Study of a Power System Stability considering Three-Pole and Single-Pole Reclosing in Single-Pole Fault incidence in the Network

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Abstract: *In order to supply the confident energy to the consumers, the power system should be able to bear different disturbance and stays active consistently. The system therefore should be operated as to be able to bear probable disturbance and provide the network consistency in the best way by transferring the maximum power without lead cut out (except areas where cut in to the Fault). Stability of the network and the scheme of single phase and three phase reclosing is different. special protective relays and control circuitry must be provided to distinguish between phase-to-ground and multi-phase fault conditions. In addition, intelligence must be provided to trip and reclose only the faulted phase. In this paper, single phase and three phase auto re-closing has been studied in one of the Iran's 400KV transmission line system between Shahidsalimi to Jalal Substation. This simulation is based on John's mathematical models using the EMTP/ATP-MODELS to simulate primary and secondary arc behavior in details. Also occurrence the phenomenon of overvoltage, because the fault occurred at various points of network has been studied.*

Key words: *Auto-reclosing, Overvoltage, single-phase reclosing, three-phase reclosing*

1. Introduction

Fault incidence in power networks is unavoidable and not only it creates stress but also, reduces the transient stability of the network and reliability, also cases torsional oscillations of the shaft of thermal generator units in the large networks. So, time and how to remove the fault with respect to the location and type of fault are significant parameters in a system designing. When there is the stability sense of power system, it is needed to improve the performance of the power system during transient turbulence. Many methods have been proposed to minimize fault as much as possible. In the past years in order to achieve sustainability, it was focused on design of the equipment, such as machines, transformers etc. However, in recent years high speed circuit breaker and relays have been widely used. High-speed equipments reduce perturbation period in transformation line and act as one of the most significant parameters on the functional improvement.

Reconnection circuit breakers are useful for immediate fault isolation considering high speed equipments. The first idea upon using the power switches (Circuit Breaker) with reclosing ability was proposed by F.E.Pickets in1916. Trip and reconnection of three-pole circuit breakers simultaneity, leads successful reconnection which is called three-phase reclosing.

Single phase operation differs from three phase in that at each terminal of the line, only the faulted phase is tripped and reclosed high speed. While the single phase is open at each terminal, power is transmitted over the remaining two phases and through ground between the neutral points of the synchronous systems, or over other transmission circuits. This flow of synchronizing power reduces the rate of rotor angle drift between the synchronous machines and tends to maintain the stability of the system. However, during the time that the single phase is open, ground currents are being circulated in the system, and may adversely affect system ground relaying. With single pole fault clearing, a voltage will be induced in the isolated phase due to capacitive coupling, and to a lesser degree, by the electromagnetic coupling between the two energized phases and the de-energized phase. The magnitude of the induced voltage is a direct function of the phase-to-phase and phase-to-ground capacitances which are directly related to the physical configuration and length of the transmission line. The induced voltage may sustain the arc for an extended period of time following the operation of the single pole breakers. This current is usually referred to as the secondary arc current [1,2].

The minimum dead-time required before allowing high speed single pole reclosing is determined by analytical studies. This time, without line compensation, has been found to be appreciably longer that required for three phase tripping and

reclosing. In those instances where a sufficiently high voltage may be induced to sustain the arc, either permanently or for a period greater than the maximum time permissible to maintain system stability, the capacitances must be compensated if a re-closure is to be successful. One method of neutralizing the induced voltage is by the application of shunt reactors (including a neutral reactor) on the transmission line. Another proposed method is the closing and re-opening of a single phase, high speed ground switch on the open phase conductor.
In this paper studies the effects, advantages and disadvantages of Single-pole and Three-phase reclosing of circuit breakers on stability of the network when the fault occurs considering stability of production units in one of the 400 KV transmission lines in Iran between Shahidsalimi to Jalal Substation by ATP/EMTP software. In the single pole reclosing, only one phase is disconnected and reclosing is accomplished with high speed, while this is only one phase of each terminal is opened and the power of two remaining phases is transmitted through other transmission circuits. This power flow reduces angle deviation of the rotor in synchronized machines and causes permanent stability of the system.

