

MicroGrid (MV Network) Restoration Using Distributed Resources After Major Emergencies

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ABSTRACT

Although power system blackouts are rare events occurring in a well-organised power system, it is essential to have a restoration plan. The objective of such a plan is to bring the power system back into a normal operating condition as soon as possible to minimise the impact of a blackout on the society. This paper discusses the restoration procedures, which are based on blackstarting distributed energy resources (DR) in a MicroGrid (MG) at medium voltage (MV) networks. The developed restoration procedures are tested on a microgrid through PSCAD simulation. The simulation results have demonstrated that the power restoration can be enhanced with the aid of distributed generation (DG) in the MG; the restoration time can also be reduced. An application of DG in restoring power after major emergencies can greatly improve reliability of power supply.

Index Terms – Blackouts, Blackstart, Power System Restoration, Distributed Energy Resources, MicroGrid

1. INTRODUCTION

Electric power systems are planned and operated to avoid any dynamic and steady state instabilities, which can lead to major system disturbances and even cause the total system collapses. Nevertheless, it is impossible to guarantee a 100% reliable system. A blackout is a condition where major portion of the network is de-energized with much of the system still interconnected [1].

Power system is normally designed based on a single contingency (N-1 contingency). Although there may be a possibility that a single event may trigger cascading outages, the typical cause of blackouts is resulted from multiple contingencies with complex interactions [2]. These multiple contingencies would lead to instability of the system, thus deteriorating the system condition. The primary concerns in a power system are frequency and voltage deviations. Both frequency and voltage deviations may cause system to break-up and eventually lead to the total system blackouts [1].

August 14, 2003 Blackout in the United States and Canada has affected approximately 50 million people and 61,800 MW of electric load. Power was not restored for 4 days in some parts of the United States, and parts of Ontario suffered undulating blackouts for more than a

week before power was completely restored. Total costs in the US were estimated to range between \$4 billion and \$10 billion [3].

The severity of consequences resulted from the system blackouts has alerted engineers to develop readily accessible and up-to-date system restoration plan. This helps to establish a quick and orderly recovery from the system collapse after major emergencies, as well as to minimise the impact on the public [4].

Restoring the power system using distributed resources (DR) or distributed generations (DG) in a MG when the system completely collapses is a newly developed idea. In the past, all electric industries have relied heavily on the restoration plan by energising and restoring HV network without blackstarting DG at MV networks. This is quite common in today's applications, but may not be the most viable solution. Nowadays, researchers are investigating MG capabilities in order to provide fast blackstart at the MV network. Such approach can enable even faster power restoration to end consumers compared to the traditional restoration plan, thus minimising the impact on the public. In a larger scale power system, the system restoration at the HV network is normally established manually by the operators, with the aid of the restoration guidelines. It is desirable to bring the system back into a normal condition swiftly. The restoration procedures would be much simpler in a MG as all the control variables, i.e. loads, switches and DG are in smaller size and number [5]. When the system collapses, restoring from the HV network without blackstarting DG would require more work comparing to blackstarting DG at the MV network before connecting the MV network back to the HV network.

The main purpose of this paper is to investigate the capability of a MG at MV networks to provide the system restoration when the system blackout spreads. More efforts are concentrated on the MG Blackstart operational strategy to build-up the MV network when a power system collapses, enabling the HV network to be energised and recovered more easily and faster.

2. MICROGRID CONCEPT

Distributed energy system, which comprises of distributed generators and distributed energy storage (DS) is anticipated to be installed massively in near future resulting from the growing demand in distribution system [6, 7]. To further understand the MG concept, the

distributed generation together with the loads must be considered as a subsystem or a “microgrid” [8].

The concept of distributed generation was (re)introduced by the Electric Power Research Institute (EPRI) in the early 1990s [9]. EPRI defines distributed generation as “the integrated or standalone use of small modular resources by utilities, utility customers and third parties in applications that benefit the electric system, specific customers or both” [10]. In general, distributed generation can be defined as “electric power generation within the distribution network or on the customer side of the network” [11].

DG is a new trend in electrical power generation. DG can be used to generate electricity for its own needs, while the excessive electrical power can be exported into the power grid. DG technologies can be categorised into renewable and non-renewable technologies. Renewable technologies refer to:

- solar, photovoltaic or thermal;
- wind;
- geothermal;
- ocean;
- microturbines (especially using landfill waste gases and biomass).

