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Dynamic Voltage Restorer for the Voltage Drop Compensation in Long Rural Distribution Feeder Application

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Dynamic Voltage Restorer for the Voltage Drop Compensation in Long Rural Distribution Feeder Application

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Abstract. Ideally, a distribution feeder should be able to assure the voltage level at the end of feeder not more or less than five percent of its nominal value as regulated in the Grid Code. However, in such circumstance where the feeder has to serve the load through a very long line with randomly load scattering characteristic, the level of voltage could be far below its allowable lower level. In some cases, the use of capacitor bank fails to solve this problem. In this paper a new breakthrough by utilizing an Intelligent Power Electronic Device to overcome voltage drop is proposed. A Voltage Restorer is introduced to install in a 20 kV distribution line of PLN Lampung to enhance its voltage profile. The simulations showed the range of voltage level is within the range of 95% – 105% of the nominal value.

1. Introduction

Lampung Province – Indonesia, which is situated at the gate of Sumatra Island, is known for its agricultural industry in the rural areas. This, consequently, results in population spread in rural areas far from major electric power substations that are usually located near the urban areas. The Rapid rural electrification program has led to poor power quality in such areas and worsened by slow transmission system expansion. These rural areas suffer from low voltage profile below the acceptable limit of 0.95 per unit. This situation is mostly due to its heavy loads and very long feeder line. A certain feeder could be up to 200 km length from the main substation.

Field measurements by PT. PLN (Persero) Distribusi Lampung (*a state own company in electricity, Indonesia*) in June 2016, revealed several distribution feeders supplying these areas experiencing end-node voltage of even below 0.50 p.u., such as Rawajitu and Mesuji areas. Consumers in these areas are supplied with electricity at about 100 volt, which is worse than the nominal supply voltage of 220 volt phase to neutral. Other area, such as Kiluan Bay, known for its tourism attraction like dolphins sighting, also suffers voltage at about 0.80 per unit.

Previous study, conducted by Electric Power System Laboratory, University of Lampung, on Rawajitu and Mesuji areas recommended PT. PLN (Persero) Distribusi Lampung to install distributed generator to support these areas. However, utilizing fossil-fueled generating plant is not an option at the moment for its high operating cost and pollution to the environment. A more environmental-friendly approach as well as less-cost generating station is required to improve power quality at these areas. This work proposes the use of Digital Voltage Restorer (DVR) technology approach to solve this set of problem. Several DVR stations consist of energy storage system and Intelligent Power

Electronics Devices (IPED) are proposed to install and aggregated through a robust Information and Communication Technology (ICT) infrastructure for the management and control among the units.

2. Dynamic Voltage Restorer (DVR) modelling

Ideally a distribution system must be able to supply electric power to the consumers in a voltage range of not less or more than five percent of its nominal value. However, delivering electricity to very distant regions with scattered population characteristics, will results in the level of voltage at the end side of feeder might be far from its nominal value, and even shrink by half. Even, the use of capacitor banks is possibly not adequate to improve this situation.

On the other hand, DVR which is one of the devices commonly used to protect sensitive loads from the effects of voltage disruptions such as voltage [1], shows the possibility to be applied to improve voltage drop in low voltage distribution networks.

In this paper, the DVR is used to recuperate the voltage profile when voltage drop occurs by assigning it at a best suited spot along the 20 kV network. From various simulations carried out by varying the loading conditions of the system, it is exhibited that the load voltage can be maintained in the acceptable range of 95% s to 105% of the nominal value.

- Typically the DVR consists of four main modules with their particular role as shown in Figure 1. The four modules are [2], [3]:
- Injection Transformer. Three single-phase transformers are connected in series with the distribution feeder coupled with a voltage source converter (VSC). The main function of injection transformers is to be an electrical insulation and to increase the low AC supply produced by the VSC to produce the desired voltage.
- Voltage Source Inverter (VSI), VSI used in this study is from the type of pulse width modulation (PWM) inverter that is composed of switching components of insulated gate bipolar transistors (IGBTs). The purpose of this inverter is to convert the DC voltage generated by the energy storage device into an AC voltage required by injection / coupling transformers to compensate the voltage drop.
- Filter. The filter consists of a capacitor bank placed on the side of the inverter or the line side of the injection transformers. The advantage of placing a filter on the inverter side is to prevent harmonics content from flowing through the transformer coil.
- Energy Storage System (ESS). The role of ESS is to generate active power for supplying the load when voltage drop occurs. ESS types commonly used are dry batteries, lead-acid batteries, flywheel or SMES (Superconducting magnetic energy storage).

