Simulation Analysis of DVR Performance for Voltage Sag Mitigation

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Abstract— **Voltage sag is literally one of power quality problem and it become severe to industrial customers. Voltage sag can cause miss operation to several sensitive electronic equipments. That problem can be mitigating with voltage injection method using custom power device, Dynamic Voltage Restorer (DVR). This paper presents modeling and analysis of a DVR with pulse width modulation (PWM) based controller using Matlab/Simulink. The performance of the DVR depends on the efficiency of the control technique involved in switching the inverter. This paper proposed two control techniques which is PI Controller (PI) and Fuzzy Logic Controller (FL). Comprehensive results are presented to assess the performance of each controller as the best power quality solution. Other factors that also can affect the performance and capability of DVR are presented as well.**

Keywords- Voltage sag; Dynamic Voltage Restore; Pulse Width Modulation (PWM); PI Controller; Fuzzy Logic Controller

I. INTRODUCTION

Recently, power quality problems become a major concern of industries due to massive loss in terms of time and money. Hence, there are always demands for good power quality, which positively resulting in reduction of power quality problems like voltage sag, harmonic and flicker [1]. Voltage sag is always considered as one of the major power quality problems because the frequency of occasion is so high. Moreover, according to the data recorded by Tenaga Nasional Berhad (TNB), 80% of power quality complaints by consumers in Malaysia were outlined to be associated with voltage sag [2]. The common causes of voltage sag are faults or short circuit in the system, starting of large loads and faulty wiring [3]. This will lead to increase in both production and financial loss for industries. Therefore, it is vital to mitigate voltage sag.

Two main characteristics that explain the voltage sag are depth/magnitude and duration of voltage sag itself. The depth/magnitude and duration of voltage drop that said to be voltage sag is between 0.1 to 0.9 pu with time interval, t about 0.5 cycles to 1 minute [4]. This classification is based on IEEE standard 1159-1995.

There are various types of voltage sag mitigation equipment that available nowadays such as Uninterrupted Power Supply (UPS), flywheel, and the flexible ac technology (FACTS) devices which have been widely used in the power system due to the reliability to maintain power quality control [5]. One of the most FACTS devices that have been created in improvement the performance of power quality is Dynamic Voltage Restorer (DVR) also known as custom power devices. In this paper, DVR which consists of the injection transformer, filter unit, PWM inverter, energy storage and control system is used to mitigate the voltage sag in the power distribution system.

Control unit is the heart of the DVR where it main function is to detect the presence of voltage sags in the system, calculating the required compensating voltage for the DVR and generate the reference voltage for PWM generator to trigger on the PWM inverter. The components of control system unit are the dq0-transformation, Phase-lock-loop (PLL) and the PI or FL Controller. PI Controller is a feedback controller which drives the plant to be controlled with a weighted sum of the error (difference between output and and desired set-point) and the integral of that value.

II. METHODOLOGY

A. Mathematical Calculation

When voltage drop occurred at load, DVR will inject a series voltage through transformer so that load voltage can be maintained at nominal value as shown in Fig.1. Thus,

$$V_{DVR} = V_L + Z_{th} I_L - V_{th} \tag{1}$$

$$I_L = \left[\frac{P_L + jQ_L}{V_L} \right]^* \tag{2}$$

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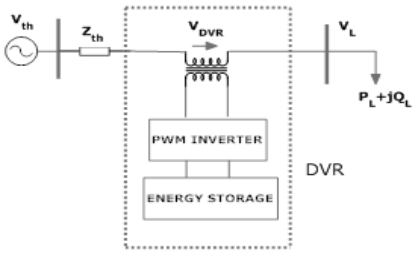

Figure 1. Calculation for DVR voltage injection

If V_L is considered as a reference ;

$$V_{DVR}\angle\alpha = V_L\angle 0^\circ + Z_{th}I_L\angle(\beta-\theta) - V_{th}\angle\delta \quad (3)$$

Here α, β, and δ are the angle of V_{DVR}, Z_{th} and V_{th}, respectively and θ is the load power factor angle with

$$\theta = \tan^{-1}\left(\frac{Q_L}{P_L}\right) \quad (4)$$

Thus, the power injection of the DVR can be written as

$$S_{DVR} = V_{DVR}I_L \quad (5)$$

B. Principal of Operation

The basic function of DVR is to inject dynamically voltage required, V_{DVR} to compensate sagging occurrence. Generally, the operation of DVR can be categorized into two modes; standby mode and injection mode [6]. In standby mode, DVR either in short circuited operation or inject small voltage to cover voltage drop due to transformer reactance losses. The DVR is turn into injection mode as soon as sagging is detected. V_{DVR} is injected in series with load with required magnitude and phase for compensation.

