energies

MDPI

Article

A Study on the Harmonic Resonance during Energizing Primary Restorative Transmission Systems: Korean Power System Case †

Minhan Yoon [1], Wonkeun Yu [2], Junghyun Oh [3] and Heungjae Lee [1,*]

[1] Department of Electrical Engineering, Kwangwoon University, Seoul 01897, Korea; minhan.yoon@gmail.com
[2] Department of Automatic Electrical Engineering Technology, Yeungnam University College, Daegu 42415, Korea; ywk@ync.ac.kr
[3] Department of Robotics, Kwangwoon University, Seoul 01897, Korea; jhyunoh@kw.ac.kr
* Correspondence: hjlee@kw.ac.kr; Tel.: +82-2-940-5147
† This paper is an extended version of our paper published in 2005 IEEE Russia Power Tech, St. Petersburg, Russia, 27–30 June 2005; pp. 1–5.

Abstract: In this paper, a power system restoration study following a massive or complete blackout was performed. The power system restoration process from a complete shutdown system without the operating generation and load starts with energizing primary restorative transmission systems. During this primary restoration process, unexpected over-voltage may occur due to nonlinear interaction between the unloaded transformer and the transmission system. This is known as the harmonic resonance phenomenon that may cause the burning out of a transformer or other devices. So far, harmonic resonances have been reported in some extra-high voltage systems around the world. Since the harmonic resonance originates from the nonlinear characteristics of the power system components, it is very difficult to predict the occurrence of this phenomenon. This paper reports the analyses of the harmonic resonance that can occur in the Korean power system. In addition, through calculating the required buffer load compared to the length of the line, a solution that changes the length of the restoration path impedance considering the specificity of the Korean system was presented. The various analyses of harmonic overvoltage, including methodologies that are used internationally as comparison groups, are provided based on PSCAD/EMTDC simulations.

Keywords: power system restoration; over-voltage; harmonic resonance; PSCAD/EMTDC

check for updates

Citation: Yoon, M.; Yu, W.; Oh, J.; Lee, H. A Study on the Harmonic Resonance during Energizing Primary Restorative Transmission Systems: Korean Power System Case. *Energies* **2022**, *15*, 290. https://doi.org/10.3390/en15010290

Academic Editor: Abdelali El Aroudi

Received: 18 November 2021
Accepted: 24 December 2021
Published: 1 January 2022

1. Introduction

Recently, as the proportion of renewable energy sources (RES) increases, there are difficulties in the operation of the power system due to the volatility and intermittency of the generation [1,2]. Due to these characteristics, the possibility of temporary but large overload of some transmission lines or transformers in the power system is increased. In such a situation, if the equipment protection circuit breaker trips, cascading overloads, and tripping of other equipment are possible to occur, leading to a wide-area outage, blackout [3]. In addition, as the penetration rate of inverter-based resources (IBR) including RES increases, the ratio of synchronous generators decreases, consequently, leading to the low inertia power system [4]. In these operating conditions, if a disturbance such as a large-capacity generator trip occurs, the system frequency will drop significantly. It can actuate under-frequency load shedding (UFLS) relays, may lead to a large-scale load outage [5].

Therefore, it can be estimated that as the proportion of IBR and RES increases, the possibility of a massive and wide-area blackout must be considered by power system operators [6]. In addition, various studies are being performed by creating a new analysis index under the name of 'power system resilience' [7]. The research on wide-area blackouts can be largely divided into the field of prevention to reduce the effect of contingencies and the field of restoration from blackouts [8,9].

The first process of the power system restoration following a complete or partial collapse is the energization of primary restorative transmission lines. The energizing process begins with starting a black-start generator, such as a hydro or gas turbine, and then charging some predefined transmission lines to provide cranking power to a large generator station [10–14]. In the primary restoration process, circuit breaker switching strategies include all-open switching and controlled-operation switching strategies [15]. All-open switching is to open all circuit breakers of all substations within the blackout area. This strategy has several advantages and is being used around the world. The system operator provides an opportunity to restore the power transmission system simply and safely by connecting only the circuit breaker necessary for restoration. The possibility of system collapse and voltage fluctuations that can occur due to unnecessary load connection or circuit energization. As a result, the recovery time can be shortened and widely used worldwide [13,16–18].

Recently, studies have been conducted to allow voltage source inverters to replace the role of such a conventional start-up generator, but this will only be possible after the installation of additional facilities and sufficient feasibility evaluation [19]. In addition, for shortening restoration time, studies on recovery strategies using robustness optimization or sectionalizing have been performed [20,21]. During the primary restoration process, the energization of high-voltage transmission lines and transformers, which is an inevitable process as the first restorative process in most countries, may initiate overvoltage and be reported [16–18]. The reason for over-voltages during the energization process can be classified into three categories—Ferranti effect, switching transients, and harmonic resonance.

The overvoltage due to harmonic resonance has a characteristic that oscillation is not damped or only weakly damped. Basically, this phenomenon can be caused by the resonance between parallel reactances. In primary restorative transmission systems from blackout, the harmonic resonant overvoltage is based on the complex characteristics due to the non-linear saturation of transformers [22]. Depending on the situation, magnetizing inrush currents caused by energizing transformers may produce harmonic currents. At this time, if transformers are overexcited due to sustained power frequency over-voltage, the harmonic resonance voltage will be maintained or even enlarged. It should be analyzed as a major factor since such a large-scale overvoltage may lead to damage to power system equipment. However, the occurrence of harmonic overvoltage is difficult to predict because it occurs depending on the system configuration as well as the nonlinear characteristics of the equipment. In addition, on-site test such as resonance is performed on a transmission-level high power system, equipment damage that occurs may lead to a long-term system outage problem. Therefore, PSCAD/EMTDC based on the electro-magnetic transient (EMT) algorithm, has been mainly used to analyze the phenomenon for the analysis of real power systems [23–25]. The maximum resonant voltage estimation using MATLAB and the power block set (PBS) has been performed, however, the precision is relatively lower than that of the EMT-based simulation [26].

In the practical power system, the harmonic resonance has been reported in extra-high voltage (EHV) systems such as Hydro Quebec [13] with 735kV and the Institute of Electrical and Electronics Engineers Power System Restoration Working Group (IEEE SRWG) report [14] with 500 kV transmission systems used in restoration. In addition, several methodologies have been proposed to solve the harmonic resonance overvoltage [13–18]. There is a method widely used in the distribution system that does not leak harmonic currents to the outside by delta-connecting the transformer [27]. Alternatively, in order to attenuate the inrush current by improving the damping ratio, the power system operator and start energization after connecting some amount of loads to the transformer in advance [28]. The methods for prevention of harmonic resonance, energizing the transformer with loads are widely used [13,14]. The guideline suggested by IEEE SRWG is 3 MW per mile. However, the amounts of loads to be pre-connected can differ from each power utility and the power system situation. The analysis is performed based on PSCAD/EMTDC simulations along with detailed power system and transformer models.