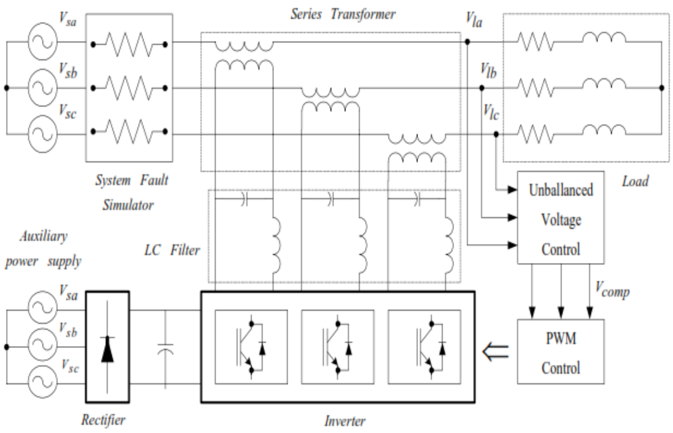

Figure 1. Typical DVR Configuration

Based on equivalent circuit in Figure 2 DVR can be modeled as [4]:

$$V_{DVR} = V_L + Z_{TH} I_L - V_{TH} \qquad (1)$$

where:

V_L Desired load voltage magnitude
Z_{TH} Load impedance in eqivalen Thevenin mode
I_L Load current
V_{TH} Sistem voltage during fault condition

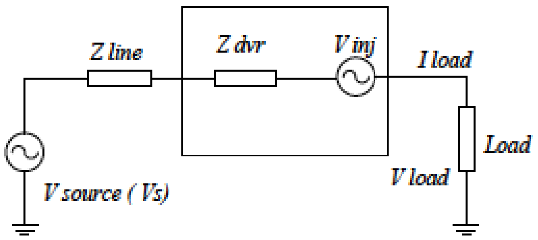

Figure 2. Equivalent circuit of typical DVR

In this reseach The DVR is modeled and installed in the system as proposed in Figure 3

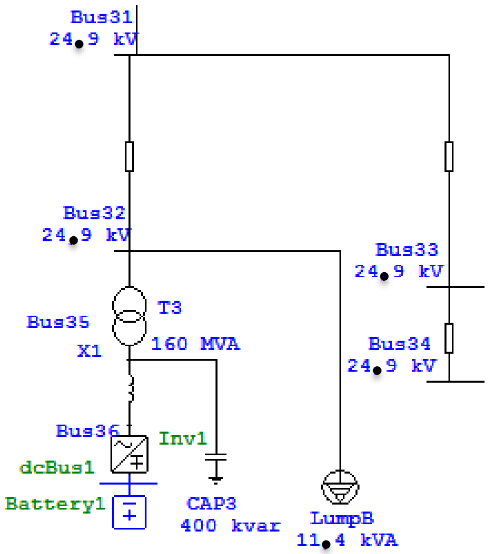

Figure 3. Proposed DVR Installation

3. Simulation Scenario

Two distribution networks were elaborated in simulations, i.e. IEEE 34 bus system and the real distribution feeder in PLN 20 kV Network. The feeder selected was a long distance type with approximately 100 km length. The IEEE 34 bus system was exerted in this study to validate the performance of this proposed approach. After selecting the mathematical model of this DVR, then ETAP software was used to analyze the impact on the system.

The IEEE 34 bus testbed system is depicted on Figure 4 [5]. It shows the one-line diagram for the IEEE 34 Node Test Feeder with no generators attached. The node has been renumbered to make it easier in inputting and analyzing data in this research.

