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STATCOM APPLICATION WITH FLC AND VOLTAGE CONTROL ON THE LOAD IN THE HYBRID MODEL OF FUEL CELL/SOLAR PANELS SYSTEM

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Abstract

In this study, both the reactive power and amplitude of the voltage on the load are controlled in the Fuel Cell (FC)/Solar Panels (SP) hybrid system. Compensation is required to reduce harmonics and to correct power factor in power systems. STATCOM, a more advanced version of these compensation systems, has started to be widely used. STATCOM has a two-level inverter and it performs the necessary adjustments by switching the capacitors to remove the reactive power in the system. The Fuzzy Logic Controller (FLC) is used here to generate and control inverter gate signals. In addition, the direct current (DC) obtained from the FC/SP system on the load side is connected to a green bus and the obtained voltage is converted to Alternating Current (AC) by means of an inverter. Again using FLC, it was tried to obtain constant voltage of 380V / 50 Hz on the loads. Therefore, the system performs both controlling the voltage on the loads and compensation. Simulation of the whole system was performed in MATLAB / Simulink environment.
Keywords: STATCOM, Fuel Cell, Solar Panels, FLC

YAKIT PİLİ VE GÜNEŞ PANELLERİNDEN OLUŞAN KARMA SİSTEMDE BMD'Lİ STATCOM UYGULAMASI VE YÜK ÜZERİNDEKİ GERİLİMİN KONTROLÜ

Öz

Bu makalede Yakıt Pili (YP) ve Güneş Panelleri (GP) karma sisteminde hem reaktif güç kontrolü hem de yük üzerindeki gerilimin genliğinin denetimi yapılmaktadır. Güç sistemlerinde hem harmoniklerin azaltılması hem de güç faktörünün düzeltilmesi için kompanzasyon yapılması gerekmektedir. Bu kompanzasyon sistemlerinin daha gelişmişi olan STATCOM yaygın olarak kullanılmaya başlanmıştır. STATCOM iki seviyeli evirici kontrollü bir eviricidir ve reaktif gücü ortadan kaldırmak için kondansatörleri devreye alıp çıkartarak gerekli ayarlamaları yapmaktadır. Burada evirici kapı sinyallerini üretmek ve kontrol etmek için Bulanık Mantık Denetleyici (BMD) kullanılmaktadır. Ayrıca yük tarafında YP ve GP sisteminden elde edilen Doğru Akım (DA) yeşil bir barada birleştirilmekte ve elde edilen gerilim yine bir evirici vasıtasıyla Alternatif Akıma (AA) çevrilmektedir. Burada da yine BMD kullanılarak yükler üzerinde 380V/50 Hz'lik sabit gerilim elde edilmeye çalışılmıştır. Dolayısıyla sistem hem yükler üzerinde gerilim kontrolü yaparken hem de kompanzasyon yapmaktadır. Tüm sistemin benzetimi MATLAB/Simulink ortamında gerçekleştirilmiştir.
Anahtar Kelimeler: STATCOM, Yakıt Pili, Güneş Paneli, BMD

1 Introduction

Solar energy is an important renewable energy source. Electricity is obtained from solar energy especially with photovoltaic (PV) panels and solar thermal power stations [1]. While PV SP turn solar radiation directly into electricity, thermal solar power plants generate electricity by turning the turbine after heating the water by focusing the sunlight to a point.

Despite the fact that FC are also an important source of renewable energy in a similar way is not yet as widely used as a source of solar energy. [2] FC is a system that convert chemical energy into electric energy. They take oxygen from the environment and produce electricity using hydrogen supplied to it [3].

Especially the cases where these resources are used together (FC / SP) are less. When FCs are used as solar energy assistant, they are energized when the sun is not in operation [4].

With these sources in place, especially in high power applications, compensation systems for both harmonics reduction and reactive power control are needed. STATCOMs can be used if compensation is required for both grid-connected and off-grid systems.

STATCOM is an advanced compensation technique. Many advanced and intelligent control systems such as FLCs, artificial neural networks, predictive control can be used as controller. These systems, which include dynamic switching, contain an inverter structure. It is often used with high-power semiconductor switching elements such as IGBT [5-6]. Fig. 1 shows the main system structure.

