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Out-of-step detection in emerging power systems key issues and challenges

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The electrical power systems function as a huge and highly interconnected network dispersed over a large area. A balance exist between generated and consumed power, any disturbance to this balance in the system caused due to change in load as well as faults and their clearance often results in electromechanical oscillations inturn variation in power flows, this phenomenon is referred as Power Swing. Stable power swings changes it operating point to new equilibrium point but unstable swings collapse the equilibrium causes cascaded trippings inturn black outs or brown outs. In this paper, several methods of power system Out-of –step detection are critically reviewed. Various OOS detection techniques are discussed in brief; comparision of available approaches are examined and presented. The key issues and challenges are OOS detection are highlighted. A vast collection of papers, books and journals are listed, which is useful for interested researchers, power engineers and utility companies.

Keywords: *Adaptive distance protection, distance protection, out of step (OOS) detection, smart grid, synchrophasors, wide area measurement systems WAMS.*

1.0 INTRODUCTION

The power grid is a very dynamic network connecting generation to load via transmission lines. Power systems under steady-state conditions operate much close to their nominal frequency and typically maintain absolute voltage differences at buses of 5%. A balance between generated and consumed active and reactive power exists during steady-state operating conditions. Any change in the power generated, load demand or in the transmission line network causes the power flow to change across the system until a new equilibrium is established between generation and load. These kinds of small changes in power flow occur continuously and are automatically compensated via control system, and normally have no detrimental effect on the power grid or its protective systems [1], [23].

However, in the era of fast growth and rapid development in power systems, there is a demand for a reliable and quality power system network. For a utility company, meeting ever-increasing demand via network expansion would incur large costs. Hence they set up tools & processes to fully enable energy markets to ensure dynamic participation of end users and also deduce a logical solution to raise the existing system operational level to meet with the growing demand. In doing so, the system may face new operational from the protection & control point of view.

2.0 FUNDAMENTALS OF DISTANCE RELAY

Selective, high-speed clearance of faults on high voltage transmission lines is critical to the security of the power system. Over current relays cannot

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provide fast, coordinated protection because the transmission system is a mesh network. Line current differential relays can meet the requirements but require complex and expensive communications links. Uniquely, a distance relay measures the apparent impedance derived from locally measured current and voltage. The impedance of a transmission line is generally distributed uniformly over its length. For this reason, a distance relay can discriminate with relatively good accuracy between a fault that is internal to the line and one that is external by measuring apparent impedance during a fault thereby providing a "zone" of protection.[1],[23].

Consider the example circuit shown in Figure 1 & 2. There are a total of 11 possible (shunt) fault types in this system: AG, BG, CG, AB, BC, CA, ABG, BCG, CAG, ABC and ABCG. The path taken by the fault current from its source to the point of the fault and back to the source is known as a fault loop.

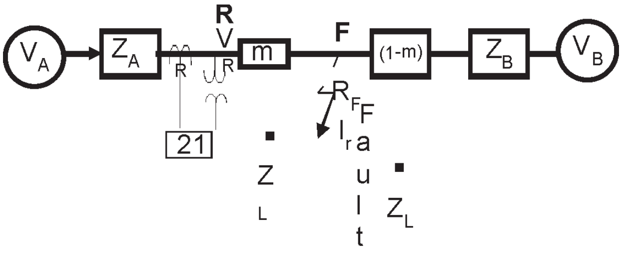

FIG. 1 TWO ENDED TRANSMISSION LINE

The voltages at the relay location (R) can be expressed as functions of relay currents (R) and voltages at the fault point (F). Using symmetrical components one can write:

$$V_{1R} - I_{1R}.m.Z_{1L} - V_{1F} = 0 \qquad \text{....(1a)}$$

$$V_{2R} - I_{2R}.m.Z_{1L} - V_{2F} = 0 \qquad \text{....(1b)}$$

$$V_{0R} - I_{0R}.m.Z_{0L} - V_{0F} = 0 \qquad \text{....(1c)}$$

Note that the positive and negative sequence impedances of a fully transposed transmission line are equal. Adding the three equations yields:

$$V_{1R} + V_{2R} + V_{0R} - I_{1R}.m.Z_{1L} - I_{2R}.m.Z_{1L} - I_{0R}.m.Z_{0L} - V_{1F} - V_{2F} - V_{0F} = 0 \qquad \text{....(2)}$$

Assuming an AG fault and recognizing that:

$$V_{1R} + V_{2R} + V_{0R} = V_{AR} \qquad \text{....(3a)}$$

$$V_{1F} + V_{2F} + V_{0F} = I_F.R_F \qquad \text{....(3b)}$$

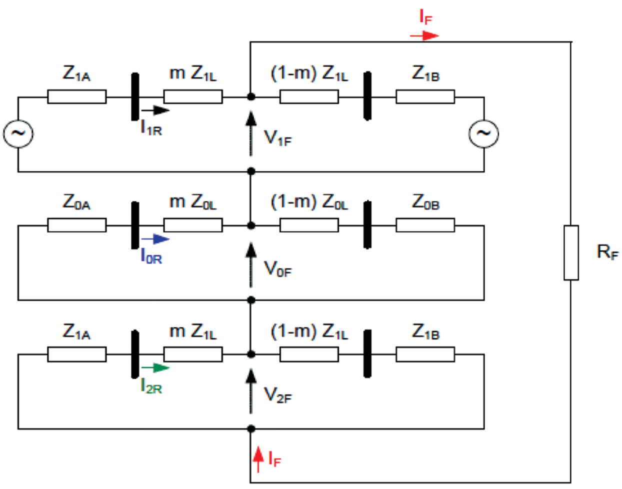

FIG. 2 NETWORK EQUIVALENT DIAGRAM FOR SINGLE-LINE-TO-GROUND FAULTS

We can re-write equation (2) as follows:

$$V_{AR} - m.Z_{1L}.[I_{1R} + I_{2R} + Z_{0L}/Z_{1L}.I_{0R}] - I_F.R_F = 0 \qquad \text{....(4)}$$