C. Modelling of DVR

Fig. 2 shows the flow chart of basic concept of the DVR operation. Typical DVR is built in Matlab/Simulink program as depicted in Fig. 3. The study considered the standard voltage used in Malaysia, supplied by Tenaga Nasional Berhad (TNB). The source is 11kV fed from TNB distribution substation (PPU). 11kV is then cabled to step down transformer, convert the 11kV voltage to 415V before deliver it to consumer's load. In this study, we applied two example of load, Load 1 and Load 2. Load 2 represents the non-sensitive equipment which means that the equipment can tolerate the sagging condition. Meanwhile, Load 1 represents the sensitive equipment like ASDs and PLCs where voltage regulation is crucial. Thus, DVR will be inserted in series with Load 1 to help improving the supply voltage before to be fed by Load 1.

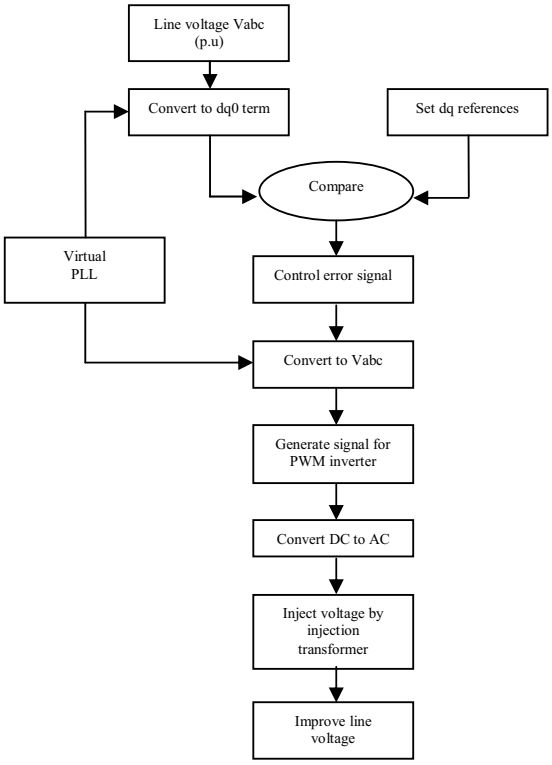

Figure 2. Flow chart of DVR operation

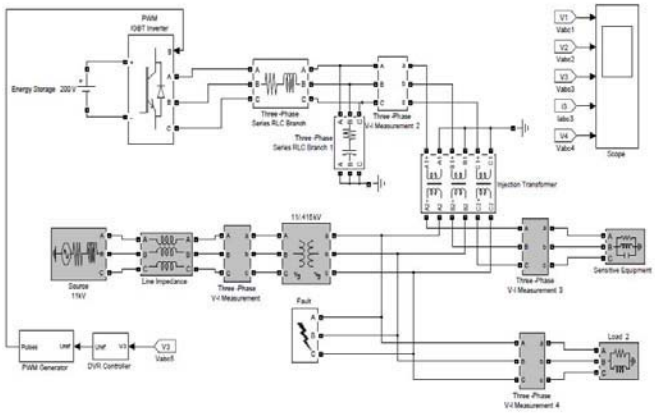

Figure34. DVR Modelling using Matlab/Simulink

Three legs PWM inverter is used to convert DC source to AC voltage and then injected into the line by injection transformer. The inverter model consists of self-commutating IGBT switches with parallel diodes. The sinusoidal pulse width modulation technique (PWM) forms the control strategy. The control block generates the firing signals for each switch with controllable amplitude, phase and frequency whenever sag is detected. The filter unit is applied to output of the inverter as it is closer to harmonic source.