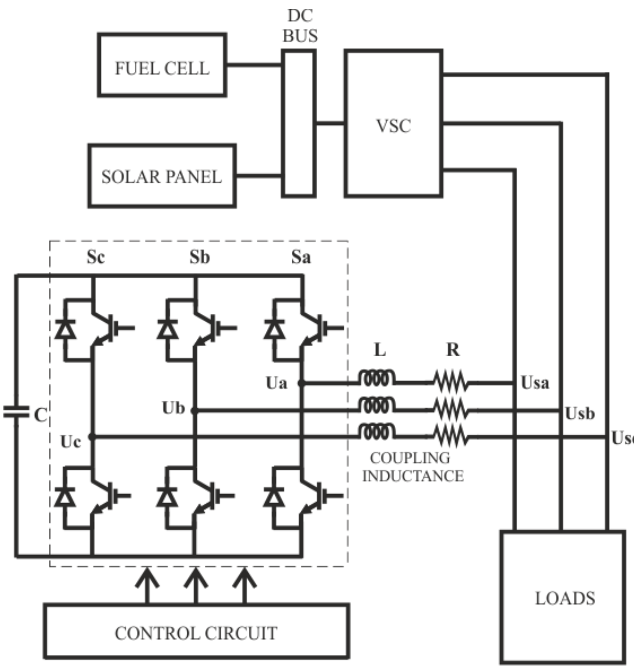

Figure 1. The main structure of the system.

Here, the DC obtained from the FC and SP systems is combined into a bus. This voltage is then converted to AC by inverter. The voltage on the load is adjusted to 380V/50Hz by FLCs. STATCOM was used to eliminate the reactive power present in the system. STATCOM consists of IGBT based inverter. The FLCs used here also control the reactive power to control the switching signals needed to activate and de-energize the capacitors to reset this power. All of the system is designed and simulated in MATLAB / Simulink environment with sub-blocks.

2 Material and Method

2.1 SP System

The equivalent circuit of the PV solar cell is shown in Fig. 2. The solar cell equivalent circuit consists of a diode inversely parallel to a current source and a series-connected resistor to the output. The power obtained solar cell changes according to the solar radiation level and the ambient temperature.

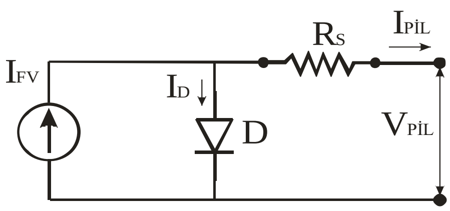

Figure 2. Equivalent circuit of a solar cell.

Output voltage of the solar cell is shown in Equation (1).

$$V_{pil} = \frac{A \times k \times T_{pil}}{e} \ln\left(\frac{I_{ph} + I_0 - I_{pil}}{I_0}\right) - R_s \times I_{pil} \qquad (1)$$

Where the symbols are defined as follows:

I_{pil}: Cell output current (A),

V_{pil}: Cell output voltage (V),

I_{ph}: Photocurrent, function of irradiation level and junction of temperature (A),

I_0: Reverse saturation of current of diode,

R_S: Series resistance of cell,

e: Electron charge (1.6021917x10-19C),

k: Boltzmann constant (1.380622x10-23 J/°K), T_{pil}: Reference cell operating temperature,

A: Curve fitting factor (100) [7].

The values of the parameters used in the unified PV array model are given in Table 1.

Table 1. Constants of PV solar cell.

T_a : 25 °C	β_T : 0.005	α_S : 0.3
S_{pil} : 100mW/cm²	γ_T : 0.02	

The output voltage of PV solar cell as given in (1), depends on cell operating temperature (T_{PV}) and the photocurrent (I_{pil}), which is a function of solar irradiation level (Sx). Using Fig. 2 and Equation (1) as the reference initial base model, the effect of the changing solar irradiation level and operating temperature are included in the modeling of the PV cell in Matlab/Simulink and shows in Fig. 3 [2].