The remainder of the paper is organized as follows:

Section 2 studies the possible existence of the harmonic resonant overvoltage during the power system restoration process in the Korean power system. Accordingly, the possibility of solving the harmonic resonance overvoltage was reviewed by applying the methodology in the previous studies. The solutions were estimated as to whether they could be applied to the actual Korean power system in terms of feasibility. In addition, it was shown that the problem could be solved by the proposed method to change the applicable line length in consideration of the characteristics of the Korean system in Section 3. Finally, the conclusions from the study are presented in Section 4.

2. Harmonic Resonance during Power System Restoration

2.1. General Description of KEPCO Power System Restoration

The decentralized restoration policies are commonly adopted in most countries for fast recovery of the power system in the event of a whole or wide-area blackout case [13–18]. In the case of Korea Electric Power Corporation (KEPCO), the entire power system is divided into seven subsystems for restoration. Figure 1 shows one of the subsystems that is selected network for harmonic resonance study. This network consists of two generator stations for black-start (hydro generator and gas turbine), two paths of primary restorative transmission lines (primary and secondary), and one generator station of which needs cranking power.

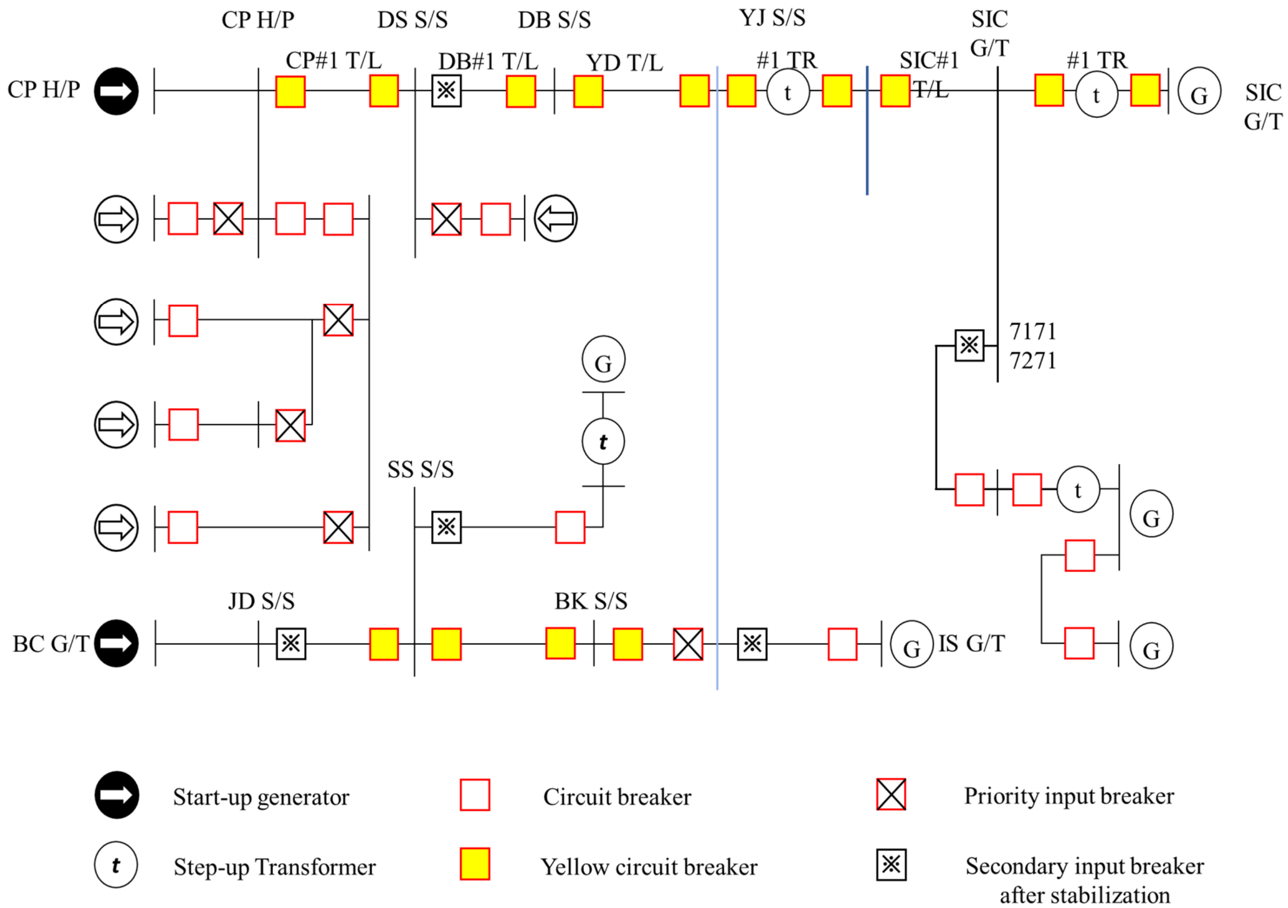

Figure 1. Configurations of the network.

In the case of the KEPCO power system, the voltage level should be maintained at 90~105% during the restoration process. The frequency has to be maintained in the range of 59.75~61 Hz. To minimize the change due to frequency during load restoration, a supply of more than 5% of the total synchronous power generation capacity at a time is restricted. Synchronous power generation capacity refers to the amount of power that can be generated within 10 min by the amount corresponding to the self-starting generator in the transmission system. Table 1 shows the simulation scenario based on the process for this study. This is based on the conventional restoration strategy formed by the Korea Power Exchange (KPX), the system operator for the restoration of KEPCO's primary restorative transmission line.

Table 1. Simulation scenario 1.

Sequence[s]	Operations	Remarks
0.0	Generators start, energize no. 1 MTR Supply power to houseload	Houseload: 5% of Gen. Cap.
5.0	Energize the T/L line by no. 1 generator	
7.0	Energize DS Substation at no-load state	
10.0	Load pickup at DS substation	2 [MVA]
12.5	Synchronization of no. 3 generator	
15.0	Load pickup at DS substation	8 [MVA]
21.5	Synchronization of no. 2 generator	
25.0	Load pickup at DS substation	10 [MVA]
30.0	Energize remaining transmission lines	
40.0	End of simulation	

2.2. Occurrence and Discrimination of Harmonic Resonant Overvoltage

Figure 2 shows the simulation result after transformer energization to pick up a load at the DS substation for maintaining the stability of the system. As a result, the maximum per phase voltage of the transformer's high voltage side exceeds 500 kV within a few cycles after energizing the unloaded transformer. Moreover, the simulation is terminated within 0.2 s after energizing the transformer due to the floating-point overflow.

