TELKOMNIKA, Vol. 11, No. 5, May 2013, pp. 2634 ~ 2640
ISSN: 2302-4046

Differential Protection for Distributed Micro-Grid Based on Agent

ZHOU Bin*[1,2], YING Li-ming[1], ZHU Yonggang[1,2]
1. School of Electrical Engineering, Wuhan University,Wuhan 430072,China
2. Hubei Electrical Power Company, Wuhan 430077, Hubei Province, China
*Corresponding author, e-mail: zhoub@hb.sgcc.com.cn

Abstract

The Micro-grid, even though not a replacement of the conventional centralized power transmission grid, plays a very important role in the success of rapid development of renewable energy resources technologies. Due to the facts of decentralization, independence and dynamic of sources within a Micro-grid, a high level automation of protection is a must. Multi-Agent system as a approach to handle distributed system issues has been developed. This paper presents an MAS based differential protection method for distributed micro-grid. The nodes within a micro-grid are divided into primary and backup protection zones. The agents follow predefined rules to take actions to protect the system and isolate the fault when it happens. Furthermore, an algorithm is proposed to achieve high availability in case of Agent it self malfunction. The method is using Matlab for simulation and shows it satisfies relay protection in terms of the selectivity, sensitivity, rapidity and reliability requirements.

Keywords: *differential protection; MAS; agent; micro-grid*

1. Introduction

The micro-grid, according to CERTS, is a micro power system including a cluster of loads, storage and multiple DGs [1]. Compared with the traditional nation grid the Micro-grid has certain advantange like it is very appropriate for renewable resources; it requires smaller financial investment and has flexibility to construct when needed and local social and natural environment meets the prerequisites; the centralized grid disturbance or outage is isolated. However, also because of these features the micro-grid requires a high and sophisticated level of automation for monitoring and controlling.

There are following methods for the relay protection of micro-grid:

(1) This method applies the same strategy both in grid-connected operation and in island operation. In this method a static switch is used to connect the micro-grid to the main-grid. When short-circuit faults occur inside the micro-grid the static switch disconnects the micro-grid from the main grid, and then the internal protective device clears the fault.

Finally, the static switch turns on to restore to the grid-connected operation. The internal protection of the micro-grid is based on the cooperation of the differential current components and the zero-sequence current components.

(2) In this method the micro-grid adds a fault current source in island operation to provide an extra short circuit that can improve the short circuit level of the inverter-interfaced distributed resources in order for the protection devise to take the right action. The disadvantage of this method is the requiring of this extra standby power supply. The efficiency is apparently low because this power supply only runs in micro-grid island operation.

(3) The pilot protection which consists of the digital relay and the communication network is applied to meet the protection requirements in different operating modes of the micro-grid.

(4) This method uses a regional pilot protection to locate and isolate the faults by using communication networks and directional elements.

(5) An adaptive algorithm is designed for fault current protection. The algorithm is based on fault current component method and is applicable in inverter distributed source based micro-grids.

Received January 16, 2013; Revised March 14, 2013; Accepted March 23, 2013

(6) This method is applied specifically to a special type of micro-grid construction. The protection is triggered by the voltage fluctuation, the happening of the short-circuit faults decided by Kirchhoff's current law, and the locating of faults by comparing strength among the currents.
(7) This method takes the consideration of having small or no requiring of communication by designing the construction of the switch station in a proper way.

The methods of the micro-grid protection can then be grouped into two categories, the networking digital protection and the local protection without communication, depending on whether or not using communication [2]-[8]. Both have pros and cons. The network digital protection based on network communication can meet the flexibility need of the micro-grid operation to maximize the performance of the micro-grid protection. However, it greatly depends on connectivity of communication network and the protection could be unworkable in case of the communication interruption. Besides, the construction of the communication network increases micro-grid investment. The local protection on the other hand has no dependency on the communication and from this point has higher reliability and less investment, but it is obviously lack of flexibility.