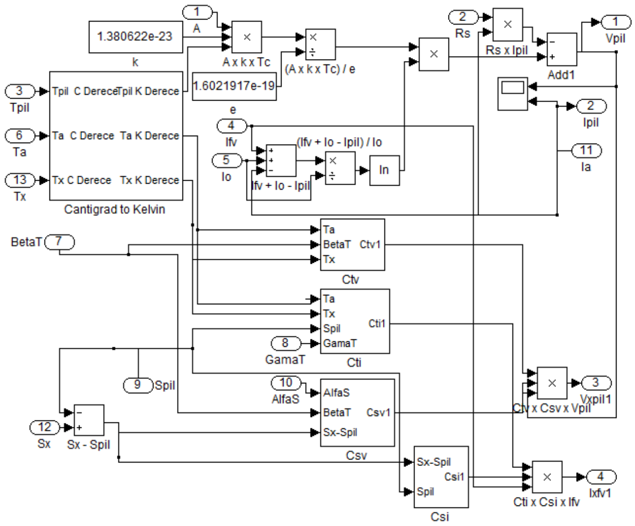

Figure 3. Simulink PV model.

MATLAB PV model has many subsystems. The mathematical expressions of these subsystems are given by Equations (2-8).

$$C_{TV} = 1 + \beta_T (T_a - T_x) \qquad (2)$$

$$C_{TI} = 1 + \frac{\gamma_T}{S_{pil}} (T_x - T_a) \qquad (3)$$

$$C_{SV} = 1 + \beta_T \times \alpha_s (S_x - S_{pil}) \qquad (4)$$

$$C_{SI} = 1 + \frac{1}{S_{pil}} (S_x - S_{pil}) \qquad (5)$$

$$\alpha_s = \frac{\Delta T_{pil}}{S_x - S_{pil}} = \frac{T_{pil} - T_a}{S_x - S_{pil}} \qquad (6)$$

$$V_{Xpil} = C_{TV} \times C_{SV} \times V_{pil} \qquad (7)$$

$$I_{XFV} = C_{TI} \times C_{SI} \times I_{FV} \qquad (8)$$

Where,

C_{TV}: Temperature-voltage coefficient

C_{SV}: Irradiation-voltage coefficient

C_{SI}: Irradiation-current coefficient

C_{TI}: Temperature-current coefficient

β_T: Temperature coefficient for PV cell voltage

T_a: PV cell operating temperature (K)

T_x: Ambient temperature (K)

γ_T: Temperature coefficient for PV cell current

S_{pil}: Reference solar irradiation level

S_x: Solar irradiation level at different times.

α_S: Temperature Coefficient of PV cell due to the variations in solar irradiation level

V_{Xpil}: PV array output voltage (V)

I_{XFV}: Cell output current (A)

Once a single model of the cell is obtained, PV SP come into play as these cells are brought together. Panels are assembled to create solar power plants.

2.2 FC System

The basic structure of a FC can be described as two electrodes (anode and cathode) separated by a solid membrane (membrane) acting like an electrolyte, as shown in Fig. 4. Hydrogen fuels pass through a channel that is separated from the anodic protons. The dissociating protons reach through the catheter membrane. Electrons collected as an electrical current by an external circuit connect the two electrodes together. Air through a similar channel network, the cathode, which is the place where the oxygen is collected together with the electrons in an external circuit, flows into the membrane in the protons and water is formed. The chemical reactions occurring in the anode and cathode electrodes of a fuel battery are as shown in Fig-4. The polymer membrane is compressed between two electrodes. Each electrode consists of a gas diffusion layer and a fine catalyst layer. The membrane-electrode assembly is compressed by two conductive layers, including the channels allowing the reactant flow. The oxygen from the cathode and the hydrogen coming from the anode combines to produce heat and water. Total cell reaction is as given in Equation (9) [8].