By adding and subtracting the zero-sequence current at the relay without changing the meaning of equation (4):

$$V_{AR} - m.Z_{1L}.[I_{1R} + I_{2R} + I_{0R} - I_{0R} + Z_{0L}/Z_{1L}.I_{0R}] - I_F.R_F = 0 \qquad \text{....(5)}$$

Recognizing that:

$$I_{1R} + I_{2R} + I_{0R} = I_{AR} \qquad \text{....(6)}$$

$$V_{AR} - m.Z_{1L}.\left[I_{AR} + I_{0R}.\left[\frac{Z_{0L}}{Z_{1L}} - 1\right]\right] - I_F.R_F = 0 \qquad \text{....(7)}$$

Equation (7) leads to the well-known concept of zero-sequence compensation and the zero-sequence compensating factor. Introducing the compensated current:

$$I_{AGR} = I_{AR} + I_{0R}.\left[\frac{Z_{0L}}{Z_{1L}} - 1\right] = I_{AR} + k_{0F}.I_{0R} \qquad \text{....(8)}$$

One gets the equation being a foundation of ground distance protection:

$$V_{AR} - m.Z_{1L}.I_{AR} - I_F.R_F = 0 \qquad ....(9)$$

Or

$$m.Z_{1L}.I_{AR} - V_{AR} = -I_F.R_F \qquad ....(10)$$

When RF is zero equation (9) can be re-written as:

$$m.Z_{1L} = \frac{V_{AR}}{I_{AR} + k_0.I_{0R}} \qquad ....(11)$$

Thus, for a ground fault under ideal conditions the apparent impedance $V_A/(I_A+k_0.I_0)$ is equal to the positive sequence impedance between the relay and the fault point and proportional to the distance to the fault.

To derive proper distance equations for phase faults, assume an AB fault (Figure 3):

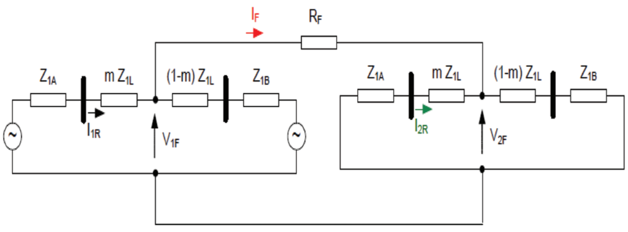

FIG. 3 NETWORK EQUIVALENT DIAGRAM FOR LINE-TO-LINE FAULTS

We can write:

$$V_{1F} - V_{2F} = I_F.R_F \qquad ....(12)$$

Substituting equations (1a) and (1b):

$$V_{1R} - V_{2R} - (I_{1R} - I_{2R}).m.Z_{1F} = I_F.R_F \qquad ....(13)$$

And setting RF = 0 gives,

$$m.Z_{1L} = \frac{V_{1R} - V_{2R}}{I_{1R} - I_{2R}} = \frac{(a^2 - a).V_{BCR}}{(a^2 - a).I_{BCR}} = \frac{V_{BCR}}{I_{BCR}} \qquad ....(14)$$

This demonstrates that the apparent impedance V_{ABR}/I_{ABR} corresponds once again to the impedance to the fault. Similar exercises show that V_{ABR}/I_{ABR} is equal to m . Z_{1LR} for three phase faults and double-phase-ground faults. Consequently 6 elements can be used to detect all fault types: three for ground faults and three for faults not involving ground.

TABLE 1

DISTANCE ELEMENT INPUT QUANTITIES

Element	Voltage	Current
AG	V_{AR}	I_{AR}, I_{0R}
BG	V_{BR}	I_{BR}, I_{0R}
CG	V_{CR}	I_{CR}, I_{0R}
AB	V_{ABR}	I_{ABR}
BC	V_{BCR}	I_{BCR}
CA	V_{CAR}	I_{CAR}

2.1 *Zones of operation*

The distance relay employs different zones of operation, Zone 1 of distance relay is used to provide primary high speed protection of a significant portion of the transmission line. Zone 2 is used to cover the rest of the protected line and provide some backup for the remote end bus. Zone 3 is the backup protection for all the lines connected to the remote end bus. Ideally, the setting of distance relays should ensure that they are not going to operate when not required (security) and will operate or trip when necessary (dependability).[1],[2],[3],[4]

2.2 *Challenges in conventional Distance Protection :*

The major challenges faced by the conventional distance relays can be classified into a) Static and b) Dynamic events, which may force mal-operation of employed distance protection. [1],[5].

Static event - Load encroachment

Dynamic event - Power Swings & Out of

Step condition - Voltage Instability

3.0 OUT OF STEP (OOS) DETECTION TECHNIQUES

Many OOS detection techniques exist in the Distance protection schemes, which are categorized into two broad classes as conventional and modern schemes. Further sub-divisions,as shown in Figure 4, are reported in the literature [2-24]; however,authors prefer to classify the available literature in the three categories, two as mentioned above and third, hybrid methods, incorporating advantages of two or more methods as a single solution.