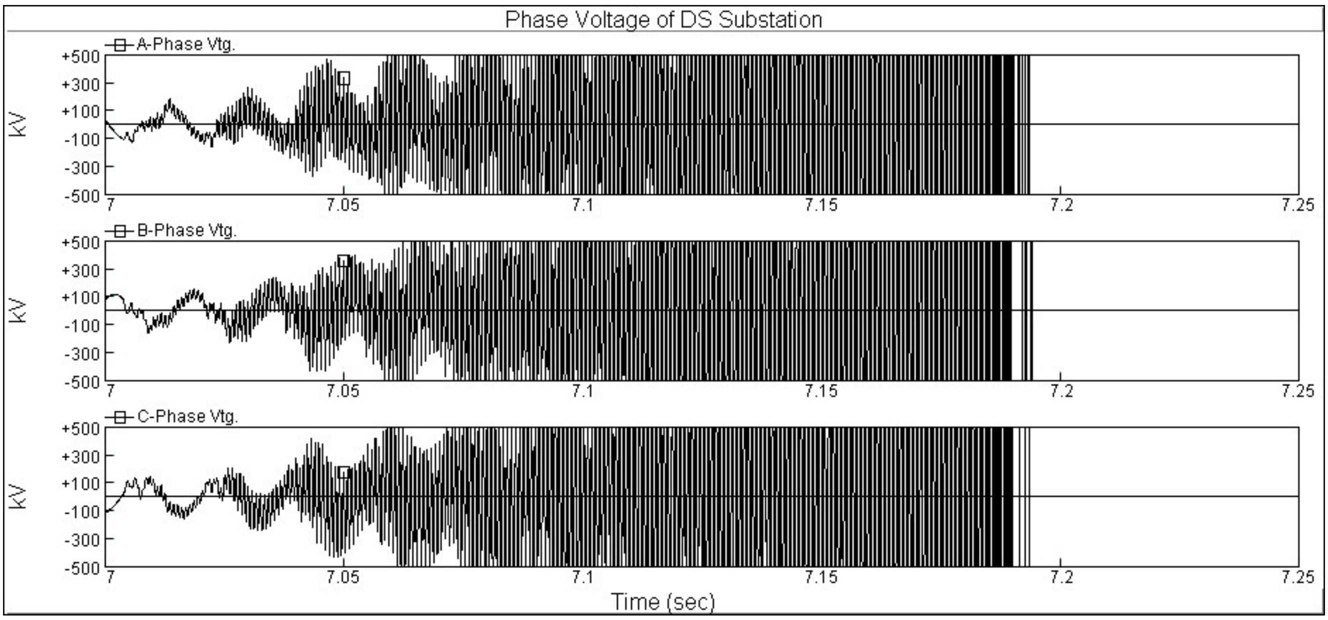

Figure 2. The voltages at the DS substation.

During the restoration of the primary restorative transmission lines process, the energization of high voltage transmission lines and transformers can induce overvoltage. This overvoltage can be classified as follows [5].

- Transient over-voltage

- Self-excitation
- Sustained over-voltage by Ferranti effect
- Harmonic resonant over-voltage

The transient over-voltage is caused by energizing the parts of the transmission line or by switching equipment, it is usually highly damped and has a short duration. As shown in Figure 2, the phenomenon is not a transient overvoltage as it is undamped and sustained enlarging overvoltage.

Since it is known that self-excitation may cause such over-voltage, the steady-state analysis is performed to verify the phenomenon in Figure 2 [29]. The result of the steady-state analysis is shown in Table 2. As the result, three black-start generators (hydro unit) can supply 55.6 [MVAR] of reactive power, while the total charging capacity of the primary restorative transmission line is 30.689 [MVAR]. This result shows that hydro generators can supply sufficient reactive power required for the energization of transmission lines. Therefore, it can be judged that the cause of the overvoltage as shown in Figure 2 is not the self-excitation phenomenon. The Ferranti effect due to the no-load situation is also irrelevant in the system configuration. This is because the simulation was performed based on the all-open strategy [15].

Table 2. The result of static analysis.

Type	Result of Static Analysis				
	Gen. No	**Lim. of Q [MVAR]**	**Supply Q [MVAR]**	**Margin [MVAR]**	**Vtg. of Gen. kV**
Primary T/L	1	14.0	8.525	5.475	9.79 89.02 [%]
	2	13.7	6.257	7.443	
	3	27.9	15.907	11.993	
	Total	55.6	30.689	24.911	

Since the harmonic resonance problem was presented in the report of the IEEE SRWG [14], these analyses imply that overvoltage during restoration is caused by harmonic resonances, not self-excitation or Ferranti effects.

2.3. The Interrelation between Harmonic Resonance and Equipment

It is known that the cause of harmonic resonant over-voltage during restoration is nonlinear characteristics of equipment such as generators and transformers. The effect of nonlinear characteristics of generator and transformer that is related to the harmonic resonance is examined to confirm the interrelation between them.

2.3.1. Effects of Generator—Ideal/Practical Model

The practical generator model is replaced by the ideal one to confirm the relation between harmonic resonance and dynamic characteristics of the generator. The simulation scenario is the same as Table 1 and the result is shown in Figure 3.

The simulation result is similar to the shape in Figure 2, and harmonic resonance occurred after the energization of the transformer. Therefore, it is clear that harmonic resonance is slightly affected by the dynamic characteristics of the generator.

2.3.2. Effects of Transformer Saturation—Transformer Modeling

The saturation enabled model of the transformer is replaced by the disabled model to confirm the relation between harmonic resonance and transformer saturation. The simulation scenario is the same as Table 1 and the result is shown in Figure 2. As shown in Figure 4, harmonic resonance does not occur after the energization of the transformer. It is clear that harmonic resonance affected considerably by transformer saturation.