The two new operational strategies that have been recently developed are the MG islanded operation and MG blackstart [5].

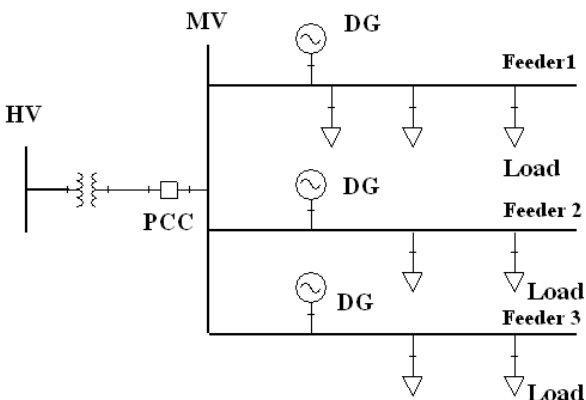


Figure 1: A typical MicroGrid with DGs

A MG system, which would allow to blackstart a larger power system using DG, is considered. A typical MG system is shown in Fig. 1 which comprises microturbines, wind turbines and PV solar stations.

The MG system shown in Fig. 1 includes DGs, radial feeders and loads. It is connected to the utility (the HV network) at the Point of Common Coupling (PCC) [8].

When the system collapses, the PCC would operate, and disconnect all loads. The DGs with blackstart capabilities are restarted to serve its own load. The MV network is then restored by the distributed generation provided that it is capable of handling the loading. The excessive loads are restored as soon as the PCC is reconnected, i.e. as soon as the MV network is reconnected to the HV network.

3. ADVANTAGES OF MICROGRID

MG can operate independently without any support from the upper stream of the network. It is of advantageous as the MG would not be affected, but rather separated from the upper stream where the fault occurs, and thus at islanding state [6].

MG has “plug-and-play” features. This means that it can always be connected or disconnected to the MV network [6].

Also, MGs integrate distributed energy resources and loads, such as combined heat and power (CHP) [6].

Overall, MGs comprise of various type of DGs, such as microturbines, wind and photovoltaic (PV) solar. Each DG has their own characteristics. However, the distinct characteristics that they all share are as follow:

- (i) **Environmentally friendly;**
They are clean sources of energy that have very little environmental impact on the community compared to those conventional energy technologies.
- (ii) **Energy for the next generation;**
They draw on infinite resources, and would never run out.

(NOTE: Microturbines technology is assumed to be generated using renewable fuel, such as landfill waste gases, hydrogen and biomass.)

Microturbines technology is a newly developed technology, which has just recently been released into the market. It is of our great interest as it is associated with the blackstart capability and could keep to bring the system back into normal condition when system blackout occurs.

4. BLACKSTART USING DG IN MICROGRID

The blackstart restoration procedure has been developed and simulated using Power System CAD (PSCAD). When the power system collapses, due to some major emergency, this restoration procedure should be implemented by the system operators immediately to restore the power. The flow chart of the restoration procedure developed is shown in Fig. 2.

This blackstart restoration procedure can be further explained as:

- (i) **Disconnect all loads.**
All loads should be disconnected to avoid frequency and voltage fluctuations resulted from energising the system network after the system collapse.
- (ii) **Blackstart DG.**
The MG should be sectionalised. The DGs with blackstart capability are switched on.
- (iii) **Reconnect the DG’s own loads.**
If loads supplied by DG not exceed its generating capacity, they can be reconnected, forming a small island.