2. Study of Network Stability

2-1. Study of the Network Stability by using the Transient Energy Function

Transient Energy Function (TEF) is a direct method to study the stability of the Power System. Indexes of this function accept different values for independent system, the higher the function fluctuating ample, the harder the system's circumstances. When fluctuation ample is more than critical values of the system, the system is unstable [3,4].
Transient Energy Function is dependent on the unstable system parameters (angle and angular velocity of the generator) which are resulted from differential equations. So, the function graph is smooth, after the fault, the angle and angular velocity of generator fluctuate in the same times and the minimum value of the graph will be appeared continuously and intermittently. This value is important for getting the time of system stability.
Since there is no practical solution to prevent reconnection in the power system for permanent fault and also as the system stability is important, reclosing does not have negative effects on permanent faults. In system stability point of view of, time optimization for reclosing, should be considered under maximum fault flow, in this case operation of reclosing has many effects on system stability.
In the power systems using more machines, time $t=0^+$ is supposed as the moment of last perturbation occurrence in system. Apart from the system damping and equivalent circuit adaption of generators with their classic models, rotor Motion model is derived from the following formula:

$$d\delta_i/dt=\omega_i \quad , M_i\, \omega_i=P_{Ti}-P_e \; i=1,2,\ldots,N \qquad (1)$$

Where the δ_i is power angle of (i) generator, ω_i is angular velocity of (i) generator, M_i is inertia constant of (i) generator, P_{Ti}-P_{ei} is respectively electromagnetic power and input power of (i) generator, dynamic behavior of the system after the last perturbation is derived from equation(1).
According to qualitative theory of ordinary differential equations, solving the related equation is dependent on initial values. If initial values is closed to Stable Equilibrium Point (SEP), the system will be stable and finally stability points of system will be converged, otherwise the system will be out from stable state. Initial values for equation (1) is angular velocity and power angle of each generators in moment of last perturbation occurrence in system. Zero as initial value is the ideal state. For example, system operation in stable equilibrium point has been finished and the system has reached to its stable state. When it is reconnected for momental fault (last perturbation occurrence in system) successfully, a time should be derived for reclosing that is more than defined time as the last time for reconnection by breaker. If the fault in system is permanent, the key will be discounted again and reconnection will be failed. In power system as soon as fault occur, this fault should be removed as soon as possible, protection time for removing the fault usually is 0.1 second.
In single-machine systems with endless shunt transient energy function after occurrence of perturbation is derived from the following formula:

$$v=1/2\, m\omega^2 - p_t\,(\sigma-\sigma_0) - p_e\,(\cos\sigma-\cos\sigma_0) \qquad (2)$$

The first phase in above equation is motion energy that is according to generators angular velocity changes and the remained parts equivalent with potential and it is according generator angle changes toward initial balance point [5-10].

Total transient energy which is the sum of motion and potential energy is calculated after the fault occurrence. If motion energy is zero, timing potential energy will be increased to maximum level, in which the difference between generator angles from balance point will be maximum, so the potential energy maximum is equal with network transient energy that is derived from maximum amount of generator angle after stable fluctuations.

For transient faults, the lowest rate of Transient Energy Function is equal to the maximum rate of the power system stability. Due to this fact, the calculation of the time, for single and three-poles reclosing in network, is not a proper scale for determining the system stability.