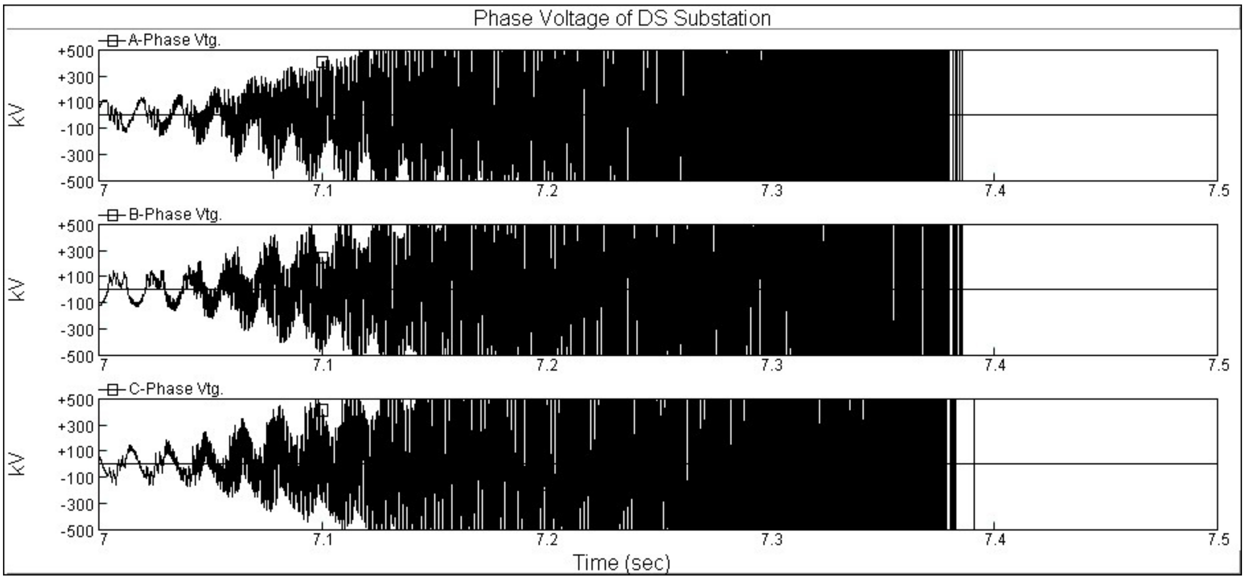

Figure 3. The voltages at DS substation (used ideal generator model).

Figure 4. The voltages at DS substation (used saturation disabled model).

3. Countermeasure against Harmonic Resonant Overvoltage

Previous studies including the IEEE SRWG report suggest the following solutions.

- Case A: Delta connection of a transformer
- Case B: Energization of a transformer with loads that are connected previously
- Case C: Change in restoration path configuration (proposed method)
- Case D: Starting more generators for reducing high source impedance

Since the number of available black start generators is limited in primary restorative transmission systems, simulations of Case D: starting more generators to reduce high source impedance are not considered here. It is also an option that is not feasible in most practical power systems.

3.1. Case A: Delta Connection of Transformer

This method changes the connection type of the high voltage side of a transformer to the delta way at a DS substation. The simulation scenario and its results are shown in Table 1 and Figure 3. As shown in Figure 5, harmonic resonance does not occur after changing the transformer connection. From this result, it is verified that over-voltage during restoration is due to harmonic resonance.

Figure 5. Voltages at DS substation. (Delta connection of transformer's high voltage side at DS Substation).

In fact, as Korean power systems have meshed and strong structure compared with other countries because transmission lines are densely and complicatedly coupled due to the domestic industrial demand and distribution of population, the possibility of wide-area blackout would be very rare [30]. However, emergency planning is indispensable. As the power systems have been gradually enlarged and have become more complex, changes in the primary restorative transmission systems are unavoidable. From the operational point of view, it is not reasonable to change the connection of the specified transformer for the purpose of preventing harmonic resonance.

3.2. Case B: Energization of Transformers with Damping Loads

It is known that the connection of damping loads can prevent harmonic resonance as IEEE SRWG has been reported [5] when transformers are energized. However, it is difficult to determine the amount of load that should be connected previously. According to the IEEE SRWG report, about 3 [MW] per mile for a 500 kV transmission line has been suggested. The Korean restorative transmission systems of KEPCO mostly consist of 154 kV transmission lines and it includes a few 345 kV transmission lines. Since the voltage level reported in IEEE SRWG is different from the KEPCO system, IEEE SWRG's result is not exactly suitable for the KEPCO system. Therefore, the amount of loads to be pre-connected is set on 0.5, 1, and 2 [MVA] for considering the capacity of the black-start generator and voltage level.

Table 3 shows the simulation scenario and simulation results are shown in Figures 6–8. As a result, temporary over-voltage occurred after the energization of the transformer (at 7 s) but harmonic resonance does not occur. By the over-voltage regulations of KEPCO, the magnitude of over-voltage in Figure 8 is satisfied but Figures 6 and 7 are not. From these results, we can figure out the amount of load that should be connected to the transformer before energization is not proportional to line length but depends on system configuration.

Table 3. Simulation scenario 2.

Sequence[s]	Operations	Remarks
0.0	Generators start energize no. 1 MTR Supply power to houseload	Houseload: 5% of Gen. Cap.
0.0	Load pickup on no load transformer at DS substation	0.5, 1, 2 [MVA]
5.0	Energize T/L line by No. 1 generator	
7.0	Energize DS substation	
12.5	Synchronize no. 3 generator	
15.5	Synchronize no. 2 generator	
20.0	Load pickup at DS substation	8 [MVA]
25.0	Load pickup at DS substation	9.5, 9, 8 [MVA]
30.0	Energize remaining transmission lines	
40.0	End of simulation	