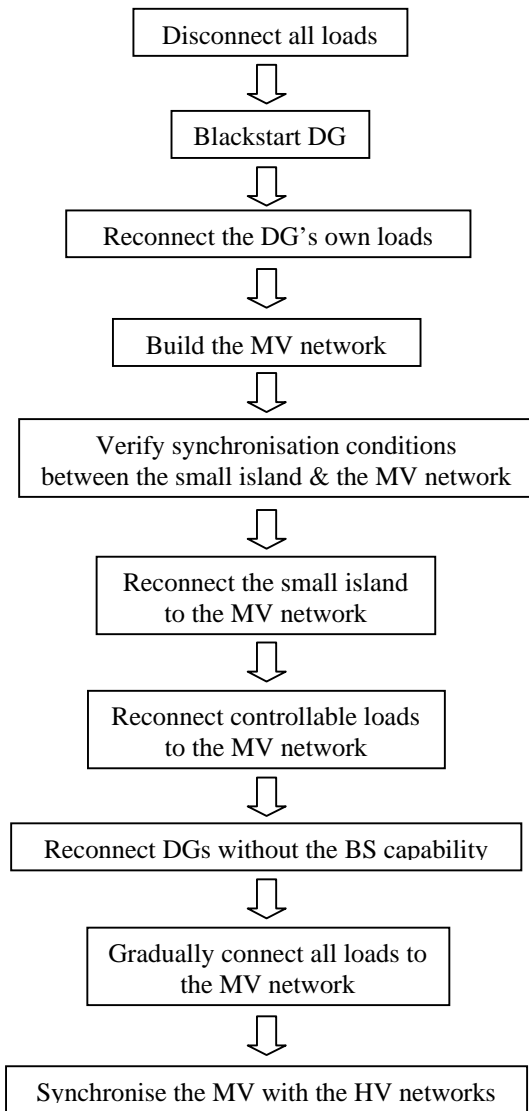


Figure 2: Flow-chart of the blackstart restoration procedure

- (iv) *Build the MV network.*
The MV network is built by reenergising distributed transformers (DT).
- (v) *Verify synchronisation conditions between small island and the MV network.*
Before the small island can be reconnected with the MV network, its synchronisation conditions have to be satisfied. This is necessary in order to avoid large transient currents and unpredictable power flows. Synchronisation conditions include the phase sequence, frequency and voltage differences.
- (vi) *Reconnect the small island to the MV network.*
Once the synchronisation conditions are satisfied, the small island is connected back to the MV network.
- (vii) *Reconnect controllable loads to the MV network.*
Additional generation is provided to the MV network when small islands are connected. Controllable loads can now be picked-up.

- (viii) *Reconnect DGs without the BS capability.*
The DGs without blackstart capability take the power from the MV network to start-up, providing them more generation into MV network.
- (ix) *Gradually connect all loads to the MV network.*
The remaining loads are connected to the MV network system. Now, the MV network system is gradually restored.
- (x) *Synchronise the MV with the HV networks.*
Before the MV network is connected to the larger system, i.e. the HV network, the systems have to be synchronised to avoid large transient currents and unpredictable power flows.

5. SIMULATION PLATFORM

PSCAD is a powerful and flexible graphical user interface to the world-renowned, EMTDC solution engine. PSCAD is used to study transient behaviours of the MV network under the blackstart restoration procedure.

Fig. 3 shows the Northern region of Launceston, Tasmania, which is of our interest in this paper. The Newham, Mowbray, Vermont and Invermay areas are investigated. Microturbines have been suggested to be employed in the MG modelling as Vermont has a landfill site whilst Invermay has a wastewater treatment plant. These sites produce gases which could be used as a “free” fuel to generate the DG, specifically microturbines. Wind generators are also suggested to be placed in the Newham and Vermont residential areas, respectively. The data on the suggested distribution generation and load profiles are shown in Table 1 and Table 2, respectively.

Table 1: Suggested Installation of DGs

Installed Area	Type	Capacity
Wastewater Treatment Plant	Microturbine	2.7MVA
Landfill & Timber Mill	Microturbine	4.5MVA
Newham	Wind	0.4MVA
Vermont	Wind	0.5MVA

Table 2: Load Profiles

Residential Load 22kV- Winter 2004				
Area	P (kW)	Q (kVAR)	Equivalent Circuit	
			R(Ω)	L(H)
Invermay	634.83	128.91	732.2	0.4733
Newham	1568.41	318.48	296.4	0.1916
Mowbay	1045.60	212.32	444.6	0.2873
Vermont	466.04	94.63	919.2	0.5941

Motor Load 22kV- Winter 2004		
	S (MVA)	PF (Lagging)
Wastewater Treatment Plant	1.245	0.813
Landfill & Timber Mill	2.285	0.793