Fig. 1 shows the electric network of the case study. This case study include connection of the ShahidSalimi Neka power plant to the grid through two 400 kV transmission lines, one from ShahidSalimi to Jalal-Tehran substation and the other one is ShahidSalimi to Ahovan-semnan. The length of this line is 252 km and does the simulation for three different statuses. Without reactor, with two reactors 50 MVar in two sides of networks and with two reactors equipped with neutral reactor 640 Ohm. Actually the power plant and Jalal substation have been modeled to single machine and unlimited endless shunt. Generator's production power is 520 MVA. Primary and secondary graph are simulated according to the Johns mathematics model, modeling and simulation of primary and secondary arc was carried out using MODELS module of the ATP/EMTP. Also, for modeling the transmission lines, we have used J.marti model and in all other cases the surge arrester in network has been used.

In this stimulation, we have put assumption on having single pole fault in different parts of the network and removing them in 100 ms. The time and performance for reclosing the three phase circuit breakers in the time of faulting, is according to the IEC-62271-100 standard and the reclosing is done as below operation:

- O-t- CO- t' – CO
- t=0.3s,t'=3min

Figs. 2-4 shows the value of minimum rate of Transient Energy Function occurs when reclosing three-poles and single-pole in different place of network. As you see, for different states of network, minimum rate of Transient Energy Function is less for single pole reclosing. So stability of network when single-pole reclosing occurs is in suitable condition.

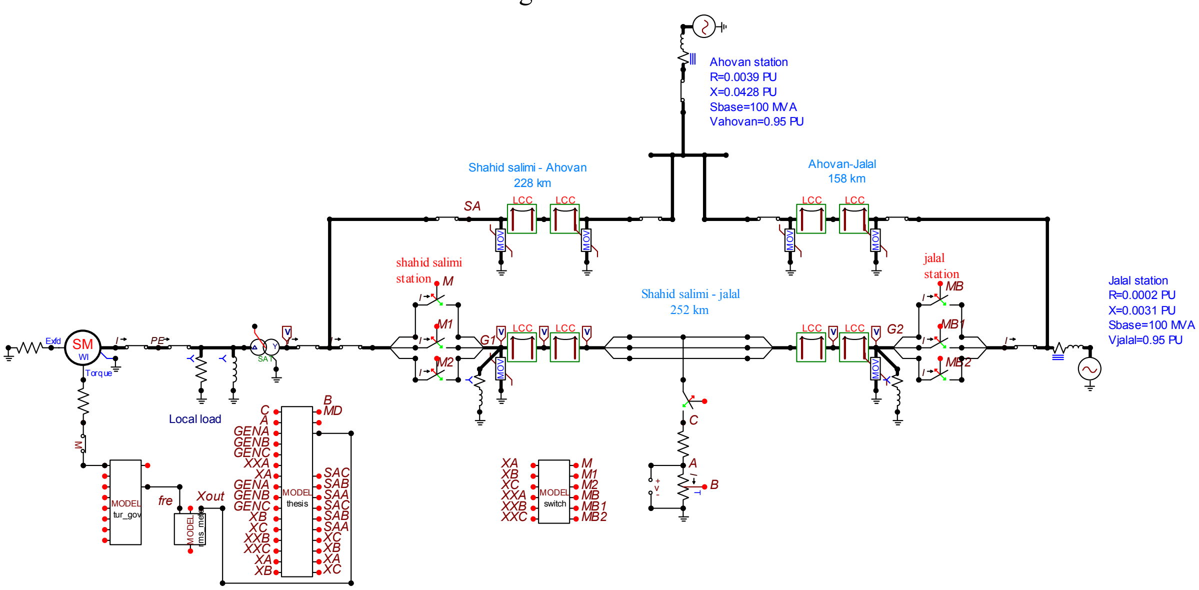

Fig 1. Electric network of the case Study

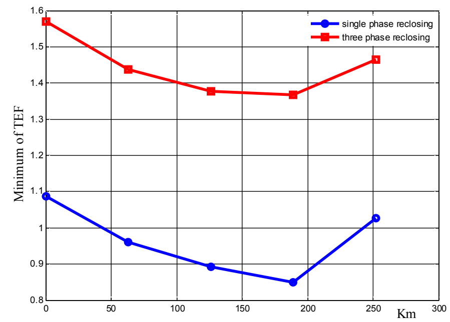

Fig 2. Value of the minimum TEF During the three-phase and single-phase Reclosing network without reactor