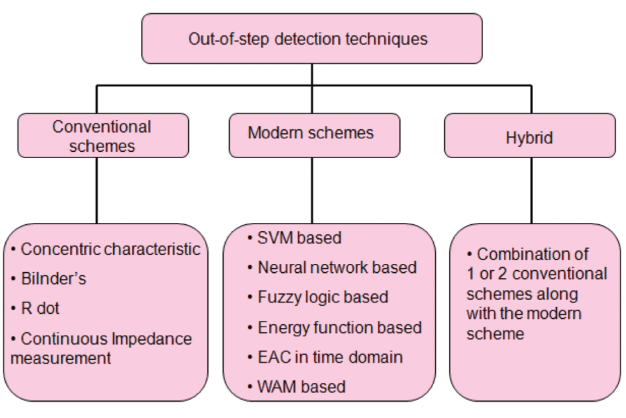

FIG. 4 OOS DETECTION TECHNIQUES

A. Conventional schemes.

1. Con centric characteristic scheme

The simplest method for measuring the rate of change of impedance is to determine the elapsed time required by the impedance vector to pass through a zone limited by two impedance characteristics. The second impedance characteristic is concentric around the first one. This is typically accomplished with either two additional characteristics, which are used specifically for the power swing function, or with an additional outer impedance characteristic that lies concentric to one of the existing distance protection characteristics. Figure 5 shows a concentric distance relay characteristics used for PSB and OST protection.[1], [2], [10]

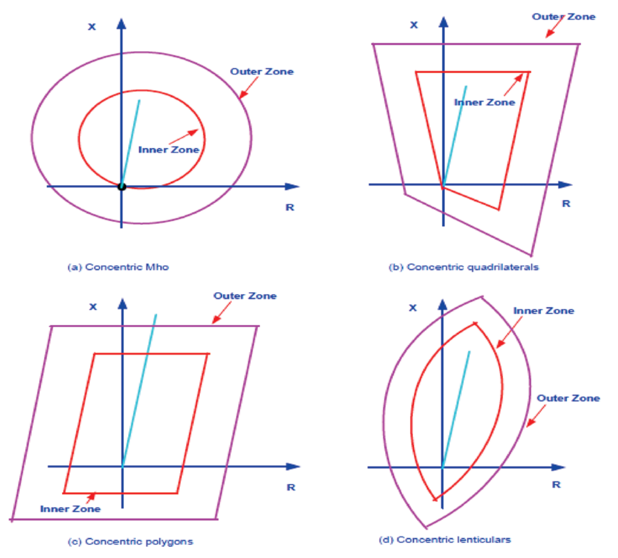

FIG. 5 CONCENTRIC DISTANCE RELAY CHARACTERISTICS

2. Blinder scheme

The two-blinder scheme shown in Figure 6 is based on the same principle of measuring the time eeded for an impedance vector to travel a certain delta impedance. The time measurement starts when the impedance vector crosses the outer blinder (RRO) and stops when the inner blinder (RRI) is crossed. If the measured time is above the setting for delta time, a power swing situation is detected. If the blinders are set in parallel to the line impedance, then they are optimized for the delta impedance measurement because the power swing impedance vectors will normally enter the protection zones at an angle of nearly 90 degrees to the line angle. Depending on certain network conditions, this may not be always correct but it can be assumed for simplification. [2], [10]

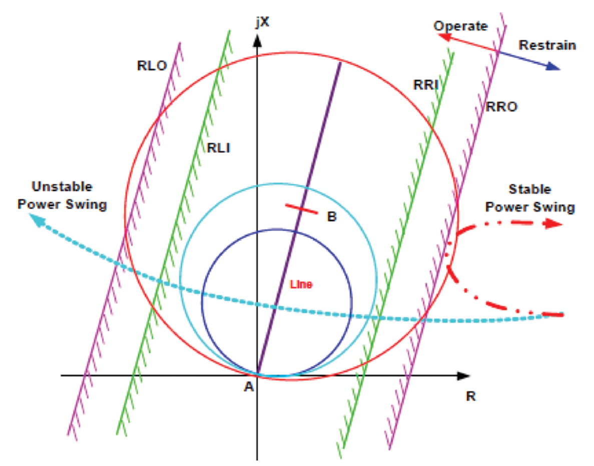

FIG. 6 TWO BLINDER SCHEME

A single-blinder scheme uses only one set of blinder characteristics. A single-blinder characteristic plus auxiliary logic can be used for an OST function. It can be used to restrict tripping of the distance relay for loads outside of the blinders.

3. *Rdot scheme*

Out-of-step tripping initiation on major EHV interconnections sometimes is required before the voltage at the electrical enter reaches a minimum value. This prevents severe voltage dips throughout the power system with possible uncontrolled loss of loads and loss of synchronism within sub-areas of utility network. The OST relay was augmented with the rate of change of apparent resistance and it was termed the Rdot scheme. Resistance based control algorithms to describe the OST detection are given by:

Conventional OST relay

$$Y_1 = (R - R1) \leq 0 \qquad \text{....(15)}$$

R-dot relay

$$Y_2 = (R - R1) + T1\frac{dR}{dt} \leq 0 \qquad \text{....(16)}$$

Where Y_1 and Y_2 are control outputs, R is the apparent resistance measured by the relay and R_1 and T_1 are relay-setting parameters. The above characteristic of the R-dot relay can be best visualized in the R-Rdot phase-plane shown in Figure 7. Y_1, and Y_2 then become "switching lines" in the phase-plane and the Rdot relay develops an output when the power-swing trajectory crosses a "switching line" in the R-Rdot plane. For a conventional OST relay without rate of change of apparent resistance augmentation is just a vertical line in the R-Rdot plane offset by the R_1 relay setting parameter. Switching line Y_2 is a straight line having slope T_1 in the R-Rdot plane. System separation is initiated when output Y_2 becomes negative. For low separation rates (small dR/dt) the performance of the Rdot scheme is similar to the conventional OST relaying schemes. However, higher separation rates dR/dt would cause a larger negative value of Y2 and will initiate tripping much earlier. [1], [10], [12]

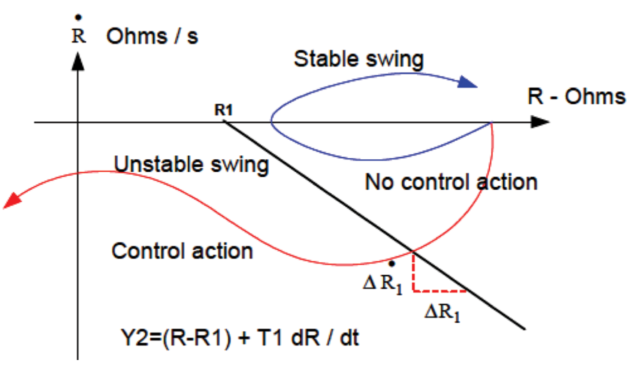

FIG. 7 R DOT SCHEME PRINCIPLE DEMONSTRATION

4. *Continuous impedance measurement schemes*

This method determines a power swing condition based on a continuous impedance calculation. Continuous here means, for example, that for each 5 ms step an impedance calculation is performed and compared with the impedance calculation of the previous 5 ms. As soon as there is a deviation, an out-of-step situation is assumed but not proven yet. The next impedance that should be calculated 5 ms later is predicted based on the impedance difference of the previous measured impedances. If the prediction is correct, then it is proven that this is traveling impedance. In this situation a power swing condition is detected. [2],[6-7],[9],[11-12].

A delta impedance setting is not required anymore, because the algorithm automatically considers any delta impedance that is measured between two consecutive calculations and sets the delta impedance for the next calculation automatically in relation to the previous calculation. This leads to a dynamic calculation of the delta impedance and an automatic adaptation to the change of the power swing impedance (Figure 8).

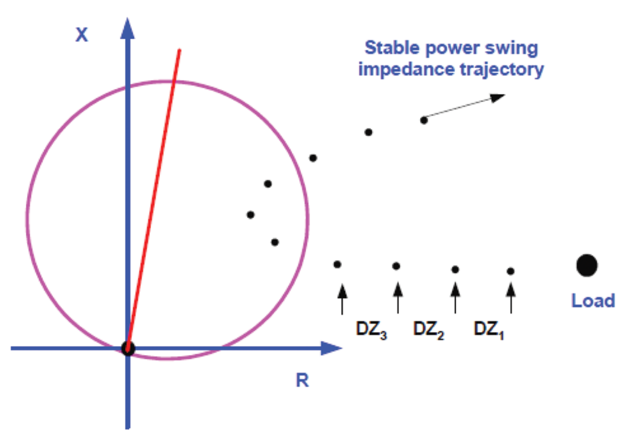

FIG. 8 POWER SWING DETECTION WITH CONTINUOUS SWING CALCULATIONS

5. *Swing-Center Voltage and its Rate of Change*

Swing-center voltage (SCV) is defined as the voltage at the location of a two-source equivalent system where the voltage value is zero when the angles between the two sources are 180 degrees apart. When a two-source system loses stability and goes into an OOS situation after some disturbance, the angle difference of the two sources, d(t), will increase as a function of time. [2], [13]

Where |VS| is the magnitude of locally measured voltage, and φ is the angle difference between VS and the local current as shown in Figure 9. In Figure 9, we can see that Vcosφ is a projection of VS onto the axis of the current, I. For a homogeneous system with the system impedance angle, q, close to 90 degrees, Vcosφ approximates well the magnitude of the swing-center voltage. For the purpose of power-swing detection, it is the rate of change of the SCV that provides the main information of system swings. Therefore, some differences in magnitude between the system SCV and its local estimate have little impact in detecting power swings.

Equation (18) provides the relation between the rate of change of the SCV and the two-machine system slip frequency, dδ/dt.

$$\frac{d(SCV1)}{dt} = -\frac{E1}{2}\sin\left[\frac{\delta}{2}\right]\frac{d\delta}{dt} \qquad ....(18)$$

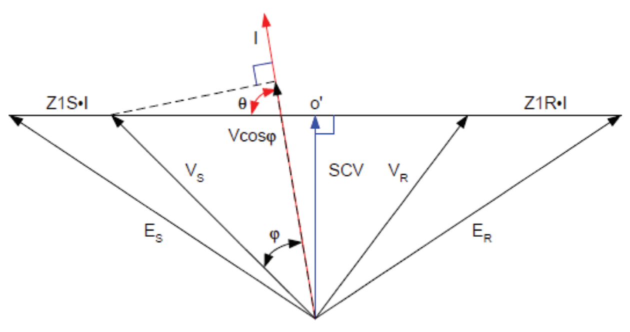

FIG. 9 VCOSφIS A PROJECTION OF LOCAL VOLTAGE,VS, ONTO LOCAL CURRENT, I

E1 is the positive-sequence source magnitude equal to ES that is assumed to be also equal to ER. SCV1 represents the positive-sequence swing-center voltage. phase-angle difference, δ.