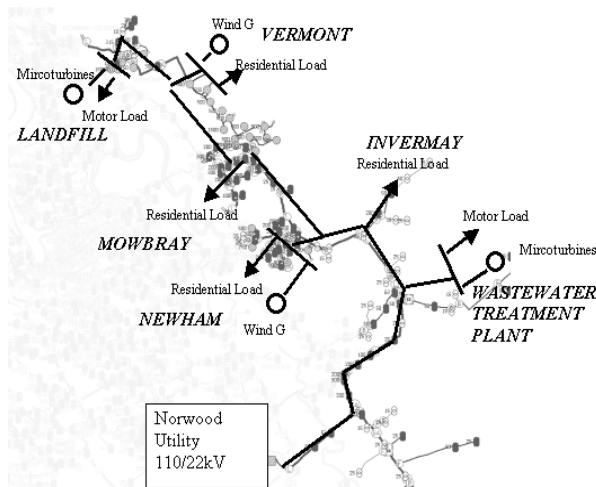


Figure 3: Nothern region of Launceston

6. SIMULATION RESULTS

The transient behaviour of the distributed system in Northern Launceston during reconnecting it back to the HV network is studied. The blackstart procedure as illustrated in Fig. 2, is followed in order to bring the system back into the normal condition.

Initially, the system is assumed to be deenergised. The microgrid (the MV network) is immediately disconnected from the HV network, including all loads by opening all respective circuit breakers.

The system is then sectionalised, and DGs with blackstart capability are restarted. Their own loads are connected, with the loading not exceeding the capacities of the generators. Small islands are formed.

Before connecting these small islands into the MV network, they are to be synchronised such that all the conditions are verified to minimise the transient effects on the system.

Microturbines located at the landfill and timber mill, and the wastewater treatment plant are to be blackstarted.

These loads are served by the microturbines, creating two islands. Fig. 5 shows the responses of both microturbines during the blackstart islanding process. The significant transient behaviour, as seen in Fig. 5 is due to the start-up of the motor load.

These two islands are then synchronised and connected back to the MV network at time $t = 2.5s$. When the connection to the MV network is completed, larger capacity of microturbine would be chosen to act as a master, whereas the other one would be the PQ generator. Residential loads located at Newham and Vermont are connected at time $t = 20s$ and $t = 25s$, respectively. As observed in Fig. 6, a large response is recorded during the connection of these two islands. The active power output of the microturbine at Landfill reaches 8.67MW instantly at time $t = 2.5s$. However, the response stabilises in about 5s. No critical response is resulted when connecting the Newham and Vermont residential loads to the MV network.