2. Agent Based Differential Protection for Distributed Micro-Grid

Recently, the development of the distributed artificial intelligence and communication technology provides some new approaches for the relay protection [9]-[16]. One approach is called MAS (Multi-Agent System). Each single Agent is an active entity as well as a computer system which has knowledge of the environment, the predefined target and enough capability in order to work independently and make decision on its own. MAS consists of a number of Agents working cooperatively to complete a certain task. The structure is illustrated in Figure1.

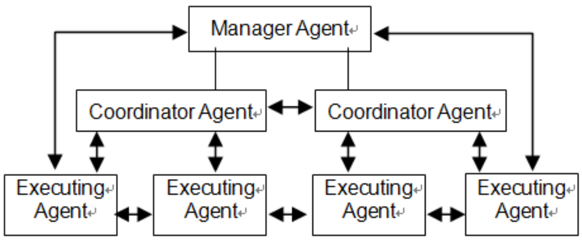

Figure 1. The classic wiring diagram of the micro grid

The MAS based relay protection has following features: Agents are distributed to different levels accordingly to the tasks assigned, such as the network-reconstructed Agent in the organization level, the searching Agent in the cooperation level, the measuring Agent in the execution level, the Agent responsible for the trip, etc. Each Agent can automatically finish its own tasks e.g. measuring, states detecting, tripping, faults detecting, faults clearing, network reconstructing, etc. An Agent can respond to the changes of the environment. If the breaker cannot trip, the Agent will search and disconnect the nearby breaker to accelerate the backup protection. An Agent can assign to another Agent for a new task and wakeup the superior Agent or cooperate with the peer Agent. When the states-detecting Agent detects the position change of the breaker, it will activate the network reconstruction Agent to adjust the protection configuration and fixed values. The information is handled locally and in the mean while shared among Agents.

The protection is accomplished by the collaboration of the Agents. The local coordinator Agents and the manager Agent coordinate the behaviors of Agents in the each level to improve the adaptability, sensitivity and accuracy of the protection. The protection as well becomes more flexible and portable.

Micro grid is an important part of the smart grid and already has the necessary communication network infrastructure. Assume that every electrical devise installs the differential protection and the mutual inductors are reachable to each other. In Figure 2, G is the distributed source, R is the installment of the protection and △ is the load. The micro grid is connected with the 35KV distribution networks through a tap-changing transformer. Figure 3 is the topology structure graph of Figure 2. N1~N13 are the nodes. N5 is the 35kV bus of the distribution network and all other nodes are the electrical elements in micro grid. R1~R19 are the installments of the protection.

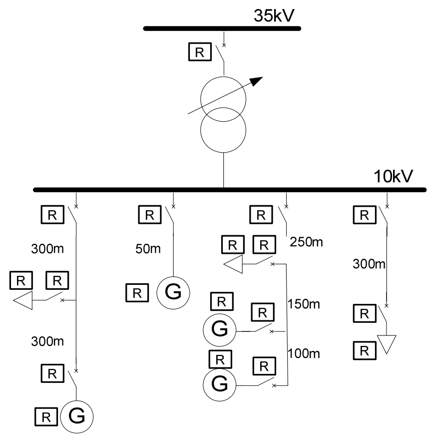

Figure 2. the classic wiring diagram of the micro grid

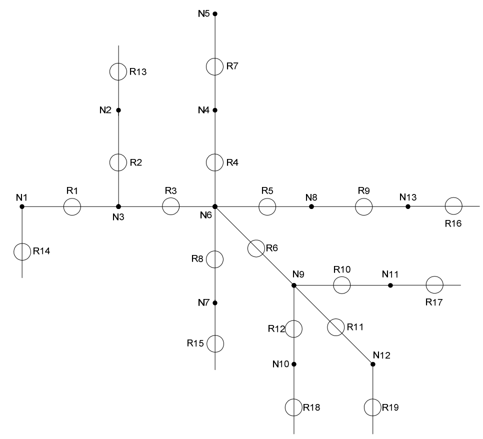

Figure 3. the topology structure graph

A breaker terminates relay protection tripping command and removes the faults. Therefore, a breaker is considered as a branch and an electrical element is considered as a node. Given that the positions of the breakers and the positions of the mutual inductors are related. Each protection is an independent Agent that can send the messages, such as the CT ratio and the connectivity status of the nodes, to other Agents in micro grid. Each Agent has its own planning of one primary protection zone and one to at most three levels back-up protection zones. Each protection zone covers one to multiple nodes according to how much the distance to them.