$$2H_2 + O_2 \rightarrow 2H_2O + ısı \qquad (9)$$

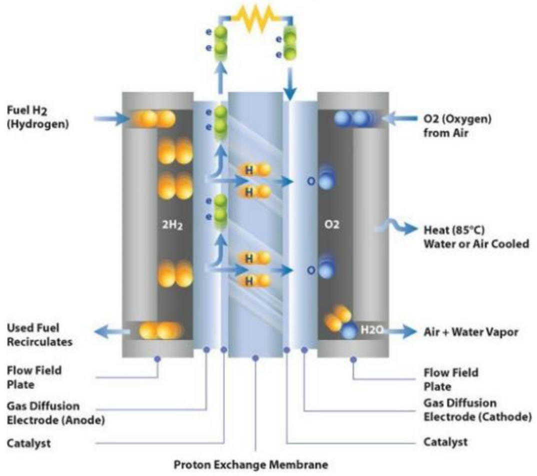

Figure 4. Schematic representation of a single FC.

2.3 STATCOM

The structure of STATCOM is shown in Fig.5 IGBTs are controlled by appropriate switching signals and the capacitor is switched on and off. Here, the width of the switching signals is adjusted using the Pulse Width Modulation (PWM) technique. The system consisting of 6 IGBTs is a 2-level inverter structure. Reactive power caused by the load is reset using this system [9].

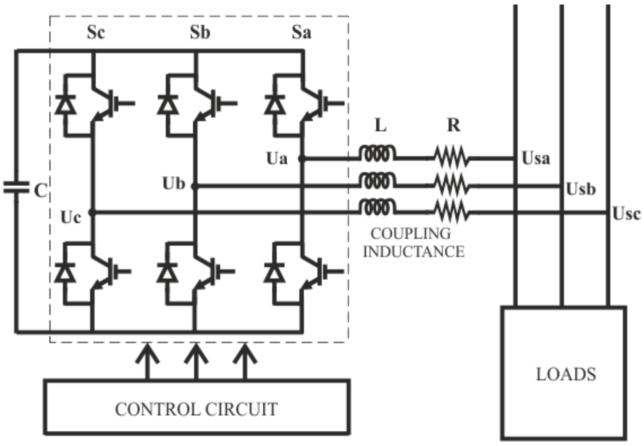

Figure 5. Structure of STATCOM.

2.4 FLCs

The general flow diagram of the fuzzy logic controller is shown in Fig. 6. The controller consists of 3 parts. These are, respectively, fuzzification, rule base and defuzzification. The first element of FLC, the fuzzification, turns the exact inputs applied to it into fuzzy values. These fuzzy values are sent to the Rule Base unit where they are processed with fuzzy rules and the resulting fuzzy result is sent to the defuzzification unit. In this section, the results are converted to the exact values from fuzzy values [10].

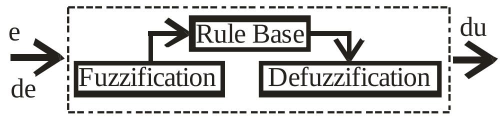

Figure 6. Basic configuration of a FLC

The triangle membership function shown in Fig. 7 is used in the study. The fuzzy values obtained from triangular membership function are calculated using Equation (10). The Simulink model of triangular membership function is shown in Fig. 8. The simulation has 5 rules.

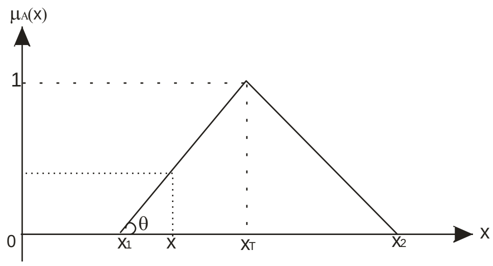

Figure 7. Triangular membership function.

$$\mu_{AÜ}(x) = max\left(min\left(\frac{x - x_1}{x_T - x_1}, \frac{x_2 - x_1}{x_2 - x_T}\right), 0\right) \qquad (10)$$

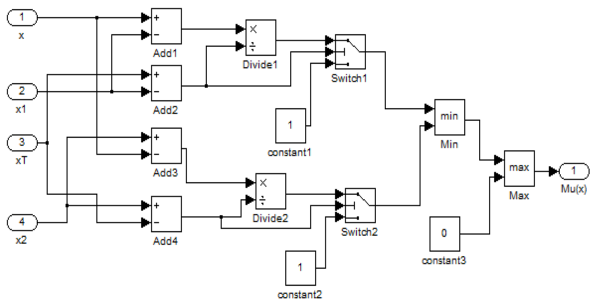

Figure 8. Model of the triangle membership function.

