Self-Healing Framework for Distribution Systems

Fazil Haneef, S.Angalaeswari

Abstract - The self healing framework for distribution systems based on multi agent system is constructed. The proposed multi agent system is designed to locate and isolate faults, then decide and implement the switching operations to restore the out-of-service loads. The function of zone agents in the first layer is monitoring, making simple calculations, and implementing control actions. Feeder agents in the second layer are assigned to negotiation. The constraints include voltage limits, line current limits, and radial topology. FLISR (Fault Location/Isolation/Service Restoration) module will help to reduce the gap between an experienced and a new operator, as the network control will effectively move from person dependent to system dependent. This method can significantly decrease the Fault Location/Isolation/ Restoration time, compared to conventional SCADA/DMS system.

Index terms – Distribution System, Multi-Agent System, Fault Identification, Isolation, Service Restoration, Voltage and current limit constraints

1 Introduction

AFTER occurrence of any fault, the key challenge to any power distribution utility is to locate/ detect the faulty section, Isolate the faulty section and restore un-faulted areas, as quickly as possible. Faster the restorations after fault- better its impact on Reliability Indices and grater is customer satisfaction. In post fault scenario, the efficiency and quality of 'isolation and restoration' depends on the experience and skill-set of the individual operator in SCADA/DMS control room.

FLISR (Fault Location/Isolation/Service Restoration) module will help to reduce the gap between an experience and a new operator, as the network control will effectively move from person dependent to system dependent. FLISR module is an Advanced Distribution Automation application which has very much importance in future Smart Grid control rooms.

FLISR module installed at field can locate or detect the faulty section and automatically generates switching sequence to isolate the section and restore the un-faulted areas. For that the distribution system is considered as a multi agent system. The control structure has two layers: zone and feeder. The function of zone agents in the first layer is monitoring, making simple calculations, and implementing control actions. Feeder agents in the second layer are assigned to negotiation. The constraints include voltage limits, line current limits, and radial topology. This method can significantly decrease the Fault Location/Isolation/ Restoration time, compared to conventional SCADA/DMS system. FLISR module is a 'must' in all future Smart Grid control rooms.

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2 OBJECTIVES

The main objective of this thesis is to develop a framework for self-healing in order to obtain FLISR and to find the solution for the proposed algorithm using C Programming

3 OPERATION MECHANISM

The objectives and the two-way communication among the control agents are shown in Fig 1. As shown in the figure, the objectives common to all agents are the maximization of the loads restored and the minimization of the number of switching operations. Each agent also has an additional objective. For example the initiator feeder agent (i.e., the feeder that has been subjected to a fault at one of its components and hence has at least one out-of service zone) will locate and isolate the faulty zone before beginning the restoration process. The responder feeder agents (i.e., level-1 or immediate-neighbor backup feeders of the initiator) and the subcontractor feeder agents (i.e., level-2 or immediate-neighbor backup feeders of the responder feeders) will provide whatever capacity they have to assist with the restoration without violating their operational constraints. This section describes the operating mechanism of each agent and the mechanism for their coordination using two-way communication during both stages of the self-healing operation (i.e., the first stage, which is the detection and isolation of the fault location, and the second stage, which is the restoration of the out-of-service load).

3.1 Detection of Fault Location And Isolation Algorithm.

Once a permanent fault occurs in a distribution feeder, the feeder circuit breaker is tripped in real-time operation. The fault location detection and isolation algorithm is then applied in order to locate and isolate the faulty section from both directions.