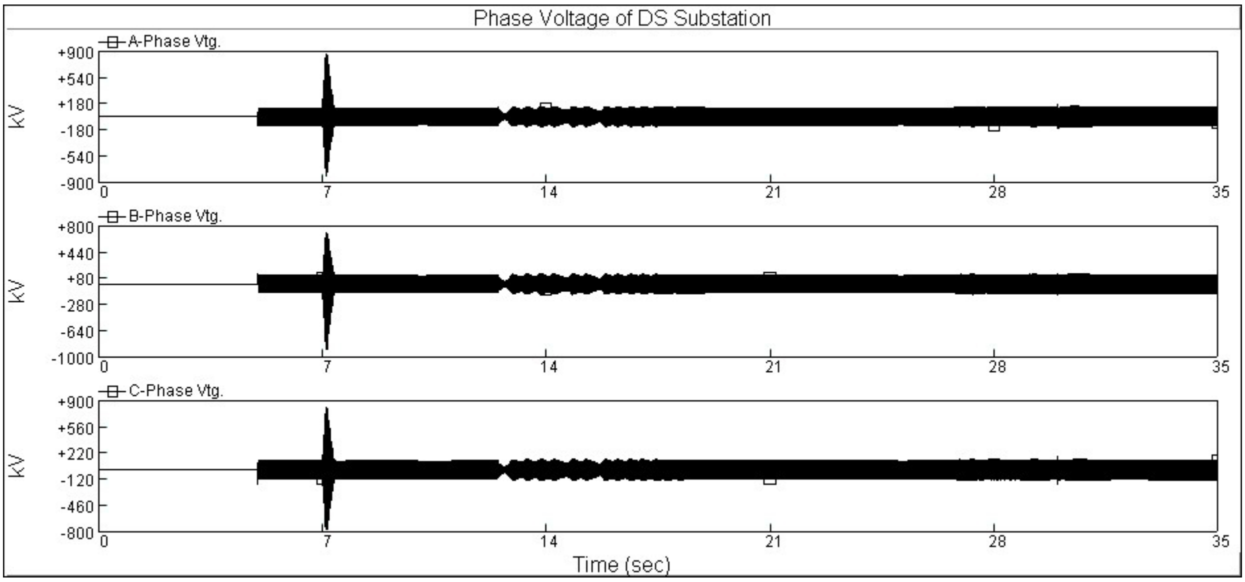

Figure 6. Voltages at DS substation (with 0.5 [MVA] load).

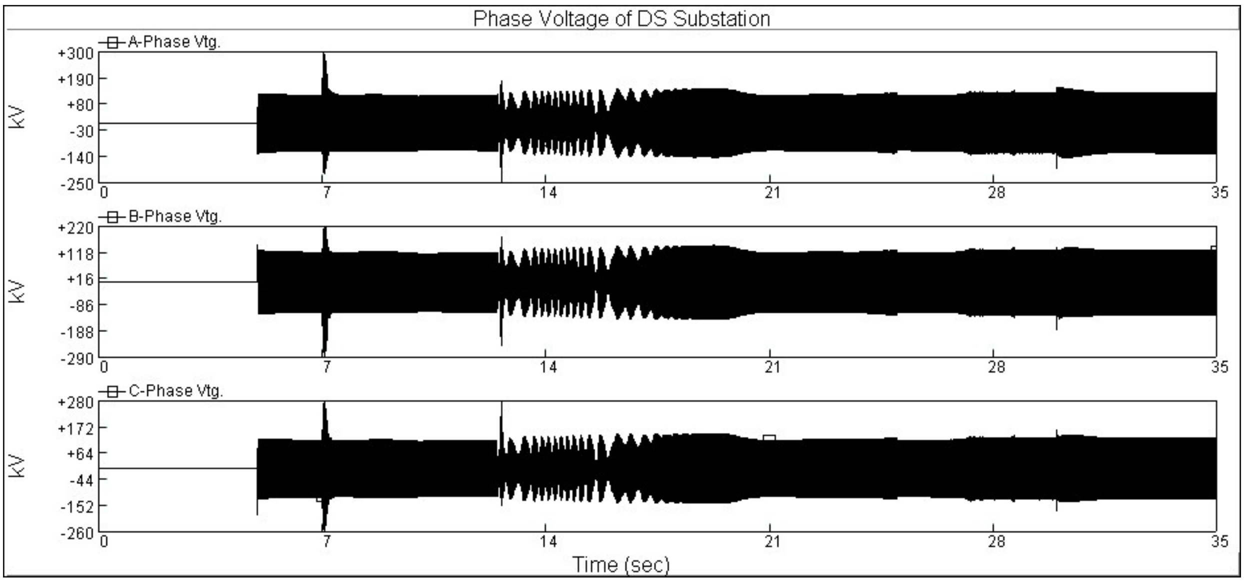

Figure 7. Voltages at DS substation (with 1 [MVA] load).

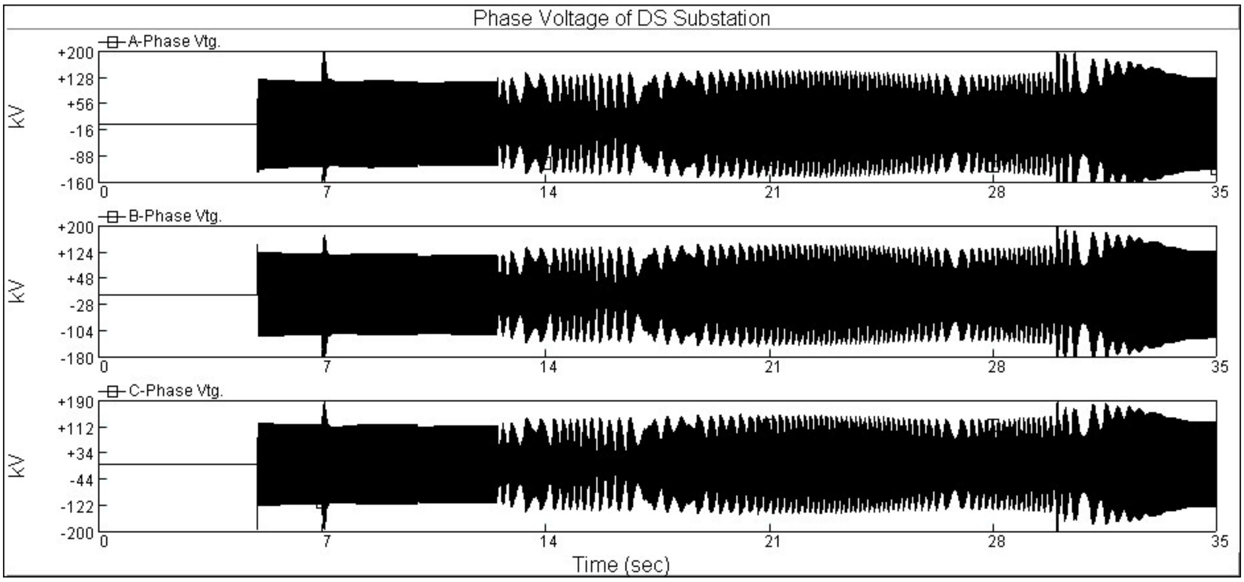

Figure 8. Voltages at DS substation (with 2 [MVA] load).

3.3. Case C: Change in Restoration Path Configuration

Even if the restoration strategy in most countries is similar, the system configurations during the early restoration stage are different due to the restoration policy, available utilities, and voltage level.