The Simulink model of the fuzzification process of FLC is shown in Fig. 9.

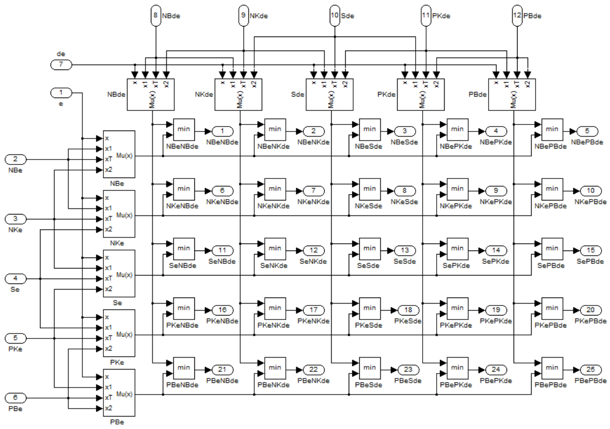

Figure 9. The Simulink model of fuzzification.

By taking the minimums of the membership values coming from the entrance space, the weighting factors required for each rule are determined. Once the required weight coefficient determined in the fuzzification unit, these values are sent to the part where the rules are processed to be multiplied. This structure is shown in Fig. 10.

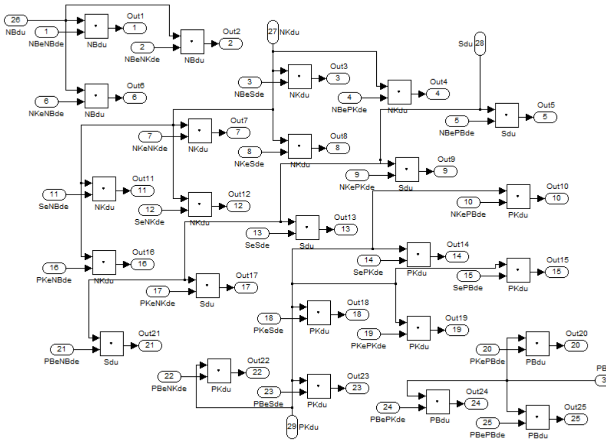

Figure 10 The parts of the rules are processed.

The defuzzification unit is as shown in Fig.11. The exact values are obtained by using the central method of the fields in the defuzzification unit. These exact values are output of the controller [11,12].

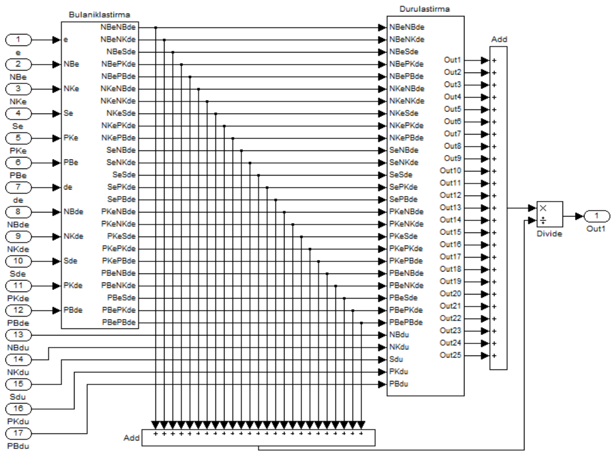

Figure 11. Simulink model of the defuzzification unit.

Fig. 12 shows all the components of FLC in MATLAB / Simulink.