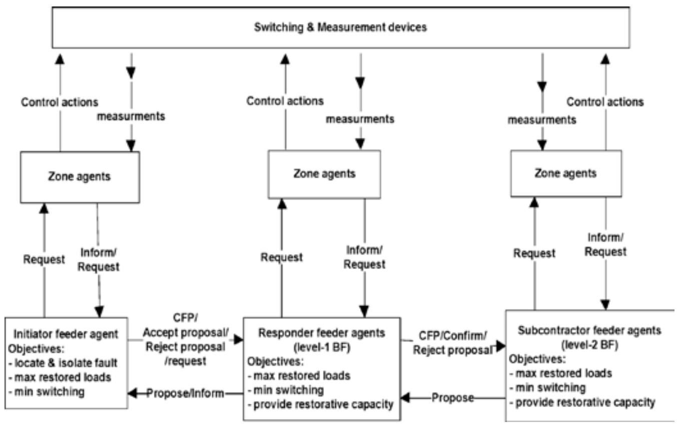

Fig. 1 Coordination via two-way communication among the control agents

As soon as the faulty section is isolated, the upstream out-of-service loads are restored through the closing of the feeder circuit breaker. A restoration algorithm is applied to restore the downstream out-of-service loads. When the faulty section is repaired, the reverse switching sequence is applied so that the distribution system is returned to its normal configuration. Due to the radial topology of the distribution feeders, the occurrence of a fault in a distribution feeder affects only its sections [i.e., sections between the substation and the faulty section as well as the downstream sections, when distributed generation units (DGs) are present]. Therefore, only the control agents of the feeder that has the faulty section will participate at this stage. Due to the voltage potential difference, the normal power flows being from the source to the grid. However, the introduction of DG units may change the direction of power flows from unidirectional to bidirectional. When a fault occurs somewhere in the distribution system, the power flow magnitude and direction change. Fault current flows from the substation and DG units to the lowest potential point at the fault location. Therefore, when a fault occurs in one of the zones between the substation and other zones that involve DG units, the following two conditions apply.

- The fault is fed by both the substation and the DG units in the downstream zones. The current in both boundary breakers of this zone will thus flow into the zone
- The current in at least one of its breakers will exceed its limit.

The former condition means that there is no fault outside this zone. The latter condition always applies because the former one can be implemented under normal conditions (i.e., a reverse power flow due to a high generation level produced from DG units in the downstream zones). On the other hand, when a fault occurs in a zone that has no downstream zones containing DGs, its entrance breaker current will exceed its limit. Based on these conditions for fault occurrence and on the proposed control structure in Fig. 1 the fault location detection and isolation algorithm for a single fault at a time can be described as follows

1. Monitoring devices using direction and over-current relays provide two signals to indicate a change in the status of the current flow. One signal indicates that the magnitude of the current exceeds its limit, and the other indicates the direction of the current.
2. Zone agents utilize these signals in a logic circuit to generate simplified binary status signals (0 or 1), as shown in Fig. 2

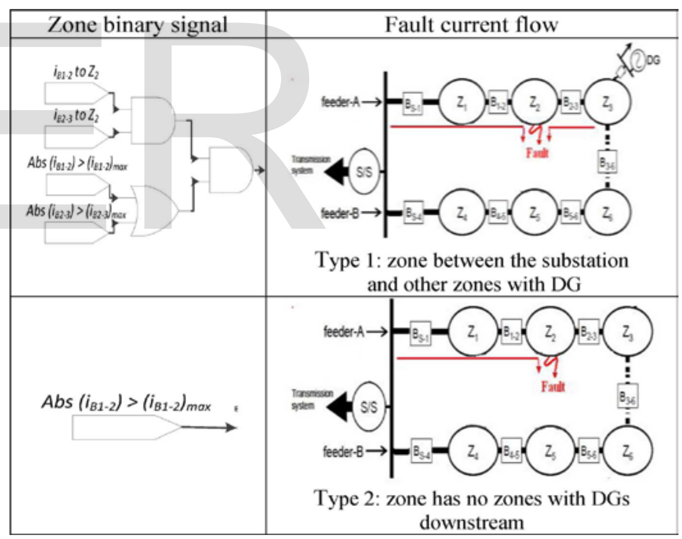

Fig. 2 Logic circuits for zone binary signal and fault current flow

3. They then send these binary signals to their feeder agent through inform messages.
4. The feeder agent determines which zone is the faulty zone as shown in Fig. 2 :
    - If it receives a binary signal with a value of one from a type 1 zone, it sends a request message to this zone agent asking it to open its boundary breakers