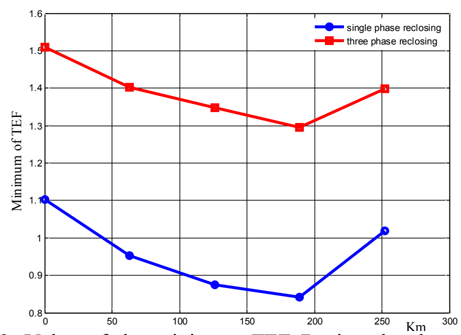

Fig 3. Value of the minimum TEF During the three-phase and single-phase Reclosing network with reactor 50Mvar

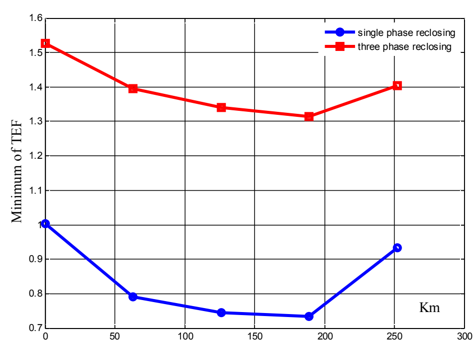

Fig 4. Value of the minimum TEF During the three-phase and single-phase Reclosing network with neutral reactor

3. Stability of the Network according to the Fatigue-Shaft of Generator in System

Switching operations (including opening and closing breaker) may lead transient torque which will impose tension to generators. Usually, when a network is in steady state, the most violent switching in fact is the reclosing of the transmission line whose two switch's angle is big. Depending on the network's Impedance, May sudden increase in the generator air gap torque, be very large. This makes response of mechanical system to original torsional natural frequency. If the generated torque is heavy, it may cause a loss of fatigue life.

Fatigue is a cumulative process in which subsequent events are added to the previous value of fatigue life, while until the end of fatigue life, visible damage such as cracks or breakers are not formed [11-14].

Although, judging bout severity of switching by the switch angle is not very useful and in this regard, impedance of the circuit, will play a significant role [14]. Therefore, intensity is measured, depending on sudden changes in generator power (ΔP). An approximate principle has been proposed by IEEE for ΔP is based on 0.5 per unit (unit basis) MVA capacity. So if Switching line in ΔP ranging lead to less than 0.5 per unit, it is known safe.

According to above index and considering generator's active power which is studied after fault in Single pole and Three poles reclosing, switching on generator shaft fatigue can be checked.

In this simulation, the system reaches its steady state, fault occurred at 12.1 seconds after the start of the simulation time that is removed after 100 ms. Figs. 5-10 Shows the generator active power for three-poles and single pole reclosing while we have fault in the middle of transmission line.