2.1. Construction Rules of the Primary and Backup Protection Zone

Each Agent searches the protection of the nearby nodes to divide the protection zones dynamically in run-time. The nodes states should be taken into consideration in planning because they have impacts on the construction of the protection zones. Following are the rules:

(1) Rules of the construction of the primary protection zone

1) Each primary protection zone contains a node and its adjacent protections.

2) There is no need to search the corresponding protection zone when a node exits from the grid.

3) When a protection adjacent to several nodes exits but the breaker is closed, the nodes adjacent to the protection zone are re-assembled into a big protection zone.

4) A protection zone that has at least two protections is one prerequisite for the differential pilot protection. When the protection in certain protection zone quits and the corresponding breaker trips, the protection zone can only exist if there are two or more remained protections, otherwise it will be removed.

Taken N6 in Figure 3 as an example, if R3, R4, R6 and R8 are put into operation, the protection zone of N6 is R3,R4,R5,R6,R8. If R5 exits, R3, R4, R6, R8 and R9 will assemble a new primary protection zone. Taken N13 as another example, when all the protections around N13 are put into operation, its primary protection zone is R9,R16. If R16 exits, this zone will be removed. Except R7, R13~R19, each Agent has two primary protection zones since every branch must have two nodes, e.g. R1 including R1,R14 and R1,R2,R3.

(2) Rules of the construction of the backup protection zone.

Each Agent searches and constructs the backup zones independently. The first level backup protection zone has one more node than that in the primary protection zone, the backup protection zone in second level has one more node than those in the first level and the zone in third level as well. Considering the Agent communication traffic volumn and reliability, the backup protection zone should not be more than three levels. Taken N3 as an example, the primary protection zone, which includes N3, is R1,R2,R3 when all the protections are put into operation. As for R1, its backup protection zones in the first level are R1,R13,R3, R1,R2,R4,R5,R6,R8 and they include N3,N2; N3,N6 respectively; each has two nodes, one more than that in the primary zone. The backup protection zones in second level are R1,R2,R7,R5,R6,R8; R1,R2,R4,R5,R6,R15; R1,R2,R4,R9,R6,R8; R1,R13,R4,R5,R6,R8; R1,R2,R4,R5,R8,R10,R11,R12 and they include N3,N6,N4; N3,N6,N7; N3,N6,N8; N3,N2,N6; N3,N6,N9 respectively; each has three nodes, one more node than that in the first level backup protection zone. The backup protection zones in third level are R1,R2,R4,R16,R6,R8; R1,R2,R4,R5,R8,R17,R11,R12; R1,R2,R4,R5,R8,R10,R19,R12; R1,R2,R4,R5,R8,R10,R11, R18 and they include N3,N6,N8,N13; N3,N6,N9,N11; N3,N6,N9,N12; N3,N6,N9,N10 respectively, each contains four nodes.

2.2. Rules of the Behavior of the Agent

Every protection is an independent Agent and one Agent could be covered by one to multiple primary and/or backup protection zones created by other Agents. The Agent communicates with those Agents belonging to the same covering protection zones. The Agent detects, locates and removes the faults for different protection zones independently. The rules are as follow:

(1) Each Agent setup the primary and backup protection zones in micro grid. Other agents covered in one of these protection zones are viewed as belong to that protection zone.

(2) One Agent can belong to several protection zones but at most two primary zones. It judges and removes the faults independently for different protection zones.

(3) The Agents covered in the same zone comprise one Agents group. Each Agent sends the data to the other Agents in the same group by the Multicast to minimize the network traffic. Every Agent receives the voltage and current samples from other Agents in the same protection zone and detects and removes the faults by using the principle of current differential protection.

(4) When one Agent adjacent to several protection zones fails to communicate or remove the faults, the Agent, which covers the current differential backup protection zones in the relevant areas, will detect and remove the faults.

