultaneity of their switching, a significant voltage increase can cause overvoltage and relay tripping.

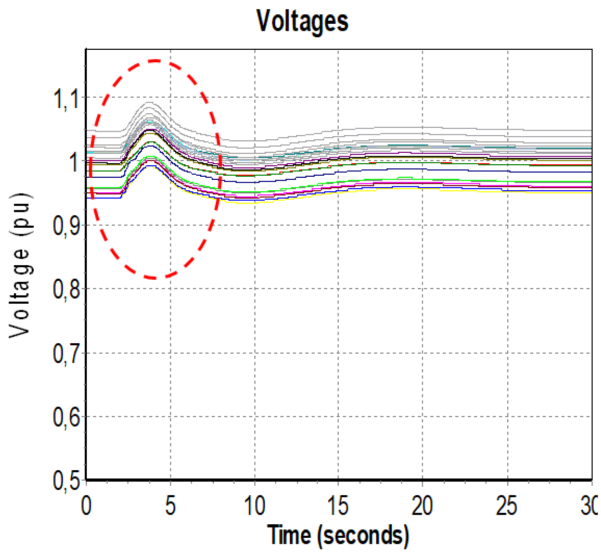

Fig. 4. The changes of bus voltage magnitudes for Case_2.

The above cases show that the attacks causing high simultaneity of switched loads can cause power disturbances such as overvoltage, overcurrent, and under-voltage. The outages can occur on transmission lines depending on the severity of the disturbances. Therefore, a methodology to improve the system strength against attacks causing unforeseen changes on transmission systems should be applied. A methodology may consist of the following steps;

- Determine the system vulnerabilities against attacks
- Determine the sensitivity of both critical lines and critical buses to the load changes
- Simulate the contingencies
- Calculate the aggregated load limits on the critical buses

4. CONCLUSIONS

To the knowledge of the authors, there seems to be no study yet in the area of both cyberattack and/or program malfunction originated intrusions on a demand response program. Especially, the effects of sudden load changes on a transmission system because of those intrusions has not been dealt with. This paper presents a study to deal cyber-related unforeseen changes on transmission system.

The unforeseen changes in aggregated load scheduling can increase the stress on the transmission grid and can cause the outages due to trips by over current based protection system. Therefore, the limits of the aggregated loads on load buses must be dynamically determined by considering the system current operating conditions using topology information, maintenance information, and vulnerability of the system against attacks, etc.

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