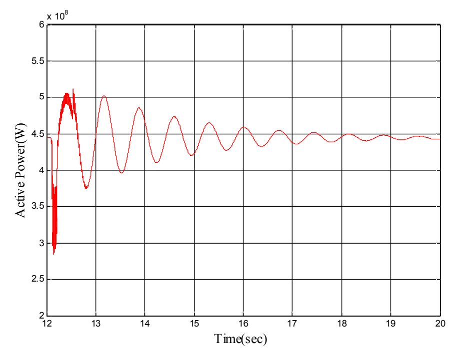

Fig 5. Generator active power for single-phase reclosing without reactor

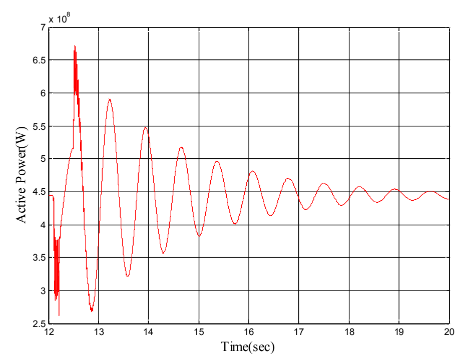

Fig 6. Generator active power for three-phase reclosing without reactor

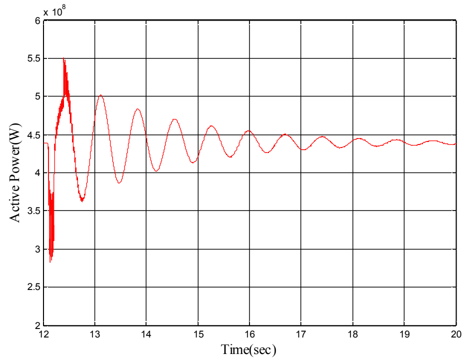

Fig 7. Generator active power for single-phase reclosing with reactor 50Mvar

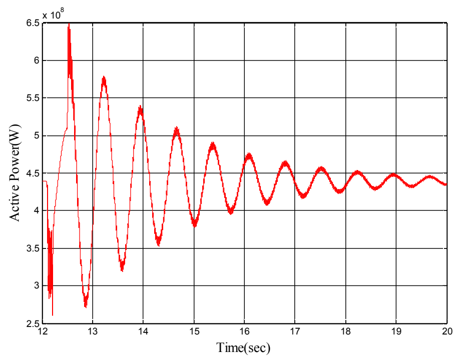

Fig 8. Generator active power for three-phase reclosing with reactor 50Mvar

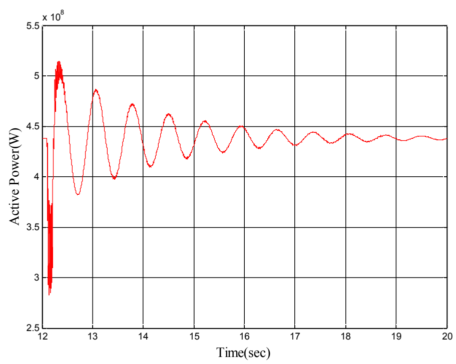

Fig 9. Generator active power for single-phase reclosing with Neutral reactor

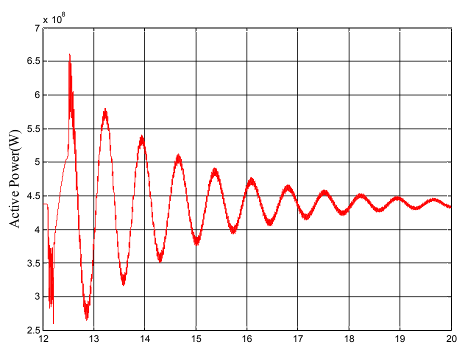

Fig 10. Generator active power for three-phase reclosing with Neutral reactor

Table1 shows the maximum generator active power curves for different modes of the network while we have single pole and three pole reclosing. In this simulation, generator production capacity is about 440 MW and according to the results, in all cases, Three-pole reclosing is more than permitted 0.5 per unit, so, its safely is out of range and in order to evaluate the bearing axis, should be studied in detail.

Table 1. ΔP_{max}(pu) based on different types of network and fault

Different types of network and fault	ΔP_{max}(pu)
Single pole reclosing-without reactor	**0.3536**
3 phase reclosing-without reactor	**0.5303**
Single pole reclosing-with reactor 50 Mvar	**0.3578**
3 phase reclosing-with reactor 50 Mvar	**0.5032**
Single pole reclosing-with neutral reactor	**0.3529**
3 phase reclosing-with neutral reactor	**0.5203**

4. OverVoltage in the Network

While breakers are switching and the high voltage equipments and high voltage equipments are interred or removed such as transformers, capacitors, reactors, or to separate various parts of the network, The network voltage exceeds the nominal amount temporary and shortly and affects isolation in different parts of the network. Curving conditions are considered as overvoltage and It is necessary to avoid it in the network. In order to prevent curving in the isolated materials, it is necessary to select the Isolation level according to the voltage level [16-20].