(5) The preventive self-healing action is taken when the communication fails to avoid the protection mal-operation:□When the communication failure happens to an Agent, the other Agents in its protection zone cannot receive the samples from all the Agents in the zone. As a result, the current differential protection in the zones of the failed Agent blocks.□An Agent stops communication when it fails to remove the faults. The other Agents in the same protection zone block because they cannot receive all the current samples in the zone.□When the reclosure happens and faults cleared, the local Agent informs all the other Agents in micro grid that which breakers have tripped. Then all the Agents will divide the primary and backup protection zones again.□When the Agent detects the unbalance current without the faults of the low voltage or over current, the differential current protection blocks to make sure the unbalance current caused by the correct switching operation of the system won't lead to the protection mal-operation.

(6) The primary and backup protection zones of the Agents have the time difference which is represented by Δt. Assume that the action time of the primary protection zone is t0, the action time of first level backup protection zone is $t0+\Delta t$. The action time in the second level is $t0+2\Delta t$ and in the third level is $t0+3\Delta t$. When a fault occurs, the unbalance current can be detected in both the primary and backup protection zones. If the Agents in the primary protection zone cannot clear the fault, the Agents in the relevant backup protection zones which cover the faulted zone will clear the faults in the predefined time.

(7) If the primary protection zone is removed, the differential protection for distributed micro-grid based Agent will be not responsible for faults clearance, other protections, however, such as current protection and distance protection, will handle the faults.

3. The Simulation of Distributed Micro-Grid Based Agent Differential Protection

3.1. The System Structure

The micro grid in Figure 2 is taken as an example. The lines are the overhead lines and the model is LGJ-150. The impedance of the lines is 0.34Ω/ km and the resistance is 0.24Ω/ km. Because the reactive power compensation device is not used in the simulation, the power factor of the load is set to 0.98 to ensure that the voltage of each node in system is not too low.

In theory, the differential protection criterion of one Agent is different from that of any other. Here, it is assumed the same ratio-braking differential criterion is used.

$$\left|\dot{I}_1 + \dot{I}_2 + \cdots + \dot{I}_n\right| > k(\left|\dot{I}_1\right| + \left|\dot{I}_2\right| + \cdots + \left|\dot{I}_n\right|) \quad (1)$$

$I_1 \sim I_n$ is the measured phase-spitting current of each Agent, and k is the ratio brake coefficient. The sampling rate of the Agent is 24 point in each cycle, which is based on full-wave Fourier Algorithm.

3.2. The Judgment of the Corresponding Agent when the Node Fault Happens

Table 1. The judgment of each Agent when the node fault happens (Agent1~Agent19)

Node	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
N1	1	1	1	1	1	1	0	1	0	0	0	0	1	1	0	0	0	0	0
N2	1	1	1	1	1	1	0	1	0	0	0	0	1	1	0	0	0	0	0
N3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
N4	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	0
N5	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
N6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
N7	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	0	0
N8	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	0
N9	1	1	1	1	1	1	1	1	0	1	1	1	0	0	1	0	1	1	1
N10	0	0	1	1	1	1	0	1	0	0	1	1	0	0	0	0	1	1	1
N11	0	0	1	1	1	1	0	1	0	1	1	1	0	0	0	0	1	1	1
N12	0	0	1	1	1	1	0	1	0	1	1	1	0	0	0	0	1	1	1
N13	0	0	1	1	1	1	0	1	1	0	0	0	0	0	0	1	0	0	0

Taken N3 for an example, N3 is the line L1 in Figure 3. It is a 300m long distribution line. As mentioned earlier, the primary protection zone of N3 is R1,R2,R3; the in first level backup protection zone of N3 are R1, R13 R3 and R1, R2, R4, R5, R6, R8; the second level zones are R1, R2, R7, R5, R6, R8, R1, R2, R4, R5, R6, R15, R1, R2, R4, R9, R6, R8, R1,R13R4,R5,R6,R8 and R1,R2,R4,R5,R8,R10,R11,R12. The backup protection zones of N3 in third level are R1, R2, R4, R16 R6, R8, R1, R2, R4, R5, R8, R17 R11, R12, R1, R2, R4, R5, R8, R10, R19 R12 and R1, R2, R4, R5, R8, R10, R11, R18. When N3 is failed, the Agents 1~15 in the relevant primary and backup protection zones detect the faults and set the values to 1. Firstly, the Agent in the primary protection zone sends the trip command. Then the Agents in the backup protection zone trip in the export after a short delay.