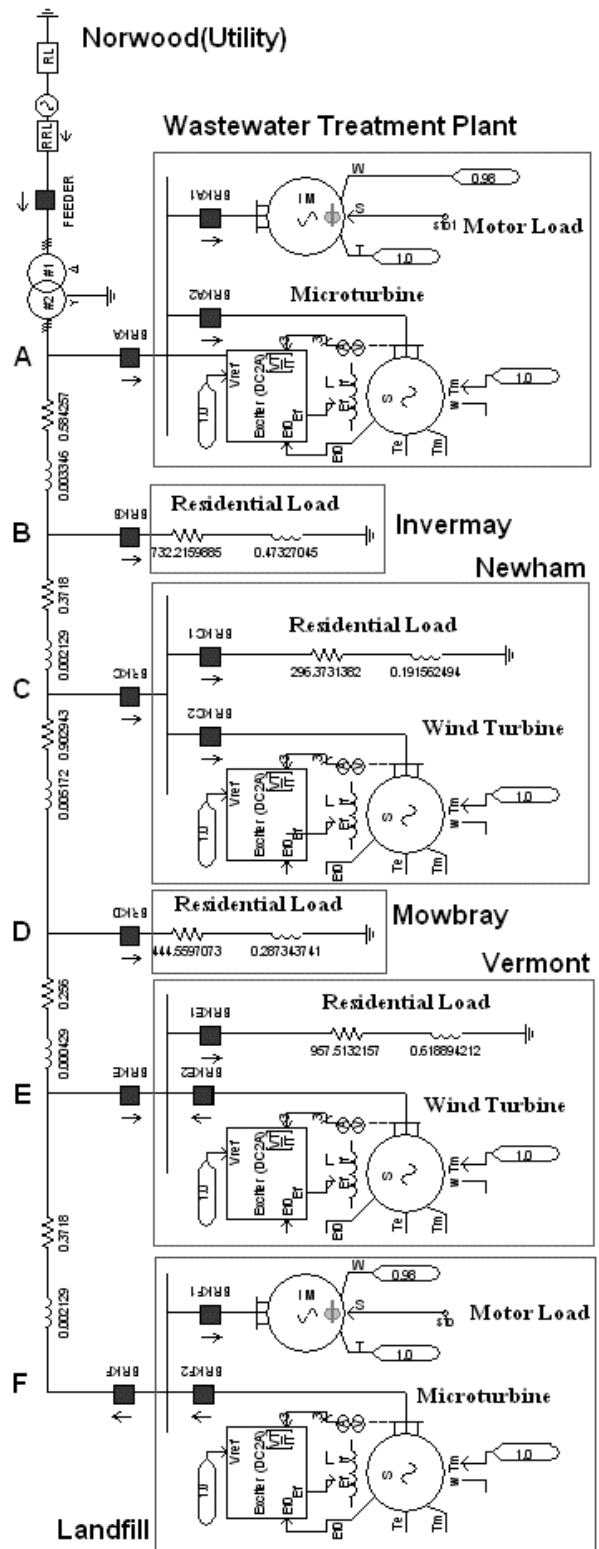


Figure 4: System Model in PSCAD

Wind resources located at Newham and Vermont, respectively, are non-controllable generators; they do not have blackstart capabilities. The wind generator at Vermont, which takes an auxiliary power from the MV grid, is connected back at time $t = 30s$, whilst the wind generator at Newham is connected at time $t = 40s$. The transient behaviour when connecting the generators can be observed in Fig. 7. As soon as the wind generators are capable of providing a stable generation, the remaining loads are picked up. The residential loads at Mowbray

and Vermay are connected at times $t = 50s$ and $t = 55s$, respectively. Thus, the MV network can be completely restored at time $t = 60s$.

Assuming that the HV network itself is to be restored at time $t = 70s$, the MV network can now be synchronised with the HV network. Now, the HV network is acting as a master.

Considering that all the generators located at the MV network now operate at their maximum capacity, the total generation would exceed the total loading, and thus, the excessive generation could be exported to the HV network. A transient response resulted from connecting the utility (the HV network) with the MV network at time $t = 70s$ is shown in Fig. 8. When the stability is reached, the utility is shown to have a negative value of the power input, i.e. $-1.45MW$ which means that the utility is consuming the excessive power from the MV network.

During the whole restoration process, no violation of the system frequency is recorded. As can be seen in Fig. 9, the frequency deviates between $50.16Hz$ and $49.88Hz$ when the MV network is connected to the utility. Also, the bus voltages are within the limitation of $\pm 10\%$, as seen from Fig. 10. The largest response or deviation of the voltage occurs when the utility and the MV network are connected.

The microgrid is restored in the following sequence of actions:

- Blackstart microturbines at Landfill and Wastewater Treatment Plant and support their own motor loads respectively at time $t = 0s$ (forming two islands);
- Synchronise and connect the islands at time $t = 2.5s$;
- Connect the residential loads at Newham and Vermont at time $t = 20$ and $t = 25s$, respectively;
- Connect the wind generator at Vermont at time $t = 30s$;
- Connect the wind generator at Newham at time $t = 40s$;
- Connect the residential loads at Mowbay and Vermay at times $t = 50$ and $t = 55s$, respectively;
- Synchronise and connect the HV and the MV grids at time $t = 70s$.

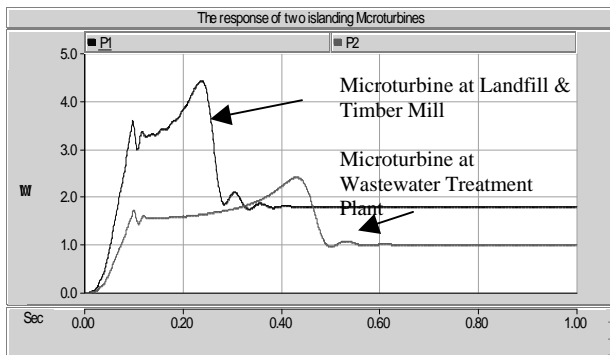


Figure 5: Active Power for Microturbines during blackstart and islanding (Landfill and Timber Mill and Wastewater Treatment Plant)