Simulation for the change in system configuration as a change in the line length is performed to confirm the effect of system configuration on the harmonic resonance. CP#1 line in Figure 1 is used for simulation and its rated voltage and length are 154 kV and 24.282 [km], respectively. The line length changed from 110 to 140% by increasing 10% of the original value.

The simulation scenario is the same as Table 1 and the simulation results are shown in Figures 9–12, respectively. As the result, temporary over-voltage occurred after the energization of the transformer (at 7 s) but harmonic resonance did not. By the over-voltage regulations of KEPCO, the magnitude of over-voltage in Figures 9–11 exceeds the over-voltage regulations, however, Figure 12 does not. From these results, it is clear that harmonic resonance has been influenced considerably by the change in system configuration.

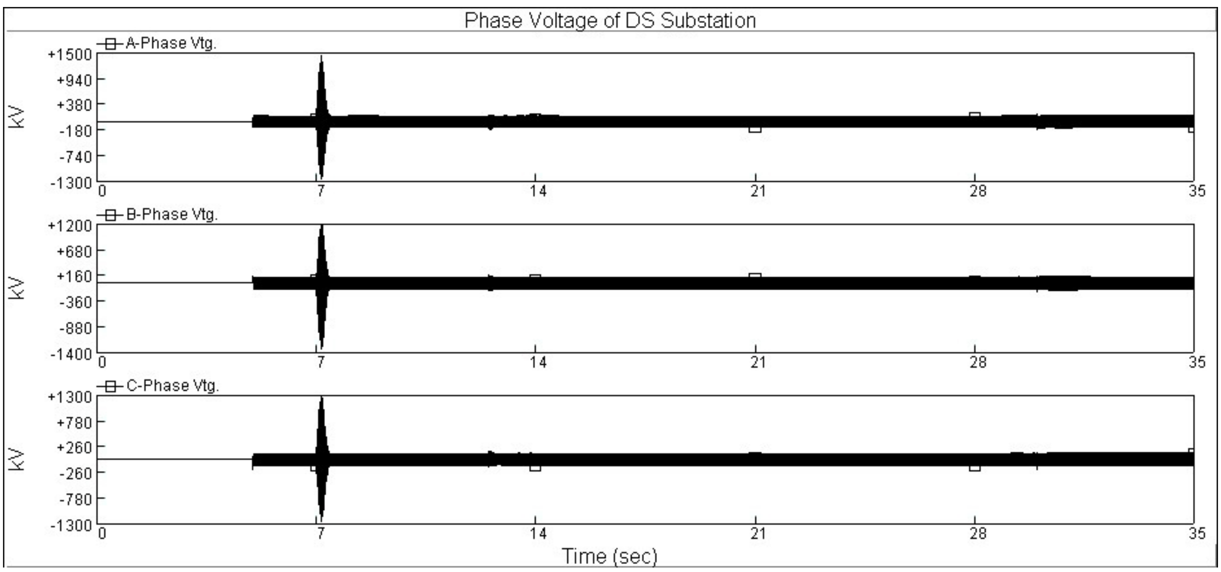

Figure 9. Voltage of DS S/S(110[%] line length of CP #1 T/L).

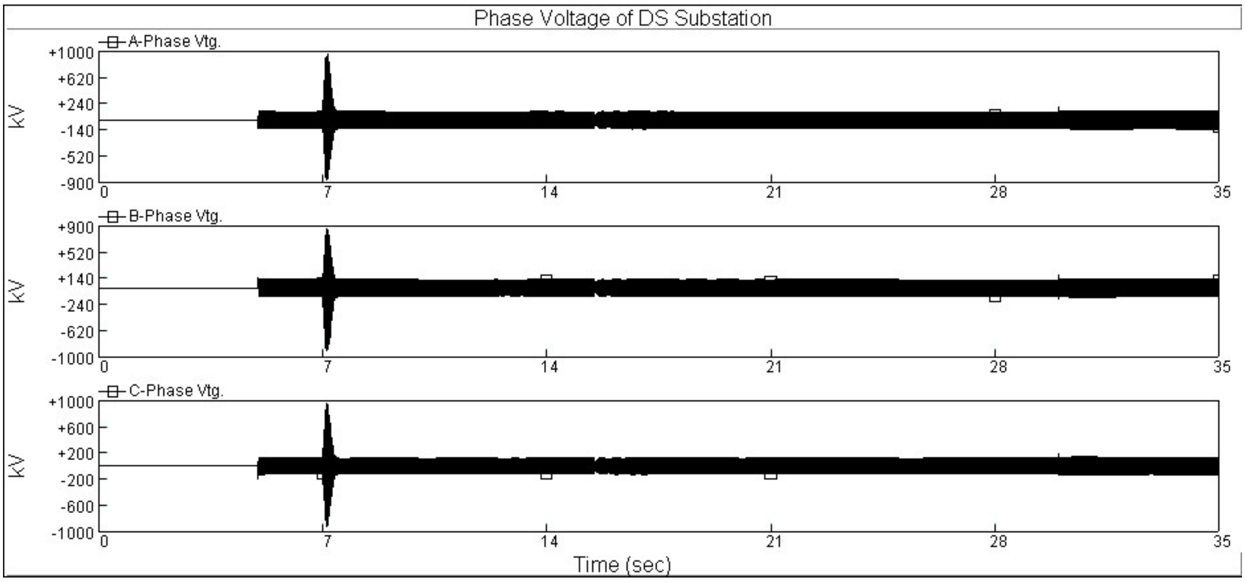

Figure 10. Voltage of DS S/S(120[%] line length of CP #1 T/L).

Figure 11. Voltage of DS S/S(130[%] line length of CP #1 T/L).

3.4. Discussion on the Result and Proposals

As mentioned above, it is sure that the delta-connection of the transformer (Case A) or connection of damping load before energization of the transformer (Case B) can prevent the harmonic resonance. However, the amounts of loads to be pre-connected are different from the result of the IEEE SRWG report and the transformer with differing pre-connected damping loads is not applicable and practical in Korean power systems. Therefore, the interrelation between harmonic resonance and variation of restorative transmission line length can be investigated (Case C).

If the conditions of the power system are changed, the possibility of harmonic resonance is varied as restorative transmission line length. In this case, if the restoration configuration is changed to include an appropriate line length, the harmonic resonance problem can be solved as shown in Figure 12. The summarized results of the contents reviewed in this paper in arranged in Table 4 briefly.

Figure 12. Voltage of DS S/S(140[%] line length of CP #1 T/L).

Table 4. Summary of solutions for harmonic resonance.