For this reason, it is very important to know the percentage of overvoltage. Over voltage, level at 220 kV is limited and it is less likely to affect the curve. In high range of voltage Un ≥ 400-750 KV ample and precedent of switching over voltage is increased significantly, as network equipment isolation system and power transmission lines is done only by specific forecasts to reduce the range of overvoltage amplitude [21,22].

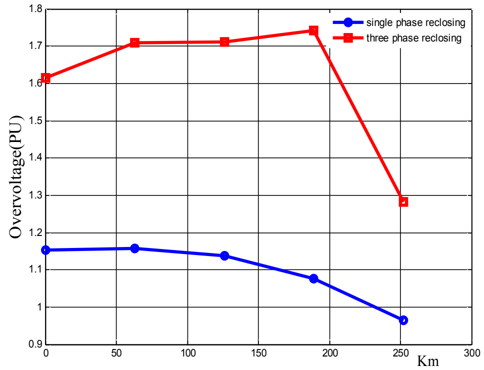

Fig 11. Voltage profile(pu) During the three-phase and single-phase Reclosing network without reactor

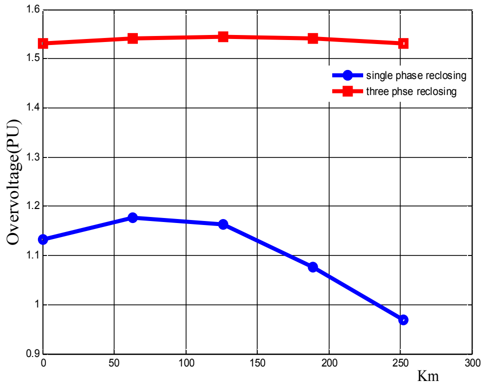

Fig 12. Voltage profile(pu) During the three-phase and single-phase Reclosing network with reactor 50Mvar

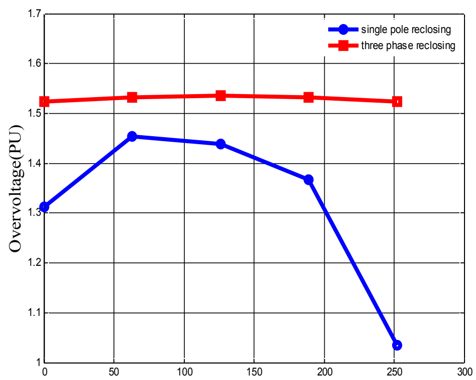

Fig 13. Voltage profile(pu) During the three-phase and single-phase Reclosing network with Neutral reactor

Figs. 11-13 shows overvoltage range of the network based on per unit while fault occurs in the middle of the transmission line for single pole and three-pole reclosing. Sharp increase in overvoltage is created by three-poles reclosing against single pole reclosing, cause stress on the equipments also reduce network reliability. Thus, according to this article, single pole disconnection leads the transient's stability of the network, reliability improvement, switching overvoltage decrease and torsional oscillations of the shaft of the large thermal generator units.

Generally three-poles reclosing have been established for below conditions:

1) Multi- pole fault
2) Unsuccessful reclosing in single pole fault to ground
3) The second phase is failed however, Single phase has fault and resolved
4) Second Phase is failed however, first phase circuit is opened
5) Auto reclosing functional proposal does not succeed with corrects two pole during the time determination

5. Conclusions

In this paper studies the effects of single-pole and three-phase reclosing of circuit breakers and overvoltage on stability of the network when the fault occurs considering stability of production units in one of the 400 KV transmission lines in Iran between Shahidsalimi to Jalal Substation by ATP/EMTP software. The results of simulation shown that single-pole reclosing against three-phase reclosing, causes to increase network reliability and reduce overvoltage in transmission line.

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