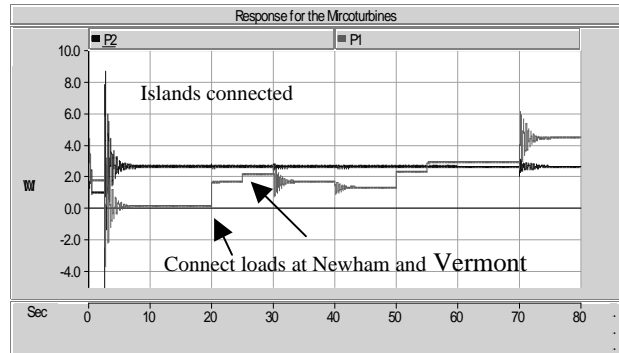


Figure 6: Active Power for the Microturbines (Landfill and Timber Mill and Wastewater Treatment Plant)

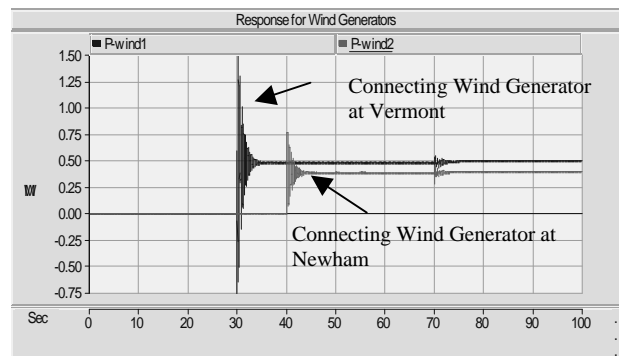


Figure 7: Active power for Wind Generators (Newham and Vermont)

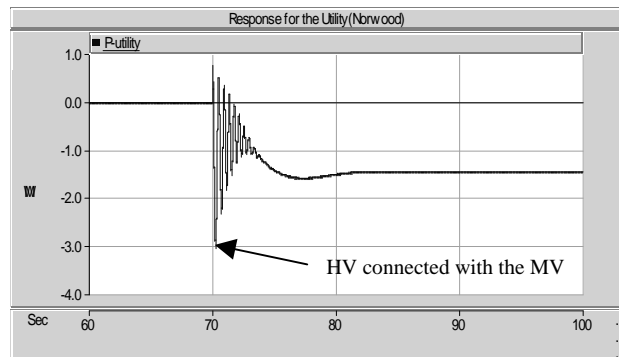


Figure 8: Utility (Norwood) Active Power

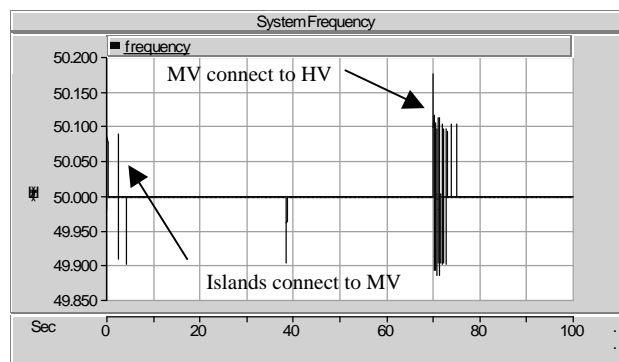


Figure 9: System frequency

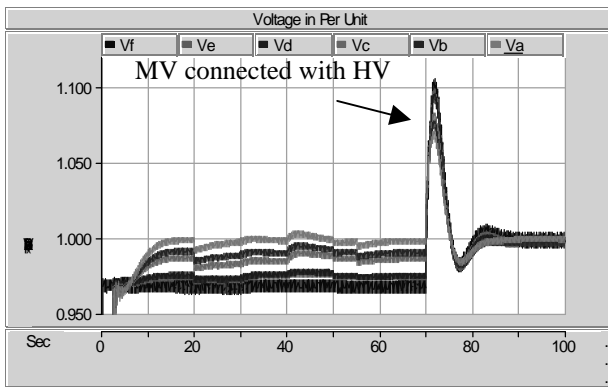


Figure 10: Voltage at each location

7. CONCLUSIONS

PSCAD simulations have shown that restoring power by blackstarting DG in the MG at the MV network would enable to bring the system back into a normal condition in approximately 80s. It is desirable to restore the power system by blackstarting DG at the MV network simultaneously with restoring the HV network. Comparing to the traditional restoration procedures, where blackstarting DG at the MV network is not emphasised, the proposed procedure has successfully restored the system in a short period of time, thus minimising power system losses, as well as the impact on consumers.

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