	Summary		
	Case A	**Case B**	**Case C**
Harmonic resonance resolution	Possible	Possible	Possible
Required action	Change the connection of the specified transformer	Pre-connect the damping load before transformer energization (2MVA)	Change the restoration path configuration (140% CP#1 T/L)
Practical feasibility	None	None	Feasible

The interrelation between harmonic resonance and variation of line length can be investigated by the simulation analysis that harmonic resonance occurred in the Korean primary restorative transmission line [12]. The rated voltage and line length used in the simulation are 154 kV and 7.938 [km], respectively. Table 5 shows the result of the occurrence of harmonic resonance for line length variation by increasing 1 [km]. Harmonic resonance occurred only in the range of 7 to 48 [km] in the result of Table 5. From the results, it is verified that harmonic resonance may not occur after the energization of the unloaded transformer in the specified boundary of the line length.

Table 5. Occurrence of harmonic resonance for line length variation.

Result of Simulation			
Line length [km]	0~7	7~48	48~
Harmonic resonance	Not occurred	Occurred	Not occurred

The simulation result for the amounts of loads to be pre-connected to prevent harmonic resonance is shown in Figure 13. An inductive simulation methodology and a heuristic binary search technique were used to analyze the load capacity. The amount of load to be pre-connected increased in direct proportion to the line length in the range from 7 to 11 [km], but the amount of load to be pre-connected decreased as a direct proportion to the line length from 12 to 48 [km]. Through the result, it can be known that the amounts of loads to be pre-connected can prevent harmonic resonance will not be increased in proportion to the line length even if in case of line length increased, which is different from

3 [MVA] per mile, the IEEE SRWG report guidelines. This means that there is a possibility of harmonic resonance being varied according to line length.

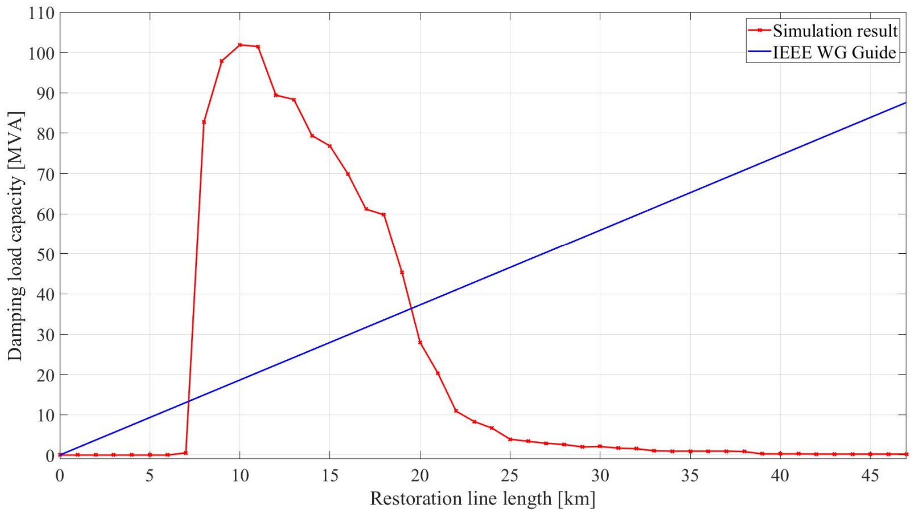

Figure 13. Result for variation of line length.

4. Conclusions

This paper described the restoration process and the possibility of overvoltage due to harmonic resonance for the Korean primary restorative transmission system. The causes and solutions based on the analysis were analyzed through PSCAD/EMTDC simulation. For this purpose, modeling of generators, transformers, and transmission lines was carried out using parameters of the actual Korean power system. As a simulation result of the relationship between harmonic resonance and equipment with nonlinear characteristics, it was found that harmonic resonance is affected by transformer saturation rather than the dynamic characteristics of the generator.

The IEEE power system restoration working group has presented guidelines on several methods for resolving such harmonic resonance. In this paper, the applicability of such guidelines was estimated through PSCAD/EMTDC simulation results. The effectiveness was analyzed on the change in the wiring of the transformer, the connection of the damping load before the transformer energization, and the change in the system configuration. Through this result, we revealed that the guidelines of the IEEE working group would not be valid for systems in other countries with different voltage levels and configurations.

In addition, to find a way to minimize reconfiguration, we reviewed the required damping load capacity compared to the length of the line and presented the results so that the line length can be inversely calculated based on existing damping load capacity. Based on the results, it was possible to avoid the harmonic resonance problem by changing the restoration process for energizing section without additional construction, facility installation, or change.

As a result, a part of the restoration guideline of the Korean power system was changed. The new guideline energizes all sections of the primary restorative transmission system without energizing the unloaded transformer. It is expected that this can be used and expanded to analyze the impact of IBR resources in the power system restoration process based on this study.

Author Contributions: Conceptualization—H.L.; investigation—M.Y., J.O. and W.Y.; methodology—H.L.; supervision—H.L.; visualization, M.Y.; software—W.Y.; writing—original draft, M.Y. and H.L., writing—review and editing, J.O. and W.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20174010201620) and Korea Electric Power Corporation grant (R21XO01-1) funded. The present research has also been conducted by the Excellent researcher support project of Kwangwoon University in 2021.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

RES	Renewable energy sources
IBR	Inverter-based resources
UFLS	Under-frequency load shedding
IEEE	Institute of electrical and electronics engineers
SRWG	Power system restoration working group
H/P	Hydro power generator
G/T	Gas turbine generator
S/S	Substation
T/L	Transmission line
DS	Distribution substation
KEPCO	Korea electric power corporation
KPX	Korea power exchange