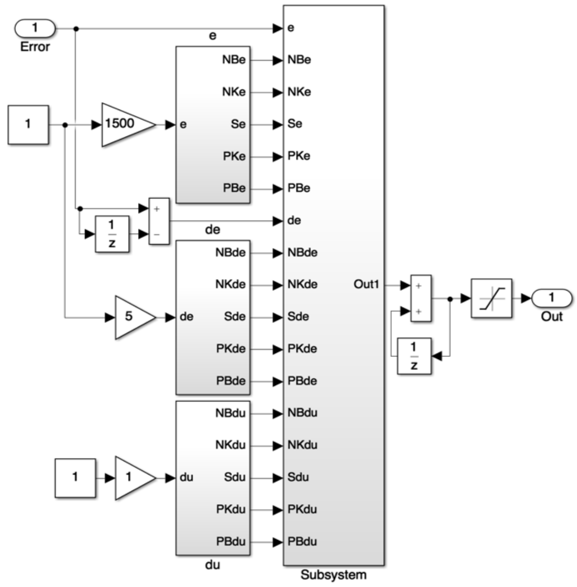

Figure 12. FLC with input and output variables

Both the control of the amplitude of the stress on the load and the FLCs in STATCOM were used to make necessary checks. For STATCOM, synchronous reference structure theoretical indirect current control method is used. In this control system, the dc voltage is held constant and the reference voltages that the inverter must produce are obtained according to the reference active and reactive power.

3 Simulation Study

Simulated system consist of SP, fuel batteries, inverter, STATCOM, controllers, SP / FC switching regulator and loads. It is composed of 40 SP and 20 parallel cables in the used SP system. There are totally 800 SP. Each has a power rating of 100Wp. The installed power is 80kW. The FC system is used to support the SP system. In the absence of the sun, or when it is not enough, it enters the circuit to provide the strength needed by the loads. Here, 5 units of 160V / 100A FC are connected to each other in series and 800V / 100A, total 80kW system is installed. A 25kW resistive load was used in conjunction with an RL load of 12kW / 8kVAr. The STATCOM used has a power rating of 100 kVAr and is connected to the system with a line inductance. The inverter used here controls a FLC-based controller and the required IGBT signals are generated in this way. Similarly, the voltage value on the load is adjusted to 380V / 50Hz with a FLC. In addition, a regulator and measuring instruments were used to switch on and off the required energy generation system, which would be appropriate for the system between SP and FC.

4 Results

The states where STATCOM is active and not active are studied separately and the results are compared. In both cases, the S_x and T_x variations of the SP are as shown in Fig. 13 and Fig. 14.

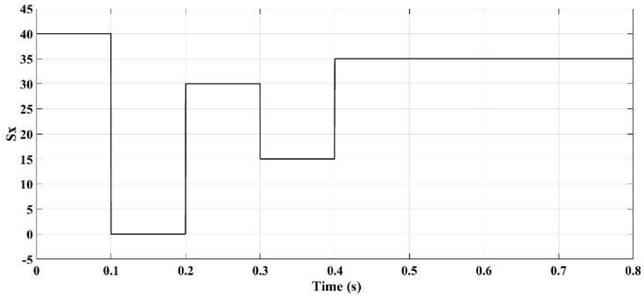

Figure 13. Change of light level in the SP, Sx

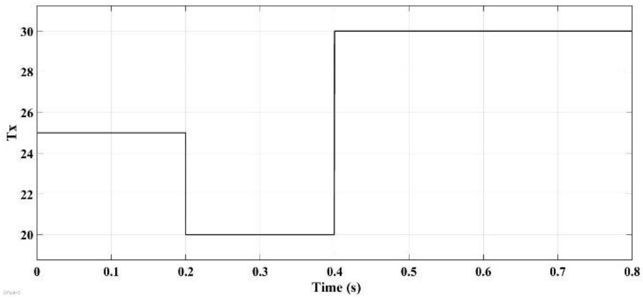

Figure 14. Change in ambient temperature of SP, Tx

4.1 STATCOM is disconnected

Fig. 15 and Fig. 16 show changes in current and voltage across the Point of Common Coupling (PCC). As STATCOM is not in operation, there is a phase difference between current and voltage and the waveforms are distorted.