- If it receives a binary signal with a value of one from a type 2 zone, it sends a request message to this zone agent asking it to open its boundary breakers

- If it receives a binary signal with a value of one from more than one type 2 zones, it sends a request message to the last zone agent (i.e., the zone at the feeder end side) asking it to open its boundary breakers

If it receives a binary signal with a value of zero, no action is taken.

3.2 Service Restoration Algorithm.

1. Initiator Control Agent Operating Mechanism:

After the fault is isolated, the downstream zones are isolated. The affected zones communicate with their feeder agent (initiator), as shown in Figs. 1, in order to build a restoration plan.

The details of the proposed architecture are as follows:

1. Each zone agent in the out-of-service area sends a request message to the initiator, including its load demand and priority

$$\text{Zone index}_i = \sum_{j=1}^{n_s} wf_i^j * S_i^j$$

Where wf_i^j, S_i^j : Weighting factor and load demand of customer j in zone i respectively,
ns : Total number of customers in zone i.

2. The initiator control agent starts negotiations using a contract net protocol (CNP) by sending call for proposal (CFP) messages to the responder feeder agents.
3. After the responder feeder agents reply with their proposal messages, which contain their available remaining capacity (ARC), the initiator agent sends these two input items to its decision maker. The input consists of the load demands and priorities from the out-of-service zone agents, and the ARCs from the responder agents.
4. The decision maker component in the initiator agent uses expert-based rules along with the input it has received in order to determine its output.
5. The initiator agent compares the maximum ARC with the total demand from the out-of-service zones

$$\text{Is} \max_{i \in n_{BF1}} (ARC_i) \geq \sum_{i=1}^{n_z} S_i$$

where S_i : Load demand of zone i
nz : The total number of out-of-service zones
nBF1: The total number of responder agents.

6. If the above equation is satisfied, the initiator decides to initiate group restoration by restoring all out-of-service zones through one switching operation.
7. The actions of the initiator agent are therefore to send an accept-proposal message to the responder agent that has the highest ARC and to send a request message to its zone agent that is the neighbor of the selected backup feeder asking it to close its tie switch for the completion of the restoration process.
8. If the equation is not satisfied, the initiator decides to initiate zone restoration by building a zone/switch relationship table
9. Based on the zone/switch relationship table and the ARCs communicated from the responder agents, the initiator agent searches for possible combinations of zone restoration. It compares the ARCs with the elements of zone combination, which are listed in descending order based on their priority indices.
10. After checking for the available restoration possibilities, the initiator agent actions are:

    1) To send accept-proposal messages to those responders that will be used in the restorations

    2) To place tie switches between the feeder agents that have accepted proposals and the selected combinations for the restoration in a switch-to-be-closed list (SCL)

    3) To place the bounded sectionalizing switches of the selected combinations for restoration in a switch-to-be-opened list (SOL) in order to satisfy the radial constraint

    4) To update the zone/switch relation table.

11. It then checks to determine whether the table is empty (i.e., whether all zones have been restored).
12. If the table is empty, the initiator sends request messages to the appropriate zone agents asking them to open their sectionalizing switches that are included in the SOL list in order to partition the outage area and then to close their tie switches that are included in the SCL list.
13. If the table is not empty, the initiator sends request messages to the responder feeder agents that are neighbors of the remaining unrestored zone combinations. This request prompts these responders to start negotiations with their neighbors (subcontractors) to find load transfers that can provide additional ARC. The request

message includes the load demand required for the remaining unrestored zone combinations.