6. *Neural network based schemes*

Neural networks are a relatively new information processing technique. They can be defined as 'a computing system made up of a number of simple, highly interconnected processing elements, which processes information by its dynamic state response

The equation (19) is used to calculate the adaptive OS condition for any case:

$$blend = \frac{\sum_{i=1}^{n} OS_i(1-cd_i)}{\sum_{i=1}^{n} S_i(1-cd_i)} \qquad ....(19)$$

Where blend is the adaptive OS decision; OSi, is the OS decision from OS prediction neural network i (0 = outof- step, 1 = stable); cdi, is the case detection decision from case detection neural network i (0 = the case, 1 = not the case); and n is the number of case detection neural networks used. [8] Different algorithms for training neural networks are used to predict the OS condition of synchronous generators. It is mentioned that the stochastic back-propagation algorithm gives acceptable results especially with an appropriate number of neurodes in the hidden layer. Many adaptive OS protection strategies have been presented based on neural networks in the literature, two are popular, the first approach depends on recognising the power network condition through case detection neural networks and then a new OS decision is calculated through an adaptive routine. The second approach depends on training a large neural network using samples from different outage cases (Figure 10).

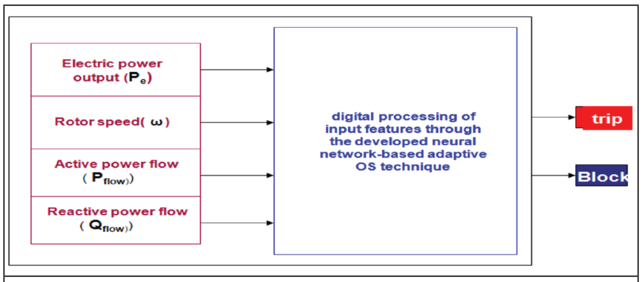

FIG. 10 BLOCK DIAGRAM USING NEURAL NETWORK FOR OOS DETECTION

7. *Fuzzy logic based schemes*

Fuzzy Inference Systems (FIS) employ the theory of fuzzy sets and fuzzy if-then rules to derive an output. Various types of FIS are oflen used either for tizzy modeling or fuzzy classification purposes. Typically an FIS scheme performs its action in several steps including (Figure 11) [14]:

- Fuzzification (comparing the input values with membership finctions to obtain membership values of each linguistic term),
- Fuzzy reasoning (firing the rules and generating their fuzzyor crisp consequent),
- Defuzzification (aggregating rule consequent to produce acrisp output).

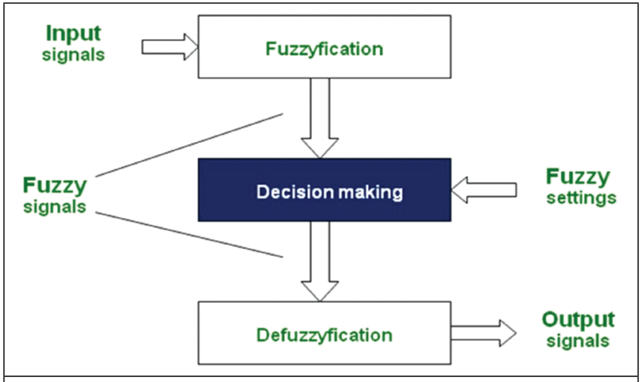

FIG. 11 FUZZY REASONING SYSTEM

The investigations described below have been done for a Sugeno-type FIS structure, Figure 12 and its general structure is shown in Figure 13. The output of each rule (y1 ... yn) is a linear combination of input variables (x1, x2, x3) plus a constant term, and the final output z is the weighted average of each rule's output.

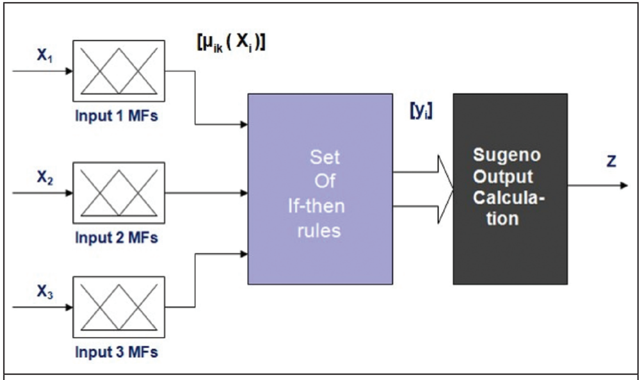

FIG. 12 FIS STRUCTURE FOR SUGENO TYPE FIS

$$z = \frac{w_1 y_1 + w_2 y_2 + \cdots + w_n y_n}{w_1 + w_2 + \cdots + w_n} \qquad ....(20)$$

$$y_k = a_k x_1 + b_k x_2 + c_k x_3 + d_k \qquad ....(21)$$

$$w_k = \mu_{1k}(x_1)\mu_{2k}(x_2)\mu_{3k}(x_3) \qquad ....(22)$$

where:

$\mu_{ik}(x_i)$ € $\{\mu_{iLOW}, \mu_{iMEDIUM}, \mu_{iHIGH}\}$

- membership functions (MF) for the linguistic terms Low, MEDIUM, HIGH associated with the i-th input signal, wi - weighting factor for the i-th rule consequent,