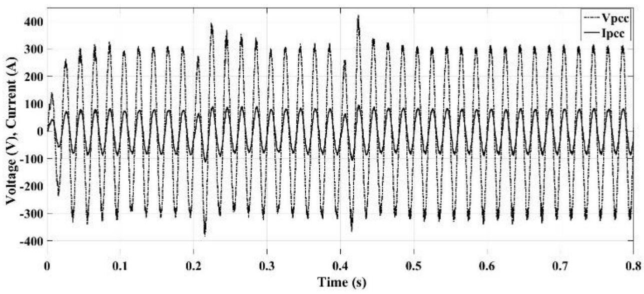

Figure 15. Change of current and voltage on PCC

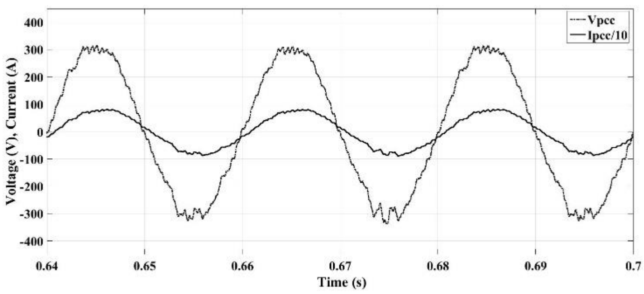

Figure 16. Detailed waveform of change of current and voltage on PCC

Fig. 17 shows changes in active and reactive power. In the areas where there are fluctuations, there are places where the system changes from the SP to the FC or otherwise. There are total 37kW of R load and 8kVAr reactive load. These loads can be seen in the Figure 17.

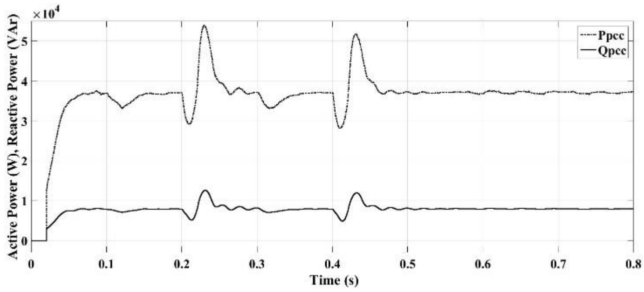

Figure 17. Active and reactive power on load.

4.2 STATCOM is connected

Fig. 18 shows the time intervals at which the SP is operation or not when the ambient conditions permit, and the current, voltage, and power waveform from the SP system accordingly. The system transfers in the range of 0-0,1 s., 0,2-0,3 s. and 0,4-0,8 s.

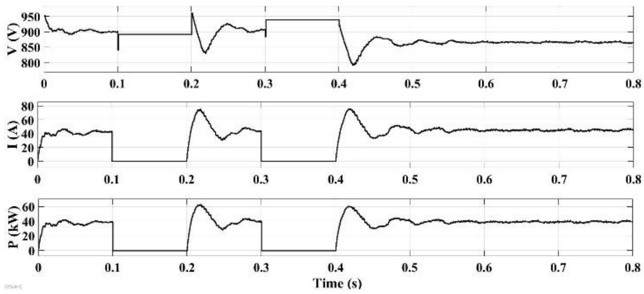

Figure 18. Change of current, voltage and power values of SP.

Fig. 19 shows the time intervals at which the FC is operation or not, and accordingly the current, voltage and power waveform from this system. The system is switched between 0.1-0.25s. and 0.3-0.425s.

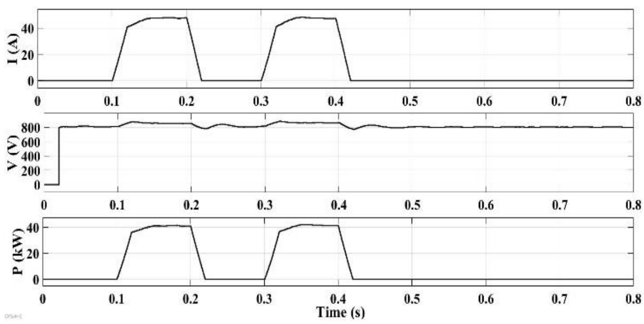

Figure 19. Change of current, voltage and power values of fuel batteries.