14. After these responders reply with their ARC, the initiator agent repeats steps 9–11.
15. If the table is empty, the initiator sends request messages to the appropriate zone agents to open their sectionalizing switches included in the final SOL list and then to close their tie switches included in the final SCL list.
16. If the table is not empty, the initiator determines the necessity for load shedding of the lowest priority load (i.e., the lowest priority zone index) in the remaining unrestored zone combinations. It then checks to determine whether all zones have been restored, as in step 9.
17. The initiator agent repeats step 16 until the zone/switch relationship table becomes empty, when it then executes step 15 in order to implement the switching actions required for the completion of the restoration process.

3.3 Level - 1 Backup Feeder (Responder) Operating Mechanism.

The operating mechanism of each level-1 backup feeder (responder) agent will be as follows:

1. After the responder agent receives a CFP message from the initiator, it starts to build its proposal (ARC)

2. It sends query messages to its appropriate zone agents about their spare capacities and bus voltage values

3. Each zone agent replies by sending an inform message that includes the spare capacity of its branch and/or the bus voltage magnitude of its bus:

$$I_M(K) = I_{max}(k) - I(k)$$

Where I_M (k) : Represents the available capacity of each zone before it becomes overloaded and before its protection device operates
$I_{max}(k)$: Upper bound current in branch K
$I(k)$: Magnitude of the current flow in branch k

4. If any zone has more than one branch, it sends the minimum spare capacity of its branches, and a zone with more than one bus sends the lower voltage magnitude of its buses
5. After the responder agent receives these replies, it calculates its ARC as follows

$$I_C = \min_{k \epsilon j}(I_M(k))$$

$$I_V = \frac{V_w - V_{min}}{Z_{path}}$$

$$I_{available} = \min(I_C, I_V)$$

Where j : Zones along the restoration path
V_w : The lowest bus voltage magnitude of the values received from zone agents
V_{min} : Minimum allowable voltage magnitude in the network (i.e., 0.9 p.u.)
Z_{path} : Series impedance of the path between the substation and the node closest to node w on the restoration path. This impedance could be determined by carrying out offline simulation if the forecasted load is available (i.e., to determine which point among the points located at the end of the feeder will have minimum voltage, hence, its Z_{path} will be used). Another option is to determine Z_{path} for those possible points in advance and based on the received minimum voltage value, the appropriate impedance is used
I_C : Maximum spare capacity of the restoration path without overloading (current limit constraint)
I_V : Maximum spare capacity of the restoration path to avoid under-voltage at any node (voltage limit constraint)
$I_{available}$: Maximum spare capacity of the restoration path without violating operating constraints.

6. If this spare capacity $I_{available}$ from this supporting feeder will be used to restore an out-of-service load $S_L=P_L+jQ_L$ at voltage V_L

$$|S_L| = |V_L| * |I_{available}|$$

to include the voltage limit $V_L \geq 0.9$ pu.
This ARC guarantees that voltage limits will not be violated for the restored zones.

7. The responder sends to the initiator agent a propose message that includes this ARC.

8. If the responder receives an accept-proposal message from the initiator, it replies to the initiator by sending an inform message to indicate that it is committed to the completion of the task.