References

1. Wiser, R.H.; Mills, A.; Seel, J.; Levin, T.; Botterud, A. *Impacts of Variable Renewable Energy on Bulk Power System Assets, Pricing, and Costs*; Lawrence Berkeley National Lab (LBNL): Berkeley, CA, USA, 2017.
2. Impram, S.; Nese, S.V.; Oral, B. Challenges of renewable energy penetration on power system flexibility: A survey. *Energy Strategy Rev.* **2020**, *31*, 100539. [CrossRef]
3. Vaiman, M.; Bell, K.; Chen, Y.; Chowdhury, B.; Dobson, I.; Hines, P.; Papic, M.; Miller, S.S.; Zhang, P. Risk assessment of cascading outages: Methodologies and challenges. *IEEE Trans. Power Syst.* **2012**, *27*, 631–641. [CrossRef]
4. Kumar, G.V.B.; Sarojini, R.K.; Palanisamy, K.; Padmanaban, S.; Holm-Nielsen, J.B. Large Scale Renewable Energy Integration: Issues and Solutions. *Energies* **2019**, *12*, 1996. [CrossRef]
5. Milano, F.; Dörfler, F.; Hug, G.; Hill, D.J.; Verbič, G. Foundations and challenges of low-inertia systems. In Proceedings of the 2018 Power Systems Computation Conference (PSCC), Dublin, Ireland, 11–15 June 2018; pp. 1–25.
6. Carreras, B.A.; Colet, P.; Reynolds-Barredo, J.M.; Gomila, D. Assessing Blackout Risk with High Penetration of Variable Renewable Energies. *IEEE Access* **2021**, *9*, 132663–132674. [CrossRef]
7. Panteli, M.; Mancarella, P. The grid: Stronger, bigger, smarter: Presenting a conceptual framework of power system resilience. *IEEE Power Energy Mag.* **2015**, *13*, 58–66. [CrossRef]
8. Ahsan, M.Q.; Chowdhury, A.H.; Ahmed, S.S.; Bhuyan, I.H.; Haque, M.A.; Rahman, H. Technique to develop auto load shedding and islanding scheme to prevent power system blackout. *IEEE Trans. Power Syst.* **2011**, *27*, 198–205. [CrossRef]
9. Ancona, J.J. A framework for power system restoration following a major power failure. *IEEE Trans. Power Syst.* **1995**, *10*, 1480–1485. [CrossRef]
10. Adibi, M.; Clelland, P.; Fink, L.; Happ, H.; Kafka, R.; Raine, J.; Scheurer, D.; Trefny, F. Power system restoration—A task force report. *IEEE Trans. Power Syst.* **1987**, *2*, 271–277. [CrossRef]
11. Adibi, M.M.; Kafka, R.J. Power system restoration issues. *IEEE Comput. Appl. Power* **1991**, *4*, 19–24. [CrossRef]
12. Adibi, M.M. Special consideration in power system restoration; The second working group report. *IEEE Trans. Power Syst.* **1994**, *9*, 15–21.
13. Morin, G. Service restoration following a major failure on the hydro-quebec power system. *IEEE Trans. Power Deliv.* **1987**, *2*, 454–463. [CrossRef]
14. Adibi, M.M.; Alexander, R.W.; Avra-Movic, B. Overvoltage control during restoration. *IEEE Trans. Power Syst.* **1992**, *7*, 1464–1470. [CrossRef]
15. North American Electric Reliability Council (Operating Committee). *Electric System Restoration, A Reference Document*; NERC: Atlanta, GA, USA, 1993.
16. Simburger, E.J.; Hubert, F.J. Low voltage bulk power system restoration simulation. *IEEE Trans. Power Appar. Syst.* **1981**, *11*, 4479–4484. [CrossRef]
17. Delfino, B.; Denegri, G.B.; Invernizzi, M.; Morini, A.A.; Bonini, E.C.; Marconato, R.; Scarpellini, P. Black-start and restoration of a part of the Italian HV network: Modelling and simulation of a field test. *IEEE Trans. Power Syst.* **1996**, *11*, 1371–1379. [CrossRef]
18. Fountas, N.A.; Hatziargyriou, N.D.; Orfanogiannis, C.; Tasoulis, A. Interactive long-term simulation for power system restoration planning. *IEEE Trans. Power Syst.* **1997**, *12*, 61–68. [CrossRef]

19. Jain, H.; Seo, G.S.; Lockhart, E.; Gevorgian, V.; Kroposki, B. Blackstart of power grids with inverter-based resources. In Proceedings of the 2020 IEEE Power & Energy Society General Meeting (PESGM), Denver, CO, USA, 17–21 July 2020; pp. 1–5.
20. Murinelli, P.P.; De Lorenci, E.V.; Zambroni, A.C.; Lo, K.L.; Lima Lopes, B.I. Robustness area technique developing guidelines for power system restoration. *Energies* **2017**, *10*, 99. [CrossRef]
21. Abu Talib, D.N.; Mokhlis, H.; Abu Talip, M.S.; Naidu, K.; Suyono, H. Power system restoration planning strategy based on optimal energizing time of sectionalizing islands. *Energies* **2018**, *11*, 1316. [CrossRef]
22. Thanomsat, N.; Plangklang, B.; Ohgaki, H. Analysis of Ferroresonance Phenomenon in 22 kV Distribution System with a Photovoltaic Source by PSCAD/EMTDC. *Energies* **2018**, *11*, 1742. [CrossRef]
23. Manitoba HVDC Center. *PSCAD/EMTDC User's Manual*; Manitoba HVDC Center: Winnipeg, MB, Canada, 1998.
24. Shin, H.; Chae, S.H.; Kim, E.H. Design of microgrid protection schemes using PSCAD/EMTDC and ETAP programs. *Energies* **2020**, *13*, 5784. [CrossRef]
25. Lee, H.J.; Lee, K.S.; Park, S.M.; Bae, J.C.; Song, I.J. Analysis of the harmonic resonance during energizing the primary restorative transmission systems. In Proceedings of the 2005 IEEE Russia Power Tech, St. Petersburg, Russia, 27–30 June 2005; pp. 1–5.
26. Ketabi, A.; Sadeghkhani, I.; Feuillet, R. Using artificial neural network to analyze harmonic overvoltages during power system restoration. *Eur. Trans. Electr. Power* **2011**, *21*, 1941–1953. [CrossRef]
27. Clinker, R.C. Harmonic voltages and currents in Y-and Delta-connected transformers. *Trans. Am. Inst. Electr. Eng.* **1914**, *33*, 723–733. [CrossRef]
28. Jamali, M.; Mirzaie, M.; Asghar-Gholamian, S. Calculation and analysis of transformer inrush current based on parameters of transformer and operating conditions. *Elektron. Ir Elektrotech.* **2011**, *109*, 17–20. [CrossRef]
29. Park, S.M.; Lee, K.S.; Bai, J.C.; Hwang, B.H.; Song, I.J.; Lee, N.H.; Lee, H.J. Development of New Algorithm for the Analysis of Self-Excitation in Primary Restorative Transmission Systems. *Trans. Korean Inst. Electr. Eng. A* **2005**, *54*, 117–121.
30. Yoon, M.; Park, J.; Jang, G. A study of HVDC installation in Korean capital region power system. In Proceedings of the 2012 IEEE Power and Energy Society General Meeting, San Diego, CA, USA, 22–26 July 2012; pp. 1–5.