In Fig. 20, the DC line voltage, the inverter voltage between phases, the load voltage between phases and the change in the modulation index are collectively shown. The transition from the SP system to the FC and vice versa is seen clearer. The modulation index, which is a measure of the frequency of the switching signals, varies with the input and output of the sources. The strength of the switches leads to the V_{dc} being serrated.

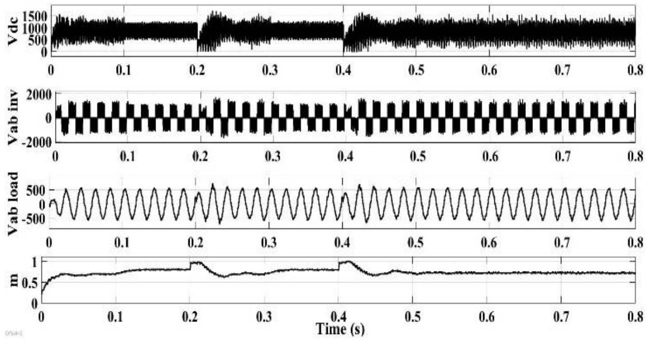

Figure 20. Change in DC line voltage, phase to phase inverter voltage, phase to phase load voltage and modulation index

In Fig. 21 and Fig. 22, STATCOM shows the change in PCC voltage and current at first. There is no phase difference between current and voltage. STATCOM has corrected this shift. The load RMS voltage varies about 380V.

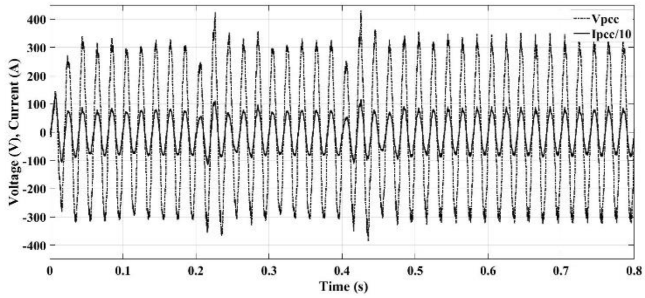

Figure 21 Change in current and voltage on PCC when STATCOM is connected to system

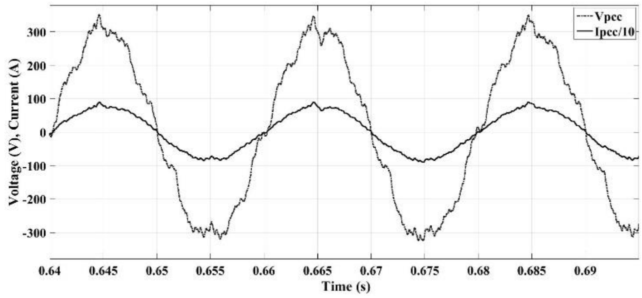

Figure 22. Detailed waveform of the change in current and voltage on PCC when STATCOM is connected to system.

Fig. 23 shows that reactive power is zero when STATCOM is connected to the system. The FLC controller is accomplishing this task properly.

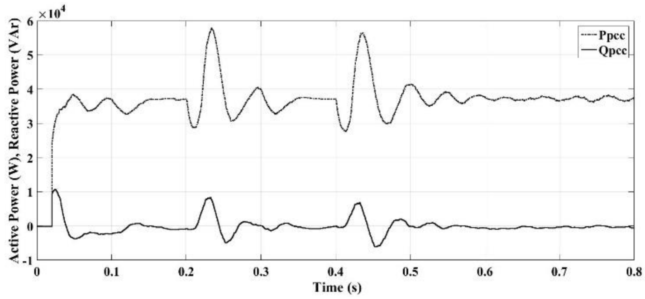

Figure 23. Change of active and reactive power on PCC when STATCOM is connected to system.

5 Discussion

Due to the fact that the STATCOM is in operation, it is seen that the reactive power is not absorbed to the grid. The active power is still 37kW. However, STATCOM has successfully eliminated 8 kVAr reactive power from loads. The FLCs used here work properly to activate and deactivate the capacitors as required. Both the voltage on the load and the load voltage can be maintained at the level about 380V.

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