9. If the responder receives from the initiator a request message for additional ARC through load transfer,

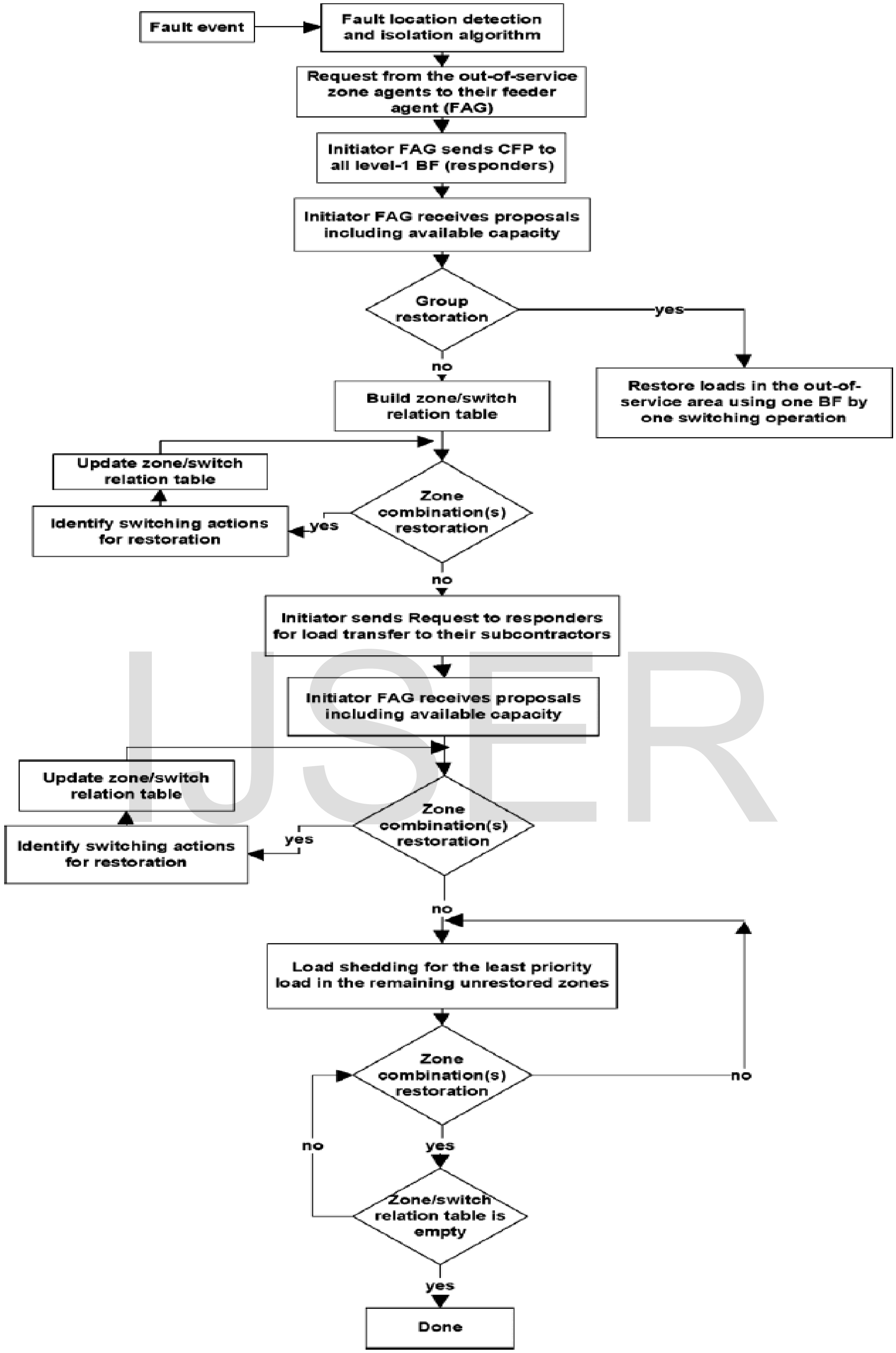

Fig. 3 Flow chart of Overall self healing procedure using agents

it begins negotiations by sending CFP messages to its neighboring feeders, if available (i.e., level-2 backup feeders or subcontractor agents).