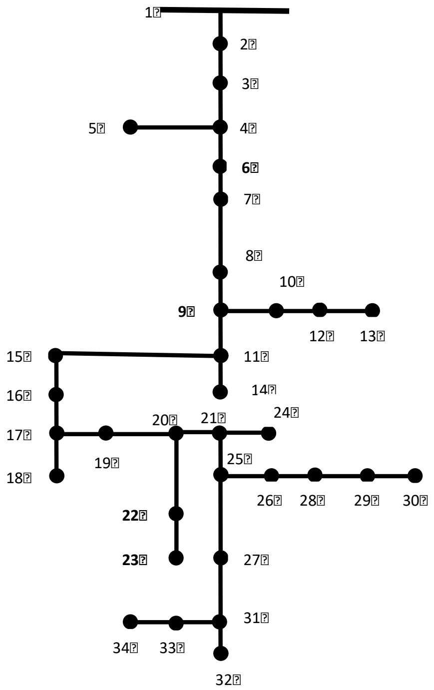

Figure 4. IEEE 34 bus testbed distribution feeder

3.1. IEEE 34 bus testbed network

To authenticate the performance of this proposed model, The IEEE 34 bus system as illustrated in Figure 4 was elaborated in simulation. To represent a long distance feeder with high loading condition, section 25-27 on Figure 4 was extended to 150 km from the original value of 0.86 km. The connected load to this section was upgraded to 150 kW – 130 kVAR from its previous value 20 kW – 16 VAR. As on its original configuration the system deliver no voltage drop at all busses along the feeder, after being modified the voltage at busses 23, 27, 31, 32, 33 and 34 are dropped simultaneously. Figure 5 depicted the application of DVR was successful handling up the voltage drop problem due to long distance feeder with high load condition.

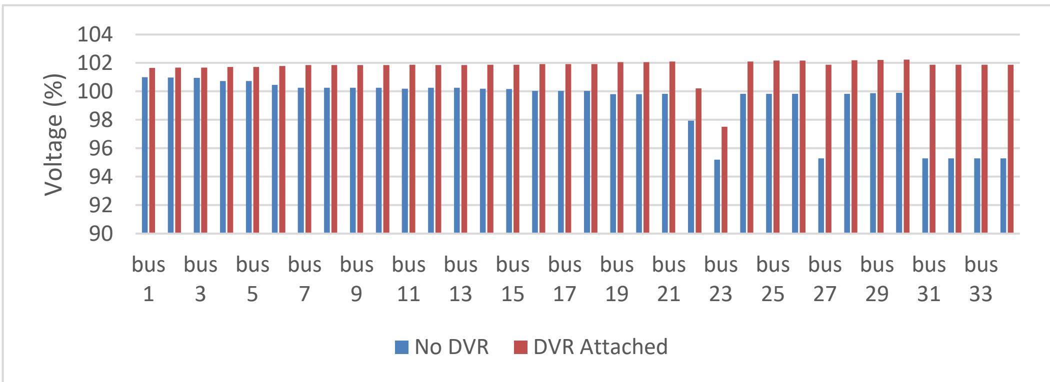

Figure 5. Voltage profile for the modified IEEE 34 bus system

3.2. Pakis Feeder of 20 kV Distribution System

Pakis Feeder is one of a very long distance feeder in Lampung. It spans almost 100 km length with scatter loading condition. Almost all the busses are drop far below the admissible voltage level. In this study, two cases of loading conditions were simulated:

- Case one, all the busses are in 100% loading to represent peak load time,
- Case two, all the busses are in 50% loading to represent normal daytime.

The results of simulations are depicted in Figure 6 and Figure 7 respectively. Those figures clearly confirm that voltage profile for all three conditions, i.e., peak load and daytime condition can be recovered by deploying DVR unit in the system.