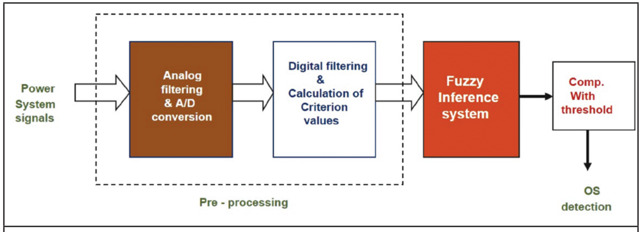

FIG. 13 GENERAL STRUCTURE OF FIS BASED OS DETECTION

The OS detection & protection scheme proposed makes use of the adaptive network version of FIS. With such an arrangement all the advantages of fuzzy processing are combined with the virtues of training on examples, as in case of neural networks. Thus all the problems connected with burden some heuristic setting process of the fuzzy system are avoided and a kind of optimization can be is realized.

8. *Energy Function based schemes*

The Energy function based schemes provide online detection of the loss of synchronism based on voltage and current measurements in that line. The conditions for system instability are derived from energy function analysis. The potential energy with generators represented by a classical model can be expressed as the sum of energies in the series elements (transmission lines, transformers, and generator reactances) .It is shown that such an expression is applicable even for the detailed (two-axis) generator model. Under certain assumptions, it is possible to express the potential energy as the sum of energies in the lines belonging to a cutset and the kinetic energy as a function of the rate of change of phase angle across a line belonging to the cutset. These schemes makes use of the potential energy in the lines belonging to the cutset and the kinetic energy.[16 – 18]

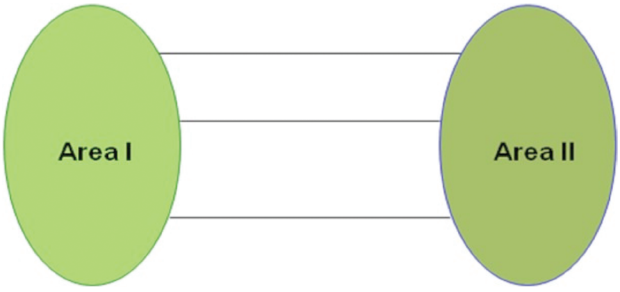

FIG. 14 COHERENT AREAS

The system can be represented by two areas connected by the critical cutset as shown in Figure 14. The potential energy can be decomposed into the energy within the two areas and the energy along the critical cutset. Assuming coherent areas,the potential energy within an area is zero as all of the buses in that area have the same frequency $d\delta_k/dt$ is zero for all series elements within an area). Hence, the potential energy can be written as follows:

$$W_2 = \sum_{k=1}^{nc} \int_{t_0}^{t} (P_k - P_{ks}) \frac{d\delta_k}{dt} dt \quad ....(23)$$

Where nc is the number of elements in the critical cutset. It can be shown that the variation of potential energy in all of the lines in the critical cutset is similar. If a series element (line or transformer) k in the critical cutset connects buses i and j.

$$P_k = V_i V_j b_k \sin \delta_k \quad ....(24)$$

$$\delta_k = \phi_i - \phi_j \quad ....(25)$$

where Vi and Vj are the voltage magnitudes at buses i(in area I) and j (in area II), respectively, and b_k is the susceptance of the series element. Due to the assumption of coherency, the variations of Vi and ϕi are similar for all of the elements in the critical cutset. This is also true of the variations of Vϕ and ϕj. Hence, the variation of potential energy can be monitored from the energy in the individual lines in the cutset.

By assumption of coherency, the rotor speeds of all the generators in an area are equal and the derivative of the angle across all of the elements in the critical cutset are the same. Hence

$$w_{eq} = \frac{d\delta_k}{dt} \quad ....(26)$$

where is the angle across any line in the critical cutset. The corrected kinetic energy is given by

$$W_1^{'} = \frac{1}{2} M_{eq} \left(\frac{d\delta_k}{dt}\right)^2 \quad ....(27)$$

The criterion derived for the detection of instability is based on energy function analysis. The power system gains kinetic and potential energy due to a disturbance. For transient stability, the system must be capable of absorbing the kinetic energy completely. If the kinetic energy is not completely converted to potential energy, the system becomes unstable. Therefore, for a stable swing, kinetic energy is zero when potential energy attains a maximum, and for an unstable swing, kinetic energy is not zero (positive) when potential energy attains a maximum. This criterion is used for the detection of instability. Since the criterion checks whether kinetic energy is zero or positive when potential energy is maximum, it is adequate to monitor $d\delta_k/dt$ instead of the kinetic energy, and the potential energy given by (23).

The critical cutset depends on the operating condition and the disturbance, and is not known beforehand. Therefore, the condition for instability is checked in all of the lines across which the angle exceeds the threshold value δ_{min}. The identification of the critical cut set is the key for these energy function based schemes.