10. This load transfer from a level-1 backup feeder to a level-2 backup feeder would involve the responder securing a margin that could enable it to restore the remaining out-of-service zone combinations. The best amount of the transferred load (TL) is then

    TL = (load of remaining unrestored zone combinations) - (remaining ARC of this level-1 backup feeder)

11. Due to the discrete nature and possibly the limited ARC of the level-2 backup feeders, the TL cannot be exactly the same as what is required. The responder thus selects its zones to be transferred to the level-2 backup feeder as follows:

    Transferred zone(s) ≈ min (TL, ARC of level – 2 BF)

12. After the responder determines the zones to be transferred, it sends a propose message to the initiator with its new ARC
13. If the responder receives an accept-proposal message from the initiator, it sends a confirm message to the subcontractor agent and request messages to the appropriate zone agents asking them to open the bounded sectionalizing switches for the selected zones to be transferred and to close the tie switch to complete the load transfer to the subcontractor. Fig. 4.6 shows the overall procedure for the proposed responder control agent.

4 CONCLUSION

The proposed control structure consists of two main types of controllers: zone and feeder. The operating mechanism of each controller has been designed based on the concept of a multi agent system. An expert-based decision maker has been proposed for each agent in order to achieve its objectives and satisfy its constraints. The proposed algorithm is programmed using C Programming and executed successfully. The results show that cooperation among agents through two-way communication provides a good solution for fault location, isolation and service restoration.

REFERENCES

[1] Aboelsood Zidan, and Ehab F. El-Saadany, "A Cooperative Multi agent Framework for Self-Healing Mechanisms in Distribution Systems" , (April 2012).

[2] Castelhano .A, Keel .B, Heydt .G, Jack .N and Pérez-Guerrero. R, "Optimal restoration of distribution systems using dynamic programming," IEEE Trans. Power Del., vol. 23, no. 3, pp. 1589–1596, (Jul. 2008).

[3] Chen. W, "Quantitative decision-making model for distribution system restoration," IEEE Trans. Power Syst., vol. 25, no. 1, pp. 313–321, (Feb. 2010).

[4] Fotuhi-Firuzabad .M, Lehtonen. M, Sanaye-Pasand. M and Kazemi.S, "Impacts of automatic control systems of loop restoration scheme on the distribution system reliability," IET Gener. Transm. Distrib., vol. 3, no. 10, pp. 891–902, (2009).

[5] Kanamori. H, Funabashi. T, Kato. T and Suzuoki. Y, "Multi-agent based control and protection of power distributed system—Protection scheme with simplified information utilization—," in Proc. 13th Int. Conf. Intell. Syst. Appl. Power Syst., Arlington, VA, pp. 49–54, (Nov. 2005).

[6] Lu. L, Wu. J, Su. S and Lee. T, "An autonomous decision approach for fault allocation and service restoration in electrical distribution systems by multi agent system," in Proc. 9th Int. Conf. Hybrid Intell. Syst., Shenyang, China, pp. 89–94, (Aug. 2009).

[7] Mallet. S, Grenard. S, Mamo. X and Coste. T, "Distribution automation: The cornerstone for smart grid development strategy," in Proc. IEEE Power Energy Soc. General Meeting, Calgary, AB, Canada, pp. 1–6, (2009).

[8] Sasaki. H and Nagata. T, "An efficient algorithm for distribution network restoration," in Proc. IEEE Power Eng. Soc. Summer Meeting, Vancouver, BC, Canada, vol. 1, pp. 54–59, (2001).

[9] Sasaki. H and Nagata. T, "A multi-agent approach to power system restoration," IEEE Trans. Power Syst., vol. 17, no. 2, pp. 457–462, (May 2002).

[10] Song. B, Li. P, Wang. T and Wang.W , "Multi-agent approach for service restoration of microgrid," in Proc. 5th IEEE Conf. Indust. Electron. Appl., Taichung, Taiwan, pp. 962–966, (2010).

[11] Tsai. M and Pan. Y, "Application of BDI-based intelligent multi-agent systems for distribution system service restoration planning," Euro. Trans. Electr. Power, pp. 1783–1801, (2011).

[12] Tsai. M, "Development of an object-oriented service restoration expert system with load variations," IEEE Trans. Power Syst., vol. 23, no. 1, pp. 219–225, (Feb. 2008).