3.3. The Judgment in the Condition of N-1.

The condition of N-1 is that one Agent is malfunctional (the condition might be caused by multiple errors, such as devise breakdown or network fault) or mistakes (the mistakenly set judgment value) when the node faults happen in the micro grid. In this paper, this is called the condition of N-1.

Still taken N3 for the example, when N3 is faulty and the protective Agent2 cannot detect the faults because of the device breakdown or network fault, the Agent2 fails to act, the Agent1 and the Agent3 will trip their own breakers and the breaker of the Agent2. When the micro grid operates normally or the N3 is normal but the protection zones outside areas have faults and the protective Agent2 mistakenly receives the incorrect data and takes incorrect action, the Agent2 will trip its own breaker and send the tripping commands to the breakers of the Agent1 and Agent3.

To solve the problem, one judgment is proposed as the following. Because in the system based on the differential protection for the distributed micro grid, the action of each

Agent will be informed to the other Agents, the tripping condition of the breakers: Σ Agent>0.5N, where Σ Agent is the sum of the output value of the Agents in the protection zone and N is the number of the Agents in the protection zone. For example, in Table 1 and Table 2, when N3 is faulty, there are three Agents in the protection zone and N is 3. Therefore, when all the Agents are fine, their output values are 1 and the condition is satisfied: 1+1+1>0.5*3, the breakers will trip. If Agent2 fails to act, still there have two other Agents functional, and judgment 1+0+1=1>0.5*3. In case Agent2 takes incorrect action due to some reason, the other two in normal state, then 0+1+0<0.5*3, only the local breaker trip but not the others.

The tripping process of the protective Agent is summarized as: when the Agent detects the faults, it sends the tripping command to the breaker and informs the other Agents in its protection zone of the breaker status. After the Agent receive the tripping status of the other Agents in the protection zone (if the Agent dose not receive the information from the other Agents, the output value of the other Agents is 0 by default), it will decide whether sends the tripping commands to the other breakers in the zone according to the judgement formula described earlier. If the inequality is not satisfied, the breaker will execute the reclosure if it has already tripped. If the breaker has not tripped yet, the Agent will cancel the command and the relay will restore.

3.3. The Judgment when a Couple of Nodes Faulty.

Some typical two nodes faulty examples are showed in the following tables.

Table 2. two nodes faulty (Agent1~Agent19)

Node	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
N1, N3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
N2, N3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
N3, N6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
N1, N8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
N9, N13	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	0
N10, N11	0	0	1	1	1	1	0	1	0	1	1	1	0	0	0	0	1	1	1
N12, N13	0	0	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	1

The above table shows that the the method still works when more than one nodes failed.

4. Conclusion

This paper illustrates a system structure of the distributed micro grid based Agent differential protection. In the system each protection installment has a protective Agent. Each protective Agent collects the values of all the current transformers in the micro grid and exchanges the messages with other Agents in the same micro grid. This paper also proposes the rules of how to setup the primary and backup protection zones and the rules how the Agent will act in case of faults. The simulation demonstrates different scenarios, the normal case in which all the Agents functional, the exceptional case that one Agent fails i.e. N-1, and the case that two Nodes fail in the same time. It shows this protection method can satisfy the selectivity, sensitivity, rapidity and reliability requirements of the relay protection. It inherits the advantage of the traditional double-ended differential protection, simplifies the setting calculation of the backup protection and improves the selectivity of the backup protection by using the communication technology in the smart grid. The simulation of N-1 shows that this solution has good robustness; the protection can selectively clear the fault even if the system has some device failure.

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