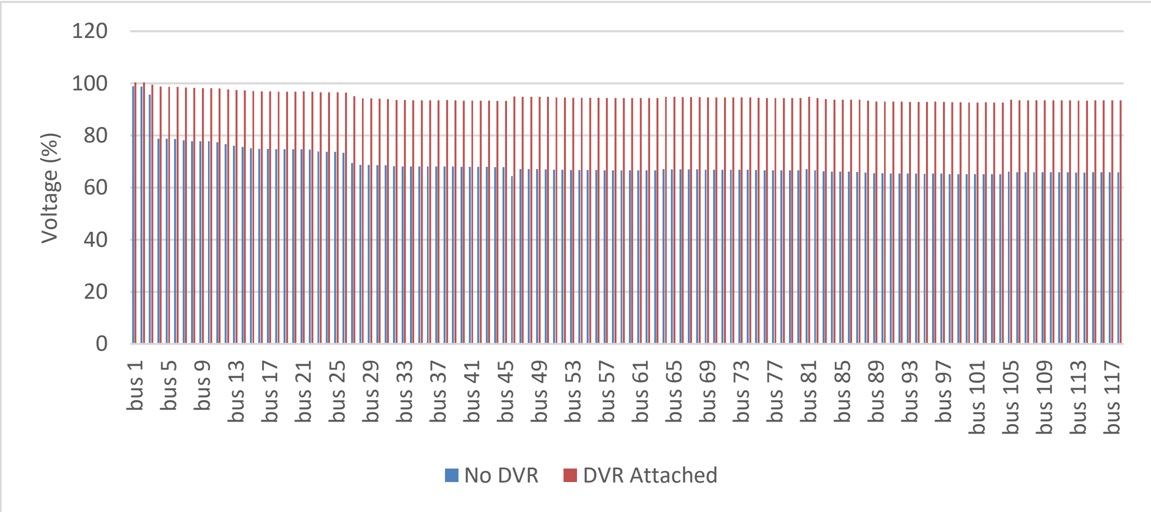

Figure 6. Peak load scenario for Pakis Feeder

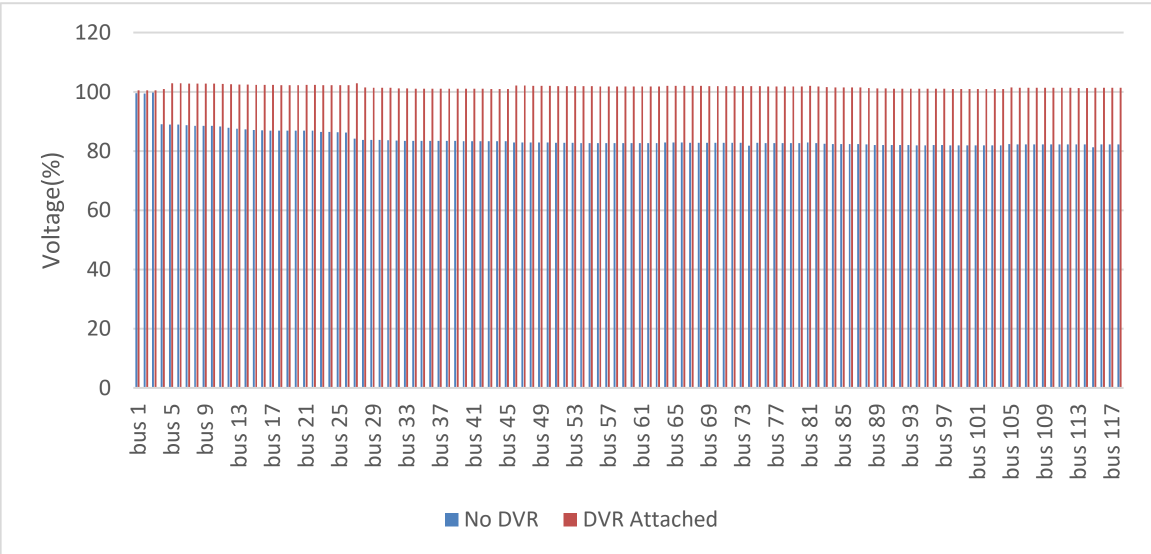

Figure 7. Daylight scenario for Pakis Feeder

4. Conclusion

Based on the simulations for IEEE 34 bus system and the real 20 kV long distance distribution; Pakis Feeder, it can be concluded that the application of Dynamic Voltage Restorer is possible to handling up voltage drop problem in a long run distribution feeder with high load and/or scattered loading situations.

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