9. *Equal area criterion (EAC) in time domain based scheme for OOS detection.*

In this scheme, the popular concept of EAC modified to the time domain. An out-of-step protection methodology is using the concept of time domain EAC. The time domain EAC is based on the power-time (Pe - t) curve instead of the Pe-δ curves. The proposed technique uses only local output power (Pe) information and does not need any other power system parameter information (line impedances, equivalent machine parameters, etc). The electrical output power, Pe, over time is calculated from local voltage and current information measured at the relay location. The transient energy, which is the area under the Pe-t curve, is computed, and the swing is classified as stable or out-of-step based on the areas computed.[1],[19]

$$A_1 = \int_{t_0}^{t_1} (P_m - P_e(t))\, dt \qquad ....(28)$$

$$A_2 = \int_{t_{10}}^{t_{max}} (P_m - P_e(t))\, dt \qquad ....(29)$$

During the transient, if area A_1 and A_2 under the Pe-t curve are equal, the system becomes stable. But if area A_1 becomes greater than area A_2, the system goes to an out-of-step condition. The area under the Pe - t curve represents energy. Thus, this concept can be referred to as the energy equilibrium criterion in the time domain. A balance of transient energy results in a stable swing whereas an unbalance of transient energy results in an out-of-step swing (Figure 15-17).

For a stable condition, the sum of two areas A_1 and A_2 becomes,

$$A = A_1 + A_2 = \sum_{t_0}^{t_{max}} \Big\{ (P_e(t))/_{t_0-\Delta t} - (P_e(t) \Big\} \Delta t = 0 \qquad ....(29)$$

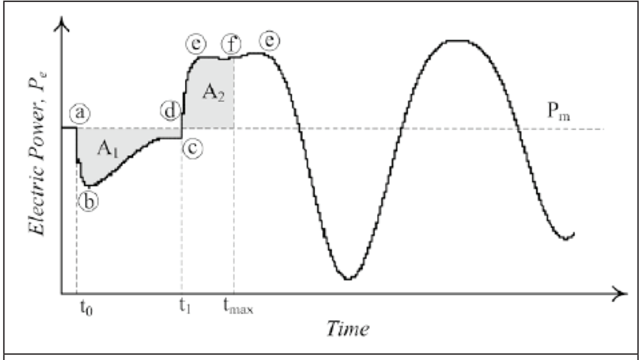

FIG. 15 PE – T CURVE FOR STABLE CASE

For an out-of-step condition

$$A = A_1 + A_2 = \sum_{t_0}^{t_{max}} \Big\{ (P_e(t))/_{t_0-\Delta t} - (P_e(t) \Big\} \Delta t > 0 \qquad ....(30)$$

Where t0 time when $P_e(t) < P_e(t)_{t_0-\Delta t}$ first occurs;

t max time when A t = 0 (stable) or time when

$P_e(t)_{t\ -\Delta t} > P_e(t)_{t_0-\Delta t}$ *and* $P_e(t) < P_e(t)_{t_0-\Delta t}$

For out of step.

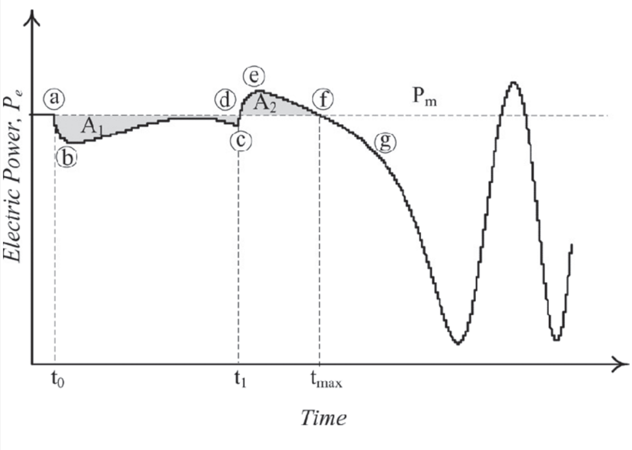

FIG. 16 PE – T CURVE FOR UNSTABLE CASE

10. Wide area measurement based OOS detection schemes

For an affective operation of the adaptive protection of the system, very precise and consistent system monitoring parameters like magnitude and angle of voltage, current and power flows are essential.

Now a days, in most of the electrical networks asynchronous measurements that are collected in the control centre and state estimation is performed. Steady state models are used in Supervisory Control And Data Acquisition (SCADA) system while measurements of various electrical quantities (voltage & current magnitudes, active & reactive power flows and injections etc) also through a SCADA. This leads to a biased state estimation, where biases mainly stem from utilization of single phases, positive sequence models and measurement time skewness. These biases can be eliminated using Phasor Measurement Units (PMU) measurements in combination with highly accurate, three phase and asymmetric power system models. Moreover, synchronized and time tagged measurements that are referenced to the Global Positioning System (GPS) signal eliminate biases from the geographic spread and separation of power systems.

WAMS based measurements are able to give real time power system phasors at a rate of 60 phasors / second. This is now possible with Phasor Measurement Unit (PMU) enabled wide area measurement system (WAMS). All the above mentioned schemes will definitely work faster with WAMS as its sampling rate is higher. [1-2],[5],[12],,[15],[20]

Many synchrophasor based OOS detections schemes are started appearing in the literature days , one of the scheme based on the synchronized swing impedance and resistance measurements. [21],[22]

Fast Fourier Transform (FFT) algorithm has been used to compute the voltage and current phasors at fundamental frequency. These phasor quantities are then converted into sequential components to calculate the positive sequence resistance seen by the relay at the locations at both ends of the transmission line. A difference signal is then generated from these synchronized positive sequence resistance values. This difference signal has been monitored for differentiating stable and unstable power swing. It has been observed that for unstable power swings the variations in the resistance difference signal someasured is substantially higher than those observed in case of stable power swing. Relay is set to differentiate stable and unstable power swings by measuring the resistance difference.

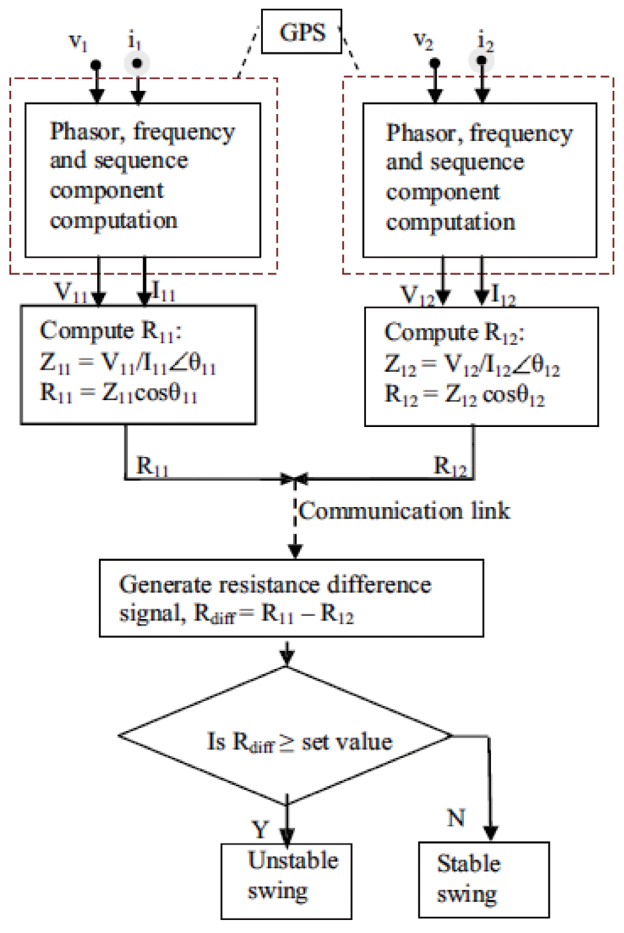

FIG. 17 FLOWCHART FOR SYNCHRONISED RESISTANCE DIFFERENCE SCHEME

In impedance difference scheme instead of resistance, impedance is monitored to distinguish stable and unstable power swing. It is observed that as the disturbance severity increases, operating time of both resistance and impedance schemes reduces.

4.0 CONCLUSION

A comprehensive review of available literature on power system protection – Distance Protection, OOS detection techniques is presented in this paper. Basic algorithms or working schemes of each technique, available merits and demerits are brought out from plethora of research papers R dot scheme is the fastest scheme from the conventional distance protection schemes. Where as, with proper training & conditional rules the Neural network & Fuzzy logic schemes can detect the system out-of-step condition much faster than other modern schemes except WAM based schemes. As the Wide area measurement system based OOS detection schemes will have much faster data recording thru PMU and they would provide the fastest OOS detection using fast detection algorithms. The WAMS based synchronized resistance & impedance system can provide quick OOS detection but they needs off-line system parameter study for fixing upon the threshold resistance and impedance values. Lot of research work is going in WAMS based OOS detection for enhancing the electrical parlance reliability & power quality.

5.0 KEY ISSUES AND CHALLENGES

- The power system parlance is becoming complex day by day. Continuous addition of Generating stations both renewable and non-renewable, load center including both linear and non-linear kind of loads taking place faster then before. The system configurations are changing for every minute demanding an adaptive, reliable, quicker and rugged protection system. The recent black outs and brown outs in 30th and 31st of June 2012 in India reveals the importance of the reliable and adaptive protection schemes.
- Selective, high-speed clearance of faults on high voltage transmission lines is critical to the security of the power system. A distance relay can discriminate with relatively good accuracy between a fault that is internal to the line and one that is external by measuring apparent impedance during a fault thereby providing a “zone” of protection. So, the OOS detection techniques should be adaptive in nature. It should also be robust against changing power scenarios and issues with the measurement system in terms of speed & accuracy of the data.
- The key issues and challenges in Distance protection – OOS detection techniques are as follows:
- For techniques based on Equal Area Criterion in time scale, though the technique provides very fast & reliable OOS detection but in some cases like Fly wheel compensation, bulk reactive power switch over etc are not properly justified.
- The convention R dot techniques works very fast and adaptive as the second derivative term accelerate its operation. However, the challenge remains in fixing the relay settings of R1 & T1. This can be properly set with the off-line study of the system parameters. Generally, this technique is used as back up protection of modern distance relays.
- The energy function criterion for loss-of-synchronism detection for a complex power system. During unstable swings, the entire power system oscillates in two groups, and series elements (called cutset) connect them. By evaluating the potential energy of the cutset, the stable and unstable conditions are predicted. The technique requires the measurements across all series elements as any of the series elements could form a cutset depending on the pre-disturbance conditions, type of disturbance, and its duration. Thus, to implement as an out-of-step algorithm, measurements across all series elements are required to find the cutset. This technique is difficult to implement as a protection algorithm because it is based on wide area information.
- For techniques based on Neural Netwoks and Fuzzy logics, it is difficult to collect sufficient training signal patterns for practical applications because the highly time-varying behavior of nonlinear loads may be unexpected. There is a need for dynamical adjustment of the size of the

neural network to effectively search for the minimum estimation errors of the measured signal.

- Modern trend of wide area measurement systems (WAMS) requires phasor measurement unit for making electric grid more intelligent, efficient and smart. These PMUs devices are very quick in sampling and dump bulk data, so the OOS detection algorithm should also be fast and accurate.

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